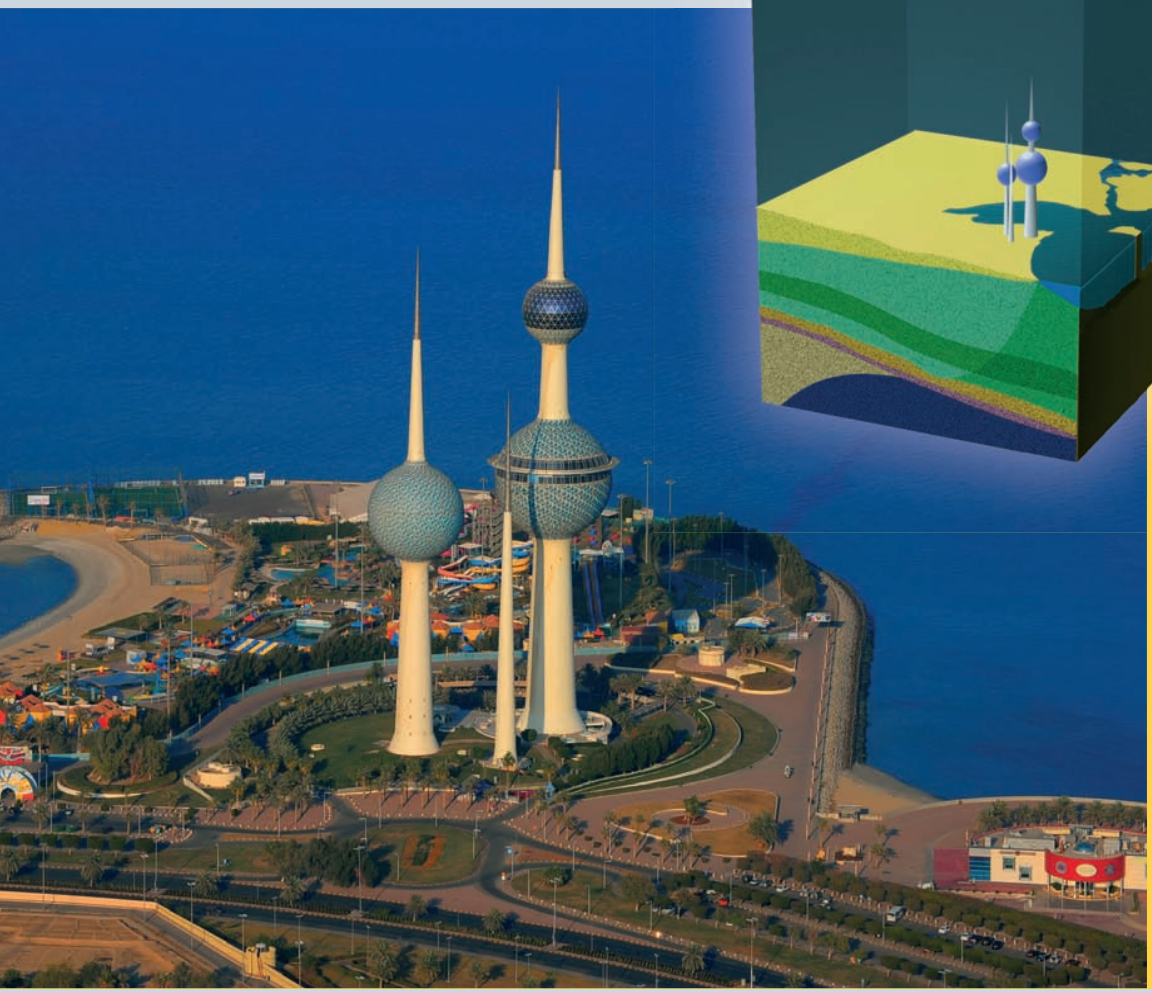
IAHR International Groundwater Symposium

Groundwater modeling and management under uncertainty



Editors: Khaled Hadi & Nadim K Copty

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GROUNDWATER MODELING AND MANAGEMENT UNDER UNCERTAINTY

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KUWAIT INSTITUTE FOR SCIENTIFIC RESEARCH (KISR), KUWAIT, NOVEMBER 19–21, 2012

Groundwater Modeling and Management under Uncertainty

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Groundwater Modeling and Management under Uncertainty – Hadi & Copty (Eds)
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Preface

In a water-starved world, wise management of every precious drop of water is of paramount importance. Groundwater is a valuable source of water that needs careful attention and appreciation. This has acquired all the more urgency in the face of current population explosion and consequent surge in demand and uncertain effects of looming climate change on this vital resource. Unfortunately, this important source of water is often subjected to unregulated exploitation exceeding its replenishment rate, pollution and poor management. Adopting a global groundwater conservation strategy is expected to ultimately ensure the sustainable development and advancement of the human race as a whole.

The Fifth International Groundwater Symposium, which was held in Kuwait between 19 and 21 of November 2012 and was jointly organized by the Kuwait Institute for Scientific Research and the Groundwater Hydraulics and Management Committee of the International Association for Hydro-Environment Engineering and Research (IAHR), aimed to bring together researchers, scientists, engineers and water professionals to raise awareness about current challenges and opportunities for the exploration and sustainable development of groundwater resources using cutting-edge technologies. The Symposium also aimed to provide a forum for the exchange of ideas and expertise among the various research and applied groups, for better understanding of the complex processes that lead to best practices in groundwater utilization and management. The interactions among the multidisciplinary participants from various countries also served to recognize the limitations of existing approaches and helped identify future research avenues.

The Symposium addressed a wide spectrum of groundwater related topics, including modeling and management under uncertainty, sustainable groundwater management in arid and semiarid environments, aquifer storage and recovery (ASR) as a groundwater management tool, management solutions for groundwater rise problems, flow and transport modeling, characterization of heterogeneous subsurface environments, impact of climate change on groundwater resources and subsurface contamination and remediation. More than 100 engineers, scientists and water professionals representing more than 20 countries, including Kuwait, United States of America, United Kingdom, Australia, France, Greece, Italy, Switzerland, Germany, Spain, Turkey, China, Japan, South Africa, Bangladesh, Egypt, Palestine, India, Iran, Tunisia, Algeria, and Columbia have participated in the Symposium. Inputs from these experts are recorded in this Proceedings and the resulting deliberations are expected to provide important guidelines for the groundwater resource managers and policy makers, and will also open up innovative lines of research for the exploration, exploitation and protection of this important resource.

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Acknowledgement

The Symposium acknowledges the contributions of the invited speakers: Drs. Philip Brunner, Peter Cook, Alberto Guadagnini, and Jennifer McIntosh to the success of the Symposium. The Symposium is also grateful to Drs. Souheil Ezzedine, Amr Fadlelmawla, Adnan Akber, Jaime Gomez, Alberto Guadagnini, Adel Al-Haddad, Wolfgang Kinzelbach, Philippe Renard, Chin-Fu Tsang, Xavier Sanchez-Vila, and Nadim Copty for their review of all submitted abstracts.

The Symposium also wishes to acknowledge Mr. Amitabha Mukhopadhyay, Ms. Ruby Crasta and Ms. Nada Al-Mahasneh for their tireless efforts towards the success of this Symposium. The Symposium also acknowledges Ms. Beatriz Comesaña, Office Manager of the IAHR Hydro-environment Division Programme, for her help in maintaining the Symposium webpage and assistance in coordinating the Symposium proceedings.

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Modeling and management under uncertainty

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Forecasting groundwater level of Shahrood plain in Iran with stochastic and artificial neural network models

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ABSTRACT

In the water resources systems planning and management prediction of ground water level is an important parameter. Several techniques such as stochastic models, fuzzy models, artificial neural networks and others methods can be used for this purpose. Stochastic model is one these techniques that formed based on time series. And also an Artificial Neural Networks (ANNs) is flexible computing frameworks and universal approximates that can be applied to a wide range of forecasting problems with a high degree of accuracy. Therefore in this study we used this ANNs and stochastic models for nonlinear time-series for predicting Groundwater Level (GWL) fluctuations for Shahrood Plain of Iran. For this purpose the rain, relative humidity, evaporation, temperature and groundwater table data as monthly collected at the study area and these data were used to train and validate the ANN model. The ANN model was performed by varying the network parameters to minimize the prediction error and determine the optimum network configuration. Also in this research different stochastic models are fitted to monthly data of ground water table. After performance of necessary tests, PARMA (2, 1) model with the least Akaike Information Criterion (AIC) has been selected as suitable model. The results show that the performance of the MLP/BP neural network was good in predicting the groundwater level rather than stochastic model. Therefore it can be used for proper water management studies in that area.

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Estimation of groundwater recharge using various methods in Neishaboor Plain, Iran

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ABSTRACT

Recharge rate is the most important component in water balance computation and groundwater modeling. Also, it is the critical factor in optimal planning and management of groundwater resources in the arid and semi-arid regions such as the eastern part of Iran. There are different techniques to quantify the recharge amount. Each of these methods has been developed in separate hydro-geological conditions and they will estimate completely different recharge value in an identical region. In this study, based on available hydro-geological information, four of these methods were selected to estimate the groundwater recharge. All of these methods are based on the water balance principle (rainfall-groundwater level relationship), including CRD (Cumulative Rainfall Departure), RIB (Rainfall Infiltration Breakthrough), WTFs (Water Table Fluctuations), and HBM (Hydrological Budget Method). These methods were useful, easy to be utilized, cost effective, simple, requiring few non-deterministic data such as groundwater level measurements, rainfall, aquifer properties, and groundwater extraction dataset. These methods were used to provide the percentage of irrigation return flow and the precipitation contribute to natural groundwater recharge. In order to apply the first three methods (WTFs, CRD, and RIB that are distributed techniques), the study area was classified to Thiessen polygons based on the existing observation wells. Thus, the natural recharge rate was estimated for each Thiessen polygon in monthly scale. Utilizing of these three methods, groundwater level was simulated and also the optimization technique was applied to minimize the Root Mean Square Error (RMSE) between the simulated and observed groundwater level. The results were shown that the simulated groundwater level was matched well with the observed amount. The forth method (HBM) was a lumped technique and it estimated an annual recharge rate of Neyshabour plain, from 378.73 to 448.95 MCM for 2000 to 2010. Finally, the estimated groundwater recharge of each method compared with each other and also the results showed that CRD, RIB and WTF methods provided more reliable groundwater recharge.

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Water resources and human health (fluoride toxicity)

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ABSTRACT

This communication, which deals with the relationships between the geological environment and health problems, highlights the endemic fluorosis and explores the harmful effects of fluorosis to the human beings and for an applicative research of endemic disease control. Fluorosis, caused due to drinking of fluoride contaminated groundwater is a major environmental health hazard throughout the world—USA, Europe, UK, and other countries, including India, spreads now among 67 million people in the entire arid and semi-arid tracts of India. Endemic fluorosis is of recent origin and developed due to certain faulty water management practices. According to UNICEF, more than 1.5 billion people worldwide do not have access to safe drinking water, leading to infectious diarrhea and other viral infections. In some areas, groundwater may contain enhanced levels of natural substances like arsenic, fluorine, nitrate, sulphate etc. that can restrict or prevent the use of groundwater because of health concerns. Although several sources of fluorine have been mentioned, only fluoride content in ground waters has been studied in the present investigation. It has been found that the levels of fluoride content are varying from 0–16.2 mg/l. Only a few samples in the study area, in Anantapur District, South India are found to contain the extreme values nearing 10.0 mg/l or even more. The reason for these extreme values may be due to the direct contact of waters with fluoride minerals.

If fluoride content is around 1.5 and 2.5 mg/l, mild dental fluorosis/mottling may appear and this disorder was caused in children drinking high-fluoride water. A more severe type of fluorosis called "Skeletal Fluorosis or Osteofluorosis" may develop, if the fluoride content of drinking water is in excess of 3.0 mg/l, among adults under Indian conditions, affecting bones and joints. It has been found that the levels of fluoride content are varying from 0–6.2 mg/l. The work at National Institute of Nutrition, Hyderabad, in 1977, has revealed the spread of endemic 'Genu Valgum' (knock-knee), crippling lower limbs from childhood, in association with fluorosis in most parts in India. Although preliminary work revealed that genu valgum is caused by drinking waters poor in calcium and rich in molybdenum, exact causes are yet to be known, to prevent its wide-spread occurrence in the fluorosis areas of India. The authors' work revealed that the fluorine content of rocks in India at most places is much less than that in most developed countries. Despite that, the fluoride content of groundwater in India is much higher than in most developed countries. As a result, fluorosis caused by excess fluoride in water is wide-spread in India and dental caries caused by deficiency of fluoride in groundwater is wide-spread in most developed countries. The present investigation reports the distribution pattern of fluoride toxicity in waters of Anantapur District, Andhra Pradesh, India. The severity of the problem is more accurate as only 30% of the villages have the fluoride content in drinking waters within the permissible limit (1.5 mg/l) and 70% of the villages above the permissible limit (>1.5 mg/l). Attempts are made to ascertain the fluoride toxicity in waters of the study area, in Anantapur District and several measures have been suggested for follow-up action. It can be concluded, that fluoride upto 1.0 mg/l in drinking water is beneficial, anything in excess of 1.5 mg/l is associated with 'mottling of enamel of teeth leading to initial manifestation in children; and that in excess of 3.0 mg/l with skeletal fluorosis, leading to final manifestation in adults.

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Multi-objective optimization using differential-evolution for the site selection of groundwater production wells

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ABSTRACT

The objective of this study is to present an approach to determine the optimum location for groundwater production wells. Several factors like the intrinsic aquifer vulnerability to contamination, the prevention of seawater intrusion and cost of well installation and pumping are considered in the well site selection process. The optimization problem is formulated as the maximization of the pumped groundwater from new wells that are added to already existing wells. Pumping rates of existing wells that are prone to seawater intrusion are optimized to prevent groundwater flux from the shoreline towards these wells. Also, the purpose of the optimization is to find new well locations that are relatively less susceptible to groundwater contamination and that are in suitable areas for new groundwater exploration with respect to land use.

A regional-scale groundwater flow model is coupled with an optimization procedure to determine the optimum location and pumping rates of new wells. The solution of the presented well site selection optimization problem is obtained by the Differential Evolution algorithm, which belongs to the class of heuristic optimization methods. The objective of the optimization is to find locations of new wells, where groundwater is the least vulnerable (i.e. more likely to obtain clean groundwater), the pumping rate is maximum and the cost of well installation and pumping are minimum for a prescribed set of constraints. The optimization problem is formulated using two objective functions; the first objective function defines the pumping rate maximization. The second objective function minimizes the cost of well installation and pumping operation. To obtain optimum well locations with respect to the groundwater vulnerability index, both objective functions include terms in the form of a penalty function, which penalizes the objective function, if the differential evolution algorithm determines well locations that happen to be in areas with a high groundwater vulnerability index (i.e. more vulnerable to contamination).

The proposed optimization process is demonstrated on an existing groundwater flow model for the Tahtalı watershed in Izmir-Turkey. The process identifies locations for up to three new production wells, where the total costs decrease with increasing number of new wells. The pumping rate per production well decreases when the total number of wells increases, thereby reduces the total pumping costs significantly. Furthermore, all well locations in the optimized solution coincide with areas of relatively low groundwater vulnerability. Vulnerability indices for new wells vary between 29.64 and 46.66 (on a scale of 0 to 100, where 100 indicates high vulnerability), depending on the total number of wells found in the solution.

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Identifying the origin of nitrogen pollutant in groundwater in the North China Plain using monitoring data and IGESF model

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ABSTRACT

Groundwater is the main source for water use in the North China Plain. However, based on the monitoring data, nitrogen pollution in groundwater is common in groundwater in the North China Plain because of intensified agricultural and industrial activities. Using the monitoring data of wells and a coupled surface water and groundwater numerical model, we try to identify the origin of nitrogen pollutant in the groundwater in the region. First, based on the 10-year monitoring data of over 200 wells, it was found that the groundwater quality at 30% wells were worse than Class III of the National Groundwater Quality Standard, and the main pollutant items were nitrogen and heavy metal, unsuitable for drinking. Second, Integrated Groundwater Environment Simulation Framework (IGESF) was developed and validated by coupling the groundwater reactive transport model (MT3DMS) and the distributed watershed model (WEP-L). Third, the application results of IGESF showed that during the 10 years from 1995 to 2004, annual average nitrogen pollutant loaded from non-point agricultural sources into the aquifer is about 38,400 t, and annual average nitrogen pollutant loaded from the polluted river water into the aquifer is about 26,000 t, with the former larger than the latter. Moreover, it was found that the nitrogen loaded into aquifer is related to the sum of precipitation and irrigation water, and the agricultural fertilization, with an correlation coefficient larger than 0.6

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Propagating conceptual and parametric uncertainty from regional to local groundwater models

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ABSTRACT

This study develops and evaluates variable statistical approaches for propagating conceptual and parametric uncertainty from regional-scale to local-scale groundwater models. Regional models are commonly used to determine boundary conditions (e.g., heads) and calibration targets (e.g., fluxes) along the boundaries of a higher resolution local-scale model developed to focus on a particular area of interest. For illustrative purposes, a three-dimensional hypothetical domain is used as a reference model for evaluating the developed tools. Five Conceptual models with a total of 1500 realizations are developed for the regional scale model. Boundary conditions (e.g., heads) and calibration targets (e.g., fluxes) are mapped from the regional models over to the local models. Different statistical approaches for mapping the regional data over the local models are tested including using all realizations with and without incorporating the weights reflecting the regional model calibration goodness of fit results. In addition, averaging the results of the regional models prior to mapping the data to the local scale model is also considered as an alternative tool. The overarching conclusion is that it is better to incorporate as many conceptually different models as possible, with small number of realizations in each model, than to rely on a single conceptual model no matter how large the number of realizations used for that single model.

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Groundwater management in the presence of uncertainty using artificial neural networks and genetic algorithms

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ABSTRACT

The problem addressed in this study is to predict development potential of a groundwater aquifer with uncertain aquifer parameters subjected to quality constraint. The quality constraint is imposed because of the presence of contamination sources near the aquifer. Dealing with this problem in the presence subsurface uncertainty using the traditional methods of groundwater simulation and optimization models needs millions of CPU hours. In this paper it is proposed to capitalize the capabilities of new computational techniques including Artificial Neural Networks (ANN), and Genetic Algorithms (GA) for creating a comprehensive analytical package that can be used to manage and evaluate groundwater resources near potential contamination sources. To test the developed package, it is applied to a case study of El-Sadat City groundwater aquifer system in Egypt. The combined tools are found to be very efficient in evaluating millions of development scenarios that would not otherwise have been evaluated with traditional techniques. The main conclusion is that ANN and GA are robust techniques that can lead to improved management plans because the end result is a tool that enhances the ability of water resources managers to maximize the benefits from groundwater aquifers while minimizing adverse impacts on the environment through minimizing the spread of potential contamination.

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Well capture zone delineation under uncertainty: The value of information for risk assessment

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ABSTRACT

We focus on the problem of delineation of the capture zone of a pumping well superimposed to a regional flow in a heterogeneous aquifer. Modeling aquifer heterogeneity through a random hydraulic conductivity spatial distribution renders uncertain transport predictions, with significant implications in the shape and extent of the well capture zone or protection areas. In the case of large extended plumes, uncertainty in the hydraulic properties translates into uncertainty assessment of the mass of contaminant eventually reaching the well. This itself can be translated into environmental or human health risk. Improvement in well influence region delineation and reduction of the uncertainty associated with transport predictions is typically performed by means of very expensive hydrogeological sampling campaigns. We focus on the assessment of the impact of data acquisition on the reduction of uncertainty linked to the environmental scenario analyzed. We investigate the significance of the amount of available hydrogeological measurements to yield predictions at an acceptable level of uncertainty of (a) contaminant concentrations captured by the well and (b) adverse health effects due to exposure of population to such concentrations. We do so by elucidating the role of the dimensionless length scales that characterize and control the well capture zone and its delineation.

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Hydro-chemical study of underground waters of Urmia plain, using statistical methods, fuzzy logic and hydro-chemical diagrams

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ABSTRACT

Fuzzy logic, an appropriate classification method to classify water chemistry samples into similar groups, is an efficient tool for describing hydro-geological environments. Geological and hydro-chemical systems, in some cases, are too complex to be analyzed by conventional graphics and statistical methods. Chemical and physical characteristic in the natural cycle of change, are often continuous and not abrupt, or, in other words, physiochemical processes do not always have separate outlets. Because of this continuity, statistical groups may not be well separated from each other and instead, they may form a sequence in which different groups may overlap. In these circumstances, fuzzy logic can be useful for modeling and grouping. In this study, 30 samples of Urmia plain underground water have been divided in three groups, using fuzzy segmentation, and then these groups have been studied for concentration of total solutes and their types. The concentration of ions dissolved in the underground water, is increased from the first group to the third group. In the first and second groups, the water type is ChloroSodic and in the third group it is calcic sulphate. In order to identify the geochemical processes governing the water table, chart combination, ion ratios and saturation indices of calcite, dolomite and gypsum samples has been evaluated. Results showed that the chemical composition of underground water supply is strongly influenced by the river feeding, sediments forming the groundwater table and surface evaporation of aquifer.

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A stochastic optimization framework for the evaluation of hydraulic conductivity uncertainty on the sustainable management of an over-exploited aquifer

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ABSTRACT

This study investigates the impact of hydraulic conductivity uncertainty on the sustainable management of the Lake Karla aquifer using the stochastic optimization approach. Lake Karla basin is an intensely cultivated agricultural region, which faces serious water deficit problems. In 1962, the former Lake Karla was drained causing a series of environmental problems in the area, with the aquifer over-exploitation and its dramatic water table drawdown being the most important. Nowadays projects for the reconstruction of the lake are being implemented. Currently it is the biggest environmental project in the Balkans and aims to reverse all the environmental consequences that have aroused during the last decades from the drainage of the lake. To reverse this situation it is foreseen that a great part of the total irrigation needs will be covered by the new reservoir, thus enabling local authorities to shut down lots of private irrigation wells.

The limited data concerning the spatially varying hydraulic conductivity parameter generates an uncertain hydrogeological environment. This makes the attempt to correctly estimate hydraulic heads and the volumetric budget of the aquifer even harder, either for the historical or for future period. This uncertainty is estimated using the Sequential Gaussian Simulation (SGSIM), for the conditional simulation of hydraulic conductivity. Conditioning is achieved by using the values of K, which are obtained through pump tests at 15 locations. Multiple realizations of the parameter are being generated and groundwater flow is simulated for each of them.

The main goal of the aquifer's sustainable management is to maximize the extracted groundwater volume, under the constraint of restoring the over exploited aquifer. The latter could be achieved by the rehabilitation of the water table to a previous, satisfying level. For that reason the optimization approach is achieved by solving the optimization problem for each one of the multiple stochastic realizations of the aquifer in a future period. The financial risk from water sales reflects hydraulic conductivity uncertainty.

In order to carry out this stochastic optimization procedure, a modeling system consisting of a series of interlinked models was developed: a hydrological model (UTHBAL), a groundwater model (MODFLOW), a lake-aquifer model (LAK3) and a reservoir operation model (UTHRL). The modeling system has been calibrated for the historical period against observed runoff and groundwater hydraulic heads. The Geostatistical Library (GSLIB) is used for the production of stochastic hydraulic conductivity maps and an optimization tool (GWM) is used for the optimization problem. The results prove that the proposed stochastic optimization framework can be a very useful tool for the groundwater sustainable management in an uncertain hydrogeological environment.

Sustainable groundwater management in arid and semiarid environments

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Keynote speech

Quantifying arid zone groundwater recharge with environmental tracers

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ABSTRACT

Groundwater recharge in arid zones is characterised by low fluxes and high spatial and temporal variability. Environmental tracers are well suited for estimating recharge in these environments because they are more sensitive than most other methods to very low rates of recharge, and because they provide inherent spatial and temporal averaging. Groundwater recharge rates can be estimated from environmental tracer measurements on unsaturated zone soil profiles, or from water samples from piezometers completed at discrete intervals within confined and unconfined aquifers. Chloride is one of the most widely used tracers within the unsaturated zone. Under steady state conditions and in the absence of significant surface runoff, a mass balance of chloride can be used to estimate rates of groundwater recharge. Where rates of recharge have changed, either from a change in land use or due to changes in climate, chloride profiles can also be interpreted to reconstruct changes in infiltration over time. Where unsaturated zones are deep, however, there may be a timelag of many years or decades before changes in infiltration lead to changes in aquifer recharge. The magnitude of this timelag can also be estimated from water content and matric potential profiles.

Recharge rates can also be estimated from estimates of groundwater age, and the most widely used technique in arid zones involves measurements of radioactive decay of carbon-14. Carbon-14 has been used to estimate rates of diffuse recharge to unconfined aquifers and rates of recharge from ephemeral streams. In areas with deep unsaturated zones, however, measurements of the initial carbon-14 activity of groundwater recharge are required for accurate groundwater age estimates.

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Keynote speech

Impacts of urbanization on groundwater recharge and water quality in semi-arid basins

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ABSTRACT

Urban population growth is putting increasing demands on groundwater resources, especially in semi-arid regions like the southwestern United States with limited surface water supplies. Capturing urban storm runoff for focused groundwater recharge in ephemeral alluvial channels is one promising strategy for mitigating groundwater shortages; yet, little is known about the quality of urban runoff and potential impacts on shallow aquifers. In the Tucson Basin (Arizona), highly impervious urban watersheds generate more summer monsoon runoff events and have greater water yields, than less developed watersheds. Routing of urban runoff into local washes likely augments groundwater resources, as shown by rapid recharge beneath alluvial channels. The composition of wash substrates strongly controls nutrient transport. Low levels of trace metals and nutrients in storm runoff and shallow aquifers suggest that urbanization does not necessarily degrade water quality. Up to 6% of atmospheric nitrate may be transported to groundwater in areas of focused recharge.

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Qanat, a source of sustainability in arid and semi-arid regions

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ABSTRACT

Arid and semi-arid regions of the world are distinguished, primarily, on the basis of their annual precipitation sum. Most deserts and (semi-)arid regions occur between 10 and 35° latitude and receive generally less than 250 mm precipitation per annum. Important geomorphic processes in the dry regions of the world differ from those in more humid environments. Streams are intermittent or ephemeral and have very irregular discharges and many rivers do not debauch into the sea but end in inland depressions without outlet. Salt lakes are a common landscape feature and physical weathering processes are prominent, making water resources management a challenging task for the inhabitants. A direct consequence has been overstressed groundwater resources in some cases to such sever extents that sustainability is no longer feasible.

Qanats, artificial underground tunnels transporting water over great distances, were invented by the inhabitants of Persia. This type of system, generally using water from aquifer drainage, was to be applied in many other parts of the world such as Egypt, India, Greece, China, the Maghreb, and the Canary Islands. Still used today, qanats are built as a series of underground tunnels and wells that bring groundwater to the surface. Practical flow measurement and water distribution techniques alongside respecting water quality and water ethics were evidently part of a greater water culture in the arid-semi arid region of the world. Developed in antiquity, qanats are traditional systems of harnessing groundwater in water scarce regions to meet water demands. During times they have formed part of the socio-economical characteristics of their respective communities, however enduring for centuries; qanats are now in decline due to various reasons.

Application of Integrated Water Resources Management (IWRM) in arid-semi arid regions with the ultimate aim of sustainable groundwater management has indicated the great importance of qanats as source inputs into the general water resources model of these regions. Their simple structures, their harmony with the environment, their ability to tap groundwater in arid areas and perhaps above all their contribution to the cultural heritage are indications of their role in sustainable development of communities. Therefore their preservation and optimum utilization should be encouraged.

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Identifying the major sources of groundwater contaminants and estimating their pollutions potential in the Mashhad plain aquifer

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ABSTRACT

Water sources available for drinking and other purposes must possess high degree of purity, free from chemical contamination and microorganisms. Groundwater is a vital natural resource for the economic and secure provision of potable water supply in both urban and rural environments, and plays a fundamental role in human well-being, as well as that of many aquatic ecosystems. The rapid growth of urban areas has further affected the groundwater quality due to over exploitation of resources and improper waste disposal practices. The sources of groundwater contamination are many and varied because, in addition to natural processes, practically every type of facility or structure installed by man and each and every human physical activity may eventually cause groundwater quality problems. The groundwater contamination is widely regarded as a major environmental problem now and in the future. Therefore, The vulnerability of groundwater, especially of groundwater supplies, to existing or potential sources of contamination underscores the need for a systematic process by which these potential threats can be recorded, identified and evaluated also an inventory of groundwater contamination sources can be provided. As the Mashhad Plain located in Iran is a great pollution sources and a serious threat for the health of groundwater supplies resources, many engineers and planners have proposed various policies and programs for controlling groundwater contamination until now. This paper discusses about identifying the major sources of groundwater pollutant and estimates their contamination potential in Mashhad Plain. The results measure the importance of different pollutants of Mashhad Plain and indicate the potential benefits of groundwater contamination abatement.

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Prediction of groundwater table under changing water utilisation in the North China plain

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ABSTRACT

North China suffers serious water shortage due to bilateral influence of semi-arid climate and dramatically increasing water demand along with economic growth. Groundwater overexploitation with deeper wells is a typically adopted measure to relieve the water issue in this area, while such activities cause various eco-environmental problems. To utterly solve the chronic and deteriorating crisis, the South-to-North Water Transfer Project (SNWTP) was put forward as a strategic approach. The planning of this project has been studied since five decades ago; the Middle Route and East Route are initiated at 2002. It is a significant issue that what will happen after uncertain change of water use and the impact of large scale inter-basin diversion to this area. However, the trend of groundwater table change in future is influenced by multiple factors, mainly the natural precipitation, water pumping and artificial recharge. These main factors cannot be only forecast by groundwater model. Therefore, analysis of uncertainty on the water demand, water allocation under dramatically changing economic growth, strategic design and regulations are the key point for forecast for the North China region.

To probe the possible approach to solve this problem, a methodology of model coupling to combine water allocation model and numerical groundwater model is put forward based on summary of current achievements of studies related to of surface-groundwater combination model. The coupling model is applied in North China Plain to forecast the evolution of groundwater under different scenarios of water utilization and other changing boundary conditions. Method of data processing from output of water allocation model to groundwater model is analyzed and designed based on data distribution on both spatial and time scale to solve the critical point of down scaling for model coupling. To simulate the continuously changing process of balance of groundwater situation, interpolation is applied to transfer the results of water allocation on level year to time series for groundwater model. The simulation of groundwater evolution is initiated from the current status with the interpolated time series represented future water pumping and recharge. Firstly, the water cycle in Haihe River Basin (mainly including North China Plain area) and water use is simulated by water allocation model with different water allocation scheme. Secondly, the groundwater pumping from water allocation model is taken as input of groundwater simulation model to calculate the groundwater table. The results of simulation in the plain areas of Haihe River Basin shows the deficit of groundwater will approach to 5 billion m^3 without South-to-North Water Transfer Project (SNWTP) compared with only 1.4 billion m^3 deficit if the Phase I of SNWTP is commenced in 2015. Meanwhile, the decline of groundwater table will be averagely 5–25 m less if the SNWTP take effect although the water table continues declining. The trend of deteriorating groundwater environment will be totally relieved with the SNWTP, but more strategies and strict measures are still necessary to reach water balance of groundwater and healthy evolution. Application in Haihe River Basin verifies the feasibility of the coupling method.

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Evaluation of the effect of runoff in contact with contaminated ground surfaces on the groundwater quality

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ABSTRACT

Impact of petroleum and seawater contaminated ground surfaces on the quality of rainfall induced runoff was investigated by comparing its quality with quality of rainfall induced runoff from uncontaminated ground surfaces. The petroleum and seawater contaminated runoff and uncontaminated runoff samples were collected from Umm Al-Aish and Raudhatain topographic depressions, respectively, along with collection of rainwater samples during a rainy season of November 2005 to January 2006. A total of nine samples, three of the rainfall, three of runoff from contaminated and three of runoff samples from uncontaminated ground surfaces, were collected. Impact assessment of contaminated ground surfaces on the quality of rainfall induced runoff was based upon comparison of TDS, ions (Ca, Mg, Na, K, SO_4, Cl, NO_3 and NO_2), organics (TOC, COD and TPH) and metals (Cu, Fe, Ni, Pb, V and Zn) concentrations. Comparison revealed 97.29, 68.16, 97.67 and 67.35% increase in TDS, TOC, COD and TPH, respectively, as compared to runoff from uncontaminated ground surfaces indicating a remarkable negative impact on the quality of runoff. Metals concentrations were detected below detection limits in all the samples. Quality comparison of groundwater samples collected from monitoring wells P18 and P1, situated in contaminated and uncontaminated ground surface areas, respectively, revealed percolation of contaminated runoff to fresh groundwater.

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Comparison study of rainwater quality of an arid and a semiarid region

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ABSTRACT

Quality comparison of rainwater of Kuwait City, Kuwait (arid region) and Lahore (semiarid), Pakistan was carried out to assess their suitability for domestic use. Total 14 rainwater samples, seven from arid and seven from semiarid region, were collected during 2005–2006 and 2007 rainy seasons, respectively. The collected rainwater samples were analyzed for pH, TDS, turbidity, cations (Ca, Mg, Na, K), anions (HCO_3, SO_4, Cl, NO_3), metals (Cu, Fe, Ni, Pb, V, Zn), TOC, total coliform and faecal coliform. The pH of rainwater of arid region ranged from 5.02 to 7.60 with an average 6.41 whereas it ranged from 6.13 to 7.56 with an average of 6.78 for rainwater of semiarid region. TDS and turbidity concentrations of rainwater of arid region ranged from 41 mg/l to 150 mg/l with an average of 93.57 mg/l and from 2 NTU to 57 NTU with an average of 22.14 NTU, respectively, whereas for semiarid region it ranged from 19.00 mg/l to 42.00 mg/l with an average of 33.00 mg/l and 0.00 NTU to 8 NTU with an average of 2.29 NTU, respectively. TOC concentration of rainwater of arid region ranged from 0.13 mg/l to 2.80 mg/l with an average of 1.80 mg/l, whereas for semiarid region it ranged from 0.10 mg/l to 1.88 mg/l with an average of 0.89 mg/l. Metals concentrations of rainwater of both regions were detected below detection limits of analytical methodologies followed for their determination. Overall analytical results indicated better quality of rainwater of semiarid region, inorganically and organically, as compared to rainwater of arid region. The concentrations of observed constituents of rainwater from semiarid region complied with limits stipulated by WHO for potable water however, surpass of turbidity and total coliform contents of rainwater of arid region indicated that filtration and chlorination treatments would be required to make it potable.

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KISR's successful experience: Production of high quality bottled water using beach well

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ABSTRACT

Rapid increases in the world population, along with improved standards of living have resulted in increase in the demand for water, in general, and for bottled water, in particular. Thus, the water bottling industry has become one of the most profitable and fastest growing industries. In addition to social and economic factors, the growth of this industry is attributed mainly to increased concerns for safety and health. Kuwait is located in an arid zone, and imports huge quantities of bottled water simply because its local production cannot meet the ever-increasing demand for water. Kuwait Institute for Scientific Research (KISR) took the initiative to utilize beachwell water for the production of high-quality bottled water. The outcome is a secure new source of drinking water for the country, a decrease in demand for the country's desalinated water, a narrowing of the gap between bottled water imports and local production, and a world-class bottling-industry model for the local market.

KISR's drinking bottled water is produced utilizing a multi-barrier approach, from source to finished product. The production plant consists of multi-processes such as filtration, desalination by Reverse Osmosis (RO), and ozonation. This paper presents evaluation of KISR'S successful model to produce high quality bottled water. Based on actual laboratory analyses, results indicate that KISR's produced bottled water meets the international standards for water intended for human consumption.

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Development of a protection plan for the coastal aquifer of Gaza and assessment of the level of salinity in the West Bank and Gaza Aquifers

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ABSTRACT

The increasing demand in the West Bank of Palestine has put a lot of pressure on the existing water resources. The gap between available water and water needs in the West Bank is more than 300 Mcm/yr. The management option to reduce this gap includes drilling deep wells in the West Bank. Two problems occurred during the drilling: one is that the yield from the deep wells is not going to be achieved as planned and the lower aquifer in eastern part of the West Bank especially up to 10 km from the Dead Sea proved to be saline. In one well the static water level was 210 m bgl and the salinity was that of fresh-water from 210 m till 770 m bgl. After that depth, i.e., from 770 till 900 m bgl, the salinity increased to 32,000 mg/l. The transition zone between fresh and saline water was 7 m thick. The total drilling depth of this well was 900 m.

The drilled wells in the West Bank were subject to an extensive investigation programme of lithological logging, geophysical logging, acidisation, pumping tests (one day step draw-down test, 3 day-constant test and recovery test for 3 days), spinner flow under static and dynamic logging, temperature and EC under static and dynamic conditions logging, video camera logging etc. This paper uses the results of these investigations to assess the groundwater potential in the West Bank and to find a solution for the salinity problems. It was concluded that there is a continuous reduction in the sustainable yield of the aquifers due to over-pumping and the saline sections in these deep wells should be cemented.

In the costal aquifer of Palestine the main problems are over pumping, pollution from raw sewage, salinity increase from the phenomenon of saltwater intrusion and saline water upconing. In order to protect the coastal aquifer from pollution and salinity two activities were conducted: the first was to develop a vulnerability map and the second was to simulate numerically the groundwater flow and salinity in the coastal aquifer. These led to develop a protection plan. This paper discusses the different components of the plan. The plan includes water balance analysis, identification of vulnerable zone to pollution, artificial recharge from storm water and reuse of treated wastewater, reallocation and shutting down some wells, skimming and scavenger pumping, wastewater collection and reuse system and rehabilitation of existing wells.

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Adopting numerical approach for groundwater management in Eocene Aquifer, West Bank-Palestine

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ABSTRACT

More than 95% of Palestinian water supplies for domestic, agricultural, and municipal and industrial use come from groundwater, either in the form of wells or springs. The fact that the Palestinian water resources consists almost exclusively of groundwater highlights the extreme importance of this limited resource. Palestinian water supply comes from three groundwater basins: the Western Basin, the Eastern Basin, and the Northeastern Basin. The aquifers of all of these basins constitute a shared water resource to some degree with the Israelis.

Eocene Aquifer is one of several groundwater systems that provide water for Palestinian communities in the northern parts of West Bank with a total area of 526 km^2, part of this aquifer is extends outside the West Bank (about 65 km^2) where most of productive Israeli wells are located. Generally, the total average extraction rate from this aquifer is about 17 mcm/y, of which 12 Mcm/y is pumping by Israeli wells while the Palestinian wells are pumping about 5.0 Mcm/y only. The pumping water from this aquifer comes through variable types of renewable water-bearing carbonate rocks of limestone and chalky limestone with a variable thickness range from 300–500 m. Rainfall is playing significant role in recharging this aquifer by reliable quantity of fresh water, the long-term average annual rainfall over the proposed area is 400–600 mm/y. The importance of this aquifer motivates Palestinian Water Authority through essential assistance from SUSMAQ Project to develop a local-scale groundwater flow model as a management tool aims to assess the sustainable yield of Eocene Aquifer for future development and to evaluate the effect of long-term pumping rate on water levels. The model was constructed through Groundwater Modeling System (GMS) and was calibrated against steady-state and against transient-state for the period of 1991–2000. The model shows that the sustainable yield is around 29 Mcm/yr; this will be subjected to many variations regarding the annual rainfall, pumping control and average simulation of the model results.

Developing and implementing a shared management program is highly requested to ensure long-term sustainable yield for this aquifer. The program will include a documentation of the decision-making process and actions necessary to protect groundwater resources.

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Groundwater flow modelling in arid and semi-arid regions using modflow: Case of Miocene aquifer of Zéramdine-Béni Hassen (East Central Tunisia)

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ABSTRACT

As all other in arid and semi-arid countries, Tunisia provides multiple examples of groundwater degradation due to its overexploitation. This is specially the case in the Zéramdine-Béni Hassen deep aquifer (central east Tunisia). This aquifer is one of the most important aquifer within Sahel of Tunisia. Its lithology is composed by clay-sandy series. Because of its tectonic complexity and the scarcity of Miocene outcrops, the hydrogeology characterization of the reservoir is not yet known. Seismic profiles interpretation highlights the existence of the Zéramdine fault corridor, the Boumerdès anticline, the Moknine, and Mahdia grabens that represent lateral boundaries for the study aquifer. The outcrop of the aquifer is located in the Zéramdine, Béni Hassen and Ain Ben Jannet regions, that represent the aquifer recharge and where two lithostratigraphic sections were realized. The piezometric study shows that the principal groundwater flow is from East to West. A secondary flow is from NW to SE. The hydrochemical study of twenty sample shows that the Zéramdine-Béni Hassen aquifer is characterized by freshwater, Na–Ca–Cl–SO_4 facies, and salinity increase from west to east that is coinciding with the principal water flow direction.

In this work, an integrated methodology was developed adopting loose coupling of the groundwater flow model MODFLOW 2000 code with ArcInfo Geographic Information System to investigate hydrological processes in Zéramdine-Béni Hassen Miocene.

The groundwater model developed in this study includes an updated geometry, new estimates of parameter values and a new conceptualization of the hydrogeological system in Zéramdine Béni Hassen region and can be regarded as a useful tool for analyzing the hydrological processes and improving groundwater management practices elsewhere affected by similar geological and hydrogeological conditions.

Keywords: groundwater, conceptual model, MODFLOW, seismic-reflexion, arid region, Tunisia

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Establishment of a groundwater monitoring network in Kuwait: A conceptual model

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ABSTRACT

A groundwater monitoring system is essential to monitor, preserve and protect the groundwater resources of an arid country such as Kuwait. The system acts as an effective surveillance tool that hinges on sound scientific postulates, and can observe periodic and long-term changes in the groundwater regime. Proper management of groundwater quality requires an efficient monitoring network that makes it possible to detect the spatial and temporal extent of subsurface contamination. Optimal design of monitoring networks is necessary due to uncertainties in predicting the movement of pollutants in the groundwater system and budgetary limitations. The processes, phenomena and activities that need to be monitored for the maintenance of the integrity of Kuwait's groundwater system include lateral cross-boundary recharge, regional groundwater quality change trends, mixing between groundwater from different aquifers, lateral and vertical flow due to potentiometric head drop in the production well fields, potential hazardous activities, submarine groundwater discharge and gaps in country-wide spatial coverage.

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Monitoring groundwater level and total dissolved solids around sabkha nabkha deposits in Kuwait

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ABSTRACT

Nabkhas are stabilized dunes accumulated around desert and sabkha perennial plants. Field studies were carried out and about 160 sediment samples were collected from surface and subsurface of sabkha nabkhas around at southern sector of Sabah Alhmed National Reserve that developed around *Nitraria retusa* plant species. The studied area shows three different zones of nabkha deposits. These zones are: The deteriorated or dead nabkhas, slightly deteriorated or transitional nabkhas and flourished nabkha zones. In order to prove the water recharge process around sabkha nabkhas in this study, a 15 month period of monthly monitoring was conducted for the groundwater level and Total Dissolved Solids (TDS) in three wells, one in flourished nabkha zone within a group of nabkhas in one sand body around *Nitraria retusa* and others in sabkha level beside the nabkha.

The survival of thriving nabkhas within a salty sabkha environment is endorsed to the existence of the shallow fresh groundwater lenses floating on the brine water bodies that are recharged by the surface drainage paths and rainwater.

The clayey sand body of the sabkha nabkhas have lower pH and carbonates content, and higher values of moisture, TDS and EC than those in desert nabkhas. The *Nitraria retusa* is the most competent plant species within all plant species in Kuwait in trapping mobile sand as it forms the hugest sand body around it with maximum 5 m^3 in volume.

Keywords: Nabkha, groundwater level, total dissolved solids, Sabkha

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Aquifer Storage and Recovery (ASR) as groundwater management tool

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Reclaimed water use optimization in the Middle East

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ABSTRACT

Groundwater resources in the Middle East are being used at unsustainable rates, as populations grow and water demands increase. Desalination is a critical source of potable water, especially in the GCC nations; however, this supply source is very energy intensive and costly. Surface water in the Middle East is rare. The only other water supply source of significance in the region is reclaimed water.

Reclaimed water use is increasing throughout the region. Uses of reclaimed water include irrigation and industrial use, saline intrusion barriers, and indirect potable reuse, generally in an unplanned manner. The authors discuss the stages of reclaimed water use from immature to mature, though optimization. During this optimization phase, the best uses of reclaimed water are given priority, as well as increased cost recovery applied through tariffs. As reclaimed water use nears 100%, Aquifer Storage and Recovery (ASR) can become an important element of reclaimed water use optimization, allowing supply to keep up with varying demand, and ensuring consistent supply to paying customers. ASR does not work in all hydrogeological or hydrochemical settings. Factors determining success or failure of below ground water storage of reclaimed water are explored, as well as water quality considerations.

Water quality concerns for reclaimed water are explored, including potential acute concerns (i.e., bacteriological exposure) and potential chronic concerns (e.g., heavy metals and contaminants of emerging concern, or CECs). Potential contaminant migration and attenuation mechanisms associated with reclaimed water in the subsurface are discussed.

Proper use of reclaimed water includes application of the multiple barriers principal to ensure protection of public health and the environment. Multiple barriers can come in the form of various treatment trains, and separation of reclaimed water application from potential receptors (e.g., potable water supplies). Different levels of treatment can be used depending on the ultimate use of the water, as water quality should only be sufficient to meet needs. An example of this would be removal of nitrates as undesirable in water used for irrigation purposes. Optimal use of reclaimed water in the Middle East, in particular the GCC Nations is explored.

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Optimization of ASR implementation for groundwater management: Experiences from the United States

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ABSTRACT

The initial testing of ASR systems began in the United States over 65 years ago, and the implementation of the technology and other managed aquifer recharge techniques has progressively increased because of their compelling water management benefits. The historic ASR experiences in the United States provide valuable insights that can be used for more successful global implementation of the technology. The most important lesson is that ASR system performance is highly dependent upon site-specific hydrogeological conditions, which may not be locally favorable. Analyses of the hydrogeology of both successful and unsuccessful ASR systems have provided much useful information on the hydrogeologic controls of ASR system performance. Detailed aquifer characterization can identify early in a project adverse conditions that may result in poor recovery efficiencies, such as the presence of dual-porosity conditions. The current state of the art involves the use of advanced borehole geophysical logs and more conventional aquifer testing data, which are up-scaled and incorporated into solute-transport models using workflow software.

ASR systems that store freshwater in overdrafted aquifers (i.e., groundwater banking systems) require accurate evaluation of the water budgets of the groundwater basins in order to determine how much of the stored water is indeed recoverable. In systems involving multiple users, a water accounting system must be devised that balances the "credits" accumulated from recharge with the capacity of the aquifer to provide additional water during times of increased demands. More detailed impact analyses are needed to evaluate the impacts of temporal and spatial changes in groundwater recharge and withdrawals resulting from system operation.

The injection of fresh water into an aquifer containing water with distinctly different composition can result in a variety of chemical, physical, and biological processes, which may be either favorable or unfavorable. Adverse fluid-rock interactions can result in the precipitation or alteration of minerals and clay swelling and dispersion, which can result in a decrease in permeability and well and aquifer clogging. The introduction of oxic water into anoxic aquifers that contain sulfide minerals has resulted in the leaching of arsenic and metals into stored water in some systems, which exceeded applicable water quality standards. The potential of arsenic leaching can be evaluated through mineralogical evaluation of storage zone strata, water chemistry analyses, geochemical modeling, and bench top testing. Field testing is underway at several sites on pretreatment options to prevent arsenic leaching by removing dissolved oxygen from injected water. Beneficial aquifer processes include the natural attenuation of contaminant concentrations, particularly the inactivation of pathogens.

A key operational and maintenance issue remains managing well clogging, which may be an issue even in wells used to inject water of potable quality. Periodic well rehabilitation is a normal element in the operation and maintenance of ASR wells, and other injection wells. A variety of different methods are available to rehabilitate wells, but it is now clear that there is no one universal preferred method. Instead site-specific adaptive management approaches are often taken to determine the well rehabilitation program that most cost effectively maintains long-term well performance.

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Evaluation of groundwater recharge experience with treated wastewater effluents in Oman

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ABSTRACT

Treated wastewater effluents in Oman are used primarily for landscape irrigation. However, during the last few years, a relatively new application of such effluents was applied in south of Oman (Salalah coastal strip) where the treated effluents were used to recharge groundwater aquifers along a 14 km recharge line. The recharge line contains 44 wells to recharge about 20,000 m^3/d of treated effluents to the groundwater. This study was carried out to understand the groundwater quality in Salalah coastal strip and its suitability for different purposes since groundwater is a major source for agricultural, domestic and livestock purposes in the study region. The study involved extensive groundwater sampling from the monitoring wells for a period of approximately one year. The analysis involved inorganic (anions and cations) parameters, biological (bacteria, Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)) parameters, and Total Petroleum Hydrocarbon (TPH) of the collected samples from the monitoring wells.

Furthermore, a dynamic model, showing the impacts of treated water injection in the groundwater of aquifers for Total Dissolved Solids (TDS), Nitrate (NO_3) and water level was developed. The model was simulated for steady state and transient state conditions. The model simulations provided information concerning predevelopment hydrologic conditions and aquifer response to changes in pumpage and recharge through time. Simulations were made using the three-dimensional finite-difference ground-water flow model (MODFLOW) and transport model (MT3D).

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Feasibility of artificial recharge at the Az-Zaqlah depression in Kuwait

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ABSTRACT

A hydrogeological investigation of the Az-Zaqlah depression in north Kuwait was carried out to assess the feasibility of storing Reverse Osmosis (RO) treated municipal wastewater in the underlying aquifer using artificial recharge through wells. The analysis of the collected data indicated that though the site may not be hydrogeologically ideal for artificial recharge, it is strategically located with respect to the source of water for recharge, power supply and distance from the demand center. Numerical modeling suggested that cyclical injection and recovery through 21 wells located within the depression can create a reserve of water that should be able to meet the demand of about 35000 people at 450 l/d/capita and, during an emergency, should be able to sustain 100,000 people through one year at the rate of 100 l/d/capita. A pilot scale artificial recharge-recovery operation through one well has been recommended to study the feasibility of the option further.

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Feasibility of treated wastewater application for aquifer recharge to defy saline water intrusion

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ABSTRACT

A rapid growth of coastal cities and industries has put a lot of stress on the groundwater in arid regions. Withdrawal of water from coastal fresh water wells sometimes exceeds the ability of underlying aquifers to replenish the fresh water supply, allowing salt water to seep into fresh water sources. Most of the agricultural development in Sultanate of Oman is concentrated along the coastal strip of the Batinah plain (north of Oman). Due to the total dependence upon groundwater by withdrawal from wells and inadequate surface water recharge, the initial equilibrium of groundwater conditions has been upset with the consequent effect of saline water intrusion. Batinah coastal plain aquifers located close to Barka (west to Muscat) are suffering from huge water deficit and consequently salt-water intrusion is constantly transgressing thereby deteriorating the water quality in wide spread areas.

Treated wastewater can be used in order to combat salt-water intrusion in coastal aquifers like in Barka area. In order to study the technical feasibility of replenishing the groundwater using treated wastewater, the Groundwater Modeling System (GMS) is used that includes MODFLOW in addition to MT3DMS module (Mass Transport Three-dimensional for Multi-Species) for groundwater transport processes. First, a conceptual model for coastal plain aquifers near Barka was developed based on available hydrogeological data. Then, the calibration of the model with steady state flow simulation of the groundwater head distribution for the starting simulation year was conducted. After calibration was made, the model was used to predict water level fluctuations. Similar procedures were followed to simulate seawater intrusion using MT3DMS in order to predict the salinity movement in response to the injection of treated wastewater. Positive responses were observed in terms of improved ground water level and water quality in terms of significant salinity reduction.

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Management solutions for groundwater rise problems

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Integrating geophysical and hydrogeological investigations into a three dimensional model of the Sphinx area, Egypt

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ABSTRACT

In recent years, urban sprawl began blockading the Pyramids of Giza plateau region, Egypt. In particular, this urban sprawl began approaching randomly around the statue of Sphinx and the surrounding ancient temples. The Pyramids area started to be surrounded by many of the masses of population and expansion in urban developments and gardens from all directions. The increased rates of water leakage from water distribution and sanitation networks of these population blocs, as well as water leakage from nearby canals led to a rise in the groundwater table in some residential areas directly adjacent to the Pyramids area. This consequently led to the leakage of part of this groundwater and its accumulation underneath some sites located in relatively low-lying areas within the Pyramids area. This problem prompted the need to determine the amounts of water that leaks from the surrounding locations. Site characterization using geophysics combined the geophysical interpretations are integrated with hydrogeologic investigations to develop an integrated picture of the hydrogeologic system surrounding the Sphinx area. The integrated combination of geological, geophysical, and hydrogeologic methods are used to develop a three-dimensional groundwater flow model for the area and use it for analysis of the potential danger posed by the developments surrounding the site and possible sources of leakage and to also evaluate the efficiencies of different preventive actions. The three-dimensional model is calibrated to a steady state condition that prevailed in the eighties and then verified using transient conditions covering the period from 1987 to 2008. The model is used to estimate the groundwater fluxes crossing each boundary segment under natural conditions. A number of preventing mechanisms are evaluated using the model and their effect on preventing the rise of groundwater levels around the Sphinx is assessed by the model.

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Effect of urban development, limestone dissolution and preventive mechanisms on the groundwater levels at the Sphinx archaeological area, Egypt

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ABSTRACT

Groundwater appearance on the land surface in the Sphinx and Pyramids area in Egypt prompted a study to identify the sources of this rising groundwater and propose short term solutions to the problem. Although a short-term solution was designed and implemented in the site, concerns remained regarding the potential interactions between the leaking water (mostly sewage water) and the limestone aquifer underlying Sphinx and the Pyramids area. These interactions may lead to widening the fracture and fault openings, thereby increasing their permeability, increasing the volumes of groundwater passing through them and affecting the stability of the archaeological structures. In this study, a two dimensional numerical model is developed to investigate the effect of limestone dissolution on groundwater fluxes entering the subsurface domain underneath the Sphinx and Pyramids area. The model generates zones of high hydraulic conductivities to represent fractures and the hydraulic conductivity field coupled with appropriate boundary conditions is used to solve the flow equation to obtain the potential field and subsequently the velocity field. The particle tracking approach is adapted to solve the transport and dissolution reactions problems. The model considered the rate of dissolution reactions at mineral surface, mass transfer of reaction products between the mineral surface and bulk fluid, and reactions involving the distribution of CO_2 gas in water as the three potential limiting conditions for dissolution. Comparisons between the case with dissolution and that without the effect of dissolution reveal the importance of the process.

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Study of the phenomenon of groundwater level rise in South el Qantara Shark area, Ismailia, Egypt

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ABSTRACT

The 'rising groundwater level' in the new reclaimed areas has become a major concern all in Egypt. Due to the increasing level of groundwater, it is not only endangering the structures and properties but also causing major environmental problem affecting the health of the area, habitats, and the biotic of the land community. The groundwater level gets seriously affected due to increasing pressure of various man-made activities. Once the natural flow of the groundwater is affected, it can result in raising the level or lessen the level creating large number of environmental problems. The authors propose an interdisciplinary planning strategy to deal with the issue of rising groundwater level. In the concerned area, fifteen peizometers are drilled to investigate the rising in groundwater level. Detailed topographical and brief hydrogeological analyses had been carried out. The strata supplying groundwater in the area are the Quaternary strata (Holocene and Pleistocene). The Holocene shallow sandy aquifer dominated the area of study, where all drilled peizometers tap this aquifer. The daily seepage from excess irrigation water may represent the main contributor of groundwater rising in the shallow aquifer. Moreover, seepage from south El Qantara canal and the municipal water supply system leakages further raise the groundwater level. The groundwater exists in the south at depth of 9 m below the ground surface and sometimes the water appears on the surface causing water logging especially in the north and northeastern parts of the area The groundwater quality grades from fresh to brackish water where the total dissolved solids ranges from 1,019 to 32,000 mg/l. The dewatering system in the study area may be suggested as a solution to overcome the problem.

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Simulation of potential dewatering system for managing high water table

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ABSTRACT

A rise in the shallow unconfined groundwater level at the Booster Station 140 (BS-140) in the Burgan oil field of the Kuwait Oil Company (KOC) is causing water logging of the underground facilities in the station. Currently, the depth to the water is not more than 2 m from the ground surface within the perimeter of the booster station. Realizing this problem, the Research and Technology Group of KOC approached the Hydrology Department of the Water Resources Division at the Kuwait Institute for Scientific Research (KISR) to conduct a study in order to identify the source of the water that is causing the rise and to develop an implementation and operation plan of the dewatering system.

Utilizing geologic input from the field investigations and the available hydrogeologic data, a three-dimensional, finite element groundwater flow model that simulated the ground-water flow system in the area surrounding and within BS-140 was developed and calibrated. The development of the conceptual hydrogeologic model for the area under investigation and construction and calibration of the groundwater flow numerical model were based on the following information and data: (1) site setting of BS-140 and its spatial relationship to important features in the vicinity and the geologic framework of the area around BS-140; (2) records of rainfall and groundwater levels; (3) topographic data on a regular grid covering a total area of 25 km^2; (4) water levels and water chemistry data from borehole census within approximately a 2.9-km radius of BS-140; (5) chemistry data for water and soil samples; and (6) drawdown in a series of monitoring wells during the pumping tests that were conducted within the scope of the study to investigate the hydraulic characteristics of the area. The groundwater model developed for this investigation utilized the numerical code MODFLOW, which solved the three-dimensional groundwater flow problems with an unconfined surface using the finite element method. The calibrated and validated model was then used to predict the dewatering requirements for managing the water table rise around BS-140 and the potential drawdown in the water table induced by this dewatering. It was recommended to pump from four production wells at a rate of 150 l/min per well, to draw the water table down to an average depth of 4.5 m under BS-140. It was recommended that the pumped water could be utilized by KOC for several purposes depending on the level of treatment.

Flow and transport modeling

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Keynote speech

Physically based modeling in surface water-groundwater interaction: How numerical tools help understand hydrological processes

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ABSTRACT

It is widely accepted that groundwater and surface water are not isolated components of the catchment water balance and that their interaction is important to stream ecology, water quality and water quantity. A quantitative understanding of the interaction between surface water and groundwater is therefore crucial for sustainable management of water resources. Because surface water-groundwater (SW-GW) interaction is inaccessible and difficult to manipulate, fully integrated models play an important role in exploring the underlying physics, and the geological and the hydrological factors which control the interaction between these two components. In this talk, recent examples of how physically based models can help to understand hydrological processes are presented. Also, the combination of state of the art inverse modeling approaches with a model simulating the interaction between vegetation, surface water and groundwater is presented. Some final conclusions are drawn.

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Quantification of methanogenesis-dominated natural attenuation processes in a carbonate aquifer

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ABSTRACT

Natural attenuation of petroleum hydrocarbons in groundwater has been extensively investigated (Davis et al., 1999 and Wiedemeier et al., 1999). Here, for the first time, the sustainability of natural attenuation processes acting on contaminant plumes associated with large and complex Light Non-Aqueous Phase Liquid (LNAPL) source zones in a coastal carbonate aquifer where methanogenesis is the dominant degradation process. The research was complicated by multiple LNAPL source zones, variable groundwater recharge rates and a layered sand aquifer which sustains vertically-downward migration to an underlying limestone unit through a separating clay aquitard.

Multilevel Samplers (MLS) were sampled over three years to characterise the distribution of the multi-component hydrocarbon groundwater plume and geochemical indicators. A transient three-dimensional site-wide groundwater model was constructed, and alternative hydrogeological models were studied to identify the most plausible conceptual model generating the observed plume behavior and biogeochemical response. Hydrogeological and hydrochemical information were integrated into a two-dimensional cross-sectional reactive transport model assuming a multi-component dissolving NAPL source; using PHT3D (Prommer et al., 2003) for a selected 2D depth transect along the main flow direction. Physical transport and reactive model parameters were constrained using the chemical concentrations observed in the field. Over 100 calibration trials were undertaken.

Scenario-modelling showed that discontinuities in the clay aquitard could sustain the necessary vertical gradients without expressing as "sinks" in site-scale water table contour maps. Despite uncertainties, the reactive transport simulations were able to reproduce the general features of the observed MLS data. Toluene and the xylene isomers were virtually degraded within the LNAPL source area. Consistent with observed data, simulations showed sulphate was consumed at the plume fringe, and bicarbonate and methane were produced within the plume core. Steep gradients illustrated the effect of low dispersion coefficients. The reactive transport simulations show that calcium was consumed and calcite precipitated under methanogenic conditions. Methanogenesis accounted for 84% of the mass removed by biodegradation, while the remainder was due to sulphate reduction. Calcite appears to precipitate during hydrocarbon biodegradation due to the high concentration of bicarbonate and sulphate in the groundwater. This behavior differs from previously reported studies. The hydrocarbon plume in this study was evidently stable in its extent and the degradation reactions appeared sustainable.

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Coupling of unsaturated and saturated soil zone models to estimate groundwater recharge in mining areas

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ABSTRACT

The demand for energy efficient and sustainable management of the water balance in mining areas is high. Groundwater recharge is one component of the water balance that is especially important for the forecast of the vertical position of the groundwater table, which is needed for the assessment of different mining water management strategies. The aim of the EGSIM project is to couple models of the unsaturated and saturated soil zone to simulate groundwater recharge in a process-oriented way. The common method of using temporal average values for groundwater recharge cannot be applied to the task of modeling future climate changes because it does not consider the intensity and variability of precipitation. However, since the development of the water balance for mining regions has to be investigated over several decades, changing climatic conditions and their influence on the groundwater recharge have to be regarded.

Basis of the coupled model is the 3D groundwater simulation tool PCGeofim® (Mueller et al., 2003) which uses the finite volume method to simulate groundwater flow and transport processes in particular in mining regions. It is coupled with PCSiWaPro® (Graeber et al., 2006) which provides a transient upper boundary condition for PCGeofim®. PCSiWaPro® is a 2D model that simulates the water balance by using the Richard's equation for transient flow and solute transport processes in the unsaturated zone with regard to non-steady atmospheric boundary conditions. These atmospheric conditions are provided by applying a weather generator that uses Markov chain approximations to produce synthetic climate time series.

In order to couple both models and to take into account the interactions between the unsaturated and the saturated zone an interface and exchange parameters as well as the processes that drive this exchange have to be defined. As the natural interface between both soil water zones is the groundwater table, it is adopted as the modeling interface into the coupled model and therefore has to be represented by both individual models. PCGeofim® provides values of the changing groundwater table as exchange parameters which are used for the lower boundary condition of PCSiWaPro®. In return the flux over this groundwater table is passed to PCGeofim®. The differing model dimensions (2D and 3D) and the different spatial and temporal scales are specific problems that have to be regarded for the coupling. A methodology is currently being developed that tackles these difficulties. Its goal is to couple 2D models of the unsaturated zone with intersections of PCGeofim®. Evaluations using lysimeter data are conducted to verify the modeled groundwater recharge fluxes with measured data.

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Stochastic modeling of conservative transport in dual porosity media using finite cell method

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ABSTRACT

In this study a two-dimensional stochastic numerical model is developed to address the effect of physical heterogeneities on conservative transport in dual porosity media. The physical heterogeneities are represented by a spatially varying and correlated hydraulic conductivity field and interregional mass diffusion rate. The finite cell approach developed by Sun (1999) is adapted to solve the transport and reaction problems. The impacts of physical heterogeneities on mean behavior (i.e., mean concentration and mean spreading) are the focus of the stochastic analysis performed in this study. It is shown from the analysis that the heterogeneity of the interregional mass diffusion rate changes the concentration of the solute at the control plane by ±10% if compared with the homogeneous case.

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Modeling analysis for Mexico City aquifer based on measured data

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ABSTRACT

The growth of the population in Mexico City, demand increased amount of water day with day today for providing the vital fluid is resorted to the exploitation of sources, both internal and external, the aquifer of Mexico City, the dependency of groundwater extracted from wells makes it necessary to review the conditions of the aquifer for evolutionary in the aquifers conditions; these revisions are made from the depths of groundwater; measurements obtained values can infer the effect that brings with it the exploitation of this source and at the same time can implement actions to enable their recovery.

The main objective of this paper is to introduce a system that enables storage of information, analysis and visualization of measurements of static, dynamic levels and specific flow, as well as behavior in the Geographic Information System (GIS) to support a better understanding of the modeling of the aquifer and better decision making in the operation of the network of the Valley of Mexico wells GIS-based data measured.

Multi-temporal analysis of the evolution of groundwater is presented until 2009 of the aquifer of the Metropolitan area in Mexico City, for which the static and dynamic level of 225 wells measurement was made. Hydraulic balance of groundwater was performed to determine the degree of overexploitation. Changes for check in the static levels of the aquifer system from policies. The behavior of the aquifer was determined in recent years.

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An efficient solution technique for coupled simulating reactive transport in heterogeneous aquifers using mixed random walk/finite element method

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ABSTRACT

Solute transport model has been the subject of intense research effort in recent years. The motivations are contamination transport and groundwater pollution with a great social impact. Classical numerical solution methods of the pollutant transport equation required restrictive spatial discretization in order to avoid numerical dispersion. The reason for this behaviour lies in the double nature of the transport equation: convection term is hyperbolic while dispersion term is parabolic. This work illustrates an attempt of modelling contaminant transport using measurements. A finite element solution of two dimensional diffusivity equation forms the flow simulation, while a particle tracking random walk solution of the two dimensional convection-dispersion equation forms the basis of the transport simulation.

Comparisons with analytical and numerical solutions and experimental data shows the reliability and advantages of this solution and the random walk method offers a robust alternative for modelling contaminant transport, which represents both the convective and the dispersive transport by individual particle stepping.

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A comparison of body-fitted and immersed boundary methods for pore-scale modeling of fully saturated flow in synthetic porous media

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ABSTRACT

Pore-scale modeling of flow in porous and fractured media is a first key step to provide a firm knowledge basis for effective aquifer management practices in environmental applications or to improved reservoir performance in the oil and gas field. We present a performance comparison of two numerical approaches for the pore-scale simulation of fully saturated flow in natural porous media. Real samples of rocks at the millimeter scale whose complex pore space geometry is reconstructed through X-ray computer tomography are considered. The governing flow equation in the system are solved by employing a Body-Fitted (BF) grid and an Immersed Boundary (IB) method, as respectively embedded in FLUENT and EULAG (*Prusa et al*., 2008) software environments. The BF technique allows solving the flow problem within the real pore space and is widely adopted in computational fluid dynamics since it allows to fit complex geometries while preserving accuracy, up to a certain level of detail. The method is associated with some limitations in the presence of extremely complex geometrical setting of the kind encountered in natural or reconstructed micro scale porous systems, mainly due to the time-demanding mesh generation stage. On the other hand, IB methods can take full advantage of uniform Cartesian grid implementations describing both the fluid and solid regions in the domain. Grain size distributions are modeled by considering an additional forcing term in the governing flow equation. This term inhibits flow through the solid matrix and hence acts to enforce the no-slip condition at solid walls. The effectiveness of such term, i.e., its ability to prevent mass flow rate within the solid domain, is controlled by a parameter, α, which is directly related to the characteristic time scale of the forcing action. First, the performance of each model is analyzed separately on the same rock samples. Grid dependence is tested for the BF method upon comparing simulations at three different levels of resolution. A detailed sensitivity analysis is performed to assess the role of the parameter α in the IB method simulations. Finally, the two models are compared in terms of resulting flow fields, mass-conservation capability, hydraulic conductivity estimates and computational resources requirement.

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Dynamics of time variable infiltration, drainage, and water table fluctuations in layered soils and sloping sand beaches (numerical modeling)

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ABSTRACT

We present analyses of unsaturated and partially saturated flow in porous media, related to soil infiltration problems and to beach groundwater hydrodynamics.

We focus on the effects of heterogeneities (soil stratification, sloping interfaces, beach drainage systems) and on the effects of time variability in soil hydrology (time variable infiltration and ponding) and beach hydrodynamics (fluctuating water tables due to sea level oscillations at various frequencies, including tidal frequencies).

The study is conducted using numerical modeling approaches, and in some cases, quasi-analytical methods. Both unsaturated and partially saturated porous systems are analyzed. The emphasis is on the role of capillary effects in the unsaturated zone, and on the competition between gravity and capillarity effects, in the presence of forced oscillations and/or in the presence of geometric heterogeneity (capillary barriers).

The results of these investigations, in the case of oscillatory flow systems, will serve to back up an ongoing laboratory experiment of groundwater flow in a sandy beach represented in vertical cross-section (cross-shore). The theoretical and numerical modeling will be used to experiment numerically (beyond the conditions of the lab experiment) the geometric effects of beach slope[1], beach stratification, and beach drainage systems[2]. The effect of stratification will also be examined in the case of rainfall infiltration. The capillary barrier effect that may occur in several cases of interest, both in soil hydrology and in beach hydrodynamics.

Keywords: beach drainage, sloping soils, stratified and multilayered soils, infiltration, tidal oscillations, macro-porous media, richards unsaturated flow equation, numerical modeling

[1] In order to couple beach subsurface flow with the open water body in Richards equation, the open water reservoir will be represented by a special macro-porous body, as in Ababou & Trégarot (2002).
[2] Beach drainage is similar to hydro-agricultural drainage; it is a soft technique used for coast stabilization; it consists in lowering the water table using buried drains; the water collected by the drains system is pumped out to the sea.

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Partially saturated oscillatory flow under tidal conditions in porous column: Experimental results

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ABSTRACT

Surface/subsurface flow interactions concern a wide range of applications, from beach morphodynamics (swash zone), coastal aquifers (seawater intrusion and tidal effects), to harbour engineering and hydrology (e.g., man-made structures such as porous dykes and earth dams).

The aim of this paper is to study experimentally the oscillatory flows in partially saturated porous media (such as beaches) under tidal/low frequency forcing using a Darcy-scale laboratory experiment (tide machine) that has been designed and constructed at the Fluid Mechanics Institute of Toulouse (IMFT). The system generates low frequency waves on a partially saturated sand column by applying an oscillatory pressure (simple harmonic function) at the bottom boundary of the column. The measurement probes include mainly porous cup tensiometers to measure pressures both positively and negatively with respect to the atmospheric pressure. In this paper, the principles of this tide machine will be presented.

A series of more than 30 experiments on a sand column (1.5 m height) were conducted using this tide machine. For each experiment, we generate a tidal forcing with different amplitudes A_0, frequencies ϖ_0, and mean water levels h_0.

The results of these experiments will be presented and discussed. The pressure evolution and the phase lag along the 1D column will be investigated. The response of the water table height to the applied tidal forcing in terms of amplitude damping and phase lag will be analyzed.

Keywords: coastal hydrodynamics, oscillations, surface/subsurface interaction, unsaturated flow, laboratory experiment, tide machine, tensiometers, phase lag, damping

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Modeling transport of hydrocarbon contaminants in the groundwater of North Kuwait

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ABSTRACT

The environmental catastrophe brought by the 1991 Gulf War posed a serious risk to the quality of the already scarce fresh groundwater resources in northern Kuwait. Numerical modeling was used for identification of the source(s) and fate of the hydrocarbon pollutants in an attempt to complement the field investigations and laboratory experiments. This paper presents the modeling activities carried out in areas most contaminated. Specifically, the work involved aimed at (i) developing a conceptual model for the groundwater flow in northern Kuwait, (ii) developing a conceptual model for the transport of hydrocarbons in the study area, (iii) simulating the transport of the hydrocarbon contaminants in the fresh groundwater resources, and (iv) predicting the contamination levels in the groundwater in the future, should contamination levels persist in the soil and groundwater.

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Groundwater vulnerability and quality of Dezful plain

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ABSTRACT

The contamination of groundwater from point and non-point sources of pollution is one of the sensations of development countries such as Iran. The Dezful plain located in North of Khozestan, South West of Iran is under the rapidly growth in industrial, agricultural and urbanization. However the study area is under agricultural, where the farmers used heavy pesticide. The main sources of supply water for the area are river and groundwater. The management of groundwater especially, the vulnerability of Dezful plain is very important. This study presents the application and estimation of aquifer vulnerability by applying the DRASTIC model using Geographical Information System (GIS).

The DRASTIC model uses seven environmental parameters (Depth to groundwater, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone, and hydraulic Conductivity) to characterize the hydrogeological setting and evaluate aquifer vulnerability.

To validate the results of vulnerability map, sample of several water quality such as EC, TDS, PH, nitrates, nitrites and ammonia of study area's wells collected for two seasons, dry and wet. Based on results of DRASTIC model for the study area the North, North West and South West of the Dezful aquifer was dominated by High vulnerability classes while the other parts were characterized by low vulnerability classes. The high values of nitrates occurs and corresponding with high and moderate vulnerability class locations, however some parts of the high nitrate area corresponding to landfill location.

For the vulnerability zone assessment, based on resulted from the GIS interpretation and the high regional development consideration of the Dezful plain it is recommended that for area of high risk, pollution from agricultural lands should be under high attention, especially the contamination caused by pesticide on agricultural land should be limited.

In addition a conceptual groundwater model by using MODFLOW is underway to determine the flow and contamination movement of the Dezful aquifer.

Keywords: vulnerability, groundwater, Dezful, DRASTIC, GIS

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Simultaneous pollution source and hydraulic conductivity zone identification with linked simulation-optimization

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ABSTRACT

In this study, an inverse solution approach is proposed for simultaneous identification of unknown groundwater pollution sources and hydraulic conductivity zone structures. Many studies have provided methodologies about aquifer parameter estimation or groundwater pollution source identification separately, but only few studies deal with the simultaneous solution of both problems. Here, the proposed approach uses a linked simulation-optimization method to solve the problem. MODFLOW and MT3DMS models are used to simulate groundwater flow and contaminant transport processes. The hydraulic conductivity zone structure is identified using the fuzzy c-means clustering (FCM) approach. The association of hydraulic conductivity zone structures with the unknown pollution sources is accomplished through a linked simulation-optimization approach. The main objective of the linked approach is to determine the release histories of the potential pollution sources together with the hydraulic conductivity zone structures and homogeneous conductivities within the zones by minimizing the error value between simulated and measured hydraulic head values and pollution concentrations at available observation locations. In the optimization model, Particle Swarm Optimization (PSO) algorithm is implemented due to its efficiency in finding the global or near global optimum solutions. Since the solution is based on a heuristic approach, there is no need to define any initial values for the optimization procedure which is an important advantage of the proposed approach. The applicability of the identification procedure is demonstrated on a hypothetical problem setting. The performance of the proposed solution approach is first compared with previously developed Artificial Neural Networks (ANN), Genetic Algorithm (GA), and Harmony Search (HS) based solution models for the known hydraulic conductivity field conditions. Then, model performance is evaluated by solving the same problem for the unknown hydraulic conductivity field conditions. With this purpose, the problem is solved for different number of zone structures until reaching the best solution in terms of the final objective function value. Further, the model performance is also evaluated by considering measurement errors. The identified results indicate that the proposed solution approach provides identical or better results than ANN, GA and HS based solution models for the known hydraulic conductivity field and can also be used for the cases where any information regarding hydraulic conductivity field does not exist.

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Optimization of flow modeling in fractured media with discrete fracture network via percolation theory

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ABSTRACT

Fractured media are very heterogeneous systems where occur complex physical and chemical processes to model. One of the possible approaches to conceptualize this type of massifs is the Discrete Fracture Network (DFN). Donado et al. (2005) modeled flow and transport in a granitic batholith based on this approach and found good fitting with hydraulic and tracer tests, but the computational cost was excessive due to a gigantic amount of elements to model. We present in this work a methodology based on percolation theory (Berkowitz, 2002) for reducing the number of elements and in consequence, to reduce the bandwidth of the conductance matrix and the execution time of each network.

DFN poses as an excellent representation of all the set of fractures of the media, but not all the fractures of the media are part of the conductive network. Percolation theory is used to identify which nodes or fractures are not conductive, based on the occupation probability or percolation threshold. In a fractured system, connectivity determines the flow pattern in the fractured rock mass. This volume of fluid is driven through connection paths formed by the fractures, when the permeability of the rock is negligible compared to the fractures. In a population of distributed fractures, each of this that has no intersection with any connected fracture does not contribute to generate a flow field. This algorithm also permits us to erase these elements however they are water conducting and hence, refine even more the backbone of the network.

This percolation theory seeks to find a network of conductive fracture smaller than the original, but without departing from the actual behavior of the fluid in a fractured medium and thus improve the calibration of the flow inverse modeling done with TRANSIN IV. Donado (2000) used 100 Different generations Fracture Network (DFN) that were optimized in this study using percolation theory. In each of the networks calibrate hydrodynamic parameters as hydraulic conductivity K and specific storage coefficient Ss, for each of the five families of fractures (tectonic defined criteria), yielding a total of 10 parameters to estimate, at each generations.

The 100 DFNs used have the following characteristics: (i) they are not a trellis system, this means that a 3D system fractures do not follow a path of any geometric shape known as a cube, diamond, or honeycomb; (ii) from any node can leave many items to other nodes (Fig. 1); (iii) the length of failure of

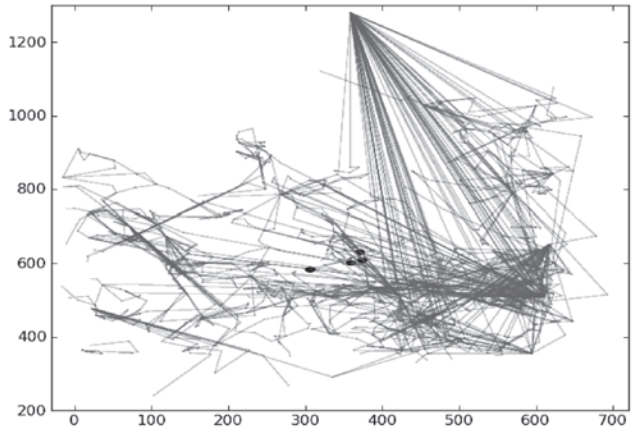

Figure 1. XY plane projection of any network.

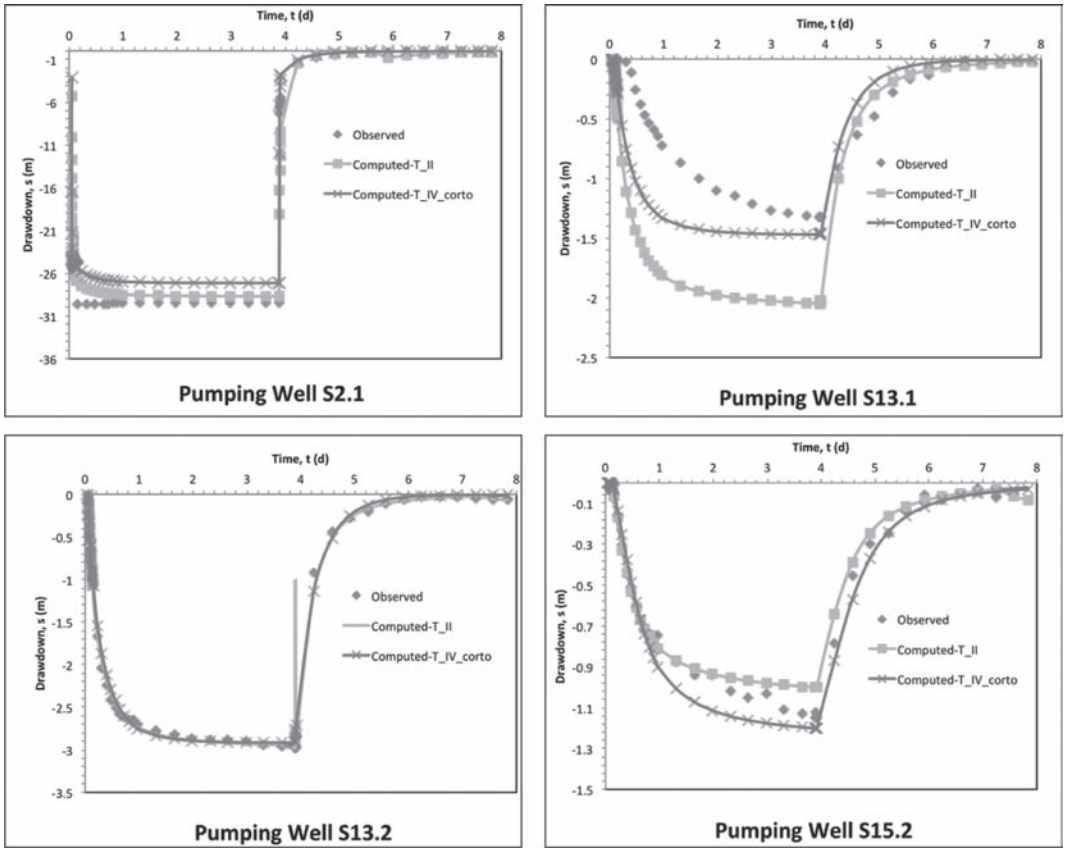

Figure 2. Comparison among fitting results of hydraulic tests in El Berrocal site.

these fracture networks are not standardized and is constant, this means that on average, the minimum length is 23 m and found the maximum length is 955 m; (iv) the fracture networks are contained in a real finite system known limits, with approximate dimensions of a rectangular $710 \times 1040 \times 576$ m. With these features the fractal dimension of this large cluster (which determines the spatial distribution of network connectivity) and the fractal dimension of the backbone (which determines the flow path) are different from those predicted by the classical theory of percolation.

Since the effect of the distribution of fault orientation changes the value of the percolation threshold, but not the universal laws of classical percolation theory, the latter is applicable to such networks. Under these conditions, percolation theory permits to reduce the number of elements (90% in average) that form clusters of the 100 DFNs, preserving the so-called backbone. In this way the calibration runs in these networks changed from several hours to just a second obtaining much better results (Fig. 2).

Green line represents the previous results using all the fractures and purple line shows new results with optimized fractures.

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Characterization of heterogeneous subsurface environments

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Groundwater Modeling and Management under Uncertainty – Hadi & Copty (Eds)
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Keynote speech

A new approach to hydrological scaling

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ABSTRACT

The literature indicates that many hydrologic (as well as other) variables exhibit isotropic and directional dependencies on scales of measurement, observation, sampling window, spatial correlation, and spatial resolution. Attempts to explain such scale dependencies have generally focused on observed and/or hypothesized power-law behaviors of corresponding structure functions. Doing so has revealed a tendency of such functions to exhibit nonlinear power-law scaling in a midrange of separation lags, breakdown in power-law scaling at small and large lags, extension of power-law scaling to all lags via a procedure known as Extended Self Similarity (ESS), apparent lack of compatibility between sample frequencies of data and their increments, and decay of increment sample frequency tails with increased separation scale or lag. Existing scaling models capture some but not all of these phenomena in a consistent manner. We describe a new scaling model that does so within a unified, self-consistent theoretical framework. The framework is based on the notion of sub-Gaussian fields (or processes) subordinated to truncated fractional Brownian motion (tfBm) with heavy tailed subordinators such as log-normal or Lévy. As tfBm is a truncated version of additive, self-affine, monofractal fractional Brownian motion (fBm), corresponding nonlinear power law scaling is not an indication of multifractality (as commonly assumed in the literature) but an artifact of sampling. We illustrate our new approach to scaling on synthetically generated as well as published laboratory and field scale log permeability data.

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Nuclear magnetic resonance and high density resistivity method in near-surface groundwater exploration

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ABSTRACT

Geophysics for hydrogeology plays an important role in groundwater investigation. It is necessary in the stage of regional, medium or large scale regional geological reconnaissance. However, confined by the capability of instruments, which are built on the basis of different method, the inversion of sounding could only reach to the stage of reasonably conclusion. Recent years, with the rapid development in the field of geophysics, some high accuracy and stability means have been introduced into groundwater exploration. They are capable of decreasing uncertainty which is frequently occurred in some routine means. To an extent, they are able to conduct accurate geophysical exploration and increase efficiency of geological reconnaissance greatly.

Subsurface contamination and remediation

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Removal nitrate, arsenic and cadmium pollution by iron nano particles in groundwater

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ABSTRACT

A population growth in Iran in last decades and consequently the development of urban, agriculture and industrial sectors cause the groundwater contamination in many areas of this country. This paper presents the results of a set of researches during four years on groundwater remediation by Zero-Valent Fe Nano particles in laboratory scale. This method is an innovative, efficient and economic method for in-situ groundwater remediation. The nitrate, arsenic and cadmium pollutants have been selected as a representative of some contaminated aquifers in this research. In the first step, the batch experimental has been applied to understand the process of nitrate, arsenic and cadmium removal at different times, concentrations and pH. Then the soil column experimental setup in homogenous and heterogeneous conditions has been used to examine the efficiency of injected Zero-valent Fe nano particles to remediate the contaminants in saturated porous media. The results show that Fe nano particle is a useful tool for reduction the rate of nitrate, arsenic and cadmium. By this research we can propose this method in a real case aquifer remediation.

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Chromium contamination in groundwater in Kanpur Dehat and its environs, Uttar Pradesh, India: A case study

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ABSTRACT

Groundwater pollution resulting from land disposal of untreated liquid and solid wastes has become a matter of serious concern. At present, contamination of groundwater by toxic constituents has become one of the major environmental problems about which awareness has come only during the last few years.

Kanpur Dehat (Rania Industrial area) and its proximity form a part of the Central Ganga alluvial plain and are underlain by a thick sequence of Quaternary alluvial deposits. The constituents are essentially clay and silt which at times are admixed with kankar (Calcareous nodules) and sands.

The present spot investigation has identified that the level of chromium (Cr^{+6}) in groundwater exceeds 0.110 mgl^{-1} at several localities of the Rania Industrial area attaining as much as 42.453 mgl^{-1} in the depth range 15 m to 40 m below ground level. The lower limit of the permeable top unconfined aquifer zone which, in turn, is underlain by persistently thick impermeable clay bed acting as a barrier to the percolating contaminated ground water. The maximum permissible limit for chromium (Cr^{+6}) is 0.05 mgl^{-1} in drinking water.

The prime cause of chromium pollution in ground water of the area is that Chromite (Cr_2O_4), an ore for chromium. Chromite is used for making dyes which are used in textile mills, tanneries etc. The chromite refuge ore is dumped indiscriminately on the ground which with the action of water percolates down and contaminate the phreatic aquifers in the area which have enriched concentration of Cr^{+6} the ground water at the specific location is observed to have higher level of toxic elements.

The high chromium in drinking water may cause corrosive action on skin and mucous membrane. Chromium and its compounds are known to cause cancer of lungs, nasal cavity and paranasal sinus and suspected to causing cancer of stomach and larynx.

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An experimental study on the denitrification of leachate continuously loaded from a municipal waste landfill

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ABSTRACT

In Japan, a huge amount of municipal solid waste has been directly dumped in landfills before issuance of the waste management and public cleansing law in 1970. It is estimated that more than 1,500 such landfill sites are distributed nationwide. Leachate from waste-dumped landfills shows completely different water quality from ordinary groundwater runoff as well as from municipal sewage waters. Most of the organic matter and phosphorous are filtered out and oxygen is completely consumed in the course of retention, infiltration and through travelling underground. On the other hand, ammonia nitrogen is the dominant pollutant components with extremely significant loads. Several denitrification technologies have already being developed in the field of sewage water treatment, where carbon and phosphorous originally contained in the water play important roles in the treatment process. However such conventional techniques cannot be applied to the treatment of leachate, since both carbon and phosphorous are missing from the leachate.

The field site in this study is a municipal waste landfill located in a mountain area in Kobe City, where huge amounts of municipal solid waste was dumped in the 1960 to 70s. During the first twenty years after the landfill construction, the leachate yielded significant ammonia load. Ammonia concentration has now decreased to a certain level but it still exceeds the target level from time to time. So far, the leachate has been denitrified in a treatment plant where methanol and phosphorus are artificially fed to nourish the denitrification bacteria. Such a concentrated treatment facility is economically feasible in the case of a young landfill but it is no longer in a case with aged landfills like the present case. The plant is now aging and needs to be replaced as soon as possible by an alternative facility that is more economic, energy-saving and free from maintenance.

Nitrogen removal techniques consist of two stages; the nitrification and denitrification processes. This study is to focus on denitrification and a laboratory experiment was carried out in order to develop an alternative technology for leachate denitrification. It has already been found from the authors' preliminary experiment that hydrogen feeding agents show high performance in activating denitrification bacteria as a carbon resource as well as acting as a reducer. The experiment was carried out in a closed test tank. However, the prototype leachate reservoir is an open system in which leachate inflow is continuously loaded from the catchment to the reservoir. In order to simulate an experiment closer to the prototype, an improved experimental model was devised in this study, where leachate was continuously fed to the test tank. What was investigated was how the denitrification rate depended on relating parameters such as leachate inflow discharge, hydrogen feeding agent, microbe-bound carrier and other additives. A functional dependency of denitrification rate on inflow discharge was quantitatively confirmed, which provides useful information for determining the dimensions and capacity of the alternative treatment plant. In addition, the hydrogen feeding agent was found to be a promising material for constructing a cost-saving and maintenance-free facility for leachate treatment. Based on the present experiment, a design concept for the leachate treatment system was proposed as well.

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Detection of groundwater contamination by solid waste leachate using electrical resistivity method and geochemical analysis

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ABSTRACT

Groundwater is the main source of drinking water and it has a vital importance in developed and developing countries. Nearly 80% of all diseases arise as a result of using unsafe and contaminated water. Dumping of solid waste in unscientific manner and discharge of sewage effluents are the main reasons for contamination of groundwater. The main dumping sites of Chennai are Perungudi, South Chennai, and Kondungaiyur, North Chennai. Perungudi dumping yard is one of the major municipal solid waste dumpsite of Chennai and started functioning since 1987. In the recent past, it is found that the site is subjected to many environmental changes. On an average 1500 ton/d waste has been dumping in open dumpsite. The precipitation seeps through the solid waste, producing contaminated water referred as leachate. Due to infiltration and normal flows of the groundwater, the leachate extends away from the dumpsite causing further contamination. The people living near the dumpsite face many problems due to contaminant groundwater source. Geochemical analyses were carried out in which it was found that the contamination is very high within half a kilometre from the dumpsite. As the groundwater flow in the area is towards east, the spread of contaminants are also towards east of the dumpsite. Several parameters such as pH, TDS, Cl^- and Pb were analysed. TDS was 6780 mg/l 0.34 km and 290 mg/l at 1.5 km from the dumpsite. Hence, this project aims to detect and monitor the polluting effect of the Perungudi dumpsite on the aquifer as well as to assist in the reduction of groundwater contamination practices and suggest appropriate remedial measures which will be useful for betterment of people living near the dumpsite. Geophysical techniques of investigating the composition, structure and nature of the subsurface have reached a high degree of sophistication with the convergence of the need to investigate the earth for scientific and societal problems. The electrical resistivity technique is particularly suited for the detection of ionic impurities in groundwater owing to the Resistivity Contrast between the polluted zone and the host rock. It is faster and more economical than going through the process of drilling to the target formation. Geophysics provides spatially integrated information, which may be superior for some purposes to the point data provided by drilling. The Electrical Resistivity method provides a veritable tool for mapping the degree and the immediate subsurface vicinity. It is a fast, economic, and non-invasive method of studying ground water contamination, as well as other environmental issues and it has proved to be promising and useful as predicted. The method is not used to directly detect contaminants. Rather, it is used in the investigation of the geological environment through which the contaminants move, and in the determination of the distribution of pollutant in space and time through monitoring.

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Modeling of nanoparticle fate and transport in saturated porous media

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ABSTRACT

In recent years nanoparticles have been proposed for numerous applications including in-situ groundwater remediation. A critical step for the development of such a technology is the effective deliverability of the nanoparticles suspension to the zone of contamination. Because of their relatively high surface energy, bare nanoparticles may undergo significant aggregation and deposition within the porous media, thereby limiting its transport. To enhance the mobility of engineered nanoparticle, surface coating with various materials have been considered. This paper reviews the state of the art understanding of engineered nanomaterial fate and transport processes and the factors influencing nanoparticle transport in porous media. In particle we examine the effect of nanoparticle concentration on its mobility. The nanoparticle considered in this study is Poly(Acrylic Acid) (PAA) supported magnetite (Fe_2O_3). The transport experiments were conducted in a water-saturated sand-packed column for nanoparticle suspensions. Particle size analysis of the synthesized nanoparticle solutions showed that PAA provides good size stability. Time-moment analysis of the nanoparticle breakthrough curves, on the other hand, revealed that nanoparticles mass recovery from the column decreased consistently with dilution, with greater attenuation, sharper fronts and longer tails compared to that of the tracer. To further interpret the experimental results, a nanoparticle transport model that accounts for deposition/detachment kinetics was developed. The best agreement between the observed breakthrough curves and model simulations was obtained using a kinetic time-dependent deposition term with finite deposition capacity and a kinetic detachment term. The model results suggest that the decrease in mass recovery with decrease in input particle concentration may be due to time-dependent blocking that hinders further deposition. The implications of these results on the use of engineered nanoparticles for groundwater remediation applications are discussed.

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Modeling the local effective dispersivity to deal with the limitations of the Advection-Dispersion Equation

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ABSTRACT

Although predicting the fate and transport of pollutants in the subsurface is basic in many environmental problems, mass transport modeling remains as a challenging subject of research. This is due to the limitations of the classical Advection-Dispersion Equation (ADE) approach applied to model mass transport. Anomalous transport is usually the expression applied when the ADE fails to reproduce real field as well as small-scale lab experiments. To solve this problem some authors model hydraulic conductivity (K) heterogeneity at very high resolutions with the support of stochastic simulation techniques. Besides, the non-Fickian behavior of transport is another issue addressed. However, the effects of the spatial variability of dispersivity, and the influence of the model support scale on this property, have been rarely study. Moreover, dispersivity is always modeled as an averaged calibrated parameter highly correlated with the model discretization size. This is mainly due to the lack of experimental knowledge on this basic parameter.

In order to study the local behavior of the dispersivity a laboratory prototype, a porous medium tank, was designed and built at the Technical University of Valencia (Spain). This paper presents some results and conclusions obtained from a detailed analysis of a solute transport intermediate scale experiment conducted in this lab tank. The flow within the porous medium tank lab is quasi-2D with steady state conditions. The porous medium hydraulic conductivity (K) field imitates the patterns of spatial variability found in a real and highly heterogeneous formation (MADE2 site experiment). The solute transport tests are run using a visible and conservative dye tracer. The tank is monitored through a grid of pressure transducers and by the sequence of digital images that are processed to map the evolution of solute concentrations in the tank. The whole system is controlled from a computer that records pressure and images data. The set of exhaustive head and concentration data is then used to obtain detail local information of the effective dispersivity field at different time steps, and at different support scales.

We have found that the dispersivity field displays patterns of spatial variability that are related with the physical nature of the local material and also with the local evolution of concentrations at every grid block. In fact, the anomalous transport behavior observed in the lab tank can be accurately modeled using the classical ADE if the dispersivity field identified from the lab measurements is used. Besides, when this exhaustive information is processed to identify the dispersivity field at different support scales, it is found a strongly dependence of dispersivity with respect to the discretization size. When the blocks size increases there is a smoothing effect that prevents a good reproduction of concentration observations by means of the ADE equation. This highlights the crucial influence of a detailed modeling of the dispersivity field to deal with the limitations of the ADE.

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Sustainability of irrigation with Barapukuria coal-mine drainage, NW Bangladesh: An environmental impact study

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ABSTRACT

Barapukuria Coal Mine (BCM), the country's first mine is in production since early 2005. Since implementation, the mine is facing groundwater inrush problem and the authority is dewatering it at a rate of 1594 m^3/h (normal water flow) up to 2636 m^3/h continuously to keep it fit for production. The mine drainage is treated primarily to settle the suspended solids, mainly fine coal particles or sludge, before releasing into canal outlet which local farmers use for irrigation purpose and as a result groundwater level in the area went down since mining started. The study was taken to investigate the environmental pollution by mine drainage and its sustainability for irrigation. Eight mine drainage samples were analyzed for major cations (Na, K, Ca and Mg), anions (SO_4, Cl, HCO_3, CO_3 and NO_3^-) and minor and trace elements (Fe, Mn, B, Cu, Zn, Pb, Cd, Hg, Co and Mo). Twenty paddy field soil samples collected at three different depth intervals from mine water irrigated and non-irrigated zones surrounding the mine and a mine sludge sample were analyzed for organic matter content, pH, nutrients (N, P, K, S, Ca, Mg, Fe, Mn, B, Zn, Cu and Mo) and toxic heavy metal (As, Pb, Hg and Cd). Nutrient contents (P, K, S, Ca, Mg, Fe, Mn, Zn and Cu) and non-essential heavy metal (As, Pb, Cd and Cr) of two composite samples of root, stem, leaf and grain of rice plant from two respective zones were also determined. The mine drainage is classified as normal chloride, normal sulfate, normal carbonate and very hard types showing calcium-sodium and bicarbonate and bicarbonate-chloride-sulfate cation and anion facies. No deleterious effects are found on soil chemistry and rice plant tissue in both mine water and non-mine water irrigation area, and therefore rice grains are safe for human consumption. So coal mine drainage has suitability, and hence sustainable for irrigation uses keeping the mine drainage quality at present level.

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Groundwater bioremediation using solid oxygen sources

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ABSTRACT

The effectiveness of the solid oxygen sources technique that is used to enhance bioremediation of contaminated groundwater sites is evaluated in this paper. The finite element model (METABIOTRANS), which simulates the fate and transport of contaminants in the subsurface, is used in this assessment study. Several scenarios were simulated to examine the sensitivity of remediation effectiveness to the number and locations of oxygen sources. Results show that an injection source placed near the plume core, where highest contaminant concentrations exist, is always desired. The nearest injection oxygen source to the contaminant source zone caused higher stimulation to bacterial growth than further down-gradient injection oxygen sources. It also exhibited longer resident time of the oxygen in the aquifer; and therefore, yielded higher biodegraded contaminant mass. Higher injection rates of oxygen are not always needed to increase bioremediation efficiency. This should be noticed in real practices of groundwater remediation design.

Keywords: groundwater, in-situ bioremediation, modeling, solid oxygen source

Groundwater is a vital resource of water, in some regions of the world the only source of fresh water. Its use for domestic use and agriculture dates back thousands of years. In recent decades the over-exploitation and unabated use of this resource has lead to severe environmental problems such as resource depletion, land subsidence and groundwater contamination. To mitigate these adverse impacts and protect this valuable resource, it is imperative that rational groundwater management practices and policies as well as robust modeling and analysis tools be developed.

This volume and the accompanying USB memory card include the abstracts and full papers that were presented at the 6th International Groundwater Symposium that was held in Kuwait between 19 and 21 of November, 2012. The Symposium was jointly organized by the Kuwait Institute for Scientific Research and the Groundwater Hydraulics and Management Committee of the International Association for Hydro-Environment Engineering and Research (IAHR). More than 100 researchers, engineers, geologists and water specialists from more than 20 countries attended the Symposium to exchange ideas and expertise relating to the latest developments in the field. The papers presented at the Symposium were organized under the following themes: modeling and management under uncertainty, sustainable groundwater management in arid and semiarid environments, Aquifer Storage and Recovery (ASR) as a groundwater management tool, management solutions for groundwater rise problems, flow and transport modeling, and subsurface contamination and remediation.

This volume provides a state-of-the-art discussion of the latest issues relating to groundwater exploration, management and protection, with an emphasis on bridging the gap between research practice and policy. The volume will serve as an important reference to students, researchers, modelers as well as practitioners and policy makers.

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