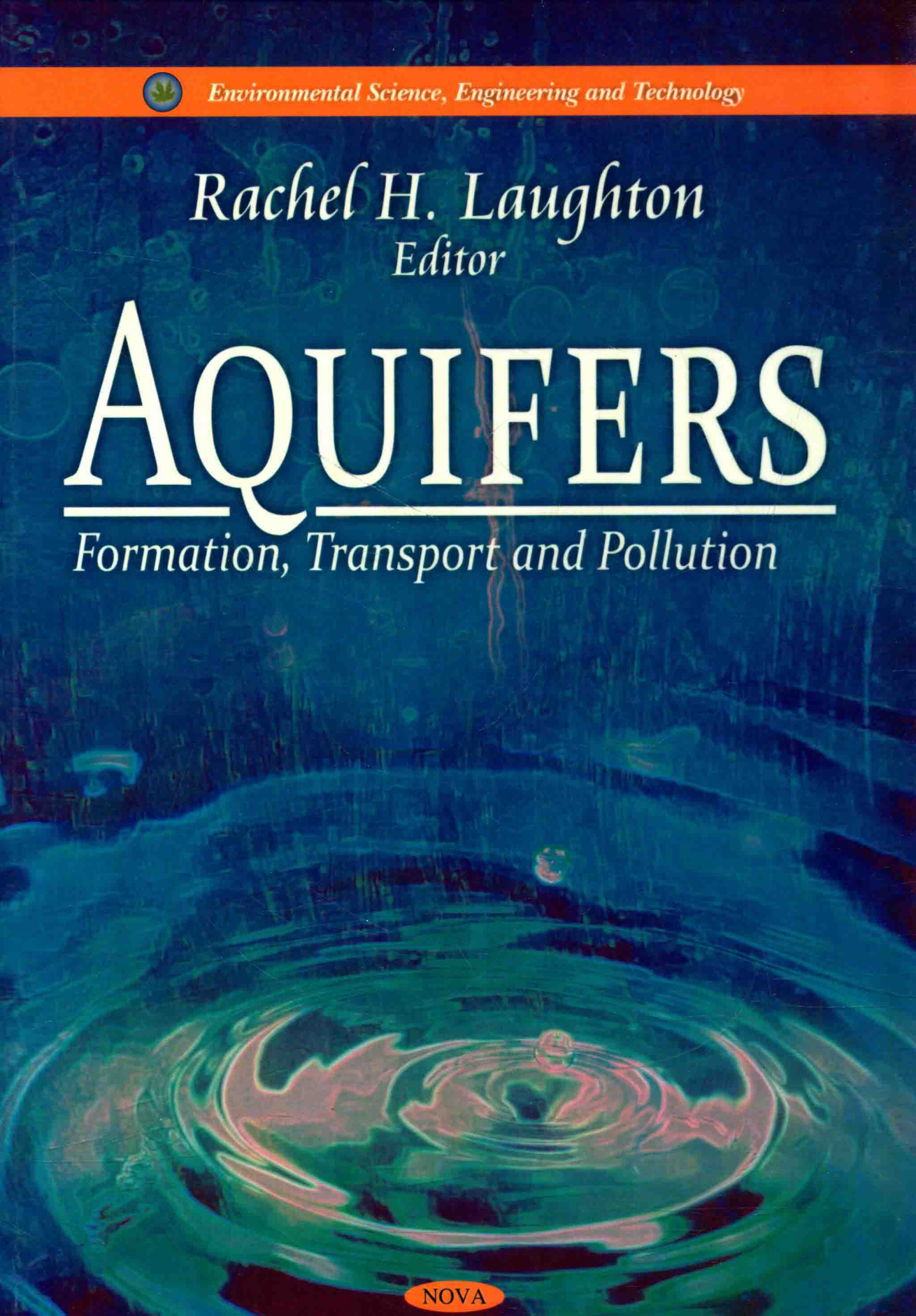
Environmental Science, Engineering and Technology
Rachel H. Laughton
Editor
AQUIFERS
Formation, Transport and Pollution
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ENVIRONMENTAL SCIENCE, ENGINEERING AND TECHNOLOGY

AQUIFERS

FORMATION, TRANSPORT AND POLLUTION

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PREFACE

An aquifer is an underground layer of water-bearing permeable rock or unconsolidated materials (gravel, sand, silt, or clay) from which groundwater can be usefully extracted using a water well. The authors of this book present important data on aquifers such as: hydrogeological studies of various dolomite aquifers in Slovenia; (GIS)groundwater modeling as an integrated tool for sustainable management of groundwater resources under changing environments; investigating different groundwater systems occurring in Brazil; an analysis of past catastrophic hydrogeological events (landslides and floods) and their affect on groundwater and aquifers and how to mitigate their damage.

Chapter 1- Human security in most drylands hinges on the accessibility of safe groundwater. The presence of ammonium and nitrate in many geologic formations renders both their runoff and seepage unfit for human consumption. As the inhabitants of downstream areas depend on such waters for their very survival, they have to accept the risk of affliction with diseases caused by the consumption of a relatively small concentration of nitrate nitrogen (10 mg pre liter, according to the USEPA and WHO). Phytoremediation of N-polluted water is an environmentally safe and economically viable scheme to supply affected desert communities with safe groundwater. River red gum (*Eucalyptus camaldulensis* Dehnh.), which is adapted to the hot desert environments, is a good candidate for N filtration from groundwater. This deep-rooted evergreen tree that explores the vadose zone down to the phreatic fringe is particularly suitable for the Mediterranean climates where deciduous trees are dormant during the rainy season. Planting the artificial recharge of groundwater sedimentation basin to the river red gum for enhancing the hydraulic conductivity of the vadose zone and environmental amelioration has had the added benefit of nitrogen filtration from the recharge water. While the floodwater on average contains >13 mgL^{-1} of nitrate-N, the red gum-filtered groundwater contains 1.60 mgL^{-1} of the same element. Both field and laboratory bioassays and well water sampling have proven the phytoremediation potential of this useful tree.

Chapter 2- Some recent hydrogeological studies of various dolomite aquifers are presented in this chapter. Slovenia presents an ideal polygon for such a study, as more than a 7 km thick sequence of almost non-interrupted carbonate deposition had occurred. Within those depositions, at least 15 different dolomite sequences can be distinguished based on their lithological, geochemical and other properties.

The knowledge of analyzed data distribution is crucial for any further statistical investigations, so the distributions of hydraulic parameters are discussed primarily. Of major

importance are the hydraulic parameters of the dolomites. Variations of these parameters can be attributed to many factors. The influences of eight factors (lithological properties of dolomites, their age, proximity to rivers, topography setting, well depth, depth to water table, degree of penetration and existence of low permeability overburden) on the five hydraulic parameters (hydraulic conductivity, transmissivity, specific capacity, specific capacity index and maximum yields) are presented. Significant differences among these parameters can be applied to the diagenetic origin of the dolomites, topographic setting and other factors, and values of hydraulic properties of matrix and fractures can be easily distinguished.

Some approaches are also of practical importance. Transmissivity and hydraulic conductivity are usually calculated from time and cost consuming pumping tests. Estimation of both parameters can be also done by quicker methods. Transmissivity can be for example estimated from the specific capacity, and hydraulic conductivity from the specific capacity index. Such studies have been generally known for alluvial aquifers, but not for dolomites, as in this study.

Much of the chapter is devoted to the analysis of flow dimension in dolomites, which represents a novel, fractal-based parameter in the study of flow and transport in fractured rocks. Observable differences in the values of flow dimension can be applied to lithological properties of dolomites, bed thickness, and to their geochemical properties and purity. No correlation of flow dimensions is observed with fractal dimensions of fracture networks. However, the observed values of flow dimensions are much lower than the overall fractal dimensions of available fractures, and this can be explained by the channeling and karstification effects; the water flow in the fractures can not take place in all fractures to fill the entire available fracture space, but is concentrated into smaller channels inside the fractures and consequently reducing the values of flow dimensions.

Though the results of this study relate to Slovenia, the analyzed aquifers extend into neighboring European countries, and the presented results might therefore be of wider significance, as they can be applied to other dolomites.

Chapter 3- Groundwater is a treasured earth's resource. Unfortunately, the worldwide groundwater overdraft or aquifer depletion, declining well yields, drying up of springs, streamflow depletion, and land subsidence due to over-exploitation of groundwater as well as the growing degradation of groundwater quality by natural and/or anthropogenic pollutants and by saltwater intrusion are threatening our ecosystems. Global climate change and socio-economic changes can further complicate the future use of groundwater and enhance stress on aquifer systems. Thus, anthropogenic and natural changes of groundwater situation can cause severe disasters and detrimental effects to society and environment. Groundwater being hidden and available in complex subsurface systems warrant for efficient tools and techniques for its sustainable management. Groundwater modeling has emerged as a powerful tool to help managers optimize groundwater use as well as to protect this vital resource. Besides the advances in modeling techniques, the recent proliferation of GIS technology, digital terrain or digital elevation models (DTM/DEM), spatial data sets, and powerful desktop computers has enabled rapid progress in the development of quantitative research tools. As more and more hydrologic and hydrogeologic data are collected, it is important that the data be assimilated into forms that are easily accessible by the models. Therefore, computer systems that can model groundwater systems and have capability to manage a vast quantity of data are essential, which can offer more accurate and versatile groundwater modeling tools.

The main intent of this chapter is to highlight geographic information system (GIS) and groundwater modeling as an integrated tool for sustainable management of groundwater resources under changing environments. First of all, an overview of GIS is presented followed by the fundamentals of modeling with a focus on groundwater modeling. Emphasis is placed on understanding the basic concepts of GIS and groundwater modeling as well as on their proper applications. Thereafter, different applications of GIS in groundwater modeling are succinctly discussed, together with the current status of GIS-based groundwater modeling. Guidelines for the GIS-based modeling of diffuse pollution and the words of caution for GIS-based modeling are also provided. Finally, important issues of distributed hydrological modeling in general and GIS-based modeling in particular are highlighted. It is concluded that although groundwater modeling using GIS has proved to be useful, the current applications of GIS in groundwater modeling are very limited. More and more studies in this direction are required under various hydrogeologic conditions along with the studies addressing important issues of GIS-based groundwater modeling.

Chapter 4- The Earth's water is always in movement, and the water cycle (hydrologic cycle) describes the continuous movement of water on, above, and below the surface of the Earth. Water can change states among liquid, vapor, and ice at various places in the water cycle, with these processes happening in different time scales. Thus, the water cycle describes the processes that drive the movement of water throughout the hydrosphere, whilst a reservoir represents the water contained in different steps within the cycle. The largest reservoir is the collection of oceans, whereas the third is groundwater. The average time a water molecule will spend in a reservoir is the residence time, which usually ranges from 100 to 200 years in shallow groundwater but over 10,000 years in deep groundwater. In general, there is a relationship between the mineral composition of natural water and that of the solid minerals with which the water has been in contact. This relationship may be comparatively simple and uncomplicated, as in the case of an aquifer receiving direct recharge by rainfall and from which water is discharged without contacting any other aquifer or other water. Or the situation may be rendered very complex by influence of one or more interconnected aquifers of different composition, mixing of unlike waters, chemical reactions such as base exchange, adsorption of dissolved ions, and other factors like anthropogenic inputs. This chapter reports how different techniques can be utilized to investigate the water movement in different aquifer systems occurring in Brazil. Conventional methods to determine the hydraulic conductivity will be described, as well the use of the natural uranium isotopes ^{238}U and ^{234}U to investigate the groundwater flow and hydrogeochemical reactions taking place along it.

Chapter 5- This study's approach is based on the analysis of past Damaging Hydrogeological Events (DHEs), which can be defined as periods characterised by heavy rainfall inducing such damaging phenomena as landslides and floods. The proposed work is focused on the relationships between these phenomena and the characteristics of triggered rainfall, to supply useful suggestions for early detection and damage mitigation. The analysis of past DHEs allows for the characterisation of the main types of DHEs, which affected a selected area in the past and could affect it again in the future.

The characterisation is based on triggering scenarios (meteorological conditions preceding the occurrence of DHEs), DHE's effects (damage caused by landslides and floods) and triggering factors (rainfall of different durations). Based on these characteristics, the typical DHEs affecting a study area can be ranked according to their severity, and specific emergency management can be planned to successfully manage them.

In order to obtain results that have a reliable statistical meaning, a large amount of data of three different types (meteorological, rainfall and damage data) must be studied, and some indices, allowing the comparative analysis of these kinds of data, have to be introduced.

After a description of the methodology, which can be applied in different climatic and anthropogenic contexts, some applications of the proposed method to the region of Calabria (South Italy) are presented.

Chapter 6- The Lower Tagus Basin occupies a large area of Portugal, from the coastal region of Lisbon and the Setúbal Peninsula, to beyond the Spanish border. It is a symmetrical, western counterpart of the large Upper Tagus Basin in the west which is centred in Madrid (Spain). Palaeogeographical reconstruction for the Basin, in Portugal, proposes the existence of a large, tectonic, closed depression filled by coarse deposits coming from the surrounding mountains. In the sedimentary rocks a complex heterogeneous and anisotropic aquifer system has been formed. The presence and the properties of this aquifer system are strongly influenced by the internal geological structure and evolution of the basin during the Cenozoic. This system is made up of an alternating sequence of confined, semiconfined and unconfined aquifers located in the conglomerates, sands, sandstones and limestones, as well as, aquitards and aquicludes in the silts, clays and marls. Sediment heterogeneity in the basin strongly influences groundwater flow path, velocity, transmissivity and yield. Regional changes in groundwater chemistry reveal the direction of flow paths and give an indication of the residence time in the flow system. This aquifer system has along been a source of concern because of the high level of extraction over the last few decades, as well as the progressive degradation of the water quality. Available groundwater resources have been affected by intensive agricultural and industrial activity.

This research on aquifers formation in the Tagus Sedimentary Basin was based on geological, hydrogeological, hydrochemical, geophysical and climatic data, which resulted in a vast amount of information that was included in specific reports gathered from Portugal Geological Survey (LNEG), National Water Institute (INAG), Meteorological Institute (INMG) and Oil Research Department (GPEPE), and from an inventory of springs and wells in the area.

Chapter 7- Groundwater plays a pivotal role in socio-economic development of the Gangetic Plains underlain by some of the most prolific aquifer systems of Indian sub-continent. A wide variation is however, observed in hydrogeological framework and aquifer potentiality in the southern part of the river Ganga. Present research has been carried out in a 1960 km^2 area, where the Quaternary deposits thickens towards north, from <5.0 m bordering the exposed Precambrian in the south, to >400 m along the northern boundary, where the geometry, hydraulic parameters and behavior of water levels of the aquifers have been investigated. The Holocene deposits are marked with fine to medium grained well sorted sand with subordinate clay and sandy clay, covering 15% of the area, adjoining the northern border. The Pleistocene deposits are predominantly argillaceous in the southern part with shallow bedrock (<140 m below ground). Lithofacies analyses indicate northward increase of sand percentage in the deeper bedrock areas. A two-tier aquifer system has been delineated, of which the deeper one contributes >90% of the gross annual draft (403.92 mcm/year). The low-potential shallow aquifer is ~30 m thick, predominantly argillaceous with thin (1.5-3.5 m) sand lenses. The hydraulic head of the deeper aquifer system rests at lower level than the shallow counterpart during the pre-, the mid- and the post-monsoon. Hydraulic conductivity of the deeper aquifer has determined by pumping tests and its spatial variation has been

ascertained. The deeper aquifers are vertically divided into 2-4 units in the southern part in areas where bedrock rests at <120 m bgl. As the bedrock surface dips northwards, the thickness of the intervening aquitards reduces and pinches out, forming a thick deeper aquifer system (>200 m). A groundwater trough spread over 110 km^2 during the pre-monsoon resulting from over-exploitation to the tune of 3.44 mcm/year has been delineated in the deeper aquifers in Biharsharif-Noorsarai area. However, no long-term desaturation has occurred as the aquifer system gets fully recharged during the monsoon through infiltration from rainfall. .

Chapter 8- Human activities such as mining of natural resources with intense withdrawals of groundwater have posed great challenge for the water environment, resulting in groundwater quality deterioration and saltwater encroachment in many regions of the world. In this Chapter, the groundwater pollution and hydro-geochemistry in relation to human activities in Shiroishi in the Saga plain (southern Japan) and in Tieling peri-urban city (in the Liaohe River plain, northeastern China) were highlighted and examined by means of analytical and numerical approaches in order to interpret the hydrogeochemical characteristics of shallow groundwater, the pollution sources and understand the transport process in these intensely farmed agriculture and urbanizing regions in each country. Firstly, hydrogeochemistry conditions in Shiroishi (Japan) were investigated and a numerical model was applied to simulate salinity intrusion process in this plain. Solution chemistry of groundwater in the Shiroishi aquifer provided valuable information related to freshwater-salinity water interaction occurring during natural process. The numerical results indicated that salinization was more serious at deeper aquifers. Secondly, on the other hand, a factor analysis was developed for groundwater quality in Tieling peri-urban city (China) in order to help understand the dominant pollutants in the water and sources of pollution. The results obtained in these two different study areas demonstrated that groundwater pollution and water quality management in each country greatly depend upon socio-economic, biological and geo-physical conditions, management policy, legislation, resource reduction, land use practices and remediation in each region.

Chapter 9- The array of environmental services or values depends on the ground water which is poorly understood. Environmental concerns related to ground water generally focus on the impact of pollution and quality degradation on human uses, particularly domestic supply. Further pollution of water and declining water level represents direct threat to sustainability of environment, agriculture as well as on other human activities. Due to high population growth and industrialization, greater amount of domestic and industrial effluents discharge which lead to the pollution of underground water. Maps of aquifer vulnerability to pollution are becoming more and more in demand because on one hand ground water represents the main source of drinking water and on the other hand various human and economic activities represents real or potential source of ground water contamination. In such a situation ground water vulnerability maps are very useful mainly for groundwater quality monitoring which is the main source of drinking water.

The concept of ground water vulnerability is based on the assumption that that the physical environment provide some degree of protection to ground water against the natural impact especially with regards to contamination entering the sub-surface environment. Consequently some land area is more vulnerable to ground water contamination than the other. There are much work, which has been done to test the underground water for trace and major elements. But so far in India very few integrated approach has been taken to study

ground water vulnerability using GIS and remote sensing techniques. This paper focuses on conceptual, theoretical and technical aspects of the use of geo-spatial tool i.e. remote sensing and GIS for assessing the aquifer vulnerability using hydro-geo-morphological parameters.

There are various methods to find out the vulnerability of ground water but this paper focuses on DRASTIC model because it is a standard system for evaluating ground water potential that has broadly used in many countries, including India. It is developed jointly by the National Water Well Association (NWWA) and the U.S. Environmental Protection Agency (EPA). DRASTIC is based on the seven data layers that provide the input to the modeling. It corresponds to initials of seven layers i.e. Depth of water, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone and hydraulic Conductivity. Each of the parameters can be mapped and classified into ranges, which have an impact on pollution potential. Weight multipliers can then be used for each factor to balance and enhance the importance of a layer. The final vulnerability, the DRASTIC index (Di) can then be computed as the weight sum overlay of seven layers: The study (DRASTIC Model) has wide range of application. It can be used in prioritization of areas for identifying the bore well sites for drinking water and also for monitoring purposes which are already polluted. It can also help the planners and policy makers for various planning purposes.

Chapter10- Brackish groundwater (total dissolved solids, [TDS] in the range of 2500 – 5000 mg/l) and limited fresh groundwater (TDS $\leq$ 2000 mg/l) constitute a strategic resource in the arid environment of Kuwait. The protection of this resource's integrity for sustainable use over the long term is the goal of water administrators in the country. As a result of the continued development of the country over the past several decades, the groundwater resources of Kuwait have been stressed by intensive production, and have also become vulnerable to contamination from various natural processes and anthropogenic activities. These processes and activities include vertical and lateral movements of saline water due to falls in the potentiometric heads in the aquifers being exploited, agricultural and industrial activities (including oil exploration and production), urbanization, leakage from sewage networks, disposal of municipal and industrial wastes in landfills, and damage to the oil wells caused during the 1991 Gulf War. Many of these pollution sources located within the territory of Kuwait have been identified.

A conceptual design for a monitoring network has been developed with the objectives of i) providing baseline information on the hydrochemical conditions of the groundwater resources to benchmark future conditions; ii) identifying national trends in groundwater quality; iii) detecting quickly negative impacts on the hydrochemistry of the groundwater due to anthropogenic activities; iv) providing information on the mixing processes among the different units of the groundwater aquifer system, and mass exchange between the groundwater and other natural resources for better understanding of the natural phenomena and detecting changing trends due to human intervention; and v) providing an early warning system for production well fields. Approximately 300 wells will be part of this network. Furthermore, recommendations have been put forward for the adoption of policies and procedures that will protect the groundwater resources of Kuwait from both intentional and unintentional deterioration in quality through environmental pollution. The recommended steps include: i) establishment of a planning team for groundwater protection in Kuwait; ii) formulation of rules for the delineation of wellhead protection areas; iii) identification of potential sources of contamination within individual source zones; iv) formulation of policies

for the management of the wellhead protection areas; v) development of a contingency plan; and vi) support of public education and participation programs.

Chapter11- A chalk aquifer of the Avedat Group of Eocene age is widely distributed in the northwestern parts of the Negev Desert of Israel. The water flowing in the fractures becomes saline because of salts diffusing from concentrated solutions in the pores of the chalk.

Samples of pore-water were extracted by the immiscible displacement method from six samples of core material obtained by dry drilling. The salinity of pore water ranges from 3,900 to 15,700 mg /l Cl, and its ionic ratios resemble that of seawater. Geochemical modeling by a PHREEQC computerized model suggests that the process involved alteration of the original sea-water by dia-genetic processes, through water-rock interaction and dilution with fresh meteoric water. Taking into consideration mass-transfer and the geological history of the region it is possible to explain the presence of Eocene sea-water with salinities of up to 15,000 mg/l of chloride in the porous medium of the Avedat Group chalk and its gradual leaching out by meteoric water.

Chapter12- Some scientists believe that subsurface life may be the main stage for the planet's biodiversity. Ever increasing information on the widespread occurrence and distribution of microbes in subterranean environments has come forward during the last 10 – 15 years and is changing our comprehension of the deep biosphere. Access to the microbial communities of the subsurface is possible by springs which emanate from great depths. The authors investigated the slightly radioactive thermal springs near the alpine village of Bad Gastein, Austria, and report on the extensive diversity of prokaryotic morphotypes in the water as well as on the evidence for archaeal and bacterial representatives. Biofilms were collected on glass slides which were submersed for up to 21 days in a spring. Microscopical examination was performed by scanning electron microscopy, following drying, fixation and sputter coating of samples with Au/Pd, or by fluorescence microscopy, following staining with 4′,6-diamidino-2-phenylindole (DAPI). A wide variety of morphotypes was detected; most prominent were long thin filaments, roundish assemblies of small cellular bodies, which occurred in aggregates, and single short rods. In addition, net-like filamentous structures were observed. Fluorescence in situ hybridization (FISH) was carried out with specific phylogenetic probes and revealed highly diverse morphologies of bacteria and crenarchaeota. While bacteria consisted mainly of thin filaments, long or short rods in chains as well as thick rods or cocci (1.5 - 2 μm in diameter), crenarchaeota always seemed to be very small rods or cocci (about 0.8 μm in diameter).

The authors are still far from understanding the mode of subsistence of the prokaryotic communities in aquifers and subsurface springs. The morphological investigations described here have revealed as yet unknown features of these communities.

Chapter13- The authors developed a full coupled model to study a fracture-matrix structure system associated with the thermo-hydro-mechanical (THM) coupling interactions. At first, a conceptual model of an idealized double porous media is proposed to represent a typical fracture-matrix structure system. Then, a full coupled numerical model is developed by mathematically defining a set of partial differential equations. The main physical phenomena are to be considered for the structural change of rock media in the geological disposal problems, such as high-level radioactive waste disposal and acid gases CO_2/SO_2 sequestration. It includes heat conduction, porous flow induced stress, temperature gradient driven flow, thermal expansion, and the mutual couplings among each other. Finally, a three-

dimensional geometrical model representing an idealized fracture-matrix system is built for a practical THM coupled numerical analysis with a Galekin's finite element implementation.

Chapter14- Nitrate – an anion is the essential compound of living organisms, has become cause of concern for hydrochemists and medical professionals of late due its detrimental effect on human health especially infants and aged people. Till recently the nitrate content in many of the water sources were well within the tolerable limits of WHO standards or those prescribed by individual countries but in the past few decades its content in both surface and ground water, has been raising profusely due to intense agriculture activity and burgeoning population growth leading to development of many stomach or gastrointestinal related health problems apart from already known methemoglobinemia (blue-baby syndrome) in infants. This has prompted the scientists to focus on nitrate contamination of water who were hitherto largely confined to high fluoride concentration issue of ground water. In years to come the nitrate contamination problem if left unchecked may become one of the major health hazards. Increased knowledge on ill effects of high nitrate content in drinking water due to continuous research has helped the statutory bodies or regulatory authorities in reducing the maximum permissible limit of nitrate in many countries. In this Chapter effects are made to dwell on the different issues of nitrate contamination in water to present a comprehensive picture. Compilation, analysis and interpretation of available literatures were carried out to delineate the causes and remedies for nitrate pollution in water resources. A holistic approach to contain the nitrate contamination was attempted by deliberating on its chemistry, distribution, sources and different examples of the world's high nitrate occurrences which will not only give wide ranging information on various aspects of the compound but also encourage researchers to initiate more studies with renewed efforts in multidisciplinary areas by polarization of scientists' world over.

Chapter15- Researchers have often paid much attention to determining horizontal hydraulic conductivity (K_h), but careful characterization of the vertical hydraulic conductivity (K_v) of an alluvial aquifer is needed for better evaluation of hydrological processes in the saturated zone, as well as in the unsaturated zone. This paper demonstrates the Geoprobe technique combined with permeameter tests for estimation of K_v of an alluvial aquifer. Six depth-profiles of K_v values were produced for a highly permeable alluvial aquifer in the Platte River valley of Nebraska. The results of this study indicate that 1) K_v is a spatially-varied parameter both in the horizontal and vertical dimension, 2) K_v values determined using the permeameter tests are compatible to K_v determined from pumping tests and no scaling effect or measurement-method effect was observed. Thus, this study shows an alternative method that can generate more detailed information on K_v in alluvial aquifers and is more cost effective than pumping tests. Most K_v values determined from sediment cores or from pumping tests for the alluvial aquifer in the Platte River Valley of Nebraska range from 1 to 10 m/d.

Chapter16- Monitoring of contaminated aquifers must be carried out based first on sound hydrogeological criteria, and secondly on budget. Designing effective monitoring systems must address the following issues: (1) development of the conceptual model, (2) spatial distribution of the monitoring network, frequency and type of sampling, (3) design of wells and/or piezometers, (4) aquifer instrumentation and its application in long term programs, (5) and optimization of programs to assure quality through time while reducing costs. The aspects of each point are analyzed from the theoretical foundation and data from four Case-Studies area taken to illustrate the relevance of each criteria.When the hydrogeological features of the

site, the biogeochemical conditions of the aquifer and the properties of the contaminant are taken into account, monitoring programs are the most important tool for (a) complementing the environmental assessment, (b) improve the conceptual model, and (c) generate indicators to determine the success of an environmental prevention, contention or remediation project.

CONTENTS

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Chapter 1

EUCALYPTUS CAMALDULENSIS DEHNH: AN EFFECTIVE REMEDIATOR OF GEOLOGIC NITROGEN IN GROUNDWATER

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ABSTRACT

Human security in most drylands hinges on the accessibility of safe groundwater. The presence of ammonium and nitrate in many geologic formations renders both their runoff and seepage unfit for human consumption. As the inhabitants of downstream areas depend on such waters for their very survival, they have to accept the risk of affliction with diseases caused by the consumption of a relatively small concentration of nitrate nitrogen (10 mg pre liter, according to the USEPA and WHO). Phytoremediation of N-polluted water is an environmentally safe and economically viable scheme to supply affected desert communities with safe groundwater. River red gum (*Eucalyptus camaldulensis* Dehnh.), which is adapted to the hot desert environments, is a good candidate for N filtration from groundwater. This deep-rooted evergreen tree that explores the vadose zone down to the phreatic fringe is particularly suitable for the Mediterranean climates where deciduous trees are dormant during the rainy season. Planting the artificial recharge of groundwater sedimentation basin to the river red gum for enhancing the hydraulic conductivity of the vadose zone and environmental amelioration has had the added benefit of nitrogen filtration from the recharge water. While the floodwater on average contains >13 mgL^{-1} of nitrate-N, the red gum-filtered groundwater contains 1.60 mgL^{-1} of the same element. Both field and laboratory bioassays and well water sampling have proven the phytoremediation potential of this useful tree.

Keywords: Phytoremediation, *Eucalyptus camaldulensis* Dehnh., geologic nitrogen , artificial recharge of groundwater; Iran.