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J.W. LaMoreaux (Eds.)

Advances in Research in Karst Media

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Advances in Research in Karst Media

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Presentation

Karst is a medium which has traditionally been the subject of hydrogeological research, given the abundant water resources that are stored in it. In many cases karst is the product of climatic and hydrological evolution in carbonate areas in recent periods of geological history. Karst contains key information on recent environmental changes. The action of water has generated a great range of karstic features that are part of our natural heritage and some of them form major tourist attractions (landscapes of natural parks, geosites and show caves, for example). Karst areas often serve as landscapes or as substrates for human activity. But karst is a highly fragile ecosystem and the exploitation of its resources or inappropriate land uses give rise to environmental problems (water pollution, subsidence, flooding, changes in the subterranean environment, etc.). Also civil engineering projects need special surveillance in karst areas.

Karstic outcrops cover approximately 12% of the terrestrial land surface and these areas have always attracted attention as a research field in which many disciplines are involved, not just geological sciences, but also physics, chemistry and biology. Recently, socio-economic science has also been closely involved with the karst medium, as many of these areas contain important natural resources (groundwater, caves, karst landscapes), for which proper management makes a significant contribution to local economies.

Karst medium has long been the object of scientific research. The results of these investigations have been presented and discussed at numerous congresses and meetings, especially in the second half of the 20th century. The threshold of the second decade of the 21st century seems a good time to reflect on the progress made in recent times and to set out some of the lines of research to pursue in the near future. This book is the result of the 4th International Symposium on Karst (ISKA-2010), held in Málaga (Spain).

ISKA-2010 is the last of the symposia on karst that have been held periodically in Málaga since 1992. These symposia are an international forum for scientific debate on the progress made in research into karst environments. The main objective of the 4th International Symposium on Karst (ISKA-2010) is to discuss and disseminate

the latest trends in research into karst media on the basis of the results obtained with different methodologies in various worldwide areas.

This book contains 80 contributions grouped into four sections:

- Karst Hydrogeology
- Karst Geomorphology
- Engineering Geology in Karst
- Research on Caves

Most contributions are on Karst Hydrogeology, more than 60%, in connection with various topics: methods for groundwater recharge assessment, impact of climate change on karst aquifers, coastal aquifers, floods, karst groundwater flow, protection of karst aquifers, pollution and vulnerability in karst, thermal anomalies in carbonate aquifers, time series analysis, hydrochemistry, dye tracer and stable isotope applications, numerical modelling in karst, etc.

Concerning Karst Geomorphology (approximately 15% of total papers), the contributions deal with karst development in gypsum, wetlands, hypogene speleogenesis, sinkholes, travertines, fluviokarstic canyons and karst geosites.

Engineering Geology in Karst group contains about 10% of the published papers, concerning the following topics: motorways, dams, reservoirs, quarrying and mining, geophysical technical for mapping buried karst, karst risk assessment, and properties of the aeration zone in karst.

Finally, Research on Caves papers constitute the remaining15% of the works, related overall with mixing corrosion and speleogenetic processes, CO_2 sources and global carbon cycle in endokarst, speleothems and other deposits in caves, condensation and corrosion in caves, underground atmosphere and the colour in caves.

The number of authors involved in this issue (about 250) indicates the wide variety and representation of the selected papers from four continents (Europe, America, Asia and Africa) and over 20 countries.

The present book may be considered an update of karst hydrogeology landforms and cavities, described by numerous specialists who have investigated various aspects of these topics. It is a good example of investigations on karst systems in the last few years, and at the same time it provides an illustrative synthesis of the research tasks being performed out, among others, as part of the IGCP 513 project of the UNESCO, and IAH Karst Commission. This Project has been useful as a forum for the exchange of results and experience accumulated by researchers over recent years concerning karst-related issues. The result is a more integrated vision on karst, taking into account the diversity of geological and climatic contexts in the world. We hope this publication will be an interesting reference for all studying the karst medium.

Acknowledgements

This book was made possible thanks to the dedicated, combined effort of the authors and members of the Scientific Committee as reviewers. The editors of this book offer to all of them our sincere gratitude. The members of the Scientific Committee composed of 40 international specialists from various karst domains are listed on following pages. They reviewed all the contributions, several times in some cases. Only manuscripts which met the criteria and quality required for the book were accepted.

The 4th International Symposium on Karst, Malaga 2010 has been organized by the Centre of Hydrogeology at the University of Malaga and the Spanish Geological Survey, in the framework of their "Advanced Hydrogeological Studies" partnership, with the cooperation of UNESCO and the IAH Karst Commission and the Spanish Group. We thank Nerja Cave Foundation for its continuous support of the series International Symposia on Karst; in fact, the two first symposia were held in Nerja. Furthermore, we must express our thanks to all the organisations that collaborated in organising, whose logotypes are included in following pages. Without these numerous collaborators, and without the support of all mentioned, it would not have been possible to publish this updated survey on karst.

This book is a contribution to projects IGCP 513 of UNESCO, CGL2008-06158 and CGL2008-04938 of Spanish Directorate of Research, to Integrated Actions HP2008-047 and DE2009-0060, and to P06-RNM-02161 project and Research Group RNM 308 of Andalusian Government. It is a publication related to the IAH Karst Commission.

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The 4th International Symposium on Karst was organized by researchers from the Centre of Hydrogeology at the University of Malaga (CEHIUMA) and the Spanish Geological Survey (IGME), in the framework of their "Advanced Hydrogeological Studies" partnership. The Symposium was sponsored by UNESCO and IAH (Karst Commission and Spanish Group).

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Karst Geomorphology

Karst Hydrogeology

Sustainable Water Resources with Case Studies in Historic Areas in Egypt and Syria

J.W. LaMoreaux

Abstract The right to water use does not imply total sovereignty by some to the detriment of others over one of the most basic natural resources necessary to sustain life. Both developed and developing countries must find a workable balance for managing water resources. Water use decisions like those affecting Figeh Spring, Damascus, Syria, and Kharga Oases, Egypt, are controlled both by natural parameters, as well as human factors such as land use and population growth. Sustainable Water Development (SWD) is an internationally accepted program for balancing water use issues and goals among competing consumers.

Introduction

Hydrogeology plays a major role in all aspects of environmental planning, execution and implementation. Without a safe sustainable water supply, life cannot exist and hopes for prosperity are limited. Much future world demand for water will be made up of the ground water component.

The United Nations has identified water resources as a top priority. Attention is particularly drawn to freshwater stress, which relates water withdrawal to percentage of water available. Based on the current rate of use, the United Nations is not optimistic about the global water outlook.

Sustainable Water Development

Water quantity and water quality are inextricably linked; therefore, there needs to be rapid movement towards Sustainable Water Development (SWD) in both devel-

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oped and developing countries. To address this issue, countries need to embrace sustainable water development. SWD is "the development of water in a manner in which [an] adequate supply of good quality water is sustained and the watercourse ecosystem is maintained for the uses of future generations" (Pichyakorn 2002).

SWD includes five specific elements:

(1) The right to use water
(2) The protection of water resources and prevention of water degradation
(3) The maintenance of water flow
(4) An ecosystem related approach
(5) The procedural elements to achieve sustainable development.

The right to use water involves comprehensive permitting with continuing review, strategic counseling, crisis management, creative dispute resolution, and enhanced relations with stakeholder and community groups. If there is the perception that one group of users is favored above another, the task of proper water management becomes more difficult.

Protection of water resources and prevention of water degradation includes addressing nonpoint sources of pollution on a national, regional and local basis; land use controls; integration of water and land management; and regulation of interbasin transfers.

Maintenance of water flow involves instream flows and environmental flows and may require appropriate controls. An ecosystem-related approach should not be limited only to watercourse mainstream or tributaries, but it should also incorporate terrestrial and marine environments interacting with it; promote health of the entire ecosystem; and utilize watershed management authorities.

To move toward SWD, freshwater needs to be managed in a holistic manner, or in other words, an ecosystem approach. Once a good scientific understanding of the nature, quantity and quality of available water resources has been gained, then proper planning for future water use is possible. Reliable scientific data must be the basis for political decisions in water policy. Developing and enacting regionally

Fig. 1 Philip E. LaMoreaux in the Kharga Oases, 1962

appropriate regulations and water use policies are important aspects of the SWD approach.

"Management of water resources is holistic when it is done on a catchment or drainage basin basis. This includes both land and water resources, since land use can have significant impacts on freshwater and related ecosystems.... Thus water legislation should provide for a holistic, ecosystem approach to the management of water ..." (McCaffrey and Weber 2005).

Projects performed by P.E. LaMoreaux & Associates, Inc. (PELA) under the guidance of the late Philip E. LaMoreaux, past-president of the IAH (Fig. 1) in Kharga Oases in the Western Desert of Egypt (LaMoreax 1962a, 1962b, 1962c) and on Figeh Spring in Damascus, Syria (LaMoreaux 1989, 1992), will be used to illustrate this critical problem in the world today.

Kharga Oases in Egypt

One of the longest continuous records of human use of groundwater in the world exists in Kharga Oases in Egypt. The present landscape has evolved over several million years of erosion, structure and deformation of beds. Geographic position and changes in climate over the past thousands of years have resulted in conditions favorable for inhabitation by man.

Groundwater reserves have been studied for long term socioeconomic development. The Nubian Sandstone forms a complex aquifer system and has been providing water to artesian wells and springs for several thousand years.

Kharga Oases are located in a topographic depression in the Western Desert of Egypt oriented north/south parallel to the Nile Valley (Fig. 2). The climate is arid, rainfall is sporadic and temperatures are extremely hot during the summer months. Mean annual rainfall is less than 1 mm (LaMoreaux et al. 1985).

The Nubian Sandstone (Fig. 3) there consists of a 600 m thick sequence of coarse clastic sediments of sandstone, sandy clay interbedded with shale, chalk and clay beds. Wells flow at about 800 liters per minute, with water temperatures of about 37 °C. The salinity of the water is remarkably variable, both laterally and vertically (LaMoreaux et al. 1985; El Ayouty et al. 1961).

Nearly all of the springs and wells originally in the Kharga Oases flowed (Fig. 4). Exploitation of groundwater from deeper and deeper wells for irrigation began about 1959. Artesian outflows in the springs and shallow wells declined as more and more closely spaced deep wells were drilled (Fig. 5). By 1975, many wells had ceased to flow (LaMoreaux et al. 1985).

Sustainability of water resources is related to the history of hydrogeology through the inhabitation of Kharga Oases. Caton-Thompson's work (1952) hypothesized that Paleolithic man migrated out of the desert plateau and open plains of Kharga as early as 25,000 BP. During dry seasons these groups relied on the availability of groundwater from mound springs, which are domed seeps of a rare wetland land type, more properly called a calcareous seepage fen. They occur where colder water

that is rich in alkaline minerals flows out at the seepages in waves, and over time a roughly circular mound of successive deposits of minerals and mud builds up vertically in a rough circle around the water discharge point.

Prehistoric evidence exists of a post Pleistocene lake covering much of the Kharga Oases depression at a level of 70 m above sea level. Existence of good soils in these low areas allowed desert cultures to expand around them.

Evidence indicates that prehistoric man, and subsequently the Romans, used the springs in Kharga Oases for water supply. During Pharonic times, the oases were of little interest to Egyptian administrations until the very late Dynastic Period. Caravan routes crossed the area from Sudan to Libya. Stone temples, fortresses, and brick strongholds were built and remain as evidence of occupation by Persia, Greco/Roman, Roman, Coptic and subsequently Arab peoples.

Kharga inhabitants continue to use these ancient springs and wells, supplemented at present by groundwater from deep artesian wells penetrating the deeper Nubian

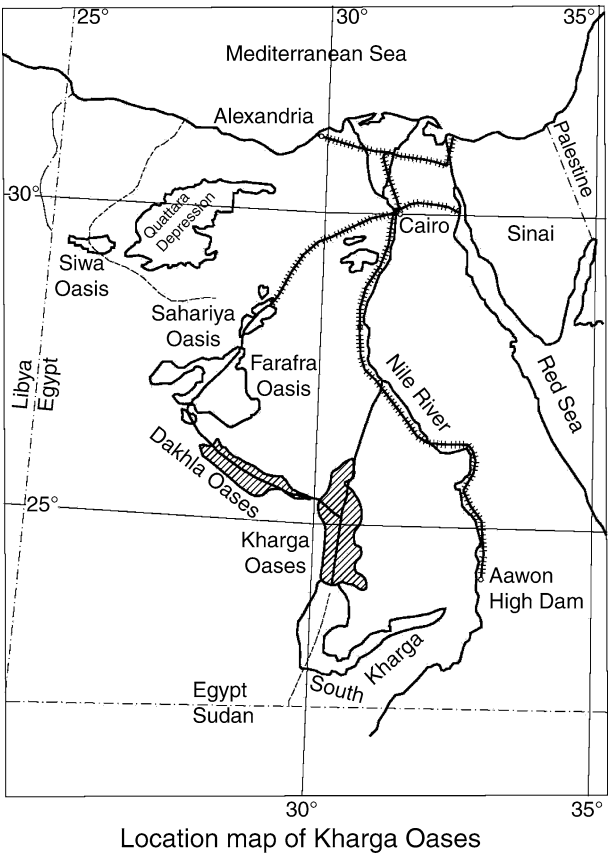

Fig. 2 Location of Kharga Oases

sandstone layers. The challenge today is to manage the water resources in the area to allow continued usage in a prudent manner. Large reserves of groundwater remain in the Western Desert of Egypt. Reserves can be used effectively into the future but they must be developed cautiously and ideally combined with safe water reuse programs. Today water continues to flow at a reduced rate. Crop lands have a thin layer of salt, diminishing the productivity of the land.

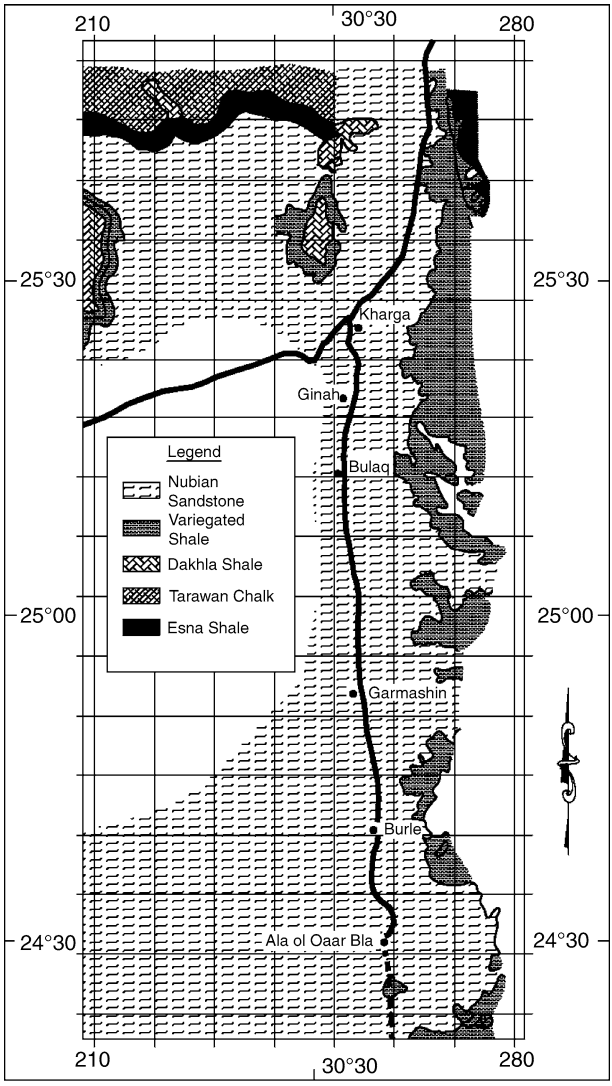

Fig. 3 Generalized Geologic Map, Kharga

Fig. 4 Artesian Well in the Oases of Kharga, 1995

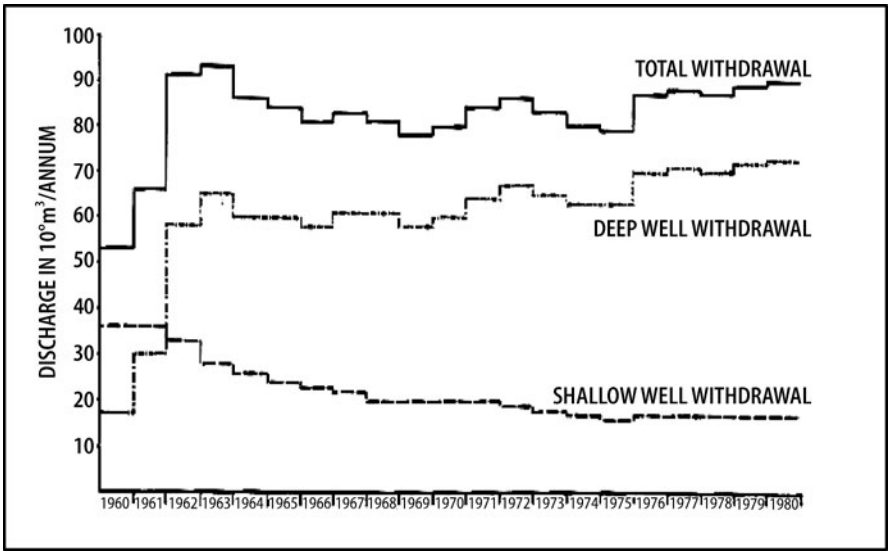

Fig. 5 Annual withdrawal from shallow and and deep wells and total withdrawal, Kharga area, 1960–1980

The Nubian, being a complex geologic unit, comprises a very large storage system containing good quality water that moves through the sandstone beds very slowly (LaMoreaux 1964; LaMoreaux et al. 1985). This slow movement in a way comprises a safety factor. Even though these resources may have been misused in the past and artesian heads have been reduced drastically in some local areas, much water remains for future development. Applying the ideas of sustainable water resources and utilizing state of the art technologies available today will help to better manage this resource for future generations.

Figeh Spring in Damascus, Syria

Figeh Spring in Syria (Fig. 6) is the third largest spring in the world, after Krasny Kutch (Red Spring) in Bashkortostan, Russia (Gareev 2004) and Silver Springs in Florida, USA (Wilson 1989). Figeh Spring has an average discharge of about 8.5 m^3/s, and the average temperature is about 14 °C. The waters are used for the supply of the city of Damascus, Syria. The spring was developed first by the Romans. Remains of Roman baths and of aqueducts leading south toward the city of Damascus are evidence of early development.

PELA performed hydrogeological studies in the vicinity of Figeh Spring to determine groundwater flow paths, recharge, storage, and discharge and the maximum reliable yield (LaMoreaux 1989; LaMoreaux et al. 1989). PELA's project provided information upon which to base pumpage to augment low-season flows from the spring which is the major water supply for the city of Damascus.

Studies performed include detailed surface geologic mapping, aerial photograph interpretation, well and spring inventory and a systematic water quality sampling program. Geologic structural work included mapping jointing, faulting, and folding and an analysis of their impact on groundwater movement.

Detailed quantitative studies were made on the large springs supplying the Damascus water supply with detailed monitoring during pumping. Pumping test results indicated that, with proper control and managed modifications at Figeh Spring, flow augmentation at an average annual rate of 4 m^3/s is available to support the needs of Damascus during the low flow season. The reduction in storage is replaced first by rains and then by snowfall during the primary recharge season from November to January.

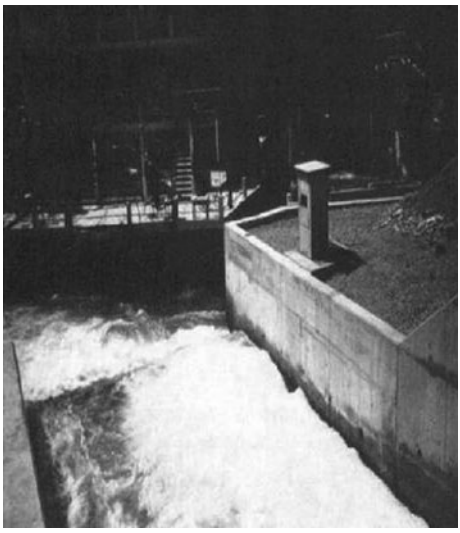

Fig. 6 Figeh Spring, Syria: Discharge to the Barada River, 1988

Understanding the reservoir system from which water flows, the flow direction, and the rate of water withdrawn allows determination of the area around Figeh Spring in which environmental restraints should be imposed on development.

Three protection zones were identified with decreasing limitations:

(A) Total Protection
(B) Permit Restriction
(C) Permit Proper Development of light agriculture

Since PELA performed its studies in the 1980s, demands on water resources and arable soils have grown enormously due to high population growth rates. Water scarcity, over-extraction of groundwater and deteriorating water quality are common occurrences and are increasing over time. Water shortages in urban areas and limited access to clean drinking water are creating a water crisis.

In 2001, the population of the area had grown to about four million, irrigation use was increasing, and the average pumping rate was nearly 6 m^3/s. Water supplies were turned off on a rotating basis for between 16–20 hours a day during the summer months of 2001. Syria's Statistical Abstracts show that for the years between

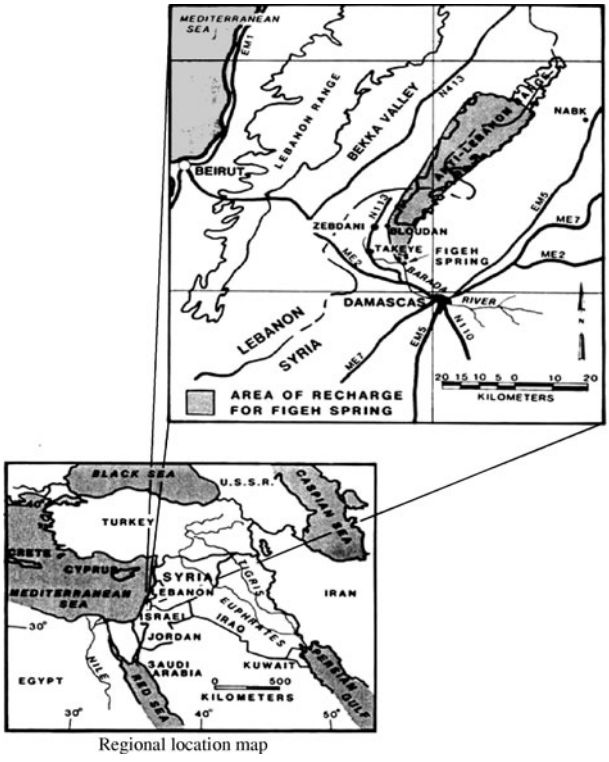

Fig. 7 Location of Figeh Springs in Syria

1967 to 1984, average annual water flows for Figeh Spring fluctuated between a low of 4.227 m^3/s and a high of 12.9 m^3/s. For the years between 1996 and 2000, average annual water flow recorded a low of 3.9 m^3/s and a high of only 6.85 m^3/s (Elhadj 2004).

Limited arable lands are endangered by intensification of land use and by increasing contamination, degradation and desertification. Socio-economic development of the region is limited by these factors and holds potential for even greater conflicts at the national and international level. The Federal Ministry for Economic Co-operation and Development, Germany (BMZ 2008), and the Arab Center for Studies of Arid Zones and Dry Lands (ACSAD 2008) are performing work in Syria to address these problems.

As it is difficult to estimate the results of management decisions in complex systems characterized by natural parameters such as those affecting Figeh Spring, as well as human factors such as land use and population growth, BMZ and ACSAD are developing a Decision Support System (DSS) involving visualizing and discussing the status quo and possible scenarios with relevant stakeholders.

The purpose of DSS is for stakeholders to be able to make joint decisions. In this way acceptable water allocations can be established and conflict between current water users can be reduced, which will help lead to more sustainable management of limited water resources for current and future years.

Conclusions

Historically, sustainability of water resources has been a problem which has been difficult to manage without today's detailed knowledge of hydrogeological systems. History can be used as the basis for ongoing and future studies. Well planned investigations with quality control protocol and management provide better information upon which to base decisions.

New technologies allow more detailed investigations and the acquisition of accurate and verifiable data with which to make projections and model various scenarios. New management systems make it easier for stakeholders to be involved to minimize conflict and to collectively arrive at optimal solutions. This process embraces socio-economic development and sustainable water resources for future generations.

References

Arab Center for Studies of Arid Zones and Dry Lands (2008) The Damascus Ghouta Pilot Study Area. http://www.acsad-bgr.org/

Bearden B (2009) Legal regime of water resources in Alabama. IN Proceedings of 23rd Annual Alabama Water Resources Conference and Symposium, Auburn University, Auburn, Alabama

Caton-Thompson G (1952) Kharga Oases in Prehistory. Athlone Press, University of London, 231 p

EL-Ayouty MK, Ezzat MA (1961) Hydrogeological Observations in the search for underground water in the Western Desert of Egypt, UAR. General Desert Development Authority, Cairo.

Elhadj E (2004) The Household Water Crisis in Syria's Greater Damascus Region. Occasional Paper 47, School of Oriental & African Studies Water Resources Group, King's College London, University of London

Federal Ministry for Economic Co-operation and Development, Germany (2008) Partner Country Information: Syrian Arab Republic. http://www.bmz.de/en/countries/partnercountries/syrien/zusammenarbeit.html#t4

Gareev EZ (2004) The Nature Geological Monuments of the Republic of Bashkortostan: Bashkir State University, Ufa, Taw, 296 p

LaMoreaux PE (1962a) A review of the New Valley Project, Western Desert of Egypt. Cairo, UAR Desert Institute, The General Desert Development Organization, Ministry of Reclamation, 18 p

LaMoreaux PE (1962b) Reconnaissance report and recommendations for ground-water investigations, Wadi el Natrun, Western Desert of Egypt. Cairo, UAR, Desert Institute, The General Desert Development Organization, Ministry of Reclamation, 56 p

LaMoreaux PE (1962c) A review of the New Valley Project, Western Desert of Egypt. Cairo, UAR, Desert Institute, The General Desert Development Organization, Ministry of Reclamation, 30 p

LaMoreaux PE (1964) A review of the New Valley Project, Western Desert of Egypt, with special reference to the development of a quantitative consultant's study. Cairo, UAR, Desert Institute, The General Desert Development Organization, Ministry of Reclamation, 8 p

LaMoreaux PE (1989) Environmental aspects of the development of Figeh Spring, Damascus, Syria. IN Beck, BF (ed) Proceedings of the Third Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Sinkholes and Karst, St. Petersburg Beach, Florida, Oct. 2–4, 1989; AA Balkema, Rotterdam, The Netherlands, 17–23

LaMoreaux PE (1992) Hydrogeotechnical hazards – Figeh Spring, Syria IN Proceedings of the 1992 National Conference of the American Institute of Hydrology

LaMoreaux PE, Hughes TH, Memon BA, Lineback NG (1989) Hydrogeologic assessment – Figeh Spring, Damascus, Syria. Environmental Geology and Water Sciences: Springer-Verlag, New York, New York, 13(2):73–127

LaMoreaux PE, Memon BA, Idris H (1985) Groundwater development, Kharga Oases, Western Desert of Egypt: A long-term environmental concern. Environmental Geology and Water Sciences, Springer-Verlag, New York, 7(3):129–146

Meinzer OE (1927) Large springs in the United States; U.S. Geological Survey Water-Supply Paper 557, 94 p

McCaffrey SC, Weber GS (2005) Guidebook for Policy and Legislative Development on Conservation and Sustainable Use of Freshwater Resources; United Nations Environment Programme, Nairobi, Kenya, 136 p

Pichyakorn, Bantita (2002) Sustainable Development and International Watercourse Agreements: The Mekong and the Rhine, International Union for the Conservation of Nature (Draft 30 June 2002)

Veni G, DuChene H, Crawford NC, Groves CG, Huppert GN, Kastning EH, Olson R, Wheeler BJ (2001) Living with Karst: a Fragile Foundation; American Geological Institute, Alexandria, VA 69 p

Wilson WL, Skiles, WC (1989) Partial Reclassification of first magnitude springs in Florida; IN Beck, BF (ed.) Proceedings of the Third Multidisciplinary Conference on Sinkholes and the Engineering and environmental Impacts of Karst, St. Petersburg Beach, FL

Resources Assessment of a Small Karstic Mediterranean Aquifer (South-Eastern, Spain)

J.M. Andreu, P. Martínez-Santos, A. Pulido-Bosch, and E. García-Sánchez

Abstract Groundwater from small aquifer systems is frequently used for urban supply in southeastern Spain. Aquifers such as the Ventos system, located in Mediterranean semiarid environments, are sensitive to climatic and anthropogenic changes. Many of them have been severely depleted due to intensive pumping. Drawdowns in the Ventos aquifer amount to approximately 80 m over the last three decades. Adequate knowledge of groundwater resources is necessary for water planners and managers to guarantee suitable abstraction. This paper presents a methodology to estimate groundwater recharge in these kinds of quick-response semiarid karst aquifers. A distributed model has been used to evaluate the fraction of rainfall that ultimately results in aquifer recharge, as well as the correlation between the magnitude of rainfall events and infiltration rates. Modelling results are then compared with direct observations of the recharge processes and discussed to evaluate the implications of time scales.

1 Introduction

Groundwater resources contribute substantially to the supply of water in Alicante, southeastern Spain. The use of groundwater has increased significantly during the

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