

# Sustaining Groundwater Resources

A Critical Element in the Global Water Crisis

International  
Geographical Union  
Commission for  
Water Sustainability



J. A. A. Jones (Ed.)



United Nations  
Educational, Scientific and  
Cultural Organization



IUGS  
International Union of Geological Sciences



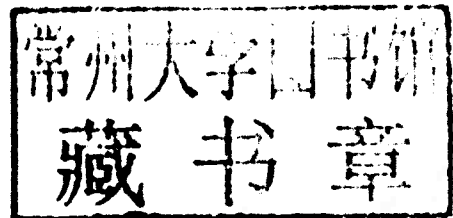
Springer

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## Sustaining Groundwater Resources

# International Year of Planet Earth

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## Series Editors:

Eduardo F.J. de Mulder  
Executive Director International Secretariat  
International Year of Planet Earth

Edward Derbyshire  
Goodwill Ambassador  
International Year of Planet Earth

The book series is dedicated to the United Nations International Year of Planet Earth. The aim of the Year is to raise worldwide public and political awareness of the vast (but often under-used) potential of Earth sciences for improving the quality of life and safeguarding the planet. Geoscientific knowledge can save lives and protect property if threatened by natural disasters. Such knowledge is also needed to sustainably satisfy the growing need for Earth's resources by more people. Earth scientists are ready to contribute to a safer, healthier and more prosperous society. IYPE aims to develop a new generation of such experts to find new resources and to develop land more sustainably.

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## Foreword

The International Year of Planet Earth (IYPE) was established as a means of raising worldwide public and political awareness of the vast, though frequently under-used, potential the earth sciences possess for improving the quality of life of the peoples of the world and safeguarding Earth's rich and diverse environments.

The International Year project was jointly initiated in 2000 by the International Union of Geological Sciences (IUGS) and the Earth Science Division of the United Nations Educational, Scientific and Cultural Organisation (UNESCO). IUGS, which is a non-governmental organization, and UNESCO, an inter-governmental organization, already shared a long record of productive cooperation in the natural sciences and their application to societal problems, including the International Geoscience Programme (IGCP) now in its fourth decade.

With its main goals of raising public awareness of and enhancing research in the Earth sciences on a global scale in both the developed and less-developed countries of the world, two operational programmes were demanded. In 2002 and 2003, the series editors together with Dr. Ted Nield and Dr. Henk Schalke (all four being core members of the Management Team at that time) drew up outlines of a science and an outreach programme. In 2005, following the UN proclamation of 2008 as the United Nations International Year of Planet Earth, the "year" grew into a triennium (2007–2009).

The outreach programme, targeting all levels of human society from decision makers to the general public, achieved considerable success in the hands of member states representing over 80% of the global population. The science programme concentrated on bringing together like-minded scientists from around the world to advance collaborative science in a number of areas of global concern. A strong emphasis on enhancing the role of the Earth sciences in building a healthier, safer and wealthier society was adopted – as declared in the Year's logo strap-line "Earth Sciences *for* Society".

The organizational approach adopted by the science programme involved recognition of 10 global themes that embrace a broad range of problems of widespread national and international concern, as follows:

- Human health: this theme involves improving understanding of the processes by which geological materials affect human health as a means identifying and reducing a range of pathological effects.
- Climate: particularly emphasizes improved detail and understanding of the non-human factor in climate change.
- Groundwater: considers the occurrence, quantity and quality of this vital resource for all living things against a background that includes potential political tension between competing neighbour nations.

- Ocean: aims to improve understanding of the processes and environment of the ocean floors with relevance to the history of planet Earth and the potential for improved understanding of life and resources.
- Soils: this thin “skin” on Earth’s surface is the vital source of nutrients that sustain life on the world’s landmasses, but this living skin is vulnerable to degradation if not used wisely. This theme emphasizes greater use of soil science information in the selection, use and ensuring sustainability of agricultural soils so as to enhance production and diminish soil loss.
- Deep Earth: in view of the fundamental importance of deep the Earth in supplying basic needs, including mitigating the impact of certain natural hazards and controlling environmental degradation, this theme concentrates on developing scientific models that assist in the reconstruction of past processes and the forecasting of future processes that take place in the solid Earth.
- Megacities: this theme is concerned with means of building safer structures and expanding urban areas, including utilization of subsurface space.
- Geohazards: aims to reduce the risks posed to human communities by both natural and human-induced hazards using current knowledge and new information derived from research.
- Resources: involves advancing our knowledge of Earth’s natural resources and their sustainable extraction.
- Earth and Life: it is over 2½ billion years since the first effects of life began to affect Earth’s atmosphere, oceans and landmasses. Earth’s biological “cloak”, known as the biosphere, makes our planet unique but it needs to be better known and protected. This theme aims to advance understanding of the dynamic processes of the biosphere and to use that understanding to help keep this global life-support system in good health for the benefit of all living things.

The first task of the leading Earth scientists appointed as theme leaders was the production of a set of theme brochures. Some 3500 of these were published, initially in English only but later translated into Portuguese, Chinese, Hungarian, Vietnamese, Italian, Spanish, Turkish, Lithuanian, Polish, Arabic, Japanese and Greek. Most of these were published in hard copy and all are listed on the IYPE web site.

It is fitting that, as the International Year’s triennium terminates at the end of 2009, the more than 100 scientists who participated in the 10 science themes should bring together the results of their wide ranging international deliberations in a series of state-of-the-art volumes that will stand as a legacy of the International Year of Planet Earth. The book series was a direct result of interaction between the International Year and the Springer Verlag Company, a partnership which was formalized in 2008 during the acme of the triennium.

This IYPE-Springer book series contains the latest thinking on the chosen themes by a large number of earth science professionals from around the world. The books are written at the advanced level demanded by a potential readership consisting of Earth science professionals and students. Thus, the series is a legacy of the science programme, but it is also a counterweight to the earth science information in several media formats already delivered by the numerous national committees of the International Year in their pursuit of worldwide popularization under the outreach programme.

The discerning reader will recognize that the books in this series provide not only a comprehensive account of the individual themes but also share much common ground that makes the series greater than the sum of the individual volumes. It is to be hoped

that the scientific perspective thus provided will enhance the reader's appreciation of the nature and scale of earth science as well as the guidance it can offer to governments, decision makers and others seeking solutions to national and global problems, thereby improving everyday life for present and future residents of planet Earth.



Eduardo F.J. de Mulder  
Executive Director International Secretariat  
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## Series Preface

This book series is one of the many important results of the International Year of Planet Earth (IYPE), a joint initiative of UNESCO and the International Union of Geological Sciences (IUGS), launched with the aim of ensuring greater and more effective use by society of the knowledge and skills provided by the earth sciences.

It was originally intended that the IYPE would run from the beginning of 2007 until the end of 2009, with the core year of the triennium (2008) being proclaimed as a UN Year by the United Nations General Assembly. During all 3 years, a series of activities included in the IYPE's science and outreach programmes had a strong mobilizing effect around the globe, not only among earth scientists but also within the general public and, especially, among children and young people.

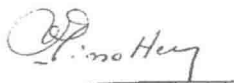
The outreach programme has served to enhance cooperation among earth scientists, administrators, politicians and civil society and to generate public awareness of the wide ranging importance of the geosciences for human life and prosperity. It has also helped to develop a better understanding of Planet Earth and the importance of this knowledge in building of a safer, healthier, and wealthier society.

The scientific programme, focused upon 10 themes of relevance to society, has successfully raised geoscientists' awareness of the need to develop further the international coordination of their activities. The programme has also led to some important updating of the main challenges the geosciences are, and will be confronting within an agenda closely focused on societal benefit.

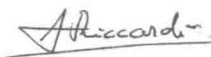
An important outcome of the work of the IYPE's scientific themes includes this thematic book as one of the volumes making up the IYPE-Springer Series, which was designed to provide an important element of the legacy of the International Year of Planet Earth. Many prestigious scientists, drawn from different disciplines and with a wide range of nationalities, are warmly thanked for their contributions to a series of books that epitomize the most advanced, up-to-date and useful information on evolution and life, water resources, soils, changing climate, deep earth, oceans, non-renewable resources, earth and health, natural hazards, and megacities.

This legacy opens a bridge to the future. It is published in the hope that the core message and the concerted actions of the International Year of Planet Earth throughout the triennium will continue and, ultimately, go some way toward helping to establish an improved equilibrium between human society and its home planet. As stated by the Director General of UNESCO, Koichiro Matsuura, "Our knowledge of

the Earth system is our insurance policy for the future of our planet". This book series is an important step in that direction.



R. Missotten  
Chief, Global Earth Observation Section  
UNESCO



Alberto C. Riccardi  
President  
IUGS

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## Preface

This volume commemorates the International Year of Planet Earth. The UN General Assembly ratified the IYPE in 2005 and the International Year was launched with great ceremony at the UNESCO HQ in Paris in February 2008. The International Union of Geological Sciences (IUGS) and the International Geographical Union (IGU) were among the prime initiators. This book is a contribution from the IYPE Groundwater team and from the IGU Commission for Water Sustainability.

The IYPE celebrates 50 years since the International Geophysical Year kick-started global collaboration in the geosciences in 1957–1958. In the 1950s, the only water-related activities in the IGY were in glaciology and the emphasis was purely on the physical science. The world has changed very much since then. In many ways it seems more hazardous, and science is focusing more and more on service to humanity. The themes of the IYPE include megacities, climate change, soils, natural resources, hazards, and health and life, as well as deep geology and the ocean, and, of course, groundwater, the topic of this volume.

In preparation for the IYPE, the International Council for Science (ICSU) established the Geo-Unions Joint Science Programme in 2004. As part of this programme, the ICSU Groundwater Committee, under the chairmanship of Dr. Mary Hill (USGS), produced the brochure *Groundwater – reservoir for a thirsty planet*, which was published by the IUGS in 2005. The brochure outlined the key issues facing groundwater resources in the 21st century: rising rates of abstract and over-exploitation, pollution, lack of agreement over internationally shared aquifers, and undervaluing groundwater as a vital resource for both human beings and the environment.

Each theme within the IYPE has been administered by a “science implementation team” (SIT) that vetted proposals for a key research project to be selected as a flagship for the IYPE. The Groundwater SIT selected a project put forward by Dr. Steve Silliman of Notre Dame University, Notre Dame, IN, USA, in collaboration with colleagues from Bénin. The IYPE’s “badging” of this project allowed the group to acquire sufficient resources to continue work for another 4 years. The ongoing research, which is reported later in this volume, is identifying the threats to groundwater in Benin, especially the spread of saltwater intrusion in coastal aquifers, and testing new solutions. It involves a combination of modelling, field research, and interaction with the local population. Getting local government to maintain a network of observation wells is a major aim.

The SIT held its defining conference at the 33rd International Geological Congress organised by the IUGS in Oslo 2008, at which most of the contributors to this Legacy volume delivered research papers. The team also sponsored two other international conferences on groundwater: the International Conference on Groundwater Dynamics and Global Change, organised by Professor Amarendra Sinha at the

University of Rajasthan in Jaipur, which was co-sponsored by the International Hydrological Programme, UNICEF, and the Indian Department for Science and Technology, and the Workshop on Aquifer Storage and Recovery Methods organised by the Deputy Leader of the SIT, Professor J.P. Lobo Ferreira, Head of the Groundwater Section at the Portuguese National Laboratory for Civil Engineering (LNEC) in Lisbon.

As the world population burgeons, human demand for water expands and one in ten rivers run dry for part of the year; humankind is turning increasingly to groundwater as a resource. Like oil reserves, the true extent of groundwater reserves is difficult to estimate and, whilst billions of dollars have been spent searching for valuable oil reserves, groundwater has rarely been ascribed a monetary value at all. As a result, most exploitation has been based on relatively unsophisticated exploratory methods, estimates of available reserves have been and continue to be largely based on limited data, and the world is only just waking up to the long-term damage done by reckless pollution. This comes right at the time that many parts of the world are turning more and more to groundwater as a supposedly reliable source of water and when impending climate change is set to have significant impacts on resources in many regions, especially in areas already under stress.

This volume aims to highlight these issues and to try to point towards ways of overcoming the problems.

Leader, IYPE Groundwater team  
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# Groundwater in Peril

J. Anthony A. Jones

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## Abstract

Groundwater is being exploited, overexploited and polluted as never before. Agriculture is a major cause, with rising levels of irrigation and overuse of artificial fertilisers. High levels of pollution in surface water bodies have also led to greater use of groundwater. In some areas, however, downdraft has led to oxidation of bedrocks and release of arsenic, most notably in West Bengal and Bangladesh. Falling water tables in the Ganges delta may be intensified by management of surface water, especially river diversions. Internationally shared aquifers, as between Israel and the West Bank, continue to be a source of disagreement and present a potential cause for 'water wars', although the 'Berlin Rules' brought groundwater into the realm of international law for the first time in 2004. Less well publicised is the complex interaction between groundwater and the sea, with groundwater acting as both victim and booster. The latest drive to extract oil and gas from shales by 'hydrofracking' holds new threats for groundwater resources. So too does climate change. Sustainable management of groundwater resources will require better monitoring; data capture; storage and accessibility; improved modelling; more efficient water use, particularly in agriculture; and more measures to improve groundwater recharge.

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## Keywords

Groundwater • Pollution • Overdraft • Salinisation • Sea level rise • Shale oil • Arsenic • Uranium • Artificial recharge • Internationally shared aquifers

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## Introduction

Groundwater is a vital resource for many people around the world. As surface water supplies are diminishing or becoming polluted, people are turning

increasingly to groundwater. Yet groundwater reserves are also suffering, as a result of overexploitation, pollution and climate change. Whilst the impact of climate change on glaciers and ice sheets is receiving wide media attention, the future of groundwater resources hardly gets a mention. For most human societies, what is happening to groundwater resources is at least as important, if not more so. Loss of ice resources is a serious concern for communities that depend on meltwaters from the Himalayas, Andes,

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