SECTION 1
General considerations

Intensive use of groundwater: introductory considerations

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1 INTRODUCTION

Groundwater use is *intensive* when the natural functioning of aquifers is substantially modified by groundwater abstraction. This implies the use of at least part of the freshwater storage in the aquifers and a series of impacts that are commonly called *problems*. The term *intensive* only describes but does not qualifies what is really happening, as do other terms such as excessive use, overexploitation, overdraft or stressed aquifer.

Aquifer use provides large social benefits but there are also the indirect costs, which refer to other users and to the impact on Nature. They are commonly designed as *problems*. To get the right picture, the net balance has to be considered. Results largely depend on how benefits and costs are evaluated, which are largely case-dependent. For this evaluation, technical aspects are important but economic, social and ethical considerations are often even more relevant.

These introductory considerations aim to the better understanding of this book. The book aims to: 1) consider the most relevant aspects of intensive use of groundwater; 2) cover the basic scientific and technical aspects from a general point of view, to make it easily understandable by water managers and decision-makers without need for specialised training in hydrogeology; 3) introduce the economic and social aspects that complete the picture needed to understand the issues related to intensive use of groundwater from a multidisciplinary approach; and 4) present some overviews of the current situation of aquifer intensive use in different parts of the world.

2 MAIN OBJECTIVE OF THIS BOOK

The main aim of this book is to contribute to a more transparent, objective, and unbiased information on the *pros* and *cons* of intensive groundwater development, based on the experience in many countries during the last decades. The following meetings and corresponding publications have been a source of data and inspiration for this book.

1) A Symposium convened by the Spanish Chapter of the International Association of Hydrogeologists (IAH), in Almería, Spain (Pulido *et al*. 1989).
2) An IAH International Congress, in Puerto de la Cruz (Tenerife), Canary Islands, Spain (Candela *et al*. 1991, Simmers *et al*. 1992).
3) A United Nations meeting in Las Palmas de Gran Canaria, Canary Islands, Spain, which reported on the World's situation (Dijon & Custodio 1992).

The editors of this book have invited a first group of authors to present the positive and/or negative general aspects of intensive use of groundwater. A second group of authors provide an overview on the specific situation in some significant regions, without trying to cover all the world regions where there is intensive groundwater use.

From the onset it should be made clear that what this book tries is to focus on the most important issues, considering the benefits and the costs or problems from groundwater development. It should be clear that groundwater development may not easily solve any water problem in the world, although it is an important alternative to be considered and evaluated. In this respect, different scientists, experts and stakeholders may interpret a given situation very differently, perceptions also change through time, and possible solutions are not unique and may often involve trade-offs, and accommodation to local circumstances, established policies and politics.

The editors of this book expect that this volume may constitute a step-forward to clarify the importance of groundwater and its far-reaching implications. However, it will obviously not be the final say on this topic. As a matter of fact, it is expected that this topic will be discussed at depth during conferences to be held in the near future, like the IAH Congress (Mar del Plata, Argentina, October 2002), the Symposium on Intensive Use of Groundwater (Valencia, Spain, December 2002), the 3rd World Water Forum (Kyoto, Japan, March 2003), and the 11th Congress of the International Water Resources Association (Madrid, Spain, October 2003).

3 INTENSIVE USE OF GROUNDWATER

Groundwater is an important component of the water cycle in Earth. Two essential roles can be defined for groundwater: first in Nature as ecosystem support, and second as a natural resource that meets vital human and economic needs. Besides these two main roles, water has intangible values related to cultural and religious significance.

In Nature, groundwater is a key factor in many endogenous geological processes: it works as the carrier of dissolved mass in the ground and constitutes the main cause of rock weathering and diagenesis. It also acts as the medium where many mineral deposits are formed, the component that sustains spring discharge, river base-flow, and many lakes and wetlands. It is also a geotechnical factor in soil and rock behaviour.

Groundwater is a key resource for urban and rural supply, a strategic resource in case of failure of other water sources like during droughts, major breakdowns, and pollution accidents. It is also an important resource to develop irrigation, and a reliable resource for industrial uses.

Groundwater had been traditionally used by tapping springs and diverting river base-flow, and in minor quantities by direct abstraction through wells and horizontal galleries, especially in arid and semiarid regions. The situation changed recently, about 150 years ago, when the scientific basis for understanding groundwater occurrence and flow was established, and more so when, half a century ago, drilling machinery and well pumps were made easily available. At the moment a deep well can be drilled and installed in just in a few days. Thousands of drilling rigs of varied sizes and requirements are available. Man-powered and solar energy pumps can be installed in poor rural areas with low technology and cost, while electric turbine pumps are capable of pumping tens of litres per second from 100 to 500 mm diameter wells from depths down to several hundred metres.

This is a revolution, still largely ignored by many water decision-makers, water engineers and the media, who are not fully aware of this development. It could also be that they have decided to ignore this revolution because of vested interests in large, expensive water projects, mostly surface water ones, which often are economically more expensive and that may have serious social and ecological impacts.

Private owners with their own funds have mostly driven the groundwater revolution. They pay the direct full cost of groundwater abstraction, even if in some cases they may benefit from some subsidies, like tax reductions or reduced energy supply cost. Groundwater development has been mostly generated in arid and semiarid areas, in densely populated coastal areas and islands, and around large cities and industrial settlements. Additionally, large aquifer developments are found in open-pit mining areas to desiccate the ground, and also in mining areas in arid lands in order to obtain the water needed to transport the grinded ore by pipe to treatment plants far-away.

Large groundwater abstractions usually modify the hydrological cycle in a significant way. It affects springs and river base-flow, water table depth, piezometric levels, groundwater storage, groundwater-dependent wetlands, groundwater quality, river-aquifer relations and even land surface elevation (subsidence). The editors of this book define this situation of significant alteration of the water cycle as *intensive development (or use)*.

4 INTENSIVE USE OF GROUNDWATER *VERSUS* AQUIFER OVEREXPLOITATION

The term overexploitation has been frequently used during the last three decades. Nevertheless, most authors agree in considering that the concept of aquifer overexploitation is one that eludes a useful and practical definition (Llamas 1992, Collin & Margat 1993, Custodio 2000, 2002, Sophocleous 2000).

In simple terms, the 1985 Spanish Water Act defines that an aquifer is overexploited when pumpage is close or larger than the natural recharge, in line with the common misconception that considers that the safe yield or sustainable yield is practically equal to the natural recharge. This misconception, already pointed out by Theis as early as 1940, has been voiced by many other hydrogeologists (see Custodio 2000, Sophocleous 2000, Hernández-Mora *et al*. 2001). Bredehoeft *et al*. (1982) describe the issue in the following way:

> "Water withdrawn artificially from an aquifer is derived from a decrease in storage in the aquifer, a reduction of the previous discharge from the aquifer, an increase in the recharge, or a combination of these changes. The decrease in the discharge plus the increase in recharge is termed capture. Capture may occur in the form of decreases in the groundwater discharge into streams, lakes, and the ocean, or from decreases in that component of evapotranspiration derived from the saturated zone. After a new artificial withdrawal from the aquifer has begun, the head of the aquifer will continue to decline until the new withdrawal is balanced by capture". "In many circumstances the dynamics of the groundwater system are such that long periods of time are necessary before any kind of an equilibrium conditions can develop".

A number of terms related to overexploitation can be found in the water resources literature. Some examples are: safe yield, sustained yield, perennial yield, overdraft, groundwater mining, exploitation of fossil groundwater, optimal yield and others (see Glossaries in Fetter 1994, Acreman 2000). In general, these terms have in common the idea of avoiding the undesirable effects resulting from groundwater development. However, this undesirability depends mainly on the social perception of the issue. This social perception is more closely related to the legal, cultural and economic background of the region than to pure hydrogeological facts (Custodio 2002). For example, in 1940, according to Theis, water was gained by lowering the water table in areas of rejected recharge or where the recharge was *lost* through transpiration from non-beneficial vegetation (phreatophytes). In Theis' times wetlands were wastelands, in clear contrast with the current appreciation of the high values of these ecosystems. Other terms such as *excessive* imply a bias.

A possible alternative definition is to consider an aquifer overexploited when the economic, social and environmental costs derived from a certain level of groundwater abstraction exceed the corresponding benefits (Llamas *et al*. 1992). The estimation of the monetary evaluation of *in situ* services of groundwater (like avoiding subsidence, wetland conservation, or maintaining the base-flow of rivers, among others) is a very complex and difficult task where available research is still scarce (NRC 1997). Although some of these variables may be difficult to measure and compare, they must be explicitly included in the analysis so that they can be taken into account in the decision-making processes.

The fact that groundwater development is affecting significantly aquifer water conditions (quantity, levels, quality, pattern, land elevation, …) is here termed *intensive* use. Only the facts are pointed out, without qualifying them. If the term *excessive* is used, as some authors point out, there is a bias towards negative impacts, as does the term *overexploitation*, like it is commonly used nowadays. These terms should be avoided as much as possible in trying to achieve a broader scope and an unbiased attitude.

To address intensive use of groundwater, both realistic and optimistic approaches are much needed. The editors agree with Kessler (1998) and Lomborg (2001) in considering that the frequent pessimistic litany of the doomsday preachers and environmental exaggerations often have had serious consequences. It makes people scared and it makes them more likely to spend limited resources and attention to solving phantom problems while they ignore real and pressing (possibly non-environmental) issues. This is why it is fundamental to know the real situation of intensively developed groundwater areas. The best possible information is needed to guide the best possible decisions.

5 PRIVATE AND PUBLIC FUNDING IN WATER RESOURCES MANAGEMENT

Most surface water developments are capital-intensive and need a long time to achieve full economic production. This is even more obvious in arid and semiarid countries, where interannual variability is large. Also these areas are much more sensitive to the effect of droughts, especially when the full use of available water resources is approached. Most developments are carried out by public institutions, with the co-operations of large national and multinational corporations (constructors, lenders, donors). Private funds are mostly used for small works, in small river basins and in springs to tap groundwater. This undertaking is often carried out by the wealthiest sector of the local society.

The development of groundwater is less capital-intensive and can be carried out by individuals or small groups through their own resources or by means of moderate loans. Thus, it is not surprising that, once drilling machinery has become easily available and pumping facilities are at hand with very simple installations, groundwater has started to be widely used. This is the origin of intensive aquifer development, which has dramatically improved health conditions, local economies and livelihoods in many – previously poor – regions. Since groundwater users often pay the direct full cost of water, they are motivated to get a higher efficiency in water use. This common situation may change if there are significant energy subsidies or if the cost of groundwater abstraction is negligible in the wider economic process for which groundwater is used.

Large surface waterworks are often carried out through public funds and only small fractions of the charges are transferred to the water user. This does not encourage efficient water use, which is necessary when available resources are used to their full potential, like in the case of arid and semiarid countries. Moreover, the public funds invested are only beneficial to a sector of society, depriving other sectors from the benefits that could be reaped from these funds. This is not the case in private groundwater developments. Nevertheless, a large number of small independent developers may lead to intensive groundwater use, which may be qualified as excessive or as an overexploitation. Frequently stakeholders are unaware of this situation and institutions to cope with this do not exist. There are possible solutions to these problems, which have to be tailored on a case by case basis. The so-called problem of common pool resources (Aguilera 1991) – or the Tragedy of the Common – which predicts the exhaustion of the resource due to unlimited access, does not necessarily apply, as recently analysed by Milinski *et al*. (2002). One goal in this book is to suggest possible approaches to solve this problem.

6 QUANTITY AND QUALITY ASPECTS

Avoiding the degradation of groundwater quality is perhaps the most significant challenge to the sustainability of groundwater resources. Restoration of contaminated aquifers can be a costly and difficult task. Most often groundwater quality degradation is not the result of intensive abstraction. It is related to other causes such as point or non-point source pollution from various sources such as return flows from irrigation, or leakage from septic tanks and landfills, or industrial liquid wastes. These problems are not exclusive to industrialised countries and may also be serious in developing countries (Janakarajan 1999, Burke & Moench 2000). It can also seriously jeopardise their future prospects.

Commonly, the first issue taken into account in groundwater development is quantity. Most often it is linked to the population to be supplied with and the surface area to be irrigated. When water is scarce or expensive this is the value that attracts the most attention.

Yet groundwater quality is what determines whether water is fit for its intended use, either directly or by means of treatment which increases its cost and needs expertise. Thus, quality is also an essential consideration, which is often neglected by water managers. This oversight may lead to obvious problems, like public health problems, or the degradation of arable soil (Simpson & Herczeg 1991, Custodio 1997).

7 MANAGEMENT INSTITUTIONS, PUBLIC AWARENESS AND STAKEHOLDERS PARTICIPATION

A clear advantage to achieve sustainable groundwater development is to ensure the slowing down of degrading processes. In most cases, it can take one or two generations before these negative effects are noticed by the general public. This situation may allow time to correct these problems if people are aware of them.

In this book –and mainly in its first and last chapters– the main solutions will be illustrated in order to avoid or mitigate problems or impacts from intensive use of groundwater. These problems or impacts are related to hydrological or legal interferences with other surface or groundwater uses, groundwater quality degradation and negative impacts to aquatic ecosystems and others.

The corresponding solutions are site-specific, and take on board, not only the hydro-geological framework, but also the social, economic and political backgrounds. Nevertheless, it seems that some basic pillars are common to most solutions. These common ground are: 1) monitoring to get an acceptable knowledge of the situation; 2) public education programmes; 3) stakeholders participation in the design and control of management plans; 4) a clear inventory of groundwater rights and rules; and 5) building the capacity of public water authorities, who can then act mainly as catalizers for education and participation programmes.

8 ETHICAL ISSUES

Scientific and technological advances over the past several decades have resulted in dramatic changes to the lives of societies and individuals. Since the 1990s, there is an increasing interest and awareness focused on the need for a better understanding of the ethical, religious, or philosophical principles that underpin the development of Science and Technology and their application. This interest is probably paramount in the field of Biomedical Sciences, because of its immediate effect on society. Increasingly this is also the case in other areas, like energy or climate change, where more and more researchers are concerned about ethical implications. The Ethics of freshwater use, hazards and management have also become increasingly the focus of research of a number of people. In the last five years, several meetings have been devoted to this issue. The main relevant issues are summarised in Llamas & Delli Priscoli (2000), and in WHAT (2000). These ethical aspects are considered in most of the chapters of this book.

One way to look at the close connection of water to the broader social and ethical concerns is to consider how water management issues relate to what many people consider universal ethical principles, like the 1948 United Nations Universal Declaration of Human Rights. Some of these principles are:

- Human dignity: all persons are worthy of respect and the human person is not a mean but an end. There is no life without water, and those to whom it is denied are denied life. The principles of water for all, and meeting minimum basic needs, are vitally tied to that of human dignity.
- Sociability: the person, as well as sacred, is a social being.
- Participation: individuals, especially the poor, must not be excluded from participating in the institutions needed for their human fulfillment, e.g. in water management.
- Solidarity: humans are all equal, and connected; we are our brothers' keepers, and loving our neighbour relates directly to a growing sense of interdependence. More than almost any other natural resource, water continually confronts humans with their upstream and downstream interdependency, and calls humanity to a higher level of solidarity. Indeed, the current call for integrated water management could be seen as a direct subsidiary teaching of this principle.
- Stewardship: this teaches respect for Creation or Nature, and moral responsibility to that Creation. However, it also calls for the wise use of Nature and not the extreme reverence for it. Indeed, much water management is about finding the ethical balance between using, changing and preserving land and water resources. The

consensus on sustainable development can be seen as an ethical norm directly descendent from this principle. Sustainable development aims to achieve a balance between its utilitarian use and the respect for the intrinsic value of the Earth's resources.

The common good is understood as the social conditions that enable people to reach their full human potential. Almost everyone's definition considers water as a common good.

Water is one of the enduring human symbols for life, regeneration, purity and hope. It offers a medium for a global project that unifies humanity in a single cause for peace, stability, amity, and ecological sustainability. Water offers a medium for creating a culture of peace and rarely becomes a real cause for wars (Asmal 2000).

9 CONTENTS AND PLAN OF THE BOOK

The practical limits on the number of contributing experts and the number of pages imposed boundaries for later tasks. The editors have tried not to move away from the main objective of this book: the intensive use of groundwater. Therefore some interesting issues have been left aside or some important groundwater topics have only been considered tangentially. Such is the issue of groundwater contamination, which is surely the most serious threat on the sustainability of groundwater resources. It is however largely unrelated to intensive use of groundwater and more to land use and other anthropogenic activities.

There is a major emphasis in this book on irrigation since this type of water use largely exceeds other water abstractions, and is also a key factor for poverty alleviation in developing countries. In most intensively developed aquifers groundwater is mainly used for irrigated agriculture.

Intensive use of aquifers for industrial purposes is not explicitly considered since it is mostly carried out under similar circumstances in urban areas.

Intensive use of aquifers in relation to mining is also not explicitly considered in spite of its local importance in some regions, and large possibly related social and ecological impacts. An expert has not been found to present existing on social and ecological impacts.

As it is to be expected in a series of chapters written by different authors, there are some overlaps, omissions and contradictory points of view. The editors have not attempted to change this. A unification of terminology used has also not been done, except for some small suggestions to the authors on the common definitions of some terms. The editors believe that preserving the original thoughts of the authors is both useful and rich, and allows the appreciation of the different ways of interpreting facts under different circumstances. A three-day Workshop, held in Madrid (13 to 15 December 2001) to openly discuss the preliminary drafts of the chapters, was considered sufficient to make authors aware of the main objectives in order to finalise their drafts into the final chapters here presented.

Cross-references in the book have been substituted by concept (including locality) and author indices, which may provide a more useful tool in order to find topics and localise examples.

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ANNEX:
GLOSSARY OF TERMS

Aquifer: A formation saturated with water from which groundwater can be pumped or drained, obtaining flows of local importance.

Aquifer, confined: An aquifer bounded above and below by confining beds and in which the static head is above the top of the aquifer (ASTM, D 4043–91:1)*.

Aquifer system: A formation that contains aquifers and aquitards, and behaves hydrogeologically as a unit. See groundwater body.

Aquitard: A formation saturated with water, unable to yield groundwater flows of local importance.

Background concentration: The concentration of a substance in groundwater, surface water, air, sediment, or soil at a source(s) or nearby reference location, and not attributable to the source(s) under consideration. Background samples may be contaminated, either by naturally occurring or manmade sources, but not by the source(s) in question (ASTM, D 4043–91:131).

Baseline concentration: See background concentration.

Borehole: Any mechanical drill; generally it includes the casing and some kind of screen.

* ASTM is the American Society for Testing and Materials. ASTM International is an organization that provides a global forum for the development and publication of voluntary consensus standards for materials, products, systems, and services (http://www.astm.org).

Computer code: The assembly of numerical techniques, bookkeeping, and control language that represents the model from acceptance of import data and instructions to delivery of output (ASTM, D 4043–91:114).

Computer programme: See computer code.

Conceptual model: A simplified representation of the hydrogeologic setting and the response of the flow system to stress (ASTM, D 4043–91:1). An interpretation or working description of the characteristics and dynamics of the physical system (ASTM, D 4043–91:90).

Conjunctive use: The variable use of different sources of water to try to optimise some function, such as available flow. Generally includes surface and groundwater sources.

Contaminant: Substance, including any radiological material, that is potentially hazardous to human health or the environment and is present in the environment at a concentration above its background concentration (ASTM, D 4043–91:131).

Cost, direct: The cost directly associated to the production of a good, e.g. the abstraction of groundwater (energy, maintenance, capital cost, taxes).

Cost, indirect: Any cost that is not accounted as a direct cost and should be beared by others, e.g. the extra cost for pumping by others due to the drawdown, the impairment of groundwater quality due to abstraction, the reduction of river base-flow, spring flow and well yield, etc.

Drawdown: Vertical distance the static head is lowered due to the removal of water (ASTM, D 4043–91:17).

Externalities: Economic effects, costs and benefits of an activity upon other activities and upon the society in general, that are not included and charged to this activity (see cost, indirect).

Flux: The volume of fluid crossing a unit cross-sectional surface area per unit time (ASTM, D4043–91:103).

Groundwater: Any water existing below the ground surface. The term is generally restricted to water in the saturated zone.

Groundwater, intensive use: Groundwater development that has a significant impact on the hydrological cycle.

Groundwater, mining:

a) (Strict) groundwater is persistently withdrawn at a rate clearly exceeding interannual recharge.
b) (Extended) groundwater storage is continuously depleted.

Groundwater, overexploitation:

a) (Strict) abstraction is assumed to exceed recharge.
b) (Common) negative effects of aquifer development that concern administrators and/or the general public.

Groundwater body: See aquifer system. This is a new term introduced by the European Union Water Framework Directive.

Head, static: The height above a standard datum of the surface of a column of water that can be supported by the static pressure at a given point (ASTM, D 4043–91:22).

Infiltration: The penetration of surface water into the ground through the land surface (it should not be mistaken as recharge).

Intensive use: See groundwater, intensive use.

Intergenerational, equity/solidarity: Distribution of access to economic riches and social welfare among persons, groups or societies:

a) of the present and future.
b) of the present, with differences of nationality, culture, gender, race, religion, etc.

Intrusion: The encroachment of a different kind of water into an aquifer.

a) saline: if encroaching water is saline.
b) marine: if encroaching water is seawater.

Maintenance: Any action directed to sustain the operativity of the elements which allow the use of a given natural resource, including the substitution of elements.

Management: Any action directed to improve the use of a given natural resource, including decision-making.

Mathematical model: Mathematical equations expressing the physical system and including simplifying assumptions. The representation of a physical system by mathematical expressions from which the behaviour of the system can be deduced with known accuracy (ASTM, D 4043–91:114).

Model: An assembly of concepts in the form of mathematical equations that portray understanding of a natural phenomenon (ASTM, D 4043–91:90).

Observation well: A well open to all or part of an aquifer, and used to make measurements (ASTM, D 4043–91:1).

Overdraft: See groundwater overexploitation.

Overexploitation: See groundwater overexploitation.

Percolation: The flow of water through the unsaturated zone.

Piezometer: A device constructed and sealed as to measure head at a point in the subsurface (ASTM, D 4043–91:59).

Player: See user.

Recharge: The process of introducing water into a groundwater body.

a) Natural: Produced naturally as a result of rainfall, streamflow, snowmelt.
b) Artificial: Produced by the direct intervention of man.
c) Enhanced: When some human activity increases the infiltration of rainfall or runoff.
d) Induced: Produced as a consequence of aquifer development, mostly by pumpage near rivers.
e) Rejected: When available water at the surface (rainfall, runoff) cannot infiltrate as a consequence of the water table being at the ground surface.

Safe yield: See yield, safe.

Salinization: The process of increasing total dissolved solids in water.

Saturated zone: Part of ground in which the pores and fissures contain only water.

Simulation: One complete execution of the computer programme, including input and output (ASTM, D 4043–91:103).

Stakeholder: See user.

Sustainability: Ability to meet the needs of the present generations without compromising the ability of future generations to meet their needs (Bruntland's report definition).

Unconfined aquifer: An aquifer that has a water table (ASTM, D 4043–91:1).

Unsaturated zone: Part of ground below land surface in which the pore and fissures contain air and water.

User, groundwater: Any person, real or legal, that has an interest in groundwater from a given groundwater body.

a) Direct: any user of springs, wells, drains or water galleries.

b) Indirect: any person supplied by groundwater or affected by groundwater; it may include Nature (environmental use).

Users association: Any organisation created by the users to manage, protect, defend or represent a given natural source of goods.

Vadose zone: See unsaturated zone.

Water harvesting: Any process directed to collect local storm runoff, and rainwater.

Water reserves: See water storage.

Water resources: Volume of water that can be used during a given time from a given volume of terrain or water body.

Water storage: Water that exists in a given moment in a given volume of terrain.

Water table: The upper limit of the saturated zone where pore water pressure equals atmospheric pressure.

Well: Any vertical hole in the ground prepared to allow groundwater abstraction. It includes casing, screens, groutings, surface protections...

Yield, maximum sustained: The maximum rate at which water can be drawn perennially from a particular source.

Yield, perennial: The flow of water that can be abstracted from a given aquifer without producing an undesired result.

Yield, permissive mining: The maximum volume of water in storage that can economically and legally be extracted and used for beneficial purposes, without bringing about some undesired result.

Yield, permissive sustained: The maximum rate at which water can economically and legally be withdrawn perennially from a particular source for beneficial purposes without bringing about some undesired results.

Yield, safe: Water that can be abstracted from an aquifer permanently without producing undesirable results (Meinzer 1920) This was a concept developed from the point of view of developers (i.e. managers and engineers), without considering ecological aspects.