Draft Edition

Groundwater Governance
Synthesis Report

Groundwater Governance
A Global Framework for Action

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Groundwater Governance – A Global Framework for Action

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Synthesis Report

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It is work in-progress, intended for the members of the Project Consultation Mechanism (PCM) and other stakeholders, as part of the project wide consultation. Comments, remarks and questions should be sent to:
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1. Introduction

People's initial attitude of taking groundwater - a fundamental natural resource and vital component of our environment - for granted and simply exploiting it according to individual demands had prevailed in most countries of the world until the mid twentieth century. More recently, demographic pressures, economic and technological development and other factors have triggered unprecedented changes in the state of our groundwater systems, which has resulted in a growing awareness as to the finiteness and vulnerability of this critical resource.

In response to this new awareness, groundwater resources management (or groundwater management) has been embraced and developed in most countries. Usually initiated by governments, it pursues the controlled exploitation and adequate protection of groundwater to achieve broad society goals. Groundwater resources management comes in many forms and needs to be tailor-made to local conditions. It is action-oriented and uses technical instruments, legal and regulatory instruments, and incentives/disincentives to achieve its goals. While groundwater management is an inseparable part of overall water resources management, it deserves special attention due to the hidden, invisible nature of the resource, its high stock-to-flow ratio and the relatively dominant role of encouraging a change in behaviour as a tactic for achieving management goals. The common pool resource characteristics of groundwater, the close interaction between groundwater and land use and the often-limited understanding among policy makers of its characteristics and of the geological processes that control its behaviour, are additional challenging features.

In spite of the efforts being made across the planet to introduce some degree of management to the use of this invaluable resource, groundwater exploitation at the global level is, however, far from being sustainable. Groundwater resources are being rapidly degraded in terms of quality and quantity, and the opportunities that currently exist for the *strategic* expansion of groundwater use are being compromised, or simply remain unknown to stakeholders. Effective management is often hampered by poor coordination and co-operation between relevant actors and/or by a lack of capable institutions and instruments, including technical, which can align stakeholder behaviour with policy objectives.

In view of this alarming situation, the concept of groundwater governance has (only recently) emerged. Groundwater governance can be qualified as "*an overarching framework and set of guiding principles that determines and enables the sustainable management of groundwater resources and the use of aquifers*". The lack of adequate governance – i.e.: overarching enabling frameworks and guiding principles – hinders the achievement of groundwater resources management goals such as resource sustainability, water security, economic development, equitable access to benefits from water and conservation of ecosystems.

It is for these reasons that the Global Environmental Facility (GEF) has joined forces with the Food and Agricultural Organisation of the United Nations (FAO), UNESCO's International Hydrological Programme (UNESCO-IHP), the International Association of Hydrogeologists (IAH), the World Bank, and a multitude of scientists and water managers from across the globe, in the project *"Groundwater Governance – A Global Framework for Action"*. The project represents an ambitious effort to raise global awareness on the urgent need for improved groundwater governance, set the foundations for a global response to this new challenge, and catalyse the necessary action.

This Synthesis Report highlights a number of key findings from the Project's first Component, which was designed to provide a science based consolidation of knowledge of the groundwater resources economically exploitable under presently prevailing conditions, and their state (both quantity and quality), with focus on governance relevant aspects. As a part of this Component, twelve thematic papers have been prepared by leading international scientists and experts. The full text of these papers, together with short summaries ('Digests'), can be downloaded from the internet, at the address http://www.groundwatergovernance.org/resources/thematic-papers/en/. Readers who want to access the information in full detail should consult these papers. This Synthesis does not present a summary of these papers, but distils from them key messages, paying particular attention to the interactions between the different thematic fields, to the main governance issues and constraints, and to the most significant prospects and recommendations for improving groundwater governance. It aims to contribute to achieving broad agreement on the scientific and economic issues in relation to groundwater and a consensus on the scope for future action.

BOX 1: THEMATIC PAPERS

- No.1 – Trends in groundwater pollution; trends in loss of groundwater quality and related aquifers services. *By Emilio CUSTODIO, DET–CIHS / UPC, RAC, Barcelona*
- No.2 - Conjunctive Use and Management of Groundwater and Surface Water. *By W R Evans, R S Evans & G.F. Holland (SKM Australia)*
- No.3 – Urban-rural tensions; opportunities for co-management. *By Ken Howard on behalf of the IAH Urban Groundwater Network*
- No.4 - Management of aquifer recharge / discharge processes and aquifer equilibrium states. *By Peter Dillon, Enrique Fernandez Escalante, Albert Tuinhof*
- No.5 - Groundwater Policy and Governance. *By Robert G. Varady, Frank van Weert, Sharon B. Megdal, Andrea Gerlak, Christine Abdalla Iskandar, and Lily House-Peters. Major editing by Emily Dellinger McGovern.*
- No.6 – Legal framework for sustainable groundwater governance. *By Kerstin Mechlem*
- No.7 – Trends in local groundwater management institutions / user partnerships. *By Marcus Moench, Himanshu Kulkarni, Jacob Burke*
- No.8 - Social adoption of groundwater pumping technology and the development of groundwater cultures: governance at the point of abstraction. *By M.J. Jones*
- No.9 – Macro-economic trends that influence demand for groundwater and related aquifer services. *By Jacob Burke (no full paper, but only a summary available)*
- No.10 - Governance of the subsurface and groundwater frontier. *By Jac van der Gun, Andrea Merla, Michael Jones and Jacob Burke*
- No.11 - Managing the Invisible - Understanding and Improving Groundwater Governance. *By Marcus Wijnen, Benedicte Augeard, Bradley Hiller, Christopher Ward and Patrick Huntjens*
- No.12 - Groundwater and climate change adaptation. *By Craig Clifton, Rick Evans, Susan Hayes, Rafik Hirji, Gabrielle Puz and Carolina Pizarro*

2. Groundwater: facts and features

2.1 Some general characteristics of groundwater

Groundwater is present in pores and other open spaces inside the geological formations below the ground surface, in quantities much larger than any other liquid. Subsurface bodies of granular material or fissured rock capable of storing and transmitting significant volumes of groundwater are called *aquifers*. Aquifers thus are not only reservoirs, but also conduits for water. They are usually subject to replenishment (recharge) and outflow (discharge) that link them dynamically with the other components of the water cycle. Replenishment makes groundwater a renewable resource, characterized by stock (= the volume stored) and flow (=the flux maintained by recharge and discharge). The relatively high stock-to-flux ratio (compared to that of atmospheric water, surface water and soil moisture) explains the buffer capacity of groundwater.

There is an endless variation in groundwater systems around the world, mainly as a result of variations in geology and climate. As figure 2.1 shows, different climatic conditions may lead to very significant differences in groundwater state within geologically similar aquifer systems.

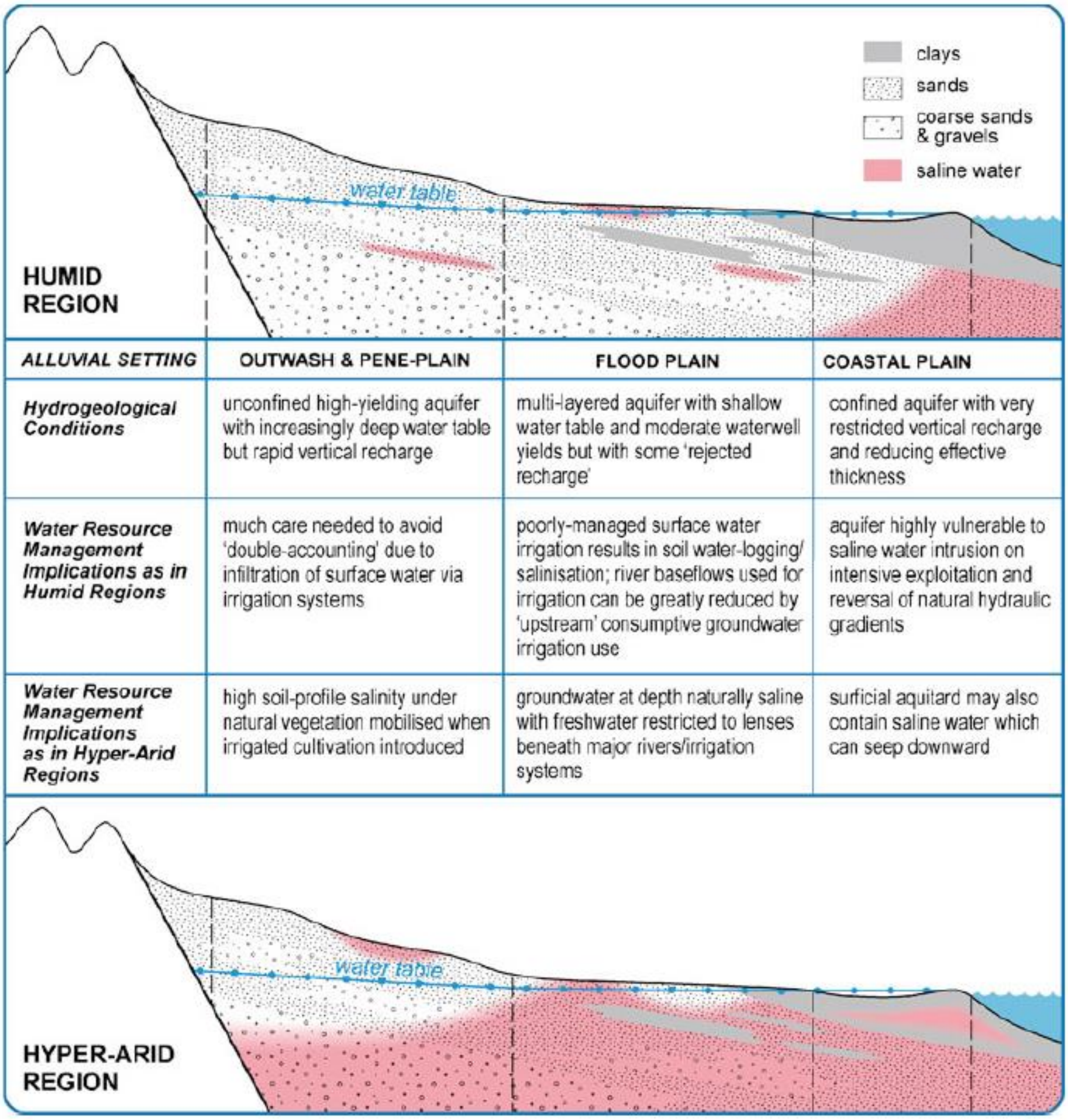
Groundwater represents almost 99% of all liquid freshwater on Earth, but its global flux is relatively small compared to that of other water cycle components. The rate of groundwater replenishment varies highly in time and in space. If an aquifer receives no or only insignificant quantities of recharge, due to geological or climatic conditions, then its groundwater is classified as 'non-renewable'.

Groundwater at such great depth that it has become isolated from the active water cycle is usually saline. Most of the groundwater at shallow and intermediate depth - the depths within reach of conventional water well drilling equipment - is fresh, however, and fit for common water use purposes. Only in some zones does the natural groundwater quality impose some restrictions, e.g. by a high degree of mineralization, or by high contents of arsenic or fluoride.

2.2 Early exploitation of groundwater

From time immemorial, people have exploited groundwater to satisfy their water demands. Initially, only shallow groundwater was accessible and no more than animal or human muscular power was available to abstract it. The abstraction works that have been developed in different parts of the world can be subdivided into two categories: gravity-based abstraction works (infiltration galleries, subsurface dams, spring capturing works, flowing wells) and abstraction works (mainly wells) that need an external energy source to lift groundwater to the surface. Several of these abstraction techniques were implemented by local communities rather than by individuals, either because the source was considered to be common property (e.g. a spring, or the subsurface flow inside small river beds) or due the project's size (like in the case of constructing, operating and maintaining qanats). In the case of wells, private ownership and community ownership have often developed in parallel.

The limited technology available before the twentieth century caused groundwater abstraction to remain modest in terms of volume, and thus usually without significant impact on local groundwater regimes or environments. In spite of the relatively low quantities abstracted, the importance of groundwater in ancient times should not be underestimated. It served and still serves vital needs, especially in areas where no other water sources are available year-round. The first recorded signs of governance arrangements are found in the arid and semi-arid zones, in the form of customary laws for groundwater access and use.



ALLUVIAL SETTING	OUTWASH & PENE-PLAIN	FLOOD PLAIN	COASTAL PLAIN
Hydrogeological Conditions	unconfined high-yielding aquifer with increasingly deep water table but rapid vertical recharge	multi-layered aquifer with shallow water table and moderate waterwell yields but with some 'rejected recharge'	confined aquifer with very restricted vertical recharge and reducing effective thickness
Water Resource Management Implications as in Humid Regions	much care needed to avoid 'double-accounting' due to infiltration of surface water via irrigation systems	poorly-managed surface water irrigation results in soil water-logging/ salinisation; river baseflows used for irrigation can be greatly reduced by 'upstream' consumptive groundwater irrigation use	aquifer highly vulnerable to saline water intrusion on intensive exploitation and reversal of natural hydraulic gradients
Water Resource Management Implications as in Hyper-Arid Regions	high soil-profile salinity under natural vegetation mobilised when irrigated cultivation introduced	groundwater at depth naturally saline with freshwater restricted to lenses beneath major rivers/irrigation systems	surficial aquitard may also contain saline water which can seep downward

Figure 2.1 Schematic profile of a typical alluvial groundwater system located between mountains and sea, for two different climatic settings, detailing the variation in groundwater surface water connectivity and salinization hazards (*Evans et al., no date; after Foster et al., 2011)*

2.3 Groundwater withdrawal and use in modern times

Advances in drilling and pumping technology have strongly influenced the intensity and pattern of groundwater withdrawal and use worldwide. As a result, deeper aquifers can be tapped and higher rates of abstraction have become possible. The evolution of groundwater development and use has been different for different countries and among zones within these countries. Although other abstraction works still continue to function, pumped wells have become the most common tool for groundwater abstraction around the world.

For centuries, hand pumps had been used to supply domestic water to communities or individual households, and they continue to play an important role in rural water supply in developing countries. In order to satisfy criteria set during the International Drinking Water and Sanitation Decade (IDWSSD, 1981 – 1990) hand pumps should be robust, affordable and easily maintainable. These criteria are not always met and this has resulted in many failures. The Village Level Operation and Maintenance (VLOM) concept, introduced during the 1980s, initially focused on hardware only, but this was later expanded to also include the management aspects of maintenance, such as community decisions on when to service and by whom, and how to pay for the cost of repairs.

Today, groundwater pumping for urban water supply makes use of energised rotodynamic pumps and metropolitan centres have access to the latest technologies. Robust diesel and electric powered pumps have also enabled an exponential growth of groundwater-irrigated agriculture, and energy costs therefore make up a large part of total cost for groundwater. While urban water supply is a collective provision (although often in the hands of private companies), most of the groundwater for irrigation is abstracted by private farmers on an individual basis. Rather than being seen as a public good, there exists a widely entrenched perception that groundwater belongs to the owner of the land where it is withdrawn.

Globally aggregated groundwater abstraction has increased approximately sixfold during the last 50 years and is estimated to have reached a rate of 986 km^3/year in 2010. Figure 2.2 shows the observed trends in nine countries with intensive groundwater exploitation.

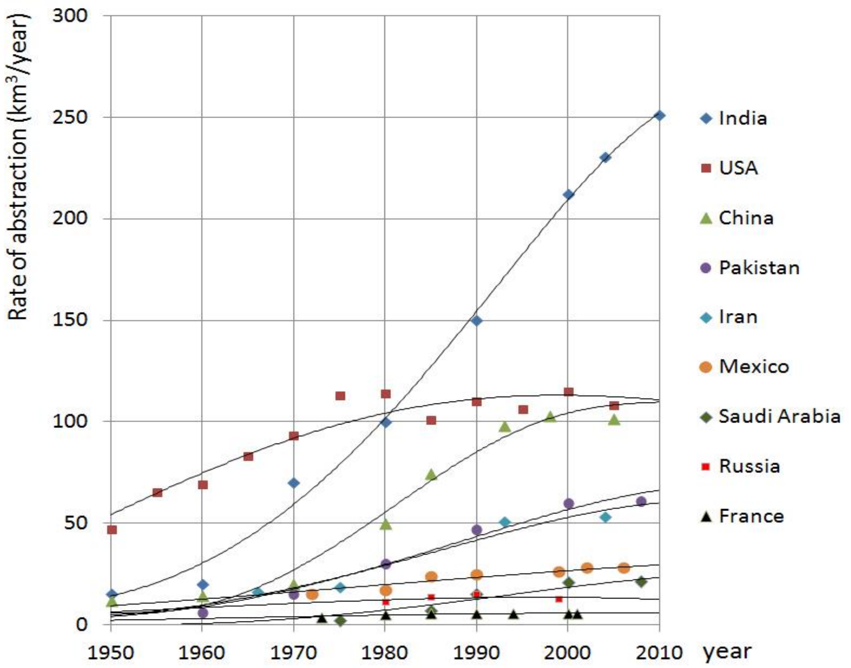


Figure 2.2 Evolution of groundwater abstraction in selected countries, period 1950-2010 *(Custodio, E., no date; after Margat and Van der Gun, 2013)*

Figure 2.3 illustrates the global variation of groundwater abstraction intensity, expressed in mm/year (1 mm/year = 1000 m^3/year per km^2). The three countries with the largest national groundwater abstraction are India, USA and China, which are also the three countries with largest area of groundwater-irrigated agriculture. The sum of their withdrawals is equivalent to 48% of the global total. Globally, approximately 70% of all abstracted groundwater is used for irrigation, 21% for domestic purposes and 9% for industrial water. The share of groundwater in total global freshwater abstraction is 26%, but this share varies widely between countries (and smaller spatial units) and between the main water use sectors.

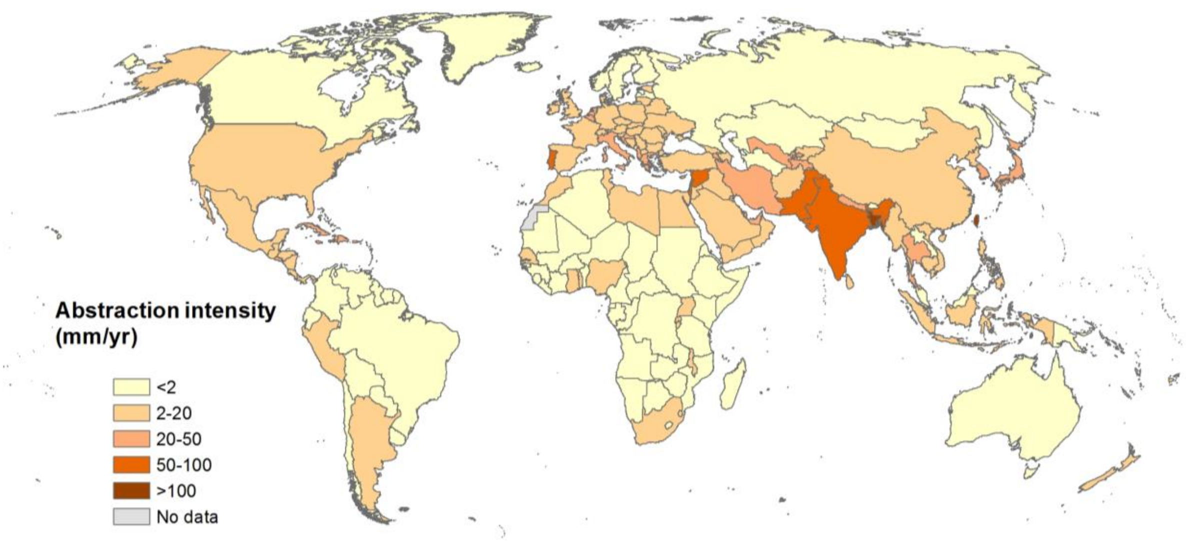


Figure 2.3 Intensity of groundwater abstraction by country for the year 2010, in mm/year
(After Margat and Van der Gun (2013), estimated on the basis of statistics in global databases)

These numbers and percentages are illustrative of the huge importance of groundwater as an extractable resource. The percentages would be even higher still if they represented not the volume abstracted, but the added value of the abstracted water as an indicator of the relative importance of groundwater. This is due to the fact that groundwater is almost always more reliable than surface water, greatly reducing the risk of unforeseen water shortages.

As far as is known, the aggregate economic contribution of groundwater to national economic development has been estimated in only a few cases. For instance, the Planning Commission of India has estimated that groundwater used for agriculture makes a 9% contribution to the country's GDP. This is an under-estimate of the total contribution of groundwater because the array of urban, municipal and industrial water supplies from India's aquifers have not been factored into the estimate. The International Water Management Institute (IWMI) estimated the world's groundwater-irrigated agriculture to have a value of USD 150 to 170 billion at the beginning of the 21st century.

In addition to the main categories of groundwater use (domestic water supply, irrigation and industrial water), several other uses deserve mentioning. The first is the use of groundwater in thermal baths or spas, undeniably important for therapeutic or touristic purposes, however the quantities of water involved are comparatively low. A related use is mineral water, originally consumed at the source (at spas or springs) but nowadays mostly distributed as bottled water (like ordinary bottled water that does not qualify as 'mineral water') and likely included in the statistics on industrial water. Groundwater is also used for the exploitation of geothermal energy and for seasonal subsurface heat storage and recovery. In both types of use the pumped groundwater is usually re-injected, resulting in low levels of consumption. Globally, only a small portion of the available high-temperature groundwater resources suitable for electricity generation (the so-called *high enthalpy* geothermal resources) are exploited, while the direct use of the huge amount of natural heat contained under normal gradient[1] conditions (*low enthalpy* geothermal resources) are being developed very slowly. Thus, there is scope for significant expansion of these groundwater uses in the future.

[1] 25 °C / km of depth

2.4 Development of non-renewable groundwater resources

Most groundwater resources currently being exploited are renewable, which implies that in principle they offer the possibility for sustainable use. This means that if exploited with sufficient care and control, the aquifers will remain in a long-term dynamic equilibrium, i.e. the volume stored and the groundwater levels will remain stable. Some aquifers face less favourable conditions (be it by geological or dry climatic conditions) and receive no or only insignificant replenishment, meaning their groundwater is classified as 'non-renewable'. Withdrawing groundwater from non-renewable resources will necessarily lead to steady depletion of the volumes of groundwater and thus require special exploitation strategies that differ from those adopted for renewable groundwater resources. Such strategies will have to consider explicitly the finiteness of the exploitable resources, indicate to what extent the benefits of present-day groundwater use may contribute to future wealth, and include an 'exit strategy', i.e. a clear idea on the sources of water to be tapped for basic needs after the non-renewable groundwater resource will have been exhausted.

2.5 Artificial groundwater discharge by drainage

Withdrawal for water use is not the only way in which humans actively interfere in groundwater regimes. In some parts of the world there is a long tradition of draining shallow-water table zones in order to prevent water-logging and make the land suitable for intended land use purposes. In such cases, the water pumped or drained by gravity is only a by-product of the activity and is usually dumped (without being used). Around 167 million hectares of artificially drained land have been identified around the world, but how much groundwater is discharged in this way is not yet known. Typical examples are the low-lying polder areas of The Netherlands and the Nile delta in Egypt. Similar activities include the drainage intended to facilitate mining and various types of use of the subsurface, as well as temporary drainage of building pits. Again, the volumes of groundwater pumped annually in this way are not known.

2.6 Ecological and environmental functions of groundwater

Groundwater is not only relevant as an extractable resource. In many zones it is also indispensible for, or at least contributes to, sustainability of surrounding ecosystems. Groundwater maintains the permanent or seasonal baseflow of streams, feeds springs, supports ecosystems and shallow-water table agriculture and can play a role in maintaining the stability of the land surface. Valuing these groundwater functions in economic terms is very difficult and inherently subjective. In many countries there is a steadily growing awareness of the value of these functions of groundwater and this awareness tends to grow in tandem with broader economic development. These ecological and environmental functions are often negatively affected by groundwater withdrawal.

2.7 Groundwater and land use

Groundwater and land use are strongly interconnected. On the one hand, the presence of groundwater and its quantity and quality may have a significant impact on the land use, in particular if the land is used for agricultural purposes dependent on specific water- table conditions or requiring irrigation. On the other hand, the type of land use and the adopted land use practices may have a profound impact on the groundwater regime (e.g. on groundwater recharge) and in particular on the groundwater quality. Many near-surface aquifers around the world are exposed to pollution and most sources of groundwater pollution are related to land use practices. The application of manure, fertilizers and pesticides in agriculture is a primary source of groundwater pollution, in addition to many other sources such as leaking sewerage systems, accidental spills of contaminants, waste dumps and wastewater discharge.

2.8 Groundwater withdrawal and other uses of the subsurface space and its resources

Groundwater is only one of the interests of mankind in the subsurface. Mining activities also have a very long tradition and are expanding in many parts of the world, targeting a large variety of valuable solid materials (like metals and minerals), and more recently also energy (oil, gas and geothermal energy). But the subsurface is also increasingly in use for other purposes. At shallow depth, this includes the construction of pipelines, sewerage systems, cables, tunnels, subways, underground car parks and subsurface parts of buildings. Various geological formations at greater depths are judged to be an attractive option for the disposal of hazardous waste (e.g. nuclear or hydrocarbon waste) and for injection and recovery purposes, such as carbon capture and sequestration (CCS).

2.9 Groundwater and its many interdependencies

It is clear that groundwater is not an isolated resource. It is subject to many interdependencies. It interacts with other components of the hydrological cycle (see e.g. Figure 2.4), but is also involved in other natural cycles such as the geochemical cycle and the global carbon cycle. It is affected by climate variability and climate change and it interacts with numerous ecosystems. The state of groundwater is influenced by many human activities, above and under the surface, and in turn groundwater abstraction affects all of these activities. Groundwater plays an important role in livelihoods and economies, and these socio-economic conditions, in turn, produce feedback to the state of the groundwater systems. Understanding groundwater and how it varies over time requires an appreciation of these complex resource interdependencies.

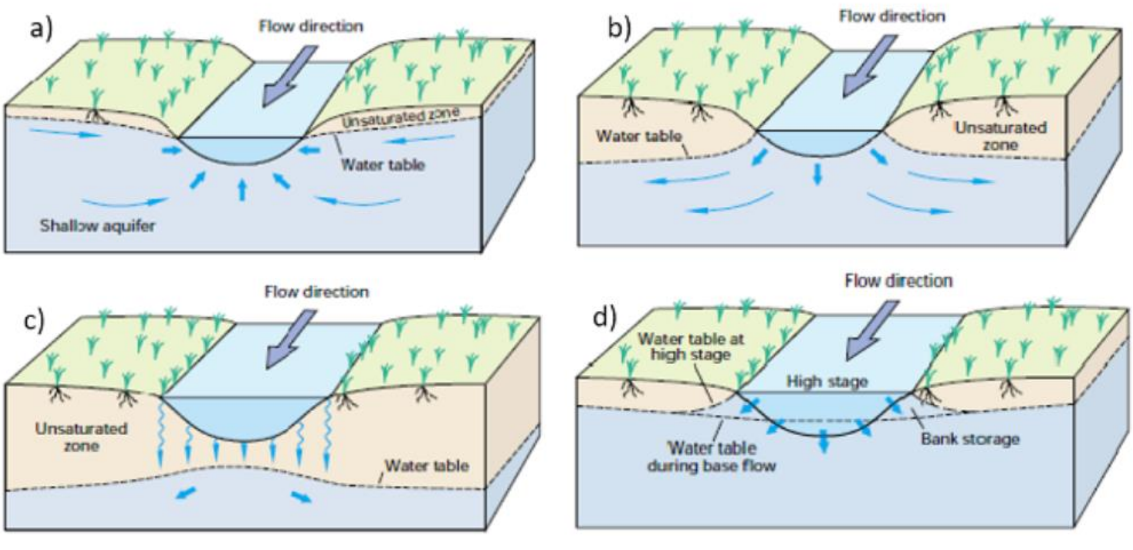


Figure 2.4 Connectivity relationships between groundwater and streams: a) gaining connected system; b) losing connected system; c) disconnected system; d) fluctuating connected/disconnected system *(Evans et al., no date; modified after Winter et al., 1998)*

3. Groundwater resources management and groundwater governance

3.1 The need to organise an orderly path

As outlined previously, groundwater plays an important role in daily life. It is essential for meeting vital water demands of numerous people and ecosystems and for the socio-economic development of most areas in the world. It is immediately obvious that ensuring the sustainability of this role is of crucial importance. Nevertheless, a strong and steadily increasing interaction between individuals and groundwater systems is observed and the cumulative effects of individual action and behaviour usually do not result in socially optimal situations. On the contrary, individuals tend to act solely in their own short-term interests, which often diverges significantly from the long-term interest of the wider community that he or she belongs to. As a result, actions of individuals may produce negative impacts on communities, other individuals, the resource base or the environment (externalities). Individuals are often not aware of these impacts, or they give no priority to preventing them, partly because the common-pool resource nature of groundwater is a complicating factor. In addition, there are also external factors (like climate change and population growth) that generate changes in groundwater conditions and may cause problems that are beyond control of individuals. Driven by their collective responsibility, many communities or governments feel the need to respond to these problems and to organise an orderly path. These responses fall within the domains of groundwater resources management and groundwater governance.

3.2 Groundwater resources management and governance - and how they differ from each other

Groundwater resources management and groundwater governance are closely related. They come into being when societies realise that actual conditions urge that human efforts related to groundwater should go beyond mere exploitation.

Groundwater resources management was the first of the two paradigms to be adopted, and this happened at different times in different countries. It can be defined as follows:

> *Groundwater resources management is a planned and ongoing activity to optimize the exploitation and use of local, regional or national groundwater resources, taking into account the sustainability of the groundwater resources and of the groundwater-related environment and ecosystems.*

Groundwater resources management is action-oriented and the operational instruments used include technical interventions, legally enforceable regulations and positive or negative incentives. The latter two categories aim at influencing human behaviour, which is the cornerstone of groundwater resources management and governance. Compared with situations of mere groundwater exploitation without any coordination or precaution, groundwater resources management integrates all water users and water use sectors and introduces a 'resource custodian', often the government, that is in charge of preventing degradation of the groundwater resources due to pollution or overexploitation. In addition to these objectives of maintaining resource sustainability and maximizing economic profit, groundwater resources management often aims to improve access to groundwater, for spreading the benefits of groundwater more equitably and for protecting the ecological and environmental functions of groundwater. In many countries, groundwater resources management has gradually evolved from an isolated or stand-alone activity into a component of integrated water resources management (IWRM), involving close coordination with the management of surface water, land use and the environment.

There is diversity of opinion on the effectiveness of groundwater resources management in practice. While there are some examples of successes, there is also ample evidence that in many cases groundwater management fails to meet set objectives. This can be attributed to a range of factors including the inherent complexity of the groundwater setting, limited awareness and information, low levels of political commitment, groundwater being undervalued, flaws in legislation, weak institutions, inadequate financing, lack of co-ordination and stakeholder involvement, etc. The dominant opinion is that ineffective governance is the main bottleneck to successful groundwater resources management.

Governance is a complex concept, which is reflected in the fuzzy and often rather long definitions produced by a variety of authors. A comparatively concise definition of governance is presented by Wijnen *et al.* (2012):

> *Governance is understood as the operation of rules, instruments and organizations that can align stakeholder behaviour and actual outcomes with policy objectives.*

Sanier and Meganck (2007) provide the following definition of groundwater governance:

> *Groundwater governance is the process by which groundwater is managed through the application of responsibility, participation, information availability, transparency, custom and rule of law. It is the art of coordinating administrative actions and decision making between and among different jurisdictional levels – one of which may be global.*

The specific elements mentioned in this second definition (responsibility, participation, etc.) are value-laden terms that define '*good* governance' as opposed to just 'governance'. These qualities may be the views and preferences of some actors, but not necessarily all.

According to Foster and Garduño (2013), the term 'governance' is generally understood to mean the exercise of political, economic and administrative authority of national affairs at all levels – and comprises the mechanisms, processes and institutions through which citizens articulate their interests, mediate their differences and fulfil their legal rights and obligations. Consequently, they conclude that:

> *Groundwater governance comprises the promotion of responsible collective action to ensure socially-sustainable utilisation and effective protection of groundwater resources for the benefit of humankind and dependent ecosystems.*

In spite of some room for differences in interpretation of these definitions, it may be concluded that they characterise groundwater governance as being process-oriented rather than action-oriented.

BOX 2: GROUNDWATER GOVERNANCE OR GROUNDWATER RESOURCES MANAGEMENT?

It is difficult to draw a sharp and clear line between 'groundwater resources management' and 'groundwater governance'. With some degree of simplification one might say that (ground)water management focuses on "what is being done", while the local, regional or national government frameworks define "who participates" in formulating strategies and in implementing them, and "how the different actors interact". However, the differentiation between the two concepts in practice may partly depend on the different views, perceptions and jargon between the pioneers of groundwater resources management (mainly engineers and hydrogeologists) and those of groundwater governance (social scientists). This seems to be in line with social scientists describing groundwater governance as "an overarching framework and set of guiding principles that determines and enables the management of groundwater resources and the use of aquifers", while hydrogeologists and engineers rather look upon groundwater governance aspects as the "enabling environment" of groundwater resources management. In reports and publications on groundwater governance one may find issues discussed that according to what is outlined above primarily belong to the domain of groundwater resources management, and vice versa.

Even within the groundwater community there is some confusion on the difference between the concepts ‘groundwater resources management’ and ‘groundwater governance’. This has resulted in the two terms being used both inconsistently and interchangeably (see Box 2).

3.3 Principles of good groundwater governance

General principles of good groundwater governance – like the governance of all other natural resources - are included in the above-mentioned definition by Sanier and Meganck: the application of responsibility, participation, information availability, transparency, custom and rule of law.

A number of important aspects and considerations in this context, subdivided into four categories, are listed in Table 3.1. These aspects give an impression of the variety of elements and dimensions attributable to groundwater governance.

Table 3.1 Important aspects to be considered in groundwater governance
(after Varady et al., 2012)

Political and institutional	Socio-cultural	Economic	Ecological
Accountability Representation Consistency Scalar match Institutional match Institutional capacity to adapt to change and uncertainty	Perceptions about groundwater Religious and spiritual traditions Social learning Social inclusion Ethics Multi-level/ multi-scale/polycentric governance models	Imperfection of price signals (market failures) Role of water scarcity and groundwater storage Water quality impacts Inadequate water use monitoring Role of private sector Role of public-private partnerships Ability to pay External costs	Diffusivity and conduciveness Attenuation rates Renewability Vulnerability Provisioning versus ecosystem services

As groundwater is a ‘common-pool resource’, groundwater governance is likely to benefit from an application of the principles defined by Elinor Ostrom for developing institutional arrangements for the management of such resources (Foster and Garduño, 2013):

- Clearly defined boundaries for resource evaluation and allocation
- Congruence between proposed resource allocation and prevailing natural constraints
- Formal recognition of the rights of the local communities to organise resource use
- Collective arrangements for the participation of stakeholders in decision-making
- Nested stakeholder groups to cope with geographically large resource systems
- Effective independent monitoring of resource status
- Graduates sanctions on resource users or polluters who do not respect community rules
- Mechanisms for conflict-resolution that are accessible, rapid and inexpensive.

There are no generally valid blueprints for dealing with all these aspects or applying all the aforementioned ‘good governance principles’. As Elinor Ostrom wrote: “context matters”. This implies that the adoption of widely embraced ‘good governance’ paradigms such as sustainability, market approaches and decentralisation need to be critically viewed in the particular context of each case.

Finally, it needs to be emphasized that ‘good governance’ and ‘effective governance’ are two different concepts. Groundwater governance is effective if the goals set out by the government are being met. Governance is good if countries attempt to reach these goals in a way that incorporates ‘good governance principles’ as outlined above.

4. Observed trends and other factors challenging groundwater governance

4.1 Groundwater state and observed trends in state

Groundwater quantity and quality are major determinants of how much groundwater can be withdrawn at a certain location and for which purposes it can be used. Under natural conditions, the long-term averages of these state variables tend to be stable. Human influences, however, have caused changes in the groundwater state (quantity and/or quality) in many locations, often in the form of a trend over time and usually making groundwater less attractive for withdrawal.

Groundwater quantity refers to a number of interlinked groundwater variables: groundwater level, stored volume, recharge, flow and discharge. Together they constitute the groundwater regime and the corresponding numerical values define the groundwater budget. From the point of view of withdrawal, relatively shallow groundwater levels are preferred, because the cost of abstracted groundwater (including the cost of infrastructure, energy and other operation and management components) increases with greater depth. The volume of groundwater stored is decisive for the buffer capacity of the groundwater system, which keeps groundwater available during dry periods without any recharge events. Such dry periods may vary from several months for groundwater systems with a small volume stored to many thousands of years for aquifers with huge reserves. Natural groundwater discharge is not a loss, but is often essential for maintaining ecosystems and the baseflow of streams.

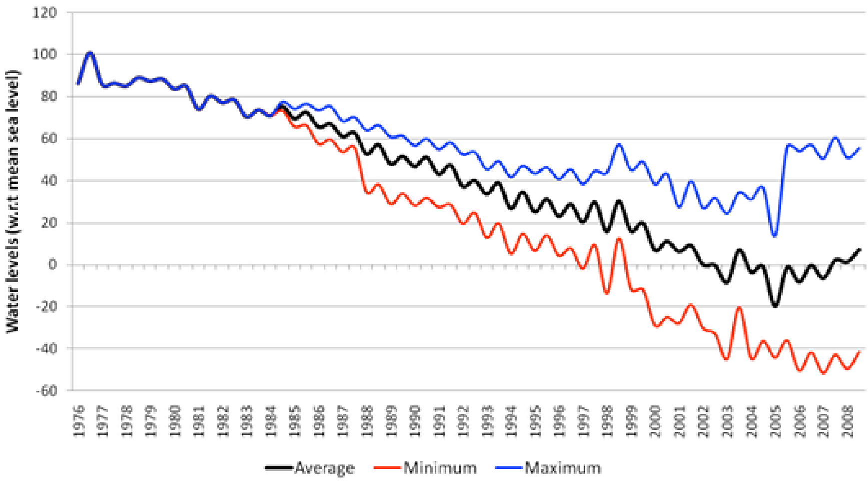


Figure 4.1 Declining groundwater levels in the Kukarwada sub-district, Mehsana region, Gujarat, India *(Jones, 2012; source: http://water.columbia.edu/research-projects/india/gujarat-india/)*

Anthropogenic changes in the two connected groundwater quantity state variables – groundwater level and groundwater storage – are observed in many parts of the world. Most frequently these changes consist of declining groundwater levels (illustrated in Figure 4.1) and an associated reduction of the stored groundwater volume (groundwater depletion), caused by intensive groundwater abstraction, drainage or land use practices, and increasing impermeabilisation of the land surface. The root causes of these pressures, in turn, are demographic factors (population growth and urbanization), economic development and technological innovation that lead to steadily growing water demands (see below) and to modification of groundwater recharge rates. Climate change is expected to aggravate the pressures in many parts of the world, in particular in the arid and semi-arid zones, where water demands tend to increase under simultaneously decreasing groundwater recharge rates (see Table 4.1).

Table 4.1 Summary of climate change impacts on recharge under different climatic conditions *(Clifton et al., 2010)*

High latitude regions	Temperate regions	Arid and semi-arid regions
Recharge may occur earlier due to warmer winter temperatures, shifting the spring melt from spring toward winter.In areas where permafrost thaws due to increased temperatures, increased recharge is likely to occur	Changes to annual recharge will vary depending on climate and other local conditions. In some cases little change may be observed in annual recharge, however the difference between summer and winter recharge may increase	In many already water stressed arid and semi arid areas, groundwater recharge is likely to decrease.However where heavy rainfalls and floods are major sources of recharge, an increase in recharge may be expected. E.g., alluvial aquifers where recharge occurs via stream channels, or bedrock aquifers where recharge occurs via direct infiltration of rainfall through fractures or dissolution channels.

Source: Holman et al, 2001; Döll and Florke, 2005; van Vliet, 2007; Dragoni and Sukhija, 2008.

Global groundwater depletion was still insignificant until 1950, but since then it has increased rapidly (see Figure 4.2) and currently adds up to around 145 km^3/year (Margat and Van der Gun, 2013). This not only affects the water resource conditions on the continents, but is also contributing to an increase of the volume of water stored in the oceans (sea level rise). Long-year trends of groundwater level rise are also observed in certain areas, but the total area concerned is much smaller than that of groundwater depletion and problems can be solved relatively easily by technical measures.

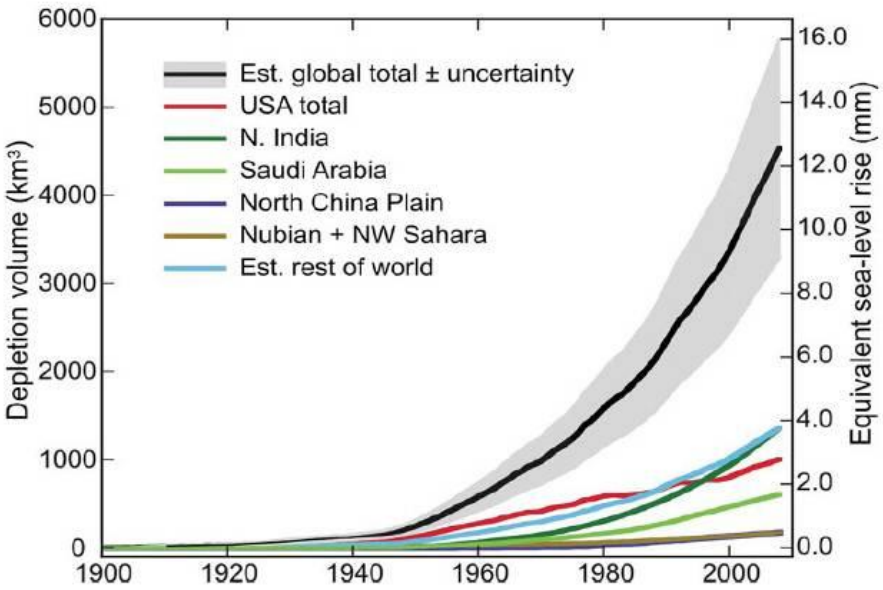


Figure 4.2 Estimated cumulative global depletion, period 1900-2008 *(Dillon et al., no date; after Konikow, 2011)*

The impacts of groundwater depletion include higher cost of abstracted groundwater; reduction of well yields, spring discharges and baseflows; degeneration of ecosystems; reduction of the yields of phreatophytic agriculture; land subsidence; reduction of the groundwater buffer (smaller potential bridging periods); inflow or migration of saline or brackish water into the aquifer; reduction of the yield of infiltration galleries; springs falling dry and permanent loss of artesian conditions; a contribution to sea level rise; and in extreme cases the loss of an exploitable groundwater resource.

Groundwater quality is a complex concept as it depends on the physical properties of groundwater, its bacteriological content and in particular the large number of dissolved constituents that define its chemical composition. Groundwater abstracted from the upper few hundred metres below the ground surface is usually of a good natural quality, meaning that it is suitable for most domestic, agricultural and industrial uses. At this depth there are only a limited number of areas worldwide that contain groundwater that is saline or brackish in its natural state, or characterised by excessive concentrations of certain components such as arsenic or fluoride.

Human activities are also affecting groundwater quality. An example is the intrusion of seawater into a coastal aquifer triggered by groundwater abstraction, as illustrated in Figure 4.3. However, quality degradation is more widespread by the influx of many types of pollutants produced by humans. Zones with growing pollution trends can be found in virtually every country. The sources of pollution are manifold: domestic and industrial waste and wastewater; animal husbandry and its waste products; manure, fertilizers and pesticides used in agriculture; irrigation water; landfills and subsurface waste deposits; leaking tanks; accidental spills, etc. Pollutants may degrade in the subsurface to some extent, but often they simply appear in the aquifers after a period of delay. These delays, and the large spatial dimensions of aquifers, mean that the pollution trends of groundwater often are detected late. This is a serious handicap for aquifer protection efforts. Phreatic aquifers with shallow water tables are particularly vulnerable to pollution. High population densities, poor sanitary conditions and intensive agriculture and industry contribute to the pollution risk. Figure 4.4 gives an impression of the complexity of groundwater pollution in urban environments. Pollution is a virtually irreversible and continuing phenomenon worldwide.

The impacts of groundwater pollution are often severe. Minor pollution makes groundwater unsuitable for uses that are sensitive for quality, in particular for domestic water use. If significant pollution occurs, in terms of type and concentration of pollutants present in groundwater, then in practice it usually means that an exploitable groundwater resource is lost.

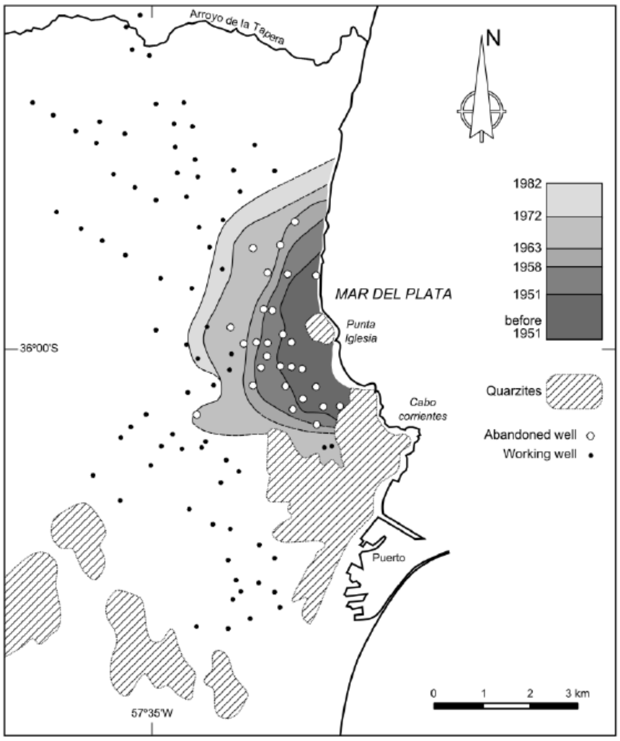


Figure 4.3 Salinity advancement in groundwater in the Mar del Plata urban area (Argentina), due to local intensive pumping *(Custodio., no date; after Bocanegra et al, 1992)*

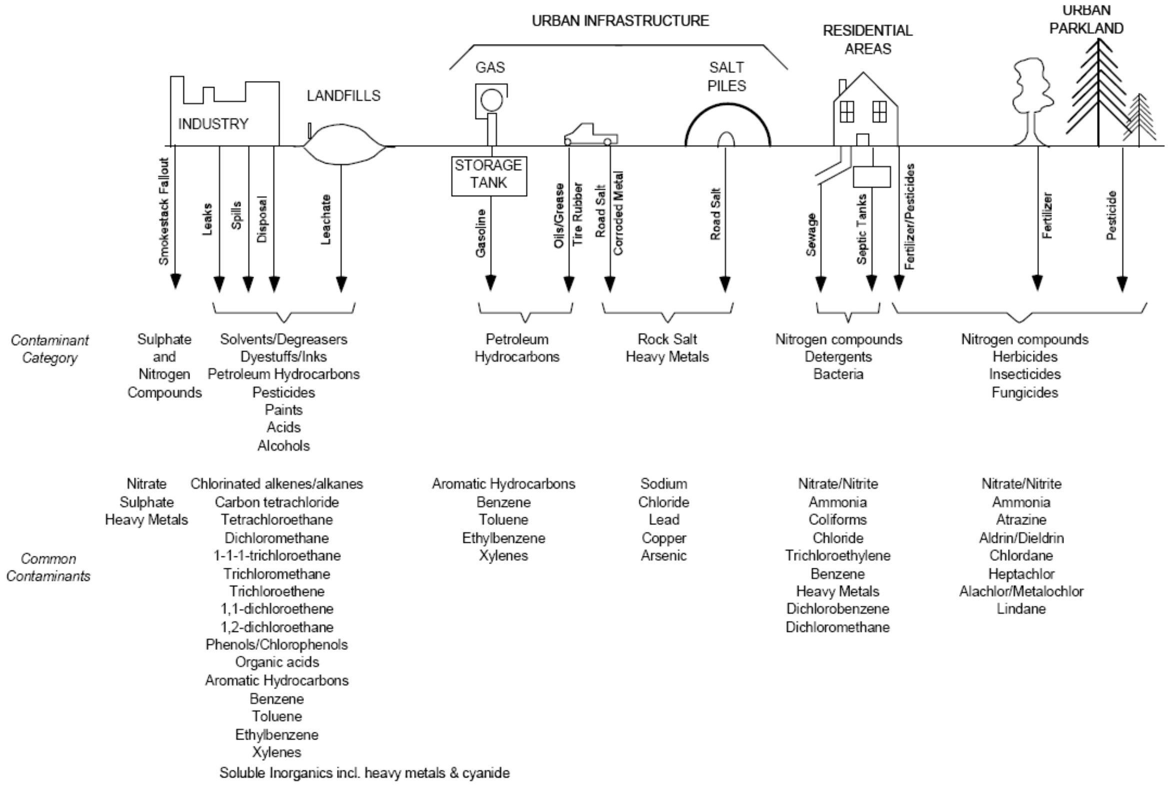


Figure 4.4 Sources of groundwater contamination in urban areas *(Howard, no date)*

4.2 Groundwater demand

Groundwater demand should be seen in the context of total water demand. In principle, most water demands can be satisfied by any source of fresh water, be it surface water, groundwater or any other source, including non-conventional sources such as desalinised seawater. Whether to opt for groundwater or for another source depends on the availability and capacity of the different sources and on the comparative attractiveness of groundwater. For instance, in arid and semi-arid regions groundwater is often the only source that can supply water throughout the year, and it is therefore indispensable for satisfying dry-season water demands. In addition, groundwater is often preferred because of its predictable good quality or because it can be withdrawn close to where it is will be used. On the other hand, surface water may be less expensive and thus a preferred source for irrigation in the floodplains along numerous permanent rivers around the world.

In general, water demands are increasing continuously over time, and this includes demand for groundwater. A major driver behind this increase is population growth, followed by economic development (including the expansion of the irrigated acreage), urbanisation and the ambition to significantly improve water supply and sanitation facilities in those parts of the world where these are currently inadequate (as stipulated in the Millennium Development Goals). While global population has approximately doubled during the period 1960-2000, total global groundwater withdrawal has more than tripled during the same period. Annual rates of growth of groundwater withdrawal are still high in several Asian countries (3% or more), but withdrawals have stabilized or are even slightly decreasing in most of the industrialized countries of Europe, North America and Australia. It will be clear that increasing groundwater withdrawals lead to increasingly stressed groundwater systems, because the quantity of the exploitable groundwater resource – subject to artificial recharge, but also to depletion and quality degradation and changes in recharge – is at best more or less constant.

It is not easy to analyse how macro-economic trends affect the demand for groundwater. The macro-economic conditions under which many private decisions to pump groundwater or pollute aquifers are taken may have little impact where (and when) demand is inelastic because there is no alternative source or a means of disposal. In addition, while agricultural groundwater supply may be highly elastic with respect to commodity price signals, evidence points to highly inelastic demand for groundwater when input subsidies for energy are removed or fuel taxes imposed.

4.3 Perceptions and public behaviour

The general public is usually largely uninformed about the groundwater in their local area. This means that in general the public have no knowledge about the invisible groundwater stored below their feet, nor do they understand groundwater recharge, flow and natural discharge. The majority of those who dump waste and wastewater on the surface or apply fertilizers and pesticides to their crops are not aware that these practices may pollute the groundwater resources. Likewise, those who abstract groundwater usually do not know how this affects the groundwater regime in their area and that this may contribute to undesirable side-effects such as declining groundwater levels, reduced spring flows and baseflows, degeneration of ecosystems and in extreme cases the loss of an exploitable groundwater resource.

Even if people become aware of the potential impacts of their behaviour on groundwater quantity and quality – either by awareness campaigns or by experiencing the negative impacts – this does not mean that they will automatically adjust their behaviour for achieving maximum societal benefit. Human behaviour is driven more by personal motives than by benefits for society at large. The problem is exacerbated by the conflict between the ‘common pool’ characteristics of groundwater and the fact that people in many parts of the world still consider groundwater ownership or user rights on an individual basis and directly linked to ownership of land. This perception is an enormous obstacle to exploiting groundwater systems optimally as a ‘common property resource’. Gradually, governments of many countries have recognised this problem and as a result there is a trend in redefining legal groundwater ownership as national property, with regulatory and control powers being held by the government. Nevertheless, many obstacles remain, such as dealing with existing private groundwater ownership rights and the lack of agreed principles for groundwater tenure.

4.4 Other factors

Several other factors contribute to the need for improved groundwater governance. Primarily, land use is steadily becoming more intensive in many parts of the world, which is often commensurate with significant impacts on groundwater recharge and increased pollution risk. This does not only refer to agriculture, but also to urbanisation and industrial development. Likewise, as mentioned before, the use of the subsurface is quickly expanding for a wide range of purposes: not only for mining and withdrawal of oil and gas, but also for geothermal energy development, waste disposal, temporary storage (e.g. carbon dioxide capture and storage) and construction into the underground space (subways, parking space, etc.).Figure 4.5 gives an impression of the depth ranges typical for these subsurface uses. Ignoring the interdependence between groundwater and all these activities at or below ground surface may produce unpleasant surprises. Boreholes into the earth’s crust have reached great depths, but technical and economic constraints are a limitation to pumping heads, in particular for groundwater withdrawal (see Box 3).

Climate change has the potential to amplify all of the above factors. Despite many uncertainties, it is clear that climate change will exert considerable influence on the water resources conditions of most areas in the world. The challenge is to simultaneously protect vulnerable groundwater systems and use the buffer capacity of groundwater to mitigate increasing water scarcity problems.

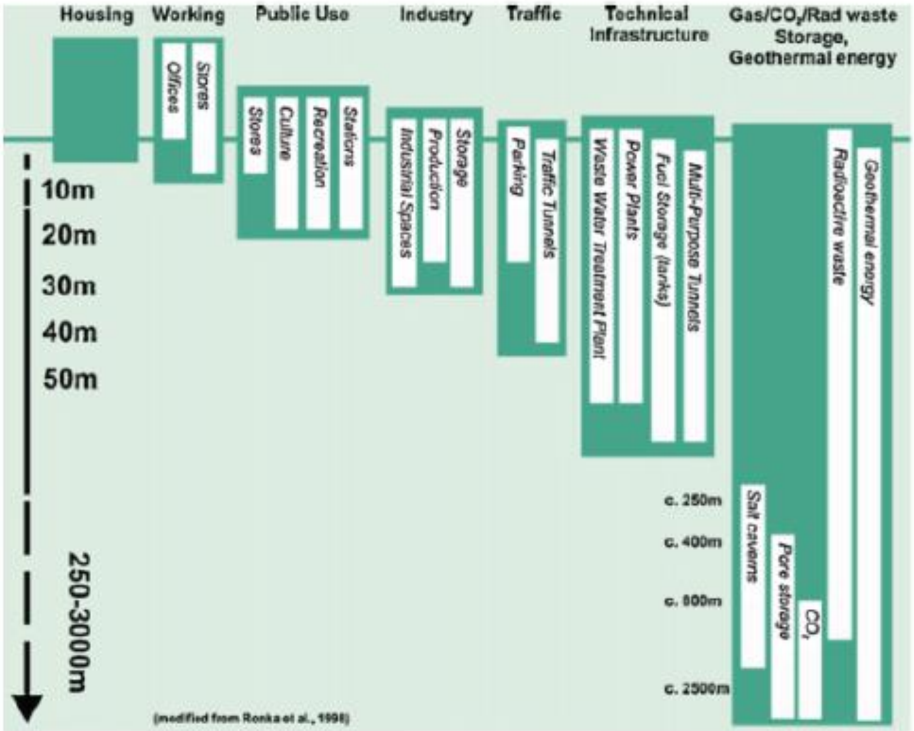


Figure 4.5 Feasible depth ranges for subsurface uses other than groundwater abstraction
(Van der Gun et al., 2012; based upon Ronka et al., 1998)

Box 3: The limits to drilling into the earth's crust.

Groundwater, oil and gas are most efficiently abstracted by wells and the first hand-dug wells are dated to 10,000 BP: The deepest hand dug well (385m) for water supply purposes was completed in 1858 at Woodingdean in southern England. The first drilled wells were constructed using percussion techniques to extract natural brines for salt production in Sichuan, China around 2,000 years ago. Between the 3rd and the early 19th Century (1835), the depth drilled increased from 140m to over 1000m. Since then the capacity to mechanically drill deeper boreholes has steadily increased and the current depth record is held by the Kola super-deep, scientific investigation borehole in Russia at 12,262m. The deepest water wells rarely exceed 1,500m and currently the deepest oil wells rarely exceed 7,500m vertically.

Oil and gas wells are the second most wide-scale intrusion into the underground space after water wells.

Since 1950, 2.6 million oil and natural gas exploration and production wells have been drilled in the United States: In 2009 there were 363,107 producing oil and 460,261 producing gas wells[2] in number. According to the American Ground Water Trust, the number of domestic water wells in the United States exceeds 15 million and there are over 250,00 public water supply wells: During 2012 some 6,00 new water wells are drilled each week in the United States..

Extracting groundwater from wells becomes increasingly technically and economically restricted as the pumping head increases. Positive displacement reciprocating pumps can be used to lift groundwater from considerably more than 1,500m, yield performance and efficiency limits their economic application for large scale groundwater abstraction. The head limit for regular commercial 200mm electric submersible water pumps is 600 to 650m but high performance 750 kW multistage submersible pumps used in oil wells can handle heads up to 3,700m.

4.5 The main challenges related to the physical environment

Given the general objective to keep groundwater systems in such a state in which they can perform their many functions in a sustainable way, the primary challenges are to *control groundwater levels* and to *prevent groundwater quality degradation*. Other relevant functions of groundwater, as mentioned, include the role of groundwater in maintaining a stable land surface (i.e. preventing land subsidence), the supply of baseflow to streams and maintaining the health of wet ecosystems.

Controlling groundwater levels in stressed aquifer systems may include measures to augment the resource and measures to reduce the demands (demand management). It should be ensured that the allocation of costs and benefits of these measures is consistent with government policies and societal preferences. Most of the measures devised for controlling groundwater levels and quality intend, in one way or another, to change or regulate human behaviour. This underscores the importance of significant stakeholder involvement in groundwater management and governance.

But groundwater resources management and governance are not only a response to threats and problems. They may contribute also to *achieving a greater benefit from groundwater*. In some cases, this is possible by abstracting and using more groundwater or by expanding groundwater use to unorthodox purposes (e.g. producing geothermal energy). In many other cases there is scope for increasing the benefits from groundwater by reallocation to higher-valued social or economic uses.

5. Elements of a groundwater governance framework

5.1 Groundwater resources management measures

Control of groundwater quantity: water levels and stored volume

Groundwater quantity control measures have the purpose of avoiding or eliminating groundwater overexploitation. These measures fall into three broad categories: (a) augmenting the groundwater resource and protecting recharge areas ('managed aquifer recharge' or MAR); (b) using alternative supplies; and (c) demand management. Figure 5.1 shows schematically how a combination of these measures may turn an overexploited aquifer into an aquifer in dynamic hydrological equilibrium, where groundwater withdrawal does not cause unacceptable negative impacts.

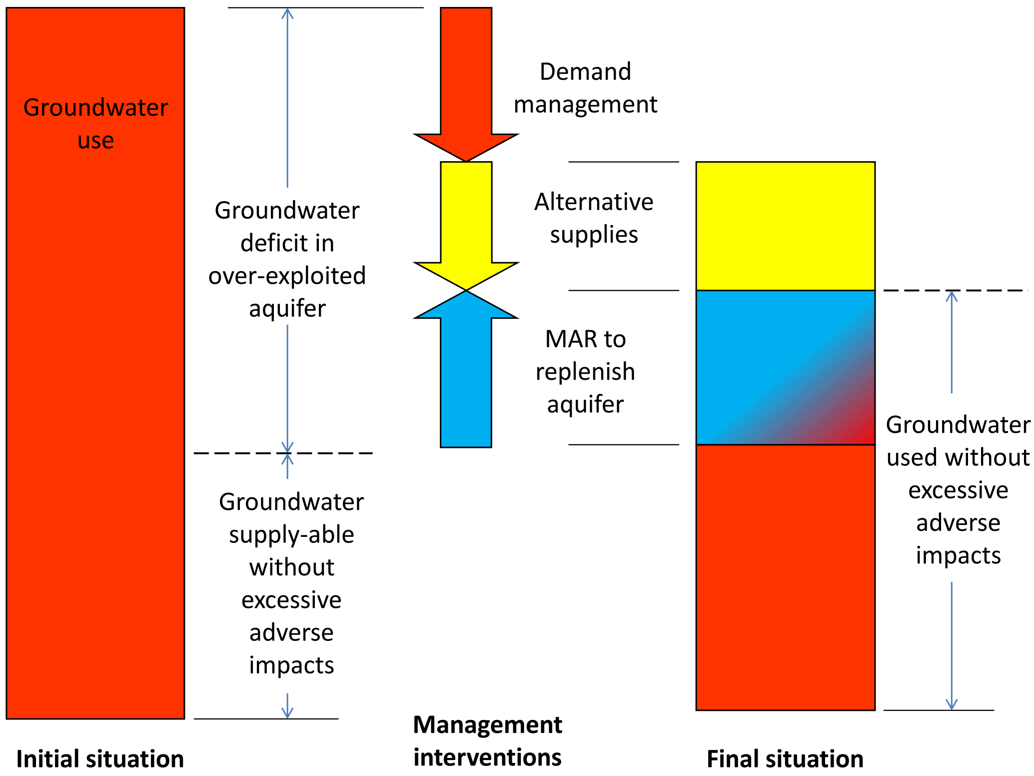


Figure 5.1 Management interventions to convert an overexploited aquifer into an aquifer from which groundwater is withdrawn without causing excessive adverse impacts *(Dillon et al., no date)*

Managed aquifer recharge (MAR) is a technical activity by which additional water from an external source (streams, lakes, urban stormwater, treated sewage effluent, desalinated seawater) is recharged into an aquifer in order to augment its renewable volume. MAR makes use of a variety of methods and infrastructural works (recharge dams, sand dams, subsurface dams, recharge wells, recharge basins, barriers, bunds, etc.) and the schemes vary from very small to large (see also Figure 5.2). MAR augments and sustains groundwater storage. Consequently, it increases the quantity of groundwater to be abstracted per unit of time without causing unacceptable negative side-effects.

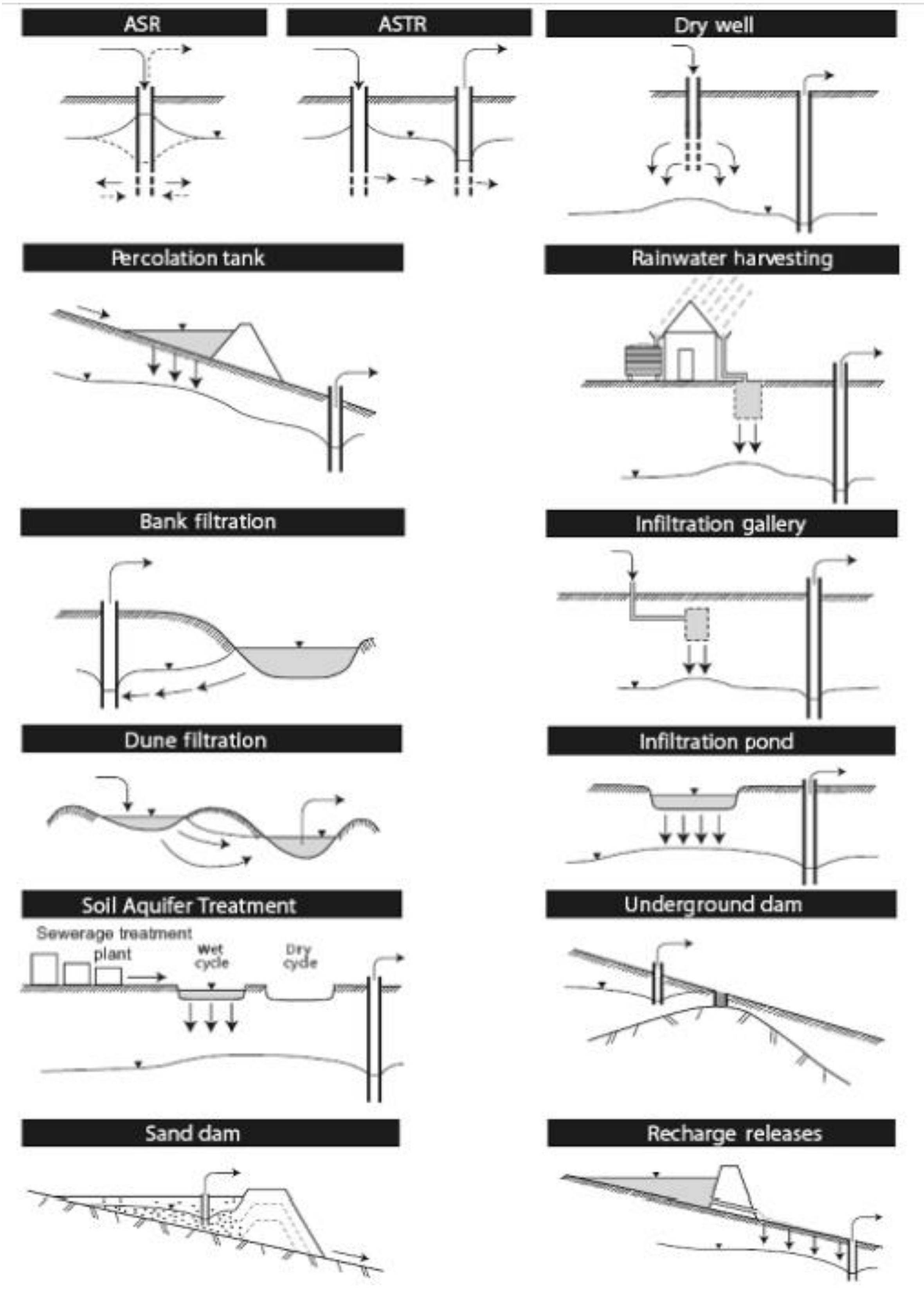


Figure 5.2 Types of managed aquifer recharge *(Dillon et al., no date; adapted from Dillon, 2005)*

Tapping alternative supplies to satisfy part of the water demand, e.g. from surface water sources, is a method to reduce the abstraction from an intensively exploited aquifer. Together with MAR, sourcing alternative supplies belongs to the category of 'conjunctive management and use of groundwater and surface water'. The opposite of tapping non-groundwater supplies –tapping groundwater to supplement temporarily scarce surface water (making use of groundwater's buffer capacity) – is part of the same category. Conjunctive management and use approaches refrain from looking at groundwater and surface water systems in isolation from each other, but pay due attention to their physical interconnection and the interdependency of the demands for, and use of, water resources.

Measures of the third category – demand management – are non-technical and rely on influencing human behaviour. To this end, regulations may be enforced *(rights and regulations approach)*, incentives and disincentives may be used *(incentives-based approach)*, and/or responsibility for groundwater management may even be delegated to the local level *(subsidiarity approach)*. Common types of regulations in this context are related to permits for drilling wells and for abstracting groundwater. If permit systems have been introduced by mandated groundwater management institutions, then applying for a permit is obligatory (usually above a certain threshold) and ignoring the corresponding formal decision is in contravention of the law. Demand management by creating incentives or disincentives, is an indirect measure and less compelling in general. The incentives or disincentives are commonly produced by economic instruments, such as abstraction fees, energy prices (including subsidies and taxes), subsidies for adopting desired practices (e.g. higher water use efficiencies) and credits for new wells and pumps. But also non-economic tools are used in some cases, e.g. awareness campaigns and limiting energy supply.

It should be ensured that the allocation of costs and benefits of the implemented measures is consistent with government policies and societal preferences. This holds also for any of the measures mentioned below. The strong reliance of the measures on human behaviour underlines the importance of stakeholder involvement in groundwater resources management.

Protecting groundwater quality

Protecting groundwater against pollution and preventing poor-quality water from migrating into or through valuable aquifer systems are two important components of groundwater quality control.

Pollution control measures focus primarily on eliminating or controlling sources of pollution (see Table 5.1). This includes technical measures such as constructing adequate sewerage systems, treating sewage and other wastewaters, ensuring that landfills (waste dumps) are properly designed and removing buried oil tanks that may produce leakage risks. Other measures attempt to influence human behaviour. Again, the main instruments used are legally binding regulations and incentives/disincentives. For example, some regulations may prescribe obligatory provisions for treatment or storage of potentially polluting substances, others may impose restrictions on land use practices in certain groundwater protection areas (e.g. related to the use of fertilizers and pesticides) or prohibit the use of certain substances anywhere. Incentives and disincentives that attempt to reduce pollution include awareness campaigns and pollution fees (*'polluter-pays-principle'*), respectively.

A classical example of undesired migration of poor-quality water is seawater intrusion into coastal aquifers as a result of groundwater withdrawal (see also Figure 4.3). An appropriate measure to prevent seawater intrusion is to reduce groundwater abstractions close to the sea in coastal aquifers; well drilling permit systems are convenient instruments for this purpose. Arresting migration is important in cases where part of the groundwater system is already polluted. Physical confinement is feasible only in exceptional cases, but hydrodynamic isolation techniques (creating 'zero gradient around the polluted zone') are more widely applicable. Remediation of polluted groundwater by 'pump-and-treat' is practiced in cases of localized point pollution.

Table 5.1 Some methods for controlling pollution sources to be considered for groundwater quality governance *(Custodio, no date)*

Pollution source	**Possible control method**
Landfills	Regulation of sitting, operation and closure Monitoring the site
Underground storage tanks	Periodic inspection Pressure testing Improved construction
Spill, leaks, improper disposal of hazardous wastes	Control of distribution and use Storage regulations Effective fining of malpractices Mandatory inspection of: • transportation • storage • use Fast removal of spill damage Monitoring the facility
Agrochemicals: • fertilizers • pesticides • herbicides	Introducing good agricultural practices: • application limits • timing of application • application methods • permits for use Ban dangerous substances Control the disposal of used containers
Feedstock wastes	For intensive farms: • sufficient storage facilities • document waste use and disposal • control of pharmaceuticals use For extensive farms: • Limits to animal spatial density
Septic systems	Regulation of • sitting • installations Periodic inspection Licensing installers

Pursuing highest benefit from groundwater to society

Groundwater resources management and governance are not only a response to threats and problems, but they may also contribute to *achieving greater benefits from groundwater use*. In some cases this is possible by abstracting and using more groundwater or by expanding groundwater use to unorthodox purposes. In many other cases, there is scope for increasing benefits from groundwater by reallocation to socially or economically more profitable uses. Governments may have strategies to improve urban or rural water supplies, or ambitions to enhance overall economic or social welfare. Well drilling programmes have been widely used to pursue such goals, such as the Millennium Development Goal related to improved drinking water supply. Conflicts of interest (e.g. urban versus rural water supply) can be addressed by the aforementioned regulatory instruments in combination with clearly defined and accepted priorities. Higher socio-economic benefits ('more jobs and income per drop') can be achieved by creating incentives (awareness, technical assistance, subsidies, etc.) for individuals who adopt approaches that are likely to increase the economic efficiency of water use. But also the in-situ benefits from groundwater (related to its environmental functions) should be valued and protected or, where possible, even enhanced. In addition, innovative uses of groundwater – for example the development of geothermal energy – will require special projects by governments and/or private parties to explore the local conditions and implement exploitation programmes.

5.2 Creating the enabling environment for groundwater resources management

Area-specific information and diagnostics: making groundwater visible

Groundwater resources management should be guided by area-specific information that enables: (i) the characterisation of the groundwater system of the management unit under consideration – aquifer system or river basin; and (ii) understanding of trends and impacts of groundwater management measures, on the basis of observed time-dependent variables. This information should cover all relevant aspects related to groundwater and its use and should be collected with the degree of detail and accuracy that is required for deriving reliable diagnostics on the *status quo* related to groundwater, plus the trends and issues to be addressed. Multidisciplinary assessment studies and systematic monitoring programmes of time-dependent variables are needed to generate the area-specific information. These tend to be expensive and time-consuming, meaning that they should be planned as a structural component of groundwater governance, thus not be postponed until major problems will have appeared.

Legislative and regulatory framework

The legal framework for groundwater management forms the basis for regulating access to groundwater resources and the right to abstract. Legal frameworks are also instrumental in setting criteria for groundwater allocation, dealing with protection against depletion and pollution, establishing monitoring and planning tools and arranging for stakeholder participation. In relation to transboundary aquifers, special legal and regulatory frameworks may focus on transboundary impacts, harmonization of activities and cross-border cooperation.

At the country level, groundwater ownership and user rights are fundamental issues to be defined by the law. There is a worldwide trend to vest water ownership or control in the state and to separate it from land ownership. This defines water as a 'public good'; however people often continue to perceive groundwater as a 'private good'. Customary, community-based and informal arrangements still govern access to groundwater in large parts of the world. If new formal rights are defined, then they should be harmonised with customary rights. An important issue to be addressed by the law is liability in the case of external impacts of human activities; the 'polluter pays' principle is a case in point. Groundwater-related regulations, based on the principles stipulated in the law, are needed to ensure transparent and consistent law enforcement and also the institutional mandates for enforcement need to be based on the law.

The legislative and regulatory framework for groundwater contains a number of important instruments at the regional and international level. Regional instruments include the UNECE Convention on the Protection and Use of Transboundary Water Courses and International Lakes (Helsinki Rules, 1992) agreed upon by the member countries of the Economic Commission for Europe and recently opened for global adoption, the Water Framework Directive (2000) as a legally binding instrument for the members of the European Union and its daughter Directive on Groundwater (proposed in 2003) – see also Box 4. The most important global instrument is the Draft Articles on the Law on Transboundary Aquifers, adopted in 2008 by the International Law Commission (UNILC). Similar to the UN Convention on the Non-Navigational Uses of International Watercourses (1997), the Draft Articles are currently non-binding; however the aim is to achieve broad country endorsement. The Draft Articles are a convenient reference for treaties and other legal instruments involving aquifers. Only a few aquifer-specific agreements exist between countries sharing an aquifer: the Genovese aquifer, the Nubian Aquifer System, the North Western Sahara Aquifer System, the Iullemeden Aquifer System and the Guaraní Aquifer System. Groundwater is also included as a component in a number of bi- or multilateral treaties on rivers or lakes.

Box 4: EU Directives

EU directives are supranational law which is unique in nature. Supranational law is neither international law, which is binding only between and among states, nor domestic law. EU directives are developed in legislative processes at the EU level but then have to be transposed into domestic law, i.e. the content of EU directives becomes part of the domestic legal system. In case members states fail to transpose EU directives the European Commission can initiate an infringement procedure before the European Court of Justice which may impose financial penalties. Under certain circumstances, EU directives may also be directly effective in member states' national legal orders.

Groundwater legislation and regulation should take into account the linkages between groundwater, surface water and all types of subsurface and land uses. Laws and regulations should also be drafted with due consideration of macro-level policies, institutional capacities and other relevant local factors. They may also define the roles and responsibilities of groundwater user groups and other non-governmental entities in relation to those of public institutions.

Institutions

Institutions, defined here as the formal organisations or informal groups created to pursue specific goals, are the leading actors in groundwater governance and management. All aspects of groundwater governance and management should be covered by an institution in one form or another. Consequently, most governments have established, among others:

- institutions for assessing and monitoring groundwater, as well as for identifying and studying relevant issues;
- institutions for developing groundwater management strategies – often incorporated in IWRM strategies – and area- or aquifer-specific strategic planning;
- institutions responsible for operational management, which includes the implementation of technical measures, the enforcement of laws and regulations, the provision of incentives or disincentives and the interaction with local stakeholders and the general public.

Apart from government organisations there are other institutions that play a role. They include scientific institutes and consultancy firms providing services to the government, but also water supply companies, mining companies, industries, agricultural organisations, water user associations (see Box 5), environmental action groups and others. Some of the local institutions have a long legacy, e.g. those around shared springs or devoted to qanat systems. All these groups have their own agenda and priorities, and as a result there are often conflicting interests. It is a challenge to establish open communication, mutual trust and effective cooperation in order to develop balanced courses of action that do justice to the interests of all groups.

Box 5: Groundwater User Associations in Spain, the US and Mexico (COTAS)

The legislation of a number of countries provides for the establishment of (ground-)water user associations or aquifer management organizations, for instance in Spain (Lopez-Gunn and Cortina 2006), Mexico, Australia and the western states of the US. They have been established especially where aquifers are at risk of being degraded or depleted. For instance, the Spanish Water Law of 1985 makes the establishment of groundwater user organizations compulsory in overexploited aquifers (Hodgson 2006, p. 41). In a number of western states of the US groundwater management or conservation districts, a form of water users association, have been established in respect of about 89 percent of groundwater resources. They are controlled by local users and may set limits on pumping and wells, adopt groundwater management and development policies and programmes, and propose water allocations criteria. In Mexico, where groundwater resources are severely overexploited, COTAS (Comités técnicos de aguas subterráneas – technical groundwater committees) have been created. They are civil society organizations, whose set up has been carefully facilitated by the National Water Commission and who are supported financially by the public hand. Inter alia, the COTAS support the implementation of groundwater management plans, support the government in groundwater rights administration, provide services to groundwater user, support consensus-building for future integrated water resources management and establish dialogue with and improving data on groundwater users (e.g. by helping the water administration to validate, update and correct databases on wells) (Foster, Garduño and Kemper 2004).

Awareness raising, communication and stakeholder participation

The general public does not know very much about groundwater. Therefore, to obtain public support for groundwater plans and interventions there is a need to make the general public aware of relevant local groundwater features and inform them on planned action. This is even more crucial if people are expected to change their behaviour or to play an active role as stakeholders in the management process. Transparency, accountability and good communication on decisions and planned action builds trust, which is essential for developing smooth co-operation.

Effective public participation can be achieved through different modalities and degrees of involvement. The approaches range from informing or consulting stakeholders to full delegation of groundwater management responsibilities. Local conditions and expectations about feasibility and effectiveness determine which method is chosen. Experience and research have found that stakeholder participation can be improved by: building on existing social capital, promoting equity and inclusion, starting in areas of good potential, adopting a step-by-step process and adapting to lessons learnt.

Policies, strategy development and operational activities

Groundwater governance distinguishes decisions and actions at three levels: the policy level, the strategic level and the local or operational governance level.

Activities at the *policy level* have a strong political dimension and result in setting overall objectives and priorities. These have to be adapted to the local context and be tailored to the size and nature of reliably identified critical issues and opportunities. Which generic types of management units to be chosen, e.g. aquifers versus river basins, or aquifers versus groundwater bodies, are also defined at the policy level. Opting for a IWRM approach to address groundwater is also a decision at policy level.

Governance at the *strategic level* establishes institutions and defines strategies and instruments in order to achieve the policy goals set. At this level it is decided whether, to what extent and how to incorporate groundwater resources management in IWRM and to harmonise it across sectors. This requires sufficient information and knowledge, thus governments should be persuaded to invest in these components and the institutions in charge. Next, the main paradigms to be adopted are identified and defined, e.g. sustainable development, market approaches, adaptive management and decentralisation. These paradigms should be consistent with those adopted in a wider context, for water, the environment and natural resources in general. With reference to influencing the behaviour of individual stakeholders, three approaches are commonly distinguished: a rights-and-regulation approach, an incentives-based approach and a subsidiarity approach. Rights-and-regulatory approaches are very demanding to implement and meet usually resistance by stakeholders. However, for large and formal sector users they often tend to be most feasible and the best option. Adjusting the incentives structure is a mechanism that even a weak government can undertake, but the political feasibility of adjustments is often a problem and they can have unexpected adverse effects or unintended side-effects. Delegating governance to the local level can produce good results and requires a framework for encouraging subsidiarity. A mix of approaches will normally be indicated, which requires flexibility, adaptation, and keeping an eye on equity. Finally, in anticipation of conflicts over groundwater becoming more frequent, it is worthwhile to develop conflict resolution mechanisms.

It is at the *local or operational level* that measures are implemented. Within the boundaries defined by policy and strategy, an operational plan can be made to guide the systematic implementation of measures and other interventions, at the same time to be used for communication with stake-holders. Partnerships between local stakeholders and public agencies are often an effective approach, but these require long-term commitment on both sides. However, there is a risk that participation may reflect and even reinforce existing inequalities. Empirical evidence suggests that local collective management can be effective in certain settings.

5.3 Constraints and opportunities

Constraints related to knowledge, perceptions, experience and vision

Insufficient information on local conditions forms often a fundamental constraint to groundwater governance. This information deficit may refer not only to the physical groundwater systems, but also to water demands and use, socio-economic factors, as well as to the physical, socio-economic and political characteristics of interconnected policy areas. If this is the case, investments in studies and/or monitoring evidently have to be made to provide a reliable basis for diagnostics and the development of area-specific strategies and plans.

What decision-makers, planners and local stakeholders know about local the groundwater-related conditions usually lags behind the availability of information. Very often a limited knowledge of both general groundwater principles and the local situation causes decision-makers to have a poor perception of the groundwater realities in their area and the opportunities and problems offered. This weakens the motivation to play a constructive role in groundwater governance. Public awareness campaigns can help eliminate this constraint.

Furthermore, those who are professionally involved in strategy development and planning for groundwater governance, depend on their own experience and knowledge, inevitably with inherent limitations. For example, the potential role of groundwater in public water supply is often underestimated or even ignored (which is a lost opportunity for more integrated management) and tools for urban water management usually fail to take the time scales of groundwater into account. Further, looking for alternative water sources is often a primary response to water scarcity, rather than analysing the potential offered by integrated water resources management. Methods with demonstrated effectiveness for combating chronic groundwater depletion are not yet widely used, probably because the water resources managers are insufficiently familiar with MAR, conjunctive use and other options, or their organisations lack implementation capacity. Finally, the potential role of the groundwater buffer is often ignored and experience on how to exploit fossil groundwater resources most profitably is still missing.

Other constraints to making a quick start and gaining support

Groundwater is invisible to the general public and it is difficult to untangle its contribution to national welfare from that of surface water. This produces a very skewed public perception of the value of groundwater, and for that reason groundwater does not easily reach the political arena (unless serious problems develop). Additionally, politicians are unlikely to call attention to groundwater governance due to , the significant budgets required and the very long reaction times of groundwater systems, meaning it takes many years before the effect of any intervention can be observed. Groundwater management and governance are, unfortunately, politically unrewarding and fraught with political risk.

Constraints presented by specific properties of the groundwater resource

Due to the more or less continuous existence of groundwater over large areas and down to considerable depth below ground surface, groundwater resources assessment is complex and expensive. This is exacerbated by the fact that locally observed state variables often have relatively limited spatial representativeness (this applies in particular to water quality). Abstraction and use of groundwater is highly decentralised and scattered over large areas which makes monitoring and management difficult and expensive.

The inertia of groundwater systems is another significant constraint. Large time lags between cause and effect add difficulty to defining adequate measures and make many undesired changes of state (water levels, water quality) almost irreversible in practice. Errors or lack of required action thus do not remain unpunished. Groundwater depletion and contamination will result in spiralling costs for access to water, claiming valuable economic resources with the poor often suffering the most.

Constraints presented by the overall physical environment

A myopic focus on groundwater systems and groundwater users is unlikely to lead to good groundwater management. In the first place, there are often preferences of the society to maintain certain environmental conditions (protection of ecosystems, springs, baseflows, stability of land surface, etc.), which in practice turn these preferences into constraints to groundwater withdrawal.

Secondly, in parallel to groundwater abstraction and groundwater level control, many other activities are independently carried out in the area, with potential impacts on groundwater quantity and quality. These activities include waste and wastewater disposal, urban development, agricultural land use (including all chemicals used), industrial activities, mining, oil and gas exploration and exploitation, geothermal energy development, subsurface storage, construction and use of tunnels, subways, pipelines, etc. Groundwater governance should require that communications and negotiation with all parties involved be established, allowing in a pragmatic way for a certain level of interferences to be accepted.

Countless well owners have appropriated groundwater and it should be taken into account that they tend to respond more to powerful economic incentives than to the rules that management would impose.

Constraints related to human behaviour and conflicts of interest

Perceived or formal groundwater entitlements based on land-ownership fail to recognise the 'public good' nature of groundwater and its environmental role. Human behaviour related to groundwater, therefore, more often aims to achieve personal gain ('selfish behaviour') rather than contribute to maximum societal benefit. It is difficult to change human behaviour because groundwater users drawing as competitors from a common pool need external support to guarantee that all comply equally with the same imposed restrictions on groundwater abstraction. This is not only true for groundwater withdrawal, but holds also for abandoning behaviour that easily contributes to groundwater pollution or other forms of groundwater quality degradation. A certain natural resistance to change, delayed recognition of the impacts of abstraction and other human behaviour, and reluctance to address these impacts also play a role. Cooperation and voluntary agreements for changing behaviour may not only be a possibility but rather a logical need. However, evident incentives should enable these. Creating an atmosphere of trust and willingness to cooperate requires serious efforts and sufficient time.

Conflicts of interest between individuals or groups that have a stake in groundwater cannot be ignored and require special provisions to find solutions that are acceptable to all (conflict resolution mechanisms, priority setting methodologies, etc.). The urban-rural interface in particular, is a breeding ground for conflicts on groundwater quantity, quality and access. Elsewhere, however, there may be conflicts of interest between those who want to exploit groundwater and activists who want to conserve it for environmental reasons.

Constraints related to institutions and legal frameworks

In many cases, public agencies in charge of addressing water scarcity and mitigating its impacts have limited or even insufficient mandate, capacity and budgets, especially in developing countries. Institutional fragmentation is also very common: separate institutions and governance arrangements do often exist for managing groundwater and surface water – which forms an obstacle to integrated management. Poor communication and co-ordination with agencies active in related fields (water supply, irrigation, mining, oil and gas development, geothermal energy production, etc.) form additional constraints to more holistic approaches in groundwater management.

Community engagement is helpful, but the groups involved may lack community structure, well-defined rights and adequate political representation.

Centralised water supply systems often are unsatisfactory, but attempts to decentralise them have often failed too (e.g. by keeping finances at the central level or by lack of capacity building).

Legislation and regulatory frameworks related to groundwater is insufficient and/or fragmented in many countries. At the global level, the Draft Articles on the Law of Transboundary Aquifers (2008) have been adopted by the United Nations International Law Commission. They represent non-binding 'soft law', providing guiding principles at global level.

Opportunities

Indirect management action for governance seems promising in many settings, but there is currently insufficient experience available to underpin this.

Investment in active awareness campaigns for decision-makers and the general public has the potential to put groundwater and its governance higher on political agendas. Groundwater is certainly more important than most decision-makers probably think and there is much at stake. The advocates of governance and change need to choose their cause carefully, identifying the really critical issues, and preparing and presenting the options persuasively.

Groundwater with its unique buffer capacity will undoubtedly play an important role in mitigating problems caused by climate change and affecting surface water sources and 'green water' much more.

6. Present state of groundwater governance and prospects

6.1 Preamble

The picture presented in this chapter is only tentative, because it is based mainly on expert judgement by the authors of the Thematic Papers and not on a systematic world-wide assessment. Such a comprehensive assessment would require huge efforts and the definition of adequate assessment criteria and indicators. A proposed list of such criteria is shown in Table 6.1. The organisation of this chapter does not follow this list systematically, but - for pragmatic reasons – has been adapted to the themes addressed and the information provided in the Thematic Papers.

Table 6.1 Checklist of 21 key benchmarking criteria for the evaluation of groundwater governance provision and capacity *(Howard, no date; modified after Foster et al., 2010)*

TYPE OF PROVISION/ CAPACITY		CHECK LIST	
	No.	CRITERION	CONTEXT
Technical	1	Existence of Basic Hydrogeological Maps	For identification of groundwater resources with classification of typology
	2	Groundwater System Conceptual Model Development	
	3	Groundwater Body/Aquifer Delineation	
	4	Groundwater Potentiometric Head Monitoring Network	To establish resource status
	5	Groundwater Pollution Hazard Assessment	For identifying quality degradation risks
	6	Availability of Aquifer Numerical 'Management Models'	At least preliminary for strategic critical aquifers
	7	Groundwater Quality Monitoring Network	To detect groundwater pollution
Legal & Institutional	8	Waterwell Drilling Permits & Groundwater Use Rights	For large users, with need of small users noted
	9	Instrument to Reduce Groundwater Abstraction	Waterwell closure or constraint in critical areas e.g. overexploited or polluted areas
	10	Instrument to Prevent Waterwell Operation	
	11	Sanction for illegal Waterwell Operation	Penalizing excessive pumping above permit
	12	Groundwater Abstraction and Use Charging	"Resource tariff" on larger users
	13	Land-Use Control on Potentially-Polluting Activities	Prohibition or restriction since a potential groundwater hazard
	14	Levies on Generation/Discharge of Potential Pollutants	Providing incentive for pollution prevention
	15	Government Agency as 'Groundwater Resource Guardian'	Empowered to act on cross-sectoral basis
	16	Community Aquifer Management Organisations	Mobilizing and formalizing community participation
Cross-Sector Policy Coordination	17	Coordination with Agricultural Development	ensuring 'real water saving' and pollution control
	18	Groundwater-Based Urban/Industrial Planning	To conserve and protect groundwater resources
	19	Compensation for Groundwater Protection	Related to constraints on land-use activities
Operational	20	Public Participation in Groundwater Management	Effective in control of exploitation and pollution with measures and instruments agreed
	21	Existence of Groundwater Management Action Plan (see Figure 7.)	

6.2 Available information

Fundamental to groundwater governance is a correct and sufficiently detailed understanding of the local groundwater resource, its use and the overall setting. This requires much more than hydrogeological information, but also information on hydrology, total water demands and use, socio-economic conditions, ecosystems, the environment, agricultural practices, etc. It is impossible to present here a full, balanced picture of the current availability of such information in different parts of the world. Instead, only a few remarks will be made:

- The availability of local information relevant and needed for groundwater governance varies enormously from country to country and also between areas inside countries
- In many countries, very significant progress has been made during the last few decades regarding the availability of such information and in particular the access to this information (Internet). Nevertheless, information on the groundwater conditions is in numerous areas around the world still minimal or missing
- International cooperation programmes have contributed very significantly to the improvement of groundwater related information in many developing countries
- At the global level, several initiatives have been taken by international organisations for projects and institutions that intend to enhance and disseminate world-wide area specific information and knowledge (WHYMAP, ISARM, IGRAC, TWAP, etc.)
- The private sector – in particular the mining industry – possesses very substantial information on the subsurface, but most of this information is not yet available to third parties.
- Monitoring networks and other methods to systematically observe time-dependent groundwater variables are the weakest part of the information chain. Monitoring networks are often quickly abandoned in times of scarce means and if started as a project activity they usually stop not very long after the project's expiration. In some countries, special institutional or legal arrangements affect the continuity of monitoring activities very positively, e.g. in India (Groundwater Estimation Methodology used as a basis for management decisions) and in the European Union (obligations imposed by groundwater daughter directive of the WFD).

It is expected that, in the near future, planners and investigators will tend to broaden the scope of information to be collected, guided by a shift in focus from hydrogeology and water supply to the more holistic approaches of groundwater resources management and groundwater governance. Without strong advocacy for the need and benefits of additional information, the continuity of assessment and monitoring seems at risk.

6.3 Dealing with main issues of concern

The geographic variation of the main issues in groundwater resources management and governance is even higher than that of the state of information. A few main issues will be briefly reviewed.

Control of groundwater levels

This is in the first place an issue in areas where artificial drainage is needed to make the land suitable for residential purposes and land use (e.g. in flat coastal lowlands such as in The Netherlands), or to facilitate mining and other subsurface activities (scattered around the world). Traditions and practices of artificial drainage have been long established, but they are subject to modifications due to technological innovations.

More complex from the point of view of management and governance is the control of groundwater levels (which also means: control of groundwater volume stored) in areas where groundwater withdrawal is of sufficient intensity to modify the local groundwater conditions and budget markedly. Figure 6.1 distinguishes schematically four typical stages of groundwater development intensity, each with its own impacts of the groundwater budget.

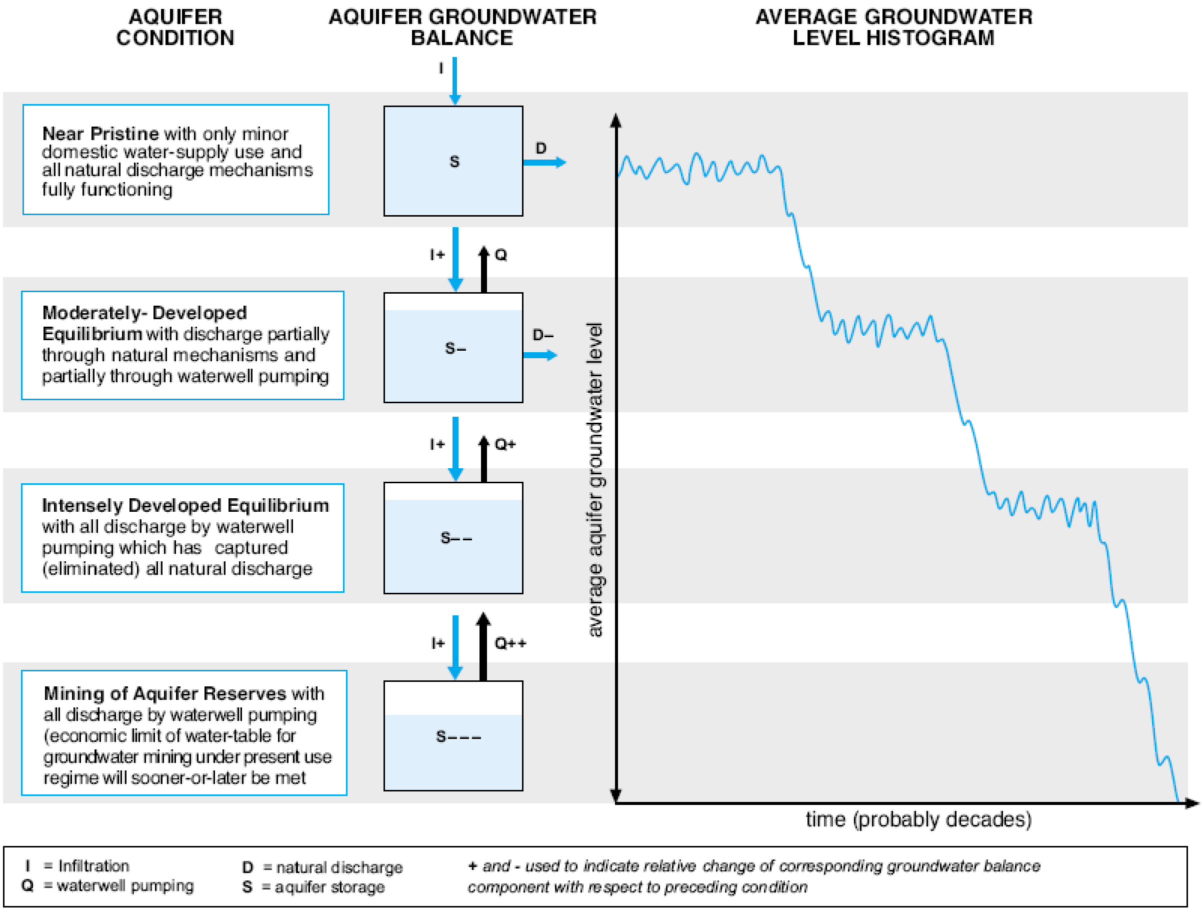


Figure 6.1 Typical stages of groundwater development and the corresponding impact on the natural discharge and storage of groundwater bodies *(source: GW-MATE, 2009)*

The first stage represents situations where groundwater abstraction is absent or insignificant. The hydrogeological regime is characterised by long-term stability in groundwater levels, groundwater storage and natural groundwater discharge (dynamic equilibrium). If groundwater abstraction becomes significant but still moderate, then groundwater levels will decline (reduction of storage) and the natural discharge will be reduced to some extent, until after some time a new dynamic equilibrium is established (stage 2). Under a more intensive abstraction rate, groundwater levels and natural discharge will further decrease until a new equilibrium is reached where all natural groundwater discharge has stopped (stage 3). At higher groundwater abstraction rates, a dynamic equilibrium can't be established anymore: groundwater levels are declining progressively and groundwater storage is depleted (stage 4).

Stage 1 conditions do not require any management interventions. Areas that can be classified as stage 2 are abundant around the world, in particular in humid zones. The groundwater levels under the new equilibrium conditions usually have not declined much compared to the pristine situation, which means that there is not yet a strong need to implement measures of control, unless there is scope for undesired side-effects such as land subsidence or degradation of ecosystems. In practice, where land subsidence in urban areas develops, it usually is addressed by implementing measures, but controlling the degradation of ecosystems mainly gets attention in relatively rich developed countries. Stages 3 and 4 typically occur in almost all moderately- to densely-populated areas in the arid and semi-arid zone. Depletion of groundwater storage develops spontaneously in such areas, given the high profitability of groundwater, especially as a source for irrigation. Once the diagnosis of progressive depletion (stage 4) has been made, a choice has to be made between possible management scenarios for the near future. Figure 6.2 shows the main options.

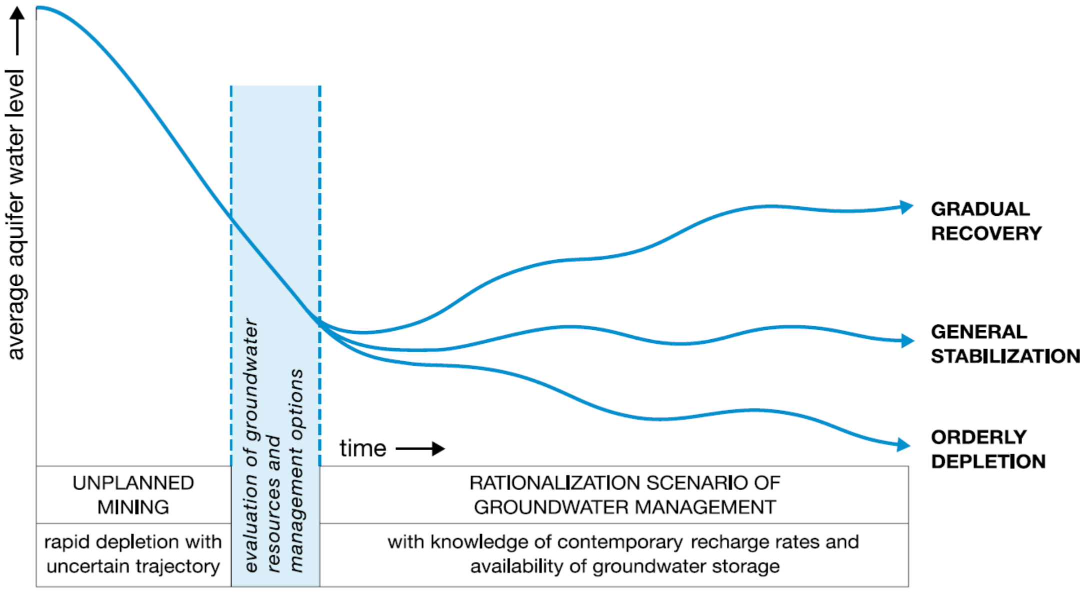


Figure 6.2 Targets for groundwater resources management in 'rationalization scenarios' following indiscriminate and excessive exploitation of groundwater *(source: GW-MATE, 2005)*

Gradual recovery from an undesired state of depletion is usually an unfeasible target in arid and semi-arid zones, but there are exceptions like the Great Artesian Basin in Australia and the Alluvial Basins of Arizona. Even achieving a general stabilization (which means returning to stage 3) is, for many aquifers in such zones, an overambitious target given the socio-economic importance of the water pumped, the scarcity or absence of alternative sources of water and the general political and socio-economic context. In case continuous depletion is unavoidable, then 'orderly depletion' should be adhered to with a clear plan for what to do after the groundwater resources have been completely exhausted (exit strategy). No real cases of such 'orderly depletion' are known, neither for renewable nor for non-renewable groundwater resources.

Licensing systems for drilling and/or pumping, with the objective of restricting groundwater withdrawal, have been introduced in many countries. Although satisfactorily operational in some countries, often these systems are not effective in practice, because of the absence of strict enforcement, the reluctance of pumpers to comply, the lack of clear criteria for granting or refusing a licence, or the licensing system simply considered as a means to generate income for the government (license fees). Some countries opt for incentives and disincentives to influence pumping behaviour. Most commonly this is by means of energy pricing (subsidies) or limiting access to energy.

Another approach to achieving a desired rationing target or to prevent an excessively stressed groundwater regime from developing is managed aquifer recharge and other forms of conjunctive management of groundwater and surface water resources. It is already being applied in many parts of the arid and semi-arid zone, but there is scope for expanding it considerably in the near future. In contrast to measures that restrict groundwater pumping, these methods are less likely to be opposed by groundwater users.

Groundwater quality control

As mentioned in Chapter 5, groundwater quality control addresses two main types of water quality degradation: pollution by the influx of undesired substances produced by humans; and the flow of poor-quality water into masses of fresh groundwater of good quality. Pollution is the more ubiquitous of the two and poses the largest threat to the groundwater resources. There are many sources of groundwater pollution: sewage, solid waste, fertilisers and pesticides used in agriculture, accidental spills, industrial waste products, improper waste disposal practices, etc. It is important to note that polluters and those who abstract groundwater are different groups: polluters do not necessarily have a stake in the groundwater resources they affect. Groundwater pollution has encroached in nearly all shallow aquifers around the world underlying either densely populated zones or intensively-used agricultural land. The pollution process is virtually irreversible. A wide range of measures has been implemented to halt pollution, but mainly in relatively wealthy, developed countries: sewerage systems and adequate solid water management, land use restrictions in groundwater recharge areas, groundwater protection zones around important well-fields, obligatory treatment of industrial waste waters, prohibition of the use of certain chemicals, pump-and-treat projects, coordination between groundwater management and land use planning, etc. They certainly have positive effects, but especially diffuse pollution caused by agriculture remains difficult to control. It should be noted that over time there has been substantial progress in improving the detection level of groundwater contaminants (see Table 6.2). This has influenced the groundwater pollution control agendas.

Table 6.2 Progress in detection levels of possible groundwater contaminants
(Custodio no date; adapted from Ronen et al., 2012)

Moment	Contaminant	Level of detection
1950s	Major solutes Nitrates Dissolved organic carbon	mg/L (10^{-3} g/L)
1960s	Heavy metals Rare heavy metals Pesticides and herbicides Hydrocarbons	µg/L (10^{-6} g/L)
1980s	VOCs (volatile organic carbons) Chlorinated solvents	ng/L (10^{-9} g/L)
1990s	Hormones and endocrine disruptors Antibiotics Other emergent contaminants	pg/L (10^{-12} g/L)

Groundwater quality degradation may also take place as a result of groundwater abstraction, causing intrusion of seawater into coastal aquifers, upconing of connate brackish or saline groundwater overlain by fresh groundwater or other migrations of poor quality groundwater into freshwater bodies. Many aquifers around the world, especially in coastal zones, have suffered from salinization processes by these mechanisms. Measures for quality reversal or for preventing continued salinization – including reducing or reallocating abstractions, artificial recharge and intrusion barriers – have been implemented successfully in several of these aquifers. In general, it is reasonably known where seawater intrusion and other abstraction-induced forms of quality degradation may occur. Implementing measures for control is usually not controversial, because stakeholders easily understand the need for it and see that it will benefit them.

The overall prospect for groundwater quality is that some degradation will continue to occur: increasing salinity, nitrate build-up, deleterious organic compounds and emerging contaminants

(PCCPs, EDCs). Future climate change may influence groundwater quality according to how it will modify recharge. However, land use changes may in many parts of the world have greater effect on recharge and on groundwater quality than climate change. Finally, it needs to be highlighted that correcting groundwater quality degradation is much more expensive that preventing it; this should be taken into account when allocating budgets for groundwater quality control.

Allocating groundwater and enhancing its beneficial use

In most parts of the world, groundwater exploitation has largely developed as a private activity, triggered by the needs of individuals or specific groups and without coordination between groundwater exploiters. Only after it has become so intense to cause interference between wells or significant declines of groundwater levels, then in many cases communities have become aware that some kind of regulation would be useful, or, in advanced cases, even conflict resolution mechanisms are required.

Many countries that have been confronted with such conditions have defined relative priorities between water use sectors, usually assigning the highest priority to groundwater use for drinking water and other domestic purposes. Often, however, it is not clear whether such a declared allocation priority is also made effective in practice, by playing a decisive role in granting abstraction permits or any other measures.

The urban and semi-urban environment forms a special case, likely to produce severe urban-rural tensions. Without urban spatial and infrastructure planning, opportunities to provide adequate water and sanitation services are seriously compromised. Left unaddressed, urban slums threaten both national and international security, human health, and environmental sustainability. It seems that current problems with urban groundwater management will only be resolved if governments work in association with groundwater users rather than attempting to regulate and control them.

Conflicts that may arise as a consequence of externalities produced by groundwater exploiters need conflict resolution mechanisms. Apart from the obligation to supply financial compensation in cases of proved damage, no other mechanisms are known to be implemented. It is expected that conflicts over groundwater will become frequent in the future, due to increasing water scarcity.

Investment in drinking water projects in the framework of the Millennium Development Goals will certainly stimulate beneficial use of groundwater, provided that those who plan the projects are aware of the opportunities offered by groundwater. Promoting the global priority for improving the status of drinking water supply by direct investments instead of by policies and regulations alone is undoubtedly a powerful contributor to enhancing beneficial use of groundwater.

Withdrawal of deep-seated groundwater, development of geothermal energy and a wide range of uses of the subsurface are expected to gain importance in the future and affect the allocation of groundwater and the benefits from its use. So far, groundwater governance has largely ignored these activities.

Finally, intergenerational allocation of groundwater is an issue that deserves attention in areas where aquifers are currently being depleted by intensive groundwater withdrawal. Currently, no plans are known that address this issue in sufficient detail.

6.4 Legal and institutional matters

Legislation and regulatory frameworks

Most countries have legislation on water or even specifically on groundwater. It captures the ideas, perceptions and knowledge available during the period of preparation; consequently, in many cases there is a need for updating legislation, in order to make the law consistent with modern views.

One of the legal issues that deserve more attention is groundwater ownership, or – more broadly – tenure. Unlimited entitlements to groundwater based on land ownership currently still prevail in many countries, defying the laws of nature and forming an obstacle to controlled exploitation of the groundwater resources.

A wide range of developments will require new or improved legal responses. This is, firstly, because environmental concerns and climate change are becoming more prominent. Next, there are increasing needs to measure water policy and legislation against human rights. In addition, new legal rules are needed to deal with the use of deep-seated aquifers and different other uses of the subsurface. In most countries these activities in the deeper domains of the subsurface are not regulated by water law but by mining law. Furthermore, there is a tendency towards more holistic approaches in groundwater resources management and governance. Legislation of interfering policy fields therefore needs to be made coherent.

International legislation on groundwater includes the Water Framework Directory of European Union and the Draft Articles of the Law on Transboundary Aquifers. The former – with its Groundwater Daughter Directive – has catalysed and intensified enormously the activities of member states related to groundwater quality monitoring and control. The latter (the Draft Articles) are non-binding, but may play an important role in guiding countries that are planning to draft international treaties with neighbouring countries on shared aquifers.

At the level of regulatory frameworks, permits systems are increasingly being challenged. This calls for analysis of the reasons of malfunctioning and perhaps also for new creative approaches to address scarcity.

Organisations and stakeholders

Government organisations in charge of assessing, monitoring and/or managing groundwater are widespread. They used to be part of entities in charge of irrigation or water supply, but in recent decades there has been a tendency in many countries to separate water resources management from water use sector organisations. As a result, groundwater resources management (and often also assessment and monitoring) has been entrusted to sector-independent organisations, for example a special water resources management ministry or agency, instead of a ministry or agency in charge of public water supply or irrigation.

The capacity and effectiveness of these government organisations vary considerably. However, except for a number of developed wealthy countries, the general picture is that these organisations are usually understaffed and have insufficient budget to address the large number of challenges and problems related to groundwater. Changing this for the better obviously requires action that puts groundwater high on the agenda of decision-makers.

At the local level, there is a long legacy of local institutions around groundwater sources, such as shared springs, dug wells and qanat systems. They used to function independently from government organisations, like the more recently emerged NGOs dedicated to groundwater projects in several countries. The effective involvement of stakeholders in groundwater resources management is, in most countries, non-existent or still in its infancy. Where it does exist, sector-related central government organisations (like ministries of irrigation, public water supply, or the environment, etc.), or related agencies, are often supposed to represent the stakeholders. Involvement of local stakeholders is still rare, with the exception of some countries where local water users associations have been established. There is still a long way to go before 'participation' (as defined as one of the characteristics of good groundwater governance) becomes a reality around the world.

6.5 Policies, strategies and operational activities

As a result of its specific characteristics, governance of groundwater is inherently more complicated than that of surface water. Many of the impacts associated with emerging groundwater problems depend not only on the resource base and its use, but also on a much wider array of social, economic and environmental conditions. Therefore, these conditions have to be taken into consideration for effective groundwater resource management. Policies and strategies on groundwater, however, are in many countries still focused on groundwater as an extractable commodity, without considering the broader context. It will take commitment and time to make a transition, if this is opted for.

Recommended principles and considerations of 'good' groundwater governance are many, covering political, institutional, socio-cultural, economic and ecological aspects. Spatial and temporal contexts determine the applicability and potential success of the different governance paradigms (state-, market or collective action-driven) and management instruments.

7. How to improve the state of groundwater governance?

Generally, valid recipes for improving groundwater governance do not exist, given the large diversity in conditions around the globe. This diversity does not only relate to the current stage of groundwater governance in a particular area (ranging from non-existent to well-developed), but even more to differences in physical settings, socio-economic conditions, culture, political situations and other factors. Nevertheless, the steps below are suggestions that may contribute to improving groundwater governance in a particular area. These suggestions are presented under five broad categories:

- Approaches to groundwater governance
- Information, awareness raising and communication
- Legal and institutional matters
- Stakeholder participation
- Anticipating the future.

Local institutions with a mandate for groundwater management have to make their own judgement which ones of the suggestions would be feasible and effective in their particular situation. Without in-depth inventory it is hard to tell which ones of the suggestions are likely to be most relevant, on a global level. Nevertheless, in the majority of cases, the impression exists that it is neither the technical nor legal instruments that form bottlenecks in groundwater governance. Instead, it is often perceived that the challenge lies in the process of getting all relevant parties to commit and co-operate towards a common goal.

7.1 Approaches to groundwater governance

Principles of good groundwater governance

In the endeavour to transform a given present situation into 'good groundwater governance' it will be helpful to start by analysing to what extent the general principles and considerations of good groundwater governance are already incorporated and which ones are not. The outcomes of this analysis will give guidance to enhance groundwater governance, subject to the feasibility of the envisaged improvements in the local context. These principles and considerations fall into four main sets of principles and considerations:

- *Political and institutional:* This includes accountability, representation, consistency, scalar match, institutional match, and institutional capacity to adapt to uncertainty and change. Groundwater is mostly a local issue and solutions need to fit institutionally and socio-culturally—recognising that paradigms and social constructs change over time.
- *Socio-cultural:* Deals with perceptions about groundwater, religious and spiritual traditions, social learning, social inclusion, ethics, multi-level/multi-scale/polycentric governance models.
- *Economic*: Here attention is required for the imperfection of price signals, the role of scarcity and groundwater-storage conditions, water-quality impacts, inadequate measurement of groundwater usage rates, the growing role of the private sector and public-private partnerships, and the importance of ability to pay. In addition, water prices may not fully reflect the costs of extraction, and rarely include third-party and environmental impacts of groundwater use. Economists often see market mechanisms as having potential to match demands with supplies, but the incidence of externalities related to the common-pool nature of groundwater should not be overlooked.

- *Ecological*: Focusing on physical characteristics that define movement, storage, attenuation rates and renewability. In addition, groundwater development may rival existing land uses. Groundwater systems can be considered as common-property resources, vulnerable to over-exploitation and/or under-management. Aquifers are to be valued not only for their provisioning services (for consumption, agriculture, or industry) but also for their environmental and ecosystem-supporting services.

Holistic approach

Groundwater management consists of sets of policies or decisions that impact groundwater use and protection. Opting for an integrated water resources management approach (IWRM) is a logical response to the close interaction between groundwater and surface water, and reflects a guiding governance principle fostering conjunctive management. However, there may be many decisions, public and private, that appear to fall outside the domain of 'water governance' but still affect the use and protection of the water resources. Examples are decisions related to land use, irrigation, energy development and agricultural subsidies. There is evidently scope for improving groundwater management if attempts are made to harmonise the policies of all these interfering fields, preferably by formal links between the processes to develop them.

Selection of management instruments and measures

Not all groundwater resources management instruments and implemented measures are effective in a given context. Their effectiveness depends on the local physical, institutional, economic and social conditions, but also on the way these measures are designed and implemented. In cases of poor results, it is, therefore, important to identify the reasons why and to analyse whether obstacles can be removed that prevent the measures from being effective. A typical example is the permit system for abstracting groundwater: in some countries it functions satisfactorily, in many others not at all.

Adaptation is a still a relatively underused but promising approach. In terms of measures it includes indirect management strategies that motivate users to adapt to local conditions (e.g. power pricing/rationing, crop price support, etc.), but it encompasses also adapting social and economic systems to groundwater conditions and changing socio-economic context for reducing or mitigating problems. Such measures attempt to adjust water demand to water availability (demand management), rather than supply to demand (supply management). In a more general sense, adaptation can also be chosen as a leading principle of strategies and planning. This results in *adaptive management* characterised by an incremental approach, which allows a step-wise adjustment of policy and measures on the basis of observed impacts.

Conjunctive management of groundwater and surface water has the potential to contribute in the future much more than at present to good groundwater governance. This includes 'managed aquifer recharge' (MAR) as a prominent measure. Groundwater also still has large unused potential for developing geothermal energy and for improving domestic water supply in areas where this is still deficient.

Unequivocal 'best measures' for groundwater resources management do not exist. Which measures would be most effective in a particular case depends on the local physical, institutional, economic and social conditions. Given the complexity of groundwater and its context, measures should not be selected on an *ad-hoc* basis and in isolation. The development of a wider policy perspective is essential to frame 'good groundwater governance'.

7.2 Information, awareness-raising and communication

Information and knowledge

Information and knowledge regarding local conditions – i.e. the baseline characterisation of the groundwater resources and of the local socio-economic context – are essential inputs to good groundwater governance. Without them, groundwater governance has no real content, as they are indispensible for proper diagnostics, development of rational strategies and assessing the impacts of implemented measures. It is thus vital that governments consolidate a sufficient level of information and knowledge on groundwater. In particular, much more attention than is presently given is required for monitoring the most relevant time-dependent variables related to groundwater state, groundwater withdrawal and also the benefits and side-effects of groundwater withdrawal.

Carrying out projects for collecting data and information is not enough. Responsibility for developing groundwater information and knowledge should be vested in special national agencies (e.g. geological surveys) that are dedicated to this task and ensure its continuity and objectivity. Such agencies should develop user-friendly tools and procedures for the retrieval of data and information.

Awareness raising and communication

Except for groundwater professionals, most people are unfamiliar with groundwater systems, the opportunities they offer and the problems that are to be solved or controlled. It is therefore not realistic to assume that politicians and other decision-makers are motivated to put groundwater high on their agendas and to make budgets and other means available for groundwater governance, unless they are made fully aware of what is at stake and of the benefits their contributions may produce. Likewise, without correctly understanding groundwater systems and their context, many stakeholders in groundwater only react to problems and are neither motivated nor capable of cooperating pro-actively. Therefore, developing awareness on groundwater among stakeholders is an essential component of good groundwater governance.

Awareness-raising is also needed because all partners in groundwater should understand each other properly. This means that groundwater specialists and planners should engage with policy makers in order to understand their objectives, concerns, priorities and constraints. They should also make efforts to identify and understand perceptions of stakeholders, their dependency on groundwater, their preferences and problems they experience.

Reaching an effective level of awareness is a first step towards structural communication between decision-makers, planners, groundwater specialists and stakeholders. This communication is essential to build confidence among the parties involved, to ensure that all relevant aspects and considerations are addressed in a balanced way, and to agree on solutions in case of differences of opinion or conflicts of interests.

7.3 Legal and institutional matters

Policy coherence across sectors

Good groundwater governance implies that the laws related to groundwater allow for coherence between the policies for groundwater and those in related fields such as surface water management, land use planning and environmental protection. They should also attempt to harmonise groundwater governance with the different categories of use of the subsurface space and resources that come under other laws and institutions, and ensure that they assign clear mandates to the organisations in charge of enforcing groundwater management measures.

Adapting laws

Where laws related to groundwater no longer reflect the current conditions or views, these should be updated. Special care is needed to ensure that they assign clear mandates to the organisations in charge of enforcing groundwater management measures. Private groundwater ownership and user rights might be perceived in some cases as posing constraints to good groundwater governance. In such cases, it might become necessary to amend to law better protect the common good. In cases where state ownership has been accepted, but introduced permit systems for groundwater withdrawal are not functioning properly, the reasons of this malfunctioning have to be explored in order to improve these systems or replace them by other demand management instruments.

An institutional home for groundwater

In many countries, the bottleneck hindering adequate groundwater management is probably lack of powerful, effectively operating organisations in charge of groundwater. If a real 'institutional home' for groundwater is missing, then it should be established – either as one organisation or in the form of a few, each with its own clearly defined tasks, such as assessment and monitoring, policy development and planning, and operational management. Crucial requirements for such organisations are clear mandates, adequate budgets and sufficient staff that are not only well trained but also capable of cooperating with the different actors in groundwater governance.

7.4 Stakeholder participation

Empirical evidence suggests that stakeholder participation can be an effective contribution to achieving good groundwater management. There is a great diversity between participatory approaches to groundwater management: they range from informing or consulting local stakeholders to fully delegated local groundwater management. Despite its generally good potential, participation may also have its drawbacks. For example, there is a risk that participation may reflect or even increase existing inequalities, and participation may in some cases cause long delays in decision-making and planning.

As groundwater problems intensify, incentives for participation and collective local management grow among the local population. Cooperation by partnerships between local stakeholders and dedicated public agencies is usually an effective approach, but it requires long-term commitment on both sides.

Experience shows that it is important to build on existing social capital, promote equity and inclusion, start in areas of good potential, go step-by-step, learn lessons and adapt. There is a wide range of methods and tools available to support stakeholder participation.

7.5 Anticipating the future: demography, climate change, new frontiers, etc.

Good groundwater governance takes into account that the world around us is not static but subject to continuous change. Consequently, drivers of change should be identified and assessed, in order use most realistic estimates of autonomous trends as boundary conditions to any predicted future.

Besides the more classical demographic trends, commonplace in water resources planning and management, two issues deserve special attention: climate change and new frontiers in the use of subsurface space and resources.

Climate change is still subject to many uncertainties, but this should not prevent countries from building preparedness. Even under uncertain predictions of local climate change, it is already possible to provisionally explore impacts, to identify the most vulnerable areas and look for options for mitigation and adaptation. The role of groundwater management may be, on the one hand, to identify groundwater systems and functions at risk and designing measures in response. On the other hand, in an integrated water resources management context, it can promote the use of groundwater as a buffer to mitigate the water scarcity problems that may affect surface water most of all. International organisations may contribute by carrying out projects in developing countries, resulting in valuable lessons and experiences.

Use of the subsurface space and its resources, other than groundwater, are still beyond the scope of common groundwater resources management and groundwater governance endeavours. Good groundwater governance should require that the increasing intensity of these activities and their interference with groundwater are no longer ignored.

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