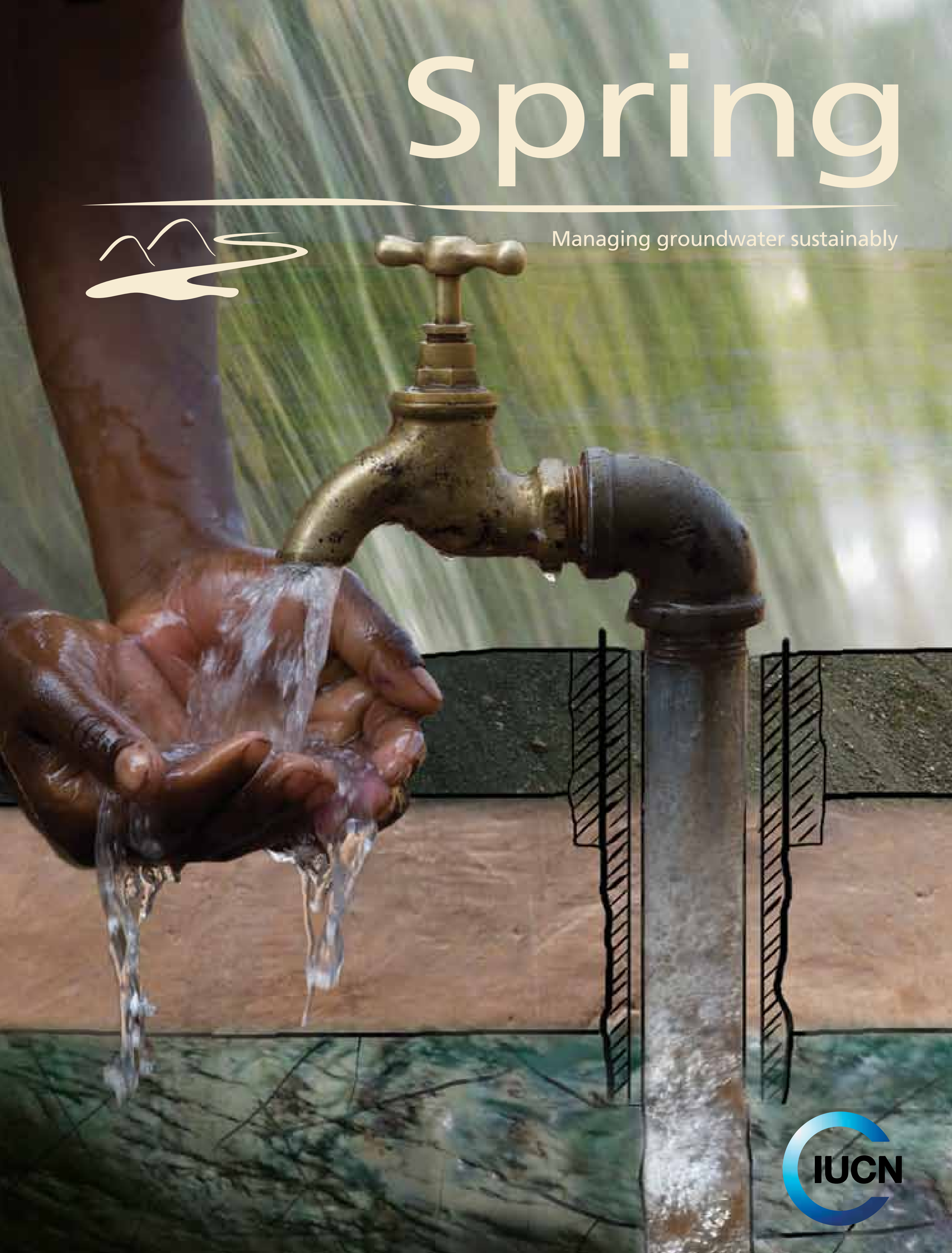
Spring

Managing groundwater sustainably



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Spring

Managing groundwater sustainably

Water & Nature Initiative

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Key messages

1. Groundwater Challenges and Risks

Groundwater is the most abundant source of freshwater on Earth
The total volume of fresh groundwater stored on Earth is between 8 and 10 million km^3, or 96% of non-frozen freshwater. Groundwater provides almost 50% of all drinking water worldwide and 43% of all consumptive use of water for irrigation in agriculture. Changes in groundwater availability and quality impact human health, livelihoods, food security and national economic development. Many aquatic ecosystems and their biodiversity depend on groundwater. Failure to manage groundwater sustainably puts at risk massive benefits for human well-being, sustainable development and biodiversity conservation.

Exploitation of many globally significant aquifers is not sustainable
Global abstraction of groundwater has at least tripled over the last 50 years. Groundwater levels have declined significantly in major aquifers, reducing stream flows and causing the degradation of riparian and wetland ecosystems. The long-term viability of irrigation-based economies in these regions is threatened, creating long-term risks for global food security. Over-exploitation of groundwater and contamination threatens drinking water supply for hundreds of millions of people. Degradation of groundwater reduces resilience of communities and economies to climate change.

Sustainable groundwater management supports biodiversity conservation
Changes to groundwater levels or the timing, quantity or quality of groundwater discharge is a driver of biodiversity loss in groundwater-dependent ecosystems, including springs, rivers, lakes and certain types of wetlands and forests. Conservation of these ecosystems depends on sustainable groundwater management. Ecosystem conservation also helps to sustain groundwater recharge. Groundwater management and ecosystem management work together to underpin the continuing availability of groundwater and of benefits from groundwater-dependent ecosystems.

Sustainable and climate resilient development must address groundwater management
Sustainable groundwater management supports climate-resilient supplies of water to help meet goals for food security, energy development and access to drinking water. It supplies water for sustainable cities and for industrialisation. Achieving sustainable groundwater management demands coordination with surface water management for conjunctive use and that local groundwater users, technical specialists and policy makers work together. Each has a role to play, whether at local, basin, national or international levels, to implement multi-actor, collaborative and participatory strategies for catalysing sustainable management of groundwater.

2. Groundwater Systems

Improving management of groundwater requires understanding of groundwater systems
Groundwater resources are poorly understood and hence poorly managed in many parts of the world. When things go wrong, the damage can be lasting or even permanent. Groundwater systems vary tremendously, with the solutions needed for sustainable management depending on how each responds

to different pressures. Sustainable groundwater management requires knowledge of the types of rock making up an aquifer, how recharge occurs, risks of pollution and how much water can be taken from an aquifer sustainably.

The two major threats to groundwater are overuse and pollution
The vast majority of groundwater is stored within porous and fractured rocks. Groundwater recharge primarily occurs as precipitation or sometimes as leakage from rivers, lakes and canals. Recharge water infiltrates below ground and slowly flows to discharge naturally through springs, rivers and wetlands or into the sea. Intensive abstraction of groundwater, usually by pumping, reduces natural discharge and can also deplete groundwater storage. Groundwater can be contaminated where recharge water carries chemical pollutants – usually from agriculture, waste disposal or industry. Groundwater management requires a good understanding of both contaminant and abstraction pressures, including interactions with surface water management.

Understanding aquifer characteristics is key to moving from diagnostics to actions and solutions
Diagnostics for current and future groundwater problems depend on good information on aquifer conditions and monitoring of groundwater levels and water quality. National monitoring systems are essential for identifying when interventions are needed. Estimation of the capacity and vulnerability of an aquifer is based on mapping of soil and rock characteristics. The water balance is estimated by comparing recharge into the aquifer with natural discharge and abstraction. Determination of an aquifer's storage capacity, transmissivity, hydraulic conductivity and porosity is needed to understand response over time to pumping or pollution and is the basis for developing a numerical groundwater model.

Groundwater protection and remediation rely on sound planning and prevention
The aim of sustainable groundwater management is to prevent groundwater from becoming severely depleted or highly polluted and to minimise unwanted impacts on others. Zoning is used to ensure that land uses are compatible with protection of vulnerable aquifers. Key technical interventions for groundwater management include control of groundwater pumping to sustainable levels, control of discharges to groundwater and in some areas managing aquifer recharge. Remediation of groundwater contamination once it has occurred is possible, but may only be partially successful and is very costly.

3. Policy, Law and Institutions for Effective Groundwater Governance

Water governance puts in place the structures and norms needed for groundwater management
Weak water governance in a country puts at risk the health and food security of its people, its economy, as well as the sustainability of its natural environment and, for transboundary aquifers, good relations with its neighbours. Effective governance relies on policies, laws, institutional arrangements and implementation and enforcement mechanisms. Strengthening water governance uses processes – mobilised in conjunction with social organisation, stakeholder dialogue and citizen action – that starts with a vision, evolves into policies, then is codified into laws and is reflected in institutions that develop norms and mechanisms for the coherent enforcement of the law.

Groundwater policy is a government's strategy for how to manage groundwater
Groundwater policies should be integrated within broader national water policy while ensuring they address specific needs for groundwater management. Policies should promote integration across sec-

tors and between surface and groundwater, tailored to local contexts and vulnerabilities. Policy principles include efficiency, equity, sustainability, public participation, transparency, accountability, subsidiarity, conjunctive use and the precautionary principle. Water users should take part in developing policies and measures needed to achieve policy goals. Roles and responsibilities for all stakeholders in translating policy into action should be identified clearly, including in a national groundwater management plan that is articulated with integrated water resources management.

Law on groundwater establishes the rules for preventing unsustainable uses and pollution
Laws are established to codify policies. They set the rules for exploitation and protection of groundwater and who has the right to use it. They should create a stable framework enabling governments and users to plan over the long term. Law puts in place regulations in which competing interests of all users, including ecosystems and future generations, can be fairly taken into account. Cornerstones of law on groundwater include permitting or licensing used by governments to administer rights to extract groundwater, mechanisms to control pollution, land-use zoning and the means of enforcing rules through the courts.

Water institutions translate decisions into action
Water institutions at national, basin, aquifer or local level, or at international level for transboundary aquifers, ensure that the regulations, procedures and enforcement mandated in law are carried out. The best institutional set up for any country depends on its system of government, its climatic and hydrological context and its social and economic circumstances. An effective institutional architecture combines for example ministries, national water agency, aquifer management organisation, river basin authority and local water user associations, while ensuring effective public participation. Coordination of water institutions is guided by the subsidiarity principle that decisions and activities should be carried out at the lowest possible administrative level.

4. Economic Principles and Instruments for Sustainable Groundwater Management

Economic principles guide choices about groundwater use
Groundwater users have not generally had to pay anything like 'full economic cost' for groundwater use, nor have groundwater polluters had to pay for clean-up of their contamination. Undervaluation of groundwater contributes to problems of excessive abstraction, low productivity of groundwater use, and inadequate private and community investment in protection of groundwater quality. Realistic economic valuation of groundwater, translated into economic instruments, can create incentives for sustainable management and protection. Economic instruments must complement effective public administration of water resources, in a framework of public participation, and in a way appropriate to the local hydrogeological, socio-economic and institutional context.

Valuation helps to set priorities for equitable and efficient groundwater management
Economic values for groundwater are estimated from benefits gained through its use, less the costs of abstraction and management. Values for a specific aquifer depend also on local availability of groundwater compared to alternative sources of water. Valuation that considers a full range of groundwater uses and users enables public policy-makers to identify priorities that favour allocation to high-value and high-productivity uses, while ensuring pro-poor social protection. Inclusion of ecosystems in deci-

sion making on management options is made possible by factoring in valuations for ecosystem services – both for ecosystems dependent on groundwater ('groundwater-for-nature') and those that sustain recharge of groundwater ('nature-for-groundwater').

Economic incentives encourage voluntary adoption of groundwater protection measures
Imposing charges on groundwater abstraction is the most direct method of creating an incentive for users to economise on groundwater use. This requires metering of water use, or a reliable method of estimating abstraction, as well as effective public administration of the resource, including for compliance and enforcement. An alternative where administrative capacities are low is to use rural electricity pricing as an incentive to reduce pumping. Another option for encouraging allocation to higher-value uses is trading of groundwater use rights in 'water markets' within an enforceable cap on consumptive use. Payments for ecosystem services can be used to reward farmers and land managers for protecting groundwater recharge zones.

Incentives for control of pollution apply the 'polluter-pays-principle'
Under the 'polluter-pays-principle', industrial or agricultural enterprises are charged for the water pollution they produce. In the case of groundwater, however, culpability for pollution is often difficult to establish and polluter-pays should hence be interpreted as the 'potential polluter pays for the reasonable cost of groundwater protection.' Strong sanctions for non-compliance are needed, complemented by incentives for polluters to invest in wastewater treatment, recycling and disposal. Eliminating fertiliser and pesticide subsidies contributes to control of diffuse agricultural pollution, especially if re-targeted as land-management payments to control agrochemical leaching.

5. Social Organisation Around Groundwater Management

Everyone needs a seat at the water table
Because water is necessary for life, it is everybody's business. All stakeholders must be brought around the 'water table' to discuss groundwater use and management. Enhancing effective social organisation is hence a prerequisite for good governance of groundwater resources and sustainable groundwater management. Social organisation facilitates informed decision-making and eases conflict resolution, using mechanisms that allow for the active involvement of all stakeholders in dialogue, planning, decision-making and implementation of activities in ways that, as much as possible, address each stakeholder's interests and concerns.

Participatory platforms help all stakeholders to become accountable
Participatory stakeholder platforms allow the voices of relatively powerless groups, which may include women and vulnerable people, to be heard. Participation offers especially local people the opportunity to know their rights and roles, meet their responsibilities, attain ownership, and claim rights. Through genuine stakeholder dialogue and concerted action processes, with representation from across sectors, all stakeholders become more accountable to good groundwater management. Changes in attitudes and behaviour may emerge among individuals, institutions, professionals, and decision-makers. These changes will not happen overnight, but once social organisation processes become the norm, they usually persist because they are well-liked and effective.

Effective social organisation puts in place processes for managing change

Social organisation for groundwater management implies change processes that need to include vulnerable groups and the environment as stakeholders. This requires the support of those in power to institutionalise the changes made, and hence integration of social organisation and formal, governmental processes in strengthening water governance. Social organisation for change requires respectful listening and sharing of solutions in open dialogue, creating ownership and building capacity at all levels, as well as recognition that social processes are a good investment.

Facilitated stakeholder dialogue is the basis for planning of concerted action on change

Social organisation begins with mapping of stakeholder interests at all levels, before creating platforms for stakeholders to engage in participatory planning and decision-making. Experienced process facilitators help to bring different actors together to negotiate conflicting interests. An agreed information base helps all stakeholders understand the extent and causes of groundwater problems and to engage in dialogue that leads, through visioning and scenario-building, to detailed planning of concerted action. Learning throughout the process is used to correct mistakes and provide lessons in how to do things differently in the future.

6. Taking Action in Groundwater Management

Managing groundwater sustainably requires joint action

A paradigm shift is needed in groundwater management, from technocratic approaches to use of collaborative, participatory knowledge systems. Groundwater users, technical specialists, scientists and policy makers need to work jointly. With the support of facilitators, and backed by demonstration results, learning and communications, they should collaborate to align groundwater knowledge, governance reforms, economic incentives, investment and social organisation.

Management action should be embedded in comprehensive strategies for change

Government agencies, scientists and NGOs should all contribute to public information campaigns to raise awareness that threats to groundwater require urgent action. On its own, however, this does not lead to change. Advocates for sustainable groundwater need to go further and bring together coalitions for action that lead strategies for change. These must empower stakeholders at all levels to take action, while facilitating communications and two-way exchange of knowledge between local users and higher levels needed for large-scale transformation of groundwater management.

Agents of change for groundwater management have to be mobilised at all levels

Groundwater users – women, men, youth and users across all sectors – must take part in the process of change in groundwater management, as they must ultimately agree to implement the management actions, plans and regulations decided upon. Groundwater users need help from technical specialists to take agreed actions as well as to inform and receive support from policy makers. Technical specialists play a critical role as knowledge brokers helping to build consensus. Legislators and policy makers in ministries, legislative bodies and financing institutions provide the policy and legal framework and allocate finance that enables local groundwater users and technical institutions to take action at each level. They have a vision for how groundwater legislation fits within a larger management framework, and they promote dialogue at higher levels on how to integrate groundwater sustainability into wider societal, economic and environmental priorities.

Without political engagement, the goal of sustainable groundwater management will not be met
Advocates for sustainable groundwater management need those holding political power to understand the issues and take action on current and future problems associated with groundwater. Advocates need to build the social rationale and economic case for groundwater management, and demonstrate the evidence base for it. They need to cultivate political champions for groundwater and work with them in coalitions for change. Champions need information and evidence they can use to justify action in terms that carry political weight: if action is not taken on sustainable groundwater management, there will be costs nationally and globally, for economic growth, poverty reduction, food security, safe drinking water, biodiversity and climate change resilience.

Foreword

Empires have risen and fallen because of groundwater. The history of no region tells this story better than the Middle East - and no country knows this better than Jordan, one of the driest on Earth. Today, the importance of groundwater is undiminished, yet around the world the gravity of threats to groundwater continue to mount.

Ensuring that water resources are sustainable is a vast challenge. It is felt in households and on farms, in nature's quiet and in roaring mega-cities, in boardrooms and at cabinet tables. Meeting water needs of the world's peoples and ecosystems is a complex problem, there are no simple solutions, but there are solutions. A water secure future depends on good science, increased finance and water resource management that brings people, sectors and countries together in common cause. It demands cooperation and capable institutions - to cut pollution, adapt to climate change, protect us from water-related disasters, conserve biodiversity and supply all people, everywhere with safe water.

Can we be surprised that alongside these many faces of water, groundwater – unseen and silent – is so often overlooked?

This must change. Al most all of the freshwater we have is underground, and half of the water we drink is supplied from aquifers. Sensible management and utilisation of groundwater resources is, inarguably, a top priority for meeting basic human needs. With emerging understanding of the close inter-dependencies between water and development, however, these needs go further. Groundwater management is an essential requirement in strategies for coping with the threats of future water, energy and food scarcity. It is critica! for optimising solutions in the water-energy-food and human security nexus, and therefore to developing greater capacities for resilience. In the Levant, this necessitates the establishment of a supranational commission for water and energy that takes into consideration human-centred approaches. Boosting renewable energy through administrative and spatial planning governance would bring significant influence to bear on the region. This can be achieved by launching a regional grid Clean Energy Initiative to integrate greater amounts of renewable electricity in the Levant.

Climate change magnifies the urgency of raising the priority given to groundwater management and increasing its effectiveness. More frequent or intense drought will increase withdrawal of groundwater while reducing the replenishment of aquifers. The consequences of inaction in dry, groundwater-dependent regions will be stark, with potentially irreversible aquifer compaction, lowering of groundwater levels and loss of storage capacity.

Groundwater cannot be invisible in the 2030 development agenda. It is vital to combating water scarcity, and hence the ultimate success of the Sustainable Development Goals. In the Middle East, regional cooperation on groundwater management will be key to this agenda, as well as to overcoming instability and humanitarian crisis in our hydro-insecure region.

I encourage everyone committed to building a sustainable and water secure future to use this book, to promote its message that stopping the over-exploitation and pollution of groundwater is urgent. SPRING presents concepts, tools and strategies that make sustainable groundwater management achievable.

SPRING shows us how to treat groundwater like treasure.

HRH Prince El Hassan bin Talal
Chairman of The WANA Institute

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I am deeply grateful to all of the authors who have contributed to SPRING. Production of the book suffered a series of delays after 2011. I thank each of them for their extreme patience and for their kind and professional support when I was at last able to finalise editing of SPRING in 2016.

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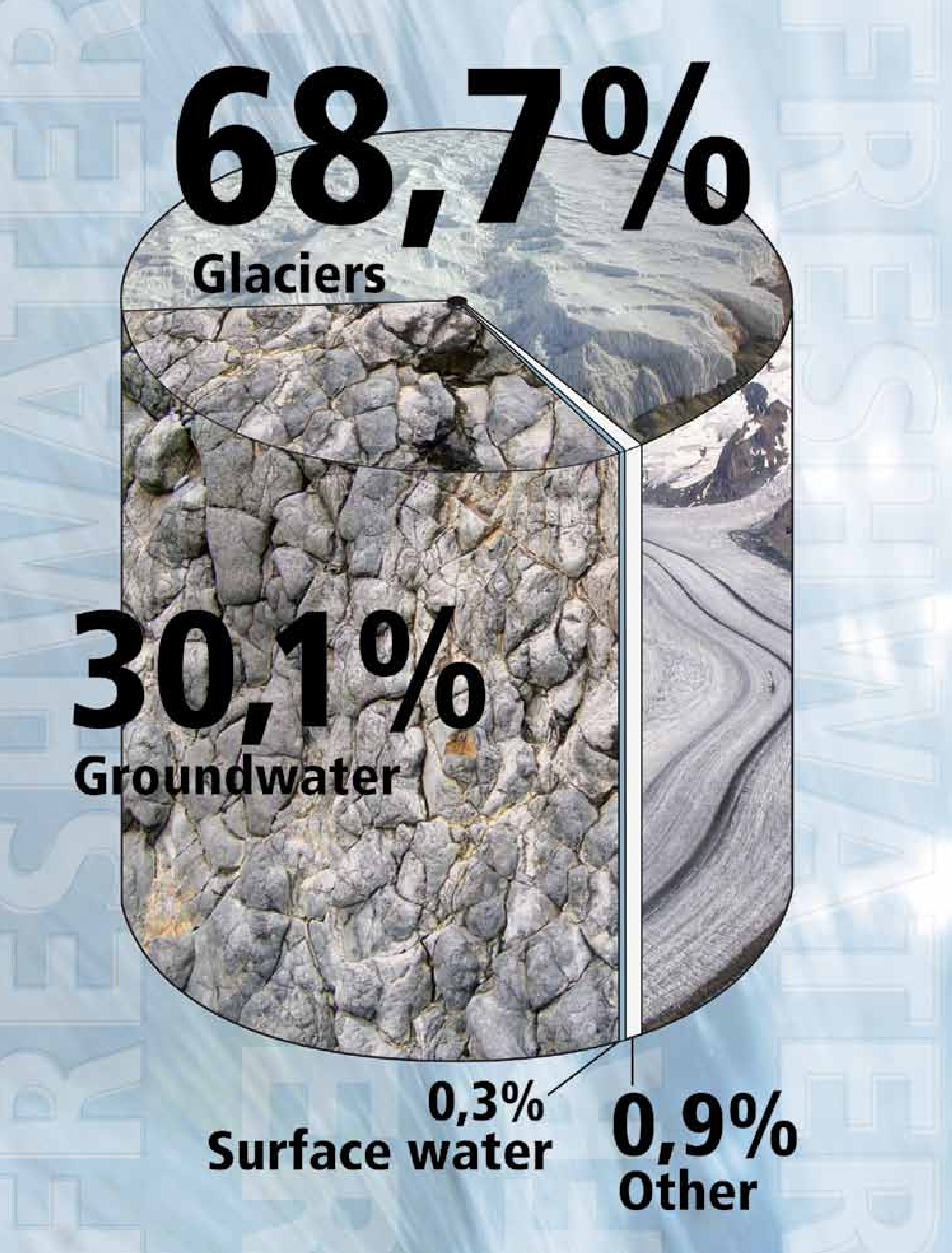
Lastly, there was a substantial delay between initial drafting of the chapters in 2010-2011 and final publication in 2016. Authors were able to provide updated information in final revisions to chapters, but responsibility for any gaps that readers find in recent information is solely mine.

Mark Smith
Lead Editor


68,7%
Glaciers
30,1%
Groundwater
0,3%
Surface water
0,9%
Other

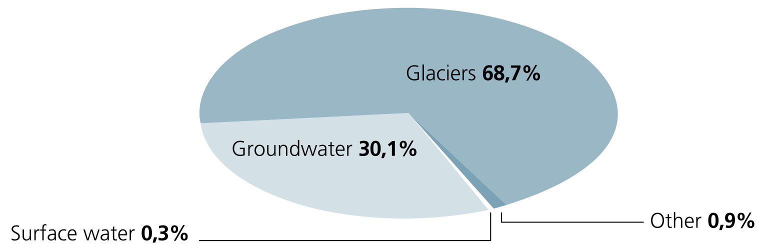
Chapter 1

Groundwater Challenges and Risks

1.1 The Urgency for All of Sustainable Groundwater Management

Hydrogeologists – the scientists who specialise in the study of groundwater – like to remind people that most of the world's available freshwater is stored underground. Dams, reservoirs and irrigation are top of the priority lists for water infrastructure development. Rivers, wetlands and lakes provide the images used to motivate freshwater conservation. Watersheds and river basins are the primary targets of integrated water resources management. Yet, hydrogeologists elicit almost unfailing surprise when they state that fully 96% of freshwater, excluding frozen water in glaciers, is stored as groundwater (Figure 1.1). It is the most abundant source of freshwater on Earth.[1] Because it is unseen and hidden below ground, however, groundwater is the poor cousin of surface water resources. Groundwater is not given the priority and does not receive the attention needed to ensure that the benefits it provides worldwide to human societies and to ecosystems will be sustained.

Figure 1.1 The distribution of freshwater on Earth[2]



"FULLY 96% OF FRESHWATER, EXCLUDING FROZEN WATER IN GLACIERS, IS STORED IN GROUNDWATER."

The total volume of fresh groundwater stored on Earth is estimated to be between 8 and 10 million km3. Total abstraction of groundwater worldwide in 2010 was approximately 1000 km3 per year, or approximately 26% of all freshwater withdrawals globally.[3] Of all groundwater abstracted, 67% was used for irrigation, 22% for domestic purposes and 11% for industry (see Table 1.1).[4] Groundwater provides almost 50% of all drinking water worldwide and 43% of all consumptive use of water for irrigation in agriculture. An estimated 2.5 billion people rely solely on groundwater for drinking water supply.[5] Groundwater use and quality is intimately tied to the health of human populations, their livelihoods and food security and to national economic development and prosperity. With hydrological interactions between groundwater and rivers and wetlands, the health of many aquatic ecosystems is dependent on the condition and functioning of aquifers.[6] Failure to manage groundwater sustainably puts at risk massive benefits for human well-being, sustainable development and biodiversity conservation.

Table 1.1 Estimates of global groundwater abstraction[7]

Continent	Groundwater Abstraction					Compared to Total Water Abstraction	
	Irrigation km³/y	Domestic km³/y	Industrial km³/y	Total km³/y	Total %	Total water abstraction km³/y	Share of groundwater %
North America	99	26	18	143	15	524	27
Central America & the Caribbean	5	7	2	14	1	149	9
South America	12	8	6	26	3	182	14
Europe (incl. Russian Federation)	23	37	16	76	8	497	15
Africa	27	15	2	44	4	196	23
Asia	497	116	63	676	68	2257	30
Oceania	4	2	1	7	1	26	25
World	**666**	**212**	**108**	**986**	**100**	**3831**	**26**

Groundwater resources are under pressure. Global abstraction of groundwater has at least tripled over the last 50 years and continues to increase at an annual rate of between 1 and 2%.[8] Groundwater levels declined in 21 of the world's 37 largest aquifer systems between 2003 and 2013.[9] However, groundwater abstraction is not evenly distributed and is concentrated especially in the arid and semi-arid regions of the world where population growth and expansion of irrigated agriculture have led to rapid growth in water demand. Over-exploitation of groundwater reserves has caused groundwater levels to decline significantly in major aquifers such as:

- the California Central Valley and the High Plains aquifer system of the United States
- the aquifers of the Upper Guadiana basin of Spain
- the Western Sahara and the Nubian Sandstone aquifer systems of North Africa
- aquifers of the Arabian peninsula and the Levant
- aquifers of the Indus and Ganges basins and of Central and Southern India
- the North China Plains aquifer, and
- the Great Artesian Basin of Australia.

"GROUNDWATER RESOURCES ARE UNDER PRESSURE."

Falling groundwater levels in regions such as these are a warning that rates of abstraction are not sustainable. For example, groundwater levels across the High Plains aquifer, which supplies irrigation water to high-value agriculture across 450,000 km^2 stretching from South Dakota to Texas in the United States and drinking water for 2.3 million people, have fallen by an average of 4.3 m. In some locations, groundwater levels have dropped by 60 m. Severe decline of groundwater levels is similarly occurring in other regions of the world that are critical for global food security, including the North China Plains, the Indian states of Rajasthan, Gujarat, Punjab, Haryana and Andhra Pradesh and Eastern Australia.[10] Such decline increases the cost of groundwater while reducing stream flows and causing the degradation of riparian and wetland ecosystems. It threatens the long-term viability of the irrigation-based economies of these regions and therefore creates long-term risks for global food security. Over-exploitation of groundwater as well as contamination because of pollution or salt-water intrusion, threatens drinking water supply for hundreds of millions of people. Degradation of groundwater resources also reduces buffering of drought and water scarcity provided by underground water reserves, which are critical for sustaining ecosystems, and hence conserving biodiversity, and for climate change adaptation and resilience.

1.2 Groundwater for Sustainable Development

As a hidden resource, the importance of groundwater in social and economic development is easily overlooked. Its value in the economy and in economic development is frequently underestimated when policy makers in governments, business investors or local farmers and communities assume that the springs, wells and boreholes they rely on will continue to supply high quality freshwater, forever. Where these mistaken assumptions continue, the benefits of groundwater for development will be lost.

Where groundwater management is sustainable, its potential contributions cross multiple dimensions of sustainable development. Sustainable groundwater management can ensure climate-resilient supplies of water needed to help meet goals for food security, energy development and access to drinking water. It can supply water for sustainable cities and for industrialisation.

Sustainable groundwater management is key for the conservation of groundwater dependent ecosystems in groundwater discharge areas. Examples are rivers and lakes, wet forests and deep-rooted savanna forests. Marshes, swamps and bogs in peatlands depend on groundwater, and coastal ecosystems such as salt marshes and mangroves can rely on freshwater inflow from groundwater.

Photo 1.1 The Azraq Oasis, Jordan, a groundwater dependent ecosystem threatened by over-abstraction.

Changes to groundwater levels or the timing, quantity or quality of groundwater discharge is a driver of degradation and biodiversity loss in these ecosystems.[11] Sustainable groundwater management is an important part of effective strategies for biodiversity conservation where ecosystems depend on groundwater.

Ecosystems are also important in groundwater recharge areas. For example, changes in vegetation cover for rangelands and forests, or shrinking of wetlands can reduce the amount of water entering an aquifer. In groundwater recharge areas, good management of ecosystems is needed for sustainable groundwater management. The relationship between groundwater and ecosystems thus works both ways, and groundwater management and ecosystem management overlap. Working together, they underpin the continuing availability of the ecosystem services from groundwater and from groundwater-dependent ecosystems. Benefits for people secured through management of ecosystems associated with groundwater include for example water supply, water filtration, fisheries, tourism amenities and agricultural production.

"GROUNDWATER MANAGEMENT IS KEY TO THE CONSERVATION OF GROUNDWATER DEPENDENT ECOSYSTEMS."

1.3 Groundwater Management: Need for Change

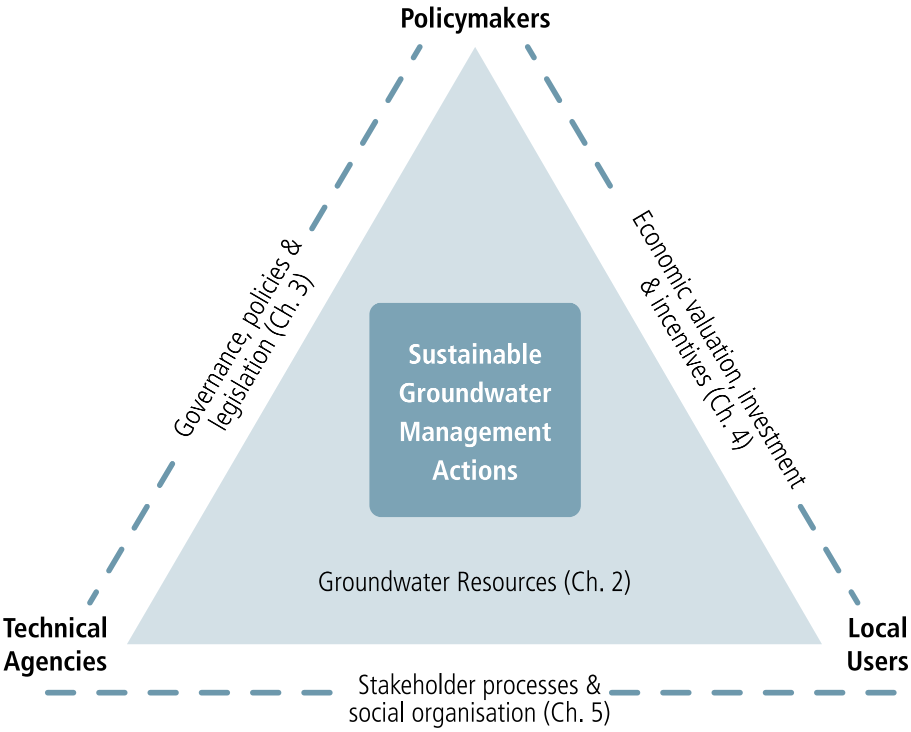
The chapters of SPRING build a change agenda for groundwater management. SPRING is a guide for how groundwater users and managers, hydrogeologists, advocates for sustainable groundwater management and policy makers (among others) can put in place the tools and steps needed for a transition from business-as-usual, over-exploitation of aquifers to sustainable groundwater management. SPRING provides practical guidance on the roles these groups should play, and how they can work together in coalitions, to translate the 2016 *Global Framework for Action to Achieve the Vision on Groundwater Governance*[12] into effective change processes.

"THE NEED FOR ACTION IS URGENT."

The structure of SPRING lays out the principles for and actions needed to implement a collaborative approach to sustainable groundwater management (Figure 1.2). Groundwater management is an inter-disciplinary activity that relies not only on expert knowledge of aquifers and their technical specifications, but also on economics, effective policies and legal frameworks. Knowledge in all these areas provides the technical foundations for management actions, good policy and law – including mechanisms for compliance and enforcement – economic incentives and the business case needed to justify investment. Moreover, for groundwater management to be sustainable and to succeed in its objectives, it is fundamental that groundwater users participate in the design of governance, incentive schemes and management interventions – otherwise groundwater management will remain a top-down, technocratic activity with unsatisfactory results. Implementation of good management can only succeed if groundwater users themselves agree to implement the actions required. SPRING therefore also provides guidance on processes for improving social organisation and stakeholder participation in groundwater management. Finally, SPRING provides guidance on how to mobilise implementation. The chapters of SPRING are organised as follows:

- Chapters 2 - 4 – principles and foundational tools (hydrogeological, governance, economic)
- Chapter 5 – how to organise groundwater users to use and apply knowledge, and
- Chapter 6 – guidance on how to catalyse and mobilise change processes.

Figure 1.2 Collaborative model for sustainable groundwater management, in which actors work together to apply tools to catalyse and implement groundwater management actions



Achieving sustainable groundwater management demands that local groundwater users, technical specialists and policy makers work together (Figure 1.2). Each has a role to play, whether at local, basin, national or international levels, in driving the necessary change strategies, but also in working collaboratively to implement the tools and actions needed. The paradigm for groundwater management of the past, which has favoured control by technical agencies, has to change if groundwater is going to meet expectations of its contributions to sustainable development, biodiversity conservation and climate change resilience.

The need for action is urgent. The pressures on groundwater are creating accumulating costs and risks for societies and for ecosystems that are evident in, for example, lack of access to safe water, land degradation, loss of rural livelihoods, climate vulnerability and biodiversity loss. SPRING outlines how different actors, from local groundwater users and technicians to scientists and policy makers can work together, practically, to implement multi-actor, collaborative and participatory strategies for catalysing and managing the changes needed for sustainable management of groundwater.

Chapter 2

Groundwater Systems

2.1 Groundwater Knowledge: The Starting Point for Management Solutions

Groundwater is a vulnerable resource. As schemes are developed to pump out huge quantities of water, and with the advent of particularly persistent contaminants, the resource needs to be protected and managed (see Table 2.1). Despite groundwater's pivotal role in sustaining ecosystems and providing water supply, the resource is still poorly understood, and hence poorly managed, in many parts of the world. When things go wrong, the damage can be lasting or even permanent. For example, over-pumping and continuous long-term contamination by urban effluents and agricultural practices in the Gaza Strip has led to some groundwater becoming unfit for drinking or agricultural use. Even if pumping and contamination stopped today, it would take hundreds of years for the contaminants and intruding saline water to be flushed out of the groundwater system. Some groundwater resources were accumulated aeons ago and are no longer replenished (e.g. many of the sandstone aquifers of North Africa), thus using them is similar to mining non-renewable minerals.

If groundwater systems were all alike, their management would be simple. However, groundwater systems vary tremendously, which means they respond differently to pressures and, therefore, require different management solutions.

A vital starting point for improving management of groundwater is to develop a technical understanding of how groundwater systems work. For example:

- what types of rocks make good aquifers
- why some aquifers are naturally recharged while others are not
- how to determine how much water can be sustainably taken from an aquifer, and
- which types of aquifers are at most risk of pollution.

With this type of knowledge, and supported by effective monitoring, communities and groundwater managers can develop reasonable visions and plans for groundwater management and identify management actions needed.

Table 2.1 Advantages and limitations of using groundwater for water supply[13]

Advantages of groundwater	Limitations
• Groundwater is often available close to where it is required	• Groundwater is not ubiquitous and considerable effort may be needed in some situations to locate suitable sites for boreholes
• Groundwater can be developed relatively cheaply and progressively to meet demand with lower capital investment than many surface water schemes	• As overall coverage increases, the more difficult areas which are left can become more costly to supply
• Groundwater generally has excellent natural quality, and is usually adequate for potable supply with little or no treatment	• Natural quality constraints such as high fluoride and arsenic occur in some areas
• Groundwater generally has a protective cover provided by the soil and unsaturated zone	• As development increases more rapidly, pollution can exceed the capacity of the soil to attenuate contaminants
• Groundwater is generally available during times of surface water drought	• As demand for groundwater increases overexploitation of the resource can occur; climate change may reduce recharge in some areas

2.1 How Groundwater Works

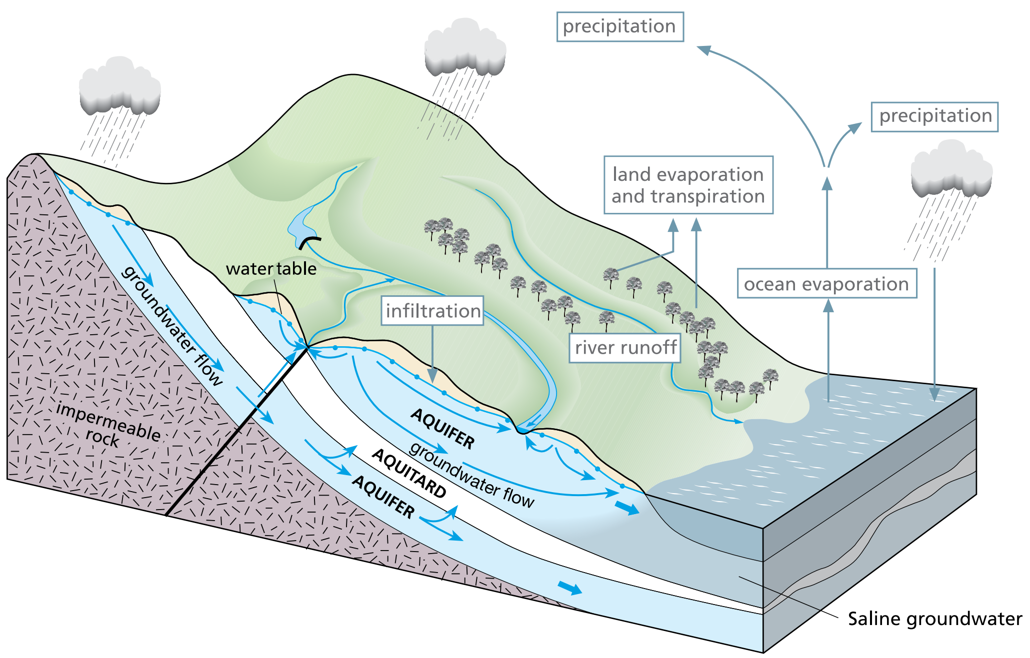
2.1.1 Groundwater systems

Understanding how to identify and diagnose groundwater problems requires a basic understanding of the Earth's natural hydrological cycle, of which groundwater is an integral, but often neglected, part (see Figure 2.1). The cycle, driven by the energy of the sun, takes water from the land and the oceans and transfers it through the atmosphere back to the oceans through various routes. When rain falls onto the land surface, some of it infiltrates into the soil with the remainder evaporating or running off into rivers. Most water stored as soil moisture is either taken up by plant roots and moved up through their leaves where it transpires back into the atmosphere, or it flows quickly (a few days to years) into a river.

"GROUNDWATER HAS A VITAL ROLE IN SUSTAINING AQUATIC ECOSYSTEMS."

However, some of the water infiltrates the soil more deeply, eventually accumulating above an impermeable layer, saturating any available porous space in rocks and forming an underground aquifer. An *aquifer* is a saturated underground layer of water-bearing permeable rock or unconsolidated materials (gravel, sand, or silt). The groundwater flows slowly (years, decades, even millennia) by gravity through pores and fractures in the rock to eventually discharge into springs, rivers, lakes, or the sea. Figure 2.1 shows a shallow aquifer above a semi-permeable layer (an aquitard) and a deeper aquifer between the aquitard and a layer of impermeable rock.

Figure 2.1 Groundwater's place in the wider hydrological system[14]

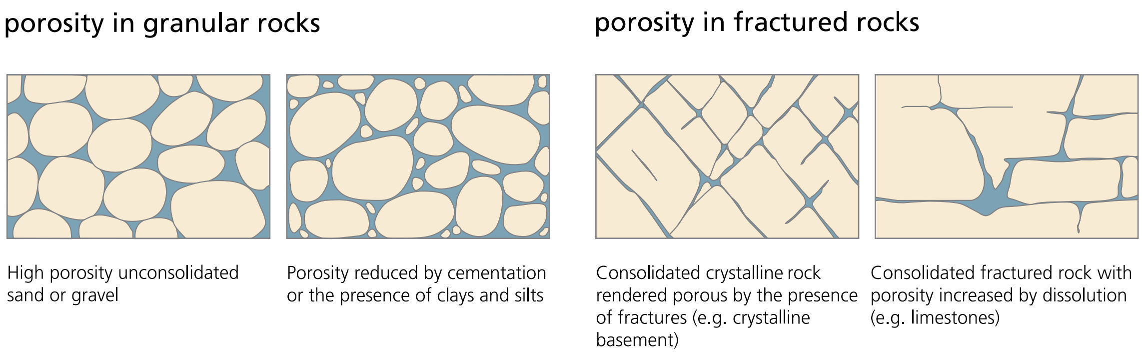


Groundwater has a vital role in sustaining aquatic ecosystems. It provides a reliable year-round discharge to streams, rivers, and wetlands sustaining flows through dry seasons and droughts. In some lowland catchments, groundwater can account for more than 90% of river flow during dry periods. Even in upland catchments, where groundwater storage is limited, 30% of the river flow may have passed through rocks as groundwater.

2.1.2 Aquifers and groundwater storage

Although some groundwater can occur in underground lakes in caves or major cavities, the vast majority is stored within pore spaces and fractures in rocks. The rock characteristics (see Figure 2.2) determine the storage capacity and productivity of an aquifer. Rocks with many voids that can hold water are said to be *porous* and if the pores and fractures are joined so water can flow easily, the rocks are said to be *permeable*. Unconsolidated granular sediments, such as sands or gravels are highly porous and the water content in these aquifers can exceed 30% of their volume. Porosity progressively reduces both with the proportion of finer materials (such as silt or clay) and with consolidation of sediments into solid rock under pressure. In highly consolidated sedimentary rocks, the porosity may be less than 10%. The least permeable sedimentary rocks are clays, which generally do not allow groundwater to move through them, and therefore act as barriers to groundwater movement. Some sedimentary rocks (such as limestones) are soluble. In soluble rocks, fractures may become enlarged as the groundwater slowly dissolves the rock to form fissures and caverns, where groundwater can flow rapidly in discrete 'underground rivers'.

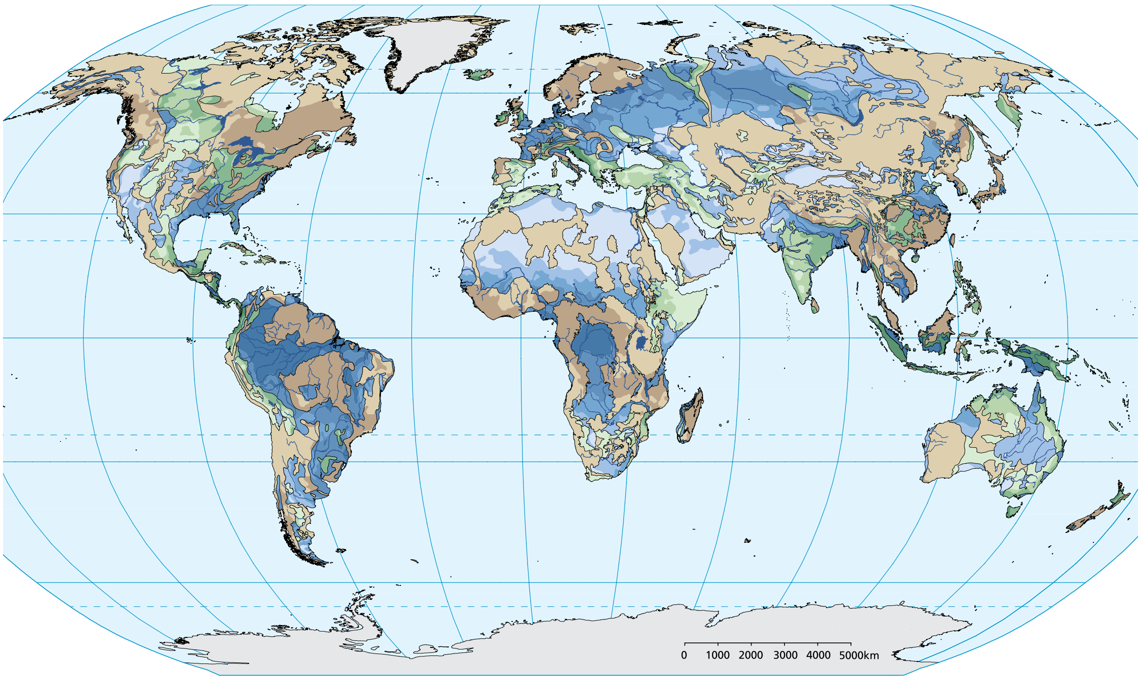
Figure 2.2 Rock texture and porosity for typical aquifers[15]



In crystalline rocks, such as igneous and metamorphic rocks, groundwater is found only in fractures and rarely exceeds 1% of the volume of the rock mass. These rocks are common; for example, they cover approximately 34% of the land area of Africa. Fortunately, these rocks are often weathered to a depth of 20 meters or more to form a deep soil with groundwater stored in the resulting sands, gravels, and decomposed rock. In unweathered crystalline rocks, groundwater will be found only in areas that are fractured.

The deeper they are in the Earth, the more compression rocks undergo from the weight of the rocks and soil above them and the more their pores and fractures close up. It is not known how deep usable groundwater can be found, but it is thought that about 1 km is the usual limit. For most uses, only shallow groundwater is exploited, but increasingly there are examples of its extraction for high-value uses to depths of 150-500 m. A global map of the major aquifer types is shown in Figure 2.3.

Figure 2.3 Map of groundwater resources of the world showing major groundwater basins (blue), areas with complex hydrogeological structures (green) and local and shallow aquifers (brown)[16]



"RECHARGE WATER TYPICALLY TRAVELS VERTICALLY DOWNWARD THROUGH THE UNSATURATED ZONE TO THE WATER TABLE"

2.1.3 Recharge and renewability

Groundwater is normally recharged by precipitation (i.e. rainfall and snow-melt), but in some topographic settings it can also be recharged by seepage from rivers, lakes, or canals. In arid climates, recharge from precipitation becomes less significant than seepage from riverbeds and ephemeral streams. The recharge water typically travels vertically downward through the unsaturated zone to the water table, the level at which the groundwater pressure head is equal to atmospheric pressure. Once below the water table, groundwater flow is predominantly horizontal, according to pressure gradients, and eventually reaches depressions in the land surface (see Figure 2.4), where it discharges, usually into a stream, spring, or wetland. In effect, the aquifer becomes saturated to a level at which the outflow matches the recharge.

Figure 2.4a shows groundwater recharge, flow, and residence times for a typical sedimentary aquifer in a region with a humid-temperate climate, where rainfall above 700 mm ensures significant annual recharge. The groundwater has a relatively rapid shallow circulation and discharges into rivers as well as into a deeper level of groundwater, which is under pressure. This lower portion of the aquifer system is geologically confined and isolated from the surface, and contains much older, essentially non-renewable, groundwater.

Figure 2.4 Groundwater flow regimes in present-day (a) humid and (b) arid regions[17]

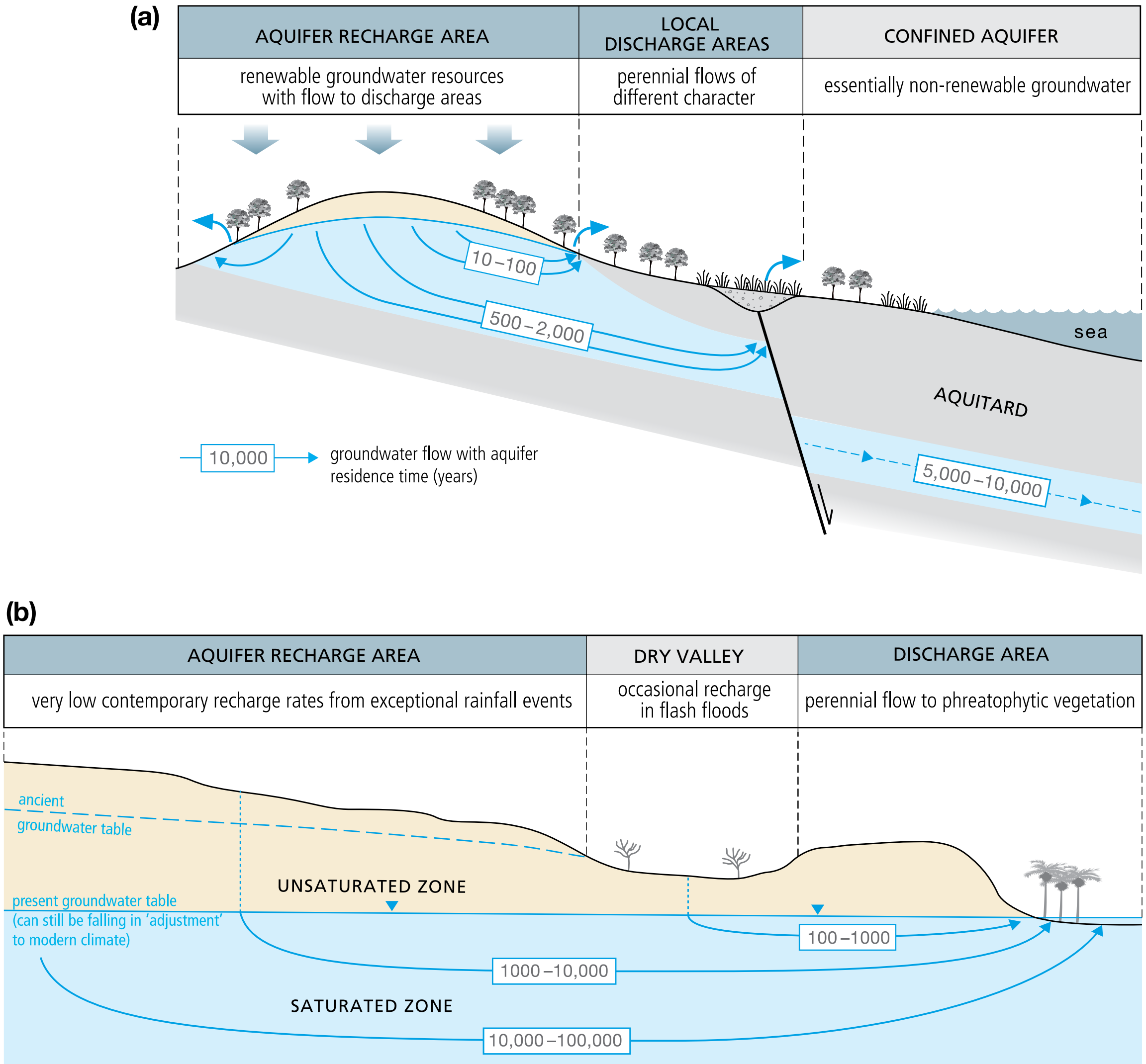


Figure 2.4b shows the corresponding situation in a region with a hyper-arid climate (rainfall below 200 mm per year). Most groundwater (except a very small local component originating in a dry valley) is extremely old (having infiltrated in past episodes of much wetter climate), but is still slowly flowing to an oasis discharge area. Note that the groundwater has been lowered from the ancient groundwater level to the present level by natural discharge of groundwater, which is not now replaced by rainfall. Note that at the higher ancient groundwater level, the dry valley was an oasis.

The proportion of rainfall that becomes groundwater recharge is determined by the soil characteristics and vegetation. Where the soil is poorly permeable or the vegetation requires much water, groundwater recharge is limited. The intensity of the rainfall can also have an effect. Recent evidence indicates that infrequent but large, high-intensity rainfall events are important for recharging aquifers, particularly in semi-arid areas.

In some cases the relationship between groundwater and surface water bodies can change. Historically, Las Tablas de Daimiel wetlands in central Spain were supplied with water by upwelling from the underlying aquifer. Following major groundwater pumping to support irrigated agriculture, the water table fell and water reaching the wetlands from rainfall and river flow percolated downwards to the aquifer, thus altering the interaction from one of groundwater discharge to groundwater recharge.

"AS WATER IS ABSTRACTED, USUALLY BY PUMPING, GROUNDWATER LEVELS FALL."

As noted earlier, most groundwater is actively recharged, thus it is a renewable resource. The manager's task is to figure out a way to 'harvest' it sustainably. However, some aquifers have little or no recharge. Their current groundwater is from rainfall from a wetter period – maybe 5,000 or 10,000 years ago (see Figure 2.4). Such groundwater – sometimes called 'fossil groundwater' – is not renewable under current conditions. Major areas of he world with essentially non-renewable groundwater include much of northern Saharan Africa, the Middle East and Central Asia. In the Sahara desert, for example, deep groundwater was formed when rainfall was higher during high-latitude glaciations.

As water is abstracted, usually by pumping, groundwater levels fall, making room in the aquifer for recharge. If abstraction is less than recharge, natural discharge to springs and rivers will achieve a new equilibrium. The time taken for this transition depends on a number of factors and may be

Photo 2.1 Groundwater, seen down a well.

decades or hundreds of years. If abstraction is greater than recharge, water levels will continue to decline as the volume of stored groundwater is diminished. Thus a good knowledge of the aquifer recharge rate, water level variations, and abstraction regime is fundamental to any management of groundwater resources.

Groundwater in aquifers can be under pressure. When a well is drilled in an aquifer under pressure, water will rise above the top of the aquifer and sometime even above the ground surface, so that no pumping is needed (these are called artesian wells). Pressurised water is usually found in aquifers *confined* between semi-permeable or impermeable layers. Shallow aquifers in recharge areas are generally *unconfined*, and the groundwater is at atmospheric pressure. An unconfined aquifer recharges more quickly. A confined aquifer has a longer recharge time. It may be less prone to pollution, but if polluted, especially with long-lived contaminants, it may not be able to recover in the foreseeable future.

2.1.4 Groundwater, rivers, and ecosystems

Groundwater is intimately linked to rivers, wetlands, and lakes and helps sustain many important aquatic ecosystems. In humid areas, groundwater generally discharges to rivers, sustaining their baseflow and aquatic ecosystems (see Figure 2.6). In more arid areas, the relationship is more complex and rivers often lose their water to the groundwater system. This loss can occur in many ways, for example: seepage through the base of large perennial rivers, the periodic infiltration of water from ephemeral rivers or wadis, or flood events recharging floodplain aquifers.

> *"GROUNDWATER-FED AQUATIC ECOSYSTEMS CAN BE GOOD INDICATORS OF THE HEALTH OF AN AQUIFER."*

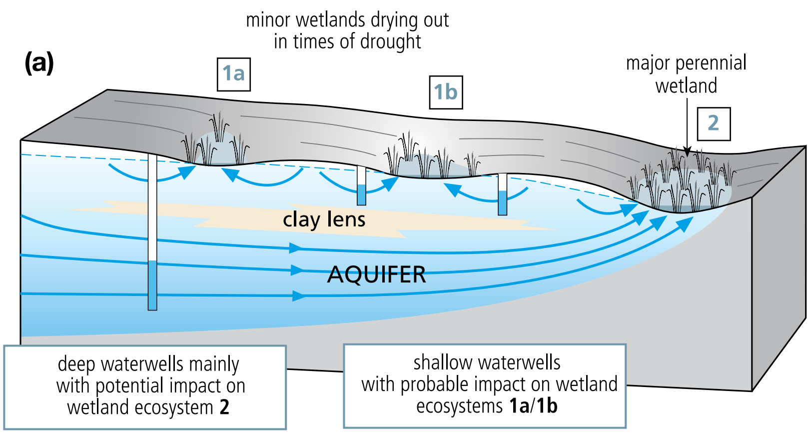
Groundwater-fed ecosystems tend to exhibit slow changes in flow or water level, called the hydroperiod, giving rise to specific plants and animals that thrive in stable water regimes, such as in chalk rivers or fens. In these ecosystems, groundwater tends to be at constant temperature (e.g. 10-11°C), usually warmer than surface fed rivers in winter and cooler in summer. Thus, lowland groundwater-fed rivers can support fish, such as salmon, normally found in cooler mountain rivers. Differences in groundwater chemistry, such as high pH in chalk rivers, also support unique flora and fauna. Groundwater-fed aquatic ecosystems can also be good indicators of the health of the aquifer in terms of both water quantity and quality. In particular circumstances, groundwater supports unique or endemic species such as stygobites (e.g. *Niphargus glenniei* - small shrimp-like crustaceans) and Blind Cave Fish (*Astyanax mexicanus*) in Mexico. In desert environments, groundwater may be the only source of water and groundwater-fed oases often include highly productive aquatic ecosystems that provide crucial natural resources and ecosystem services for people, such as fish and grazing lands, within surrounding arid environments. Evaporation is often very high from these areas, but the overall volume of water tends to be low because of their small spatial extent.

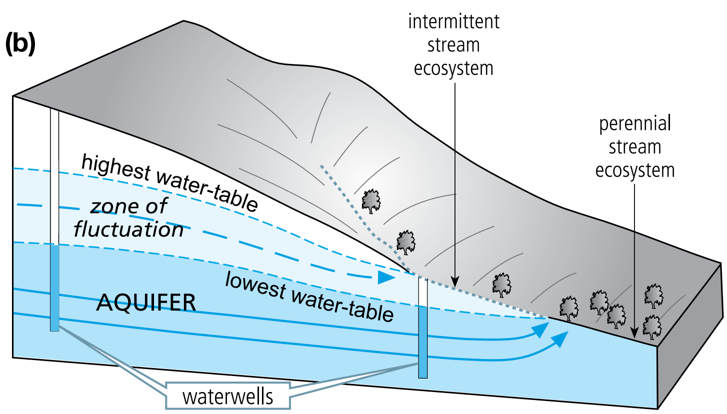
Wetland ecosystems can depend on groundwater that flows from different depths, and thus the depth of a well from which water is pumped can determine the impact on a wetland. Figure 2.5a shows how shallow wells might pump water away from minor wetlands in surface depressions, whereas over-abstraction from a deep well, even far from a major perennial wetland, could seriously affect the water levels in that wetland. Figure 2.5b shows how pumping from deep wells, again far from the ecosystem, can cause a fluctuation in the water table that causes part of the stream to dry up periodically.

Irrigation can enhance groundwater and surface water interaction: surplus water from irrigated fields leaches into the groundwater; leaky canals or pipes can also recharge aquifers. This leakage is not always beneficial to groundwater as it can lead to an increase in groundwater salinity, which, if not diagnosed and controlled, will result in a serious decline in agricultural productivity. There are several distinct mechanisms by which irrigation water can affect groundwater: (1) canal seepage can cause the water table to rise (this can also occur from rivers); (2) irrigation water can leach through the soil picking up salts, which increases the salinity of groundwater; and (3) over-abstraction can lower the water table and allow saline water from an estuary or ocean to flow 'backwards' into the aquifer.

Figure 2.5 Ecosystem dependence on groundwater for (a) wetlands associated with a multi-layered aquifer in a humid area and (b) a stream in an arid area.[18]

In (a) the potential impact of waterwell abstraction depends on the depth and level of water intake. In (b), with the upper stream fed in part by intermittent groundwater flow and the lower stream by perennial discharge, the impact of waterwell abstraction will depend on distance from the stream, period of pumping and aquifer characteristics.

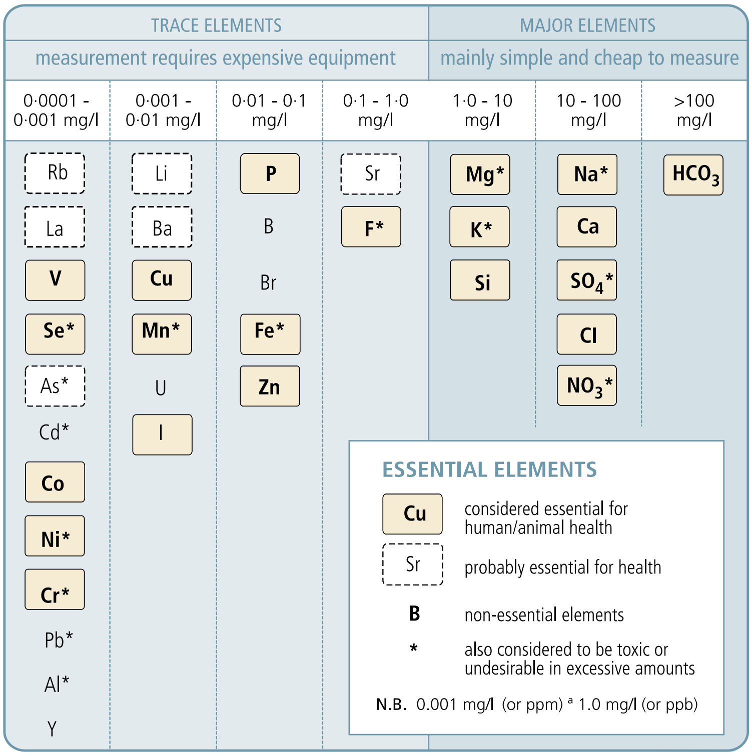




2.1.5 Groundwater chemistry

Most groundwater has excellent natural microbiological quality and adequate chemical quality for most uses. Indeed many people buy (at great expense) bottled water from natural groundwater sources in preference to public supplies, which may be treated river water. Nine major chemicals (sodium, calcium, magnesium, potassium, bicarbonate, chloride, sulphate, nitrate, and silicon) make up 99% of the solute content of natural groundwater. The proportion of these chemical constituents in the groundwater reflects the geology and history of the groundwater flow. Minor and trace constituents make up the remaining 1%, and their presence (or absence) locally can give rise to serious health problems or make the water unacceptable for human or animal use (Figure 2.6).

Figure 2.6 Chemical constituents naturally found in groundwater[19]



"PROBLEMS OCCUR WHERE RECHARGE WATER CARRIES CHEMICAL POLLUTANTS."

Groundwater can become contaminated if protective measures at wells, boreholes, or springs are not soundly constructed and maintained. Further problems occur where recharge water carries chemical pollutants from agriculture, waste disposal, or industry. Thus, it is essential to assess these risks and also test groundwater supplies used for drinking to make sure they meet health standards. It is also essential for water managers to appreciate that groundwater quality in an aquifer is not uniform, and important variations in both natural quality and levels of contamination occur vertically as well as horizontally (see Figure 2.7).

Two natural constituents — arsenic and fluoride — are of particular concern to health. One of the most dramatic demonstrations of this is the arsenic crisis in South Asia (notably Bangladesh, India-Bengal and the Nepal terai), where shallow boreholes constructed to supply safe drinking water often provided water with naturally high arsenic concentrations (see Figure 2.7). Arsenic is a poison that can cause skin cancers and gangrene among other ailments. Natural fluoride in groundwater is of growing concern with more than 200 million people at risk of drinking water with elevated concentrations. High exposure to fluoride can lead to severe dental problems, and even higher concentrations can cause skeletal fluorosis, which limits mobility and can be crippling.

Figure 2.7 Stratification of groundwater and arsenic (As) contamination in the alluvial flood plains of Ganges-Brahmaputra delta in Bangladesh and terai of Nepal[20]

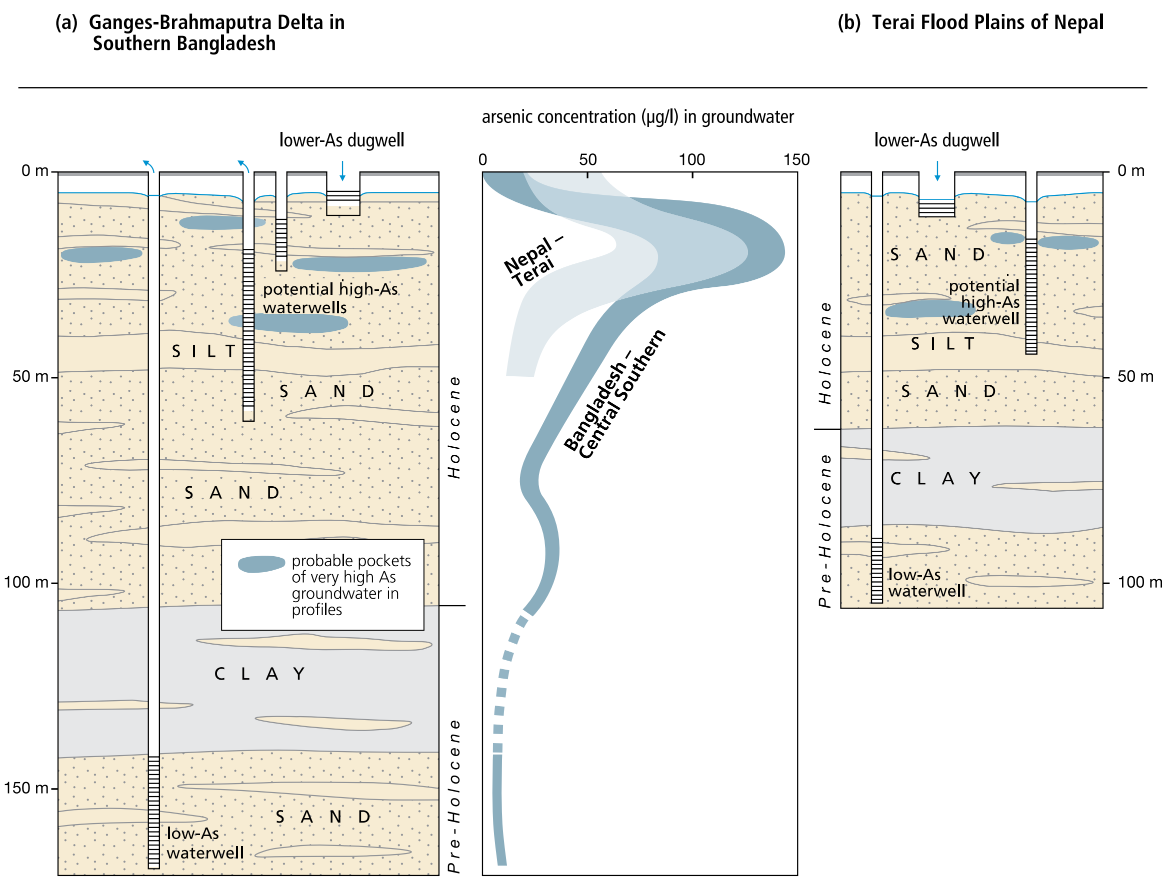


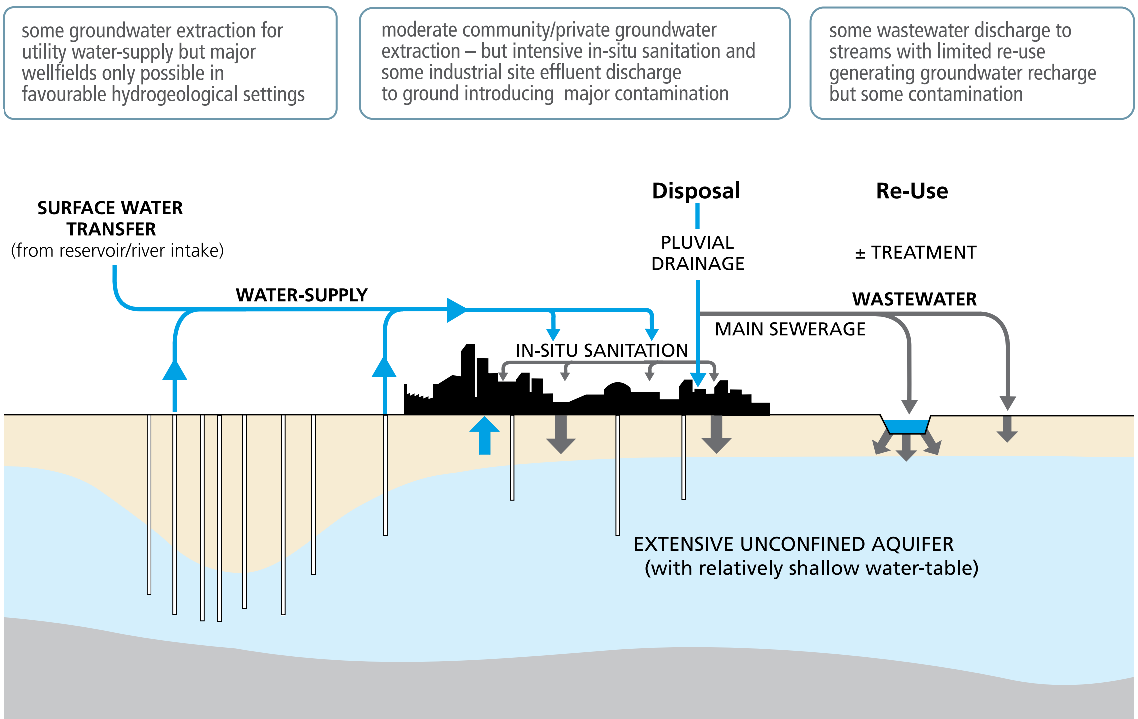
Figure 2.7 shows high concentrations of soluble arsenic occurring at a depth of 5 to 30-40 meters below ground level as a result of natural variations in the hydrochemistry in the aquifer. Drilling deeper wells bypasses the pockets of arsenic-laden water and provides safe drinking water (at greater expense). However, over time, arsenic contaminated water may be drawn down to the deeper layers by pumping.

2.2 Threats to Groundwater: Overuse and Pollution

2.2.1 Drivers of groundwater degradation

The two major threats to groundwater are overuse and pollution. Urbanisation, industrialisation and intensification of farming practices have led to an escalating demand for groundwater as a reliable source of water supply. This situation has been complicated by rapid population growth and climate-change pressures. These practices can also produce a high contaminant load, which is often released into the natural environment and ultimately contaminates groundwater. The scale of perturbation to the natural groundwater system under a large urban area is illustrated in Figure 2.8. Different groundwater systems react differently to these threats. Managers need to know not only the threats, but the susceptibility and vulnerability of the groundwater system in question. Figure 2.9 shows a city in which some groundwater is used in conjunction with surface water for the water supply. Discharge of some wastewater and industrial chemicals cause contamination of both groundwater and streams. Intensive on-site sanitation, with waste discharged to ground can cause major groundwater contamination.

Figure 2.8 The close relationship between groundwater and urbanisation[21]



2.2.2 Impacts of overuse

Intensive abstraction can deplete the groundwater in an aquifer. A lower water level increases pumping costs at the very least, and can cause serious damage by allowing intrusion of saline water into the freshwater system or even land subsidence if the tiny voids previously filled with groundwater are compressed and cave in. These effects can take several decades to manifest themselves and can be irreversible. Falling water tables can reduce the yield of shallow wells, or even cause them to fail, if the groundwater level falls below the bottom of the well. In some susceptible systems, even a small drop in the groundwater level can have a major impact on the flow of springs or the health of wetlands, as the natural discharge of groundwater reduces to accommodate the abstraction.

"INTENSIVE ABSTRACTION CAN DEPLETE THE GROUNDWATER IN AN AQUIFER."

These effects sometimes happen in a limited area (for example around a well) even when overall abstraction is less than overall recharge, because as groundwater flows toward the depression caused by abstraction the hydraulic gradient in the surrounding aquifer is changed. If surrounding (including overlying and underlying) aquifers contain saline or brackish water, this water can flow into the depression, degrading the fresh groundwater. Saline intrusion is most common in coastal aquifers, where salty water from the sea flows inland in response to pumping (Case 2.1). Saline waters can also be found deep in some aquifers, or in arid areas with shallow water tables as a result of direct evaporation.

Case 2.1 Sea water invades Cyprus aquifer[22]

The development of the coastal limestone of south-eastern Cyprus is typical of many islands and coastal areas with highly permeable aquifers. The groundwater table was naturally higher than sea level. However, uncontrolled pumping for irrigation plus the construction of dams that reduced recharge led to a major reduction in the level of the water table. Between 1960 and 1980, water levels in wells had widely fallen to more than 25 m below sea level. Saline water near the sea flowed 'backwards' into the depression leading to major landward intrusion of sea water into the aquifer for several kilometres from the shoreline.

The long-lasting effects can be observed today by many abandoned wind pumps and uncultivated fields close to the shore. One report estimated that it would take 12 years of no pumping to restore the groundwater to its previous levels and then longer to rid the groundwater of nitrate pollution caused by irrigation, which makes most of the groundwater unfit for drinking. Decreased rainfall has caused a reduction in the flow of rivers and aquifer recharge, which combined with over-pumping, has negatively impacted groundwater resources, stretching sustainable extraction levels to the limit.

The country has developed a participatory action plan for river basin management focused on a drastic reduction of pumping to sustainable levels and increasing the recharge with natural and artificial methods, but it will take decades of discipline to restore the resource.

"HOW RAPIDLY A GROUNDWATER SYSTEM WILL DEPLETE DEPENDS ON ITS HYDROGEOLOGY."

Groundwater abstraction reduces the pressure in the aquifer's pore spaces. If the rock is compressible, it can collapse and its ability to hold water, even after recharge, can be permanently reduced. If thick clay layers are present, either as interlayers or as overlying beds, compression can be significant and lead to land subsidence, which, in heavily developed urban or coastal areas, can have severe impacts on infrastructure.

2.2.3 Susceptibility to side-effects of overuse

How rapidly a groundwater system will deplete or how susceptible it is to secondary degradation, such as saline intrusion or land subsidence, depends on its hydrogeology. Table 2.2 details the impacts of excessive abstraction and which hydrogeological factors determine the susceptibility of different aquifers to experiencing these effects.

If symptoms, such as a decline in water quality and well yields, or a deterioration in a dependent ecosystem, have started to appear (see Table 2.2), the hydrogeology must be quickly assessed to predict future deterioration and assess which management options will be most effective. The more quickly a diagnosis can be made, the better. Routine monitoring of water quality, water levels, and ecosystem health are important for early detection of problems.

Table 2.2 Hydrogeological factors affecting the susceptibility of an aquifer to overexploitation

Symptoms of Excessive Abstraction	Hydrogeological Factors Affecting Susceptibility of the System to Excessive Abstraction
• Falling water levels: increased pumping costs; declining borehole yields; drying up of shallow wells; reduction in spring and baseflow	• Aquifer properties: transmissivity and storage coefficient • Annual recharge • Aquifer volume
• Vegetation stress: as groundwater levels fall, some dependant vegetation will become stressed, appearing to wilt or die; wetlands may also begin to dry out leading to significant stresses on the dependant ecosystem	• As above, plus the depth of the groundwater
• Saline water: falling water levels can cause poor quality water to flow into the aquifer – often from the sea, but also from other sources – with symptoms such as change in taste, reduction in crop yields, and increased corrosion, easily measured as change in salt content or electrical conductivity of pumped water	• Proximity of saline or polluted water • Presence of physical and hydraulic barriers
• Loss of aquifer capacity: overuse can cause loss of pressure and compaction of the porous rocks, thus reducing their capacity to hold water, which can lead to reduced well yields	• Aquifer compressibility
• Land subsidence: as groundwater levels fall, some aquifers compress significantly causing land subsidence with corresponding damage to infrastructure	• Aquifer compressibility • Compressibility of overlying and interbedded aquitards • Thickness of aquitards

2.2.4 Pollution processes

Urbanisation, industrialisation, and agricultural intensification can lead to serious groundwater pollution. Some major sources of groundwater pollution are shown in Figure 2.9. Agricultural pollution tends to be widespread across areas with intensive agriculture. It can produce elevated nitrate concentrations from fertilisers and animal waste as well as more exotic compounds from pesticides. Industries can give rise to different pollutants including many different kinds of hydrocarbons and heavy metals. Mining can lead to severe water pollution with elevated concentrations of iron and other metals, acidic water, and a high level of sulphates. Human wastewater can also be a major source of pollution, especially through seepage from on-site sanitation such as latrines and septic tanks, or where sewers exist, through application of the collected wastewater directly to irrigation of crops, which can result in elevated nitrate, chloride, and organic carbon concentration and, in some cases, to faecal contamination of groundwater and even the crops.

"POLLUTION OF GROUNDWATER MAY NOT BE DETECTABLE UNTIL YEARS AFTER THE APPLICATION OF FERTILISERS."

Conceptually, groundwater is at risk of pollution if the natural capacity of the soil, unsaturated zone, or confining layers of an aquifer are not sufficient to contain and attenuate the contaminant load or the pressure applied. Because the movement of water in the ground is often very slow, pollution of groundwater may not be detectable until years after the application of fertilisers or disposal of effluent and it may last well beyond any cessation of the pollution.

Figure 2.9 The range of activities that can generate a subsurface contaminant load and pollution of the underlying aquifer. The blue line represents the water table and the dark grey shading below ground shows the type of groundwater pollution plume that can result in a granular aquifer system.[23]

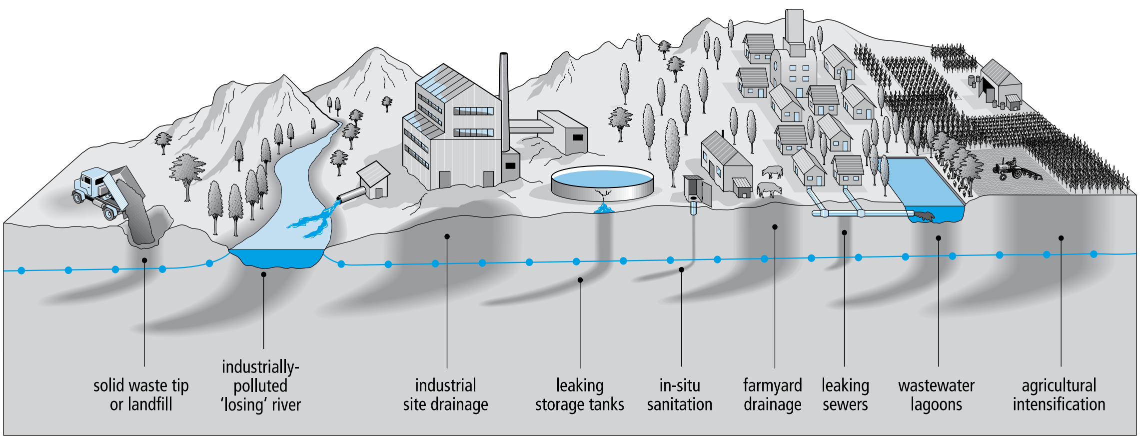


Figure 2.9 shows the range of activities that can pollute groundwater in a shallow aquifer. The figure illustrates the type of groundwater pollution plume that can result in a granular aquifer. If these activities are contemplated, or already exist, in areas with vulnerable aquifer types (see next section), or if the groundwater extracted is used for potable water-supplies, selected pollution control measures should be identified and implemented.

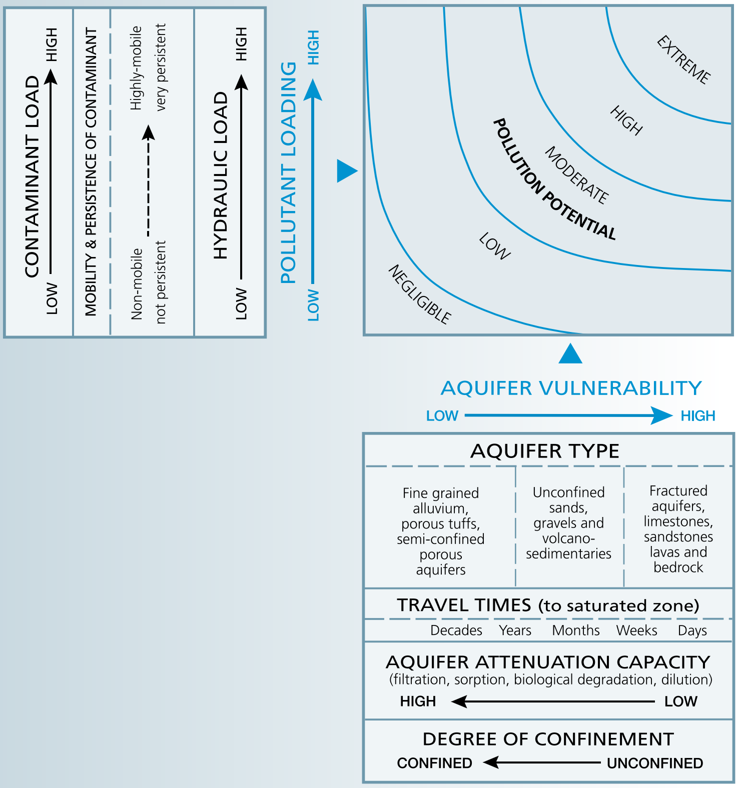
Box 2.1 Determining the vulnerability of an aquifer to pollution

How seriously groundwater is polluted depends on two things: the nature of the pollution and the nature of the aquifer. Figure 2.10 shows how one might consider each on a scale of low to high. The chart "pollution loading" considers three characteristics of pollutants (a) the amount of pollution (level of contaminant load), (b) the mobility and persistence of the pollutant, and (c) the hydraulic load. In general a contaminant load that is at a high level, mobile, persistent, and flushed into the ground is more serious than pollutants that are at a low level, not easily mobilised, not persistent and not driven by a strong hydraulic gradient.

Mobility is governed by geochemical reactions; the prevailing groundwater environment influences which pollutants are mobilised. Mobile contaminants are generally those that are readily soluble in water, such as nitrate, solvents and some light oils. The mobility of metals (e.g. lead, chromium) depends on the pH and redox state of groundwater. Heavy oils are generally not very mobile, and pesticides can be difficult to predict with some types more mobile than others.

Four characteristics impact an aquifer's vulnerability to pollution (Figure 2.10): (a) type of soil and rock, (b) travel time of water through the aquifer, (c) the aquifer's ability to adsorb pollutants, and (d) its degree of confinement. In general, the most vulnerable aquifers are fractured bedrock, with a short travel time (days), show a low ability to filter out pollutants, and are unconfined by semipermeable layers. Aquifers are better able to deal with pollutants if they are made of fine grained materials, have travel times measured in decades, have a high filtration capacity, and are confined by semipermeable layers or aquitards.

Figure 2.10 Influence of pollutant loading and aquifer vulnerability on potential for pollution of groundwater[24]



2.2.5 Vulnerability to pollution

Some groundwater systems are intrinsically more vulnerable to pollution than others. Shallow unconfined aquifers are more at risk of pollution because there are fewer layers to filter out contaminants. For deeper aquifers, the natural subsoil profiles afford protection, and can actively attenuate many water pollutants through biochemical degradation and chemical reactions, as well as retard contaminants that can adhere to the surfaces of clay minerals and/or organic matter (see Box 2.1).

The properties of the strata separating a saturated aquifer from the land surface generally determine the sensitivity of the aquifer to pollution from the land surface. For land management purposes, an intrinsic vulnerability of different aquifer types can be defined and matched with land uses (see Section 2.4.2, below). Some hydrogeologists advocate the use of 'specific vulnerability maps' for individual contaminants (such as nitrates or a pesticides group), but there are rarely adequate data or sufficient human resources to adopt this approach on a routine basis.

2.3 Information Needs for Improving Groundwater Management

Getting good information on groundwater resources is vital for improving groundwater management. This requires using appropriate scientific tools to diagnose and monitor the status of the aquifer system. The best methods for characterizing groundwater systems are described below, followed by an introduction to some technical tools for management, such as groundwater modelling to foresee potential problems, land zoning to help limit pollution, and a range of engineering solutions to mitigate damage that has already occurred.

2.3.1 Groundwater balance

The *water balance* is estimated by comparing the recharge into the aquifer with the natural discharge and abstraction. Unfortunately, this is not a straightforward process, as there can be many discharges and abstraction points, and recharge cannot be directly measured. As a short cut, it is worth trying to put together a history of groundwater level variations, ideally from data obtained by monitoring boreholes over time, which can indicate if groundwater is being steadily depleted over the long term. If historical data are not available, some general information on the state of groundwater resources can be gained from discussions with a variety of groundwater users about their recollections of past situations. Only with some history can a picture be developed of how the system responds to different events over time.

The methods required to develop and test the groundwater balance in an aquifer are shown in Table 2.3. One of the most important steps is to make an inventory of all groundwater abstractions. Without this information, it will be difficult to define and implement effective groundwater management measures. Measuring recharge, the input side of the equation, is complex and data intensive. Recharge can come from diffuse infiltration of excess water through the soil, or in episodic events such as high-intensity rainfall, and can also result from human activities such as excess agricultural irrigation or seepage from water infrastructure in urban areas.

One of the best methods of testing the water balance of an aquifer is to construct a numerical groundwater model (see Section 2.3.3). Creating this model involves applying the recharge and pumped discharge to the *aquifer geometry* with known aquifer properties, and then comparing model-predicted and field-measured groundwater levels and natural discharges. Numerical models are an excellent tool for understanding and prioritising what additional information needs to be collected.

Table 2.3 Methods for assessing groundwater conditions

Purpose	Method	Requirements
• Estimate discharge	• Inventory of boreholes/wells/springs • River gauging	• Locate every major abstraction and gain current abstraction details and pumping patterns. Search for historical information • Analyse existing stream gauge data to assess groundwater baseflow. If none exists, use ungauged catchments methods and consider installing monitoring
• Estimate recharge	• Soil moisture balance, or threshold methods for more arid areas • Chloride balance method • Residence time indicators	• Daily rainfall, evapotranspiration and soil and vegetation information • Measure chloride in uncontaminated groundwater and compare with rainfall (particularly effective in arid areas) • Stable isotopes or dissolved gases used to indicate the residence time of groundwater
• Assess water levels	• Measure groundwater levels in unpumped wells	• Monitoring of water levels in the aquifer, not in individual pumped boreholes
• Test water balance	• Analytical equations • Groundwater model	• Water balance assessed simply by balancing discharge, recharge and changes in storage • Much more robust assessment of aquifer understanding and water balance, but time, and data intensive
• Assess water quality	• Water quality survey	• Survey of the groundwater quality from boreholes, wells and springs, with rigorous sampling and analysis to distinguish pollution or saline intrusion from natural geochemical changes

2.3.2 Groundwater quality

Characterising groundwater quality is more straightforward than estimating the water balance, but requires detailed and systematic sampling. A survey of pumping boreholes, shallow wells, and springs can be carried out relatively quickly, but must be undertaken in a systematic manner and the samples analysed by a reputable laboratory. Monitoring data can be interpreted to distinguish contamination or saline intrusion from the natural geochemical evolution of the groundwater. Historical information on groundwater chemistry is invaluable to determine how quality has evolved or pollution advanced. The World Health Organisation publishes *Guidelines for Drinking-Water-Quality.*[25] Certain contaminants can be compared against these guidelines or the baseline conditions expected in a natural system.

Case 2.2 Arsenic in groundwater in Bangladesh[26]

A detailed and systematic survey of groundwater quality in Bangladesh carried out by the British Geological Survey and the Bangladesh Government shed light on the nature, scale and causes of arsenic contamination in drinking water.

The study mapped the distribution of arsenic in groundwater on a national scale and showed that problems with arsenic contamination lay in groundwater from a young, shallow (Holocene age) aquifer. Of the groundwater samples tested from this aquifer, around a quarter had arsenic concentrations above the national standard for arsenic of 50 µg/L and almost half exceeded the WHO guideline value of 10 µg/L. A deeper (Pleistocene age) aquifer beneath contained groundwater with concentrations almost invariably below the WHO guideline value (Figure 2.7). The study showed that the source of the arsenic was likely to be naturally-occurring iron oxides residing in the Holocene aquifer and concluded that the arsenic release would have been taking place over thousands of years. The mapping indicated that up to 35 million people in Bangladesh could be drinking water with arsenic concentrations exceeding the national standard and up to 57 million people drinking water exceeding the WHO guideline value.

The national arsenic map identified priority areas for mitigation, patient identification and treatment, awareness campaigns and further testing. The findings also provided a framework for defining national policy on water supply and have provided background data and information for many scientific groups working subsequently on the arsenic problem in the Bengal Basin and elsewhere.

2.3.3 Determining aquifer characteristics: data, mapping and modelling

Moving from diagnosing groundwater problems to managing them requires an understanding of the nature of the aquifers. The first requirement is to know where the aquifers are. Next, the characteristics of their soils, sediments, and rocks need to be assessed to give information on the aquifer's capacity and vulnerability. Table 2.4 lists methods used to determine the nature of an aquifer.

Although aquifers may initially be envisioned on a flat map, they must ultimately be understood in three dimensions and over time as a functioning system. With sufficient information, a numerical groundwater model can be constructed, which can be a useful step in both identifying the knowledge gaps of a groundwater system, and forecasting potential outcomes from management strategies.

Geological maps are the basis of any hydrogeological understanding of an area. Most countries will at least have a national geological map at some scale. However maps are not always available at the more useful scale of less than 1:250,000. Fortunately new geological mapping techniques using a combination of satellite information and targeted field studies are making geological mapping more rapid and less expensive. With the addition of information about the aquifer properties of the different rock types, the groundwater levels, and sometimes groundwater chemistry, these maps can be transformed into hydrogeological maps. They can be printed or developed in a digital geographic information system (GIS). Ultimately, their utility depends on the reliability of the data.

"DIAGNOSING GROUNDWATER PROBLEMS REQUIRES AN UNDERSTANDING OF THE NATURE OF THE AQUIFERS."

Transforming a two-dimensional map into three dimensions requires information on the thickness of the geological strata. Data from deep boreholes drilled through the aquifers can reveal information on the rock variations. Where the aquifers are very deep, other methods, such as geophysics, can be used.

Table 2.4 Methods for characterising aquifers[27]

Purpose	Method	Requirements
• Locate aquifers	• Hydrogeological mapping	• Good geological information and maps. Information on the hydrogeological properties of various rock formations. Information on the aquifers, boreholes and water-levels
• Understand aquifers in 3-dimensions	• Interpret existing borehole information • Geophysical surveys • Drill exploration boreholes • Geophysical logging	• Detailed interpretation of drilling logs from borehole records if they exist • Geophysical surveys to provide information on aquifer thickness and structure • Purpose-drilled exploration boreholes If there is insufficient information on the aquifer • Downhole geophysical logging to help characterise aquifer structure and identify the main flow horizons.
• Quantify aquifer properties	• Review available pumping test data • Detailed pumping tests in boreholes across the aquifer • Laboratory tests to measure porosity and permeability	• Collate existing information from disparate institutions • Pumping at a controlled rate for a period of several days to several weeks, and monitoring the response in other boreholes • Analysis of core samples from boreholes for further aquifer properties

To understand how a groundwater system will respond over time to pumping or pollution, one must determine the aquifer's capacity to store water ('storage coefficient') and the rate at which the water flows through the aquifer ('transmissivity'). These terms, and two related terms for aquifer properties: 'hydraulic conductivity' and 'porosity', are defined in Box 2.2. If information is not available on these important parameters,[28] a series of investigations can be undertaken. The storage coefficient and transmissivity can be measured by carrying out controlled pumping tests at boreholes and measuring the response of the water table. These aquifer properties can vary by many orders of magnitude across the same rock type, therefore tests at a sufficient number of boreholes must be carried out to provide confidence in the results. Hydraulic conductivity and porosity are generally measured by taking core samples of rocks and performing tests in the laboratory.

Specialised tools, such as geophysical tools and tracer tests, are sometimes used to help characterise aquifers. Borehole geophysics can identify how groundwater flows in the aquifer – whether through single fractures or diffusely through many pore spaces. For example, this technique was used successfully in the south of England to map seasonal variations in salinity in individual fractures in a major chalk aquifer, which led to improved management of the aquifer to control saline intrusion. In Africa, electrical currents passed through the ground are used to indicate types of rock layers that might bear water as good locations to drill boreholes (Case 2.3).

Case 2.3 Geophysical techniques used to locate groundwater in Africa[29]

Throughout Africa, where rural people usually depend on groundwater from wells, geophysical techniques are often used to locate the best sites for boreholes wherever the geology is complex, such as in crystalline basement aquifers. Two techniques that measure the electrical properties of the rocks are often used: resistivity and electromagnetic surveying. Electrical currents are passed through the ground and instruments measure how easily the ground conducts electricity. Solid rock generally does not conduct electricity, so higher measurements are usually associated with increased porosity of the rock and thus some water content. Using this technique reduces the chance of drilling a dry borehole, thus helps reduce the overall cost of a project.

Tracer tests, which involve introducing a dye into the water, are used in highly fractured aquifers and karstic limestones to trace connections between boreholes and the ground surface or rivers.[30]

Box 2.2 Four aquifer properties needed to predict groundwater behaviour

Porosity - the total void space within the rock, which therefore usually defines the total amount of groundwater stored in an aquifer.

Storage coefficient - a truer measure of the amount of groundwater available within an aquifer; it is defined as the amount of groundwater released from storage within the aquifer when the water table falls by 1 m.

Hydraulic conductivity - the velocity (measured in m/day) that groundwater would flow through rock if there were a pressure gradient of 1 m over a distance of 1 m.

Transmissivity - the ability of an aquifer to transmit volumes of groundwater (measured in m^2/day), calculated by multiplying the hydraulic conductivity by the aquifer thickness.

2.4 Technical Framework for Management

2.4.1 Groundwater monitoring

Once a database and map of the aquifers is developed, both groundwater levels and groundwater quality must be regularly monitored across the aquifer to determine trends. Are the water levels rising or falling? Are nitrate concentrations increasing dramatically? Effective groundwater monitoring should be driven by a specific objective and the data collected should be systematically stored for future use.

Acceptable levels of abstraction and of pollution in different areas should be determined at the policy level based on national or international health guidelines. Monitoring reveals how the actual situation measures up to these yardsticks. Contaminant levels can be compared to the World Health Organisation guidelines for groundwater quality.[31]

For best results in monitoring groundwater levels, boreholes should be constructed specifically for that purpose, with their locations carefully chosen to ensure they are monitoring what is specifically required for management (e.g. natural water level in the aquifer or levels affected by well-field pumping). To sample baseline water chemistry, it is best to use abstraction boreholes that are pumped regularly, and to sample a large part of the aquifer. However, for targeted pollution sampling, it is best to construct boreholes in the area of pollution. Sufficient investment should be given to continue monitoring over the long term, and to construct a robust and usable database to store and report data easily.

When a problem is found, action should be taken to correct it. For example, in Scotland, careful monitoring identified rising nitrate concentrations in several major aquifers. Although still below the WHO health guidelines, the data showed that continued agricultural practices would lead to the groundwater eventually exceeding these limits. As a precautionary measure, these areas were designated as nitrate-vulnerable zones and special measures introduced to restrict the quantity and timing of nitrogen application and the disposal of slurry.[32]

2.4.2 Land zoning for groundwater protection

Accurate maps of the location and types of aquifers can be used to create land-use zoning maps that allow only land uses compatible with the capacity of the underlying aquifer. Many countries have policies that combine land surface zoning with a code of practice that advises what activities are acceptable in the different zones. Land surface zoning usually has two elements:

- *resource protection* based on the vulnerability of a groundwater system to pollution and,
- *source protection* around individual groundwater sources, such as boreholes or springs, to especially protect them from pollution.

In zoning, the land is divided into areas ranging from extreme to negligible groundwater vulnerability to contamination. Extreme vulnerability is associated with highly-fractured aquifers with a shallow water table, and negligible vulnerability is assumed if the aquifer is separated from surface activity by impermeable layers (see Table 2.5). Vulnerability maps have proved to be a simple and effective tool in many countries easily fitting into a land-use planning system. In some countries, the maps are used to determine the level of site investigation required before development, rather than prohibiting certain land activities altogether.

Source protection zones are capture areas around an abstraction borehole, well or spring, either determined by numerical modelling or by using standard analytical shapes, which serve to avoid contamination of the water supply. For readily degradable contaminants (e.g. pathogens) a basic strategy is to reduce the risk of their entering the ground in areas where the groundwater travel times from the pollution source to abstraction sites is insufficient for them to be eliminated through filtration or adsorption. For more persistent contaminants (e.g. industrial chlorinated hydrocarbons and certain pesticides) the best strategy is to prevent their discharge into the ground.

Table 2.5 Broad classification of aquifer vulnerability

• Extreme	Vulnerable to most water pollutants with relatively rapid impact in many pollution scenarios
• High	Vulnerable to many pollutants, except those highly adsorbed and/or readily transformed, in many pollution scenarios
• Moderate	Vulnerable to some pollutants, but only when continuously discharged or leached
• Low	Only vulnerable to the most persistent pollutants in the long-term, when continuously and widely discharged or leached
• Negligible	As demand for groundwater increases overexploitation of the resource can occur; climate change may reduce recharge in some areas

2.4.3 Groundwater numerical modelling

A dynamic groundwater model for an aquifer is an excellent tool for managing abstraction, and can also be used to help assess saline intrusion and the movement of pollutants. A groundwater model is a numerical representation of an aquifer system that can be run using computer packages on a standard PC.[33] A reliable model requires a considerable amount of data: the geometry of the aquifer, the river network, location of boreholes, distributed recharge and the aquifer properties. Various computer modelling packages such as MODFLOW or ZOOM, can be used. It is useful to have a dedicated groundwater modeller carrying out the work in tandem with hydrogeologists. To help refine a model, reliable and time-variant data on groundwater levels, river flows, rainfall and recharge are necessary. However, even with limited data, a preliminary model can help confirm understanding of an aquifer behaviour, indicate the magnitude of likely responses, and determine priorities for data collection.

With a well-constructed and calibrated groundwater model, questions can be asked and future scenarios can be investigated. For example: what would be the effect of continuing abstraction at current or increased rates on the aquifer and dependant ecosystems? The model can also estimate the time needed for physical changes to be observed or for management policies to take effect. Despite the resources required to set up a groundwater model, the results can be cost effective because a model allows potential future options to be investigated without the financial, political, and economic risks of actual implementing any scheme (see Cases 2.4 and 2.5).

Case 2.4 Modelling groundwater in Death Valley[34]

The USA's the Death Valley in southern Nevada and eastern California is an area of complex hydrogeology with controversial groundwater management issues. In addition to ongoing groundwater abstraction, there is a legacy of contamination from historical underground nuclear testing, and also a reoccurring proposal to construct a repository for high-level nuclear waste at Yucca Mountain. An understanding of groundwater movement is crucial to knowing how contamination might spread.

A numerical three-dimensional (3D) transient groundwater flow model of the Death Valley region has been developed by the U.S. Geological Survey for the U.S. Department of Energy. Decades of study of the groundwater flow system, investigations of the hydraulic properties of the rocks and conceptualizations of flow were evaluated together to develop the complex, digital model.

The groundwater flow model MODFLOW-2000, a 3D finite-difference modular groundwater flow model was constructed for the region using all available geological and hydrogeological data and calibrated against water level monitoring data and spring flows for the period 1913-1998. The model represents the large and complex groundwater flow system of the Death Valley region with a greater resolution and accuracy than has been possible previously. The model is now being used to help simulate the effects of pumping on water availability, contamination migration, and water-dependent ecosystems.

Case 2.5 Groundwater modelling of the Nubian Aquifer System, eastern Sahara[35]

The Nubian Aquifer System (NAS) in the eastern Sahara is the largest groundwater system in Africa, extending over more than 2 million km^2 and providing water for much of the population in this area outside the Nile valley, for domestic, agricultural, and industrial uses. The NAS is formed by four basins (a) the Kufra Basin, of south-eastern Libya, north-eastern Chad and north-western Sudan; (b) the Dakhla Basin of Egypt; (c) the north-western basin of Egypt; and (d) the Sudan Platform. In the centre and north of the system, average precipitation is low (50 mm/year) and consequently, there is no current groundwater recharge in most parts of the system and most of the available resources were recharged during wetter periods in Saharan history.

To improve existing groundwater modelling of NAS, GIS databases were developed for both regional and local scales, and a database was created that comprises all the available hydrogeological information from the previous studies and incorporated hydrogeological data from the newly drilled water wells in Egypt and Libya up to year 2001. Telescoping meshes were developed in this regional model for the inclusion of local details. Building on the GIS database, an integrated GIS-based numerical time-dependent three-dimensional transient groundwater flow model was developed using MODFLOW. This was used to simulate the response of the aquifer to the climatic changes that occurred in the last 25,000 years. The model calibration relied on simulating palaeolakes that existed in this period to estimate and calibrate the groundwater recharge throughout the duration of this time period.

Results of the study showed that the groundwater reserves of the Nubian Sandstone Aquifer in Egypt and Libya are currently being mined. The model showed that by expanding the presently established well fields to their full capacity by year 2020, the water-levels will continuously decline and may fall below economic levels of abstraction.

2.5 Management Interventions for Groundwater Protection and Remediation

Sustainable management of groundwater should aim to prevent groundwater from becoming severely depleted or highly polluted, since prevention is always less expensive than trying to remediate problems once they have occurred. However, sometimes groundwater degradation may have to be mitigated with technical measures, either because the aquifer will not recover on its own, or because other pressures mean that groundwater will continue to be exploited from an increasingly degraded system. Numerous measures have been used globally with various rates of success.

Several measures can be used to maintain a supply of groundwater:

- optimising the location of wells and boreholes to limit overall aquifer drawdown at the same abstraction rate
- control of pumping regimes to minimize drawdown or reduce saline intrusion
- use of standby boreholes, in extreme cases, to sustain sensitive ecosystems or river flows for periods when natural discharge of groundwater is lost, and
- scavenger wells in coastal areas to protect productive areas of the aquifer by pumping out saline water (although this exacerbates the overall water balance deficiency so must be managed carefully).

Management of aquifer recharge to increase groundwater recharge rates is growing in popularity and several methods are being used: (1) constructing infiltration ponds and basins (see Case 2.6), (2) modifying surface water channels and building small dams; (3) directly injecting groundwater through boreholes, and (4) constructing small-scale structures in agricultural fields.

Case 2.6 Managed aquifer recharge in Mexico[36]

More than half of Mexico is dominated by arid and semi-arid climatic conditions, making groundwater an essential resource for national development. Total groundwater abstraction has been estimated at of 28,000 million m^3/year with agriculture using 71% and urban and industrial areas consuming 26%. Currently, over 100 regional aquifers are considered to be over-exploited. To respond to this, a pilot aquifer recharge project was carried out in the Comarca Lagunera Region of northern Mexico, a major agricultural area. Water for irrigation purposes, domestic and industrial use is abstracted from the Nazas and Aguanaval rivers and from 3500 boreholes drawing groundwater from the Comarca Lagunera aquifer. At present, it is estimated that abstraction is at least three times greater than recharge, resulting in a significant decline in the groundwater level and deterioration in groundwater quality.

The pilot scheme aimed to manage aquifer recharge as a means of replenishing groundwater supplies. The scheme used an adapted recharge sand basin near to the Nazas River Bed, in Torreon City, covering an area of 13 ha with a storage capacity of about 197,000 m^3. Waterworks were implemented to transport surface water from the Zarco dam to the recharge basin. A trial period between May and August 2000 saw a total volume of 5.2 million m^3 transported to the recharge basin. Of this volume, 0.2 million m^3 was lost to evaporation and 5.0 million m^3 infiltrated into the subsurface.

Recommendations from this pilot scheme include building new structures to control delivery of the water to the basins, to release only 0.5 million m^3 per week to avoid basin spills, to construct parallel sedimentation basins to reduce clogging and to construct adsorption wells 20 m deep and >0.3 m in diameter to avoid low conductivity horizons.

"PREVENTION IS ALWAYS LESS EXPENSIVE THAN TRYING TO REMEDIATE PROBLEMS."

Even more important, measures can be taken to reduce abstraction by controlling demand for water. Over the past 15 years or so, there has been much progress on engineering designs that make more efficient use of water. In agriculture for example, drip irrigation (in which crops are only given the volume of water required for optimum growth) can result in major decreases in the amount of water applied and pumping energy consumed per unit area of crop cultivated, whilst maintaining or increasing yields. However, it is conceptually a mistake to associate 'improving irrigation water-use efficiency' with 'real groundwater resource saving' – the latter will only follow when parallel action is taken to reduce groundwater pumping, since most of the so-called efficiency improvements result from eliminating previous excess irrigation which was already being returned to the aquifer by infiltration.

At the municipality level, physical measures aimed at reducing domestic water consumption and supplementary use of rainwater in gardens can reduce demand on aquifers. Of greater significance: (a) the reduction of frequently high rates of urban water main leakage, bearing in mind that, in some cases, leaky water mains can recharge groundwater, and (b) appropriate handling and treatment of urban wastewater to allow its reuse for agricultural and/or amenity irrigation as a substitute for fresh groundwater, bearing in mind that such reuse can generate a contaminant load to aquifers.

"MEASURES CAN BE TAKEN TO REDUCE ABSTRACTION BY CONTROLLING DEMAND FOR WATER."

Many methods have been developed to remediate groundwater that has been contaminated, initially as a consequence of litigation in the USA or under the implementation of the EC Water Framework Directive. Most methods are specific to the contaminant and the hydrogeological conditions, may be only partially successful, and are expensive to implement. A key aspect of any remediation programme is clear agreement on the targeted end point and on how it will be monitored and measured. Remediation measures can be done in situ (introducing oxygen, nano particles, or bacteria to help speed up natural biogeochemical processes) or ex-situ (commonly pumping contaminated groundwater to the surface and treating it or erecting barriers to contain contaminated groundwater.

2.6 Checklist: Application of Technical Knowledge and Information to Groundwater Management and Protection

Build knowledge of hydrogeology and groundwater resources

- Promote improved understanding of how groundwater systems work among groundwater users, technical agencies, policy makers and legislators.
- Communicate knowledge of threats to groundwater including excessive abstraction and pollution. Explain the implications of groundwater degradation to the general public, groundwater users and policy makers in terms of risks to the economy, health, food and water security, biodiversity and the environment.
- Build technical knowledge among stakeholders and technical agencies including of how aquifer characteristics and chemistry determine how groundwater can be used sustainably and priorities for groundwater management and protection.

Generate and make available information needed for improving groundwater management

- Build technical capacities for diagnostic analysis and monitoring of groundwater systems.
- Assess aquifer characteristics using geological information on rocks, sediments and soils and through scientific studies of transmissivity and the capacity of aquifers to store water.
- Gather information on long-term variations in groundwater levels or, if not available, start monitoring as a priority.
- Make an inventory of all groundwater abstractions and estimate the water balance of aquifers by comparing natural recharge with discharge and abstraction.
- Characterise groundwater quality by implementing a systematic programme for sampling of boreholes. Establish baselines to enable monitoring of changes relative to water quality standards.
- Develop national hydrogeological maps to show the locations of aquifers and national databases to systematically store aquifer and groundwater data for use in groundwater management.
- Assess the vulnerability of aquifers to pollution and develop vulnerability maps for use in land-use planning.
- Develop dynamic numerical models of aquifers where the needed resources and skills are available. Apply the model to assess the implications of alternate management options and scenarios for future exploitation of aquifers.

Identify management interventions

- Put in place a national system for regularly monitoring groundwater levels and groundwater quality, including a network of monitoring boreholes.
- Create a system for land-use zoning that only allows land uses that are compatible with the capacity of the underlying aquifer. Use vulnerability maps to identify where conditionalities need to be in place before development proceeds and to delineate source protection zones where restrictions on land-use are needed to avoid contamination of groundwater.
- Identify and implement controls needed to limit groundwater pumping to sustainable levels. Complement these with measures designed to control water demand.
- Implement managed aquifer recharge where increased recharge rates are needed, though for example construction of infiltration ponds or direct aquifer injection.
- Assess the need for and appropriateness of alternate remediation methods where groundwater has become contaminated.

Chapter 3

Policy, Law and Institutions for Effective Groundwater Governance

3.1 Groundwater Governance Capacity

Effective water governance puts in place the structures and norms needed for good management of groundwater. Without appropriate governance arrangements for groundwater, a country may be exposed to the depletion and degradation of its groundwater resources. Weak groundwater governance in a country puts at risk the health and food security of its people, the success of its economy, the sustainability of its natural environment and, in the case of transboundary aquifers, good relations with its neighbours.

Effective governance relies on coherent policies, laws, institutional arrangements and implementation and enforcement mechanisms. These collectively make up the 'water governance capacity' of a society. The IUCN-WANI Toolkit *RULE*[37] provides guidance on how to create and strengthen effective water governance capacity at the national level. As *RULE* presents, reforms in water governance must be appropriate to the governmental and legal system of a country. There are many varieties of successful policies, laws and institutional arrangements for water, each suited to the traditions and form of government of a country. There is no blueprint for good water governance, but there are guiding principles that can help policy makers, who can also learn from the experiences of other countries.

"WEAK GROUNDWATER GOVERNANCE IN A COUNTRY PUTS AT RISK THE HEALTH AND FOOD SECURITY OF ITS PEOPLE."

Strengthening water governance capacity depends on ensuring that policies, laws and institutional arrangements are well articulated. They need to be coherent and not contain contradictions that could create conflicting requirements, or weaken their implementation or enforcement. Unfortunately, for most countries, water governance arrangements have accumulated over time, and often in a fragmented way, with a focus on specific sectors (e.g. agriculture, energy, industry, health and sanitation, environment) and without adequately addressing the needs of other sectors in a holistic way. Water governance is therefore commonly fractured and uncoordinated. This is especially true for groundwater, because it is invisible and because it is so often poorly understood. In this context, the development of a well-articulated system of policies, laws and institutions for groundwater, that is integral to and well-coordinated with governance of surface waters, is a critical building block of sustainable groundwater management.

Water governance also encompasses social organisation, stakeholder dialogue and citizen action, necessary for local water governance, as described in Chapter 5, and use of economic instruments as described in Chapter 4. Good governance is based on scientific information and data as described in Chapter 2. The focus in this chapter is the core governmental processes and structures needed for good governance of groundwater. These begin with groundwater policy, which is a government's plan and strategy for how to manage groundwater. Laws are established to codify policies, setting the rules for exploitation and protection of groundwater resources, and determining who has the right to use groundwater. The certainty of law is a vital component of groundwater governance, because it allows for example local authorities and businesses to plan ahead and invest for the long-term, while enabling citizens to participate in groundwater management and claim their rights. Appropriate institutions, whether at national, basin, aquifer or local level, or at international level for transboundary aquifers, are needed to carry out the mandates of the laws.

3.2 Policy for Groundwater Management

3.2.1 Differentiated but integrated approaches to groundwater and surface water

Groundwater differs from surface water and hence requires specialised policies. However, these should be developed as a differentiated issue within broader national water policies. What is needed is a holistic approach that not only promotes the adoption of appropriate management strategies for groundwater sustainability, but also ensures that these address the inter-linked economic and social concerns of relevant stakeholder groups and sectors. Policy for groundwater management should be developed within an overarching framework for Integrated Water Resources Management (IWRM).

IWRM brings a focus on integration, implying coherence in resources management, in water management across sectors and water users (e.g. agriculture, energy, health and sanitation, industry, ecosystems, etc.) and among diverging, yet interdependent, interests and uses of water. To be consistent with an IWRM framework, groundwater policies must consider economic efficiency, ecosystem sustainability and social equity. Exploitation and protection of the resource must consider not only the interconnections between groundwater and surface water bodies, but also the links between water, land and other natural resources and ecosystems, including wetlands, river basins and adjacent coastal zones. Due account needs to be given to ecosystem services and their benefits for society, water users, climate resilience and biodiversity conservation. An ecosystem approach should indeed be part and parcel of an IWRM framework.[38] An IWRM framework will help foster sustainable development, not least by ensuring that cross-sectoral linkages with groundwater resources are recognised explicitly in policy and encouraging multiple sectors and stakeholders to pursue common objectives. However, integration of groundwater in IWRM is a complex process. Policies should therefore promote flexible and adaptive processes of change that ensure meaningful stakeholder participation are supported by learning-by-doing.

> *"DUE ACCOUNT NEEDS TO BE GIVEN TO ECOSYSTEM SERVICES AND THEIR BENEFITS."*

Integrating groundwater and surface water management is blocked by loopholes in water policies in many countries that result in rules and institutional arrangements that are inadequate for governing groundwater. It is common that surface and groundwater bodies are linked hydrologically (excluding fossil groundwater), with water exchanged between them in the landscape (see Chapter 2). Unsustainable use of surface water has impacts on groundwater recharge, excessive groundwater abstraction can influence surface water availability and surface water pollution can lead to contamination of aquifers. Despite this, water policies have widely neglected surface-groundwater interactions and traditionally focused on the regulation of the protection and utilisation of surface waters, potentially leading to institutional fragmentation and the creation of communication and coordination barriers over groundwater among the many actors (e.g. water users, technical experts, operational managers and policy-makers) involved in the planning and management of water resources.

The necessary arrangements for groundwater governance vary from one place to another, because of the physical and chemical differences between aquifers. The location of recharge areas, for example, and storage characteristics of aquifers, flow boundaries and velocities, residence time, evaporation losses, pollution and persistence all shape the vulnerability of groundwater to pollution or over-abstraction (see Chapter 2). In addition to these hydrogeological differences, there are also differences in the social context for groundwater management, relating to awareness of the value of groundwater and priorities given to the development of groundwater resources. Groundwater management hence requires policies that are specialised but work within broader national water policy while promoting integration between surface water and groundwater and across sectors, but that also allow management to be tailored to local contexts and vulnerabilities.

3.2.2 Developing groundwater policy

While demands on groundwater policy are complex, there are practical steps to developing a suitable and effective policy framework for groundwater. The first step is to determine a national 'groundwater management vision' that is embedded within a national vision for water resources. In South Africa, for example, the vision is that "groundwater is recognised, utilised and protected as an integral part of South Africa's water resource."[39]

"THE FIRST STEP IS TO DETERMINE A NATIONAL 'GROUNDWATER MANAGEMENT VISION'."

Policy goals should aim to achieve an adequate balance among the exploitation of available groundwater resources and the increasing demand for water, while respecting and preserving groundwater quality, quantity and a sustainable path for utilisation. They should set out the scope of policy and results required, and therefore help to identify the institutional arrangements and management measures needed. Goals have to remain broad, but also have to address specific issues, for example:

- to implement 'source-directed' controls to prevent and minimise – at the source of impact – the impacts of development on groundwater quality by imposing regulatory controls and by providing incentives
- to implement 'resource-directed measures' in order to manage impacts on groundwater resources, when they occur, to protect the reserve and ensure sustainability for beneficial purposes, and
- to remedy groundwater quality and ensure at least fitness for uses served by the groundwater body.

The third step is to identify measures needed to achieve policy goals. These should use as basic guiding principles (see also the IUCN-WANI toolkit *RULE*):[40]

- *efficiency* – that use of groundwater is maximised under rational patterns of consumption that benefit most consumers while taking into account not only water but also other resources, including social and human capital
- *equity* – that both benefits and costs are shared and a transparent process is used to arrive at decisions about groundwater management
- *sustainability* – that management of groundwater supports the ability of society to endure over time without undermining the integrity of the hydrological cycle or the ecosystems that depend on it, including an adequate balance between groundwater abstraction and recharge
- *public participation* – that groundwater management is based on a participatory approach, involving users, planners and policy makers at all levels

- *transparency* – that dialogue, deliberation, decision making and documentation are open to scrutiny, through open public meetings, a free press and regular communications among stakeholders and public authorities
- *accountability* – that groundwater managers and decision makers are publicly accountable for their actions
- *subsidiarity* – that key decisions and activities are carried out at the lowest appropriate administrative level
- *conjunctive use* – that the utilisation of surface and groundwater reserves should be balanced to avoid excessive pressures or over-utilisation of either one of them, and
- *precautionary principle* – that in the case of doubt about the potential damage to groundwater resources from the implementation of policies or activities, lack of full scientific certainty shall not be used as a reason for omitting or delaying measures to prevent environmental degradation.

3.2.3 From policy goals to concrete action

Groundwater policy sets out the framework for national action on groundwater management. To enable implementation, it is then crucial, that roles and responsibilities, and how these are differentiated between national, sub-national and local levels, are clearly defined and understood by all stakeholders. For example, the relationship to national food security policy, or well-drilling and pumping subsidies should be decided at national level. National institutions should, likewise have responsibility for financing a system of groundwater monitoring and for the management and dissemination of information on groundwater. At local level, stakeholders establish local interest groups such as Groundwater User Associations, in which local water users reach agreements on local management actions that take account of priority issues and local interests, and then directly take charge of implementation.

"A NATIONAL GROUNDWATER MANAGEMENT PLAN SHOULD BE DEVELOPED THROUGH AN OPEN AND TRANSPARENT PROCESS."

With goals and principles from groundwater policy in place, determining what actions are needed depends also on information and assessments of needs and demand. Information and data should be gathered together – in a participatory way by staff of technical agencies and local water user representatives – to enable evaluation of:

- the existing legal and institutional framework
- the availability of technical knowledge and skills
- what data are available for aquifers
- the classification of aquifers according to hydrological characteristics and potential management concerns, and
- who are the stakeholders in groundwater management.

A national groundwater management plan should be developed, making use of diagnostic assessments drawn from available information to identify and prioritise actions needed. The plan should be developed through an open and transparent process in which all relevant stakeholders can contribute. Ensuring effective participation (see Chapter 5 and the IUCN-WANI toolkit *NEGOTIATE*)[41] is a vital means of improving consensus and building commitments to action.

The national groundwater management plan should set goals for groundwater management and serve as a roadmap to guide implementation. Based on the framework provided by policy and diagnostic assessments, the management plan should set out the actions needed to address specific problems or pressures on groundwater for specific contexts. Table 3.1 gives examples of source-directed, resource-directed or remediation measures that might be included in groundwater management plans. Achieving the overall objective of sustainable groundwater utilisation requires that all three types of measures are combined in a coherent approach to implementing policy.

Table 3.1 Actions specified in groundwater management plans

Types of measures	Purpose	Examples
Source-directed	Minimisation and prevention of impacts at source	• authorisation and licensing requirements • quality standards for wastewater discharge • requirements for on-site management to control diffuse pollution • mandatory and voluntary demand management • economic incentives to reduce pollution • development of low waste and no-waste technologies
Resource-directed	Management of the resource	• national classification system for groundwater • assignment of groundwater management classes • setting quality objectives according to management classes • establishment of a reserve to meet basic human needs and an ecological reserve to protect ecosystems
Remediation	Restoration of groundwater quality or aquifer storage	• prioritisation of sites • clean-up of abandoned sites • emergency response to spills • reduced abstraction to re-establish the reserve

"GROUNDWATER MANAGEMENT PLANS NEED TO BE IMPLEMENTED USING AN ADAPTIVE APPROACH."

Chapter 5 elaborates further on how to implement management actions that, through groundwater governance, need to be supported by the establishment of operational rules for groundwater use and protection that are appropriate for the specific vulnerabilities and uses of an aquifer (see Case 3.1). These rules need to be accompanied by incentive programmes to discourage or encourage actions by the community and educational initiatives to raise the level of awareness and develop skills needed for communities to manage groundwater. Moreover, extension services are needed to advise and assist communities in the best use of groundwater. These should be based on research and development of new and better ways to manage groundwater, application of best practice guidelines and capacity building to help communities to regulate groundwater themselves. It is important to put in place monitoring programmes to record changes in the aquifer and to update diagnostic assessments. Groundwater management plans need to be implemented using an adaptive approach, in which monitoring and lessons from experience are used to update and improve future plans.

Case 3.1 The differentiated approach of South Africa[42]

In South Africa, groundwater characteristics and use are highly localised, and it has been recognised as physically and economically impossible to protect all groundwater resources to the same degree. South Africa's water policy therefore does not aim to prevent negative impact to the water environment at all costs, as this would not allow the country to achieve much needed social development and economic growth. For effective and focused intervention, a differentiated protection approach is implemented, based on the vulnerability and local and regional importance of aquifers. A system has been set up in which each aquifer within the country has been classified according to an assigned function – such as among others, direct consumptive uses, productive uses or the support of ecosystems – on the basis of the importance of that aquifer in terms of potential yield and the level to which communities depend on the aquifer. However, aquifers that represent the sole source of water for communities are afforded a special status irrespective of the potential yield and enjoy the highest level of protection.

3.3 Legal Frameworks for Groundwater Management

3.3.1 The role of law on groundwater

Policies for sustainable groundwater development and management need to be codified into law. The law sets the rules for the exploitation and protection of groundwater resources. A narrow, archaic view is that law establishes the means of enforcing rules through the courts. While this is necessary, law on groundwater should create a stable framework of rules that enable governments and groundwater users to plan groundwater management over the long term. The role of law in groundwater management is to put in place regulations in which the competing interests of all users of groundwater can be fairly taken into account, including the interests of the environment and future generations.

"THE LAW SETS THE RULES FOR THE EXPLOITATION AND PROTECTION OF GROUNDWATER."

Law on groundwater must provide the answers to very practical questions that governments, courts and groundwater users all need if they are going to contribute fully, and be accountable, to making the management of groundwater sustainable. The questions include, for example:

- what rights and obligations do water users have?
- how are these rights protected and how can obligations be enforced? Who has the authority to do so?
- how can activities that affect groundwater resources – such as urban development, mining or agriculture – but take place far away from sites of impact be accounted for?
- what is the role of coalitions of groundwater users?
- what is the legal basis for states in a federal country to become involved in the management of an aquifer shared with another federal state?
- on what issues can one country make legal claims in relation to groundwater management in a neighbouring country?

An effective legal framework for groundwater needs to enable those people and groups with relevant interests to avoid or remedy critical threats to groundwater such as over-exploitation and pollution (see Chapter 2). In a scenario where for example operators of wells finds that the yields of water from pumping are declining and the water is contaminated, they need the law to help them both to hold those responsible to account and establish roles and responsibilities in a remediation programme. If those responsible – for example a brewing company over-abstracting from an aquifer or mining operations causing pollution – are powerful organisations, citizens require the law to provide procedures for protecting and claiming their rights that are fair. Critically, the law should also help everyone to prevent degradation and contamination of the aquifer in the first place.

3.3.2 Groundwater extraction and use

Rights to use groundwater have often, historically, been attached to property rights for land, with landowners entitled to extract groundwater from under their property. The trouble is that a neighbouring landowner, because of the common-pool nature of groundwater, will claim identical rights over the same resource. If the neighbour pumps large amounts of water – for irrigation or in operating a bottling factory for example – this may draw water away from surrounding areas and cause a well that is used by the first landowner to run dry. Such competition for groundwater is made more severe where there are no licensing requirements that set out the terms and conditions for use of groundwater, including amounts and rates of abstraction. Disputes among landowners then lead to lawsuits and parties arguing in court. Law that gives all landowners equally valid, property-based claims for groundwater can fuel endless conflict and litigation while doing relatively little to reduce the risk of over-abstraction and eventual depletion of the resource.

Effective groundwater law should not use the courts as the place where well-drilling and groundwater-extraction rights are determined. Recognising this, there is a worldwide trend to replace rules which tie rights to use groundwater to land ownership with statutes under which, through one means or another, the State can regulate extraction and use of groundwater. To break the cycle of conflict, the common-pool nature of groundwater needs to be reflected in the law by:

- removing groundwater from the exclusive control of landowners and putting limits on their extraction rights
- placing groundwater resources under the stewardship of the State, and
- opening groundwater extraction and development opportunities to non-landowners.

"THE LAW SHOULD PUT IN PLACE MECHANISMS FOR GOVERNMENTS TO ADMINISTER EXTRACTION RIGHTS."

From the starting point of stewardship of the resource by the State, the law should put in place mechanisms for governments to administer extraction rights. Groundwater users such as households, farmers or a brewing company must then secure from the government an administrative entitlement – in the form of a permit or licence for example – before they drill a well or extract and develop groundwater (see Case 3.2). The rights carried by such an entitlement will be qualified by obligations. By incorporating both rights and obligations, the permitting or licensing scheme created allows regulators to try to balance the legitimate interests of groundwater developers with the sustainability of extraction rates. They can weigh proposed extraction rights against the water needs of groundwater-dependent habitats, notably wetlands and oases. In all cases, the necessary balancing act is performed by government, which is in a better position than landowners to canvass all of the interests at stake, including those of biodiversity and future generations. Government must also ensure, however, that there is adequate capacity in place to administer the granting and licensing of extraction rights as well as enforcement of those rights, or else the law will not be effective (see Case 3.3).

Case 3.2 Licensing requirements for groundwater extraction in Mexico's Water Laws

Mexico's Law on National Waters was enacted in 1992 and amended in 2013. The Law is underpinned by the state ownership of water resources, which includes groundwater. A government concession is required for the extraction and use of groundwater from an aquifer designated by the government as over-exploited. The concession requirement applies also to extractions in progress which, as a result, become liable to regulatory restrictions. Concessions are granted subject to terms and conditions, including, in particular, as to duration. This cannot exceed thirty years, renewable for an equivalent term. Moreover, a separate government permit is required to drill new wells, and to modify existing wells, in over-exploited aquifers. Contrary to the general rule inaugurated by the Law, whereby holders of water abstraction concessions can dispose of them – including through sale – separately from the land, concessions for the extraction of groundwater from over-exploited aquifers could, as a rule, only be disposed of together with the relevant land. This rule has been subsequently reversed, and groundwater can be disposed of separately from the land, so long as transactions do not entail out-of-aquifer transfers of groundwater, and third parties are not affected. In all circumstances, groundwater seller and buyer are jointly and severally liable for the cost of sealing unused wells.

Case 3.3 Regulation of groundwater use in South Africa[43]

In South Africa, the National Water Act (NWA; Act 36 of 1998) is the cornerstone of groundwater governance and it is based on the three pillars of social equity, economic efficiency and environmental sustainability. This Act, amongst other things, required the establishment of a National Water Resource Strategy (NWRS) to set out a national framework for managing water resources and the division of the country into 19 Water Management Areas (WMAs).

Contrary to what was established in the past, water is now considered a public resource and it is therefore subject to national control. There is no ownership of water but only a right to water for basic human needs and to meet environmental needs (called "The Reserve") or an authorisation for its use. The NWA and NWRS make provisions for the regulation of water use through registration of water use and different types of authorisations (e.g. water use, general authorisations, existing lawful use and water use licences).

The position regarding the licensing of groundwater, however, is often unclear to both users and planners, especially with regards to regulating local government (as a water user). This, combined with the slow process of assessment and approval of applications has resulted in a backlog in issuing groundwater licences. Only about 20% of registered groundwater use had been verified by 2011. Limited capacity within the Department of Water Affairs to carry out this task is detrimental to effectively regulating groundwater use, and hence the enforcement of water use licensing is weak.

Determination of drilling and extraction rights by governments aims to prevent conflict over groundwater and keep groundwater management out of the court. It aims to protect groundwater from depletion through a process of allocating extraction rights where all competing interests are taken into account. Information is key to success. Development and implementation of groundwater law therefore needs to be supported by data collection and analysis of, for example, water balances and aquifer characteristics as described in Section 2.3. Of course, decisions by governments are not immune to legal challenge and the law must ensure that legal avenues are available for courts to adjudicate disputed decisions, but on balance, the advantages of a regulated process of resource allocation, steered by government in a transparent way, far outweigh the disadvantages.

3.3.3 Groundwater pollution and coherence with land-use regulation

Courts of law are likewise ill-equipped to deal with the complexities of determining who is at fault for pollution of groundwater. Given the hidden nature of the underground movement of water and contaminants, it is often not possible to determine the source of pollution definitively. The main thrust of the law therefore should be prevention of new pollution and abatement and remediation of existing pollution. Law enforcement is an essential component of pollution control legislation, working alongside preventive regulation, with remedial action at the expense of the wrongdoer (polluter pays) or, if this is not feasible, imposition of financial penalties and the temporary or permanent cessation of polluting activities (see Cases 3.4 and 3.5).

"LAW ENFORCEMENT IS AN ESSENTIAL COMPONENT OF POLLUTION CONTROL LEGISLATION."

Different regulatory approaches are needed for diffuse and point-source pollution. The latter occurs where contaminants are discharged from a discrete source, such as a mine, chemical refinery or sewage treatment plant, and reach the aquifer. In these cases, legislation must require polluters to obtain a permit from the government for the intentional discharge of waste, subject to obligations. Regulators can then use the permitting process to place strict limits on both the quantity of contaminants released

Photo 3.1 Urban and industrial effluent, a source of groundwater contamination

and the rate of discharge. The law should hence aim to balance the interests of those producing waste with the rights of users dependent on good quality groundwater, including for supply of drinking water and conservation of ecosystems.

Discharge permits are not appropriate for regulation of diffuse pollution, as it is not usually possible to pinpoint the source of pollution. Diffuse pollution originates from the drainage of croplands or, for example, from urban storm water runoff. In these cases, regulation tends to be dealt with in laws relating to land use. The target has to shift from regulating the discharge of waste to regulating uses for land and how it is managed. The same is true for point sources of pollution such as landfills, waste dumps and underground storage facilities, from which discharge is not intentional but results from leakage.

Case 3.4 Regulation of groundwater pollution in Mexico

Under the Law on National Waters of Mexico, as enacted in 1992 and amended in 2013, a government permit is required to discharge wastewater on or into the ground if this entails a risk of contaminating groundwater. Permits are granted subject to terms and conditions, including as to treatment requirements, and as to duration. The artificial recharge of aquifers through the injection of wastewater requires a government permit.

The Law also addresses pollution of groundwater from non-point sources, notably, from irrigated croplands, by obligating irrigation water users in general to abide by the official standards and norms restricting the use of substances which may contaminate groundwater. Furthermore, the federal water administration is directed to seek consistency of land use standards with the statutory goal of protecting the quality of, among others, groundwater.

Finally, the Law lays down the principle that pollution originating from non-compliance with statutory provisions engages the wrongdoer's liability to make good the damage to the environment. This implies an obligation to remedy the pollution and to restore the water body in its condition prior to pollution, or, if this is not feasible, an obligation to pay compensation in an amount to be fixed by the competent government authority.

Case 3.5 Regulation of groundwater pollution in India[44]

The legal and institutional framework for groundwater protection in India is complex. The reason for this is legislation on water-related issues is left with the individual states rather than the central government, and most of them have enacted laws that are applicable only to certain geographical areas with the result that there are different policies in operation at federal, state and local levels.

The Water (Prevention and Control of Pollution) Act of 1974 was the first national legislation designed to control water pollution and it established both central and state regulatory bodies. However, the Environmental (Protection) Act of 1986 deals with most pollution issues in India. Moreover, there are thirteen other related policy and legal ordinances related to groundwater protection. The Central Pollution Control Board (CPCB) and, at the state level, the CGWA (Central Ground Water Authority) and CGWB (Central Ground Water Board) are the main responsible agencies. The Authority has appointed regional and local bodies (Deputy Commissioners or District Magistrates) in each state to enforce the regulatory measures in notified areas and control over-exploitation and recharge.

Statistics regarding enforcement and compliance with pollution control ordinances for the seventeen categories of highly polluting industries show that, out of the largest 2,526 industrial plants, 18% have been closed, 10%

are defaulting, and 71% are complying insofar as they have installed pollution controlled equipment. On the other hand, control of pollution from the 3-3.5 million small and medium-scale industries is less effective and a large number of common effluent treatment plants are not functioning properly.

Within this framework, enforcement is not easy and state agencies are not well-equipped (either lacking material or funding). Moreover, the legal system for groundwater management in India falls within a complex, multi-layered framework of constitutional and statutory provisions at the central and state levels. It is clear that groundwater management falls under the jurisdiction of the states and to this effect the central government has circulated since 1970 a Model Groundwater Bill that has gone through several reforms in its text until 2011. Regretfully, by the year 2013, out of India's 30 State and Union Territories, around half had passed Acts and Regulations with respect to groundwater with reference to the Model Bill and only a few had formally adopted it.

Land-use regulation is also critical in protecting recharge and discharge zones of aquifers, especially where they are at risk of depletion or pollution. Land-use regulation of this kind tends to be included in water law, through provisions that empower government water management agencies to target areas where special measures are needed to protect groundwater (see Case 3.6). These measures typically include restrictions on land use and restrictions on the extraction and use of groundwater that are more stringent than elsewhere.

Case 3.6 Regulation of groundwater pollution in Spain

The Spanish Water Act from 1985 declared for the first time all waters as a public domain resource (including groundwater). However, existing owners were able to retain private ownership but had to decide if they wanted to remain permanently in a private regime (in that case, they had to register themselves in a Catalogue of Private Waters) or remain in a transitory private regime and become a public concession after 2038. Although there have been several reforms since then – because of the need to adapt the 1985 Water Act to new challenges and to transpose the content of the European Union Water Framework Directive (WFD) – the general framework regulation of groundwater pollution has stayed the same.

Similarly to the Mexican Law, according to the Water Act from 2001 currently in force, discharge with potential to pollute groundwater is only permitted if previous hydrological studies have proved that it is harmless to the watercourse. Otherwise, discharge of pollutants requires a prior authorisation or concession that will establish, among other things, the conditions under which the spill is permitted and the total fee that has to be paid by the polluter according to the 'polluter pays principle'. Also, the Law states that permission to establish an industrial activity that can cause spills may be granted under the condition that spill authorisation is obtained and the government can forbid industrial activities that can potentially pollute waters in certain areas. In case of non-compliance with conditions provided in the authorisation or of polluting without authorisation, a sanction will be applied as well as the obligation to restore polluted waters to their condition prior to pollution.

Multiple components are hence needed to set in place an effective legal framework for control of groundwater pollution. Legislation is needed for regulation of waste discharge, supported by mechanisms for law enforcement, but water law must also be reconciled with law on land use and town and country planning. Achieving the necessary coherence in both the legislation itself and in administration on the ground is a major challenge.

3.3.4 Local groundwater user interests

Water law must aim to set in place procedures and mechanisms that can take into account all of the interests at stake. Participation in the administration of water helps to increase the fairness and accountability of the system. Participation may be possible through informal arrangements, but these commonly favour the more powerful interests, such as large corporations. Contemporary water legislation therefore increasingly calls for the establishment of formal associations of groundwater users and provides them with legal standing (see also the IUCN-WANI toolkit *RULE*). They are entrusted with administration of regulatory controls locally and they hence provide a formal means for groundwater users to communicate with and coordinate management with government authorities. They help to ensure that all interested groups are able to voice their concerns and to build consensus on measures to protect aquifers from depletion and contamination. Groundwater user associations can therefore help to counterbalance more powerful interests and increase transparency, accountability and effectiveness in implementation of the law. Chapter 5 elaborates further on social organisation processes that facilitate the engagement and responsibilities of local groundwater users.

"WATER LAW MUST AIM TO SET IN PLACE PROCEDURES AND MECHANISMS THAT TAKE INTO ACCOUNT ALL OF THE INTERESTS AT STAKE."

Case 3.7 Local Groundwater Users Association in Barcelona, Spain

The Low Llobregat (Barcelona) Groundwater Users Association (CAUDLL), was formed in 1975 when water was still a private domain under the 1876 Water Act. Favourable local factors encouraging this particular association to get started included the availability of detailed studies of the groundwater situation and the consequent awareness of the essential role of groundwater in the local economy. Most importantly, there was already a good degree of trust between the Water Administration and the water users, who at the time were dominantly water suppliers and industries rather than agriculture.

CAUDLL was registered as a private body supported by the Water Administration and the municipal authorities. Its objectives were to protect private groundwater rights, secure water availability in periods of drought, and halt and reverse groundwater degradation. The association's by-laws allowed it to raise funds, punish wrongdoers and represent the water rights of its members.

The beneficial results included the control of new groundwater developments and reduction in groundwater abstraction, bringing an end to waste disposal in pits, and the establishment of monitoring programmes. Its success meant that most groundwater users in the Low Llobregat joined CAUDLL, and also new increased public investment came to the area which might not have done otherwise.

3.3.5 Groundwater law in federated countries

Aquifers do not respect administrative boundaries and they can be expected to overlap sub-national units within a country such as provinces or states. In federal countries like Argentina, Australia, Canada, Germany, India, Malaysia and the United States, the law must establish rules and procedures for states to protect the interests of their citizens from the effects of groundwater exploitation or degradation taking place in other states. The specific arrangements for doing so depend on how jurisdictional responsibilities are distributed between the federal and state levels in a particular country.

In general, states of a federation at odds over the use of water resources straddling their border have recourse to the country's Supreme Court. For example, the Supreme Court of the United States has frequently heard and adjudicated inter-state water disputes, although none of these has so far involved groundwater. India has instituted a special mechanism for adjudication of inter-state water disputes, but it has similarly not yet addressed groundwater.

In the long term, states and their citizens will be better served by agreements that are negotiated to deal with water issues between federated states. Negotiated agreements can establish rules that are appropriate for dealing with specific uses of a shared aquifer, as well as for incorporating measures needed to protect it based on its specific characteristics. Negotiated agreements may not be needed in all cases, but where groundwater is heavily exploited or is particularly vulnerable to pollution, they provide an alternative to conflict and litigation that will be more successful in achieving the goal of preventive, sustainable management of groundwater. States in federations have successfully negotiated water agreements, with some dealing with groundwater as an adjunct to surface water. Very few have dealt only with groundwater, but some examples include the Border Groundwater Agreement (1985) between the Australian States of South Australia and Victoria, and the Pullman-Moscow Groundwater Aquifer Inter-Agency Agreement (1992) between the U.S. States of Idaho and Washington.[45]

3.3.6 Transboundary aquifers in the international context

The Internationally Shared Aquifer Resources Management (ISARM) programme of UNESCO has documented and mapped many transboundary aquifers in all continents.[46] Cross-border impacts of groundwater exploitation and management are governed by rules in international law aimed at preventing harm between States or at remedying the consequences of harm. International law relating to groundwater is guided by two fundamental rules:

- no State has the right to inflict 'significant' harm across an international border through its own actions or those of its citizens, and States are required to take measures to prevent such harm, and to take action to eliminate or mitigate harm when it occurs, and
- all States that share an aquifer are entitled to a 'reasonable and equitable' share in the uses of groundwater from the transboundary aquifers that they have in common.

These two cardinal rules of transboundary management of groundwater, and the interplay between them, lie at the heart both of what is commonly referred to as customary international law and of negotiations among States over shared groundwater resources.

"CROSS-BORDER IMPACTS OF GROUNDWATER EXPLOITATION AND MANAGEMENT ARE GOVERNED BY RULES IN INTERNATIONAL LAW."

Customary international law is binding on all States and is the basis for treaties and agreements made by States having a transboundary aquifer in common. The cardinal rules of customary international law, alongside several other complementary rules, have been codified by the United Nations International Law Commission (UNILC). The relevant instrument is a UN Resolution carrying 'The Law of Transboundary Aquifers' (2008),[47] however the resolution is not binding, and the United Nations General Assembly has ever since been debating the nature and the effects of the codification of the Law of Transboundary Aquifers by UNILC.

There are so far few treaties and agreements that specifically address a transboundary aquifer. The best known are:

- two agreements on the Geneva Aquifer (1978 and 2007), shared by France and Switzerland
- the agreement for the establishment of a consultative trilateral arrangement for the North-Western Sahara Aquifer System (2002-2008), shared by Algeria, Libya and Tunisia
- the agreement on the Guarani Aquifer (2010), shared by Argentina, Brazil, Paraguay and Uruguay, and
- the agreement on the Al-Sag/Al-Disi Aquifer (2015) shared by Jordan and Saudi Arabia.

The Geneva Aquifer agreement is a complex instrument covering controlled groundwater extractions, controlled artificial aquifer recharge operations, pollution control, the apportionment of all relevant costs, and a permanent bilateral institution for the administration and implementation of the agreement. By contrast, the Western Sahara and Guarani agreements are framework-type agreements, whose centerpiece is an inter-State institution which is to administer aquifer monitoring, and data collection and exchange.

An alternative to specific treaties and agreements on groundwater, and which is more common, is for States to include groundwater in agreements on transboundary surface waters or river/lake basins (see also the IUCN-WANI toolkit *SHARE*).[48] These arrangements typically extend to transboundary groundwater the commitments that States have made for cooperation in managing surface waters or river and lake basins. Examples include the River Danube Convention (1994), the Rhine Protection Convention (1999), the Sava River Basin Framework Agreement (2002), the Lake Tanganyika Convention (2003), the Lake Victoria Convention (2003), the Peace Treaty between Israel and Jordan (1994), and the Great Lakes Water Quality Protocol between Canada and the United States of America (1983), amending the Great Lakes Water Quality Agreement (1978).

3.4 Institutional Architecture for Groundwater Management

3.4.1 Coordination, subsidiarity and decentralisation

The role of water institutions is to implement policies and norms, to translate decisions into actions and ensure that the regulations, procedures and enforcement mandated in law are carried out. There is no simple blueprint for a nation's institutional framework for water or groundwater management. The best institutional set-up for any country will depend on its system of government as well as other factors including the climatic and hydrological context and the social and economic circumstances in which water management takes place. Water management, whether for surface waters or groundwater, must work at a range of levels, between local communities and the national and international level. In all cases, the institutions carrying out governance of water and groundwater are a mixture of ministries, agencies, basin organisations and corporations, each with different competencies and levels of jurisdiction. With the cross-sectoral character of water, institutions from other sectors, such as agriculture, land use, energy, health and sanitation also become involved in decision making on water. Roles and responsibilities must be clear for each institution, preferably through mandates that are clearly articulated in law, and coordination among them is critical.

The basic institutional architecture for water and groundwater tends to differ between unitary and federated States. There is a tendency in countries with a unitary structure of government to develop strong water institutions that work at national level, below which is a hierarchy of institutions that implement water management at lower levels. In federated States, water institutions at the sub-national (provincial or state) level generally have a greater degree of autonomy with more involvement of water users. For example, in Australia, institutions at the level of the (sub-national) states issue general policies, strategic guidelines and technical parameters for management, which are then implemented by local authorities through locally-specific and adapted water management schemes and projects.

"WATER INSTITUTIONS TRANSLATE DECISIONS INTO ACTIONS."

It is important for those leading or facilitating a process to improve groundwater management to make an assessment of the existing institutional set-up and how it can be changed to make it more effective. This can be done through a process in which institutions involved in administering or managing groundwater are identified and their roles and responsibilities described and compared. From such an assessment – as further discussed in Chapter 5 – gaps and weaknesses in institutional mandates should become clear as well as whether there are institutions with overlapping and unclear mandates that lead to blockages in the process of implementing good governance of groundwater. With this information, it is then possible to prioritise needed changes in the mandates and operations of institutions and, if necessary, creation of new institutions.

The subsidiarity principle is an important guide to institutional needs and roles and responsibilities. This principle states that key decisions and activities should be carried out at the lowest possible administrative level, as local authorities and citizens are best placed to define their needs in relation to water management and the local context. National authorities should then intervene only to carry out measures that more local institutions do not have the capabilities to implement or in case of inaction locally.

"THE SUBSIDIARITY PRINCIPLE IS AN IMPORTANT GUIDE TO ROLES AND RESPONSIBILITIES."

A direct consequence of subsidiarity is increased public participation and social organisation. The result is greater engagement of local authorities, civil society organisations and citizens and their empowerment to implement better management. As their commitment increases so do the chances of successfully achieving changes needed for sustainable management of groundwater. Chapter 5 further describes what this may entail.

Subsidiarity does not imply that higher level authorities do not have critical roles. On the contrary, the national government in fulfilling its responsibility for stewardship of all water resources designs the general framework for protection and sustainable use of groundwater. It sets out the strategic plan for groundwater management and ensures that the resources necessary for implementation are available and allocated appropriately. It also ensures that scientific studies and data analysis needed to support decision making nationally and at lower levels are undertaken and made available.

For transboundary aquifers, if there is an international institution in place, it should lead a joint process of strategic planning among the relevant countries. Depending on the terms of the treaty or agreement among countries sharing the aquifer, the international institution may also play a role in joint studies, information gathering and sharing, and in some cases, joint mobilisation of financing.

Based on the subsidiarity principle, Table 3.2 summarises a generic institutional set-up for groundwater management and the roles played by institutions working at different levels.

Table 3.2 Institutional set-up for groundwater management[49]

Institution	Jurisdiction	Function
International Aquifer Authority	International/ Inter State	• Strategic planning on shared aquifer management • Decisions affect the national level
National Water Authority or Inter Ministerial Coordinating Commission	National	• Policy making, planning and coordination • Ensuring coordination at the highest political level among different ministries and agencies • Development of Integrated Water Resources Management (IWRM) of Spatial Land Use Planning Schemes or Strategies • Procedures for coordination with local authorities, aquifer management organisations and water user organisations • Licensing of well drillers, drilling and groundwater extraction • Control of groundwater pollution from point and non-point sources • Allocation of funds for investment in the water sector
River Basin Authority	Basin / Sub basin	• Coordination of extraction rates in relation to all aquifers connected to the surface water basin • Mandate for drought and emergency management • Definition of control and protection policies • Control of artificial aquifer recharge operations • Control of groundwater pollution from point and non-point sources
Aquifer Management Organisation	Aquifer	• Setting of technical parameters for extraction and use of the aquifer • Raising awareness on protection of the aquifer • Develop programmes for integrated management of the aquifer and their monitoring • Coordination with higher-level institutions and water user associations • Sanction procedures
Water-user associations	Local	• Management relating to to municipal water supply, sewage, sanitation, small and large area irrigation and household supply systems • Participation in the formulation of groundwater guidelines • Generation of local policy proposals and local rules • Representation of local water users before the National Water Authority in topics related to the management of their groundwater resources • Monitoring the implementation of policies and management plans

3.4.2 The role of an aquifer management organisation

Water should be managed as an undivided resource, with management of surface and groundwater well-coordinated. Adding a separate agency for groundwater management at national level, in addition to an agency for management of surface waters, will tend to increase institutional fragmentation. A better arrangement is therefore to have all waters administered at national level by a single and effective government authority.

A single national water agency, with responsibilities for surface and groundwater, is consistent with the principles of IWRM and ensures that all available expertise and technical, human and financial resources are available at national level from a unified institution. It must be borne in mind however that the hydrogeological features of groundwater bodies make them different from surface waters and make their management needs different, and in any case not all aquifers are linked hydrologically to rivers or lakes (i.e. non-recharging, fossil aquifers). In addition, the upstream-downstream relationships typical of surface waters, with their associated power dynamics among water users, have little to do with groundwater, and the spatial and temporal scope of groundwater is very different to surface waters. While authority is placed within a single national agency, arrangements are needed for planning of groundwater management that ensure that while it is integrated into the broader IWRM framework, it is not marginalised and is not made secondary to surface water management.

"WATER SHOULD BE MANAGED AS AN UNDIVIDED RESOURCE, WITH MANAGEMENT OF SURFACE AND GROUNDWATER WELL-COORDINATED."

Below the national level, however, there are advantages to creation of organisations that are separately and specifically mandated to implement groundwater management. Such aquifer management organisations should work in close coordination with national water authorities and river basin organisations, as well as with water-user associations at local level. With a separate mandate, however, an aquifer management organisation can work to counteract the historic and widespread tendency, because of the invisible nature of the resource, for groundwater management to be marginalised and poorly resourced (Case 3.8).

Case 3.8 Technical Committee of Huichapan-Tecozautla-Nopala, Mexico

The territory of the municipalities of Huichapan-Tecozautla-Nopala is located in the north-west of the state of Hidalgo, Mexico. Surface water is scarce in the region and, with complex challenges in meeting water needs, this has led to intense exploitation of groundwater. In response, a strategy has been put in place that encourages conservation and management of groundwater as a basis for sustaining the ongoing development of the aquifer.

In this context the Technical Committee of the Aquifer Huichapan-Tecozautla-Nopal was established with the purpose of formulating, proposing, promoting and monitoring the implementation of groundwater management. The Committee's mandate is to ensure the efficient use of groundwater and to achieving in the shortest time possible the stabilisation of groundwater levels. This requires that over-extraction of 10.4 million m^3 per year is overcome. To meet this objective, the Committee developed an Aquifer Management Plan using participatory processes involving representatives of water users, multi-disciplinary experts and units of three levels of government (Municipalities of Huichapan, Tecozautla and Nopala, the State of Hidalgo, and the Federal State of Mexico represented by the National Water Authority, CONAGUA).

Activities implemented by the Technical Committee include: promotion of further scientific research; projects and activities for enhanced sustainable development; modernisation of irrigation systems; improvement of the application of the legal framework; regulation of the aquifer; fostering of institutional development for the comprehensive management of the aquifer; establishment of communication and coordination mechanisms; promotion of a culture of water; strengthening and streamline the operation of drinking water systems; and the development of infrastructure for urban development and profitable cropping patterns in the region.

The main tasks of an aquifer management organisation are given in Table 3.2. In addition, aquifer management organisations should prioritise scientific research that leads to better understanding of the aquifer and its management needs. Good groundwater governance will only be possible if decisions, plans and approvals for groundwater development and management are based on needed, and regularly updated, data and information. Aquifer management organisations therefore have a critical role to play in increasing knowledge of groundwater resources in their jurisdictions and then ensuring that it is available to be applied to support the good governance needed to attain sustainable management of the groundwater resources.

3.5 Checklist: Enhancing Good Groundwater Governance

Develop groundwater vision and policy goals

- Develop a national groundwater management plan (GWMP) through a stakeholder dialogue and concerted action (SDCA) process, formulating vision, policy goals and necessary measures to achieve an adequate balance between recharge and abstraction and between sustainable use and demand.
- Gather, cross-check and organise relevant data and information on groundwater resources and their use.

Develop adequate groundwater legislation

- Develop groundwater laws with mechanisms for government to administer water resource allocation and abstraction rights, based on permits and licences, including obligations to ensure sustainability of the resource.
- Place strict limits on both the quantity of contaminants released and the rate of discharge.
- Balance the interests of those producing polluting waste with the rights of users to access good quality groundwater, including supply of drinking water and conservation of ecosystems.
- Regulate land use to protect recharge and discharge zones of aquifers, especially where they are at risk of depletion or pollution, including measures that put restrictions on land use and on the extraction and use of groundwater.
- Facilitate legal frameworks for aquifer management organisations and local Groundwater User Associations.

Assess and develop the necessary institutional architecture

- Map which institutions are involved in administering or managing groundwater and their roles and responsibilities to identify gaps, weaknesses and blockages that prevent implementation of groundwater policies and laws.
- Prioritise needed changes in the mandates and operations of institutions and, if necessary, new institutions that should be created.
- Ensure that management of surface and groundwater can be managed as an undivided resource under a single national water authority, but that arrangements needed to ensure that groundwater management is not marginalised are in place, such as aquifer management agencies under the national authority.
- Implement close coordination, according to clear definitions of roles and responsibilities, between aquifer management agencies and national water authorities, river basin organisations and local water user associations.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Chapter 4

Economic Principles and Instruments for Sustainable Groundwater Management

4.1 Economic Dimensions of Groundwater

Groundwater of good quality has become increasingly scarce in some humid areas and in most arid regions. The primary reason for this is the common failure of governments to control abstraction to levels that avoid serious environmental degradation and impacts on third parties, and to provide aquifers with effective protection against pollution.[50] A contributory factor is that individual groundwater users have not had to pay anything like the 'full economic cost' of groundwater use, nor have groundwater polluters had to pay for clean-up of their contamination.[51] Assigning value to groundwater is less important in situations of plenty, but as high-quality water becomes scarcer and subject to competing demands, groundwater value is increasing with time. Thus choices have to be made about whether and when to use it, and how to manage and price its use.[52]

Economic principles can be used to guide these choices. Improved understanding of the economic dimensions of groundwater will help governments, and groundwater users and polluters, to develop and apply economic instruments – which are mechanisms for creating economic incentives and disincentives – as a contribution to the promotion of more sustainable groundwater management.[53] Application of economic principles to groundwater management benefits from knowledge of:

- the socio-economic drivers of demand for groundwater and of pollution of aquifers
- principles and methods for making a sound economic valuation of groundwater resources, and
- economic incentives and policies that encourage behaviour in line with sustainable groundwater management.

"GROUNDWATER USERS HAVE NOT HAD TO PAY ANYTHING LIKE THE 'FULL ECONOMIC COST' OF GROUNDWATER USE."

Economic principles and instruments are important tools for implementing groundwater management policy. They are used in conjunction with a mix of regulatory measures and participatory mechanisms, appropriate to the local hydrogeologic, socio-economic and institutional setting. To be effective, economic instruments for groundwater management must be deployed in packages alongside the other tools and measures presented in SPRING, and using a sequencing that is adapted to the specific context of groundwater management.[54]

Undervaluation of groundwater resources contributes to problems of excessive abstraction, low productivity of consumptive water-use, and inadequate individual and community investment in quality protection. However, it is over-simplistic to think that groundwater degradation problems can be addressed simply through the use of economic instruments such as higher charges for abstraction or use and for contaminant discharge. This is essentially because water is just one of many cost components in urban development, agricultural production and industrial enterprise. The behaviour of groundwater users or polluters can therefore be rather insensitive to variation in groundwater cost.[55]

In general terms, the promotion of sustainable groundwater resource use and effective groundwater quality protection will require the following principal economic and financial elements:

- realistic valuation of the benefits of sustainable groundwater resources to human livelihoods and well-being, including ecosystems in groundwater recharge and discharge zones
- finding synergies and making trade-offs between groundwater conservation and economic development, by reducing rates of resource exploitation and stimulating higher water productivity
- incorporating more positive economic incentives for groundwater conservation at the national policy level, and at the local level through charging for use, imposing sanctions on polluting activities and maintaining ecosystem services critical for aquifer recharge, and
- mobilising finance for the implementation of specific management and protection measures.

4.2 Socio-Economic Drivers of Groundwater Use and Pollution

4.2.1 Identifying the drivers

An assessment of the main socio-economic factors driving excessive groundwater use and causing groundwater pollution risk is essential for diagnosing how groundwater resources came to be depleted or why they are at high risk of their quality being degraded.[56] This is a critical starting point when trying to identify effective and sustainable solutions to these problems[57] – and for this purpose it is helpful to distinguish clearly between:

- extensive irrigated agriculture – the major consumer (and sometimes an important polluter) of groundwater resources,[58] and
- urbanisation and industry – a major user (and polluting user) of groundwater resources.

Normally the overriding factor controlling groundwater exploitation is its cost relative to alternative sources of water supply. While taking into account the advantages it offers of excellent quality and drought reliability, these costs are often distorted in some subtle ways. It is essential therefore to assess carefully whether any existing public (or sometimes private) policies are the source of 'perverse incentives' that constitute a major obstacle to implementing groundwater management measures.[59]

The agricultural sector is often the beneficiary of measures put in place by government to stimulate agricultural development, because of its importance to the economy of most countries.[60] Some of these measures make sustainable management of groundwater all the more difficult, for example:

- price guarantees for water-consuming crops (such as paddy rice and sugarcane)
- grants or soft loans for waterwell construction
- flat-rate tariffs for rural electricity for groundwater pumping in irrigation areas[61] and,
- cost subsidies for synthetic agricultural chemicals (and sometimes common industrial chemicals) that are persistent in the subsurface environment and pose a risk to groundwater.

When formulating approaches to groundwater management, it is always necessary to ask the question 'what is the balance between the economic benefits and environmental costs of each given resource use or polluting activity' – and then to prioritise management action in relation to those uses and activities which offer only small economic benefits for large environmental costs.[62] A classic example of this is the excessive application of nitrogen fertiliser to arable crops, especially at times of the year when natural soil nitrification is sufficient to meet crop needs, with most then leached to groundwater.[63]

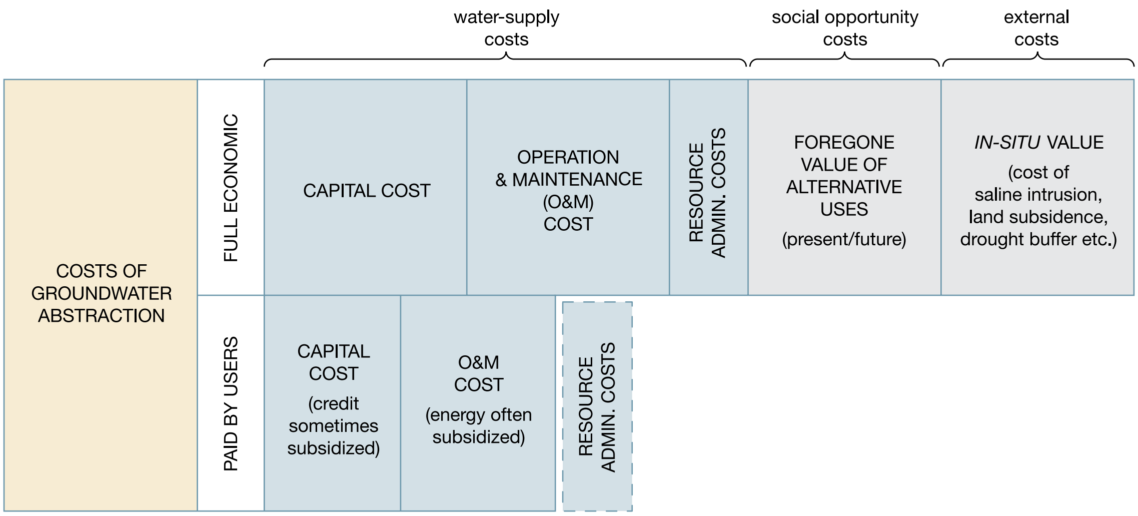
4.2.2 The problem of under-valuation

Groundwater tends to be undervalued, especially where its exploitation is uncontrolled. In this situation the user of the resource (in effect) receives all the benefits of groundwater use but (at most) pays only part of the costs, in many cases only the capital cost of waterwell construction and the recurrent cost of pumping. Even these costs may be reduced by well construction grants and rural electricity subsidies. This under-valuation of groundwater typically leads to problems of inefficient use and excessive abstraction.

"GROUNDWATER TENDS TO BE UNDERVALUED."

The 'full economic cost' of groundwater use is summarised in Figure 4.1, including costs for capital, operations and maintenance and administration. There is often a gap (especially in the developing world) between costs typically met by users and full economic costs,[64] when environmental externalities, social opportunity costs and resource administration costs are included. In some more developed economies this gap has been closed at least partially – for example, by applying a sizeable empirical weighting to the 'resource administration charge' for all waterwells in the vicinity of key aquatic ecosystems or in areas prone to land subsidence induced by groundwater abstraction.

Figure 4.1 Comparison between the full economic costs for groundwater use and the costs commonly paid by users[65]



Economists use the term 'externalities' to pinpoint costs that are shifted to society as whole and not included directly in the cost of the activity or product concerned. Externalities for groundwater use arise where one person's use has consequences on third parties, but there is no compensation provided for damages caused or reward for benefits generated. Critically, the result is that the people who abstract, use or pollute groundwater resources do not themselves bear all of the costs of their actions. They then have little incentive to take these costs into account when making decisions. The same holds true when inadequate land management impacts negatively on groundwater quality. For example, industry can operate at lower cost if chemicals and effluents are not managed at an industrial site so as to protect underlying groundwater, but society has to pay the costs of the environmental damage and may have to spend more on ensuring a public water supply of acceptable quality.

Groundwater does not generate value only through its extraction and productive use. There is also a value associated with the *in situ* services that occur as a consequence of water remaining in place within the aquifer. For example, there is value associated with the capacity of groundwater reserves to buffer against periodic droughts affecting surface water, or with protection provided by groundwater against sea-water intrusion and land subsidence.[66]

The net result of under-valuation is that decisions relating to groundwater are often not adequately informed about the 'true costs' of excessive use or insidious pollution. The broader social and economic costs associated with aquifer depletion or degradation are then often ignored and decisions that can result in unsustainable scenarios are made more palatable.

4.3 Valuation of Groundwater Resources

4.3.1 Why value groundwater?

The value that people place on groundwater (and the desirability of different uses) depends on many factors in addition to economic aspects, but putting an economic value on the resource should help planners to decide what are priority uses and to provide advice on how to manage it in a more equitable and efficient way. Economic valuation of groundwater requires a sound appreciation of the important difference between:

- groundwater fluxes – the renewable component of the resource, and
- groundwater stocks – the natural storage component of aquifers needed for drought mitigation and climate-change adaptation, and for which exploitation often implies larger environmental and third-party externalities.

From an economic perspective, it is important to assess which uses of groundwater fluxes and stocks yield the highest monetary returns – and valuation thus involves weighing-up the comparative benefits and costs of different options for groundwater use. However, this is far from a straightforward task, and many considerations need to be taken into account to ensure that the resulting values are as accurate and inclusive as possible.

"PUTTING AN ECONOMIC VALUE ON THE RESOURCE SHOULD HELP PLANNERS DECIDE WHAT ARE PRIORITY USES."

Some argue that putting a more realistic price on groundwater use will deprive the poor of access to the resource for clean drinking water and subsistence agriculture. However, it is the average charge levied that is relevant to water resource management, and subsidies can be incorporated into fee structures to take account of pro-poor considerations. For example, the developers of a highly-productive diamond mine in the Botswana Kalahari during the mid-1980s, using largely non-renewable groundwater stocks in a deep aquifer, were required to deepen all village and livestock waterwells within a very large radius and to compensate their owners and operators for the 'predicted worst-case' increase of their waterwell pumping costs.[67]

4.3.2 How to value groundwater

Rigorous economic valuation techniques for groundwater are less developed than those for surface water. Valuation is made more difficult by the complexity of hydrogeological factors determining the response of aquifers to an imposed abstraction regime and pollution load, and the resultant socio-economic impacts. Economists can only readily take account of values for which there is a clear market price, but many of the costs associated with excessive groundwater use and pollution pressure lie outside of formal markets, accrue slowly over time, and are subject to considerable uncertainty. The use of valuation techniques for groundwater thus needs to combine the specialist skills of hydrogeologists and environmental economists.

It is important to distinguish between groundwater valuation from the water-user perspective (for example an irrigation farmer, a domestic water-user or a water-supply company) and that of public policy-makers (such as an environmental ministry or water resources agency).[68] In most cases, water users will be concerned only with the costs and benefits that enter directly into their private production or consumption equation – which is referred to by economists as *financial analysis*. In contrast, public decision-makers are (in principle at least) concerned with the good of society as a whole, and maximising public interest goals – which requires consideration of a full range of costs and benefits across all groundwater uses and users, and is referred to as *economic analysis*.

As a starting point for valuation it is sensible to look at methods of valuing groundwater from a purely financial point-of-view, leaving aside for the moment environmental externalities. The economic value of a resource depends on what one can do with it (the benefits it generates and the services it provides) and on its relative scarcity compared with alternative resources. Thus, the economic value of groundwater in a specific aquifer is derived from the use it can be put to, and from its local availability and quality compared with alternate sources of water (Case 4.1). For instance, an aquifer in a region with abundant unpolluted surface water will generally have lower economic value than one in an area with polluted surface water or in an arid region without much surface water. As a result, in many regions, the economic value of groundwater is increasing because of:

- population growth and economic development (which increases demand)
- pollution of surface waters (which decreases supply), and
- increased climatic variability (requiring aquifer storage for 'drought-secure water supply').

"THE ECONOMIC VALUE OF GROUNDWATER IS DERIVED FROM THE USE IT CAN BE PUT TO."

Case 4.1 Valuation of the Orange County groundwater system, California, USA[69]

The case history of Orange County, from processes undertaken during the 1990s, provides an example of the valuation of an aquifer through estimation of how much it would cost to replace use of groundwater resources. The Orange County Water District groundwater system was threatened by seawater intrusion with the following principal impacts:

- impairment of the aquifer as a storage reservoir – if groundwater storage was not continuously available for daily and seasonal peak-supply purposes, alternative surface facilities would be required at very high cost because of elevated land prices and construction costs
- degradation of potable water supply stock – if partly salinised, a new source of potable water supply would need to be constructed, and economic losses related to the capital investment in existing water-wells would be substantial, and
- loss of a natural distributor of freshwater – if groundwater was not available, then a distribution system to deliver the alternative surface supply to consumers over a large area would be needed.

The value of the potable water supply function is particularly important. Groundwater is generally less expensive than imported water, primarily because of lower development, transmission and treatment costs. Commercial and industrial users were able to meet about 75% of their water demand by pumping local groundwater – and the price of this water was estimated at US$ 0.11/m^3 compared with a cost of imported water of US$ 0.23/m^3 (for a seasonal supply) to US$ 0.35/m^3 (for a perennial supply). Local users rely first on local groundwater, and supplement it with purchases of imported water at discounted rates during the winter months. In 1995 the total cost of water purchases was about US$ 92 million, but if the groundwater system was lost the cost would have doubled to US$ 183 million. This cost saving is one objective measure of the value of local groundwater resources (albeit a lower-bound estimate of the true value). These high economic values help to justify investment in measures to protect the groundwater system, and were an important consideration in the decision to commission an advanced wastewater treatment plant and two water injection projects designed to prevent seawater intrusion (at a capital cost of US$ 57 million and operating cost of more than US$ 6 million per year).

The economic value of groundwater can be estimated basically by looking at the benefit to be gained from putting it to a particular use, less the costs of abstraction and management (Case 4.2). Valuation almost always involves comparing different options. There are very few situations where groundwater is the only possible source of water supply – and it is the availability of other options which determines 'resource value'. If there are many competing demands for scarce resources, the relative value of groundwater will also increase. When groundwater is located close to or underlying an agricultural or industrial area, or near to an urban area, it will normally have a higher value than if found in a remote location.

Case 4.2 Groundwater resource valuation for the stampriet aquifer, Namibia[70]

The case history of the Stampriet Aquifer of Namibia provides an illustration from the 1990s of the importance of ensuring that the full range of costs and benefits associated with groundwater are taken into account when policies are formulated to manage, allocate and price water. Namibia is one of the world's most sparsely populated countries as well as one of its most arid, and water is widely seen as a critical constraint in development policy, especially affecting the important mining, agriculture and wildlife-based tourism sectors. About 50% of national water use is supplied from groundwater, but appropriate price setting for this supply was difficult because most users are not metered. Some data were available on the financial cost of local water supplies, based on costs for physical infrastructure required for abstraction and distribution, together with costs for any storage and treatment facilities. Information did not exist on the full economic value of water resources, including private marginal benefit, opportunity cost and externalities.

The Stampriet Aquifer is the largest in the country (underlying an area of 65,000 km^2) and was being depleted, because the local commercial-farming community had virtually open-access for groundwater use. While farmers were paying the full financial cost of their groundwater abstraction (waterwell siting, drilling, completion and pumping), no economic value (resource rent and opportunity cost) for groundwater abstraction and aquifer depletion had been estimated or charged. Additionally, the administration of waterwell-use permits and licensed volumes was poorly enforced. Residual value techniques were applied to calculate the economic value of the groundwater, using a farmer questionnaire and enterprise model to compute the value of irrigated agriculture and livestock production. The study suggested a groundwater financial value of US$ 0.005/m^3 and an economic value of US$ 0.010/m^3 and found that the economic-use efficiency of this scarce resource in agriculture was poor. Additionally, various agricultural subsidies actually increased the incentive for farmers to abstract groundwater excessively. A new national water policy was needed that took account of the cost of excessive groundwater exploitation to the wider economy, and of broader economic and social considerations in water pricing.

The basic aim of valuation is to determine user preferences: how much they are willing to pay for a given groundwater supply, and how much better or worse off they would consider themselves to be as a result of changes in its availability or quality. One obvious way to measure this is to look at market prices – the tariffs or charges that people pay for groundwater. This, however, is not generally possible

since in most cases there is simply no market price for groundwater, and in others the prevailing price is distorted and does not accurately reflect either the 'willingness-to-pay' of users or the full cost associated with groundwater use. In such situations, it is necessary to use other valuation methods (Table 4.1).

Table 4.1 Possible alternative approaches to economic valuation of groundwater

Method	Description	Main applications
Highest-Use Value	Economic value derived from use groundwater can be put to, and from its availability and quality compared with surface water	Making decisions about: • whether to supply water for given use(s) from surface water or groundwater sources • how to allocate new groundwater abstraction demands between competing uses and users, and • comparing the economic and financial value of water.
Benefit-Cost Valuation	Economic value calculated from the benefit gained by putting groundwater to a specific use, less the cost of abstraction and management	
Residual Value Technique	Value of goods produced by groundwater use minus costs involved in their production (valued at market price) with the residual being the value of groundwater used	
Contingent Valuation	People asked to state directly their willingness-to-pay for groundwater or acceptable compensation for its loss	Justifying investments in groundwater protection or development projects, and identifying possible user charges or pricing structures to finance them
Hedonic Pricing Technique	Difference in price that can be ascribed to existence of groundwater (usually estimated through differences in property values between otherwise similar locations)	
Mitigative Expenditure	Estimates the value of groundwater from investments made to avoid or alleviate the effects of water shortage or loss of water quality	
Damage Cost or Loss Analysis	Values groundwater in terms of costs incurred when aquifer depletion or degradation constrains economic activity	
Substitution or Replacement Cost	Groundwater valued as being equivalent to the least-cost source of alternative water supply providing equivalent services	

In Australia, for example, economic valuation studies have been used to provide information to support local stakeholder dialogue. A 'cost-benefit analysis framework' was applied to five aquifer management units in different Australian states.[71] The challenges for groundwater management ranged from agricultural use and groundwater salinisation in the Murray-Darling Basin of Queensland and Victoria, to urban land-use and forestry management trade-offs around the Perth metropolitan area in Western Australia, to concerns of rural communities in the Northern Territory. The valuation studies generated a 'benefit-cost ratio' for the various options for management interventions in each case. The results were then used by local stakeholders to help them better understand the economic implications of alternative choices for groundwater management. However, there were also clear limitations on the data used in these studies (mainly related to constraints on data availability and uncertainty, as well as distinctions between consumptive and non-consumptive use).[72]

Stakeholders were therefore advised to consider these limitations in their dialogue and before the results were used in final decision making.

"GROUNDWATER HAS VALUE AS AN INPUT TO THE PROPER FUNCTIONING OF ECOSYSTEMS AND THE SERVICES THEY PROVIDE."

4.3.3 Factoring in ecosystem values

Many lowland ecosystems are dependent on natural *discharge* from groundwater systems (leading to *'groundwater-for-nature'* considerations). Groundwater hence has value as an input to their proper functioning and the services they provide, including economic products these ecosystems yield such as fish, fuel, wood and other life-support services. The size of these values depends on the type, size, characteristics, state and management of the ecosystem in question, but the underlying and underpinning importance of groundwater inputs should not be overlooked. It is equally important to recognise that another set of natural ecosystems are critical to maintaining the recharge of high-quality water to groundwater systems (*'nature-for-groundwater'*). Ecosystems in both discharge and recharge zones for groundwater provide economic benefits that can be valued.

Photo 4.1 Irrigated agriculture, Jordan.

Ecosystems are thus both economic users of groundwater resources, and an economic component of groundwater resource conservation (in both quantity and quality terms). These values need to be factored in when groundwater is valued, priced, allocated and managed. Various mechanisms now exist, and are widely used, to try and reflect the value of ecosystem services related to water and the costs of ecosystem management in water pricing and investment decisions.[73] This is partly a matter of efficiency, since allocating groundwater to ecosystems generates tangible economic value that should be weighed-up against other productive values. It also relates to cost effectiveness and investment choice, because it is often less costly to invest in managing natural ecosystems to maintain their services to groundwater systems in terms of recharge, than to take action once these services are diminished. Factoring ecosystem costs and benefits into groundwater valuation also can have important equity implications for some stakeholder groups. As with groundwater valuation, ecosystem valuation has long posed something of a challenge to economists. However, techniques have advanced and it is now possible to value many of the ecosystem services associated with groundwater. Most of the techniques in Table 4.1 (see IUCN-WANI toolkit *VALUE*)[74] can also be used to value ecosystem services in relation to groundwater.

"ALLOCATING GROUNDWATER TO ECOSYSTEMS GENERATES TANGIBLE ECONOMIC VALUE."

4.3.4 Accounting for time-frame, risks and uncertainties

Differences between short-term and long-term benefits expected from groundwater use also affect how to account for economic values for groundwater. Short-term gains from intensive groundwater extraction need to be balanced against the longer-term flow of benefits, and hence constraints on the rate of groundwater extraction.[75] Most groundwater resources are renewable and thus their value is also perpetually renewed with time. For non-renewable groundwater resources (see Section 2.1.3), however, exploitation will result in a degree of irreversible depletion. A wider economic perspective is then required. Groundwater valuation should take into account the additional costs associated with use of an exhaustible resource, including the premium that should be associated with its value as a strategic reserve and the additional cost to future generations of finding alternative sources of water supply.[76]

Whether groundwater resources are renewable or non-renewable, their valuation must always consider the time-frame, because groundwater values are usually calculated as a flow of future benefits and costs that often accrue over a time-base of many decades. The usual way of dealing with time in economic analysis is to apply a discount rate in order to bring future costs and benefits to their equivalent value today. This is essentially the inverse of applying a compound interest rate, and gives values relatively less weight the further into the future they accrue. It is always important to consider carefully the sensitivity of groundwater valuation to discount rate. A relatively high discount rate will always favour short-term uses against longer-term benefits and costs.

Finally, scientific uncertainty and environmental risk are significant considerations in groundwater valuation. Risk and uncertainty are different. A risk is a situation where a probability can be reasonably assigned to the likelihood of an event occurring with outcomes that are known. In contrast, uncertainty is where not enough is known about potential impacts or the probability of some outcomes, or where the outcomes cannot even be anticipated. For example, the effects of groundwater pollution, and hence protection needs, are usually more uncertain than those for excessive groundwater abstraction, because the technical evaluation and data requirements for pollution are more complex.[77] While risk can be dealt with (at least in principle) by treating it as a cost and incorporating numerical probabilities into valuation calculations, uncertainty is much more difficult to cope with, and usually invokes use of some adaptation of the 'precautionary principle' (see Section 3.2.2).[78]

4.3.5 Limits to valuation

While none of the valuation techniques described above is without flaws, they provide a route to better valuation of groundwater resources and of incorporating the multiple costs and benefits that need to be reflected in decision-support information. However, there are several weaknesses in these methods that should be borne in mind when using valuation data:

- valuations of groundwater depend both on the ability-to-pay of water users and on their ability to access high-value markets, and thus a commercial farmer or industrial water-user will almost always show a higher return to groundwater use than a subsistence farmer or a domestic user, leading to arguments that valuations are inherently biased against the poor
- most valuation techniques are not able to accurately reflect the social and cultural values associated with clean and secure water supply, and thus ultimately the value that people place on groundwater depends on many factors aside from market and economic aspects
- valuation techniques that focus primarily on production-related values (related to industrial and commercial use, including agriculture) require adjustment for other critical inputs besides groundwater (such as labour, energy and raw materials), which can be difficult to ascertain precisely, and
- valuations tend not to consider adequately *in situ* values or ecosystem services.

Variability in groundwater valuations can also be high, because of spatial variation and variation over time. A national study of the value of groundwater use to the Australian economy,[79] for example, put the direct value of the estimated 3.5 billion m^3/year of groundwater abstracted at US$ 1.4-5.4 billion. Allowing for 'flow-on effects' into other industry and commerce, this figure rose to US$ 2.3-8.3 billion – larger than the fishing or forestry sectors for example – implying an average 'use value' in the range of US$ 0.4-2.3/m^3. An approximate figure for the total value of production dependent on groundwater (but also requiring many other inputs) was in the order of US$ 25 billion per year. Variation in these figures also depended on what was included or excluded from the analysis. Values for direct supply to rural householders ranged from US$ 1.1-4.8/m^3, while values were excluded for livestock ranching, use of groundwater as a back-up water source for drought, and ecosystem services. Valuation for groundwater use in mining varied from US$ 0.4-3.8/m^3, with the maximum values for high-value metal and gemstone production. Values for irrigated agricultural cropping were less than US$ 0.4/m^3.

"VALUATIONS OF GROUNDWATER DEPEND BOTH ON THE ABILITY-TO-PAY OF WATER USERS AND ON THEIR ABILITY TO ACCESS HIGH-VALUE MARKETS."

Limitations and variability in groundwater valuation data have critical implications for how values for groundwater are used in decision making. For example, in Spain costs for irrigation represented only 2-15% of the direct costs for production of greenhouse vegetables, citrus, grapes and olive oil, but the economic productivity of groundwater use was €2/m^3. This value was augmented further, however, by the marked increase in the value of agricultural land benefitting from a right to waterwell use compared to that of adjacent land used for dryland farming.[80] A similar phenomenon occurs in Mendoza province, Argentina, with respect to adjacent uncultivated land.[81] The danger is that in the absence of a consistent public administration, or a strong participatory regime of groundwater use regulation and management, this can lead to unsustainable exploitation, including significant impacts on aquatic ecosystems, which then has to be remediated later. It is vital, therefore, that groundwater values are interpreted and applied in conjunction with effective regulation and administration (Chapter 3) and participatory management (Chapter 5).

4.4 Economic Instruments for Groundwater Management & Protection

4.4.1 Scope and relevance of economic instruments

An economic instrument is used to stimulate a groundwater user, polluter, or ecosystem service-provider to voluntarily adopt a desired behaviour that will benefit society, or at least conform with related policies adopted by government. The underlying rationale of economic incentives is that human beings (usually) react to financial inducements and penalties. Economic instruments can provide the incentive to use groundwater more efficiently, thus contributing to sustainable groundwater management and reducing the risk of negative impacts and social conflicts.[82]

Despite the practical difficulties impeding precise valuation of groundwater resources, there is much scope and a pressing need for wider and more consistent deployment of empirical economic instruments in routine groundwater administration. It is highly desirable for water resource managers to ensure that those who use or pollute groundwater resources bear the full economic costs of their actions, since not to do so would send all the wrong signals, and in essence encourage wasteful and damaging practices.[83]

> *"ECONOMIC INSTRUMENTS CAN PROVIDE THE INCENTIVE TO USE GROUNDWATER MORE EFFICIENTLY."*

Applications of economic instruments complement other approaches and, in effect, economic instruments provide the 'carrots' that can complement the 'stick' of laws and regulations. Thus, to be effective in promoting sustainable groundwater management, economic instruments should be applied as part of a package that includes regulatory controls (see Chapter 3) and social participation (see Chapter 5) appropriate to the local hydrogeologic, socio-economic and institutional setting. Care is needed in the preparation of such packages, as well as the sequencing of how various measures are introduced. For example, the introduction of economic instruments will be required sooner-or-later in some areas of sub-Saharan Africa to address specific emerging issues, but only where, for example, appropriate governance arrangements, management capabilities and technologies are in place to enable groundwater users to respond effectively.[84]

There are a number of economic instruments commonly used to control abstraction and to deter pollution, such as the imposition of charges and costs, and subsidies for resource conservation or pollution control technologies. For such purposes a transparent system of measurement, plus social and financial sanctions for non-compliance, needs to be put in place (and this is all the more necessary when trying to use groundwater markets to facilitate the transfer of rights to more productive uses). The public administration must discourage developmental activities that offer only small socio-economic benefits for large environmental risks. The public administration and water utilities also need to consider the possibility of payments to landowners for the stewardship of aquifer recharge areas that helps to preserve groundwater recharge rates and quality.

It is prudent to undertake feasibility analyses on the implementation of economic instruments for groundwater management that include an assessment of costs and benefits of each instrument. These should also take into account organisational capacity (for administration, monitoring and enforcement) and the long-term recurrent costs involved. The expected costs and benefits should also consider possible trade-offs between the use of economic instruments and other groundwater management approaches. While it is relatively straightforward to estimate the costs of putting a given instrument in place, it can be far more difficult to estimate the benefits. Alternative assessment options include a cost-effectiveness analysis (comparing the cost of different options leading to the same target) and multi-criteria analysis (analysing different objectives according to their ranking).

4.4.2 Imposing charges and costs to constrain groundwater abstraction

Direct resource abstraction and use fees

Imposing charges to abstract groundwater is the most direct method to ensure that an incentive exists to economise on groundwater use, as users have to pay a 'resource abstraction (or commodity) fee' based on volume used (preferably actual metered, rather than authorised, use). Small individual self-supply domestic users are usually exempted from this charge. This approach can be a very effective component of management (Case 4.3).

Case 4.3 Charging for groundwater use to control abstraction in Greater Bangkok, Thailand[85]

Greater Bangkok developed in the Lower Chao Phyra Basin, over a thick accumulation of sediments containing a series of semi-confined aquifer horizons which were increasingly exploited for urban water supply (public utility and private use) from the 1950s onwards, including municipal utility abstraction which exceeded 400,000 m^3/d by 1985. This excessive groundwater abstraction resulted in land subsidence at rates of more than 10 cm/year over substantial parts of the metropolitan area, provoking serious building and infrastructure damage, and increased risk of flooding from tidal surges.

The first attempt to address this problem was during 1985-95, through the closure of municipal waterwells and substitution of a much more expensive (imported and treated) surface water supply. However, the consequent escalating price of public water supply, lack of adequate control over groundwater abstraction, and rapid increase in domestic and industrial demand provoked a massive increase in private waterwell construction. Groundwater use increased from 200,000 to 2,000,000 m^3/d by the end of this period and cumulative land subsidence exceeded 1.0 m in many areas.

From 1995, the Department of Groundwater Resources acquired greater powers to control groundwater resource use, and mounted a concerted effort to regulate groundwater abstraction to acceptable levels. It imposed bans on the use of private waterwells in 'critical areas', progressively phased-out private industrial and condominium waterwells in areas with adequate municipal water supply and, most significantly, introduced universal metering and charging for private groundwater use. The charging system included a substantial weighting that varied spatially according to water-use considerations and to groundwater system risks. Initially the highest charge was US$ 0.09/m^3 but this increased progressively to US$ 0.42 /m^3 by 2005. The outcome has been stabilisation, and even partial recovery, of groundwater levels in the most heavily-exploited aquifer horizons, with land subsidence rates tailing-off to less than 1 cm/year in most areas. Substantial revenues have been generated for planned re-investment in strengthening of the groundwater resource administration generally, and in improving field networks for environmental and groundwater monitoring.

Unfortunately, groundwater use for agriculture, which is usually the largest consumer of groundwater resources, is rarely metered and thus controlling irrigation use is not as straightforward as that of industry or commerce. Alternative techniques to estimate groundwater abstraction for irrigation include:

- taking metered electricity use as a proxy for volume of groundwater pumped (Case 4.4), which lends itself to combined electricity and groundwater billing (and sanctioning for non-payment), although it is not possible to take account of pump inefficiency
- using the rating or capacity of waterwell pumps (m^3/hour) and the estimated or monitored operating schedule (hour/month) to estimate use, and
- estimating groundwater consumption from the average water requirement of each crop (m/month) and the corresponding areas under irrigated cultivation (m^2) estimated from remote sensing or ground-truth surveys.

Case 4.4 Combined rural electricity and groundwater use charging in Mendoza, Argentina[86]

Mendoza is situated in the Andean mountain-front zone of Argentina, a hyper-arid region with some important rivers and useful outwash-fan alluvial aquifers. The Departamento General de Irrigacion (an autonomous provincial-level water resource agency) is trying to integrate groundwater into a provincial hydraulic infrastructure with a long history of surface water management for irrigated agriculture. Its initial approach was to encourage waterwell drilling around the margins of irrigation-canal commands and to permit groundwater use if surface-water allocations were insufficient. The strategy has generally been a great success, witnessed by the fact that land prices for vineyards with groundwater use rights and irrigation infrastructure had reached US$30,000–50,000 per hectare, compared with US$ 4,000 per hectare for neighbouring barren land, by 2006. But in some areas the strategy has run into problems of increasing groundwater salinity associated with intensive groundwater use and/or excessive amplification of the land area under irrigation.

Greater control and proactive management of groundwater abstraction (and its consumptive use for irrigation) have been sought through a range of measures including:

- bans on new waterwell drilling and closure of 'legal loopholes' as regards spatial transfer and reactivation of groundwater use rights in 'special restriction areas', and
- use of satellite imagery and geographic-information systems to map the location of waterwells, the land areas they irrigate (and any conjunctive surface water irrigation), and the location of corresponding electricity meters.

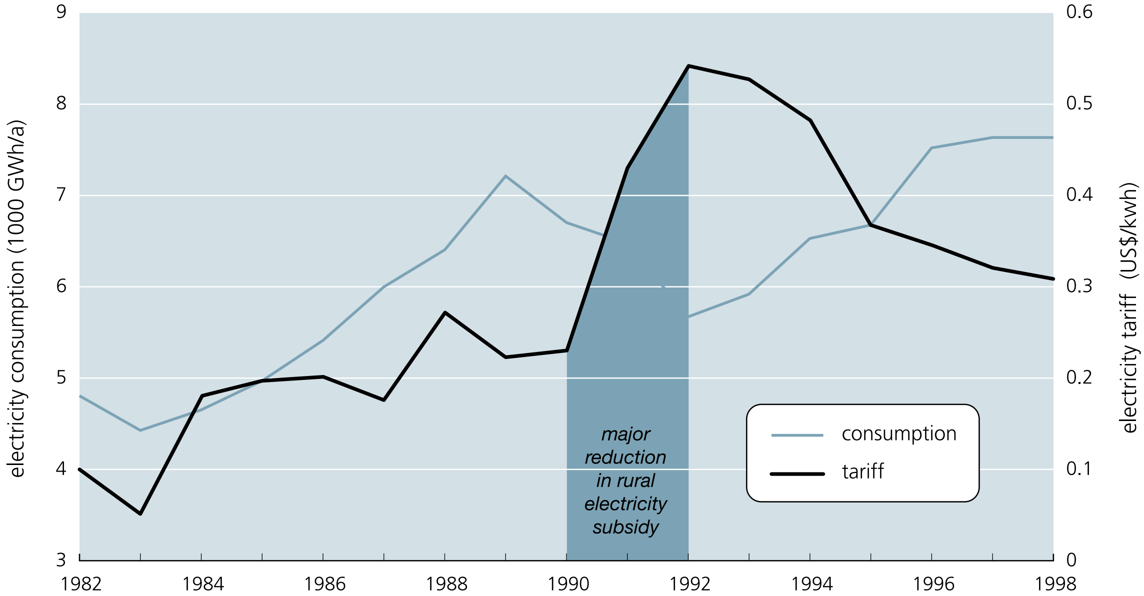
This latter approach facilitated progressive introduction from 2000 of joint charging for electricity and groundwater abstraction in priority areas, with abstraction estimated empirically from the metering of electricity. Sanctions for non-payment were applied to the energy supply. The cooperation necessary to facilitate some form of effective (albeit approximate) volume-related groundwater abstraction charging was possible even in a situation where the rural electrical utility was privatised and the groundwater resources agency was a public body.

"RURAL ELECTRICITY PRICING CAN BE A USEFUL TOOL TO INFLUENCE GROUNDWATER PUMPING TRENDS."

Indirect pricing via electrical energy tariffs

Once a waterwell is constructed, the major cost in groundwater abstraction is the energy required to lift water. This cost will depend not only on water-table depth, aquifer characteristics and well efficiency, but also on the unit cost of energy for pumping. Thus, rural electricity pricing can be a useful tool to influence groundwater pumping trends (Figure 4.2) in the absence of adequate water resources administration capacity or political will to undertake direct volumetric charging. However, in situations where the cost of energy and groundwater is a small proportion of total agricultural production costs, the scope for application of this approach may be more restricted than it first may seem.[87]

Figure 4.2 Historical influence of rural electricity tariff variations on energy consumption for groundwater pumping in Mexico. There is a positive influence of a major reduction in subsidy in 1990-1992, but this is not sustained because of other economic factors in agricultural production and political lobbying.[88]



Paradoxically, in many areas of the world, energy prices are used in the opposite way, with large subsidies to rural electricity supplies in place to decrease farming costs.[89] In many cases, these go some way to reducing the difference in price between use for irrigation of groundwater and canal-water (which itself has a long history of being highly subsidised). Although rural energy subsidies can often be politically justified, it has to be recognised that the adoption of flat-rate rural electricity tariffs (relating only to pump horse-power alone) is highly perverse,[90] since it results in farmers becoming insulated from one of the principal cost items associated with a falling water-table. It can also lead to extremely inefficient pumping practices in shallow aquifers with farmers continuing to operate waterwells at groundwater levels which are far too low and at which entry and pump friction losses are very high. Such practices would be completely uneconomic if the full economic cost of electrical energy consumed had to be met.

"ADOPTION OF FLAT-RATE RURAL ELECTRICITY TARIFFS IS HIGHLY PERVERSE."

Moreover, although it is reasonable to subsidise poor farmers to improve their livelihoods, underwriting groundwater use may not be the best vehicle because excessive abstraction can erode long-term resource availability. A preferable alternative, for example, is a lump-sum payment at the beginning of the irrigation season to cover part of their estimated energy bill, as it offers an incentive to stretch these funds and use water more efficiently. Other approaches to controlling the use of irrigation waterwells by large numbers of small farmers that have been successfully piloted in India include:[91]

- rationing of the electricity supply using a dedicated grid for irrigation pumping only, while maintaining substantially-subsidised tariffs to meet political expectations, and
- delivering electrical power to centralised village-level distributors, who each also benefit from a subsidised tariff but are responsible on a commercial basis for marketing, managing and charging for the supply they make available to village-based consumers.

In many ways the introduction of solar-panel generated energy to power waterwell pumps is a welcome development, since it will reduce (perhaps greatly in the longer term) dependence on electricity generated from fossil fuels. However, it will be very important for water resources agencies to work with power companies to introduce 'buy-back tariffs' that are sufficiently attractive to avoid solar energy being used for the continued over-exploitation of groundwater resources.

Implementation and enforcement

For groundwater resources certain steps are necessary prior to introducing economic instruments:

- elaborating, and mapping, a registry of groundwater users, use and use rights
- assessing the feasibility of waterwell metering or alternative techniques to estimate groundwater use, and
- consulting with groundwater user groups on implementation and enforcement options.

Perhaps the most crucial issues in making economic instruments work in the cause of sustainable groundwater resources are compliance and enforcement.[92] Groundwater use is a highly decentralised activity with large numbers of private users normally involved, who drilled their own waterwells, installed their own pumping equipment and follow their own pumping schedules. In the case of a major aquifer, there will be many thousands of users, and enforcement of waterwell use measurement will only be possible if there are clear incentives to comply.

The active participation of waterwell users in groundwater resource management is essential (see Chapter 5), and can be facilitated by:

- providing data on the status of groundwater resources
- promoting stakeholder participation in aquifer management associations (through which users exert peer pressure to achieve management goals)
- combining charging for rural electricity and groundwater use, and
- making increased use of innovative technologies.

One such technology is remote sensing. Satellite images are now affordable and many organisations have developed interpretation tools to map aquifer outcrops and consumptive use of groundwater, as well as direct estimation of total actual evapotranspiration at high resolution.

It will also be necessary to impose sanctions for non-compliance with groundwater regulations and charging. This requires political will, organisational capacity and a strategy that penalises very publicly a few serious cases of non-compliance.

4.4.3 Groundwater markets for trading of use rights and allocations

The establishment of 'water markets' is often advocated to facilitate resource management, since it can help to allocate water to higher-value uses in a manner acceptable to all parties and thus to promote economic growth while diminishing social tension. While this may be the case, it is very important to realise that in this form markets do not serve to restrict the total amount of groundwater abstraction or consumptive use, and indeed unconstrained they may have the opposite effect.[93] However, if they are deployed within a well-established framework of groundwater resource administration in which an enforceable cap on total consumptive use is in place (in effect as a market for a fixed volume of groundwater abstraction rights) they can become useful as a resource management tool, but even then it will often be necessary to constrain trading within specific zones of an aquifer for specific uses.

In the case of groundwater resources, the concept of the water market thus refers to the market trading of use rights or allocations, and not to the sale of bulk water supply nor to the transfer of such rights at the time of property sale and land deed transfer. A gradual approach is essential for the successful introduction of 'groundwater markets' of this type:

- first, putting into place an adequate system for measurement of groundwater use, establishing and defining use rights and water-user participation mechanisms, while giving stakeholders time to adjust to the new set of rules, and
- second, once this system is in place, making groundwater use rights tradeable.

In essence, groundwater rights trading will only work effectively if built upon a solid public administration utilising a regulatory framework for resource management. It is not a substitute for resource regulation, but a complement that requires additional effort in terms of public administration in return for additional economic benefits to society.

"THE CONCEPT OF THE WATER MARKET REFERS TO THE MARKET TRADING OF USE RIGHTS OR ALLOCATIONS."

Normally the goal will be to reduce consumptive use of groundwater in the interest of long-term sustainability of economic production and aquatic ecosystems, with groundwater rights trading providing the mechanism to ensure new and more productive users are able to gain access to the resource. To achieve this goal while protecting existing legal users and dependent aquatic ecosystems, the market will require significant regulation to:

- constrain the transfer of groundwater rights to within specific hydrogeological units (defined in space and depth on a basis of resource availability, quality trends and environmental functions) and to specified uses that do not increase consumptive use or pollution load, through standard publicised rules
- protect existing legal users (including the aquatic environment) through supplementary conditions on individual transfers established through case-by-case appraisal, and
- enforce periodic reductions of the total volume of groundwater use rights over time.

There are an increasing number of countries or federal states (notably, but not exclusively, in the EU, the USA and Australia) which have attempted, or are attempting, to introduce some form of trading of groundwater use rights or allocations. These may be applied to specific priority aquifer systems or groundwater management units, and are typically part of a broader integrated strategy for groundwater resource management. Emerging experience of groundwater markets, while limited, has shown that operational steps to help the public administration ensure success in the trading of groundwater use rights and allocations include:[94]

- public provision of aggregate information on trading volumes and trends to facilitate the market
- encouraging temporary trade (seasonal or limited period) of groundwater use allocations, since

where feasible these trades are easier to process and can be used both to evaluate and stimulate permanent transfer of the groundwater use rights

- maintaining a 'resource reserve pool', after discounting an agreed proportion of groundwater resources as environmental flow, so as to be able to cope with pressing social needs outside of the market
- ensuring that the evaluation of available groundwater resources recognises interconnectivity with surface water systems (and that no double accounting of resources has occurred) and, in turn, that the relation and interaction between groundwater and surface-water use rights trading is consistent
- having provision in drought conditions to reduce rights proportionally, since it is at these times that third party and environmental impacts of individual abstractions are most severe (or expressing rights as a fixed fraction of a variable total allocation according to antecedent conditions), and
- having adequate tracking and monitoring procedures in place to keep under continuous appraisal the modifications to groundwater abstraction and use resulting from rights and allocation trading, and its impact on the aquifer flow regime and its environmental discharges.

4.4.4 Economic instruments in the control of point-source pollution risk

The economic concept usually prescribed to constrain point-source water pollution is the 'polluter-pays-principle'. Under this principle, an industry is charged for the amount of water pollution it produces (usually when this rises above a pre-determined limit or transgresses a set water-quality standard). The less it pollutes, the less it pays. This principle incorporates the cost of pollution externalities into the cost of industrial production, rather than leaving them for society to pay.[95] Alternatively, a market may be constructed which allows for trading in 'permits to pollute'. Industries can sell their permitted allocation to others, and thus have an incentive to avoid or reduce pollution.

However, in the case of groundwater the burden of proof of pollution is often onerous, because determining who is to blame is made difficult by both hydraulic complexity and the very large time-lag in pollutant transport typical of many (if not all) aquifer systems. Thus, trading in pollution permits is not readily applicable to groundwater pollution. It is largely ineffective as regards precautionary protection of aquifers, because of the extreme persistence of some contaminants in the subsurface and the frequent impracticability of remediation (clean-up), together with the elevated cost of some pollution episodes.

"TRADING IN POLLUTION PERMITS IS NOT READILY APPLICABLE TO GROUNDWATER."

Thus in the case of groundwater the, 'polluter pays principle' must be interpreted instead as the 'potential polluter pays the costs of required aquifer protection'. These costs vary spatially with the soil profile and underlying geology. They are highest in the most important groundwater recharge areas.[96] Moreover, in drinking-water protection zones, a combination of regulatory provisions and economic instruments are often used to exclude hazardous activities.

Finally, it is far preferable to introduce economic incentives for potential polluters to improve wastewater handling, treatment, re-use and disposal in existing industrial facilities, and for the minimisation and safe disposal of solid wastes. Such incentives are especially important in areas where aquifer vulnerability assessments suggest high risk of groundwater pollution. The imposition of strong sanctions for non-compliance, in addition to incentives for compliance, is also essential.

4.4.5 Payments for ecosystem services

Payments for ecosystem services have, over the last decade, become a more commonly-used instrument to secure important hydrological services – for example the contribution that forest, wetland or grassland ecosystems make to water runoff or recharge and water quality. As explained in the IUCN-WANI toolkit *PAY*,[97] they involve the beneficiaries of water-related ecosystem services – such as hydropower producers, irrigated farmers, urban consumers or large-scale industrial water users – making cash or in-kind payments to groups that are responsible for managing the ecosystems that generate these services, for example protected area authorities or rural watershed communities.

The rationale in relation to groundwater is that, while waterwell users stand to gain considerable benefits, the land or resource managers whose actions lead to the provision of such services (basically through sustainable land and water management practices) are not rewarded for the positive externalities they generate. They thus have little incentive to engage in sustainable land and resource management practices, even though these generate valuable off-site or 'downstream' benefits for underlying groundwater systems and their stakeholders. The payments aim to reward provision of these valuable services and to compensate for the cost of providing them (relative to other, environmentally-damaging land-use options).[98]

Although there are a growing number of examples of payment for ecosystem service benefits to surface water supply, experience in relation to groundwater in the developing world in particular is more limited. A number of groundwater examples have, however, emerged including:[99]

- in a number of countries in the EU (eg. Germany, UK and Denmark) water utilities have reached agreements with land owners, who farm the 'capture zones' of their major groundwater sources, to compensate them for introducing 'groundwater-friendly' farming practices (low-density grazed grassland, reduced inorganic nitrogen-fertiliser applications, prohibiting the use of certain pesticides, etc) in return for a negotiated annual or one-off lump-sum payment,[100] and
- the development of a market for groundwater ecosystem services that would be provided by conservation of the Upper Tuul catchment in Mongolia (Case 4.5).

Case 4.5 Investment in the Upper Tuul ecosystem, Mongolia for groundwater resource conservation[101]

Ulaanbaatar, the capital of Mongolia, has a looming water crisis. Over past decades the Tuul River catchment has become progressively degraded, resulting in maximum and minimum river flows becoming more extreme and a falling groundwater table in the main aquifer of the area, whose only source of recharge is the river. Thus seasonal water shortages have become more frequent. Integrated ecological, hydrological, and economic analyses provide a strong justification for the conservation of riparian land in the Upper Tuul watershed as a central plank of water sector investments, as ecological protection of the forest and grassland in this area has a direct link to the timing and intensity of Tull river flow and the rate of groundwater recharge. Although watershed conservation alone, will not guarantee water security nor abrogate the need to develop additional water supply sources, it will allow the built infrastructure to deliver adequate water to Ulaanbaatar for a considerable period.

Investing in watershed conservation had the potential to generate significant downstream benefits and save substantially on downstream costs. If the Upper Tuul catchment continues to be degraded, the cost to national economy from the loss of ecosystem goods and services was estimated to be around US$27 million/year (at 2009 prices). In contrast, every US$1 invested in upper watershed conservation should generate additional urban water benefits of US$15, such that a fully-protected upper watershed should generate incremental goods and services worth US$37 million/year in the longer-term.

4.5 Alignment of Macro-Economic Agricultural Policy Incentives

Since irrigated agriculture is by far the predominant consumer of groundwater resources in many countries, macro-economic agricultural policy is a very important driver of groundwater use. Improving the alignment of related policies with sustainable groundwater management objectives would greatly facilitate local management efforts.[102] For instance, eliminating guarantee prices or subsidies for the cultivation of highly water-intensive cropping (eg. rice, sugarcane or alfalfa) in semi-arid countries will greatly aid groundwater resource management. Moreover, even international trade policy can have an indirect impact on groundwater use by creating barriers to the import of high water-use crops.

The introduction of modern irrigation technology and improved management of irrigation water should facilitate major energy savings on groundwater pumping, and also under some conditions lead to important groundwater resource savings (in situations where pre-existing irrigation practices resulted in large non-beneficial evaporation losses). Financing for improvements in irrigation technology, and their possible preferential implementation through subsidies and grants, is potentially an important groundwater management measure, providing that there is clear scientific evidence of non-beneficial losses. It should be noted, however, that reductions in irrigation water returns to groundwater (commonly a major component of so-called irrigation 'losses') will save pumping energy but not water resources.[103]

"MACRO-ECONOMIC AGRICULTURAL POLICY IS A VERY IMPORTANT DRIVER OF GROUNDWATER USE."

Another important issue is the control of non-point pollution from agricultural practices via macro-economic incentives.[104] Consideration should be given to eliminating the widespread subsidy of certain types of fertiliser and pesticide, which can cause serious complications for groundwater quality if used excessively or inappropriately. Crop subsidies tend to lead to monocultures over large land areas almost regardless of soil and climatic suitability, which are sustained by heavy applications of fertilisers and/or pesticides (themselves sometimes subsidised). This can have a major negative impact on groundwater quality due to agrochemical leaching, the cost of which was not initially taken into consideration.[105] In the northern states of the EU in particular, a start has been made on voluntary land-use management actions following 'best agricultural practice' guidelines to reduce plant nutrient and pesticide leaching, although in highly-vulnerable groundwater recharge areas this may not be fully effective.[106] Action is thus also being taken to re-target agricultural subsidies, and thereby provide incentives for individual farmers to reduce agrochemical leaching as a 'groundwater ecosystem service', and there may also be an argument for going further and imposing an 'environmental tax' on fertilisers and/or pesticides to generate funding for groundwater quality monitoring.

4.6 Checklist: Creating Economic Incentives

Understand the economic value of groundwater

- Make an inventory of how groundwater is being used and the social and economic outcomes of groundwater use. Assess the main social and economic drivers of excessive groundwater use and pollution risk.
- Undertake studies of the economic value of groundwater. These require expert analysis by environmental economists working with hydrogeologists. Valuation studies apply methods that estimate, in various ways, the value of benefits gained from putting groundwater to particular uses, less the costs of abstraction and management.

- Factor ecosystem valuations into assessment of groundwater value. Account for values both of ecosystem services dependent on groundwater discharge ('groundwater-for-nature') and of ecosystems that sustain groundwater recharge ('nature-for-groundwater'). Valuation of ecosystems provides information needed to prevent the costs and benefits of conservation from being left out of decision-making when weighing-up options for management of groundwater use and recharge.
- Communicate information on the economic value of groundwater to policy makers, planners and stakeholders to support dialogue and to help them to decide and agree on priority uses for groundwater and incentives for more sustainable and equitable groundwater management.

Improve the alignment of macro-economic and agricultural policies to groundwater management

- Review economic and agricultural policies to identify where improvements can be made to facilitate groundwater management. In particular, consider whether there are subsidies, price guarantees or trade policies that encourage water-intensive cultivation in agriculture, or whether subsidies and incentives for fertiliser or pesticide use lead to negative impacts on groundwater quality.

Identify economic incentives for groundwater management and protection

- Consider which economic instruments will create effective inducements or penalties to address over-exploitation and pollution of groundwater. Imposing fees to abstract groundwater according to volume used is the most direct means of creating incentives to reduce consumption. An indirect alternative is to incorporate abstraction fees into pricing of electricity in rural areas. In designing such incentives, however, be sure to include protections for poor or vulnerable groups through exemptions or subsidies.
- Consider the use of 'groundwater markets' as a mechanism for encouraging efficiency and allocation of water to higher value uses, only where a system of establishing and defining groundwater use rights is in place. Making use rights tradable then will require an effective and appropriate public regulatory system including protection for poor and vulnerable groups, establishment of environmental reserves and provisions to reduce water allocations during drought periods.
- Ensure that mechanisms are in place to sanction polluters using the 'polluter-pays principle', and extend the principle to encompass the concept that the 'potential polluter pays for appropriate groundwater protection' according to the local hydrogeological setting. Consider providing support for compliance through incentives for investment in wastewater treatment, recycling and disposal such as subsidies for pollution-control technologies.
- Assess options for applying payments for ecosystem services to groundwater management and protection, particularly for protection of groundwater recharge and quality in highly-sensitive groundwater recharge zones. Applicable mechanisms could compensate land-owners in these areas for 'groundwater-friendly' management through cash or in-kind payments by groundwater users.

Put in place the enabling environment for successful application of economic incentives

- Undertake feasibility analyses on the implementation of proposed economic instruments that compare their costs and benefits over the long-term and assess whether needed organisational capacities are in place.
- Ensure that monitoring and data management facilities are in place to meet the operational needs of economic instruments, including for example metering or remote-sensing technologies.

- Ensure that there are effective means of organising the participation of groundwater users in the design, implementation and enforcement of economic instruments.
- Put in place arrangements to promote and enable compliance with regulations and applications of economic instruments, while ensuring that there are sanctions and penalties that are effectively applied for non-compliance.

Chapter 5

Social Organisation Around Groundwater Management

5.1 Participation in Water Governance

Because water is necessary for life, it is everybody's business. Everybody must be brought around the 'water table' to discuss its use and management. Effective social organisation is thus a prerequisite for good governance of groundwater resources. Why? Why not leave management of this invisible, complex resource to the technical and legal experts? Because it is a life-giving resource sought by everyone, from poor families to powerful agricultural and industrial companies. Managing it in a way that is both equitable and sustainable over generations requires the involvement of all stakeholders. In this sense managing groundwater requires processes for managing change.

Using social organisation concepts for effective water governance facilitates informed decision-making and eases conflict resolution. Social organisation involves setting up space and mechanisms that allow for the active involvement of all stakeholders in dialogue, planning, decision-making and implementation of activities around a certain issue in a way that, as much as possible, addresses each stakeholder's interests and concerns.

Participatory platforms allow the voices of relatively powerless groups, such as women and vulnerable people, to be heard. Participation offers people the opportunity to know about their rights and roles, meet their responsibilities, attain ownership, and claim their rights. Through this process, all stakeholders become more accountable to good groundwater management. Using a participatory social process may require changes in attitudes and behaviour among individuals, institutions, professionals, and decision-makers – and these changes will not happen overnight. However, once social organisation processes become the norm, they usually persist because they are well-liked and effective.

"PARTICIPATORY PLATFORMS ALLOW THE VOICES OF RELATIVELY POWERLESS GROUPS TO BE HEARD."

Local or communal governance, as used in tribal or other indigenous settings, is the oldest form of water governance. As nation-states formed, water management usually became the responsibility of national governments because groundwater was recognised as a common-pool resource.[107] In their efforts to manage it, governments have taken different tracks including privatisation (granting water rights to landowners or others who purchase them); strict government control over allocation; or even allowing a free-for-all of water abstraction, which can result in a 'tragedy of the commons'.[108] In legal terms, public ownership of water resources has become increasingly favoured, however, under the concept that it is controlled by the State for the common good.[109]

In many cases, however, government management practices are bureaucratic, top-down, and biased by high-level vested interests, while often giving little attention to community concerns. Poor management practices, lack of institutional coordination, policy deficiencies, and power relations at the local level all add to inequity in situations where groundwater is unavailable, especially to poorer people in urban settings and small-scale farmer families in rural areas.

Because water is so important to life, people will protest over misuse of this resource, possibly resulting in conflict, acrimony, legal battles, and even violence. Conflict also arises when water is an ingredient in creating wealth. For example, in the aquifer underlying Jordan's famed Azraq Oasis (Case 5.4), part of which is a Ramsar wetland site, armed government forces trying to identify and shut down illegal wells that were taking water for unsustainable cash crops were faced by armed workers from the large farms. Armed conflict was avoided only when the government pulled back its forces.

In contrast, local governance approaches guide stakeholders to develop shared responsibility and norms to manage the common resource for the common good. In such an approach, people do not simply elect representatives to do the work of governing, but they remain active participants in governance, especially around crucial local issues, such as the management of their water supply. Local governance involves concepts of social organisation, negotiation, fairness, and stewardship. It not only allows many voices to represent different interests, it pushes them to come to decisions that meet the needs of the present and encourages them to accommodate the needs of the future, both in their own lifetimes, and those of their descendants.

5.2 Principles of Social Processes for Change

How can we encourage an inclusive social process that results in better and more equitable development of groundwater resources? The answer rests on eight principles that form the major conceptual building blocks of an effective social organisation process.

Principle 1: Include vulnerable groups – The social process must be inclusive, admitting all stakeholders, including the powerful, but also, and especially, those most affected, such as women and small farmers. The most vulnerable groups must be included, even if they do not immediately come to mind as 'stakeholders'. Special emphasis must be given to the needs and rights of the poor and women and special efforts made to bring them into the management process. Recognise that they may need financial assistance and capacity building to even participate in the process.

"THE PROCESS MUST BE WHOLEHEARTEDLY SUPPORTED BY LOCAL AND NATIONAL GOVERNMENT."

Principle 2: Include the environment as a stakeholder – As management plans must leave enough water to sustainably maintain ecosystem processes, the environment can be considered a stakeholder in any dialogue. It may be represented by an environmental advocacy group, but whether or not such a group is present, ensuring adequate water to sustain ecosystems must be an objective of any process. The process is not about stakeholders simply dividing up all water resources among themselves, but rather about how to maintain an equitable and sustainable groundwater system that includes supplying ecosystems with needed water.

Principle 3: Get the support of those in power – To be effective, the process must be wholeheartedly supported by local and national government authorities. It should not be used simply to defuse tensions without making fundamental change. Those in power must be willing to accept the decisions developed through the social organisation process. Case 5.1 gives an example of an elaborate social process involving computer-based scenarios that succeeded in its efforts to develop a plan, but failed when the plan was later disregarded by heads of a government department that was not involved.

Case 5.1 Government department disregards stakeholder action plan, Kiribati[110]

In South Tarawa, the capital of the Republic of Kiribati in the Pacific, government and landowners were in conflict over who owned the rights to groundwater.

A government agency and an international non-governmental agency initiated an intensive process to facilitate dialogue among government, institutional, and community representatives. The process featured a role-play game with computer based scenarios that could be played out based on different decisions. The workshop was a success and developed an acceptable plan of action. However, the Sanitation, Public Health and Environment Department (SAPHE) later disregarded the plan because of pressures from above to proceed with acquiring more groundwater. In retrospect, it would have been beneficial to have representatives from the higher levels of SAPHE and/or the national government participating in the programme to ensure commitment and ownership over the process and outcomes.

Principle 4: Institutionalise the process – Community capacity building and empowerment will rarely be effective and sustainable if it is not supported by government policies and legal frameworks.[111] Local government that engages with the community in planning must have adequate political, administrative, financial, and fiscal authority, supported and endorsed by the national government, to carry out the decisions made. Local government needs to have both the authority and resources to plan and coordinate local strategic plans and provide local frontline services. For example, in the Marj Sanour watershed in Palestine (Case 5.5), a participatory watershed committee was institutionalised and now represents the watershed's seven villages in wider fora. The villages now have a legitimate pathway to present proposals to the government agencies and the donor community, based on watershed studies and the watershed development plan.

"PEOPLE WITH DIFFERENT INTERESTS MAY HAVE DIFFERENT PERCEPTIONS OF THE SAME PROBLEM."

Figure 5.1 It's all how you look at it

Principle 5: Facilitate respectful listening and shared solutions through open dialogue – This process requires development of a dialogue among participants who listen to, value, and understand other points of view and even possibly change their attitudes – or at least their behaviours – in response to others' viewpoints and needs. It is important to be aware that people with different interests may have profoundly different perceptions of the same problem and thus have difficulties even seeing how others may look at that problem. The idea of differing perceptions is illustrated in Figure 5.1 in which one can see – but not at the same time – either a vase or the silhouettes of two faces.

In a dialogue, participants must recognise others' perceptions and points of views, jointly analyse problems, and come to shared solutions. Most diverse groups, and especially groups whose members are already in conflict or have conflicting interests, may not be able to achieve this perspective without help. Thus, difficult negotiation processes and finding win-win situations usually require a professionally trained facilitator with no direct stakes in the issues to be resolved and to act as a guide through the entire process.[112]

Principle 6: Create ownership – Most people are unlikely to participate in dialogue about problems and possible solutions in groundwater management unless these relate to daily concerns. People are only willing to participate when the issues deal with urgent problems of today and of the near future, and the time spent on discussions leads to concrete results. Engaging people in dialogue through a practical and factual visioning, assessment, strategising and planning process has proved to be effective. Participants then 'own' the decisions taken together for concerted action.[113]

Participating in such a process can make government agencies more accountable to the decisions taken. Participating community members ensure that their interests and benefits, as well as their rights and access to the groundwater resources, are taken into account. This result, plus the growing sense that they can influence decisions as they build their own capacities, are key reasons that community members participate and eventually assume accountability for managing their groundwater resources.[114]

Principle 7: Build capacity and persevere – The participatory process takes time, but once the foundation is established, this process gets better results than the old way of working because it reduces conflict and focuses communities on the long-term management of resources for the benefit of the community as a whole. Moreover, it ensures the buy-in of government authorities (local and national) as they recognise that working in this way is more effective and is improving their credibility among local communities.[115]

Such a capacity-building and empowering process starts by exploring the substantial skills that communities already have as well as their ability to innovate. Recognising and making use of different knowledge systems (of for example farmers, extension officers and researchers) will contribute to necessary innovation both in technology and participatory processes.[116] Intentional capacity building through on-going reflection and documentation of changes are part of the social organisation process.

Building capacities for social organisation and local water governance around groundwater management is a continuous process. It may take a long time to replace the old way of doing things, but once established, the social organisation process can go on forever as a new way of doing things.

"THE PARTICIPATORY PROCESS TAKES TIME BUT GETS BETTER RESULTS THAN THE OLD WAY OF WORKING."

Case 5.2 Persevering for social change, Oregon, USA[117]

For example, in the State of Oregon, USA, a county board of commissioners appointed a 20-member task force to develop a far-sighted plan to manage an aquifer for the future. The task force opened the process to the community through 'collaborative learning,' a learning-based form of public participation, which draws on systems thinking, conflict management, and alternative dispute resolution. After four years, the programme was still in its infancy, but growing public awareness of the need for wise groundwater management had led to passage of allocations of funds by the legislature for regional aquifer recovery assessment.

Principle 8: Know that a good social process is a good investment – The social organisation process requires financial and institutional investment, but it is less costly than many alternatives that involve protest, conflict, violence, property damage, delay, lost elections, and continuing disagreement. Although social organisation approaches may seem expensive and time intensive at the start, their cost is relatively small when compared with the alternatives as well as to the overall cost of investments in water infrastructure. They have the potential to pay off in terms of effectiveness, ownership, and sustainability of results, as shown by the example given in Case 5.3.

Case 5.3 Facilitating social organisation pays back

Cost calculations were made for up-scaling a participatory stakeholder-led planning approaches in the water sector in Jordan. In 2007, a GTZ- funded four-year drinking water infrastructure project was proposed in four governorates with an approximate budget of €4 million/year. The cost of facilitating a social organisation/planning approach would have been €240,000 per year, assuming 30 communities per governorate. Per community, the cost of such a social organisation process would be roughly €8,000 per year per community, or €2 per year per person for an average of 4,000 inhabitants in each community. An investment in such a facilitation processes would be about 6% of the total investment cost of the drinking water networks proposed - a worthwhile option. Such an investment would have created greater ownership for the installation and maintenance of the drinking network and hence less repair cost and higher sustainability.

5.3 Activities in a Management and Change Process

Building on the principles in Section 5.2, a practical sequence of steps is needed for developing a participatory social organisation process around groundwater resource management. The process can be managed by a government agency, a non-governmental organisation or a consultancy office specialised in facilitation processes, provided it has been given the authority and agreement to do so by the major stakeholders and the relevant government agencies. The process sets up multi-stakeholder platforms in which issues can be discussed and decisions made.[118]

Three groups of activities (sub-processes A, B, and C in Table 5.1) can, in practice, be implemented in parallel, in a more or less iterative way. Sub-process A, in which stakeholders at different levels are identified and engaged, is a pre-requisite for meaningful planning and decision-making in sub-process B. Learning, capacity building, reflecting, documenting, and sharing in sub-process C take place throughout.

Table 5.1 Summary of sub-processes and steps in a management and change process

A. Facilitate stakeholder analysis and engagement (Section 5.3.1)	**B. Plan and make decisions for concerted action** (Section 5.3.2)	**C. Learn, document, share, and build capacities** (Section 5.3.3)
• Map stakeholder interests at different levels and scales and ensure in-depth stakeholder analysis	• Engage in a participatory planning and decision-making process with visioning and scenario-building for at least the mid-term (5 to 10 years)	• Document and share the development and decision processes
• Create relevant stakeholder platforms	• Develop shared and agreed-on basic information base	• Engage in capacity building and empowerment
• Through effective process facilitation ensure participation of different interest groups in the local platform and their representation in other platforms	• Undertake more detailed social analysis (water access and rights as well as local level accountabilities, differentiated by gender)	
• If possible, institutionalise agreed groundwater resource management arrangements	• In a genuine participatory way come to shared decisions and commitments preferably in the form of groundwater management plans at both community and broader levels (watersheds, districts)	

5.3.1 Stakeholder analysis and engagement

The first three principles of social organisation involve getting the right players to the 'water table' and making sure they are committed to a decision-making process. Doing so begins with knowing how to identify and engage stakeholders and how to map out their water use, rights and responsibilities, and knowledge of the resource.

Mapping stakeholder interests

A conscious effort is required to 'map' the different levels and stakes involved and to analyse their interests, capacities, mandates, roles, tasks, and responsibilities. A good stakeholder analysis could include urban households, the informal sector of small and medium enterprises that use water for their production processes (breweries, food production processors, laundry, quarries, car wash, urban greening and many others), large institutions like hospitals, schools, hotels, and all the heterogeneous groups in villages and towns in rural areas. Generic groups of users (e.g. farmers, urban households) cannot be considered as homogenous parties. Depending on each situation and scale, a further refinement of user and management groups needs to be made, taking account of possible differences in interests and priorities between men and women.[119]

Case 5.4 shows the problem of leaving out important stakeholders, who were outside the immediate area of interest, but who make use of the aquifer, as well as the problem of dealing with stakeholders who will not abide by decisions.

"A CONSCIOUS EFFORT IS REQUIRED TO 'MAP' THE DIFFERENT LEVELS AND STAKES INVOLVED."

Case 5.4 Stakeholder inclusion in management of the Azraq Oasis, Jordan

The legendary Azraq Oasis (Qa'a Azraq) is one of Jordan's largest sources of good quality groundwater. The oasis is the lowest part of the Azraq basin, which stretches from the mountains of Syria (the main water recharge area) across Jordan towards the border with Saudi Arabia. Because its water is so close to the surface, Qa'a Azraq has been inhabited since the Stone Age. Listed as a Ramsar site, it is a marsh in a semi-arid region that attracts birds migrating from Africa to Europe.

The aquifer is now seriously over-pumped, including through illegal wells, with water going to the city of Amman for drinking water and to large commercial farms to irrigate vegetables and fruit trees. Total abstraction is almost three times higher than recharge. In the early 1990s, the four natural springs in the middle of the Azraq Oasis discharging fresh, good quality water for thousands of years, dried out completely. Local people have been left feeling that their livelihoods are at stake because of water scarcity and soil salinisation associated with degradation of the aquifer. Large landowners, however, through their influence in the capital, are a powerful group.

In 2007, a first attempt was made to establish a stakeholder platform to identify solutions. The focus was on the oasis, including local water and land use concerns and the preservation of the Ramsar site. Unfortunately, the forum did not become institutionalised and made little progress. Later, the scope of the forum was enlarged to the entire groundwater basin. An in-depth analysis was made of stakeholders' interests, problems, roles and political relationships. In this new platform, local residents as well as technical government departments were more involved and better represented. A more comprehensive planning process involved detailed visioning, scenario-building and strategising. The long-term vision was updated to include wider concerns including the drinking water needs of Amman and the conflicting interests between the local residents and the large land holders.
Much energy has been put into a sincere dialogue and the development of a sound vision and plan, supported

by most government officials involved. The process has given the local community a larger voice and access to funding for projects in their interest. However, the government has not made the difficult decision to curtail the over-extraction of water by the large farms. Nevertheless, the fact that many stakeholders are united in a common vision should eventually force action from the government. The Azraq Dialogue has been instrumental in the establishment of the Highland Water Forum (HWF) for the Azraq Basin by the Jordanian-German Water Programme and hosted by Jordan's Ministry of Water and Irrigation. The HWF should foster capacity building, shared learning, networking, and exchange of experience between the major actors in the ground water sector in Jordan.

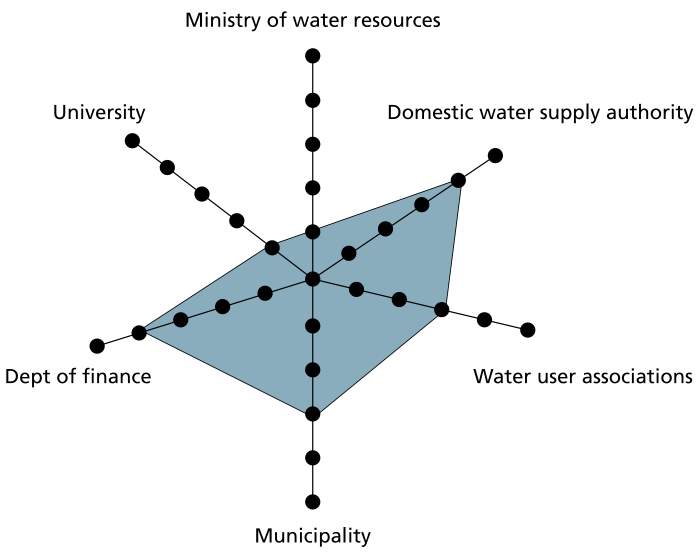
Assessment of different stakes at different scales

A key challenge in groundwater management (and better water governance) is to break down sectoral barriers to planning and decision making, and to provide common platforms and frameworks for the development and management of all water resources. To help meet this challenge, for each water stakeholder or user group, including women and men and those representing ecosystem needs, organisers need to assess:

- **what rights each really has in formal legal terms but also in terms of practices and customary conventions**
- **how each organises access to water and how it is transported from source to the point of us.**
- **how accessible are private licensed or illegal wells to others**
- **what tasks are given to whom to distribute water (e.g. in an irrigation system or in a drinking water network or even through tankering from a filling point), and**
- **who has the influence and power to make decisions, formally but also socially and politically.**

Many tools are available to map, rank, visualise or describe this information. For instance, Figure 5.2 depicts one tool, the radar diagram, in which staff or participants can map how much influence they perceive each key stakeholder has in groundwater decisions.

Figure 5.2 Example of a radar diagram of key stakeholder influence on domestic groundwater supply (note: 1 is low influence; 5 is high influence)[120]



Avoiding three wrong assumptions
Understanding dependency and hierarchical relations, political affinities, hidden conflicts, as well as opportunities for solutions, is also part of a stakeholder analysis. Three common, but wrong, assumptions can impede stakeholder mapping efforts at the local level: (1) assuming that a local village is a homogenous entity, (2) assuming that all necessary information can be obtained from the head of the village or village council, and (3) assuming that men's opinions also reflect those of women and all social or user groups in the village.

Looking for and examining existing forms of organisation
Most places have existing 'stakeholder platforms', groups of stakeholders that already work together on water issues, that may or may not be representative of all stakeholders. These groups must be considered, but analysed for their inclusivity and effectiveness.

> *"THE ART OF SOCIAL ORGANISATION IS BASED, FUNDAMENTALLY, ON STRENGTHENING COMMUNICATION."*

It does not make sense to duplicate existing forms of organisation. The question of functionality and effectiveness however remains, and an inquiry for existing bodies needs also to look closely into how these bodies function in reality. To what extent do they exist merely on paper, how much are they recognised and trusted by different parties, do they include all actors that are considered important? What authority do they have for planning, problem-solving, conflict resolution, decision-making and implementation? At lower levels of scale, is differentiation made among different interest groups in local communities?

Engaging stakeholder platforms in a social organisation process
The art of social organisation in groundwater management is bringing most of the stakeholders together in a meaningful way that makes sense to everybody and where everybody feels committed to contribute to a shared vision and objectives with the specific resources he or she has available. Stakeholder Dialogue and Concerted Action (SDCA)[121] is an effective approach. It is based, fundamentally, on strengthening communication among stakeholders, to enable them to understand each other better and to take more effective and coordinated actions.

A 'stakeholder platform' is a group of stakeholders with a common interest that can make decisions and undertake actions together. Critical to success is that stakeholders share important concerns – for example, concerns about scarcity and quality of groundwater – and acknowledge they cannot solve them alone. Also critical is that the decisions made through the stakeholder platform are binding on all. Important decisions must not be made outside the platform.

Because management of common-pool water resources is such a common concern, throughout the world, traditional or indigenous platforms have been devised by local communities (e.g. aflaj systems in Oman and Yemen), without official government mandates. Experience from many parts of the world shows that these types of stakeholder platforms are the most effective locally and can often be knit into a larger network.

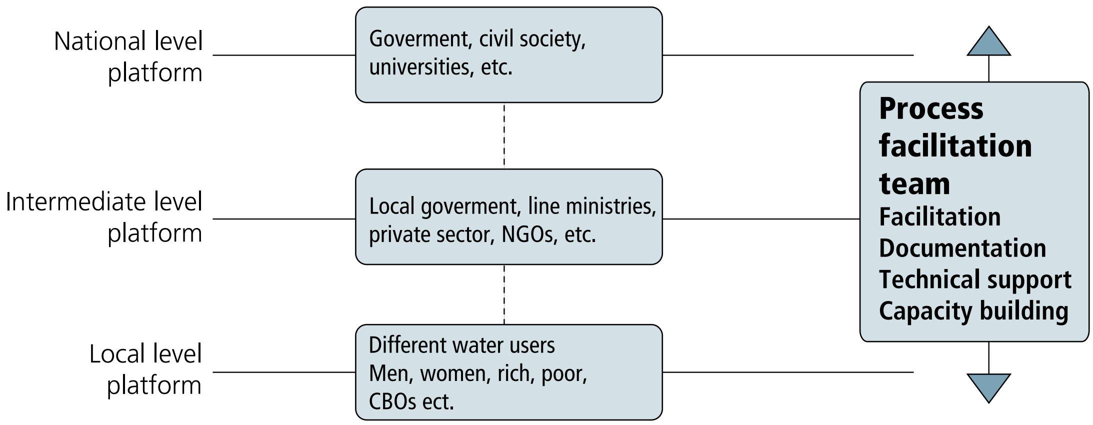
The core belief underlying such platforms is that (ground) water stakeholders who communicate effectively with each other on a regular basis in the structured form of a joint platform will find locally appropriate and concerted ways to solve pressing water-related problems. It is important to ensure that the interests and priorities of women are equitably considered and that local stakeholder platforms are gender sensitive. Building on small successes, such a platform can be institutionalised into more formal frameworks (a watershed committee, a groundwater basin committee, a community water supply network, an inter-ministerial working group for management of a groundwater basin).

In principle, the SDCA process aims to identify (and where necessary initiate) and strengthen stakeholder platforms at local (village/town, small watersheds), intermediate (district/governorate, river or groundwater basin), national or even trans-boundary levels – and to ensure smooth flows of communication within and between these levels (Figure 5.3).

"BRINGING DIFFERENT ACTORS TOGETHER REQUIRES THE SKILLS OF AN EXPERIENCED FACILITATOR."

Following the concept of subsidiarity, that decisions should be made at the lowest possible level,[122] stakeholder platforms are best organised at the level where shared interests can be focused and made relevant for the required scale of operations. However, creating the necessary *vertical linkages* between these more-or-less *horizontal platforms* is essential to ensure that higher levels are informed about local concerns and priorities and understanding at local levels of the bigger picture, enabling all to better relate their priorities to those at other scales (Figure 5.3).

Figure 5.3 Typical levels of stakeholders in water governance, with the Process Facilitation Team enhancing dialogue and concerted action within and between stakeholder platforms at different levels.[123]



Ensuring effective process facilitation

Bringing different actors together, recognising their perceptions, negotiating conflicting interests, and finding win-win solutions requires the skills of an experienced facilitator with no direct stakes in the issue to be resolved. A facilitator can help others listen to each other, find common ground where possible, or at least come to reasonable compromise. Good process facilitation can contribute to better planning and implementation of activities.[124] Process facilitation has a cost that will pay-off in the long-term by making the process run more smoothly and attaining better shared results. Without high-quality process facilitation, a participatory stakeholder-led planning process for (ground) water management is unlikely to succeed.[125]

Process facilitation goes beyond facilitating single meetings and has to ensure that the whole process functions. The process facilitator's job involves stakeholder identification, team building, conflict resolution and mediating, and guiding and brokering processes in planning and decision making among government agencies (officials), local communities (end-users, both women and men), and other relevant parties.

Process facilitators help the different actors articulate their interests, perceptions, preoccupations, assumptions, and judgments. They identify opportunities to improve the exchange of information, social organisation, and decision-making among stakeholders. They may create awareness about constraints and opportunities that affect the performance of relevant actors.

"IN CONFLICT-SENSITIVE PROCESSES, A NEUTRAL FACILITATOR IS A KEY CONDITION FOR SUCCESS."

A good facilitator can identify potential actors who do or could act effectively together to remove constraints and make use of new opportunities. A well-trained facilitator can manage conflict and resistance to change which often arise when people perceive a threat (physical, emotional, power, status, etc.) to their well-being and which are usually detrimental to achieving positive, shared outcomes. Often seen as a purely negative element in change processes, conflict, or potential conflict can, with good facilitation, and some luck, become a powerful agent for change in its own right.[126]

Experiences indicate that in conflict-sensitive processes, a neutral facilitator is a key condition for success. Facilitators should create an environment of trust, transparency, and respect in which shared visions and goals can be developed. They need to know the different parties and their relationships as well as the institutional environment and interests of the issue at stake. At the same time they need to be a strategist and have a vision for possible outcomes. Box 5.1 describes how to select a facilitator.

Box 5.1 Selecting a process facilitator

Process facilitators should be acceptable and credible to both government agencies and community organisations in order to have the leverage to play this role.[127]

In selecting an institution to provide process facilitation services, look for one that is: (1) relatively neutral with no specific sector agenda and independent from the government; (2) well-rooted in a country's civil society; (3) unconventional and non-bureaucratic; (4) accepted by most, if not all sectors in civil society and government; and (5) experienced in working with local communities while taking gender equity into account.

The institution should have experience in communicating with government agencies and community groups; general knowledge about the water sector; experience in conflict resolution and management of change processes; and familiarity with participatory and stakeholder approaches.[128]

5.3.2 Planning and decision-making for concerted action

Planning for water resource management

With stakeholder engagement in social organisation emerging, a well-structured approach for planning and decision-making is needed to identify and agree on concerted actions for improving groundwater management. The EMPOWERS Planning Cycle[129] provides such an approach. It comprises an iterative sequence of six steps (Figure 5.4) to facilitate and make concrete and tangible the work of multi-stakeholder platforms:

- Step 1 - shared problem analysis and visioning
- Step 2 - assessing and shared data collection and analysis
- Step 3 - strategising and scenario building
- Step 4 - planning
- Step 5 - implementing concerted action, and
- Step 6 - reflecting on the process.

Figure 5.4 The EMPOWERS planning cycle for integrated water resource management (IWRM)

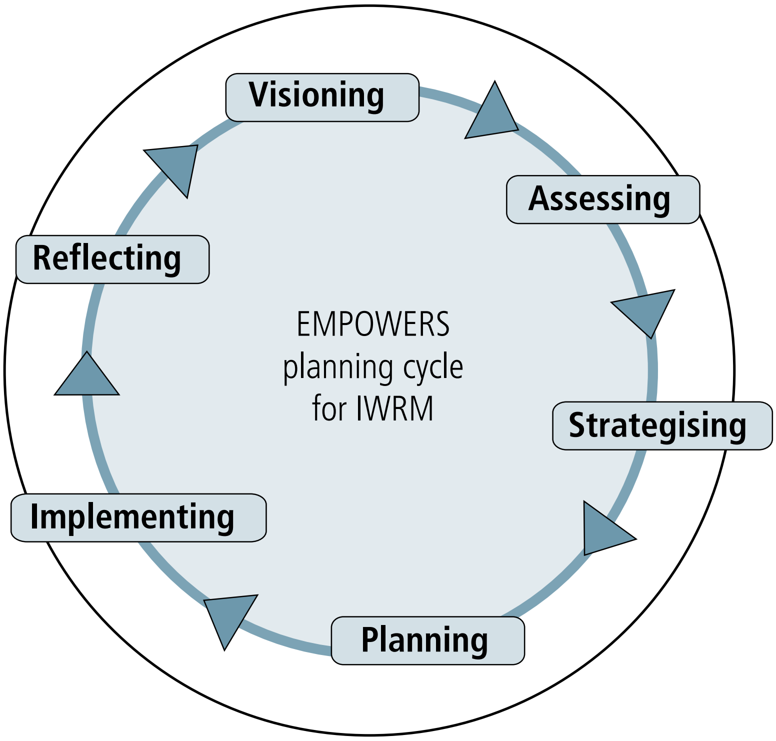


Table 5.2 summarises these six steps as well as their objectives, how they can be used in planning, and their outputs as applied to a social organisation process around groundwater management. The EMPOWERS Planning Cycle (Case 5.5) is designed to use visioning of the future of groundwater management as a basis for building scenarios around which strategies for change can be built. Critically, these are complemented by processes to build and reinforce local accountability and ownership of activities through genuine and gender-balanced participation in planning.

Case 5.5 Using the EMPOWERS planning cycle in the Marj Sanour, Palestine

Marj Sanour is a small watershed in the Jenin governorate in the northern part of the West Bank in historic Palestine. The watershed covers about 60 km^2, with a valley floor of 16 km^2. Much of the surrounding hills are planted with fruit orchards, dominantly olives, the most important cash crop in the country. Seven villages are situated in the watershed with a total population of 24,000.

The valley has no surface water outlet and the valley sometimes fills like a bathtub because surface run-off from the hills, caused by poor land management and water conservation, cannot penetrate the heavy nutrient-rich clay soils of the valley. Recharge of the aquifer is limited and most water is lost to evaporation and cannot be used in the following dry season when there is water scarcity. Thus, farming is limited both by the flooding and the lack of water in the dry season, which in turn puts further pressure on groundwater. It was urgent to understand the options for dealing with both water scarcity and flooding, two main problems that were blocking development and to find watershed management solutions with benefits for all stakeholders. The watershed development plan should enhance sustainable use of surface water while diminishing the pressure on the groundwater reserves.

Application of the EMPOWERS Planning Cycle began with an in-depth stakeholder analysis involving most relevant ministries – the Palestine Water Authority (PWA), Ministry of Agriculture (MoA) and Ministry of Local Government (MLG) and Environmental Quality Authority (EQA) – at both governorate and national levels, water and land use groups and other community based organisations (CBOs), village and municipality councils, non-governmental organisations (NGOs) working in the area, and a Jenin-based university. The analysis looked at how these groups related to the watershed in terms of their tasks, roles, interests and mandates. It also looked at information flows among them and their decision and coordination patterns.

Two platforms ensured participation of different local interest groups as well as the buy-in of government institutions. An informal local stakeholder platform was set up for village council and civil society groups in the seven villages, NGOs working in the area, and officials at the governorate level. A national steering committee was also created involving community representatives, NGOs and national government agencies.

Through the local platform, a participatory planning and decision-making process was used to work towards a vision for a long-term management plan for the Marj Sanour watershed. At the same time, and with the support of the national steering committee, a shared information base of scientific and engineering data was developed as well as a decision support system for planning and testing different scenarios and strategies under which the vision for the watershed could be achieved.

Following intensive discussions, seven villages decided to develop the Marj Sanour Watershed Committee to coordinate and implement activities for all water and agriculture related activities, from drinking water supply and irrigation practices to soil and water conservation in the hilly parts of the watershed.

The Watershed Committee, formally registered with the government, represents the villages in wider forums where it can present proposals to government agencies and the donor community, based on the completed studies, results from the decision support system and the watershed development plan.

To solve the flooding problem and carry over water to the dry season, the stakeholder group – using the mutual planning and multi-criteria analysis – recommended several projects centring on stopping floodwaters before they reach the valley by improving the terracing and water retention of soils in the hills and by building cisterns in the hills to hold water. They also recommended building artificial aquifer recharge wells and more cisterns in the valley to carry over water to the dry season. Thus, through land management (rehabilitation and reclamation and water harvesting), the water can be more evenly distributed over time to benefit both the hill and valley dwellers as well as the ecosystems in the watershed, while releasing pressure on groundwater reserves.

Table 5.2 Stakeholder Dialogue and Concerted Action (SDCA) and the EMPOWERS Planning Cycle[130]

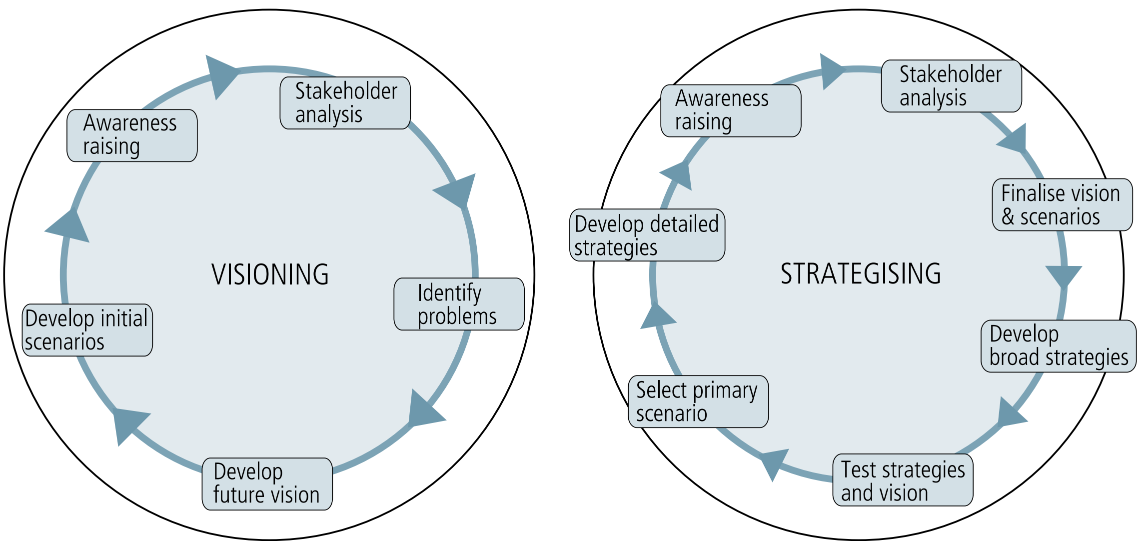
Step	Objectives	Actions (SDCA)	Outputs
1. Visioning	• Stakeholders involved and interested • Broad scope of work identified and agreed	• Stakeholder identification and analysis • Problem analysis • Initial visioning and scenario building • Identifying priority communities for action	• Stakeholder platforms • Problem trees • Initial visions at district level • Initial scenarios
2. Assessing	• Main causes of water problems identified • Agreed and shared information-base developed	• Stakeholders involved in: information collection and analysis; quality control and cross-checking • Assessment of accountability and rights	• Analysis of Water Resources, Infrastructure, Demand and Access (RIDA Analysis) • Provisional database • Social analysis (rights, benefits, accountabilities)
3. Strategising	• Shared basis created for vertically and horizontally integrated action planning	• Update visions and scenarios • Develop broad strategies • Assess and validate scenario / strategy combinations • Select key scenario and related strategies • Prioritise activities • Define decision modalities	• Water Resource Assessment (WRA) reports • Community and District Water Fact Sheets • 'Final' visions, scenarios and strategies for IWRM
4. Planning	• Detailed plan(s) for concerted action developed, budgeted and agreed	• Plan community and provincial level activities • Identify tasks and responsibilities • Define information flows • Prepare project proposals • Define Monitoring & Evaluation plans • Acquire funding	• Log frames for project proposals • Funded IWRM project proposals for community, district and provinces
5. Implementing	• Activities implemented according to plans within a transparent and high quality approach and in a concerted way	• Implement activities • Awareness raising • Tendering (transparent) • Capacity building • Information sharing • Quality control	• Achieved results • Capacities built • Information base improved
6. Reflecting	• Implementation process documented • Achievements monitored • Lessons drawn from preceding planning cycle	• Documenting processes (+ video) • Monitoring & Evaluation • Learning and reflecting	• Process reports & videos • Evaluation reports • Conclusions drawn as input for next planning cycle

Visioning of future groundwater management

During the first step visioning process (Figure 5.5), stakeholders develop a precise, shared and agreed-upon description of the water resources and services they would like to see in their area of interest at a well-defined future time (say in 5 to 10 years). A vision should be SMART (Specific, Measurable, Acceptable, Realistic and Time-bound). To help stakeholders in envisaging the future, facilitators support them in carrying out a scenario building process. Stakeholders define a range of possible future circumstances that will influence the extent to which a vision can be realised. These future circumstances depend on the evolution of critical external factors (climate, global economy, demography, abstraction from other aquifers, conflict). Based on current trends and assessment of the most important factors that are also of greatest uncertainty, stakeholders build narrative scenarios. A mix of qualitative and quantitative information, these scenarios also help stakeholders to recognise the uncertainty inherent in planning in the water sector. Scenario building enables strategies and plans to be developed later in the planning cycle, including for best- and worst-case scenarios.

"TO HELP STAKEHOLDERS IN ENVISAGING THE FUTURE, FACILITATORS SUPPORT THEM IN BUILDING SCENARIOS."

Figure 5.5 Visioning (Step 1) and strategising (Step 3) in the EMPOWERS Planning Cycle



Assessing local level accountability, ownership and rights in ground water management

During the assessing step in the planning cycle, stakeholders participate in and collaborate in an assessment of local accountability and rights with regard to use and management of groundwater resources. This is a practical process for exploring to what extent conditions are met for local people to assume ownership and accountability for water resources management and use in their community. In many cases local people will not assume such accountability because they do not feel that the activity or its results are really theirs (ownership). Rather these activities are seen as provided temporarily by an outside institution (an NGO or a government agency), while they do not see the direct benefits of the activity and results do not meet their real priorities or longer term interests.

Accountability is used here in the sense of 'taking responsibility for one's own behaviour and actions, and at the same time being able to account for the effects of such behaviour and actions on others'.[131] Accountability has to be defined at all levels in discussions on sustainable management of groundwater resources. It forms an important part of effective social organisation around groundwater governance.[132]

> *"GROUNDWATER MANAGEMENT WILL ULTIMATELY DEPEND ON THE SENSE OF OWNERSHIP AND DEGREE OF ACCOUNTABILITY THAT PEOPLE HAVE."*

For good planning of sustainable water resource management it is critical that local people participate in the accountability and rights assessment. Such assessment will analyse the preconditions under which they build their capacities and willingness to assume accountability for groundwater management (Figure 5.6). The first step is to assess how local people see their benefits (financial, influence, other) from groundwater resource management; second to see how confident they are of possessing the knowledge necessary to do it; then how they perceive they can exercise their rights to the groundwater resource, and finally how empowered they are to get their benefits and rights (claim-making power). The analysis, especially when done with a gender perspective, will clarify which pre-conditions are not fulfilled and hence will stand in the way of sustainable groundwater management. Groundwater management will ultimately depend on the sense of ownership and degree of accountability that people have and can assume.

Figure 5.6. Framework for assessing to what extent pre-conditions are met (or not) for communities to assume accountability for sustainable water resource management [133]

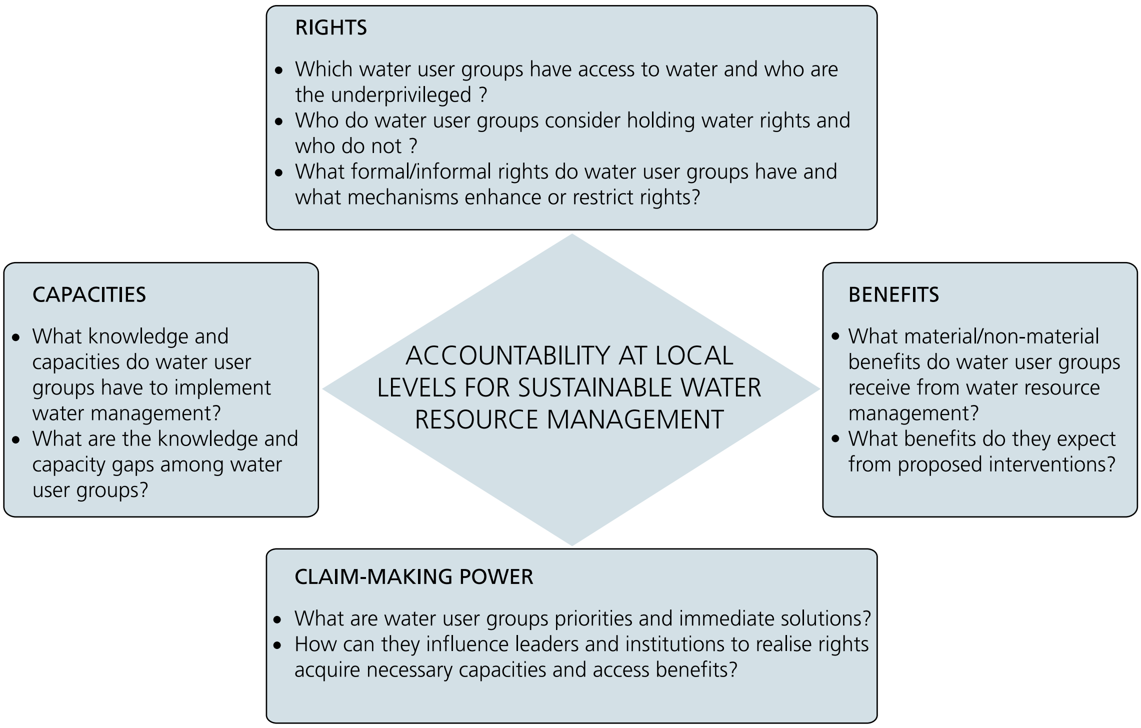


Photo 5.1 Water is everyone's business, Jordan.

Through participation in analysis of questions such as those in Figure 5.6, water users – both women and men – working with the EMPOWERS Planning Cycle can then tailor strategies and specific plans to local priorities and constraints. They should use more in-depth analysis to explore how these are affected by inequalities in benefits, rights, capacities and claim-making power between genders and among categories of water users. With the support of facilitators, water user groups should identify options for overcoming constraints and restrictions, whether within or outside communities, on ownership and accountability for water management interventions.

"IT IS CRITICAL THAT THE LOCAL COMMUNITY DOES NOT END UP ISOLATED FROM HIGHER LEVELS OF PLANNING."

Local-level accountability has to be seen as a long-term goal rather than a prerequisite for a development programme or an investment in the water sector. Nevertheless analysis of the preconditions under which local people are likely to assume a degree of responsibility for the use and management of their groundwater resource is essential for understanding how the necessary social organisation can be facilitated.

Real participation at many levels

As stakeholders continue to work on the EMPOWERS Planning Cycle and acquire more information, facilitators help them to further elaborate scenarios for water management. They can then devise strategies for achieving their vision for water management under alternate scenarios for the future (Figure 5.5). Detailed planning of concerted actions is then possible. It is important that decisions and recommendations made at the village, watershed, district, or larger scales are documented in plans that, in most cases, must be endorsed by different government authorities. Hence, in organising groundwater management, it is critical that the local community does not end up isolated from higher levels of planning. Government agencies and NGOs, therefore, need to focus on enabling participation and dialogue between communities and higher institutional levels. They can do so for example by:[134]

- facilitating interactive processes among the full range of stakeholders at different institutional levels
- disseminating a broad understanding of the groundwater resource situation at different scales
- promoting measures to improve the groundwater resource balance (if necessary), through reduced consumptive use, pollution protection measures, and groundwater recharge enhancement
- providing a conducive, legal, institutional and policy framework, clarifying different levels of accountability (see Chapter 3), and
- setting realistic management targets and monitoring progress.

Participation of stakeholders must favour transparent and empowering approaches to participation – the higher levels on the participation ladder[135] (Table 5.3) – over 'extractive participation'. Participatory Rapid Appraisal (PRA) and Participatory Learning and Action (PLA) are tools designed to help local people better understand their own situation, set priorities and find feasible solutions.[136] Unfortunately, PRA and PLA are too often used in an extractive way that only helps development workers develop projects without involving local people in the reflection, analysis, social, and cultural implications of the project.

Table 5.3 The levels on the participation ladder [137]

Level	Features
1. Passive participation	People participate only by being told what is going to happen or has happened. The information communicated to local people belongs only to external professionals
2. Participation in information giving	People participate by answering questions posed by extractive researchers using questionnaire surveys or similar approaches. People cannot influence information and findings that are extracted from them
3. Participation by consultation	People participate by being consulted without any share in decision making, and external agents only listen to their views. Problems and solutions are defined by external agents
4. Participation for material incentives	People participate by providing resources, for example labour in return for food, cash or other material incentives. They benefit in the short-term but often do not see the interest to continue activities when incentives come to a stop
5. Functional participation	People participate by forming groups to meet pre-determined objectives related to the project, which can involve the development or promotion of externally-initiated social organisation. Functional to a project, such involvement is organised mainly after key decisions have already been made by the project
6. Interactive participation	People participate in joint analysis, which leads to action plans and the formation of new local institutions or the strengthening of existing ones. People can take control over decisions and have hence a stake in sustaining activities and results
7. Self-mobilisation	People participate by taking over initiatives from external institutions to change systems and processes. Such self-initiated mobilisation and collective action may or may not challenge existing inequitable distributions of wealth and power

5.3.3 Reflection, active learning, and documentation

An important step in managing change, and in the EMPOWERS Planning Cycle in Section 5.3.2, is reflection, active learning and documentation to consolidate the lessons learned. Rather than being implemented as a final step, it is implemented throughout the management cycle.

A reflection and active learning process takes place whenever a group of people (e.g. a stakeholder platform) decides to look objectively at things that have happened and to understand why and how they have happened. Allowing space for structured and unstructured learning throughout the process is essential to avoiding or correcting mistakes, understanding differences in perception among stakeholders, and providing insights into how to do things differently in the future.

Reflection can be done in brief, but structured, periods at the end of each major activity. It can be aided by monitoring and benchmarking key indicators of change and by process documentation. Reflection is an on-going learning process through which participants improve their skills, not just a form of evaluation.

Documenting change processes can highlight the not-so-visible changes that occur during implementation of a project, explore some of the reasons for these changes, and give guidance to both stakeholders and facilitators for improving implementation. The documentation process relates to issues such as empowerment, attitude/belief changes, decision-making, and stakeholder dynamics.[138] Process documentation not only serves internal learning but also allows stakeholder platforms to share insights and results with the wider community.

Staff and financial resources are needed for documentation but the results are worth the investment of resources. One of the key products from process documentation can be a story book that collects short tales from different actors on how they perceived what was happening in the change process (Case 5.6).[139]

Case 5.6 Opening the channels for dialogue in Beni Sueif Governorate, Egypt[140]

In Egypt, the EMPOWERS project supported social organisation for improved water management. Process documentation was an integral part of the development approach used. This began with capturing the process (step 1). Regular interviews were held with representatives of key stakeholders and focus groups, diaries were kept by project staff, minutes and observations of meetings made, while short videos were made and photographs taken. This material was further organised (step 2, filing and structuring) as a basis for simple articles, photo books, case studies, columns in newspapers for quick dissemination. 'On the spot' use of these materials is one of the pillars of process documentation. Analysing the information (step 3) was important for learning and reflection in the project. Finally, relevant and interesting information was disseminated (step 4) through different channels and to specific audiences. One such a channel was the EMPOWERS story book distributed to inform water practitioners and government officials to convince them of the effectiveness of the approach. Below is one of the multiple stories in this book.

"Officials knew that they would achieve better outcomes if they coordinated activities, but no one had been ready to take the first step. EMPOWERS brought the different stakeholders together into a single room. Immediately, officials from different departments started to talk about similar problems, and this was the start of a process of coordination. They asked each other why certain things were not happening and why certain decisions had been taken. The bureaucratic procedures gave way to open dialogue. The EMPOWERS meeting had made the first step possible by getting the officials from the different ministries (water, agriculture sanitation) together.

"Eman Ismail, Director of the Under-Secretary's Office of the Ministry of Water and Irrigation in Beni Sueif said that the EMPOWERS approach gave them tools to solve any problem. She mentioned that through the EMPOWERS process the officials of the Irrigation and Agricultural Directorates started to build a dynamic

> working relationship where they could engage with each other in a much more direct way. For example, an official from one Directorate could enquire about the causes of a problem through a phone call to an official of another Directorate without having to resort to long complex and time-wasting bureaucratic procedures."
>
> "These informal processes led to more formal cooperation between the two ministries of Agriculture and Water & Irrigation through a Memorandum of Understanding. The memorandum called for agronomists to increase awareness about rational use and conservation of water, in cooperation with water engineers. It was also agreed that the irrigation officers would attend the weekly meetings of the Agricultural Guidance Department and explain the water situation in cooperation with the agronomists. However simple this may seem, in the bureaucratic context of Egypt these were important milestones."

Documenting processes are less about recording the measurable outcomes or impacts of an intervention, which can be done by project monitoring, but rather about capturing how the process happened. It aims to (1) capture the change in stakeholders' perceptions as the process develops; (2) support reflection and learning to constantly improve the action; (3) understand the underlying reasons why a project is working well or failing badly; and (4) help those outside the process understand the changes in knowledge, attitudes and behaviours that were necessary to achieve results.

5.4 Checklist: Designing Stakeholder Dialogue and Concerted Action

Initiate and engage stakeholders

- Implement and document in-depth stakeholder analysis.
- Organise and activate relevant stakeholder platforms, if necessary at different levels and scales
- Mobilise effective participation of different local interest groups in the local platform, with representation in other platforms.
- Undertake a detailed social analysis (water access and rights as well as local level accountabilities; Figure 5.6) with results feeding-in the below planning and decision-process.

Undertake a participatory planning and decision-making process

- Follow the steps of the EMPOWERS IWRM Planning Cycle (Figure 5.4 and Table 5.2): visioning, assessing and strategising.
- Ensure that conclusions and decisions of this participatory planning and decision-making process are shared by the most relevant stakeholders, and is based on SMART visioning and scenario-building at least at the mid-term (5 to 10 years).
- Establish an shared and agreed-on information/data-base that is accessible to all relevant stakeholders.

Engage in further action to consolidate social organisation

- Engage in and pursue capacity building and empowerment.
- Make detailed groundwater management plans at both community and broader levels (watersheds, districts) that are based on the above shared decisions and commitments of the most relevant stakeholders.
- Document the above outcomes, plans and decision processes and share with wider audiences.
- Where possible institutionalise agreed groundwater resource management arrangements and platforms.

Chapter 6

Taking Action in Groundwater Management

6.1 Catalysing Change for Sustainable Groundwater Management

Groundwater knowledge must lead to management action. With almost 50% of all drinking water worldwide and 43% of all water used for irrigation provided by groundwater, failure to manage groundwater sustainably puts at risk safe water supplies, food security and the development gains of vulnerable people, as well as investment by business and economic growth.[141] With the baseflow of rivers and important ecosystems sustained by groundwater, failure to manage groundwater sustainably puts at risk biodiversity. With the capacity of aquifers to store water in times of plenty, and release it in times of need, failure of groundwater management leaves people more vulnerable to drought and less resilient to climate change. Reducing these risks means turning the principles, tools, practices and examples from SPRING into action that drives change in the way groundwater is managed. People must work together, across levels, to catalyse and manage the changes needed, as represented in the collaborative model for sustainable groundwater management introduced in Chapter 1 (Figure 1.2). Local groundwater users, large-scale users, technicians, scientists, policy makers and politicians – assisted and supported by facilitators – all have important roles to play.

6.1.1 Prioritising joint action on groundwater management

Specific strategies are needed to help all stakeholders to make the contributions needed from them to more effectively and more rapidly translate groundwater knowledge into action and implementation that leads to sustainable groundwater management. A key to progress is to take steps to improve the engagement in groundwater management of stakeholders at all levels and to build shared understanding of the roles they can play and of the benefits that will be gained through joint action. In most situations, stakeholders are likely to need help from individuals or organisations who can facilitate better engagement and build bridges that improve the flow of knowledge among technical specialists, groundwater users and policy makers and legislators. Efforts to improve use of knowledge – whether local or scientific knowledge – to empower people to take action will then be stronger and more successful.

"FAILURE OF GROUNDWATER MANAGEMENT LEAVES PEOPLE MORE VULNERABLE TO DROUGHT."

Much of the technical knowledge needed for groundwater management is very specialised, reflecting the complexities of hydrogeology and the hidden nature of the resource. Groundwater knowledge is too often privileged to circles of technical specialists and, as a result, the dominant paradigm for groundwater management has tended to be expert-driven and technocratic. Barriers to the use and application of groundwater knowledge are widespread. Overcoming these barriers requires collaboration among technical specialists and the groundwater users, policy makers and political processes able to mobilise action. A paradigm shift is needed in groundwater management, from technocratic to collaborative and participatory knowledge systems, where scientific and local knowledge is combined and used for action.

Table 6.1 Examples of measures for groundwater management [142]

Level	Features
Reducing groundwater consumption	Promoting higher water productivity in agriculture • changing cropping pattern, varieties and agronomic practices • micro-irrigation and root-zone irrigation • improved water conveyance • increasing water-holding capacity of soils • reducing waste in processing and marketing
	Reducing urban groundwater use • leakage detection • reducing domestic water loss and use • urban landscaping
	Use of economic incentives • user fees • pricing of energy supplies • redirecting subsidies to water-saving measures • removing subsidies from water-intensive crops • water-efficiency incentives • smart-card controlled abstraction and quotas
Promoting recharge and retention of groundwater	Intercepting and retaining surface runoff and floods • field bunding and terracing • contour bunds and gullies • seepage wells and maintaining natural pits • injection wells • water harvesting from roads • recharge ponds, dams and sand-dams • flood water retention
	Improving infiltration capacity of land surfaces • permeable urban surfaces • penetration of clay layers • increasing infiltration by burrowing action of animals • sand dams
	Retaining subsurface flows • gully plugging of drainage canals • subsurface dams
	Conjunctive management of surface and groundwater • adjusting surface water delivery to recharge and reuse potential • storage of seasonal excess water
Regulating groundwater development	Promoting self-regulation • enabling laws • developing and applying local rules • participatory monitoring and assessment • joint crop planning • local investment in recharge
	Well licensing and well regulation • geographical bans • licensing of drilling rigs • tracking of drilling rigs

There is no shortage of opportunities to act and intervene in the cause of sustainable groundwater management, as the principles and practices presented in the preceding chapters of SPRING show. A wide range of measures to protect groundwater availability and quality is known that need to be tailored and prioritised according to hydrogeological, ecological, social and economic circumstances (Table 6.1). However, to achieve the changes needed to successfully and sustainably implement such measures, scientists, groundwater users and policy makers must align around strategies for change that combine knowledge on groundwater systems (Chapter 2), governance (Chapter 3) and economics (Chapter 4) with social organisation and mobilisation (Chapter 5). To succeed, change strategies for groundwater management have to mobilise action at multiple levels – local to national, regional and international – while differentiating the roles of different stakeholders.

6.1.2 Change strategies

A critical starting point for change strategies is to build a sense of urgency. It is important to build awareness of threats to groundwater and the costs and consequences of failure to manage groundwater sustainably or to protect groundwater resources from pollution. Government agencies, scientists and NGOs can all contribute to public information campaigns on groundwater. Information campaigns should avoid making the argument that groundwater is a special case in natural resource management that needs special treatment, because stakeholders with other priorities will not pay attention. Limiting awareness raising to specialised, technical concerns will lead to narrow stakeholder engagement, with unsatisfactory results. A better goal for public information campaigns is showcasing of how sustainable groundwater management will help address the issues that are top priorities for the public and politicians. The case for urgent action on groundwater management can then be framed using key messages that relate to, for example:

- economy and jobs – depleted and polluted groundwater drives investment elsewhere, reduces industry profitability and costs people their livelihoods and jobs
- drinking water supply and health – sustainable groundwater management provides reliable and safe water supplies
- food security and sustainable agriculture – without sustainable groundwater, food security is at risk
- climate change and drought – aquifers provide sub-surface storage of water that builds resilience to climate change, and
- conservation of nature and biodiversity – protecting nature protects groundwater recharge, and sustainable groundwater management helps biodiversity conservation.

Raising awareness of the importance of groundwater management and protection is useful but does not, on its own, lead to change. Advocates for sustainable groundwater management should think beyond awareness raising and make sure that public information is embedded in a more comprehensive strategy for change. They should develop plans and actions to engage stakeholders in strategies for change that use the principles for social organisation in Section 5.2 in:

- building a sense of urgency
- creating a shared vision for the future
- mobilising coalitions of stakeholders to be champions for change
- empowering stakeholders at all levels to take the actions needed for sustainable groundwater management, and
- demonstrating solutions for groundwater management, learning from them and delivering short-term results that encourage stakeholders to persevere and scale-up success.

6.2 Engaging Stakeholders

6.2.1 Facilitating the process

Water is everybody's business – and achieving the changes needed for sustainable groundwater management therefore requires that all stakeholders are brought around the 'water table'. As shown in Chapter 5, getting people to this table and then creating a fair, equitable and constructive process requires facilitation.

Processes for change in groundwater management are most likely initiated by local or national advocates for sustainable groundwater management, by a government or NGO-led project or by sector-specific interest groups (e.g. drinking water supply, agriculture) – or possibly a coalition among these groups. One of the first actions then needed will be to identify and engage process facilitators. Good process facilitators are service providers. As outlined in Box 5.1, they are usually independent from government and widely seen as neutral, knowledgeable and committed. They are trusted by most stakeholders. If the process is going to succeed in building the participation of groundwater users, it is vitally important that the process facilitators selected have experience of working with local communities and in helping them participate effectively and equitably in multi-stakeholder processes. As a result, process facilitators usually come from civil society. Examples of process facilitators could be independent advisors with experience of facilitation, NGOs with staff who have built credibility and a trusted mandate for facilitating change, or a project specifically designed to develop and facilitate stakeholder planning processes.[143]

Required actions

Process facilitators need to create a platform for stakeholders to come together. A critical early activity is therefore mapping of stakeholder interests, including differentiation of the interests of women and men, and an in-depth stakeholder analysis. This should be used to ensure that all relevant stakeholders are identified, that necessary outreach to them takes place, that the process is designed to be open to their participation and that men and women can participate equitably. Process facilitators need to build communication channels with community groups, government agencies, scientists and policy makers. They need to be skilled in moderating forums that bring these groups together in processes in which participants are able to jointly engage in a planning cycle of visioning, assessing and strategizing (see Section 5.3.2). Most importantly, process facilitators have the task of ensuring that local groundwater users are comfortable with and are empowered in processes and decision making, and that this is done in a transparent way. To succeed, process facilitators may have to help stakeholders to resolve conflicts, as well as ensure that there is support available to build capacities and skills of participants needed for good process, for improved technical understanding and for implementation of management actions.[144] Process facilitators assist with establishing shared databases and mechanisms for compiling and sharing information. They also support documenting of learning, decisions and plans, and ensure these are shared and communicated among communities, sector groups, technical agencies and government ministries who each, at various levels, have responsibilities for implementing agreed plans and actions.

6.2.2 Groundwater users

The need for participation of groundwater users in groundwater management is seemingly self-evident, yet too often overlooked or restricted to superficial engagement. Simply put, if management actions, permitting and licensing requirements and regulations are going to succeed, groundwater users have to agree with them and understand and feel comfortable with implementing them. Otherwise they will remain words on a page.

Groundwater users bring local knowledge of groundwater use, management practices, availability and quality to planning processes that help to make plans and strategies for groundwater management and protection more robust, locally-relevant and hence sustainable. They often have local rules for groundwater management that should be integrated into plans and strategies. Groundwater users, both women and men, should also be able to demand accountability and put pressure on more powerful actors, for example in government or business, to engage and to live-up to their responsibilities. They are hence critical agents of change for sustainable groundwater management and when mobilised effectively in well-facilitated, equitable and transparent change processes, they strengthen the results achieved.

All groundwater users are, of course, not the same. It is especially important to differentiate between:

- those that use groundwater in commercial and business activities, including large-scale farmers and others who invest in irrigation, businesses that make use of groundwater for energy exploitation (e.g. power-plant cooling, shale oil extraction), and other industrial users; and
- local, small-scale family farmers, other artisanal users and poor families that use groundwater for household drinking water and their livelihood activities.

"GROUNDWATER USERS, BOTH WOMEN AND MEN, SHOULD BE ABLE TO DEMAND ACCOUNTABILITY."

Large-scale users in the first group should be able to cover the costs of groundwater abstraction and use from income generated through their investments, according to accounting of full economic costs (Section 4.2.2). Small-scale users in the second group may not be able to do so entirely, in which case policies for reduced pricing and subsidies need to be considered (Section 4.3.1).

Photo 6.1 Safe drinking water, a critical benefit of sustainable groundwater management

Both groups, however, share interests in taking management actions to maintain access to sufficient groundwater of high quality for good health and food security, and to sustain their livelihoods and economic activities. This assumes that all groundwater users, but especially the first group, make decisions with a long-term perspective and that their goals for groundwater use are not short-term and exploitative. Where groundwater users do not recognise their interests in equitable and sustainable groundwater management, advocates for groundwater and process facilitators will need to build and present the case for change, using analytical results and evidence. They will need to build consensus on the case for action through multi-stakeholder dialogue and planning processes (Section 5.3).

Required actions

Groundwater users are expected to contribute to sustainable groundwater management through, for example:

- building awareness of groundwater management needs and sharing local knowledge
- setting up and following local rules for regulating groundwater consumption
- creating and activating a local stakeholder platform and working to mobilise different local interest groups to participate
- participating in stakeholder mapping and social analysis to improve shared understanding of access, accountabilities and rights
- following the visioning, assessing and strategising steps in the planning cycle locally and through representation in national planning
- pushing for and then organising representation of local users in local planning and decision processes for groundwater and in the preparation of local and national groundwater management plans, as well as forums on groundwater policies and law
- lobbying for and participating in capacity building and skills development, in diagnosis, monitoring and analysis as well as planning and management of groundwater actions
- promoting and participating in the documenting and sharing of information and data, including setting-up and application of local and national databases, to improve understanding of an appropriate balance between groundwater abstraction and recharge, pollution control, protection of recharge zones and the importance of land-use zoning in groundwater management
- promoting understanding of the costs and benefits of sustainable groundwater management among groundwater users and participating in the development and operationalisation of schemes for incentivising improvements
- supporting the development of effective and participatory institutions for groundwater management, which may be Groundwater User Associations, and their representation in Aquifer Management Organisations
- compliance with requirements for abstraction permits or licences and groundwater monitoring, and
- committing to ensuring that participation of groundwater users is not a project activity but is accepted as a permanent part of water governance.

6.2.3 Technical and implementing agencies

Groundwater users cannot achieve the changes needed for sustainable groundwater management at the scale needed if they are working in isolation. To agree on and implement management actions, they need help from specialists. To inform, influence and receive support from policy makers, they need help from national and regional institutions. Agencies providing technical services and with responsibilities for implementing policies and plans therefore play key roles in change strategies as intermediaries between local groundwater users and policy makers.

Actors working at the level of such technical and implementing agencies include:

- technical staff in the Ministries of Water, Agriculture and Health
- staff in the planning departments of ministries
- technical and management staff in urban water utilities or rural water supply services
- technical and management staff in NGOs involved in water management programmes or projects (e.g. drinking water supply, irrigation) that need groundwater, and
- academics and scientists in universities, research and other specialised organisations.

Technocratic models for groundwater management give priority to the knowledge held by these specialists in top-down decision making.

In a collaborative and participative paradigm, technical specialists are knowledge brokers. They work actively to connect local and traditional knowledge on groundwater to technical and scientific knowledge. In doing so, they mobilise the practical implementation of policies decided at national levels and administer regulations. They contribute scientific knowledge and generate new knowledge through technical studies and assessments, while integrating local participation, needs and knowledge into the management and regulation of groundwater use and protection.

It is still unusual for hydrogeological studies to be communicated in understandable formats and language to those who matter most – the groundwater users. As a result technical specialists and professionals, rather than being part of the solution, often appear to be part of the problem. Thus calls for more studies, models and monitoring end up carrying more weight than calls for more management and action. There is a large communication gap to be closed, including for example to promote a culture of sharing groundwater data and rather than keeping information confidential. There is a need not just for sophisticated technical analysis, but also the sharing, study of and promotion of practical interventions that have worked. Closing these gaps will be helped by the active engagement of specialists and professionals in capacity building, communication and demystifying of hydrological science and prioritisation of action and solutions.

"TECHNICAL SPECIALISTS ARE KNOWLEDGE BROKERS."

Required actions

Actions required from technical and implementing agencies in sustainable groundwater management include:

- building technical capacities in institutions and agencies and among stakeholders, and supporting the development of capacities of groundwater professionals
- working jointly with other stakeholders including groundwater users to raise public awareness of threats to groundwater and the costs and benefits of groundwater management
- mapping and analysing stakeholder interests, concerns and roles, including differences between women and men, and supporting them to engage in stakeholder platforms equitably and at different levels
- reviewing policies and laws affecting groundwater management, including water, agricultural and economic policies
- assessing aquifer characteristics through hydrogeological surveys, mapping and aquifer modelling
- setting up national systems for monitoring groundwater levels and quality, including borehole monitoring networks

- establishing databases and information sharing accessible by all stakeholders, and gathering, cross-checking and organising data from relevant sources
- creating and administering land-use zoning compatible with sustainable groundwater management, including vulnerability maps
- promoting management of the landscape in ways that protect and improve groundwater recharge
- identifying controls needed to limit groundwater pumping to sustainable levels and complementary measures needed to control water demand
- engaging in stakeholder processes to develop local and national groundwater management plans (with at least a 5-10 year outlook), ensuring participation by groundwater users, through visioning, assessing and strategising
- ensuring that groundwater management plans are articulated with planning of river basin management and the operations of river basin organisations.
- documenting plans and decisions made though participatory planning processes and disseminating them among policy makers and wider audiences
- administering regulations required for groundwater management, including a permitting system for groundwater abstraction and for pollution control
- undertaking cost-benefit studies for groundwater management and feasibility studies for economic incentives, that take into account economic valuation of groundwater and related ecosystems ('nature-for-groundwater' in recharge areas and 'groundwater-for-nature' in discharge areas)
- administering economic incentives and compliance and enforcement mechanisms, while supporting effective stakeholder participation, and
- supporting the establishment and operation of Groundwater User Associations and Aquifer Management Organisations.

"POLICY MAKERS AND LEGISLATORS PROMOTE DIALOGUE AT HIGHER LEVELS."

6.2.4 Policy makers, legislators and financing institutions

At this level are the legislators, policy makers and decision makers who are in charge of setting the appropriate policy and legal frameworks for sustainable groundwater management. They are found in the senior levels of the technical and implementation agencies (e.g. in the Ministries), but also in the legislative bodies of a country and the national and international financing institutions. They provide the policy and legal framework, as well as allocating financial resources, that enable local groundwater users and technical and implementing institutions to take action at each level.

Legislators and policy makers need to have a vision on how groundwater legislation fits within a larger framework of management and how it is translated into an operational framework. It is not unusual for laws to being developed for a hypothetical world – either with detail that cannot be implemented, or in the complete absence of implementation mechanisms. A criticism on the Andhra Pradesh Water Land and Trees Act in India, for example, was that the operational responsibilities for registration, licensing and enforcement were never clarified. Preferably, therefore, the development of new legislation is undertaken jointly with a regulatory impact assessment. Regulatory impact assessments look at the resources and responsibilities required to make the enforcement of new laws effective, including provisions for publicly announcing the laws and instructing the institutions that are to apply its provisions. Regulatory impact assessments also assess the impact of the law, including who benefits and who loses.

Policy makers and legislators promote dialogue at higher levels to integrate the sustainability of groundwater resources into debates on wider societal, economic and environmental priorities. In doing so, they should foster and support the participation of groundwater users in these debates, to promote recognition of rights and stronger accountability, as well as ensure that local rules and practices for groundwater management are accommodated in the legal framework, strategies and plans. They should enhance communications and sharing of knowledge and data on groundwater to build public awareness of groundwater and to support the evidence base for groundwater management in the long-term.

Financing institutions, including national agencies, donors and multilateral financing institutions, play an important role at this level. They can give priority to sustainable groundwater management, including the measures and processes described in SPRING, in approval criteria for financing of groundwater development schemes. Financing decisions should account for the multiple benefits of groundwater management in economic development, including for buffering of floods, soil stabilisation and prevention of land subsidence, as well as the importance of groundwater as a strategic reserve that contributes to resilience to drought and surface water contamination. They can also encourage different actors to embrace financing that links global mechanisms to local actions and investments, and thus help to increase the flow of finance from for example the Global Environment Facility or the Green Climate Fund into sustainable groundwater management.

"A MULTITUDE OF ACTIONS ALL CONTRIBUTE TO IMPROVING GROUNDWATER MANAGEMENT."

Required actions

Actions required from policy makers, legislators and financing institutions include:

- supporting public communications on groundwater sustainability
- developing and adopting policy on sustainable groundwater management that sets in place processes for creating and activating gender-balanced stakeholder platforms at different levels, mechanisms for representation of stakeholders in other platforms, including in national dialogues, and national and local groundwater planning
- adopting legal frameworks needed for sustainable groundwater management, including systems for issuing and enforcing abstraction rights and limits on release of contaminants, and regulation of land-use to protect recharge and discharge zones
- ensuring that realistic assessments are made of impacts of laws and regulations and of resources and responsibilities required to make enforcement effective
- providing institutions with legal mandates and an effective role in water governance, including local-level User Associations, technical agencies and regulatory bodies responsible for administration of abstraction licences and pollution control
- ensuring the rights of local groundwater users, both women and men, to access good quality groundwater for agricultural and domestic use, integrating the conservation of ecosystems
- endorsing groundwater management plans that are developed through participatory stakeholder planning processes
- connecting groundwater management institutions to larger institutional frameworks such as local governments or river basin organisations
- allocating financing to groundwater management, including for technical, scientific, social and economic studies and monitoring
- taking into account the results of economic valuations in investment decisions relating to groundwater, including those that impact ecosystems

- defining economic instruments, such as abstraction fees or the pricing of electricity, that create incentives and penalties (e.g. on the basis of the polluter-pays principle) to address over-exploitation and pollution of groundwater resources
- applying 'payments for ecosystem services' to foster investments in groundwater recharge and discharge areas, and
- reviewing economic and agricultural policies to facilitate more sustainable groundwater management.

6.3 Demonstrating, Learning and Communicating

Bringing about change in groundwater management is not easy. SPRING shows that a multitude of actions related to scientific knowledge and monitoring, governance reforms, economic incentives and social organisation all contribute to improving groundwater management. The actions needed involve many different stakeholders at many levels. Making all the necessary changes at once is hence impossible. However, someone or a group of advocates for sustainable groundwater management needs to take the lead – whether local users, NGOs, scientists, technical agencies or policy makers – and promote and demonstrate change.

A good way to start is to focus on a specific problem, such as risks because of falling water tables or contamination to drinking water supply, to the livelihoods of farmers and national food security, or to wetland biodiversity and climate change vulnerability. Focusing on concrete issues that impact on priority concerns helps people to understand the urgency and motivates them to join others to take action. As a coalition, for example of local users, NGOs and a water management agency, they can then start a project to take action or create a coordinated programme. They can use Chapters 2-5 of SPRING and the Checklists at the end of each chapter (Sections 2.6, 3.5, 4.6 and 5.4) as a starting point for identifying priority actions and planning projects and programmes. They should then aim to work in a coalition to demonstrate that progress can be made in solving practical and local problems. At the same time, however, advocates and champions for sustainable groundwater management should promote dialogue on policy, law, investment and incentives, involving policy makers and businesses, while making sure that the voices of local users are also heard.

"COALITIONS FOR ACTION USE RESULTS FROM LOCAL DEMONSTRATIONS TO SHOWCASE SUCCESS."

It is crucial that coalitions for action and process facilitators proactively use the results from local demonstrations to showcase success to higher-level dialogues. Learning from and communicating good results will build trust in the process, improve consensus and promote commitment to change at all levels. Likewise, where policy change is underway or changes in law must be implemented, implementing agencies or policy makers should be proactive in engaging local users and institutions, to promote alignment of local problem solving and the priorities of higher-level change. Coalitions for action will then expand and grow, making the two-way exchange of knowledge easier and making scaling-up of sustainable groundwater management faster and more effective.[145]

6.4 Engaging with the Politics of Change

A technocratic approach tends to isolate groundwater management from political processes. Engaging with holders of political power may be seen by some as unnecessary, because the actions needed are determined according to technical diagnostics rather than through dialogue and debate. This is a fallacy.

In a collaborative and participatory paradigm for groundwater management, as outlined in Section 6.2, technical specialists broker knowledge, data and information to inform stakeholders – whether local groundwater users or policy makers and legislators – and to help them build consensus on policies, plans and management actions. Politicians are then important actors in the change strategies needed to achieve sustainable groundwater management.

Advocates for sustainable groundwater management need to understand the politics around groundwater and develop the means to engage those that wield political power and have the capacity to change. They need politicians to understand the issues and recognise current and future challenges as well as practical solutions associated with groundwater – or else those that hohld power will not likely take action. Advocates therefore need to build the social rationale and economic case for groundwater management, and demonstrate the evidence base for it. They need to cultivate political champions for groundwater and work with them in coalitions for change and for action. They need to provide these champions with the information, stories and evidence they need to justify action in parliament in terms that carry political weight: if action is not taken on sustainable groundwater management, there will be costs nationally and globally, for economic growth, poverty reduction, food security, safe drinking water and climate change resilience.

"ENGAGING WITH HOLDERS OF POLITICAL POWER MAY BE SEEN AS UNNECESSARY. THIS IS A FALLACY."

Without political engagement, there is a danger that all of the other actions described in SPRING will fall short of the goal of sustainable groundwater management. Success will not depend narrowly on technical excellence, putting well-crafted policies and laws on the books, or mobilising stakeholders to participate. It will depend on bringing all of these together, coherently with local and national political processes, to motivate societies to take action and build consensus for change.

Cases and Boxes

Tables and figures

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Spring – Managing groundwater sustainably

Sustainable groundwater management is a key to water security in sustainable development, climate change resilience and reducing water-related drivers of biodiversity loss. This guide provides an explanation of the technical challenges that must be met to manage groundwater well and how good governance, economic analysis and incentives, and effective social organisation each play a vital role in the solutions needed. Through explanation of key concepts supported by practical examples from the field, SPRING shows how communities, civil society, technical specialists and policy makers collaborate to create change in groundwater management.

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The IUCN Water and Nature Initiative is an action programme to demonstrate that ecosystem- based management and stakeholder participation will help to solve the water dilemma of today – bringing rivers back to life and maintaining the resource base for many.
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