

GROUND WATER

MANAGING THE "INVISIBLE" RESOURCE

Ground water accounts for over 95% of the Earth's useable fresh-water resources and plays an important role in maintaining soil moisture, stream flow and wetlands. From the human perspective, ground water is a vital resource, particularly in arid regions and on islands, where it may be the only fresh water available. Ground water is uniquely suited as drinking water: in general, it is widely distributed, dependable, inexpensive, and usually requires little pre-treatment. Over half the world's population depends on ground water for drinking water supplies.

This "invisible" resource - stored between sand grains and in rock fractures beneath the Earth's surface - is vulnerable to pollution and over-exploitation. Most human activities at the land's surface, including agriculture, industry and urban

development, all ultimately degrade its quality. The extraction of excessive quantities of ground water can result in the drying up of wells, damaged ecosystems, land subsidence, salt-water intrusion and, ultimately, the loss of the resource.

"Prevention is better than a cure" is particularly true in the case of ground water. Ground-water pollution often remains hidden for many years, becoming dispersed over wide areas, where it is difficult to clean up. Some of the consequences of over-pumping can be irreversible. Retroactive solutions to ground-water problems are technologically demanding, extremely expensive and time consuming. In the long run, the most effective and economic means for assuring a predictable supply of clean ground water is through the protection and careful management of this resource.

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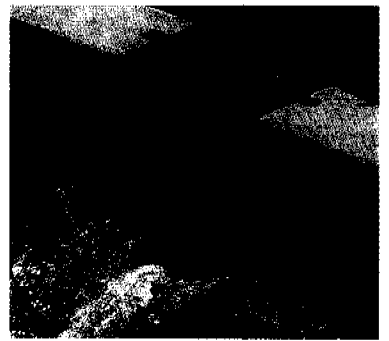
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THE NEED FOR ACTION



Ground water does not exist in isolation, but is an integral link in the hydrological cycle: the endless circulation of water between the oceans, atmosphere and land. It is estimated that 95% of the Earth's useable fresh water is stored as ground water.

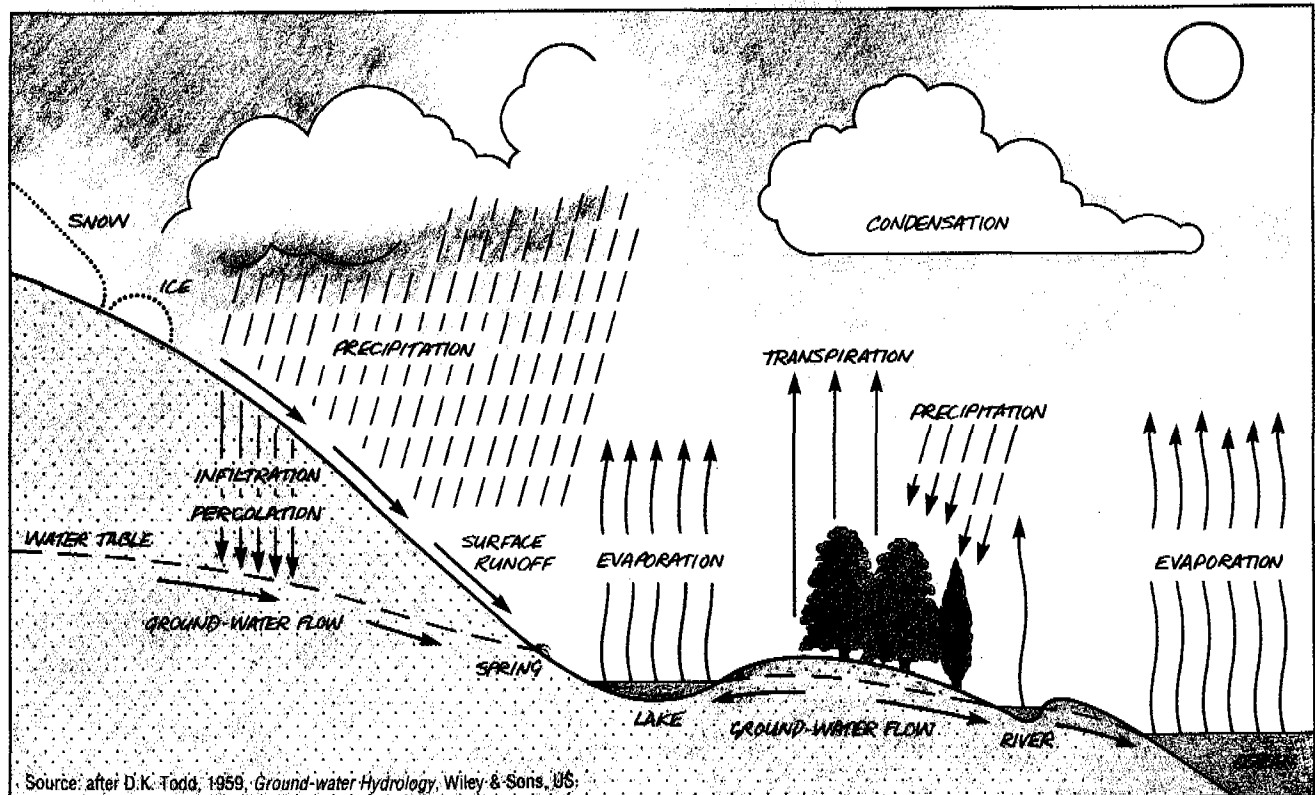
Ground-water aquifers are periodically replenished by precipitation and by surface water percolating down through the soils. The degree of replenishment, or recharge, depends on the climate, vegetation and geology of a given region. In humid areas with porous soils, for example, over 25% of the annual rainfall may recharge the ground-water system. In contrast, desert regions rarely experience ground-water recharge; aquifers in these areas often contain fossil ground water which accumulated under entirely different climatic conditions.

Water stored in aquifers is usually in motion, flowing slowly downward under the influence of gravity, until it discharges into a spring, stream, lake, wetland or the ocean, is taken up by plants or is extracted by wells. Flow rates are typically very

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GROUND WATER AND THE HYDROLOGICAL CYCLE

The hydrological cycle describes the endless circulation of water between the ocean, atmosphere and land, driven by the sun's energy.



Source: after D.K. Todd, 1959, *Ground-water Hydrology*, Wiley & Sons, US.

As precipitation strikes the Earth's surface, it may evaporate or be used by plants (transpired), run off, or percolate through to the water table and recharge the aquifer. The amount of precipitation which enters the ground-water system varies regionally and seasonally.

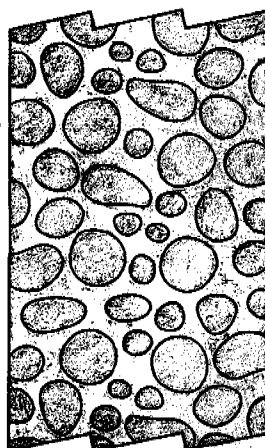
slow – in the order of several metres to hundreds of metres per year.

Surface and ground-water systems are inextricably linked. In many cases, ground water discharges into wetlands, lakes and streams, maintaining water levels and sustaining aquatic ecosystems. In other cases, these surface-water systems recharge the underlying aquifer. The direction of water flow in a given surface-water system often changes seasonally: during the wet season, water flows from the surface to the subsurface, while during dry periods, the flow is reversed.

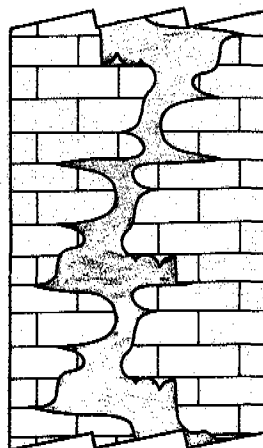
Ground-water problems are widespread and variable in their scope and severity. They can be grouped into two main categories: those caused by contamination and those caused by over-exploitation. The majority of problems are as yet unidentified, hidden from view below the land's surface. Because ground-water flow tends to be very slow, the effects of our actions may not become apparent for decades.

WHAT IS GROUND WATER?

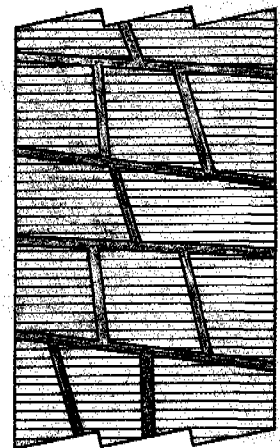
Ground water is subsurface water that fills voids in soils and permeable geological formations. There are three primary groups of water-bearing formations, called aquifers:



unconsolidated sands and gravels



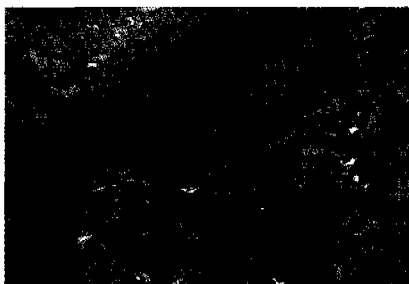
permeable sedimentary rocks (sandstones and limestones)



heavily fractured volcanic and crystalline rocks

Source: after US Geologic Survey, 1980.

- Oil spills and leaks at a large refinery on Danube Island, Czechoslovakia, have polluted ground water over a 20 square-kilometre area, resulting in the closure of Bratislava's No. 11 water supply system. Although approximately 90,000 cubic metres of oil products have been cleaned up at the refinery since 1974, oil releases continue and the water supply remains out of operation, with serious social and economic consequences for the city. (1)



Petroleum products are a common and long-lived ground-water contaminant.



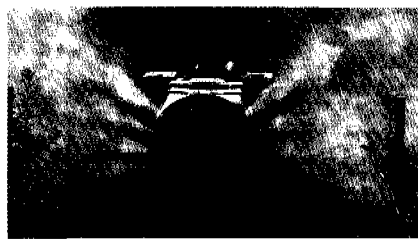
Ground-water pollution is often detected only when noxious substances appear in drinking water.

- The city of Bangkok pumps over a million cubic metres of ground water per day from a series of underlying aquifers. This extraction rate far exceeds the aquifers' natural recharge capacity. The city now faces the twin threats of salt-water contamination of its sole water supply and severe land subsidence. Subsidence, at rates of up to 10 centimetres a year, is of particular concern because Bangkok is situated near sea level and has high population densities. (3)

- In Mexico City, over-pumping of the underlying aquifer has resulted in severe land subsidence. Over the past century, parts of the old city have subsided by as much as 8-9 metres. Although the rate of subsidence has now slowed, following the stabilization of ground-water extraction rates, there has been extensive damage to buildings, roads and the city's water and sewer network. (2)



Street drainage as well as pollutants from car exhausts affect ground-water quality.



Spraying of pesticides and fertilizers can contribute to ground-water pollution.

- The Ogallala aquifer underlies a large area of the south-central United States and supplies water for approximately 5.8 million hectares of irrigated land. Recharge rates are only a fraction of annual withdrawals and nearly half of the available ground water has already been extracted. The depletion of this aquifer is likely to cause economic, environmental and social problems by the end of this century. (4)

Sources: (1) J. Vrba, 1991. (2) G.E. Figueroa-Vega, 1984, in *Guidebook to Studies of Land Subsidence due to Ground-Water Withdrawal*. UNESCO/IHP. (3) United Nations, 1986, *Ground Water in Continental Asia*. (4) G.W. Thomas, 1985, in *Water and Water Policy in World Food Supplies*.

COMMON GROUND-WATER CONTAMINANTS

Nitrates: dissolved nitrogen in the form of NO_3^- is the most common contaminant in ground water. High levels can cause methaemoglobinaemia ("blue baby syndrome") in infants, may form carcinogens, and can accelerate the eutrophication of surface waters. Sources of nitrates include sewage, fertilizers, air pollution, landfills and street drainage.

Pathogens: are bacteria and viruses which cause waterborne diseases such as typhoid, cholera, dysentery, polio and hepatitis. Sources include sewage, landfills, livestock and wildlife.

Trace metals: include cadmium, chromium, copper, mercury and lead. These metals can have toxic and carcinogenic effects. Sources include industrial discharges, pesticides and street drainage.

Organic compounds: include volatile and semi-volatile organic compounds (e.g. petroleum derivatives), PCBs and pesticides. Sources include agricultural activities, street drainage, sewage, landfills, industrial discharges, spills, air pollution and leaking underground storage tanks.

POLLUTION

Ground-water pollution is intrinsically difficult to detect, and monitoring is costly, time consuming and hit-or-miss. Contamination is often not detected until noxious substances appear in drinking water supplies, at which point the pollution has usually dispersed over a large area. The clean-up of subsurface pollution is notoriously time consuming and expensive, and can require advanced technological methods. As an example, the cost of cleaning up hazardous waste disposal sites under the USA's Superfund Program is estimated at US\$ 20-100 billion.

As ground-water monitoring becomes more common, largely in response to increasingly stringent drinking water standards, an alarming picture begins to emerge. Ground-water quality is declining slowly but surely everywhere.

Most ground-water contaminants are derived from agricultural, urban and industrial land uses. In the past, most attention was focused on point sources: large pollution sources such as industrial spills and leaks, landfills and subsurface injection of chemical and hazardous wastes. A variety of technological solutions were subsequently developed to clean up, or at least contain, this type of pollution.

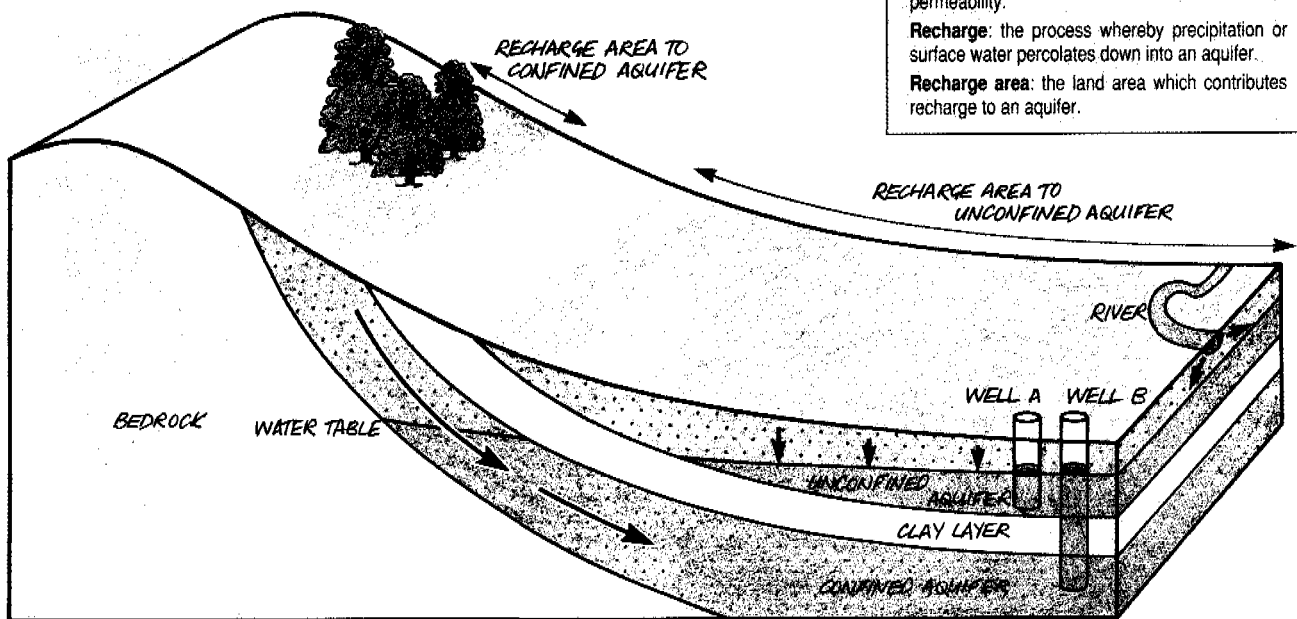
It is now becoming clear that sources of ground-water pollution are much more widespread, and are related to a variety of typical activities at the land's surface. Ground-water pollution in most non-industrial areas can be attributed to such dispersed, or non-point sources, as fertilizers, pesticides, septic systems, street drainage, and air and surface-water pollution. The only effective method for the control of this type of pollution is by integrating land use and water management.

EXTRACTION

Throughout history, people have viewed ground water as either an inexhaustible source of water, or as an extractable resource, no different from petroleum, coal or iron. With the development of modern exploration, drilling and extraction techniques, however, this attitude can no longer be sustained. Although ground water is a renewable resource in most parts of the world, few aquifers can withstand enormous extraction rates indefinitely. To ensure adequate ground-water supplies for

GROUND-WATER FLOW

The water table is higher under hills and lower under valleys, roughly following the contours of the land surface. Ground water flows slowly downwards until it discharges into surface waters, is intercepted by plant roots, or is extracted by a well. **Well A** pumps water from an unconfined aquifer, whose recharge area occupies a large area surrounding the well. **Well B** pumps water from a confined aquifer, whose recharge is derived from a smaller area located many kilometres away.



GROUND-WATER SYSTEMS

Aquifer: a water-bearing formation.

Water table: the boundary between the saturated and unsaturated zones.

Unconfined aquifer: an aquifer whose upper surface is marked by the water table; also called a water table aquifer.

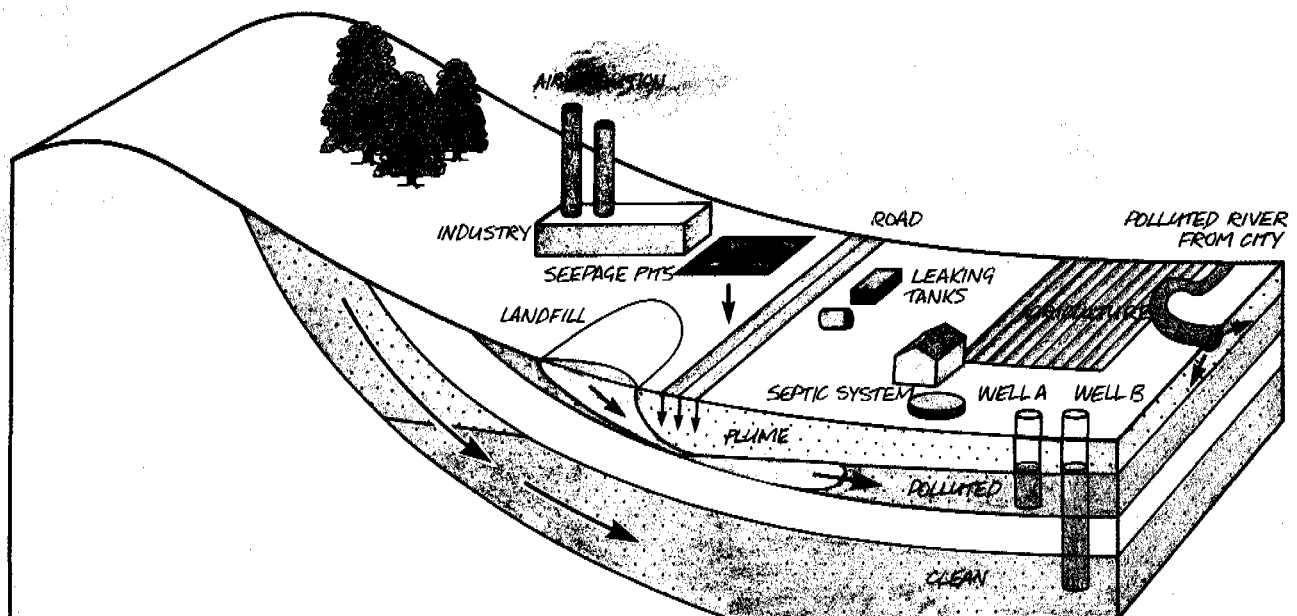
Confined aquifer: an aquifer which is sandwiched between two formations of low permeability.

Recharge: the process whereby precipitation or surface water percolates down into an aquifer.

Recharge area: the land area which contributes recharge to an aquifer.

GROUND-WATER CONTAMINATION

As recharge percolates through the soil to the water table, it transports a variety of contaminants derived from land uses within the recharge area. Point sources of contamination, such as landfills and industrial seepage pits, release large quantities of contaminants which often form an underground plume. Non-point sources of pollution, including septic systems, fertilizers, pesticides and street drainage, may be equally severe and are more pervasive. Water pumped from **Well A** is heavily polluted because its source is highly vulnerable to contamination. Water from **Well B** is much cleaner as it originates from a deeper, confined aquifer, whose recharge area is undeveloped.



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future generations, the philosophy of sustainable development dictates that ground-water extraction from a given aquifer should not exceed the recharge.

There may be situations where a conscious decision is made to exploit ground-water resources beyond the limits of natural recharge. However, such a decision must be made with the knowledge that there may be penalties to be paid. When average ground-water withdrawals exceed the average recharge rates for extended periods of time, aquifers become depleted and the water table or water pressure begins to drop. The following problems may ensue:

- Shallow wells, often used for local water supplies and irrigation, dry up.
- Production wells must be drilled to progressively greater depths, requiring more energy for pumping.
- Aquifers in coastal areas can become contaminated by salt-water intrusion.
- Subsurface materials may gradually compact and cause land-surface subsidence.

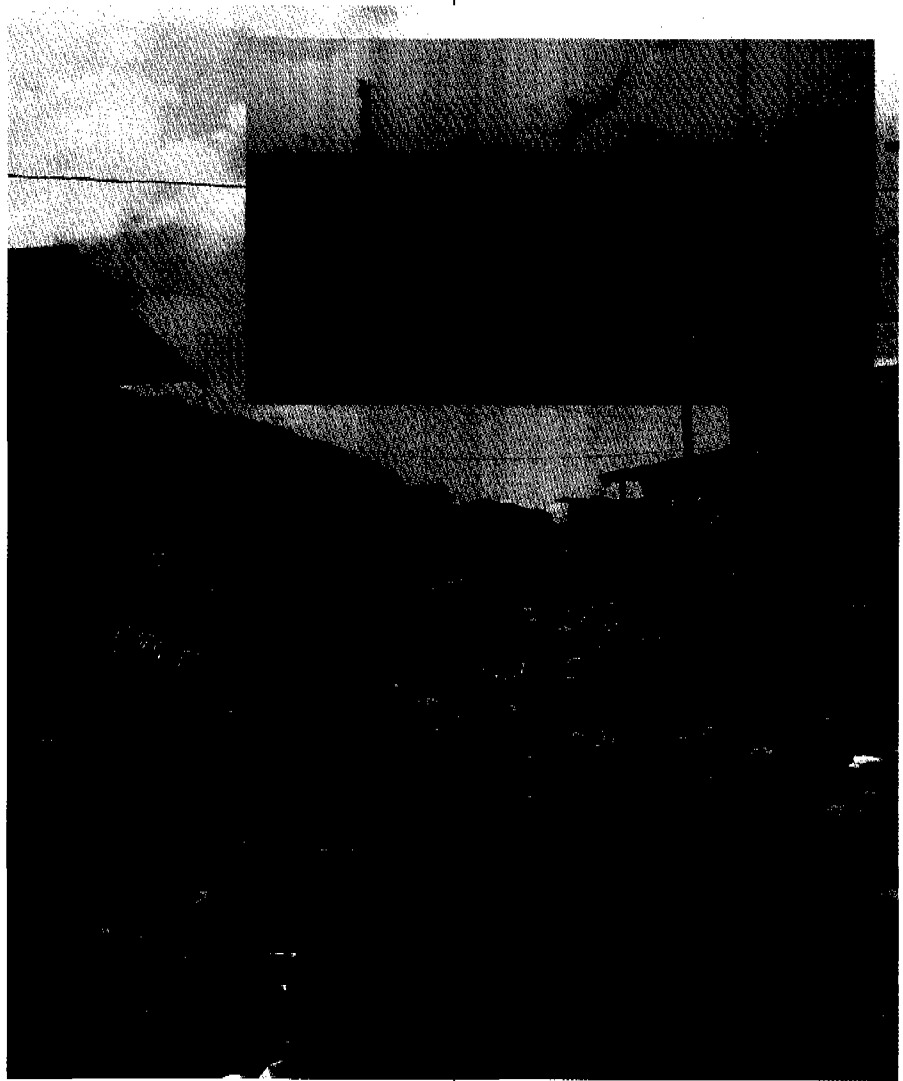
Although some of these effects can be controlled or even reversed by limiting extraction, salt-water contamination persists for many years. Land subsidence is usually irreversible. If the impact is extreme, the aquifer may need to be abandoned as a source of water.

LONG-TERM RISKS

Polluting and over-exploiting ground water can have serious consequences. Among these are:

■ **Water shortages:** contamination or loss of ground-water supplies can lead to acute shortages and require expensive interim measures. Often, a frantic effort ensues to develop a new water supply or to install more sophisticated treatment measures. Water shortages may be particularly devastating for islands, where desalination is often the only alternative source of fresh water. Where water supplies are inadequate for agricultural and industrial uses, the livelihood of entire sectors of the population may be at risk.

■ **Health hazards:** contamination of drinking water supplies places public health at risk through exposure to a variety of substances, such as pathogens, carcinogens and nitrates. Rural populations tend to be particularly hard hit because of their greater dependence on ground water. Where ground-water



supplies fail altogether, people may be forced to drink untreated surface water, greatly increasing their exposure to waterborne diseases.

■ **Damaged ecosystems:** because of the interplay between ground water and surface water, aquatic systems can be devastated by ground-water problems. Nutrient-enriched ground water discharging to lakes and reservoirs can induce algae blooms and other symptoms of eutrophication. Trace metals and organic contaminants may enter the food chain, building up to toxic levels. Ground-water over-exploitation can cause reduced base flows in rivers, declining water levels in lakes, loss of wetlands and a reduction in soil moisture.

■ **Structural damage and coastal flooding:** where land subsidence is severe, buildings and infrastructure can be damaged, and low-lying coastal areas may experience increased flooding.

■ **Economic hardship:** where money is no object, the technology exists to find,

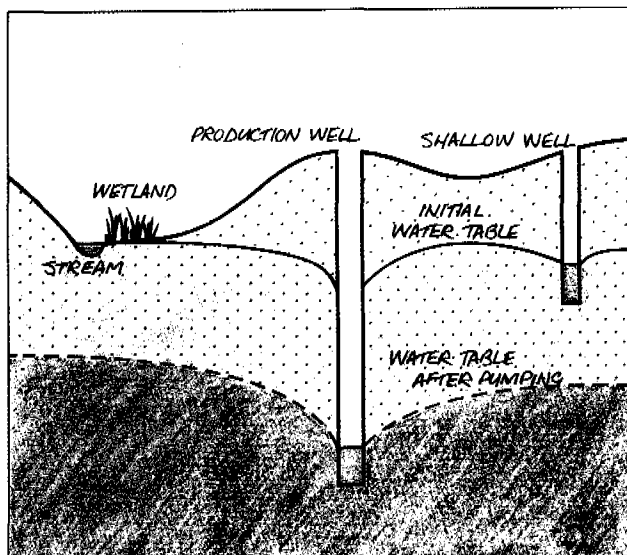
extract and purify water to meet the most stringent water quality standards. Similarly, techniques have been developed to mitigate most ground-water problems.

But the costs can be exorbitant. The replacement of a contaminated wellfield may entail the construction of a reservoir or aqueduct, treatment plant and new distribution system. Clean-up costs for a relatively minor gasoline spill into an aquifer can cost hundreds of thousands of dollars. The depletion of a major aquifer can also lead to the permanent loss of agricultural and industrial productivity.

In the long run, such risks are almost never worth the short-term benefits of mistreating ground water. The most effective and least expensive solution is to establish a programme to protect ground water.

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GROUND-WATER OVER-EXPLOITATION



Ground-water over-exploitation occurs when the long-term, average extraction rate exceeds the long-term, average recharge rate. Consequences may include:

- lowered water-table or reduced water pressures
- drying up of springs, streams, ponds and wetlands
- loss of wells or reduction in pumping capacity
- salt-water intrusion • land subsidence.

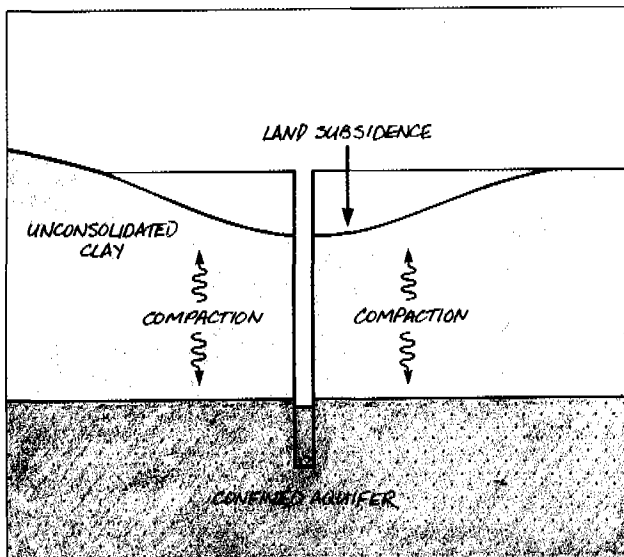
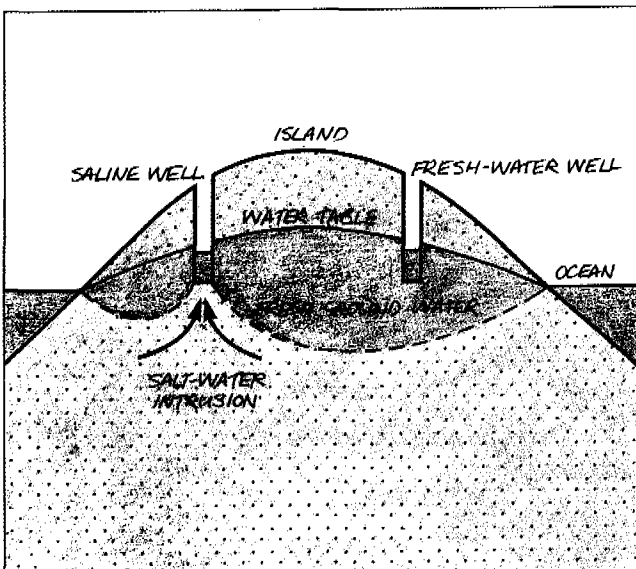
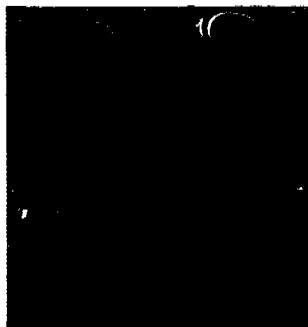


SALT-WATER INTRUSION

In coastal aquifers, fresh ground water is delicately balanced on top of denser saline ground water. On many islands, the ground-water resources consist of a thin fresh-water lens floating on top of saline ground water.

Over-pumping a well can cause the encroachment of salt water into fresh-water aquifers, rendering them unfit for most uses.

Salt-water intrusion can often be controlled in the early stages, by reducing and redistributing ground-water withdrawals, or through technologically complex and often expensive methods. Once contaminated with salt water, aquifers are very difficult to flush and must usually be abandoned.



LAND SUBSIDENCE

Land subsidence occurs when ground water is pumped from a confined sand and gravel aquifer overlain by highly compressible clays. As pressures within the aquifer drop, the aquifer materials and the overlying clays gradually become compacted. Land subsidence reflects the consolidation of these sediments.

Subsidence rates of up to 30 cm/year have been recorded. Consequences include coastal flooding, structural damage and inoperable water and sewer systems. This situation can be stabilized by reducing pumpage and reinjecting water into the aquifer.



SAFEGUARDING THE RESOURCE

The attitude toward, need for, and degree of ground-water protection varies considerably from country to country and from aquifer to aquifer.

In many parts of the industrialized world, attention has turned from ground-water exploitation to protection and remediation. On the whole, government agencies tend to be relatively well staffed and funded, basic legislation and regulations pertaining to ground-water protection have been enacted and water quality standards have been established. Data collection and monitoring programmes also tend to be well advanced. Furthermore, the standard of living in industrialized countries is such that the costs of water treatment and pollution clean-up can be supported, where necessary.

The picture is very different in the developing world, where the emphasis is still largely on ground-water development. Where the need for protection is acknowledged, implementation is difficult due to a scarcity of data, lack of trained personnel, low levels of funding, and inadequate legislation and enforcement mechanisms. The stakes are particularly

high in the developing world, where costs of developing new supplies or treating polluted ground water may be prohibitive. Finally, because of the prevalence of waterborne diseases in the surface waters of many developing countries, the maintenance of clean ground-water supplies is of critical importance.

Three interdependent steps are involved in ground-water protection. First, baseline data on both the resource and the threats should be collected, analyzed and compiled. Second, a ground-water protection plan should be prepared, reflecting national objectives, policies and priorities. Finally, this plan is implemented through a series of actions, ranging from legislation, to land-use controls, to enforcement.

The financial implications of ground-water protection should not be underestimated. Costs typically include the collection and processing of baseline data, administrative and professional salaries, land acquisition, monitoring, etc. These costs, however, are only a fraction of the cost of pollution clean-up or the development of a new water supply.

THE COST OF MISTREATING GROUND WATER

Location/activity

Estimated cost

Prague International Airport, Czechoslovakia
Clean-up of 33,000m³ aviation fuel spill (1)

US\$ 5 million

Barcelona, Spain
Projected cost for construction of 150km canal to replace ground-water supplies contaminated by salt-water intrusion (2)

US\$ 20 million

Projected cost for the clean-up of hazardous waste (3)

Denmark
Western Germany
USA

US\$ 6 billion
US\$ 30 billion
US\$ 20-100 billion

Sources: (1) Vrba, 1991. (2) E. Custodio, 1987 in *Ground-water Problems in Coastal Areas*, UNESCO/IHP. (3) OECD, 1990, *The State of the Environment*.

PLANNING FOR PROTECTION

Effective ground-water protection is based on the setting of realistic objectives, policies and priorities. What are the desired goals of ground-water protection? The protection of water quality? Sustainable rates of ground-water extraction? What degree of protection is practicable and where should efforts be focused first?

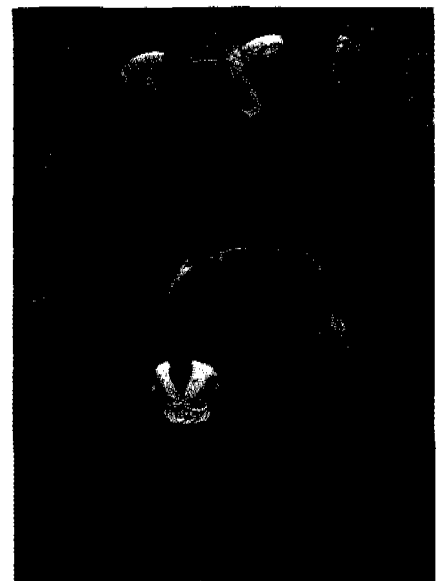
The answers to these and related questions will vary widely, depending on such factors as the availability and demand for ground water, the threats, and a country's level of economic development. At the national level, a Water Advisory Board can serve as a catalyst to set this process in motion. Board members with a wide range of expertise and differing perspectives are appointed to ensure that alternative views are taken into account.

Ground-water protection planning can be effectively carried out at the national, regional or local level. In countries with a centralized administrative structure and/or a relatively small and geologically consistent land area, ground-water protection planning is often focused at the national level. National ground-water protection plans are usually prepared by central planning, environmental protection or water resources agencies.

In nations with a decentralized form of government, ground-water protection planning is often delegated to regional or local bodies, particularly in nations with large and geologically complex land areas. Where the responsibility for protection planning is delegated, the national co-ordinating agency usually sets guidelines and minimum standards.

Although the mechanisms for planning vary from country to country, the guiding principles remain essentially the same.

- Since ground water and surface water are integrally linked, ground-water planning should ideally take place within the broader context of integrated water resources planning and management.
- Planning should be based on the natural boundaries of the resource. Aquifers rarely respect administrative or national boundaries. In cases where aquifers cross international boundaries, treaties may be required.
- Ground-water protection planning should reflect a co-ordinated effort between agencies involved in all aspects of ground water. If the goals of ground-



water protection and ground-water development agencies are at odds, effective implementation is unlikely.

- Given that protecting all ground-water resources equally is rarely practicable, priorities must be carefully targeted. For critical water supplies, long-term protection can be implemented by establishing "hydrological parks", analogous to the protective forests which surround many surface reservoirs.
- Public input and feedback, from all sectors of the community, is of critical importance throughout the process.
- Plans should be regularly reviewed and revised to reflect changing needs and up-to-date information.

DENMARK

Denmark's geology is dominated by chalk and limestone formations overlain by moraine, sand and gravel. There is an abundant supply of ground water, derived from the widespread and easily accessible aquifers, which provide more than 98% of the country's needs. Ground-water contamination by nitrates and chemical waste is a major problem.

The two primary pieces of ground-water legislation in Denmark are the Environmental Protection Act (1973, revised 1991) and the Water Supply Act of 1985. An advisory group was established in 1983 to advise the Environmental Protection Agency and the minister on water issues.

Ground-water planning and administration are carried out at the national, regional and local levels. At the national level, the Environmental Protection Agency establishes standards and sets the framework for regional and local planning and protection. Regional councils are responsible for protecting ground water from pollution and excessive use and are required to establish water resources plans for each region. Abstraction licences are then issued, based on aquifer size, regional demands and the need for environmental protection. Water supply and distribution are managed at the local level.

The latest developments in Danish ground-water protection are the 1987 "Action Plan for the Aquatic Environment" and the 1990 revised "Act on Waste Sites". The purpose of the Action Plan is to reduce nitrogen and phosphorus levels associated with agriculture, waste-water treatment and industries by 50% and 80% respectively. Major components include: changes in agricultural practices, improvement of waste-water treatment plants and an extensive monitoring plan, with special focus on ground-water quality. The total capital investment is estimated at US\$ 2 billion. The Act on Waste Sites sets the framework and standards for investigations and remedial actions for waste sites.

Sources: L.S. Anderson and R. Thomsen, 1991, in *Integrated Land-Use Planning and Ground-Water Protection*, UNESCO; Danish Ministry of the Environment, 1991, pers. comm.

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THE PROTECTION PROCESS

There is no single approach or specific sequence of actions that will guarantee the successful protection of ground-water resources. Solutions must be tailored to fit the specific needs and resources of a country and should reflect national objectives and policies.

A variety of approaches to ground-water protection have been developed, ranging from the enactment of protective legislation at the national level, to the protection of public supply wells at the local level. Many protective actions can, and should be, pursued concurrently, at the national, regional and local level.

Public involvement is a major key to successful implementation. If public input is not sought early in the planning process, and the plan does not reflect local needs and realities, local co-operation is unlikely. And without the co-operation of individuals, the best planned and technically most advanced efforts will not succeed.

Effective ground-water protection

requires the enactment of legislation, establishment of an implementing agency and a variety of regulatory and non-regulatory mechanisms.

The basic components of national legislation include defining the extent of private property rights, enacting laws for ground-water protection and establishing a national implementing ministry or agency.

OWNERSHIP

Under many traditional systems of ground-water law (e.g. Common Law and Civil Code) property owners were entitled to the full use of all resources above and below their land. Private ownership of ground-water resources is still the case in many European and Latin American countries. However, in response to environmental degradation, there has been a trend towards the formal separation of the concepts of "ownership" and "right to use". Ownership does not automatically convey the right to pollute or over-exploit ground water. In Australia,

China, Indonesia, Iran, Spain, Germany, Peru, and elsewhere, ground water is seen as a public good, either through legal tradition (e.g. Moslem) or through the suppression of private ownership rights and the transfer of the resource to the public domain. In some countries,

THAILAND

Essentially all major aquifer types are represented in Thailand, from which approximately 700 million cubic metres of ground water are extracted annually. Ground-water problems include contamination by salt water, industrial wastes and fertilizers.

In 1977, the Ground Water Act of Thailand was enacted to bring ground-water activities within designated "ground-water areas" under government control. Within these areas, permits are required for the drilling of wells, extraction of ground water and subsurface disposal of liquid wastes. The Ministry of Industry is responsible for designating regions as "ground-water areas", issuing directives and enforcement. The Director-General of the Department of Mineral Resources (DMR) is responsible for administering the Act, including the processing of permits and registration of wells.

The Act is being implemented in areas where ground-water resources are particularly critical and are threatened by over-exploitation and pollution. Bangkok and five adjoining provinces have been designated as the Bangkok Ground Water Area. Directives issued under the provisions of the Act include: specifications for drilling and well construction; methods of ground-water extraction and conservation; technical measures for pollution control; drinking water standards; and technical principles for subsurface disposal of liquids. Penalties for violations include fines, imprisonment and confiscation of equipment.

In the Bangkok Ground Water Area, over 10,000 permits have been issued for ground-water extraction. However, the DMR has adopted a policy of not granting permission to construct new wells in areas where there is adequate public water supply, and has applied a strict control on ground-water uses in the critical zones. Requests for ground-water uses by the private sector are critically assessed before any permit is granted. The Ministerial Regulations, effective from February 3, 1985, entitled the DMR to levy a charge on private users of ground water in the Bangkok Ground Water Area.

Sources: United Nations, 1986, *Ground Water in Continental Asia*; Ground Water Division, Thailand Department of Mineral Resources, 1991, pers. comm.

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notably the United States, ground water is subject to different legal regimes in different states, with a distinction being made between domestic and other uses.

LEGISLATION

In many countries, ground water is protected through the enactment of a basic Water Act which covers all water resources. Specific provisions for ground water may be included within this or may be added at a later time. This approach has been followed in Finland, Italy, Israel, Poland, Spain, UK and USA. In other countries, including France, the Netherlands, Romania and Turkey, ground-water protection has evolved through the adoption of a wide range of regulations dealing with specific aspects of ground water, such as extraction rates, well depths and environmental protection.

Primary jurisdiction for ground-water protection may be centralized at the national level, as in Mexico and Egypt, or may be largely delegated to states or provinces, as in the United States, India and China. In cases where this jurisdiction is delegated, the central government typically retains authority over certain aspects, such as minimum water quality standards, to ensure consistency.

IMPLEMENTATION

One of the key components of effective ground-water protection is the establishment of a central agency or ministry whose responsibility is the implementation of ground-water legislation. The designated agency may have a variety of responsibilities, including the



Promoting sound agricultural policy is part of the ground-water protection process.

establishment of standards and regulations, enforcement, planning, and co-ordination. To operate effectively, agencies must be adequately funded and staffed. Responsibilities may be restricted to a centralized national agency or may be partitioned between national, regional and local administrative bodies. In situations where responsibilities for ground-water use, planning and protection are fragmented, a co-ordinating board consisting of representatives from different agencies may be required.

REGULATION

A wide variety of regulatory mechanisms have been developed to protect ground water.

■ **Setting water quality standards:** drinking water standards are usually set for maximum allowable levels of contaminants. These standards should reflect national priorities and technical capabilities. The direct adoption of standards promulgated by developed nations may not be enforceable, attainable or even desirable in many parts of the developing world.

■ **Establishment of protection areas:** rather than attempting to protect all ground water everywhere, efforts can be more effectively focused on the protection of important aquifers and public water supplies by establishing special protection areas. Often, a two-tiered approach is taken, whereby the entire aquifer is afforded a basic level of

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protection and the land area contributing to public supply wells is given an additional level of protection (wellhead protection areas). In western Germany, designated ground-water protection zones comprise 10% of the total land area.

■ **Control of extraction and subsurface waste disposal:** in many countries, permits or licences are required for the installation of wells and for the extraction and use of ground water. Legal limits may be set, based on the average recharge rate of a given aquifer, or extraction fees may be imposed to encourage efficient use and raise revenues. Controls on the quantity, quality and location of subsurface waste disposal are also commonly imposed.

■ **Identification and clean-up of sources of pollution:** an inventory of major point and non-point sources of pollution should be undertaken within ground-water protection areas, or at a minimum, within wellhead protection areas. Pollution from major point sources should be controlled, cleaned up and monitored. Land-use regulations are often a more appropriate tool for the control of non-point source pollution.

■ **Regulation of land use:** a variety of regulations have been developed to protect ground water from specific substances or activities which have the potential to degrade ground-water quality. The use of certain toxic and hazardous materials may be prohibited or restricted, particularly within ground-water protection areas. Regulations may be developed to control ground-water pollution from specific point sources of pollution, such as landfills, sewage treatment and disposal facilities and

underground storage tanks. Environmental impact assessments are useful for evaluating potential impacts of large projects on ground water. Within ground-water protection areas, specific land-use regulations are often enacted which include the prohibition or restriction of certain activities, controls on housing density, limitations on clearing of natural vegetation, and regulations pertaining to the use and application of specific substances.

■ **Enforcement of standards and regulations:** the agency responsible for ensuring compliance with standards and enforcing regulations should be clearly designated within ground-water legislation. Adequate staffing and funding are a prerequisite for effective enforcement. Two different approaches can be taken: the use of penalties or incentives. Penalties typically include the imposition of fines, surcharges, taxes, confiscation of equipment, loss of licences and imprisonment. Incentives include tax concessions, grants, compensation for land-use restrictions and issue of licences.

OTHER ACTIONS

Non-regulatory actions for ground-water protection include:

■ **Acquisition of critical land areas:** probably the simplest, most effective and most expensive approach to ground-water protection, is the acquisition of land areas which overlie particularly vulnerable and/or important aquifers. Land for this purpose may be acquired by national, regional or municipal governments, by non-governmental organizations, (or, in one interesting case by the Vittel bottled-water company, in

order to ensure the quality of its source spring). In many countries, it is routine practice to acquire the land area immediately surrounding public supply wells. Where supplies are particularly critical, however, larger areas may be acquired. In France, for example, the city of Paris is considering the purchase of an entire watershed as a definitive solution to protecting one of the city's drinking water springs.

■ **Training of technical staff:** a frequently cited cause of failure in the implementation of ground-water protection programmes is the lack of trained staff, particularly enforcement staff and technical staff such as hydrogeologists and planners. Methods for improving technical training include support for national university programmes in hydrogeology and water resources planning, and participation in seminars or training programmes.

■ **Monitoring ground water:** the monitoring of ground-water resources is a critical component for effective protection. Monitoring provides information on long-term trends, aids in the identification of threats and provides feedback on the effectiveness of protection measures.





ACTIONS FOR GROUND-WATER PROTECTION

POSSIBLE ACTIONS	PURPOSE
Treaties	Protects/apportions ground-water resources which cross national boundaries
Legislation	
<input type="checkbox"/> Enact ground-water protection laws	Establishes legal basis for ground-water protection, including liability for pollution
<input type="checkbox"/> Establish responsible agency	Identifies and empowers implementing body
<input type="checkbox"/> Set water quality standards	Establishes national goals for water quality
<input type="checkbox"/> Establish ground-water protection areas (GWPA's)	Sets priorities for protection
Regulations	
<input type="checkbox"/> Ground-water extractions	Controls location and rate of extractions; sets standards for well construction
<input type="checkbox"/> Subsurface disposal	Controls location, quantity and quality of subsurface waste disposal
<input type="checkbox"/> Environmental impact assessment	Evaluates potential impacts of large projects on ground-water resources
<input type="checkbox"/> Toxic and hazardous materials	Controls the transportation, storage, use and disposal of toxic and hazardous materials
<input type="checkbox"/> Landfills/solid waste disposal	Sets standards for siting and construction of new landfills; remedial measures for existing landfills; monitoring
<input type="checkbox"/> Sewage treatment and disposal	Sets standards for location of treatment plants, level of treatment and disposal of sewage; construction of septic systems
<input type="checkbox"/> Underground storage tanks	Sets standards for siting and construction of new tanks; inspection and removal of old tanks
<input type="checkbox"/> Surface runoff	Sets standards for control and treatment of surface runoff
<input type="checkbox"/> Prohibited uses	Prohibits harmful activities in GWPA's
<input type="checkbox"/> Restricted uses	Controls potentially harmful activities in GWPA's through use of permits, licences, etc.
<input type="checkbox"/> Maintenance of natural vegetation	Maintains percentage of GWPA as natural cover to protect water quality, recharge
<input type="checkbox"/> Low housing densities	Protects water quality in GWPA's by widely dispersing sources of pollution
<input type="checkbox"/> Growth limitations	Allows time for data collection, planning and protection within GWPA's
Other Actions	
<input type="checkbox"/> Land acquisition	Permanently protects ground water from land-based pollution
<input type="checkbox"/> Technical training	Improves effectiveness of staff
<input type="checkbox"/> Public education	Informs and involves public
<input type="checkbox"/> Contingency plans	Specifies actions to be taken to protect public water supplies in emergencies
<input type="checkbox"/> Monitoring	Augments data base and establishes trends

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FURTHER READING

R.H. Brown, A.A. Konoplyantsev,
J. Ineson, V.S. Kovalevsky (eds), *Ground-
Water Studies*, Studies and Reports in
Hydrology Series, No. 7, UNESCO, Paris,
1972.

E. Custodio, G.A. Bruggeman, *Ground-
Water Problems in Coastal Areas*, Studies
and Reports in Hydrology Series, No. 45,
UNESCO, Paris, 1987.

R.E. Jackson (ed), *Aquifer Contamination
and Protection*, Studies and Reports in
Hydrology Series, No. 30, UNESCO,
Paris, 1980.

J.F. Poland (ed), *Guidebook to Studies of
Land Subsidence Due to Ground-Water
Withdrawal*, Studies and Reports in
Hydrology Series, No. 40, UNESCO,
Paris, 1985.

UNESCO, *Handbook for National
Evaluation, Water Resources Assessment
Activities*, UNESCO/WMO, 1988.

UNESCO, *Water Resources Assessment*,
UNESCO/WMO, 1991.

United Nations Department of Technical
Cooperation for Development, *Ground
Water in the Eastern Mediterranean and
Western Asia*, UNDTCD, 1982.

United Nations Department of Technical
Cooperation for Development, *Ground
Water in the Pacific Region*, UNDTCD,
1983.

United Nations Department of Technical
Cooperation for Development, *Ground
Water in Continental Asia*, UNDTCD, 1986.

United Nations Department of Technical
Cooperation for Development, *Ground
Water in North and West Africa*, UNDTCD,
1987.

United Nations Department of Technical
Cooperation for Development, *Ground
Water in East, Central and Southern Africa*,
UNDTCD, 1988.

United Nations Department of Technical
Cooperation for Development, *Ground
Water in Western and Central Europe*,
UNDTCD, 1991.

J. Vrba (ed), *Integrated Land-Use Planning
and Ground-Water Protection in Rural Areas*,
Technical Documents in Hydrology
Series, UNESCO, Paris, 1991.

GROUND WATER

THE WAY FORWARD

As the Earth's population continues to grow, there is an escalating demand for clean and dependable sources of water. At the same time, ground-water resources – essential to further growth and development – are threatened by pollution and over-exploitation. Once polluted, the rehabilitation of an aquifer can be a long-term process, accompanied by adverse economic, social and environmental effects and involving the expenditure of enormous financial resources. Managers are realizing that if their countries are to have sufficient quantities of clean water in the future, they must begin to follow the laws of the hydrological cycle.

The sustainable development and the use of ground-water resources must take place within the broader context of integrated water resources management. This requires the protection of both ground-water quality and quantity and must take into account the interconnection between ground-water and surface-water systems. As a precondition to effective ground-water management, a full assessment of all water resources should be conducted.

To date, most ground-water protection programmes have been initiated in countries with intensive industrial and agricultural development, with efforts

focused on the remediation of severe pollution and the protection of existing public water supplies. In developing countries, ground-water development often takes precedence over management and protection.

In all parts of the world, there is a need for improved protection of existing and future supplies, in both urban and rural settings. This requires the development of institutions with the necessary powers and resources for the creation, coordination and implementation of a comprehensive ground-water strategy and policy. Legislation is needed, in turn, to regulate land use and control ground-water extractions. There is a growing trend towards the decentralization of responsibilities – from the national level to the regional and local level – which reflects the importance of public understanding and involvement in effective resource management.

The costs for ground-water management – data collection, administration and enforcement – can be high. But against these costs must be weighed the greater costs of not acting in time. One thing is clear: left unmanaged, our ground-water resources will continue to deteriorate. In too many cases, the ultimate result will be the loss of this critical, albeit "invisible", resource.

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