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Environment and Development —BRIEFS-

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.

UNESCO Environment and Development Briefs are intended to improve the communication of scientific information to decision makers. Each brief focuses on a single issue presented in a policy perspective and in relation to the overall quest for environmentally sound and sustainable development.

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THE NEED FOR ACTIO

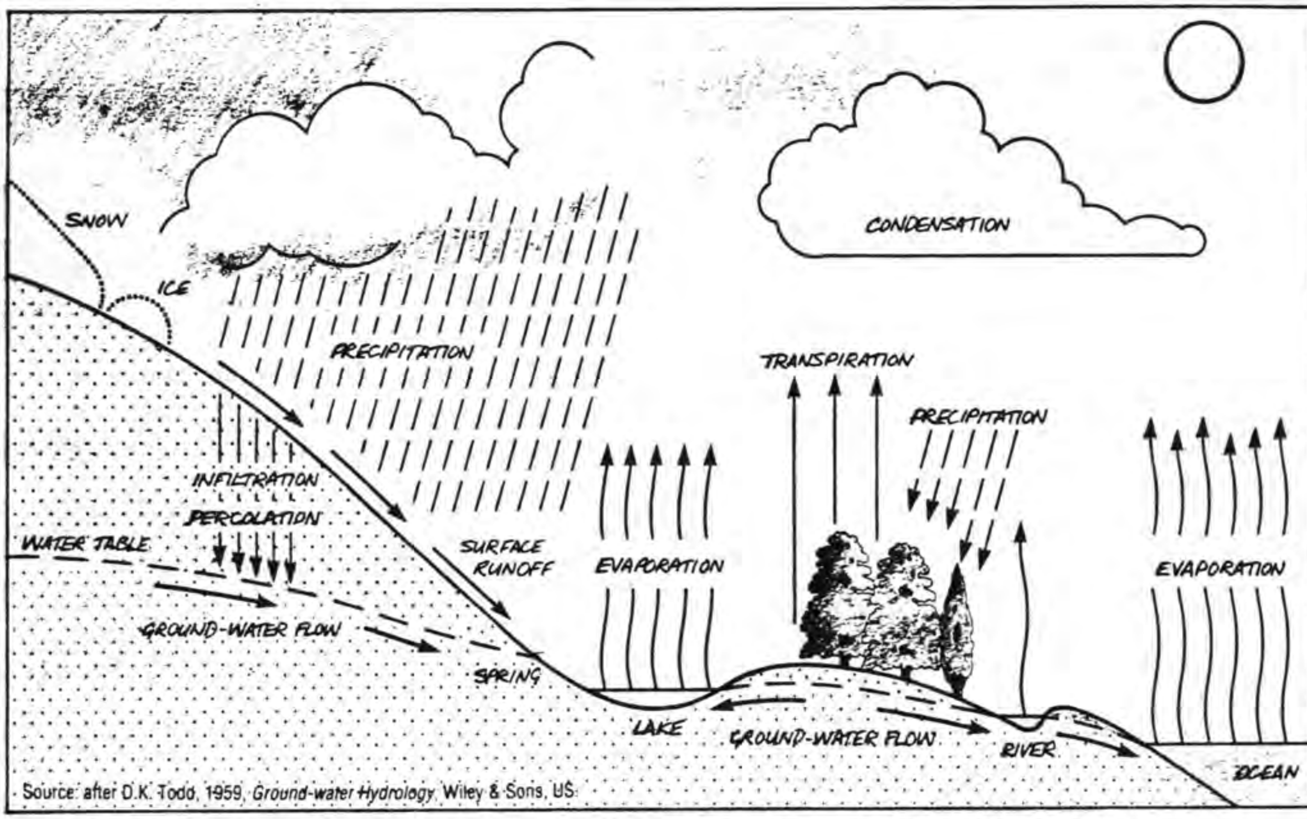
Ground water does not exist isolation, but is an integral link the hydrological cycle: the endle circulation of water between the ocear atmosphere and land. It is estimated th 95% of the Earth's useable fresh water stored as ground water.

Ground-water aquifers are period cally replenished by precipitation and b surface water percolating down throug the soils. The degree of replenishment, c recharge, depends on the climat vegetation and geology of a given regior In humid areas with porous soils, fc example, over 25% of the annual rainfa may recharge the ground-water systen In contrast, desert regions rarely exper ience ground-water recharge; aquifers ir these areas often contain fossil grounc water which accumulated under entirely different climatic conditions.

Water stored in aquifers is usually ir motion, flowing slowly downward unde 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

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.

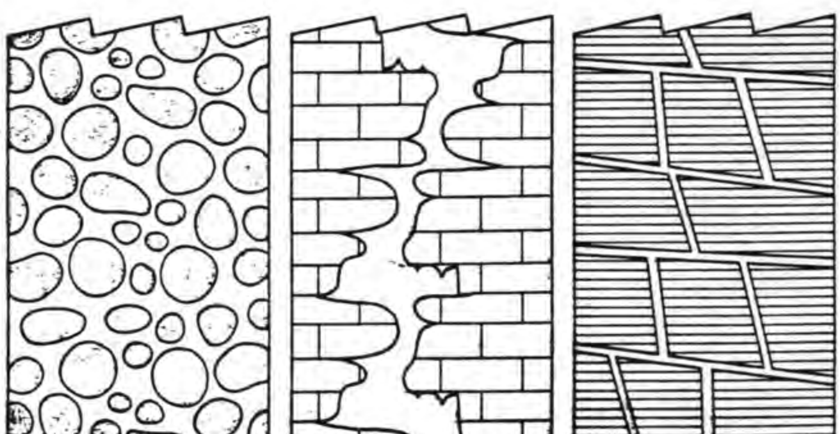
slow – in the order of several metres to hundreds of metres per year.

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. II 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.

- 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)

- 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)

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 intrinsi difficult to detect, and monitorir costly, time consuming and hit-or-ı Contamination is often not detected noxious substances appear in drin water supplies, at which point pollution has usually dispersed o\ large area. The clean-up of subsu pollution is notoriously time consuı and expensive, and can require adva technological methods. As an exan the cost of cleaning up hazardous w disposal sites under the USA's Super Program is estimated at US$ 2(billion.

As ground-water monitoring becc more common, largely in respons increasingly stringent drinking w standards, an alarming picture begin emerge. Ground-water quality declining slowly but surely everywl

Most ground-water contaminant: derived from agricultural, urban industrial land uses. In the past, ı attention was focused on point sou large pollution sources such as indus spills and leaks, landfills and subsuı injection of chemical and hazarc wastes. A variety of technological utions were subsequently develope clean up, or at least contain, this tyṗ pollution.

It is now becoming clear that sourc ground-water pollution are much r widespread, and are related to a varie typical activities at the land's surı Ground-water pollution in most ı industrial areas can be attributed to : dispersed, or non-point sources, fertilizers, pesticides, septic syst street drainage, and air and surface-w pollution. The only effective method fo control of this type of pollution is b tegrating land use and water managen

EXTRACTION

Throughout history, people have vie ground water as either an inexhaust source of water, or as an extract resource, no different from petrole coal or iron. With the developmen modern exploration, drilling extraction techniques, however, attitude can no longer be sustai Although ground water is a renew resource in most parts of the world, aquifers can withstand enorm extraction rates indefinitely. To en adequate ground-water supplies

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.

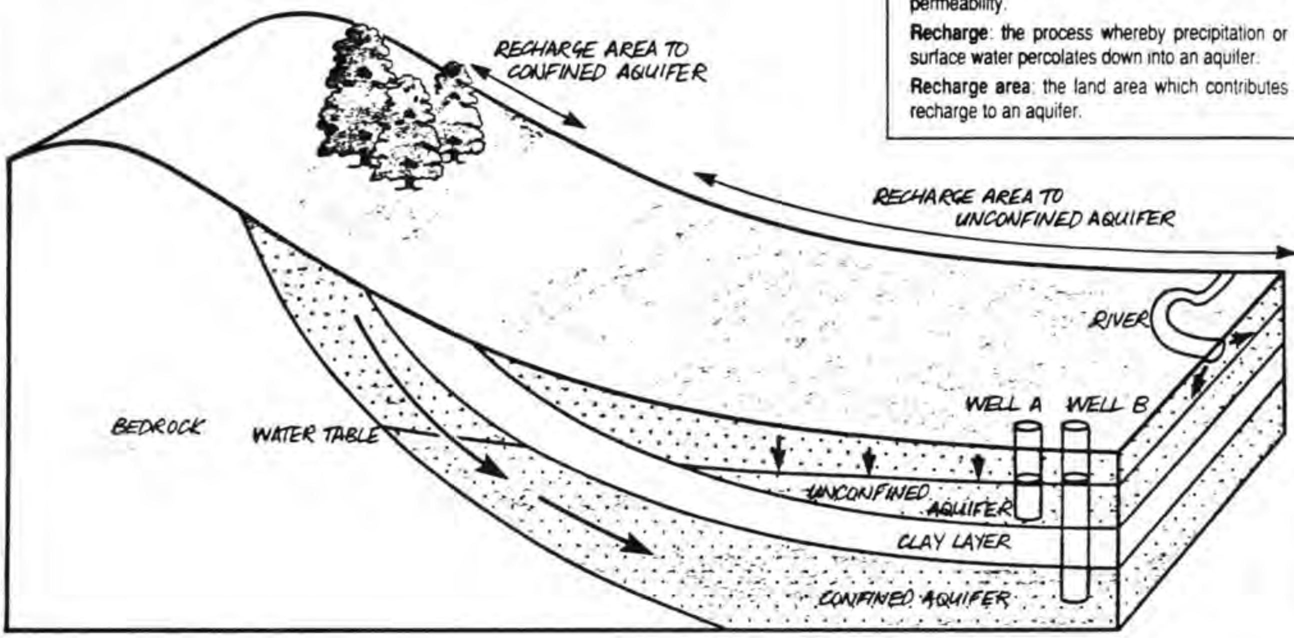
Water table: the boundary between the saturated and unsaturated zones.

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.

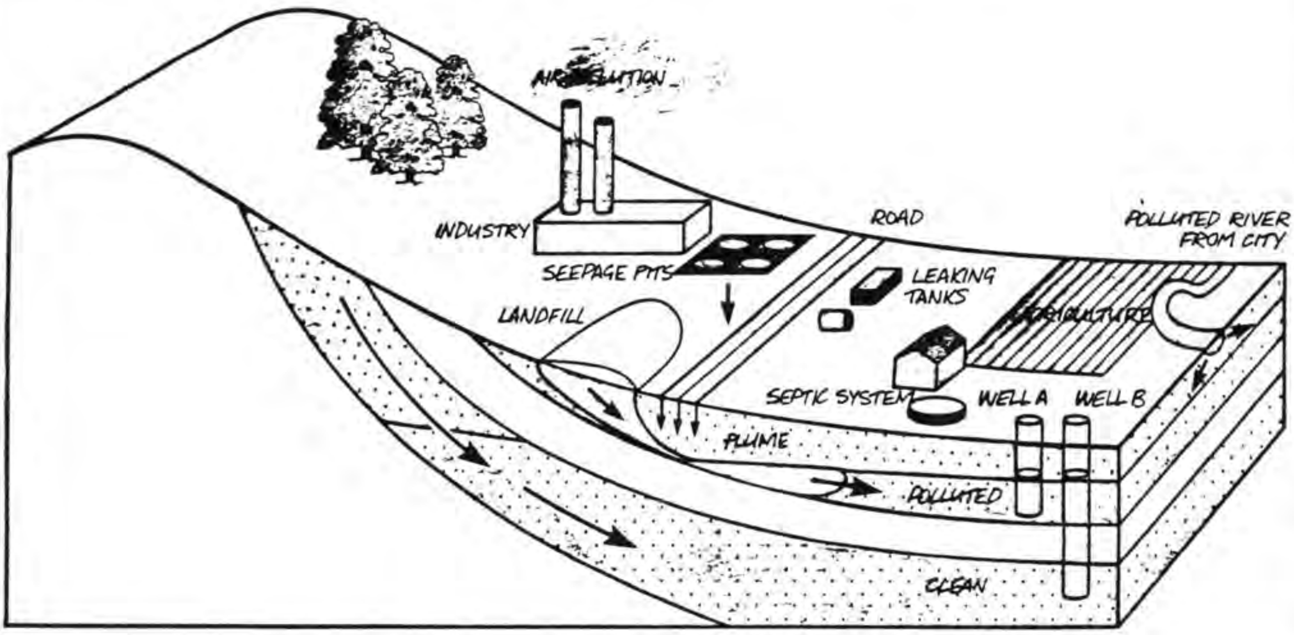
Recharge: the process whereby precipitation or surface water percolates down into an aquifer.

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:

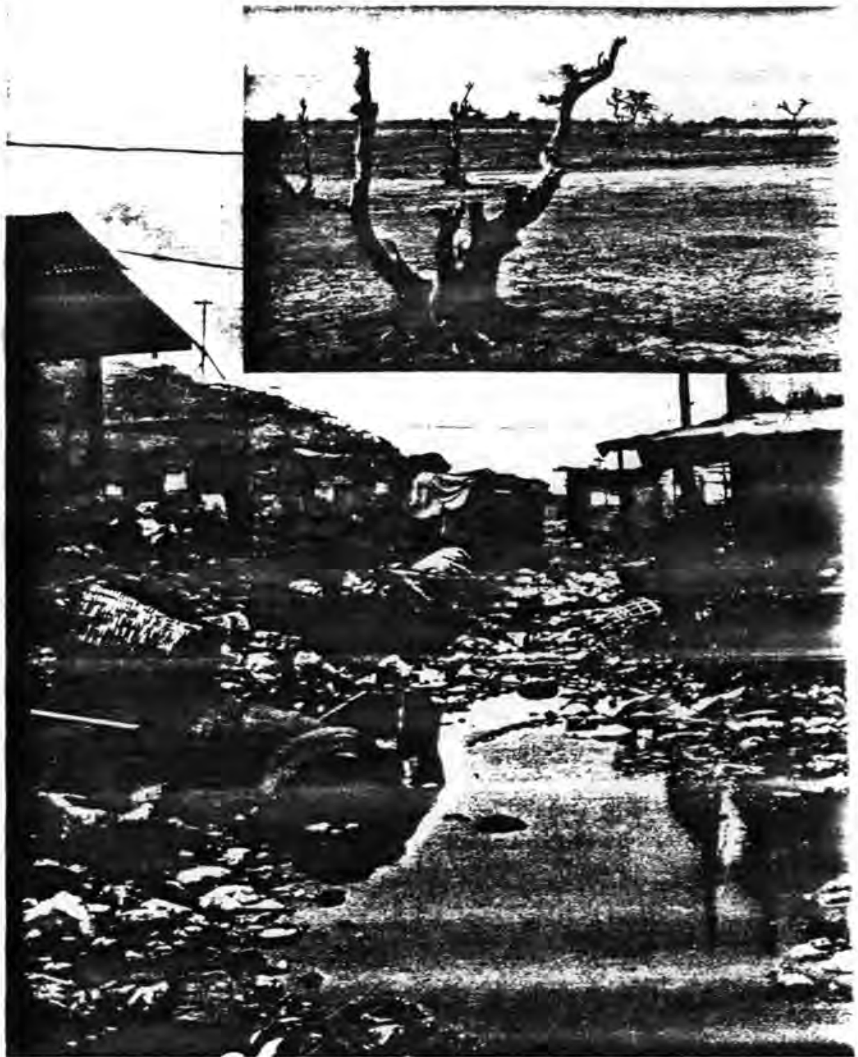
☐ Shallow wells, often used for local water supplies and irrigation, dry up.

☐ 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.

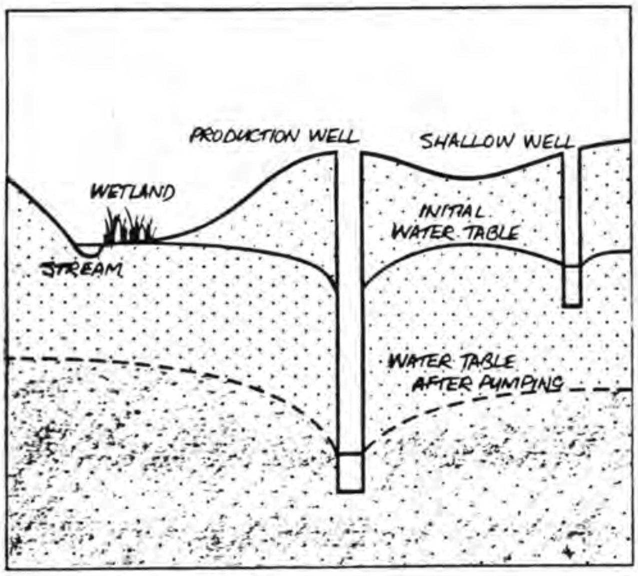
☐ **Structural damage and coastal flooding:** where land subsidence is severe, buildings and infrastructure can be damaged, and low-lying coastal areas may experience increased flooding.

☐ **Economic hardship**: where money is no object, the technology exists to find, extract and purify water to meet the r stringent water quality stand Similarly, techniques have developed to mitigate most grou water problems.

But the costs can be exorbitant. replacement of a contaminated well may entail the construction of a reser or aqueduct, treatment plant and distribution system. Clean-up costs relatively minor gasoline spill into aquifer can cost hundreds of thousan dollars. The depletion of a major aqu can also lead to the permanent los agricultural and industrial producti

In the long run, such risks are aln never worth the short-term benefit mistreating ground water. The n effective and least expensive solution establish a programme to protect grou water.

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:

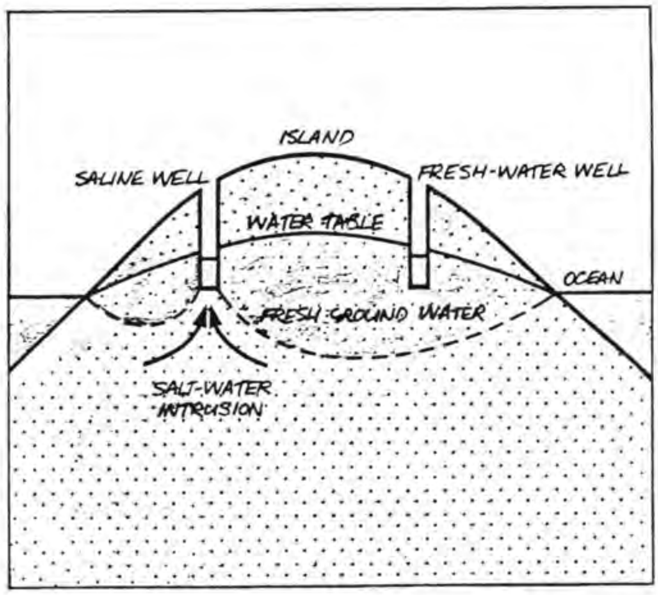
- lowered water-table or reduced water pressures
- drying up of springs, streams, ponds and wetlands
- loss of wells or reduction in pumping capacity
- salt-water intrusion • land subsidence.

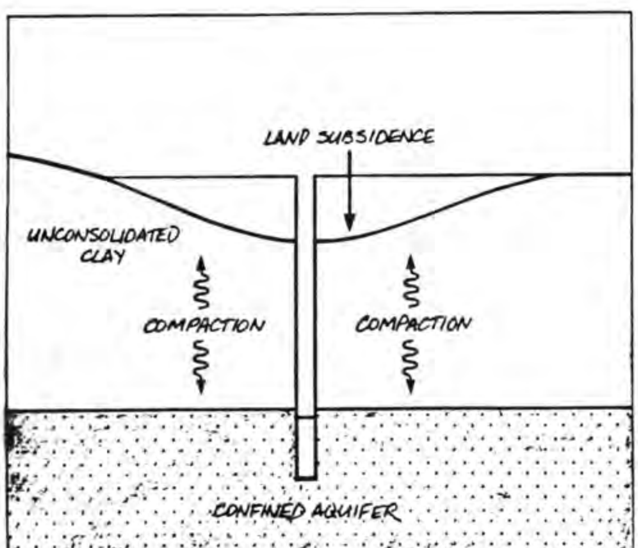
SALT-WATER INTRUSION

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.

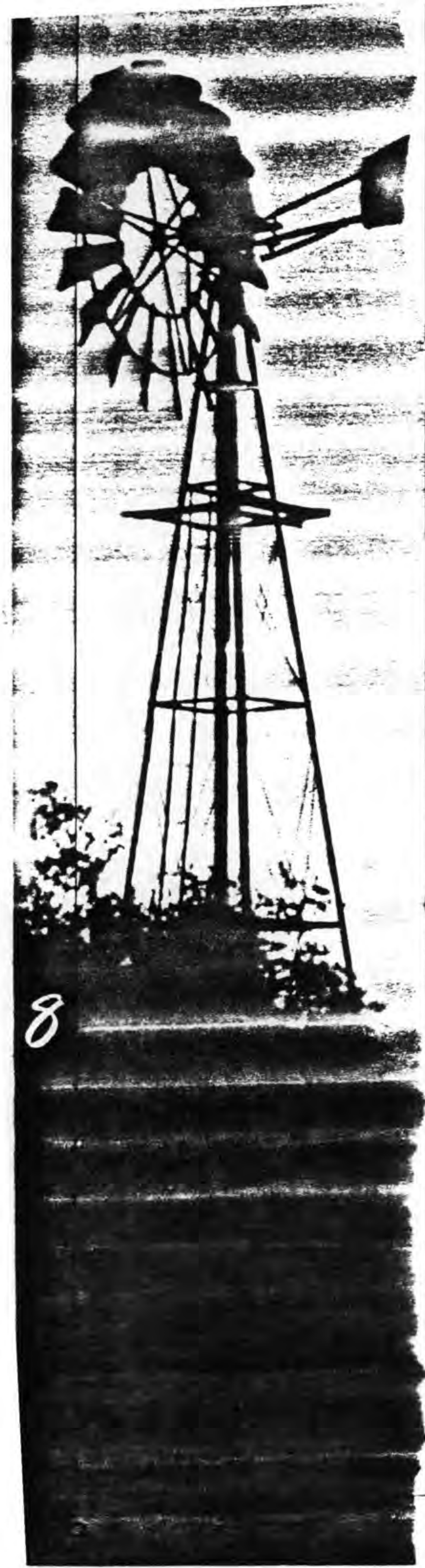




LAND SUBSIDENCE

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	US$ 6 billion
Western Germany	US$ 30 billion
USA	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*.

TAKING STOCK

A full assessment of all water resources is a necessary prerequisite for effective ground-water protection. For the ground-water component, baseline information is needed on: the location, water quality and potential yield of major aquifers; existing and potential sources of pollution; the aquifer's natural degree of protection; and the location and extraction rates of wells.

The development of a data base on the subsurface environment is a slow, continuing and often complicated process. A variety of methods, ranging from the basic to the highly sophisticated, can be used in obtaining this information. In areas where little information exists, remote sensing and/or geophysical survey methods are useful for establishing preliminary and generalized data on geology, depth to ground water, water quality and existing land use. Direct subsurface measurements require the installation of networks of monitoring wells. Conditions between wells are then usually extrapolated, or measured using indirect methods.

Once baseline conditions have been established, regular subsurface monitoring is important to augment the data base and to keep track of long-term trends. A monitoring programme involves the periodic measurement of ground-water levels and water quality in a network of wells at key locations.

Responsibility for the collection of baseline data and monitoring is often delegated to appropriate agencies (e.g. geological surveys, water development and distribution agencies and planning organizations).

To ensure consistency, specific standards should be established for well construction, water level measurements, water sampling and analytical methods. It is very important that all relevant data be transmitted to a centralized data bank.

Data should be presented in a format that is readily understood and applied. Typically, a series of maps is developed depicting geology, aquifer characteristics, ground-water quality, land use, contaminant sources and the location and extraction rates of existing wells. Geological cross-sections are useful in illustrating three-dimensional aspects.

The synthesis and presentation of a wide range of multi-disciplinary data is a major challenge. Aquifer vulnerability mapping and the use of geographic information systems (GIS) are two tools which have been developed to aid in this process. In Italy, GIS is being used to develop vulnerability maps.

The development of a subsurface data base can be expensive: the cost for drilling and installing a single monitoring well can range from tens to thousands of dollars, depending on the rock type, well depth and local conditions. Therefore, it is important to maintain a judicious balance between direct and indirect methods and to concentrate data acquisition efforts in high priority areas. Certain international organizations regularly provide advice, training and financial assistance for ground-water data base development.

Creative solutions have been devised to circumvent the problem of cost. In Denmark, a law passed in 1924 required all licensed well drillers to forward boring logs and well-construction data to the Danish Geological Survey. This simple action has produced a valuable data base at essentially no cost to the country.

COLLECTING GROUND-WATER MANAGEMENT DATA

- Geological mapping
- Subsurface borings and excavations
- Water level monitoring
- Geophysical surveys
- Pump tests
- Water quality testing
- Aerial photography and remote sensing
- Land-use mapping
- Pollution source inventory

ACTION

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.

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.

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 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.

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

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

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.

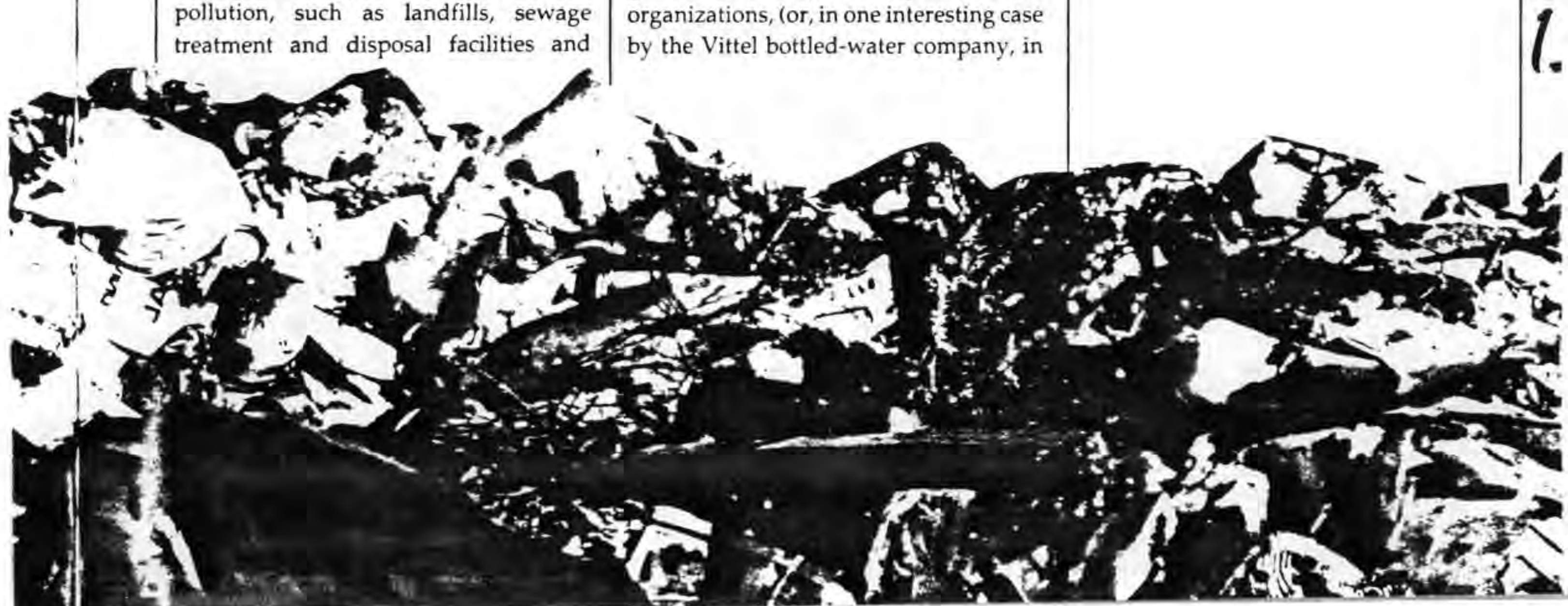
OTHER ACTIONS

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

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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.