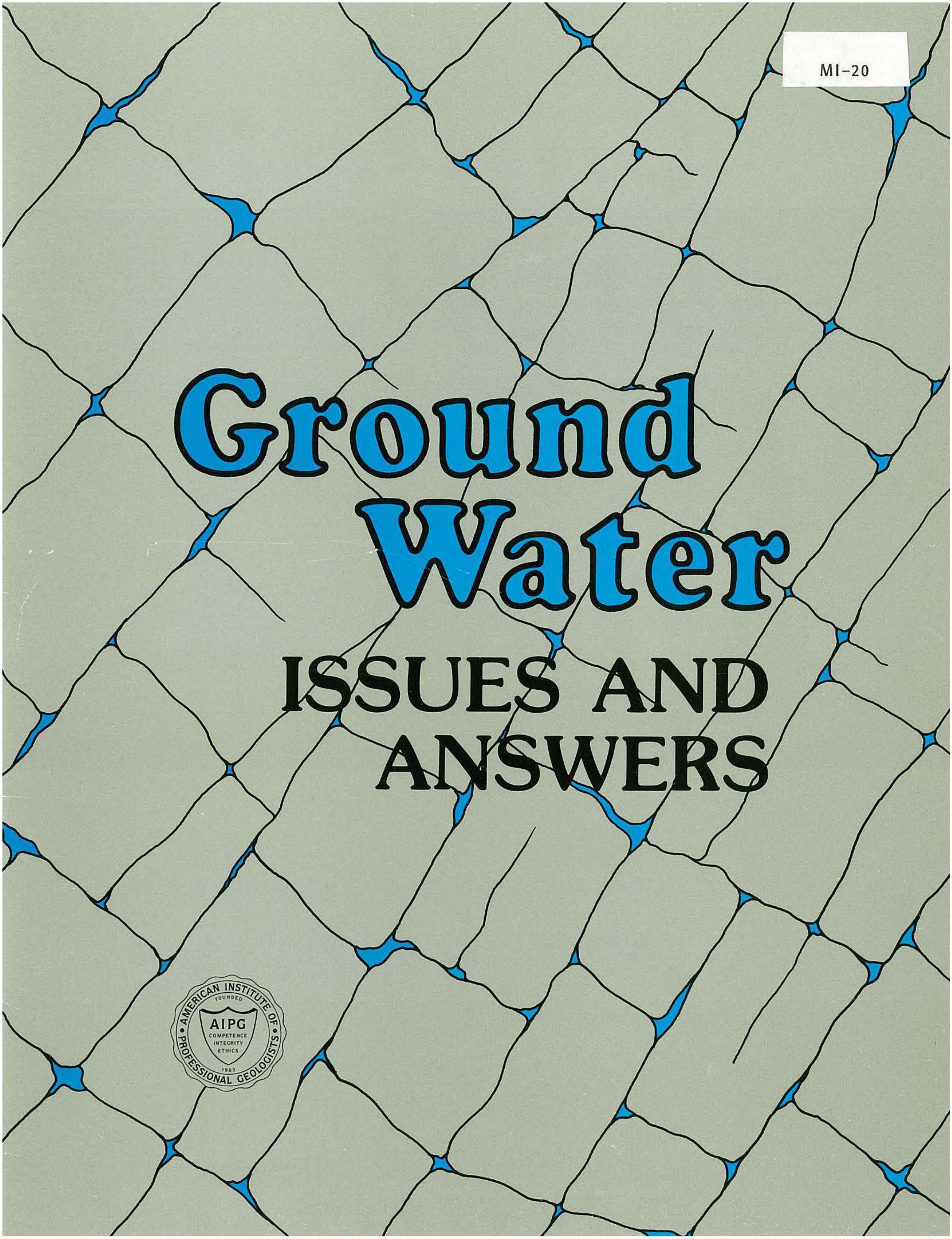

Ground Water

ISSUES AND ANSWERS

AMERICAN INSTITUTE OF PROFESSIONAL GEOLOGISTS
FOUNDED 1963
AIPG
COMPETENCE
INTEGRITY
ETHICS

Foreword

The American Institute of Professional Geologists (AIPG) is a nationwide organization of 4,700 members representing all areas of specialization in the professional practice of geology. The Institute serves both the profession and the public through its certification program and its involvement in public affairs. One form of AIPG involvement in public concerns is publication of "issue papers" such as this one, dealing with current specific matters in which geology is significant to formulating prudent public policy, legislation, or governmental regulation.

Ground water is a most important natural resource, currently the focus of considerable public interest. Wise development, management, and protection requires fundamental knowledge of ground water and its problems. The purpose of this booklet is to provide policy makers, legislators, and the general public with information and data to better understand U. S. ground-water resources — both their potential and limitations — so that they can be managed in the best long-term interest of the Nation.

We hope this booklet serves that purpose. If you have questions or comments, or if you would like additional copies, please contact:

AMERICAN INSTITUTE OF PROFESSIONAL GEOLOGISTS
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303 / 431-0831

Important Note — This booklet furnishes general information in the spirit of developing enlightened management policy. This material is introductory, and not intended to provide detailed information or professional advice. Because each situation is unique, this booklet cannot be used in solving specific problems. The direct advice of professionals in the discipline is essential. (A Directory of Certified Professional Geologists, indicating their specialties and addresses, is available without charge from AIPG.)

The material in this booklet was compiled by an AIPG ad hoc committee of ground-water experts under the chairmanship of George H. Davis. The committee members were: A. F. Agnew, R. E. Bergstrom, G. L. Faulkner, J. J. Geraghty, J. H. Lehr, G. Meyer, D. A. Stephenson, D. L. Warner, and K. N. Weaver.

The publication was produced by Fred Schroyer (editor), Dan Barker (artist), and Grafics Printing of Morgantown, WV (design and printing).

Our thanks to the National Water Well Association for providing the color photographs used in this booklet.

Production of this publication was made possible, in part, by a grant from The A.I.P.G. Foundation, Arvada, Colorado. The Institute gratefully acknowledges The Foundation's financial support. Third Printing, 1985.

Cover — Shows how ground water fills the open spaces in rock crevices.

National Water Well Association

Contents

What Is Ground Water?

Many people think of ground water as underground lakes or streams. There are such things — in areas of cavernous limestones or volcanic lava flows — but mostly, *ground water is simply water filling spaces between rock grains or in fractures and fissures in rocks.* Such openings are most common near the land surface; at great depth openings are closed by the great pressure of overlying materials.

Rain and snowmelt percolating down through the soil are the source of ground water. Plants consume much of the water that enters the soil, and a small amount is held on the soil grains by capillary forces; any surplus percolates downward to the *zone of saturation.** The top of the zone of saturation is called the *water table.* At this level, pressure is the same as that of the atmosphere, or roughly 15 pounds per square inch. Below the water table all openings are water-filled, and the pressure at any point is determined by atmospheric pressure, plus the weight of water between there and the water table.

Ground water is usually in motion, flowing under the force of gravity to lower areas where it may discharge as a spring, or to a stream, or to the ocean. The rate of ground-water flow is determined by the *hydraulic gradient* (the slope of the water table or the pressure surface) and the *permeability* (ease of conducting water).

The amount of water a rock can contain depends upon its *porosity* — the ratio of open space to total volume. In productive *aquifers* (water-bearing rock layers) that are granular, such as sand and gravel, this ratio generally is 30 to 40%. However, in crystalline igneous rocks and tightly cemented sedimentary rocks, where cracks represent the only open spaces, the porosity commonly is only 1% or less.

If water is to move freely through a rock, the openings must be interconnected, and the openings must be large enough so that wall friction does not greatly impede its flow. If a rock has many connected openings of a size sufficient to permit water to move freely, the rock is termed *permeable.* Large volumes of water can be pumped from permeable materials. Even crystalline rocks with no intergranular spaces, such as granite, may be permeable if broken by fractures of sufficient size to permit water to pass freely. Clay and similar fine-grained materials, ironically, have high porosity, but yield water very slowly, because their pores are so small that wall friction greatly impedes water movement.

Rocks containing large openings, such as solution channels in limestones and lava tubes in volcanic flows, may have low overall porosity, but can have very high permeability because the large size of the openings permits water to flow at high velocity.

Ground water does not occur downward all the way to the core of the earth. Beneath water-bearing rocks everywhere, at some depth, the rocks are water-tight. This depth may be a few hundred feet, or more than likely tens of thousands of feet.

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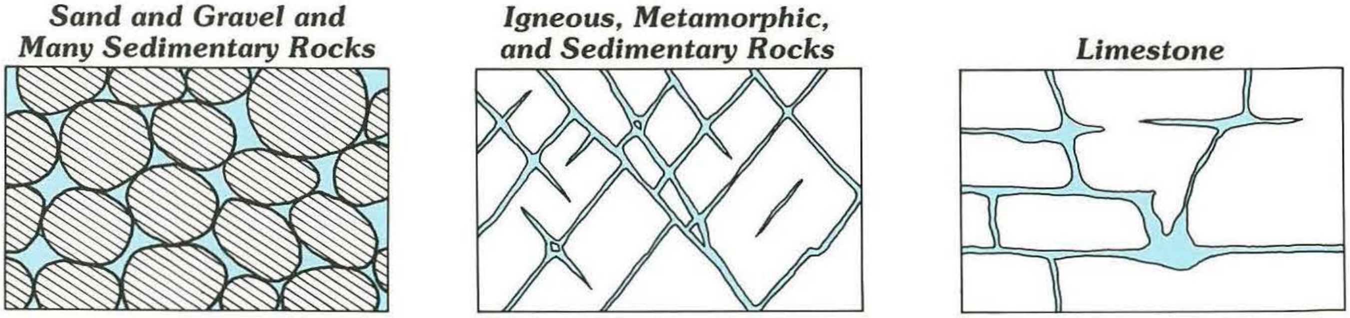
*Technical terms are defined in the Glossary, page 24.

MAIN TYPES OF POROSITY

Ground water fills the spaces between sand grains, in rock fractures, and in solution openings.



Sand and Gravel and Many Sedimentary Rocks

INTERGRANULAR

Igneous, Metamorphic, and Sedimentary Rocks

FRACTURES

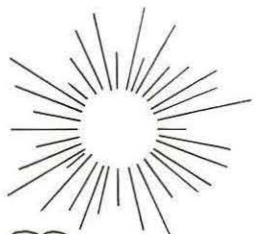
Limestone

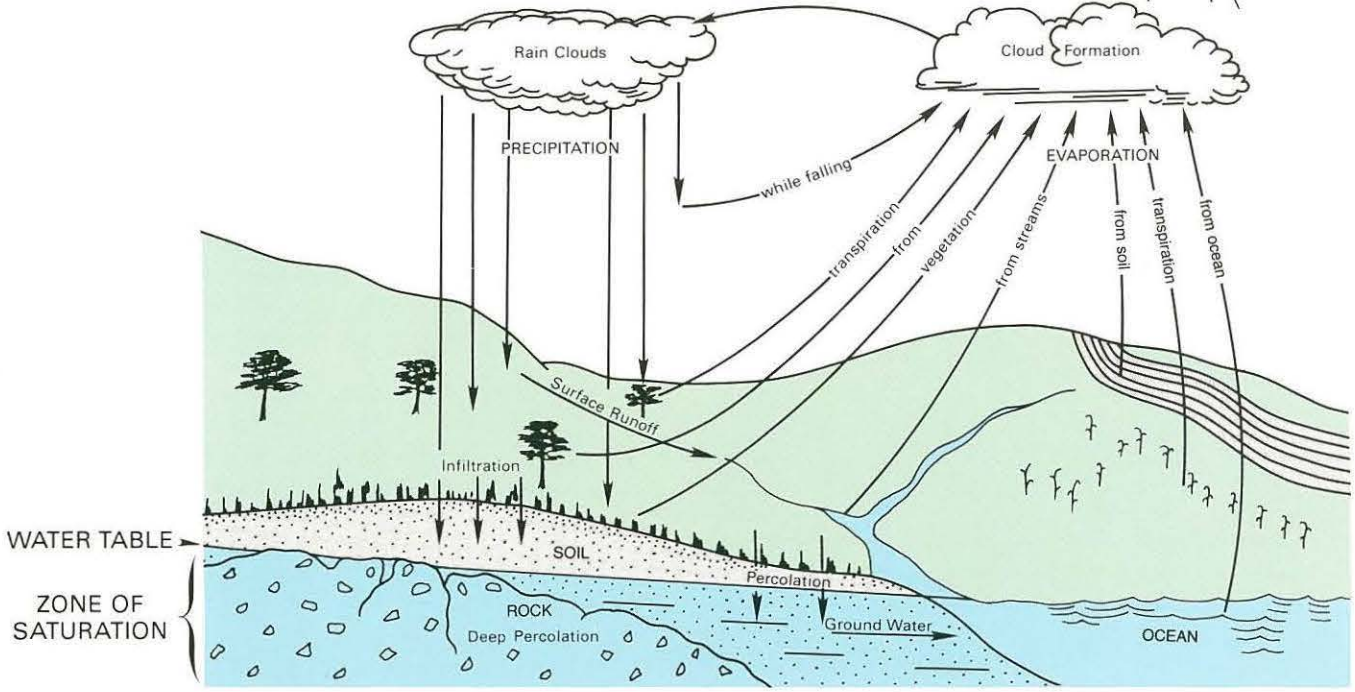
SOLUTION

(Modified from Meinzer, 1927, Figure 1)

THE HYDROLOGIC CYCLE

Ground water is the fraction of precipitation that reaches the zone of saturation after seeping through the soil or through stream beds.



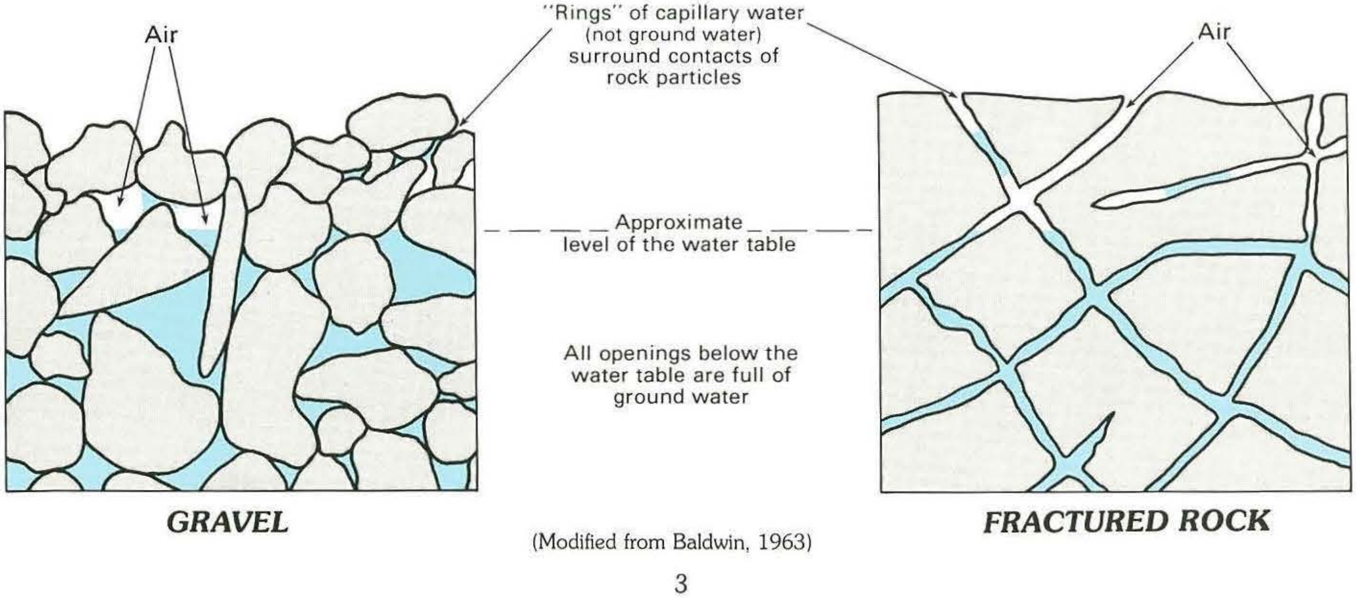


Ground water moves under the force of gravity from higher elevations to lower elevations; the rate of movement can range from several feet per day to as little as inches per century.

(After the Hydrologic Cycle, *Yearbook of Agriculture*, U. S. Department of Agriculture, 1955)

HOW GROUND WATER OCCURS IN ROCKS

The water table marks the top of the zone of saturation. Its level can rise or fall, depending upon the rate of water entering and leaving the ground.

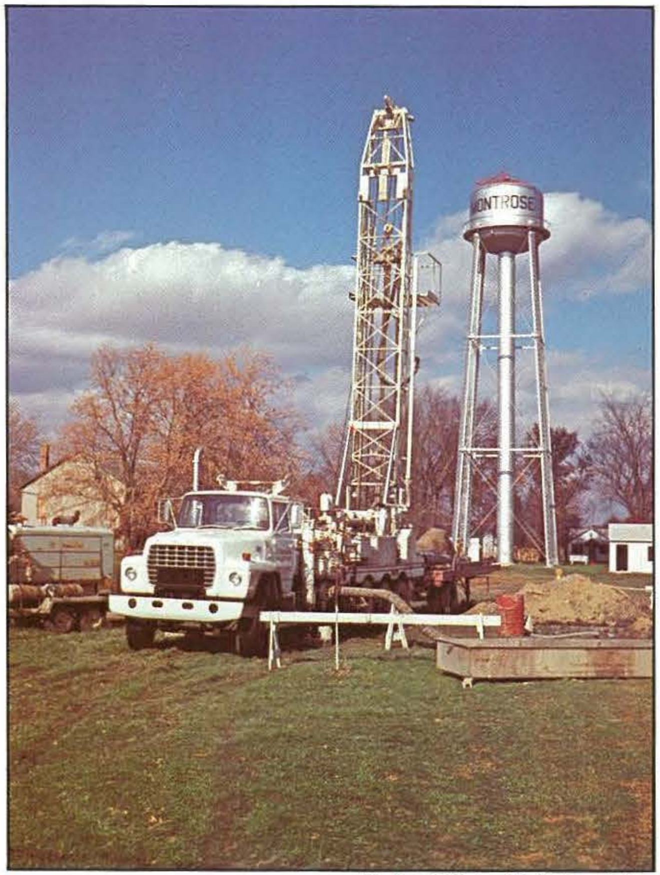


GRAVEL

FRACTURED ROCK

(Modified from Baldwin, 1963)

Aquifers Store and Transmit Ground Water



National Water Well Association

An *aquifer* is a rock layer that will yield sufficient water to serve as a water supply for some use. It may be a few feet or hundreds of feet thick. It may be just beneath the surface, or hundreds of feet down. It may underlie a few acres, or thousands of square miles.

Aquifers function in two very important ways: (1) they transmit ground water from the point of entry to points of discharge, and (2) they provide storage for large volumes of water. In a sense, they act as both pipes and storage tanks. Aquifers are classified into two principal types — unconfined and confined.

Unconfined aquifers are those in which atmospheric pressure changes are freely transmitted downward through an unsaturated zone of soil or rock to the water table. Unconfined aquifers provide water to wells by draining the materials surrounding the well. When the water table rises or falls, the change in storage is equivalent to the volume of pore space saturated or drained.

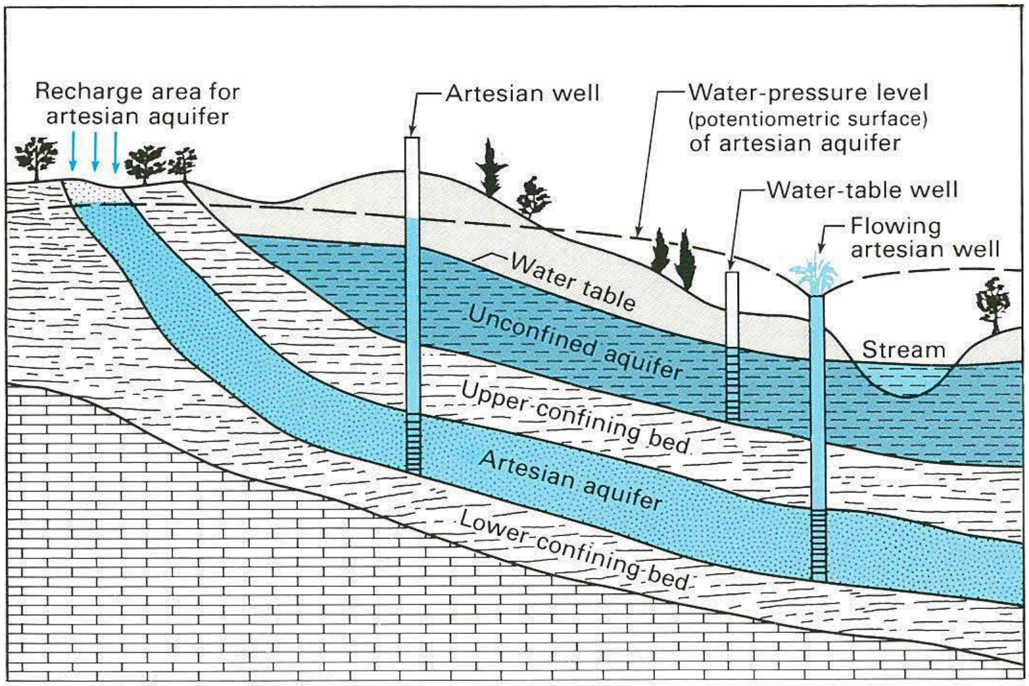
Confined or **artesian aquifers** are those overlain by impermeable rock layers that prevent free movement of air and water. Thus the water is confined under pressure, as in a pipe system. Drilling a well into a confined aquifer is analogous to puncturing a water pipe, with water under pressure gushing into the well, sometimes even rising to the surface and overflowing.

Confined aquifers yield water due to compression of the aquifer materials, expansion of the water, drainage of adjacent unconfined rock zones, and leaky confining rock layers. The "Cone of Pressure Decline" (see figure, p. 5) expands rapidly over a wide area and recovers quickly when pumping stops. Recharge is by subsurface flow from adjacent unconfined rock zones and by slow leakage from and through confining rock layers.

Because decline of water levels is a pressure response to water withdrawal, the storage in confined aquifers is small compared to that of unconfined systems. However, when the pressure level declines below the top of the aquifer, the aquifer becomes temporarily unconfined. Under these conditions, water can flow from the aquifer into a well.

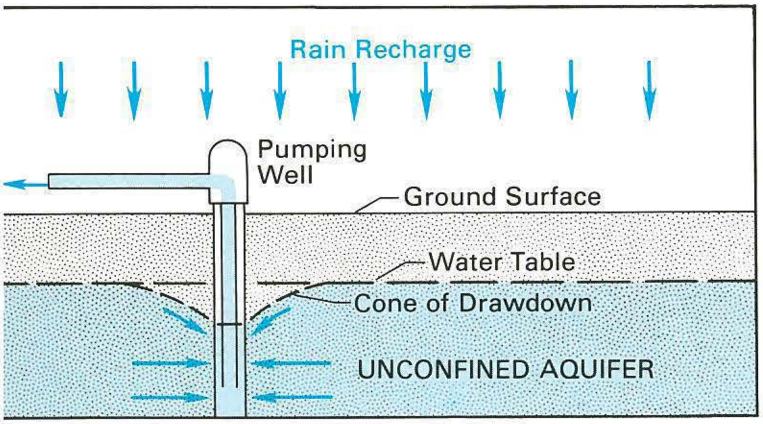
QUIFERS

quifers consist of
rmeable rocks or
anular deposits that
ansmit water freely.
hey function both as
nduits and as under-
round storage reservoirs.



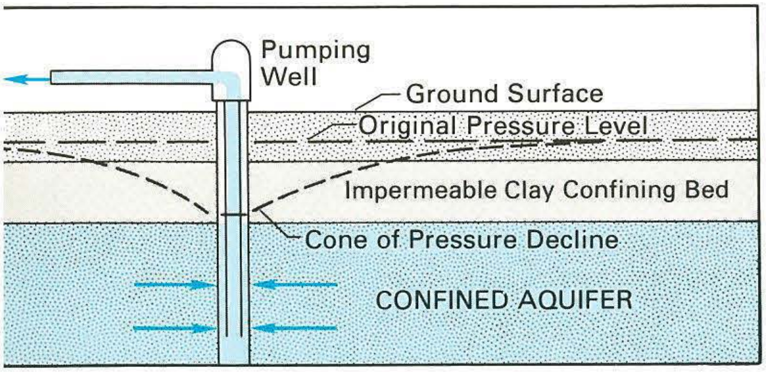
(After *Ground Water and Wells,* UOP Johnson Div., 1966)

UNCONFINED AQUIFER



Where atmospheric pressure is freely communicated to the zone of saturation, the aquifer is called "unconfined." Unconfined aquifers yield water by drainage of materials near the well. Wells produce water by lowering the water level, causing water to flow radially toward the well.

CONFINED ("ARTESIAN") AQUIFER



Where an impermeable layer, such as clay, above the aquifer prevents free movement of air and water, the aquifer is called "confined" or "artesian." Confined aquifers yield water by compression of the aquifer, expansion of the water, drainage of adjacent unconfined zones, and leakage through confining layers.

Natural Quality of Ground Water

Ground water nearly always contains more *mineral matter* than nearby surface waters, although both originate as precipitation. The main reason for this is that water passing through the soil dissolves large amounts of carbon dioxide formed by soil bacteria, producing a weak carbonic-acid solution that attacks carbonate and silicate minerals of calcium, magnesium, and sodium, causing their solution. Where soluble chloride and sulfate compounds are present, as in arid climates, they are also dissolved in the infiltrating water.

Far below the water table, relatively little additional solution occurs. However, other chemical reactions, such as cation exchange and sulfate reduction, may result in substitution of one constituent for another. But the total dissolved-solids content does not change significantly.

In *cation exchange,* the ground water generally loses calcium and magnesium, gaining an equivalent amount of sodium in a natural "water-softening" process. In *sulfate reduction,* bacteria which consume sulfate in their life cycle add an equivalent amount of bicarbonate to the ground water.

In regard to quality, ground water has both advantages and disadvantages compared to surface water:

Advantages

- Passage through soil and sediments results in filtration of particulate matter and absorption of organic compounds and some metals on clay minerals.
- Relatively constant temperature and quality.
- Relatively safe from some types of pollution, especially by airborne contaminants.
- Spread of pollution is slow.
- Sediment content is generally negligible.
- Supply is somewhat less dependent on weather variations, compared to surface water.

Disadvantages

- Dissolved solids and hardness are higher than in nearby streams.
- Once polluted, cleanup is slow and difficult.

QUALITY DETERMINES USABILITY

Domestic —

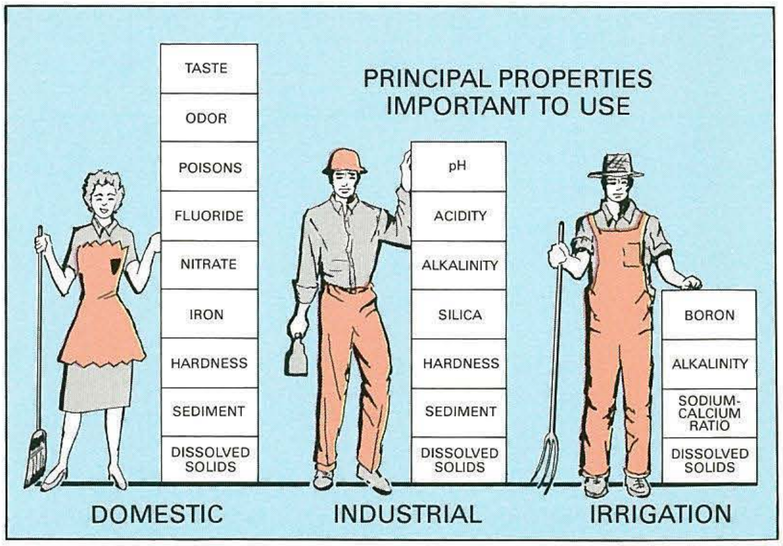
Water for domestic use should taste and smell good, be free from constituents harmful to health, and should not damage plumbing or appliances.

Industrial —

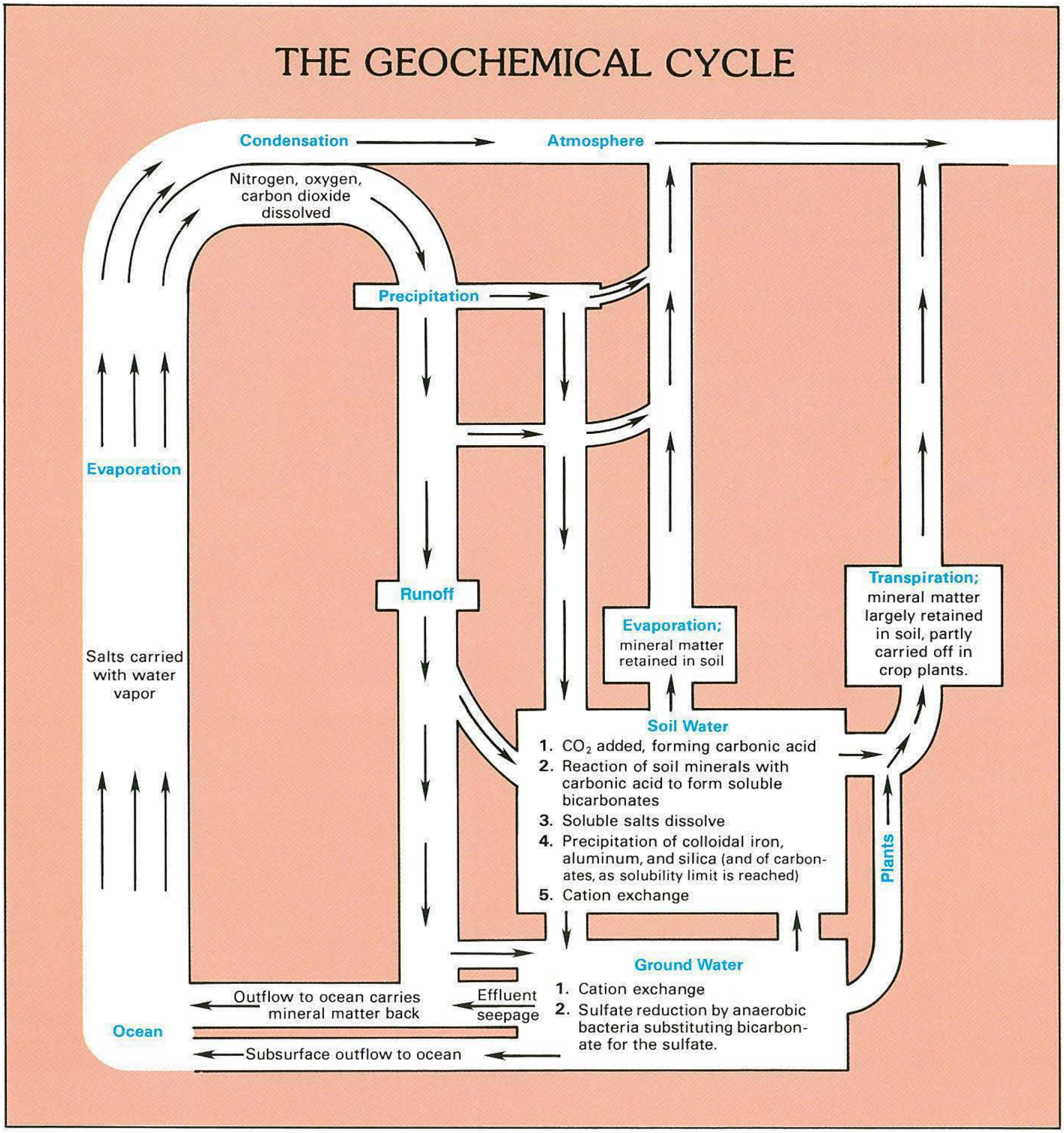
Requirements for industry vary greatly depending upon uses, but generally the water should not be highly corrosive or cause precipitates that would clog equipment.

Irrigation —

Plants are generally tolerant of a wide range of water quality. They are very sensitive to boron, a plant poison, and are sensitive to dissolved solids, which at high levels make the water unusable. The balance between sodium and calcium is important in maintaining proper soil structure.



(From Baldwin, 1963)


THE GEOCHEMICAL CYCLE

(Modified from Davis and others, 1959)

Water is an active solvent.

Gases, mainly carbon dioxide dissolved from the air and in the soil, form a weak solution of carbonic acid that attacks mineral grains, causing further solution.

Ground-Water Resources in Geologic Regions

1. **Western Mountains** —Underlain by hard, dense rocks; weathered rock locally yields modest supplies, as does alluvium in intermontane valleys. Large supplies are rare.

2. **Alluvial Basins** —Large depressed areas flanked by highlands and filled with erosional debris. Alluvial fill functions as an ideal aquifer, absorbing water readily from streams issuing from highlands and yielding large supplies to wells. Supports large-scale irrigated agriculture and provides municipal water for many cities.

3. **Columbia Lava Plateau** — Underlain by thousands of feet of basaltic lava flows, interbedded with alluvial and lake sediments. Lava rocks are highly permeable because of lava tubes, shrinkage cracks, and interflow rubble zones. Yields large supplies of water for irrigation and municipal use.

4. **Colorado Plateaus and Wyoming Basins**— Underlain by gently-dipping sediments, mainly poorly-permeable sandstone and shale. Most productive aquifers are sandstone, furnishing small supplies for stock and domestic use. Prospects poor for large-scale ground-water developments, but such supplies are found at a few favorable localities.

5. **High Plains** —Underlain by alluvium of the Ogallala Formation, as much as 450 feet thick, which yields large supplies to wells, mainly for irrigation. Opportunity for recharge from streams is small, due to low rainfall and because large streams have cut below the base of alluvium. Water table is gradually declining in much of the area due to overdraft.

6. **Unglaciated Central Region** —Complex area of plains and plateaus, underlain by consolidated sedimentary rocks. Alluvium of stream valleys provides large supplies for industry and cities. Most productive aquifers in much of the region are dolomitic limestones and sandstones of low-to-moderate yield.

7. **Glaciated Central Region** —Similar to Unglaciated Central Region, except that area is mantled by glacial deposits as much as 900 feet thick. These contain lenses and beds of well-sorted sand and gravel, which yield large supplies of water for industrial and municipal use.

8. **Unglaciated Appalachians** —Mountainous area underlain mainly by consolidated sedimentary rocks of small-to-moderate water yield. Locally, limestones yield large supplies of water.

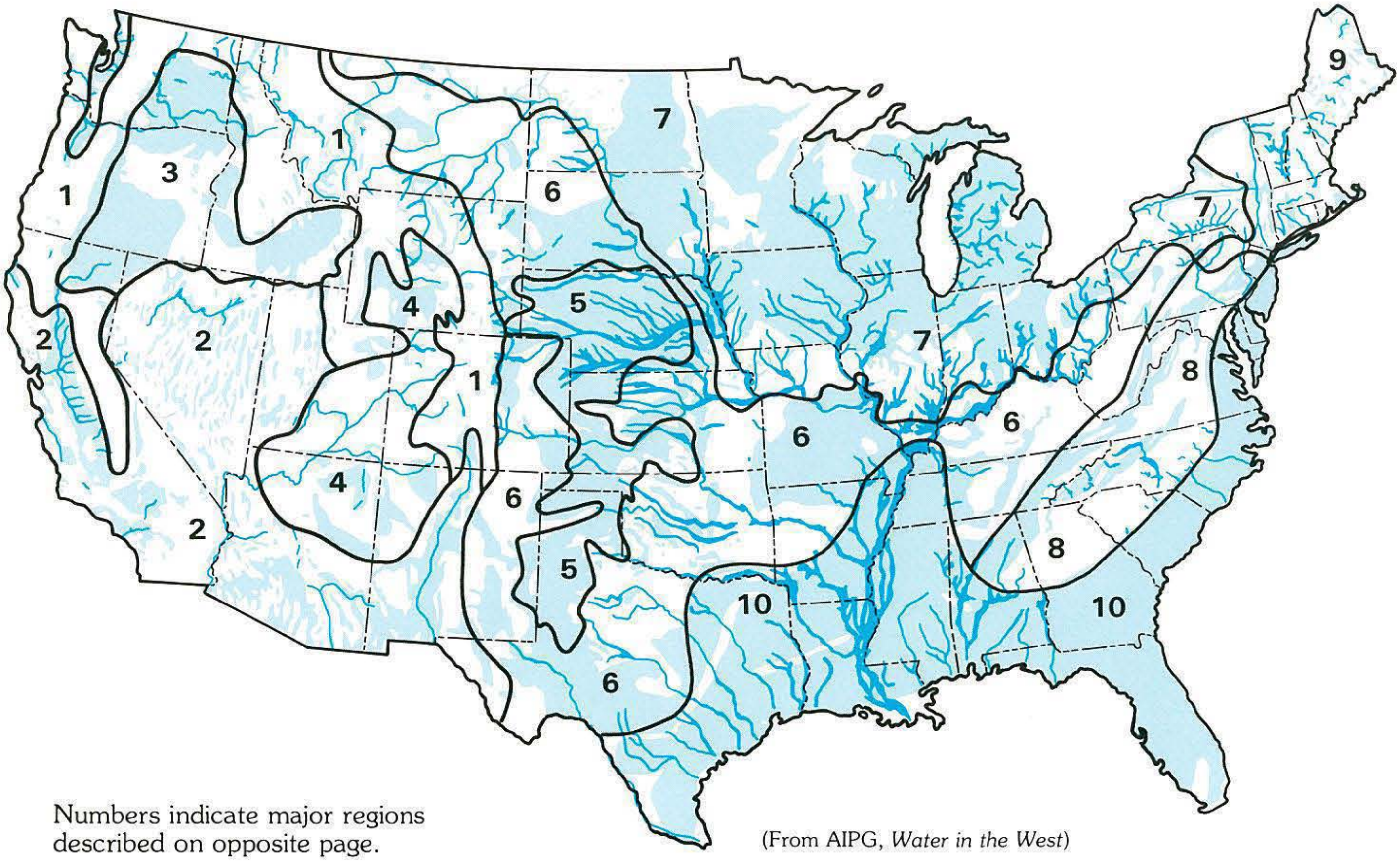
9. **Glaciated Appalachians** —Glacial deposits mantle steep areas and underlie valleys and lowlands. Yields from bedrocks are generally small to moderate. Principal ground-water sources are sand and gravel of glacial outwash plains, or channel fillings in stratified drift.

10. **Atlantic and Gulf Coastal Plains** —A huge, seaward-thickening wedge of sedimentary rocks consisting mainly of clay, sand, marl, and limestone. Thickness along coast increases southward from 300 to 30,000 feet. Large supplies of ground water can be obtained almost anywhere although salt-water encroachment is a problem locally.

Alaska — Most has been glaciated, and large supplies of ground water can be obtained from glacial sand and gravel. Permafrost is present in northern Alaska, restricting the availability of ground water.

Hawaii —Entire island chain is composed of basaltic lava flows, which are highly permeable and yield water readily to wells and tunnels. Fresh-water body forms a lens floating upon sea water, so extraction must be carefully managed to avoid sea-water intrusion.

GROUND-WATER RESOURCES



Numbers indicate major regions described on opposite page.

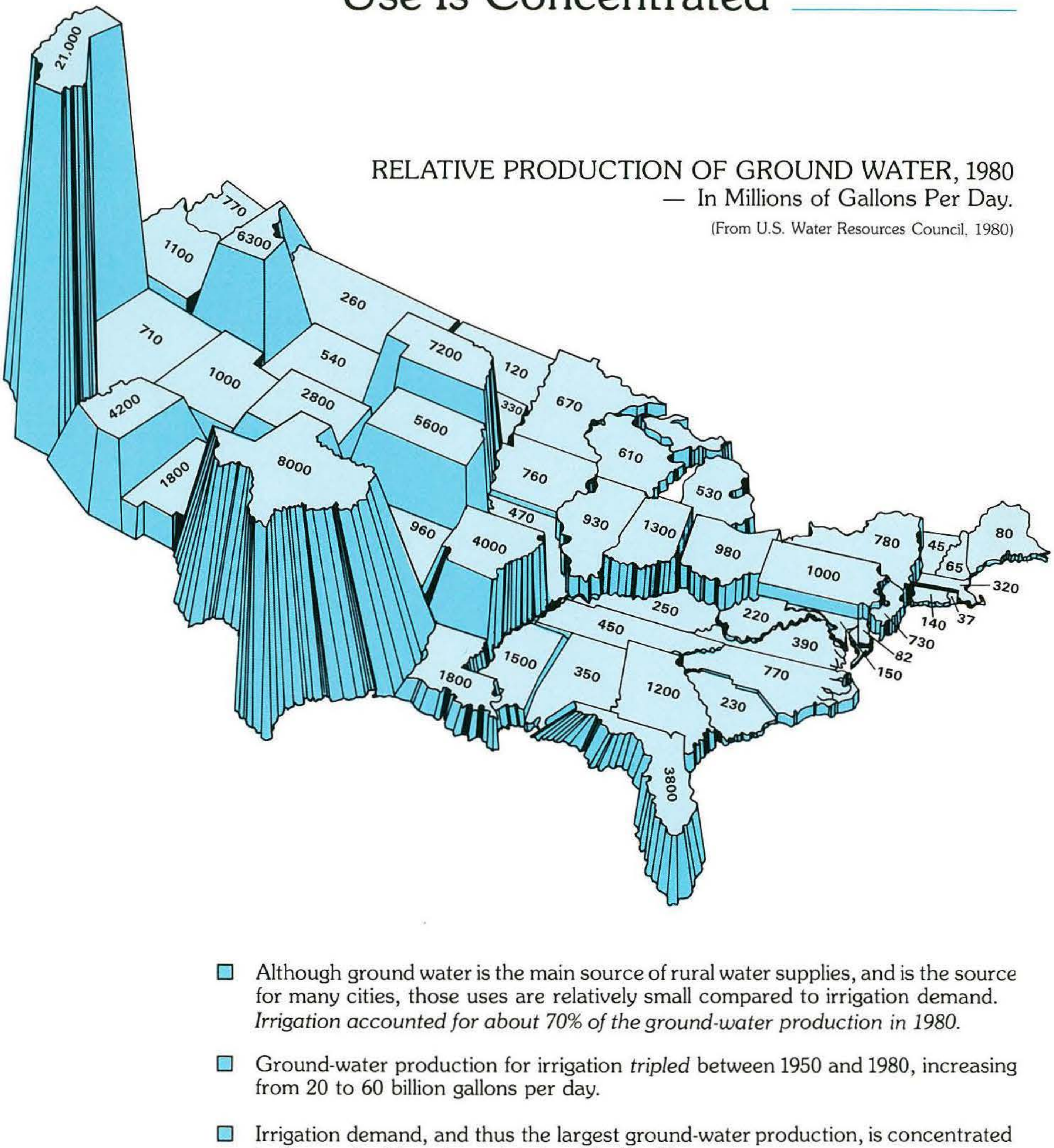
(From AIPG, *Water in the West*)

- Y **Watercourses related to aquifers**
- ▨ **Areas of extensive aquifers that yield more than 50 gallons per minute of fresh water**
- ☐ **Areas of less-extensive aquifers having smaller yields**

Ground water sufficient for domestic and livestock supplies can be found throughout the country.

Larger ground-water supplies for industry, municipal use, and irrigation are obtained from high-permeability rocks and river deposits (alluvium).

Where Ground-Water Use Is Concentrated



RELATIVE PRODUCTION OF GROUND WATER, 1980
— In Millions of Gallons Per Day.
(From U.S. Water Resources Council, 1980)

- Although ground water is the main source of rural water supplies, and is the source for many cities, those uses are relatively small compared to irrigation demand. *Irrigation accounted for about 70% of the ground-water production in 1980.*
- Ground-water production for irrigation *tripled* between 1950 and 1980, increasing from 20 to 60 billion gallons per day.
- Irrigation demand, and thus the largest ground-water production, is concentrated in the semi-arid western states and in Florida.
- The four leading ground-water pumping states — California, Texas, Nebraska, and Idaho — account for almost *half* the total national production of ground water.

Ground Water Serves Many Users

Ground water provides 23% of the fresh water used in the United States. In the 17 semi-arid western states, it provides 38% of the fresh-water supply. It is the chief supply for rural domestic and stock use, and for small community supplies throughout the Nation.

Although not generally considered a "use," ground water serves another vital function: it sustains stream flows in dry weather. In highly permeable areas, ground water is the main source of stream flow at all times.

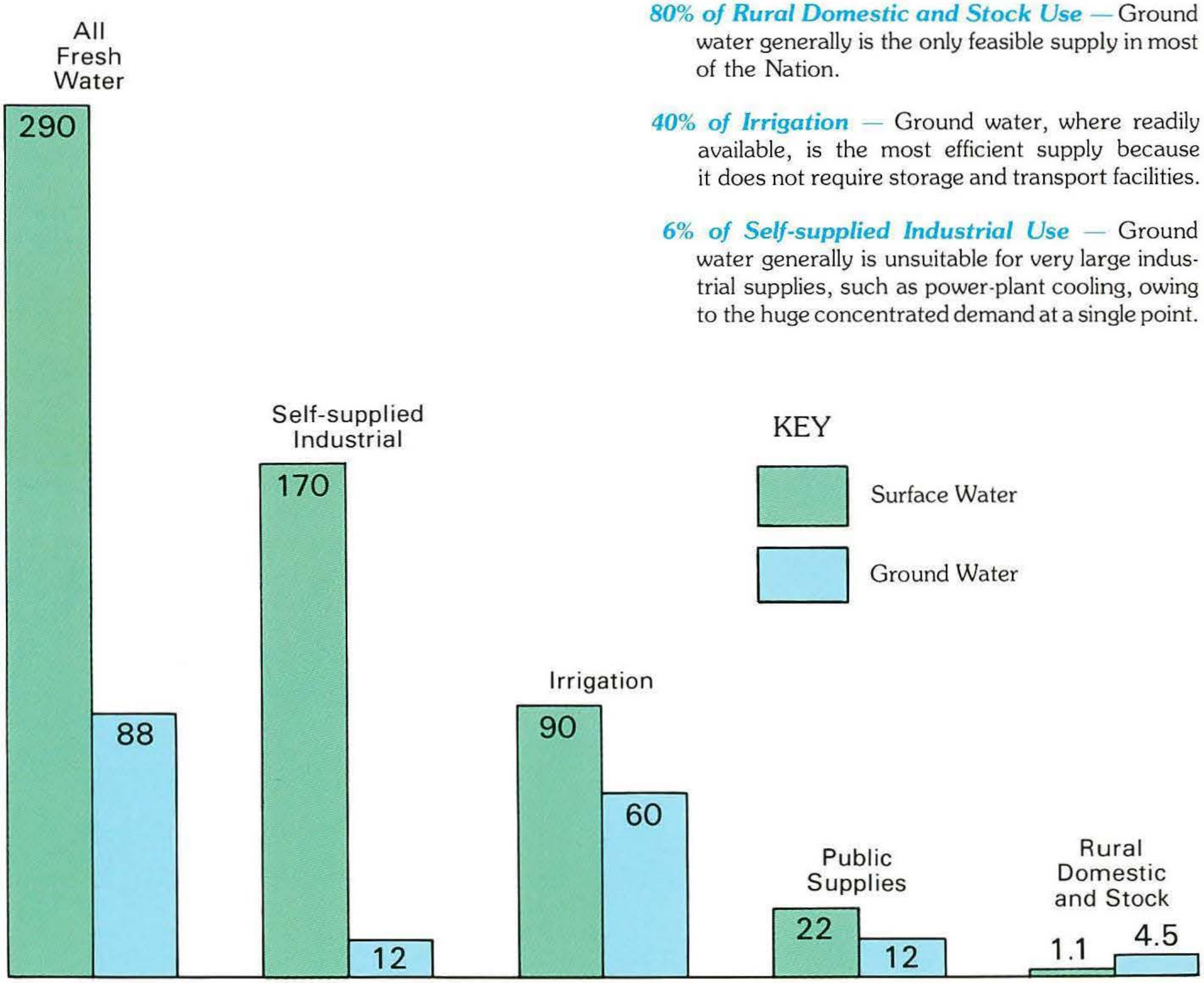
Water Uses Supplied by Ground Water

35% of Public Supply — Ground water is the most efficient supply for medium-sized cities and small communities because it does not require costly reservoirs and aqueducts. Of the 100 largest U.S. cities, 34 depend wholly or partly on ground water. The largest populations (1980) served entirely by ground water include Nassau-Suffolk Counties of Long Island, N.Y. (2.6 million), Miami (1.6), San Antonio (1.1), Memphis (0.9), Dayton (0.8), Honolulu (0.7), and Tucson (0.5).

80% of Rural Domestic and Stock Use — Ground water generally is the only feasible supply in most of the Nation.

40% of Irrigation — Ground water, where readily available, is the most efficient supply because it does not require storage and transport facilities.

6% of Self-supplied Industrial Use — Ground water generally is unsuitable for very large industrial supplies, such as power-plant cooling, owing to the huge concentrated demand at a single point.



Fresh-Water Withdrawals in the United States, 1980, in billions of gallons per day.

Major Ground-Water Problems:

Overdraft • Legal • Contamination

Overdraft, or ground-water "mining," is one of the most serious problems we must face: it comes about when withdrawals, either regionally or locally, exceed the long-term average recharge, resulting in continuing decline of water levels. In confined aquifers, the decline generally is more rapid and severe than in unconfined systems. Water levels may show sharp declines locally without a regional overdraft, when pumping exceeds the ability of the aquifer to transmit water laterally to the area of the pumping depression.

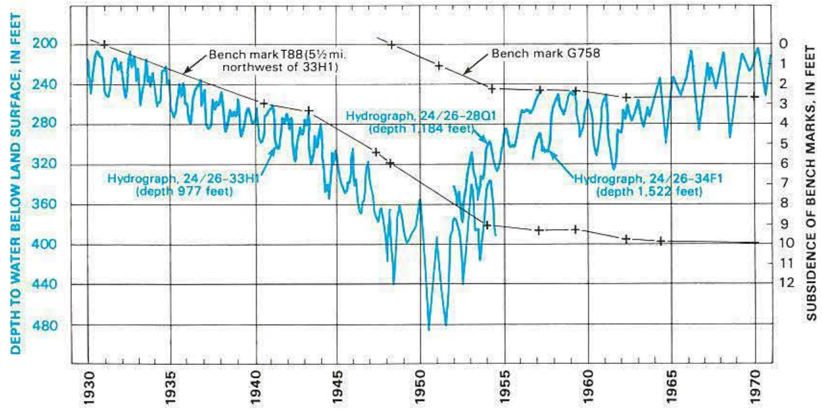
Regional overdraft generally occurs in arid areas of low recharge. Production from even a few wells may be enough to exceed natural recharge. Commonly, overdraft sets in before developers are aware of the problem. Classic cases include the San Joaquin Valley of California, the southern High Plains of Texas, the Coastal Basin of southern California, and the alluvial valleys of central Arizona.

In southern California, overdraft has induced landward movement of sea water in the aquifers, and to alleviate the problem, extensive fresh-water barriers — rows of wells into which fresh water is injected — have been installed. In limestone terranes of the southeastern U.S., water-table declines have reactivated subsidence in dormant sinkholes, sometimes with catastrophic results.

The adverse effects of overdraft include increasing energy costs for pumping as the water level declines, added maintenance costs for lowering pumps and deepening wells, land subsidence, and salt-water intrusion in coastal sites or where inland salt waters are nearby.

Local overdraft generally occurs at municipal or industrial well fields where concentrated pumping exceeds the ability of a confined aquifer to transmit water laterally to the pumping center. Well-known examples include Chicago, San Jose, and Savannah. The adverse effects are similar to those of regional overdraft, but are confined to a smaller area. With reduction in pumpage, water levels recover rapidly.

REGIONAL OVERDRAFT

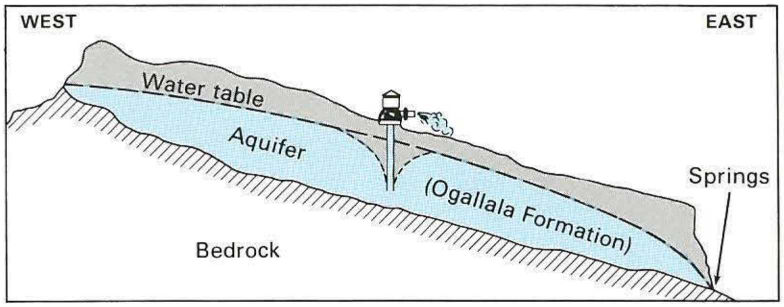


Water-level records from wells and surface elevation changes at bench marks near Delano, San Joaquin Valley, California, 1930-1970, show effects of prolonged regional overdraft on pressure levels, and land subsidence resulting from decreased pressure in the confined aquifer. Imports of surface water beginning in 1952 reversed pressure decline and halted subsidence.

(From Poland and others, 1975)

Profile across southern High Plains of Texas showing general ground-water conditions. The Plains slope eastward and are cut off from river recharge. Under natural conditions, spring discharge was balanced by small infiltration from rainfall. Irrigation pumping now is about 100 times recharge, and the water table is declining 1-5 feet per year. As the water table approaches the base of the acquifer, pumping will necessarily cease.

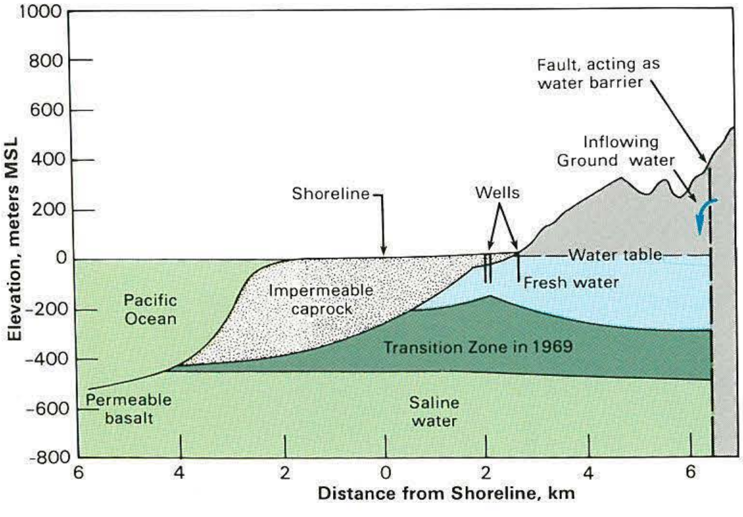
(From U.S. Water Resources Council, 1980)

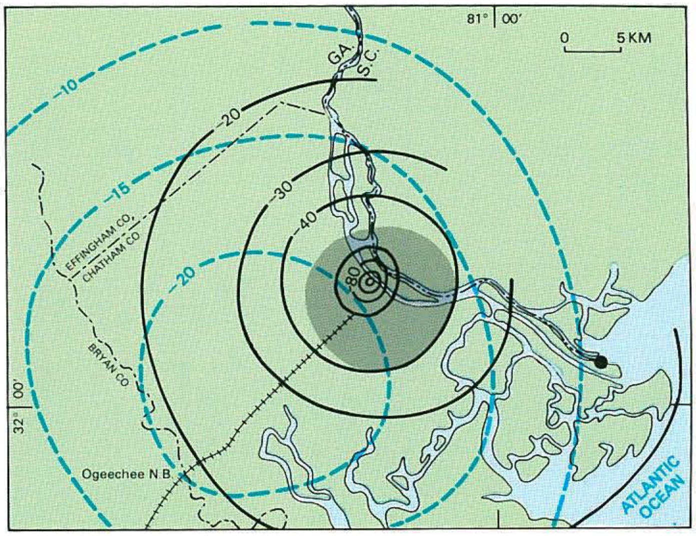


LOCAL OVERDRAFT

Profile through Honolulu, Hawaii showing effect of water table decline in permeable rocks open to the sea. Due to its lower density, fresh water floats as a "lens" on sea water. Slight lowering of water levels by pumping in the fresh-water zone causes underlying sea water to rise toward wells.

(Adapted from Todd and Meyer, 1971)





Lines of equal decline of pressure surface at Savannah, Georgia, 1933-54 (black lines) and 1955-75 (dashed blue lines), showing sharp decline due to municipal pumping during the early period, and a shift in decline toward the southwest with reduction in municipal pumping. Shaded area at center delineates moderate land subsidence during early period.

(From Davis and others, 1977)

Legal

Ownership of ground water (a property right) and its regulation have traditionally been a function of the states. Currently, four basic doctrines of ground-water ownership are applied in the U.S. In many states, existing law is inadequate to allocate the resource among existing claimants, and takes no consideration of the close relationship of surface and ground waters. Indeed, some states apply different and incompatible doctrines to surface and ground waters. Confusion abounds as to what an individual's rights include.

The Four Doctrines of Ground-Water Rights

1. ***Riparian or Common-Law Doctrine*** — Holds that an overlying landowner has absolute ownership of underlying ground waters whenever he chooses to exercise this right with no limitation on amount of uses. Clearly, this principle cannot be equitably applied in areas of water shortage.
2. ***Reasonable Use Doctrine*** — An outgrowth of the riparian doctrine. Restricts the right to ground water to reasonable use. It implies that a landowner's right to use water can be limited when the available supply is not sufficient to meet all demands.
3. ***Appropriation Doctrine*** — Recognizes the principle of "first come, first served" in that the earliest water users have the firmest right where supplies of ground water are limited. In practice, the system results in prohibition against new wells in areas deemed to be fully developed.
4. ***Correlative Rights Doctrine*** — Holds that all landowners have a proportionate right to ground water needed to supply overlying lands. Where overdevelopment exists, this leads to lengthy legal adjudications to apportion the available supply.

Overriding Rights — Even where water has been fully allocated, certain "lurking" rights may apply and be used to expropriate water from existing uses. These include: (1) Federal reserved right to sufficient water for the purpose of a land reservation; (2) Indian reserved rights, similar to Federal reserved rights, but applying to Indian reservations; (3) Pueblo rights to communal water supplies in former Spanish territories; and (4) the Federal sovereign right to water for national security purposes.

Main Problems Resulting from Legal Confusion

- Insecurity as to future rights to water, which discourages capital investment.
- Inability to jointly manage surface and ground waters in the most efficient combination.
- Unrealistic limitations on economic growth in arid areas.

GROUND-WATER LAWS

Four different systems of ownership apply to ground-water rights:

🟩 **RIPARIAN or COMMON LAW**

⬜ **REASONABLE USE**

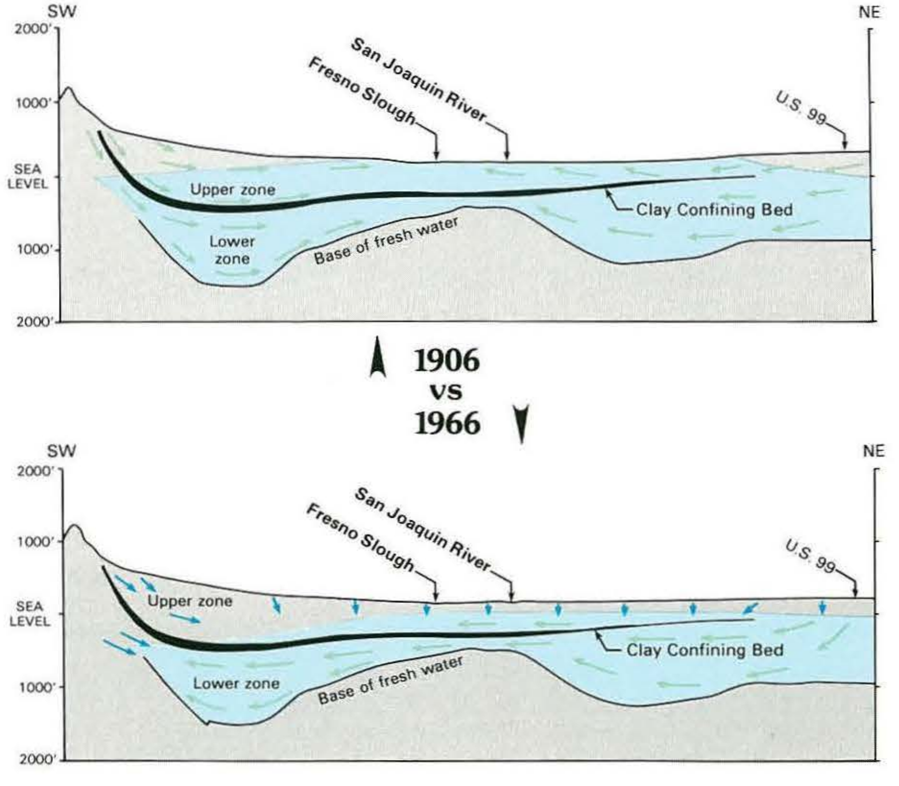
🟦 **APPROPRIATION**

▨ **CORRELATIVE RIGHTS**

(After Geraghty and others, 1973)

An illustration of legal complications from the Central Valley, California, where rights to *surface* water are governed by the Appropriation Doctrine, and rights to *ground* water by the Correlative Rights Doctrine:

Overdraft from aquifers on the West Side of San Joaquin Valley has reversed the regional ground-water flow pattern. Ground water that formerly discharged to the San Joaquin River system (1906 diagram, arrows) now flows to the west, so the river now contributes to the ground water (1966 diagram, green arrows). The possibilities for litigation are endless, with any or all of hundreds of holders of surface-water rights suing tens of thousands of ground-water users.



(After Bull and Miller, 1975)

Contamination / Principal Sources

Contamination of ground water is a severe problem because the contaminant generally travels unobserved until detected in a water-supply well. Once contaminated, an aquifer is difficult and expensive to clean up. The contaminant disperses in the ground water, is difficult to remove, and may persist for decades. In almost all cases, *prevention is simpler and cheaper than cure.*

Contaminants include an almost endless list of inorganic chemicals, organic chemicals, biological matter, radioactive compounds, and even physical loads such as heat. The impacts on ground water may range from aesthetic effects (such as unpleasant taste or warm temperature) to imminent hazards to health.

Principal sources of pollution, in order of importance nationally, include:

1. Industrial wastes
2. Municipal landfills
3. Agricultural chemicals
4. Septic system and cesspool effluents
5. Leaks from petroleum pipelines and storage tanks
6. Animal wastes
7. Acid mine drainage
8. Oil-field brines
9. Salt-water intrusion
10. Irrigation return flow

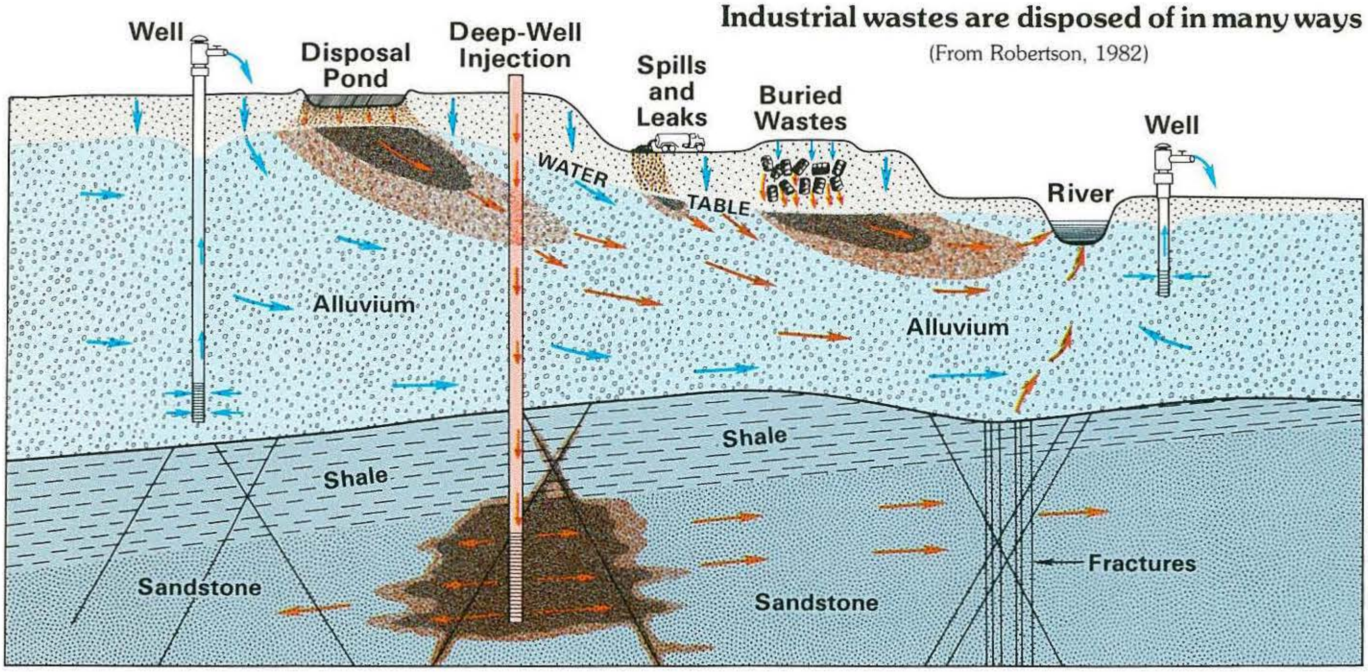
The following four pages illustrate some of the major contamination sources.

National Water Well Association

INDUSTRIAL CONTAMINATION

Industrial wastes are disposed of in many ways

(From Robertson, 1982)



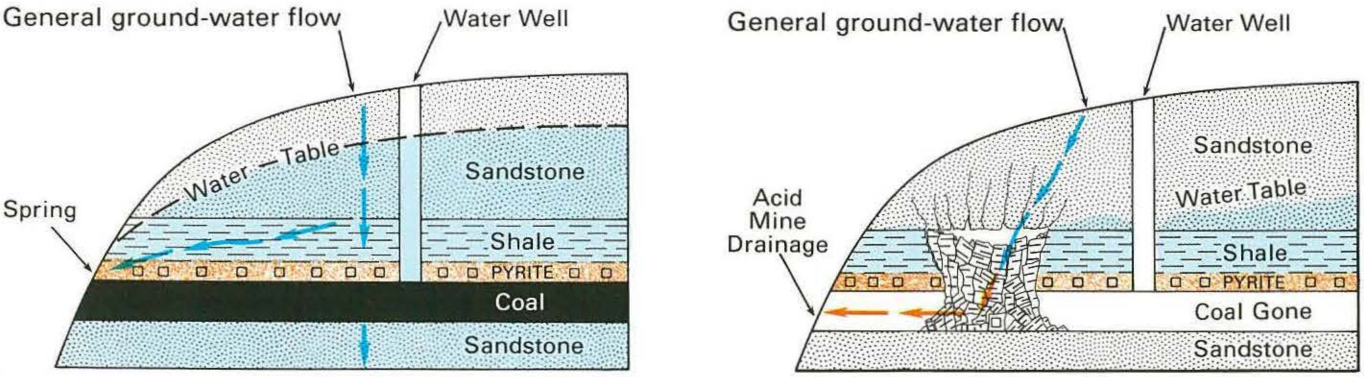
KEY: → **FRESH WATER** → **CONTAMINATION** → **CONTAMINATED GROUND WATER**

A vast array of industrial chemicals, including large volumes of liquid and solid toxic compounds, are disposed of in seepage ponds and by shallow burial. By 1981 the inventory of toxic wastes was 6 billion cubic yards at 100,000 sites in the U. S. Radioactive wastes are a special category of industrial wastes owing to their high toxicity, but the amounts and number of sites are small.

CONTAMINATION FROM UNDERGROUND STRUCTURES

Acid drainage, chiefly from thousands of abandoned coal mines in the Appalachian Region, locally contaminates ground water, which discharges to surface streams. Acid mine drainage reportedly has severely degraded 11,000 miles of streams in the Appalachian area.

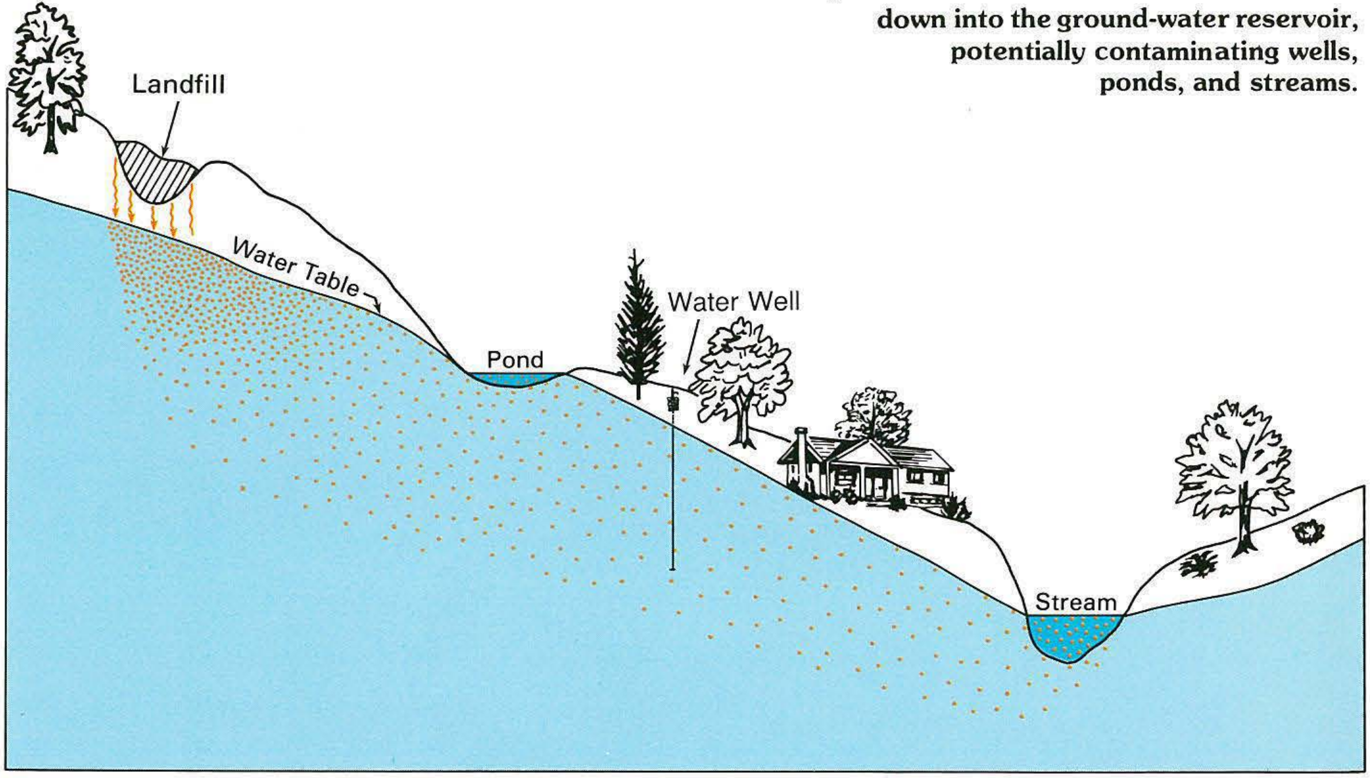
Underground coal mining is responsible for the disruption of overlying aquifers through the collapse of strata above the coal, which drains the overlying materials and aggravates acid-drainage problems, stemming from oxidation of pyrite and other sulfur compounds.



BEFORE MINING *AFTER MINING*

MUNICIPAL CONTAMINATION

Precipitation on a landfill can leach chemicals down into the ground-water reservoir, potentially contaminating wells, ponds, and streams.



In the humid areas of the country, rain and snow on a landfill may carry dissolved substances downward, delivering biologic, organic, and inorganic pollutants to the ground water. The degree of hazard depends on the geology of the site, design of the landfill, and character of the wastes.

Most municipal trash is disposed of in such landfills. Other important sources of municipal contamination include sewage effluent, sludge disposal, and leaky sewers.

Relatively Safe

Pollutants move slowly in clay and silt and many noxious compounds are adsorbed on clay-mineral grains.

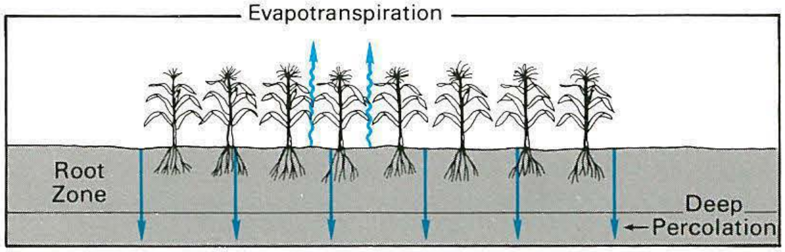
Unsafe

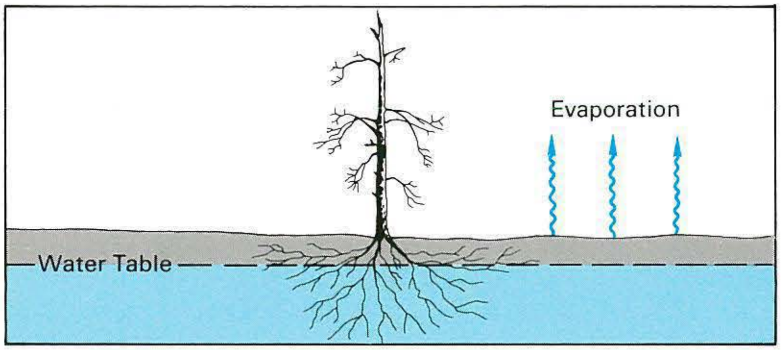
Pollutants entrained directly in ground water.

(Illustrations from Schneider, 1970)

AGRICULTURAL AND "NATURAL" CONTAMINATION

Plants consume water in the soil zone, but remove little of the dissolved mineral matter, invariably resulting in concentration of minerals in ground water. In addition, leaching of fertilizers, pesticides, and soil amendments occurs in all farming areas. In arid regions, soluble minerals in the soil are dissolved by irrigation water and carried to the water table, further increasing the mineral content.

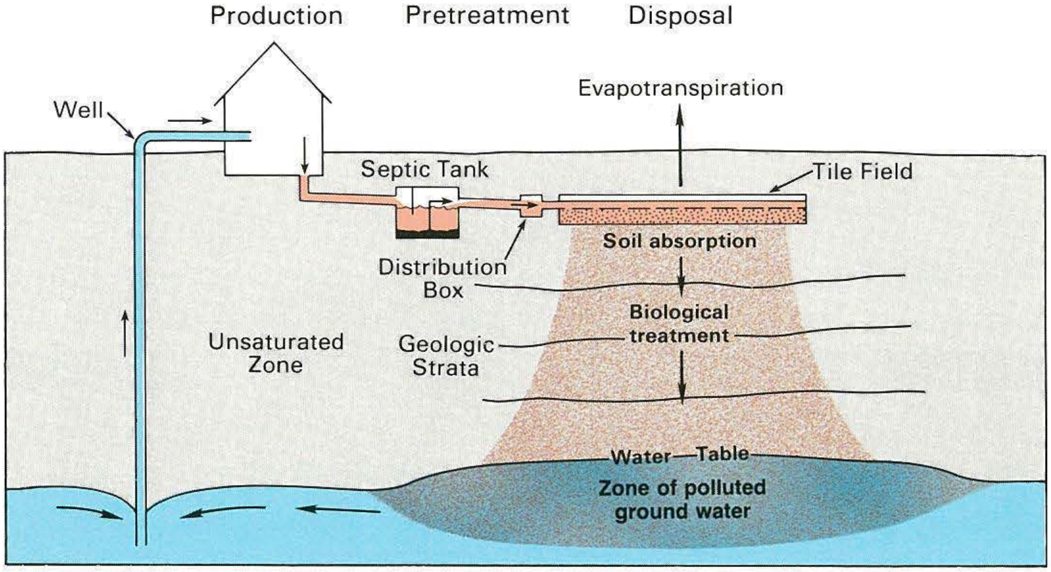




Ground water rising into the root zone drowns plants and causes soil salinization. Excessively shallow ground water can cause extensive damage to plants, soils, and structures. The remedy usually lies in lowering the water table through subsurface drains or pumping.

DOMESTIC CONTAMINATION

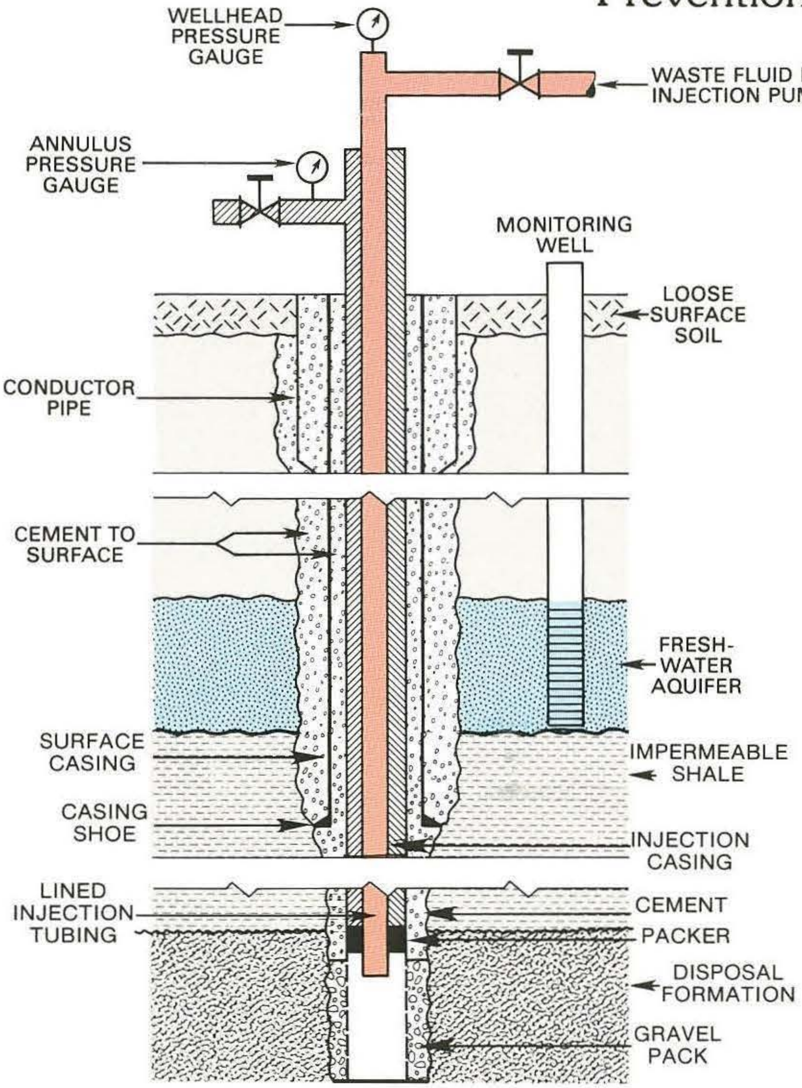
Some 40 million people in the U.S. are served by septic systems or cesspools. Even with good design, mineral contaminants reach the ground-water body. However, in well-designed systems, particulate matter, organics, bacteria, viruses, and many noxious constituents are filtered, adsorbed, or chemically altered before the effluent reaches the water table. Barn yards and feed lots also contribute animal wastes, which commonly percolate to the ground-water body.



Poorly designed water supply and sewage system recycles sewage effluent to well.

CONTAMINATION FROM LIQUID WASTE

Prevention and Reclamation



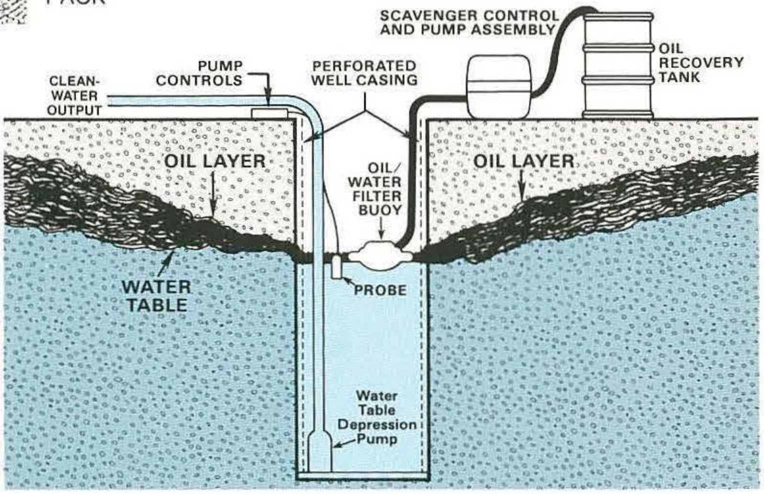
PREVENTION

Toxic liquid wastes and other noxious fluids may in some places be safely injected into deep permeable rocks far below fresh-water aquifers. Such disposal generally is to deep saline (or otherwise unusable) ground waters that are isolated from fresh-water sources. Great care is required in well-casing design and operations to avoid leakage that could endanger usable fresh-water supplies. It is important in site selection to choose places where the hydraulic head of the injection can be dissipated to avoid applying excess pressure to the well system or the receiving zone.

Properly constructed oil wells are cased in similar fashion, to safeguard ground waters, but in many old oil-producing districts saline water escapes through leaky casings and holding ponds, causing extensive local contamination.

RECLAMATION

Contaminated zones can in some cases be isolated using slurry trenches, grout curtains, or sheet piling. Reclamation methods include extraction of contaminated water by means of interceptor wells and trenches, or skimmer wells for light-weight fluids, and then treating the water. Some contaminants can be neutralized in place with chemicals or biological agents.



Floating contaminants, such as oil from surface spills, commonly can be removed with skimmer systems.

Information Required for Ground-Water Problem Analysis and Decision-Making

Physical framework

- Hydrogeologic maps showing extent and boundaries of all aquifers and non-water-bearing rocks.
- Topographic map showing surface-water bodies and landforms.
- Water-table, bedrock-configuration, and saturated-thickness maps.
- Transmissivity maps showing aquifers and boundaries.
- Map showing variations in storage coefficient.
- Relation of saturated thickness to transmissivity.
- Hydraulic connection of streams to aquifers.

Hydrologic stresses

- Type and extent of recharge areas (irrigated areas, recharge basins, recharge wells, natural recharge areas).
- Surface-water diversions.
- Ground-water pumpage (distribution in time and space).
- Precipitation.
- Areal distribution of water quality in aquifer.
- Streamflow quality (distribution in time and space).
- Geochemical and hydraulic relations of rocks, natural water, and artificially introduced water or waste liquids.

Model calibration

- Water-level-change maps and hydrographs.
- Streamflow, including gain and loss measurements.
- History of pumping rates and distribution of pumpage.

Prediction and optimization analysis

- Economic information on water supply and demand.
- Legal and administrative rules.
- Environmental factors.
- Other social considerations.

Role of Ground Water in Water Planning and Decision-Making

Ground water has often been slighted in water-supply planning and management. One reason is the belief that the resource could not be as easily evaluated as surface-water resources, in terms of availability, development, chemical quality, and economics of recovery.

However, new hydrogeologic information and understanding, and substantial progress in analytical capability, have improved ability to plan, develop, and manage ground water. Scientific analysis of ground-water systems has opened the door to more effective, organized utilization of ground water, and to protective measures from polluting activities.

Ground-water hydrology is an interdisciplinary science composed of an intermix of the physical, biological, and mathematical sciences. New concepts and methodologies have improved investigation and problem solution. Simulation methods developed within the last 20 years permit revealing model analysis of ground-water systems and their interconnections with surface water. Modeling enables prediction of pumping and waste-disposal effects on ground water, and consideration of alternative management plans.

Inadequate communication between the ground-water expert and the planning expert is partly responsible for the hesitant integration of ground water into water-resources planning. Closer affiliation of these experts is fostering increased mutual understanding of the resource and its important role in national water supply. Ground water is now recognized to be an unavoidable and fundamental consideration in the comprehensive, joint management of land, water, and waste so obviously mandatory in our industrialized, populous nation.

The magnitude and complexity of the Nation's ground-water problems continue to grow. For this reason, expanded effort is needed to insure adequate ground-water data and information, and to bring the ground-water resource into the mainstream of planning, management, and decision-making at all levels of government.

AIPG Policy On Ke

1. Overdraft and Depletion of Supply — AIPG believes that this is generally a self-correcting problem in a free-market economy, because as supply declines, cost increases, and marginal operators cease pumping. Usually the problem is of local scope, and therefore appropriate for state and local regulation, to be addressed in land-use planning actions.

a. Where ground-water depletion is of regional scope, as in the High Plains Ogallala aquifer situation, AIPG believes that the solution may require interstate transfer of water or interstate restrictions on pumping. In such cases, AIPG believes the mechanism of an interstate compact should be used to settle issues that cannot be resolved through direct negotiation.

b. AIPG urges states not to adopt uneconomic, restrictive legislation on use of ground water in efforts to protect local interest groups.

2. Ground-Water Law — Currently four basic systems of ground-water rights are applied in the 50 states. AIPG is concerned that in many states the existing law is inadequate to allocate the resource equitably among competing claimants, and commonly takes no consideration of the close interrelationship of ground and surface waters.

a. AIPG supports legislation by states to authorize the establishment of water-management agencies with power to manage surface and ground waters conjunctively.

b. AIPG supports the development of model ground-water codes by interstate groups, such as the Council of State Governments and the Interstate Conference on Water Problems.

c. AIPG urges Congress to provide for prompt quantification of Federal and Indian Reserve Rights, because these overriding rights, so long as they remain hazy and unquantified, impede efficient ground-water development in areas where they apply.

Ground-Water Issues

3. ***Ground-Water Quality*** — AIPG believes that the present patchwork of Federal and State law aimed at protecting ground water is of limited effectiveness, if not counterproductive. Indeed, Federal pressure for cleanup of surface waters has placed more stress on land disposal of pollutants, resulting in increased contamination of ground waters.

   a. AIPG supports the concept of explicitly recognizing society's need to dispose of wastes, and favors adoption of a policy permitting limited degradation of surface and ground waters in keeping with economic reality. With respect to ground waters, AIPG believes the National policy should focus on prevention of significant impairment of socially and economically important ground-water supplies.

   b. AIPG supports the concept that National policy should have the objective of protecting specific existing high-value water uses. Standards for discharges into surface and ground waters should be sufficient to protect existing uses, and uses in the reasonably foreseeable future, taking into account the cost of achieving them.

   c. AIPG urges continuation of the system of standards implemented through a National waste-discharge permit system, administered by the states under Federal guidelines. AIPG supports the concept that Federal agencies should intervene in local enforcement matters only upon a judicial finding that a state is not enforcing Federal law.

   d. AIPG believes that Federal standard-setting should be confined to protection of public health.

   e. AIPG supports the principle of use of performance standards rather than prescriptive rules, enforced through a system of permits for major-polluting facilities, requiring competent professional design, operation, and monitoring.

   f. AIPG believes consideration should be given to implementing ground-water quality laws through a system of economic incentives for compliance, including taxing of waste discharges.

4. ***Underground Operations*** — Oil production, deep-well waste disposal, mine openings, and other facilities below the water table all pose potential danger to the physical integrity of aquifers and to ground-water quality on a local scale.

   a. AIPG supports the concept that states should regulate drilling and other forms of deep construction through a system of permits and licensing of qualified operators. Permits should cover construction, operation, and proper abandonment of major facilities where they pose significant hazards to aquifers.

   b. AIPG supports Federal financial assistance to states, interstate organizations, trade associations, and professional societies to develop appropriate model codes for underground operations.

5. ***Data and Research*** — AIPG believes that, as the magnitude and complexity of ground-water problems continues to grow, there is need for continued support of data and research programs that provide the basis for rational decision-making. AIPG is concerned that funding of these programs in recent years has not kept pace with economic growth, or the increasing complexity of ground-water problems. AIPG supports the concept of matching funding of ground-water data and research programs by Federal and state governments, as exemplified by the time-tested state-Federal cooperative water-resources programs of the U.S. Geological Survey. AIPG urges Congress to appropriate sufficient funds for programs calling for equal financial contributions by state and Federal governments to assure that state offerings will be fully met.

Glossary

Hydrology, like other branches of science, has its own terminology, and an understanding of certain terms is essential. The definitions here (adapted from Hobba, 1981) have been simplified and shortened as much as possible.

Alluvium — Debris from erosion, consisting of some mixture of clay particles, sand, pebbles, or larger rocks. Usually a good, porous storage medium for ground water.

Aquifer — Rock formation that contains sufficient saturated permeable material to yield significant amounts of water to wells or springs.

Aquifer, confined (or artesian) — The water level in a well tapping a confined aquifer will rise above the top of the aquifer because of hydrostatic pressure.

Aquifer, unconfined — The water level in a well tapping an unconfined aquifer will not rise above the water table.

Capillary force — A form of water surface tension, causing water to move through tiny pores in rock or soil due to molecular attraction between the water and earth materials.

Capillary water — Water held in tiny openings in rock or soil by capillary force.

Depression, cone of — The depression in the water table or other potentiometric surface caused by the withdrawal of water from a well.

Drawdown in a well — The vertical drop of the water level in a well caused by pumping.

Evapotranspiration — Evaporation from water surfaces, plus transpiration from plants.

Fault — A fracture in the Earth's crust accompanied by displacement of one side of the fracture with respect to the other.

Fracture — A break in rock that may be caused by compressional or tensional forces.

Gradient, hydraulic — The change of pressure head per unit distance from one point to another in an aquifer.

Ground water — Water contained in the zone of saturation in the rock. *(See surface water.)*

Head — Pressure, expressed as the height of a column of water that can be supported by the pressure.

Permeability, intrinsic — A measure of the relative ease with which a porous medium can transmit a liquid under a potential gradient.

pH — A measure of the relative acidity of water. Below 7 is increasingly acid, 7.0 is neutral, and above 7 is increasingly alkaline (basic).

Porosity, primary — Interstices that were created at the time the rocks were formed.

Potentiometric surface — An imaginary surface that everywhere coincides with the static level of water in a confined aquifer.

Precipitation, atmospheric — Water in the form of hail, mist, rain, sleet, or snow that falls to the Earth's surface.

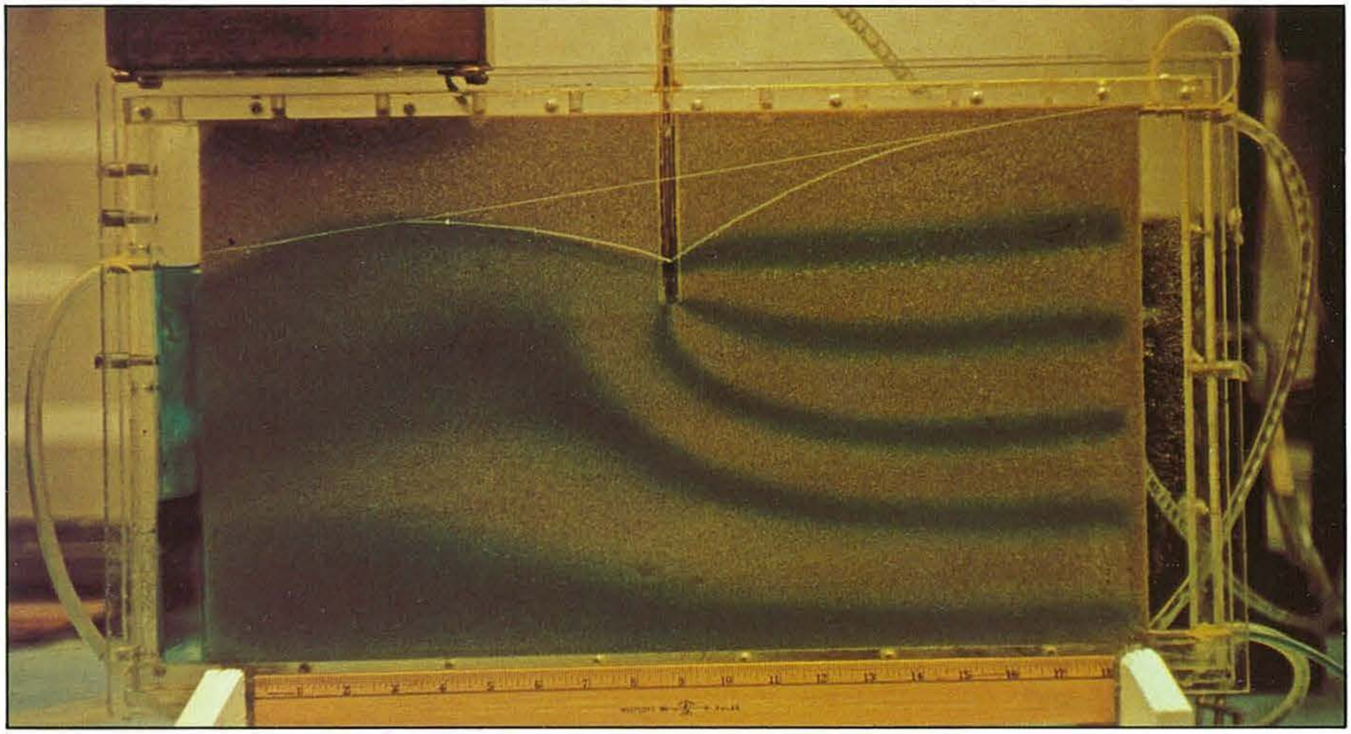
Recovery of pumped well — When pumping from a well ceases, the water level rises (or recovers) to approximately the level (static level) before pumping.

Surface water — Water on the surface of the Earth, including snow and ice. *(See ground water.)*

Transmissivity — The rate at which water of a prevailing viscosity is transmitted through a unit width of aquifer under a unit hydraulic gradient.

Water table — That surface in an unconfined water body at which pressure is atmospheric; generally the top of the saturated zone.

Zone of saturation — Rock or soil in which every available space is filled with water.



Simulated water well in action. Pumping causes dyed water (dark green) to flow through sand (aquifer) into well. Note depression of water table caused by pumping.

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