

ALASKA LEGISLATURE COMMITTEE FILES 1900-1900 00/2

4241 SRES SB 150 1121

undiscoverable federal reserved rights.

THE FIRST BILLS

The first bills were introduced by Senator Barrett. Their central theme was that "All unappropriated water in the 17 western states is declared to be free for appropriation under state law" (See Corker, WATER RIGHTS AND FEDERALISM, 45 Cal. L. Rev. 604,606 (1957)) and to require the United States to comply with state appropriation laws rather than claiming waters under the reservation doctrine.

LATER BILLS

Most of the bills introduced over the ensuing years dealt not only with the reserved rights issue, but also with the compensation question under the navigation servitude. In general they proposed that compensation be required for the loss of private property rights under the reservation doctrine and the navigation servitude, that the federal government be required to comply with state water law when it builds projects under the Reclamation Act of 1902, and that FPC licensees be required to comply with state law when they build projects under the Federal Power Act of 1920.

Various compromises were developed, under Senator Kuchel of California and others. None of these bills ultimately passed. See, Hanks, PEACE WEST OF THE 98TH MERIDIAN--A SOLUTION TO FEDERAL-STATE CONFLICTS OVER WESTERN WATERS" 23 Rutgers L. Rev. 33 (1968).

REPORT OF THE PUBLIC LAND LAW REVIEW COMMISSION. (One Third of the Nation's Land, 1970) 147-149. For commentary, see Trelease, WATER RESOURCES ON THE PUBLIC LANDS: PLLRC'S SOLUTION TO THE RESERVATION DOCTRINE, 6 Land and Water Law Review 89 (1970); Muys, COMMENTS ON "FEDERAL RESERVED WATER RIGHTS", 54 Den. L. J. 493 (1977).

The Commission recommended:

- (1) Require federal agencies to give notice of their projected water requirements for the next 40 years;
- (2) Establish administrative or judicial review of the reasonableness of the quantities claimed by the federal agencies;
- (3) For reservations created in the future, require express statement of intent to reserve water, and the quantity reserved;

(4) Require compensation for the taking of water rights vested prior to the 1963 decision in Arizona v. California.

NATIONAL WATER COMMISSION REPORT (Water Policies for the Future, 1973) pp. 467-468.

The Commission took a different approach from the PLLRC. It recommended:

(1) Require federal agencies to give notice of their projected water requirements for the next 40 years.

As to existing uses by federal agencies, the agencies would be entitled to priority as of the date of the original reservation of the federal lands.

Future uses would receive a priority date as of the date of initiation of actual use.

Compensation would be required where existing private water uses were displaced by new federal agency uses.

REASONS FOR THE FAILURE OF PROPOSED SETTLEMENT LEGISLATION

(1) Eastern suspicion of western avarice.

"The Wild West water version of interposition . . .: not only should the [western] states have the right to do as they please, but they should be able to do it with federal property, and at federal expense." Goldberg, 17 Stan. L. Rev. 1, 3 (1964).

(2) Rising influence of the environmental movement. Reserved rights tend to protect instream flows, forests, wildlife, and environmental interests.

(3) Splits in western water politics in the 1960s, e.g., over the proposed diversion of Columbia River water to the Southwest, and over the continuation of the 160 acre limitation.

(4) Enactment of Sec. 111 Rivers and Harbors Act, 1970, 33 USC Sec. 595a, reversing United States v. Rands, 389 US 121 (1967), and United States v. Twin City Power Co., 350 US 222 (1956) and providing that when condemnation occurs, compensation must be paid to riparians on navigable waters for the "highest and best use" of their uplands, unburdened by the navigation servitude. This excised one of the major problems addressed by proposed settlement legislation.

(5) The Supreme Court's interpretation of the McCarran Amendment, 66 Stat. 560, 43 USC Sec. 666 to constitute waiver of sovereign immunity for suits in federal or state courts to adjudicate, and quantify, federal reserved water rights. Colorado River Water Conservation Dist. v. United States, 424 US 800 (1976), United States v. District Court for Eagle County, 401 US 520 (1971).

(6) The fact that no one could be found whose vested water right had been destroyed by the exercise of a federal reserved right.

The PLLRC reported that "The federal lands are the source of most of the water in the 11 coterminous western states, providing approximately 61% of the total natural runoff occurring in the region. Most of this runoff comes from land withdrawn or reserved for specific purposes. Forest Service and National Park Service reservations contribute about 88 % and 8 %, respectively, of the runoff from public lands and more than 59 % of the total yield from all lands in those states." ONE THIRD OF THE NATION'S LAND, Final Report of the PLLRC, p. 141, 1970.

The PLLRC reported, however, that "Although most of the current concern relates to the doctrine's potential future impact, such potential impacts could be major". Id. at 144.

In 1964 Nicolas B. Katzenbach, Deputy Attorney General for the US said that

"for all the outcry. . . not one state, not one county, not one municipality, not one irrigation district, not one corporation, not one individual has come forward to plead and prove that the United States. . . has destroyed any private right." Hearings on S. 1275 Before the Subcommittee on Irrigation and Reclamation of the Senate Comm. on Interior and Insular Affairs, 88th Cong. 2nd. Sess. (1964). Trelease reported that "Twenty-two years after Pelton Dam this is still true." Trelease, 54 Den. L. J. at p. 492 (1977).

Corker, commenting on the "de minimus" quantity of reserved rights as to NonIndian lands, noted that

"It is the quantity beneath the accuracy of a stream gauge. It is what a bird, a butterfly, a deer, or a backpacker drinks from a stream without need of permission. [This statement was made prior to US v. New Mexico; not even these minimal drinkers would now be protected]. The rest of the water flows from the National Forests and the National Parks subject to the law of gravity." Corker, 54 Den. L. J. 499 (1977).

Professor Corker, after extensive research on a report for the

PLLRC, finally found an "injured" person. Mrs. Glenn sued under the Tort Claims Act for loss of a 1930 irrigation appropriation to a recreation area in a National Forest established in 1897. Her suit was dismissed on stipulated facts. Apparently sufficient water was made available for both Mrs. Glenn and the Forest Service. See *Glenn v. United States*, Civil No. C-153-61 (D. Utah March 16, 1963) discussed in *DEVELOPMENT, MANAGEMENT AND USE OF WATER RESOURCES ON THE PUBLIC LANDS*, by Wheatley, Corker, Stetson, and Reed. Clearinghouse for Federal Scientific and Technical Information of the Dept. of Com., PB 188 065 & 188 066. See also, Corker, *LET THERE NO NAGGING DOUBTS: NOR SHALL PRIVATE PROPERTY, INCLUDING WATER RIGHTS, BE TAKEN FOR PUBLIC USE WITHOUT JUST COMPENSATION*, 6 Land & Water L. R. 109 (1970)

THE DEVIL'S HOLE PUFFISH

While this case is cited for the implied reservation doctrine, it really belongs in the express reservation category. In *Cappaert v. United States*, 426 US 128 (1976) the court enjoined an irrigator's groundwater pumping which was lowering the level of water in Devil's Hole, and endangering the spawning grounds of the tiny pupfish. A 1952 Presidential Proclamation had expressly reserved this water for the pupfish. The court adopted a rule of "minimal need" to effectuate the reservation's purposes, saying it applied to both express and implied reservations.

The use of this reserved water did not interfere with an "existing" private appropriation right. The creation of the federal reservation clearly pre-dated the planned private use, and the water-related purpose of the reservation was clearly expressed.

THE GILA NATIONAL FOREST

In *United States v. New Mexico*, 238 US 696 (1978), the Court upheld federal reserved rights for National Forest lands. The United States claimed reserved rights for minimum instream flows, and for recreational, stockwatering, and fish purposes. But the Court said it would recognize only "primary" purposes under the National Forest Organic Act of 1897, 16 USC Secs. 473-478, 479-82, 551 (1976). These purposes did not include recreation, aesthetics, wildlife-preservation, or cattle grazing which the court called secondary purposes. They only include securing favorable conditions of water flows, and furnishing a continuous supply of timber for the people.

A second issue in *New Mexico* was whether the Multiple Use Sustained Yield Act of 1960, P.L. 86-517, 74 Stat. 215,

codified as amended at 16 USC Secs 528-531 (1976), reserved additional waters. The Court held not, saying that although Congress intended the forests to be administered for broader purposes after 1960, Congress did not intend to reserve water for secondary, MUSYA purposes.

Some 16 or 17 Articles and Notes appeared on the New Mexico case. See, e.g. "Water Rights and National Forests--Narrowing the Implied Reservation Doctrine: United States v. New Mexico, 40 Ohio State Law Journal 728 (1979); Boles, Jr. and Elliott, "United States v. New Mexico and the Course of Federal Reserved Water Rights, 51 Colo. L. Rev. 209 (1980); Fairfax & Tarlock, No Water for the Woods: A Critical Analysis Of United States v. New Mexico, 15 Ida. L. Rev. 509 (1979).

UNITED STATES v. CITY AND COUNTY OF DENVER, 656 P. 2d 1 (Colo. 1982). (Not appealed) This case is the most extensive implementation of the reservation doctrine to date and deserves careful attention.

In this complex state-court adjudication the United States submitted claims for reserved water rights covering seven national forests, three national monuments, one national park, over 1500 public waterholes and springs, two mineral hot springs, and the public domain administered by the Bureau of Land Management. The case involved thousands of claims for state law appropriation rights. 169 parties objected to the US claims, represented by at least 70 different attorneys. A Water Court decree was appealed to the Colorado Supreme Court. That court held:

NATIONAL FORESTS

Instream flows for recreational, scenic, and wildlife purposes. The United States claimed instream flow rights for watershed and timber protection, and wanted to use this water for recreational, scenic, and wildlife protection.

HELD: Instream flow claim rejected. The US failed to demonstrate that this water was needed for national forest purposes of watershed protection and timber production.

Does MUSYA expand reservation purposes? The United States claimed that MUSYA (1960) expanded the purposes for which water could be reserved under the 1897 Act.

HELD: MUSYA did not expand these purposes. While conceding the Supreme Court's statement in New Mexico was dicta, the Colorado Court said that the dicta was controlling. Congress was aware of the Reserved Rights Doctrine when it passed MUSYA, but did not choose to reserve additional water explicitly.

DINOSAUR NATIONAL MONUMENT

Reservations for Monuments. The US claimed reserved instream flows in the Yampa River for recreational boating (river rafting) within the Monument. This have seriously impaired junior appropriators upstream on the Yampa. This National Monument was created under 16 USC Sec. 431 (1976) by presidential proclamation to preserve public lands of outstanding historic and scientific interest. President Wilson created it in 1915 to preserve an "extraordinary deposit of Dinosaurian and other gigantic reptilian remains".

HELD: Recreational boating is not one of the purposes for

which water can be reserved under the National Monument Act.

Monument transferred to Park. This Monument was placed under the supervision of the National Park Service in 1938 and the US argued that its "purposes" were thus expanded to include National Park purposes.

HELD: The transfer was done for administrative convenience and did not change the purposes for which water could be reserved. The area is still a Monument, being administered by the National Park Service.

Instream flows for scientifically important species. The US claimed instream flows might be necessary for fish habitats of endangered species of historic and scientific interest.

HELD: Claim upheld. REMANDED for determination of quantity needed for these purposes. The US must quantify its claim within 6 months.

ROCKY MOUNTAIN NATIONAL PARK

National Forest transferred to Park status. This Park was created from a national forest. The land was transferred to the Park in 1915, and again in 1930.

HELD: For reservation purposes that are common to both national forests and national parks (watershed protection and timber production), the priority date is the initial national forest reservation.

National Parks also have broader purposes, inter alia, conserving scenery, historic and scientific objects, and wildlife. See National Park Service Act of 1916, 16 USC Sec. 1 (1976). The priority date for the reserved rights for these broader purposes is the date the land was made into a Park. Decrees were awarded for minimum flows and lake levels for conservation of scenic, natural and historic objects and for recreational and aesthetic purposes.

PUBLIC SPRINGS AND WATERHOLES

Reservation by Interior Dept. regulation. The federal government claimed reserved water rights for the entire field of numerous waterholes and springs, whether tributary or nontributary, located on lands withdrawn by a 1926 executive order titled "Public Water Reserve No. 107".

HELD: The Executive Order was issued under authority of

the Stock Raising Homestead Act of 1916, 43 USC Sec. 300 (1976). While the Exec. Order did not state an intention to reserve water and withdraw it from appropriation under state law, Department of Interior regulations did state such intention, and that is adequate to create a reserved right.

Anti-monopolization purpose for reservation. The Dept. of Interior REGULATIONS reserved water to "prevent the monopolization of vast land areas in the arid states by providing a source of drinking water for animal and human consumption".

HELD: These regulations reserved only sufficient water to carry out this anti-monopolization purpose, and no more. The springs and water holes contain more water than is minimally essential for this purpose. The government has 4 years to quantify its minimal needs to effectuate this purpose.

Tributary springs. The reservation applies to both tributary and nontributary springs; the reservation documents made no distinction between these two types of sources.

MINERAL HOT SPRINGS

Reservation for leasing purposes. The federal government claimed reserved water rights to hot springs for leasing purposes pursuant to the Pickett Act (43 USC Sec. 141 (1976)).

HELD: Reserved rights upheld.

Reservation for geothermal power production. The federal government claimed reserved water rights to hot springs for geothermal power production, under the Pickett Act, and under the Geothermal Steam Act of 1970, 30 USC Sec. 1001, et seq. (1976).

HELD: No reserved rights. The Geothermal Act is principally a leasing Act. No express or implied intent can be found in either Act to reserve water for power generation.

Federal licensees and contractors exercising reserved right. The federal government claimed that permittees, licensees, and concessionaires could exercise the federal reserved right, and that it was not necessary for the federal government to itself exercise these rights.

HELD: Licensees etc. can exercise the federal reserved right.

TWO OTHER ISSUES were expressly not decided by the court:

(1) whether reserved rights are limited to waters on, under, or touching the reserved lands;

(2) Whether the reserved right can be transferred to a use not within the original purposes of the reservation. These issues were not properly before the court.

RESERVED WATERS ON BLM LANDS

In Sierra Club v. Watt, 659 F.2d 203 (D.C.Cir.1981) the Court denied the Sierra Club's claim that FLPMA had reserved waters on BLM lands for "scenic, scientific, historical, ecological, environmental, air and atmospheric, water resource, and archaeological values", ruling that FLPMA merely set forth "purposes, goals and authority for uses of the public domain," and did not reserve any water.

THEORETICAL BASIS FOR THE RESERVATION DOCTRINE

This topic is considered last in this outline, or almost so, because it is a peculiar concern of academics, rather than the courts. The Courts have been concerned with results, letting theoretical bases take the hindmost. Nonetheless two theories hold some sway. Supporters of each theory claim judicial support:

(1) The federal government owns waters on lands that have been withdrawn, and therefore can do with those waters as it pleases, without regard to state law. See Hanks, FEDERAL-STATE RIGHTS AND RELATIONS, in 2 WATERS AND WATER RIGHTS Sec. 102.1, at 38-40 (R. Clark ed. Supp 1978).

(2) The reservation doctrine is explained by the supremacy clause, coupled with some incidental constitutional power (e.g. commerce power) exercised on the reserved land. See F. Trelease, FEDERAL-STATE RELATIONS IN WATER LAW 138-47 (National Water Commission Legal Study No. 5, 1971).

FEDERAL NON-RESERVED WATER RIGHTS

The argument about the existence of these oddities, and what they look like, has preoccupied a number of federal lawyers and academics. To date the courts have not been concerned with them.

If one cuts through the extensive verbiage on the subject, one thing seems clear. If Congress wants to claim waters for some federal government use, then it has the power to do so, assuming it acts under the Supremacy clause in conjunction with some other empowering clause, e.g., commerce or property. Of course if the federal use damages or destroys vested private water rights, the the owners of those rights, must be compensated. In view of past congressional history (e.g., the Acts of 1866, 1877), and Supreme Court cases (e.g., US v. New Mexico) the Congressional intention to claim such waters will have to be clearly expressed. But, that the power exists is not really be debatable.

Debate can, of course, occur about whether the Congressional intent is clear enough to pass judicial muster. That debate, especially as it concerns the Federal Land Policy and Management Act of 1976, 43 USC Sec. 1701 et seq. (FLPMA) has waxed extensively in the federal legal establishment since 1979. See:

Krulitz view: Such rights probably exist under FLPMA, and other statutes, and, indeed, are not all that hard to find. FEDERAL WATER RIGHTS OF THE NATIONAL PARK SERVICE, FISH AND WILDLIFE SERVICE, BUREAU OF RECLAMATION, AND BUREAU OF LAND MANAGEMENT, 88 Interior Dec. 553 (1979).

Martz view: Such rights probably don't exist, and certainly not unless clearly mandated by Congress; FLPMA is too fuzzy to be the basis of such rights. MEMORANDUM OF THE SOLICITOR OF THE DEPARTMENT OF THE INTERIOR, 88 Interior Dec. 253 (1981).

Coldiron view: "There is no 'federal non-reserved water right.'" NON-RESERVED WATER RIGHTS--UNITED STATES COMPLIANCE WITH STATE LAW, 88 Interior Dec. 1055 (1981).

Olson view (Office of Legal Counsel): Such rights might well exist, but only where congress explicitly or clearly provides for them! U.S. Dept. of Justice, Office of Leg. Counsel, "Federal Non-Reserved" Water Rights (June 16, 1982).

WHAT IS THE DIFFERENCE BETWEEN RESERVED RIGHTS AND NON-RESERVED RIGHTS?

Coggins and Wilkinson suggest that non-reserved rights arise when Congress delegates to a federal agency authority to administratively claim the waters of a particular stream or lake, for a particular location and purpose, e.g., a campsite. These rights have a priority from the date "the public was given notice, probably through rulemaking." G.C. Coggins, C. F. Wilkinson, FEDERAL PUBLIC LAND AND RESOURCES LAW, 1983 Supp. p. 70.

HOMAN

The Resource Development Council and Alaska Section of the
American Water Resources Association present:

WATER POLICIES AND RESOURCE DEVELOPMENT IN ALASKA

November 9, 1985
University of Alaska - Anchorage
Library 215

8:00 - 9:00 Registration

9:00 - 9:15 Introductions and Opening Remarks:
Pete Nelson; RDC Executive Committee Member

9:15 - 10:00 Water Availability

How much water is available in different regions of Alaska? When is it available? What is its water quality? How much data do we have for different regions? What are the prospects for obtaining more data?

Moderator: William Blackmer; Montgomery Engineers,
Project Mgr., Eklutna Water Project

Panelists: Phil Emery; Chief, Alaska Water Resources
Division, U.S.G.S.
Bill Long; Chief, Water Resources Section
Alaska DNR, D.G.G.S.

10:00 - 10:15 Morning Break

10:15 - 11:45 Water Rights

Who has the legal rights to Alaska's surface water and groundwater? What are water rights? How are they obtained? What data are required? Instream flow appropriations. Federal reserve water rights.

Moderator: Brent Petrie; Dir. of Systems Planning,
Alaska Power Authority

Panelists: James K. Barnett; Deputy Commissioner.
Alaska DNR
Tom Meacham; Attorney and member,
Alaska Water Resources Board
Anne Puffer; Regional Hydrologist, USFS

11:45 - 12:45 Lunch served (included in registration fee)

JUNPELL.

12:45 - 2:30

Water Quality Policies

What are state water quality objectives? What water quality criteria are applied? Why? Regional considerations. What resources (time, personnel and money) are required to meet these criteria? How do these criteria affect resource development?

Moderator: Dr. Bob Miller; Dept. of Civil Engineering, UAA

Panelists: Bob Martin; Spec. Assistant to the Commissioner, Alaska DEC
Norman Cohen; Director, Div. of Habitat, Alaska DF&G
Jim Jinks; Executive Director, Alaska Miners Association
Dr. Chien-Lu Ping; Asst. Professor of Agronomy, UAF, Ag. & For. Exp.

2:30 - 2:45

Afternoon Break

2:45 - 4:30

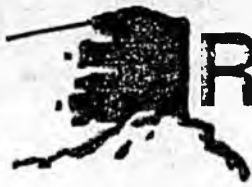
Case Studies: Water and Energy Policies

How have water policies affected resource development in Alaska? How does the developer interact with the water agencies? In what manner were conflicts resolved? In what manner could resolution of conflicts be streamlined?

Moderator: Stephen Bredthauer; R & M Consultants and President, AK Section, AWRA

Panelists: - Brent ^{Hydro}Petrie; Dir. of Systems Planning, Alaska Power Authority
- Tom Zimmer; Chairman, AOGA Operations Committee
Luke Franklin; Environmental Specialist, Diamond Alaska Coal Co.
Joseph Jordan; District VP, Morrison-Knudsen Engineers

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WATER POLICIES AND RESOURCE DEVELOPMENT IN ALASKA

Frank / cross water issues

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The Resource Development Council and the Alaska Section of the American Water Resources Association invite you to participate in a one day workshop concerning water resource issues. We've assembled panels of experts to discuss the policies concerning water use and the effects on Alaska's resource development. (A complete agenda is attached.)

There will be question and answer sessions at the end of each panel in which we urge you to take part. For more information about topics to be discussed, please call Steve Bredthauer at 561-1733.

REGISTRATION INFORMATION

Date: November 9, 1985
Time: 8:00 a.m. to 4:30 p.m.

Place: Library 215, University of Alaska, Anchorage

Registration fee: \$40.00
Student Registration: \$15.00

(Lunch is included in your registration. Please make checks payable to the Resource Development Council.)

Call Lynn Gabriel at 276-0700 with any questions concerning registration.

PLEASE RETURN THIS PORTION WITH REGISTRATION FEE

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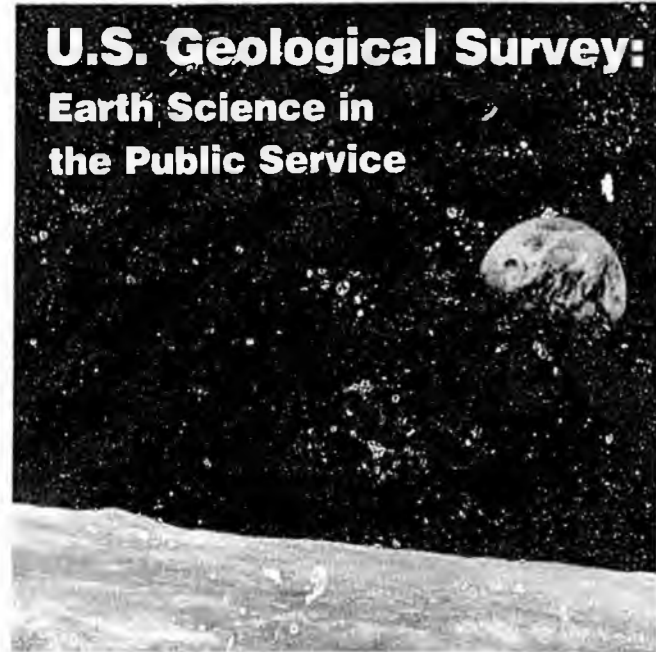
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U.S. Geological Survey: Earth Science in the Public Service



The U.S. Geological Survey (USGS), a bureau of the Department of the Interior, was established by an act of Congress on March 3, 1879, to provide a permanent Federal agency to conduct the systematic and scientific "classification of the public lands, and examination of the geological structure, mineral resources, and products of the national domain." An integral part of that original mission includes publishing and disseminating the earth-science information needed to understand, to plan the use of, and to manage the Nation's energy, land, mineral, and water resources.

Since 1879, the research and fact-finding role of the USGS has grown and been modified to meet the changing needs of the Nation it serves. Today's programs serve a diversity of needs and users and include assessing the Nation's energy and mineral resources; providing information to enable society to mitigate the impacts of earth-science hazards, such as floods, earthquakes, volcanoes,

landslides and droughts; evaluating and monitoring the quantity, quality, and distribution of surface- and ground-water resources; operating the national mapping program; providing detailed and innovative map products, such as computer-generated data for a variety of mapping and planning needs; investigating the resource potential of the ocean floor in a search for domestic sources of critical and strategic minerals; and developing geologic and hydrologic criteria to aid regulatory agencies to select the best sites for the safe disposal of hazardous wastes.

Along with its continuing commitment to meet the earth-science needs of the Nation, the USGS remains dedicated to its original mission to collect, analyze, interpret, publish, and disseminate information about the natural resources of the Nation. Specific responsibilities and programs, carried out by the Geologic, National Mapping, and Water Resources Divisions of the USGS, include:



- Conducting detailed assessments of the energy and mineral potential of the Nation's land and offshore areas;
- Issuing warnings of earthquakes, volcanic eruptions, landslides, and other geologic and hydrologic hazards;
- Conducting research on the geologic structure of the Nation;
- Studying the geologic features, structure, processes, and history of the other planets of our solar system;
- Conducting topographic surveys of the Nation and preparing topographic and thematic maps and related cartographic products;
- Developing and producing digital cartographic data bases and products;



- Collecting data on a systematic basis to determine the quantity, quality, and use of surface and ground water;
- Conducting water-resource appraisals to describe the consequences of alternative plans for developing land and water resources;
- Conducting research in hydraulics and hydrology, and coordinating all Federal water data acquisition;
- Using remotely sensed data to develop new cartographic, geologic, and hydrologic research techniques for natural resources planning and management; and
- Providing earth-science information through an extensive publications program and a network of public access points.



USGS headquarters are located at its National Center in Reston, Va. Research and data gathering programs are conducted through regional offices in Denver, Colo., Menlo Park, Calif., and Reston, Va., and through several hundred field offices located across the country. To learn more about the USGS, its research programs, and its information products, contact the offices listed below.

Sources of Book Publications and Maps

To order USGS book publications and to request USGS circulars, catalogs, and pamphlets, write:

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Reston, VA 22092
Phone: (703) 860-6167

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West 920 Riverside Ave.
Spokane, WA 99201
Phone: (509) 456-2524

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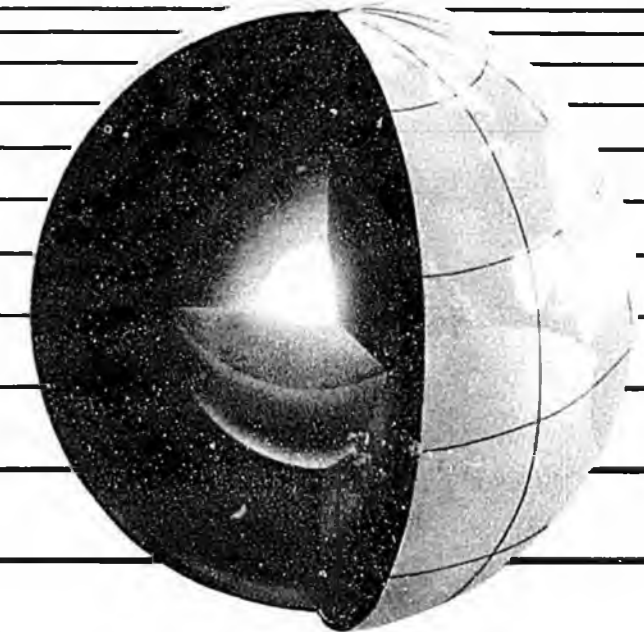
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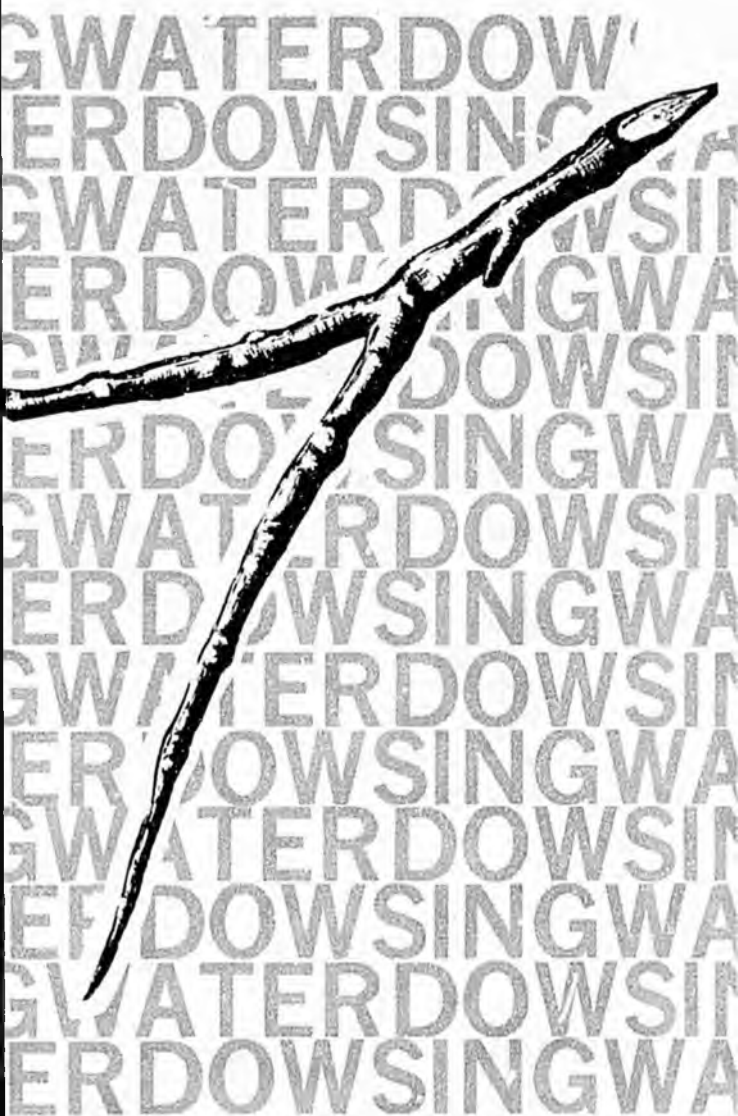


As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.

U.S. Geological Survey: Earth Science in the Public Service



Water Dowsing



Water Dowsing

One of the major responsibilities of the U.S. Geological Survey is to assess the quantity and quality of the Nation's surface- and ground-water supplies. The Survey's Water Resources Division, in cooperation with other Federal, State, and local agencies, maintains a nationwide hydrologic data network and carries out water-resource and hydrologic investigations.

Numerous general inquiries concerning water resources and hydrology are directed to the Survey, which has prepared a number of "popular publications" to help answer such requests. As part of that group of publications, this leaflet was prepared to answer some of the most frequently asked questions about the subject of water dowsing and is not intended to make editorial comment on dowsing or its practitioners.



and Roman naturalists and scientists do not mention the use of a magic rod, although they do give hints and directions for finding water.

The exact origin of the divining rod in Europe is not known. The first detailed description of it is in Johannes Agricola's "De Re Metallica" (1556), a description of German mines and mining methods. The device was introduced into England during the reign of Elizabeth I (1558-1603) to locate mineral deposits, and soon afterward it was adopted as a water finder throughout Europe.

The practice of water dowsing has always aroused widespread controversy. Its 17th century champions attempted to explain it by the principle of "empathy" or "attraction and repulsion." Its adversaries condemned it as a superstitious and vain practice. Some held that the stick was moved by a satanic influence, and others believed that the dowser received his power from God. To protect against evil, the rod was sometimes "Christianized" by being placed in bed with a newly baptized child, by whose Christian name it was afterward addressed.

Despite opposition from church and lay leaders, use of the rod spread throughout Europe. Water dowsing seems to be a mainly European cultural phenomenon, completely unknown to New World Indians and Eskimos. It was carried across the Atlantic to America by some of the earliest settlers from England and Germany. Although the published record was very slight at first, water dowsing or witching began to be mentioned after 1675 in connection with witches and witchcraft. Two articles condemning it appeared in the 1821 and 1826 issues of the American Journal



of Science and were among the first in a long line of treatises on water witching.

Despite almost unanimous condemnation by geologists and technicians, the practice of water dowsing has spread throughout America. It has been speculated that thousands of dowsers are active in the United States; many are members of the American Society of Dowsers, Inc.

What Do Dowsers Believe About Ground Water?

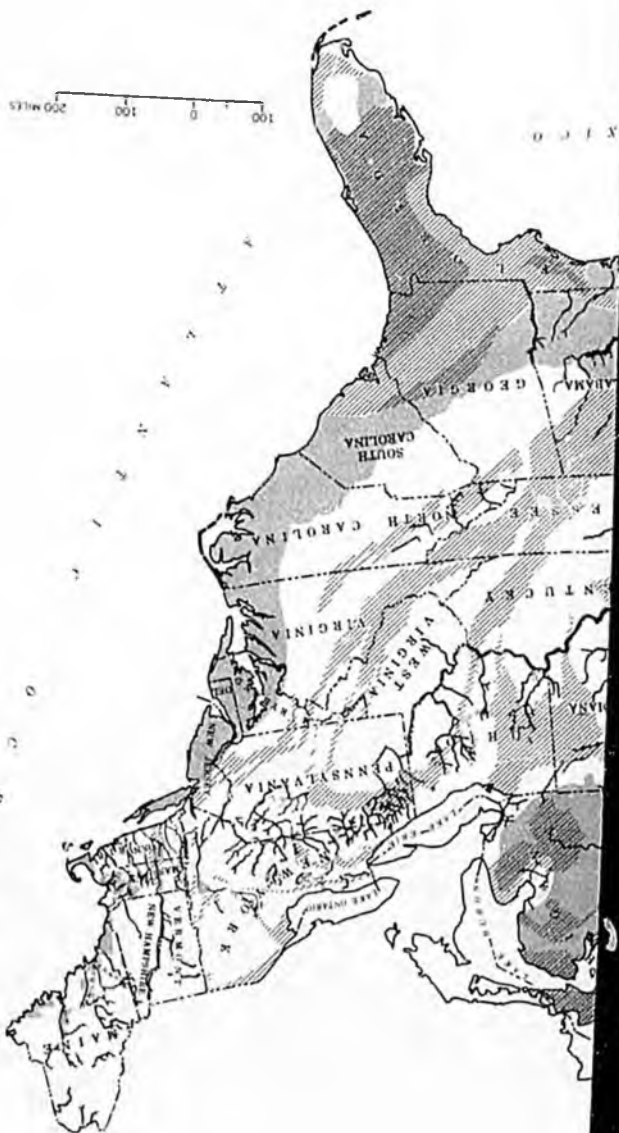
Some dowsers seem to believe that water occurs in veins resembling the veins of one's body. According to Henry Gross, one of the best known modern practitioners, underground water flows upward from great depths, forming "domes." He believes such domes to be the source of water for underground veins that flow in various directions. Three domes supposedly on top of Mount Washington, N. H., were said to be coming from a depth of 57,000 feet.

Most dowsers attempt only to locate the positions of the so-called water veins. But many of their clients ask: How deep will I have to drill, and how much water will I get? Some dowsers, therefore, do attempt to estimate the quantity of and the depth to water.

If the well driller does not find water at the indicated spot, the failure may be blamed on interference of hills with the dowsing, a short circuit of "current," incorrect drilling, or the crushing or deflection of the delicate water veins by the driller.

What Does Science Say About Dowsing?

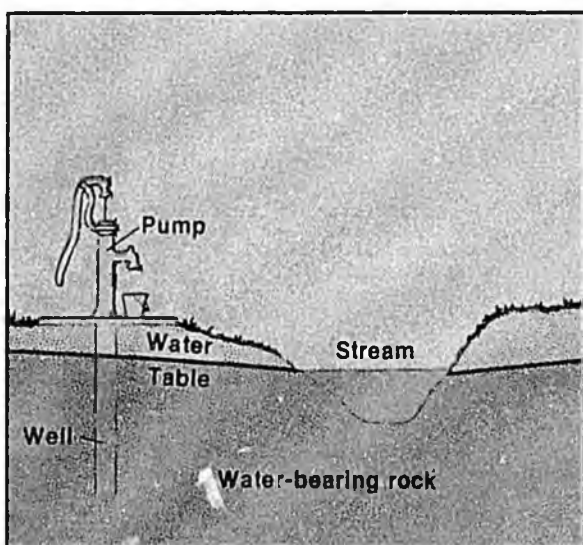
Case histories and demonstrations of dowsers may seem convincing, but when dowsing is exposed to scientific examination, it presents a very different picture. For instance, what does it mean to say that a

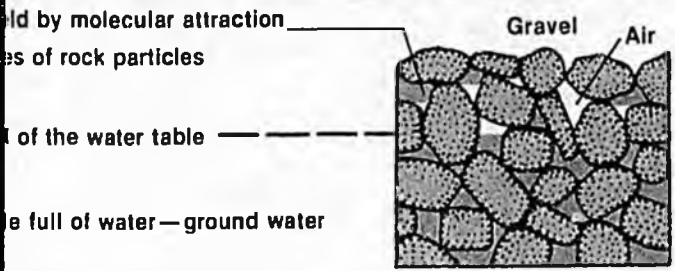
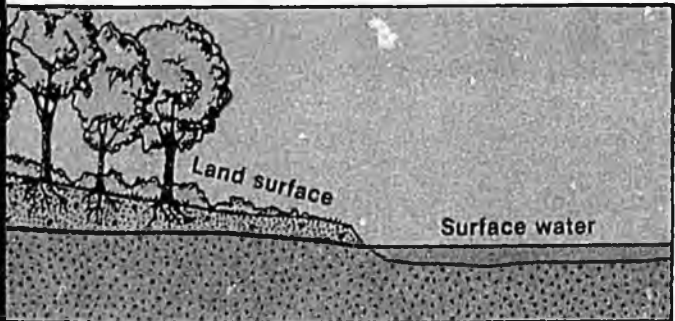


dowser is successful in 8 out of 10 cases? The dowser may find water, but how much? And of what quality? At what rate can it be withdrawn? For how long and with what impact on other wells and on nearby streams?

The natural explanation of "successful" water dowsing is that in many areas water would be hard to miss. The dowser commonly implies that the spot indicated by the rod is the *only* one where water could be found, but this is not necessarily true. In a region of adequate rainfall and favorable geology, it is difficult *not* to drill and find water!

Some water exists under the Earth's surface almost everywhere. This explains why many dowsers appear to be successful. To locate ground water accurately, however, as to depth, quantity, and quality, a number of techniques must be used. Hydrologic, geologic, and geophysical knowledge is needed to determine the depths and extent of the different water-bearing strata and the quantity and quality of water found in each. The area must be thoroughly tested and studied to determine these facts. The U.S. Geological Survey, the Federal agency with major responsibility for assessing the quantity and quality of the Nation's surface and ground waters, believes that no single





sand. An "aquifer" is any body of rock that contains a usable supply of water. A good aquifer must be both porous enough to hold water and permeable enough to allow the continuous recharge of water to a well. Gravel, sand, sandstone, and limestone are among the best aquifers, but they form only a fraction of the rocks in the Earth's crust. Most rocks are fine grained or otherwise "tight" and store or carry little water.

As a first step in locating ground water, the hydrologist prepares a geologic map showing where the different kinds of rock come to the land surface. Some of the rocks may be so cracked and broken that they provide good openings to carry water underground. The rocks may be so folded and displaced, however, that it is difficult to trace their location underground.

Next, he gathers information on the wells in the area—their locations, the depth to water, the amount of water pumped, and the kinds of rock they penetrate. Because he cannot always afford to drill a test hole to obtain information, records of wells already drilled are his mainstay.

If there are no wells in the area, or not enough information is available on existing ones, the hydrologist may contract with a well driller to put down some test holes. At these holes he will make pumping or aquifer tests. These tests indicate the water-bearing properties of the aquifer tapped by the well. From the tests the hydrologist can determine the amount of water moving through the aquifer, the volume of water that can enter the well, and the effect of pumping on the water level of other wells in the area.

For man's use of water, quality is just as important as quantity. The hydrologist will take samples of water from different wells and have them chemically analyzed.

The hydrologist's report and geologic map will show where water can be found, its chemical composition, and in a general way, how much is available. This is the scientific approach used by the U.S. Geological Survey, State resource agencies, and consulting engineers in making their ground-water studies. Information about local ground-water conditions may be found in the offices that the U.S. Geological Survey's Water Resources Division maintains in all 50 States.

Where Can I Find Out More About Water Dowsing and Ground Water?

The only comprehensive report on water dowsing published by the U.S. Geological Survey is *The Divining Rod, A History of Water Witching*, by A. J. Ellis, published as USGS Water-Supply Paper 416 in 1917 and reprinted in 1957. This report contains detailed information and includes references to several hundred papers on the use of the divining rod and related subjects.

U.S. Geological Survey Water-Supply Paper 1800 *The Role of Ground Water in the National Water Situation*, by C. L. McGuinness, 1963, summarizes the



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What Is Water Dowsing?

"Water dowsing" refers in general to the practice of using a forked stick, rod, pendulum, or similar device to locate underground water, minerals, or other hidden or lost substances, and has been a subject of discussion and controversy for hundreds, if not thousands, of years.

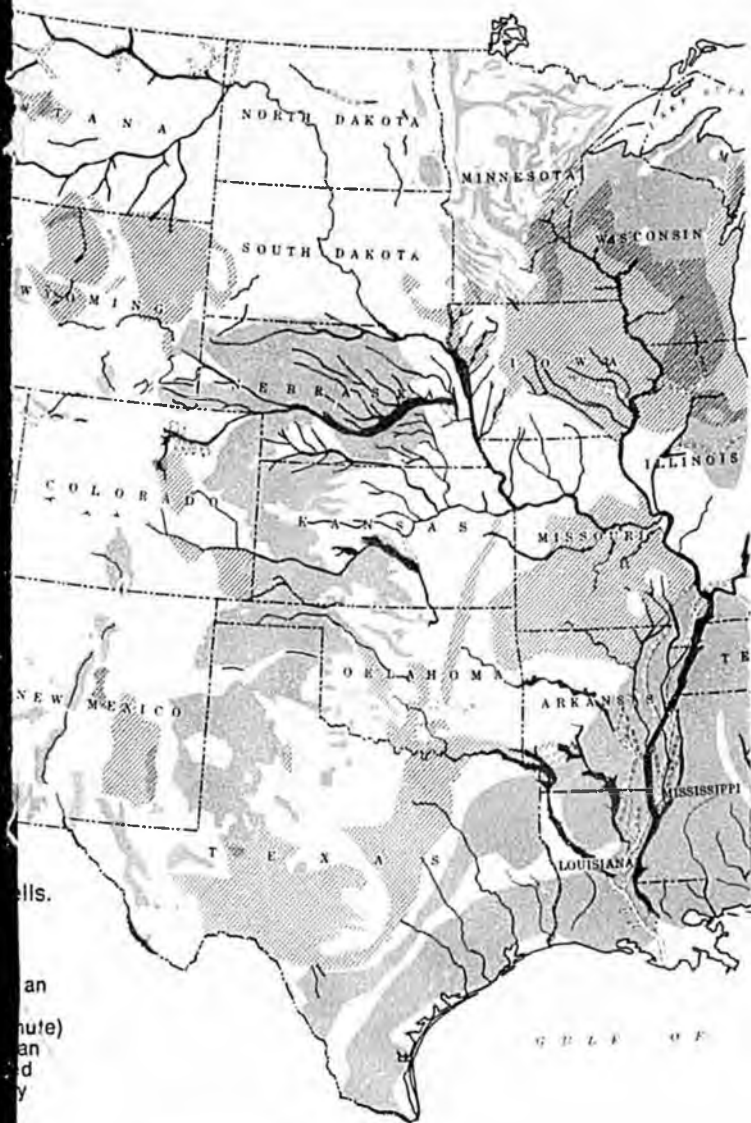
Although tools and methods vary widely, most dowsers (also called diviners or water witches) probably still use the traditional forked stick, which may come from a variety of trees, including the willow, peach, and witch hazel. Other dowsers may use keys, wire coathangers, pliers, wire rods, pendulums, or various kinds of elaborate boxes and electrical instruments. Some claim powers that enable them to "see" through soil and rock, and some are mediums who go into trances when conditions are favorable.

In the classic method of using a forked stick, one fork is held in each hand with the palms upward. The bottom or butt end of the "Y" is pointed skyward at an angle of about 45°. The dowser then walks back and forth over the area to be tested. When he passes over a source of water, the butt end of the stick is supposed to rotate or be attracted downward.

According to dowsers, the attraction of the water may be so great that the bark peels off as the rod twists in the hands. Some dowsers are said to have suffered blistered or bloody hands from the twisting.

Although most dowsing for water is done at the actual site where water is needed, some dowsers claim to be able to locate water simply by passing the stick over a map.





Consolidated-rock aquifers (mostly limestone, sandstone, or volcanic rocks).



Both unconsolidated-and consolidated-rock aquifers.



Not known to be underlain by aquifer that will generally yield as much as 50 gpm to wells.

technique suffices to locate favorable water-well sites.

Numerous books and pamphlets have been written on the subject of water dowsing. Some of these publications report on scientifically controlled experiments and investigations. From these findings, the U.S. Geological Survey has concluded that the expense of further tests of water dowsing is not justified.

How Does Ground Water Occur?

Contrary to the belief of dowsers, ground water does not commonly flow in veins, domes, or underground rivers. Ground water is the water which fills pores or cracks in underground rocks. It is replenished by nature according to the local climate and geology and is variable in both amount and quality.

When rain falls, the plants and soil take up water. Some of the excess water runs off to streams, and some percolates down into the pores or cracks in the subsurface rocks. A well that extends into the saturated zone will fill with water to the level of the water table—the top of the zone in which all the openings of the rocks are filled with water.

It is important to know whether water will flow into the well fast enough to make it useful for man's purposes. A "tight" rock such as clay or solid granite, with tiny pores or only a few narrow cracks, may give up water so slowly that it is not useful. If the openings in the rock are large enough to let water flow freely, however, water in useful amounts can be taken out.

Several water-bearing rock layers may lie beneath the surface, separated by layers of rock less capable of carrying water. This geologic configuration may give rise to *artesian* conditions, where water levels in wells that penetrate the deeper layers of water-carrying rock rise under pressure and in some instances rise so high as to create flowing wells.

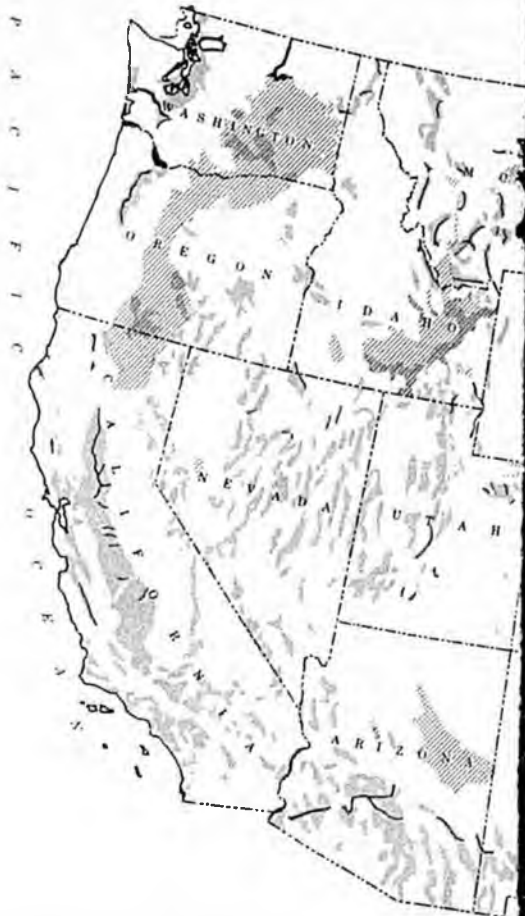
Water dowsers practice mainly in rural or suburban communities where residents are uncertain as to how to locate the best and cheapest supply of ground water. Because the drilling and development of a well often costs more than a thousand dollars, homeowners are understandably reluctant to gamble on a dry hole and turn to the water dowser for advice. The dowser, in turn, undoubtedly believes that he is endowed with a natural ability or has found a workable if unexplainable method of locating underground water.

Water is only one of many substances that different dowsers claim they can find. Divining rods have been used in attempts to locate gold, silver, lead, uranium, oil, coal, and other valuable minerals; to discover buried or hidden treasure; to find lost landmarks and reestablish property boundaries; to detect criminals or hidden soldiers; as well as to analyze personal character, and to trace lost animals. A few dowsers even claim the ability to diagnose and cure disease or to determine the sex of an unborn child.

How Did Water Dowsing Begin?

One of the first known divining rods was that mentioned in the Biblical passage in which Moses strikes a rock with his rod and water gushes forth (Numbers 20: 9-11). Cave paintings in northwestern Africa that are 6,000-8,000 years old are believed to show a water dowser at work. Divining rods were also used by the Scythians, Persians, and Medes. Most accounts, however, by Greek





Ground-water areas in the conterminous United States capable of yielding 50 gallons per minute or more to wells

EXPLANATION

Any pattern shows an area underlain by an aquifer generally capable of yielding to individual wells 50 gpm (gallons per minute) or more of water containing not more than 2,000 ppm (parts per million) of dissolved solids (includes areas where more highly mineralized water is actually used).



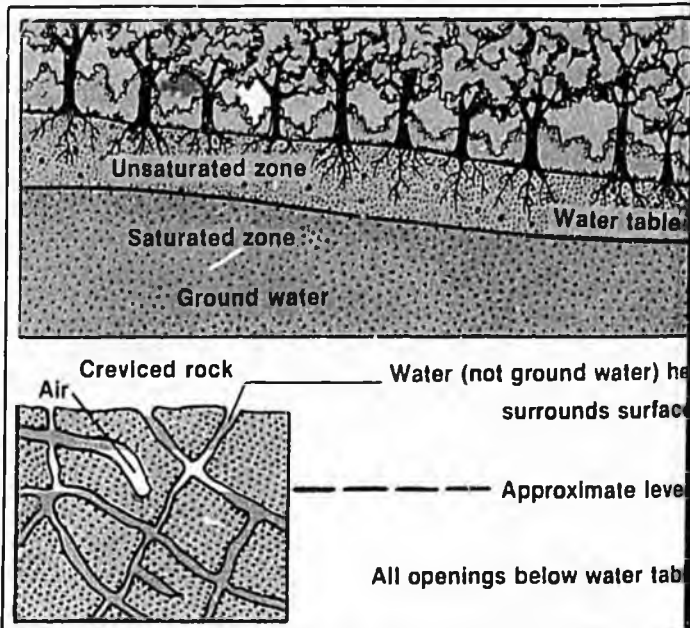
Watercourses in which ground water can be replenished by perennial streams.



Buried valleys not now occupied by perennial streams.



Unconsolidated and semiconsolidated aquifers (mostly sand and gravel).



How ground water occurs in rocks.

How Do Hydrologists Locate Ground Water?

Compared to the dowser's dramatic display, the hydrologist's procedure for locating ground water may seem dull. His patient pursuit of the unseen is interesting, nonetheless.

The landscape offers helpful clues. Shallow ground water is more likely to occur in larger quantities under valleys than under hills, because ground water obeys the law of gravity and flows downward just as surface water does. In arid regions the presence of "water-loving" plants is an indication of ground water at shallow depth. Any area where water shows up at the surface, in springs, seeps, swamps, or lakes, must have some ground water, though not necessarily in large quantity or of usable quality.

Rocks are the most valuable clues of all. Hydrologists use the word "rock" for hard, consolidated formations such as sandstone, limestone, or granite as well as for loose, unconsolidated sediments such as gravel or

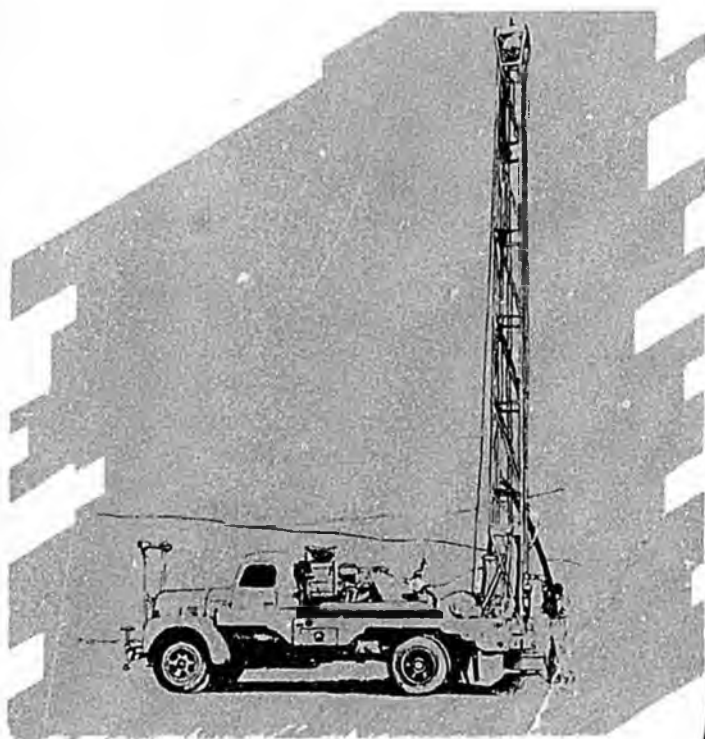
occurrence and development of ground water in the conterminous United States.

These reports are now out of print, but can be consulted at certain Geological Survey libraries and offices.

For a simple and easily understood discussion of basic facts, principles, and problems of water, consult *A Primer on Water*, by L. B. Leopold and W. B. Langbein, 1960, and *A Primer on Ground Water*, by H. L. Baldwin and C. L. McGuinness, 1963. These primers are sold by the Alexandria Branch of Distribution listed below.

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Ground Water



Ground Water



Twin Spring, Thousand Springs, Idaho.

Some water underlies the Earth's surface almost everywhere, beneath hills, mountains, plains, and deserts. It's not always accessible, it's not always fresh enough for use without treatment, and it's sometimes difficult to locate or to measure and describe. This water may occur close to the land surface, as in a marsh, or it may lie many hundreds of feet below the surface, as in some arid areas of the West. Some water, especially in very shallow zones, might be just a few hours old; in a moderately deep zone, it may be 100 years old; at great depth or after having flowed long distances from places of entry, it may be hundreds of thousands of years old.

The present usage of ground water throughout the country—most intensive in parts of the West—and the potential for much additional development, demonstrate that it is the Nation's principal reserve source of fresh water. This resource will become even more valuable in the years ahead as the Nation copes with burgeoning natural-resource and environmental problems and increased water demands.

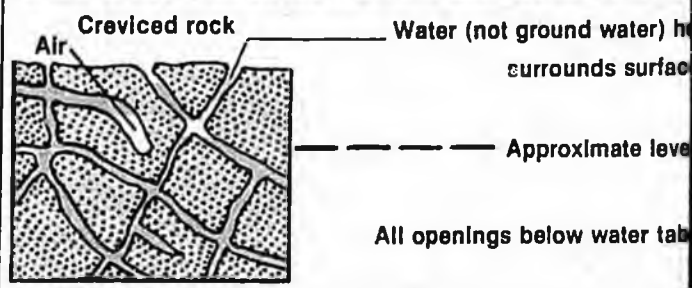
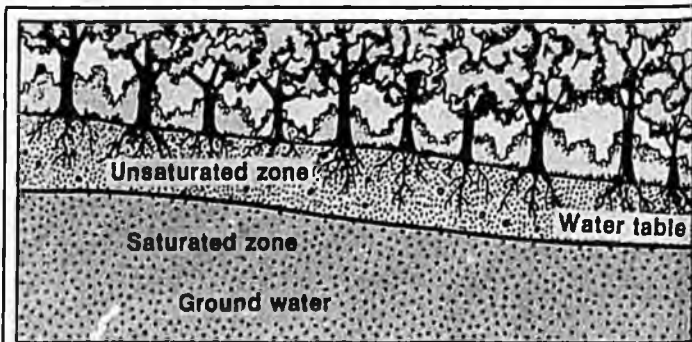
The Nation's total supply of water is large. Average annual streamflow in the conterminous (48) States is about 1,200 billion gallons a day or about three times the present water use. Much of that streamflow is water discharged from ground-water reservoirs. The distribution of water in both space and time is irregular. Some areas, however, already face serious regional water shortages—using water faster than it is naturally replenished. Further development of needed energy, mineral, and agricultural resources is dependent largely upon adequate water supplies.

How Ground Water Occurs

It is difficult to picture water underground. Some people have fanciful notions of underground lakes or of water flowing in veins or underground rivers. In fact, ground water is simply water that fills pores or cracks in subsurface rocks. It is ultimately replenished by precipitation, according to the local climate and geology, and is unevenly distributed in both quantity and quality.

The source of ground water is precipitation. When rain falls or snow melts, plants and soils take up water. Some water is evaporated to the atmosphere from plant leaves, some runs off to streams, and some percolates down into the pores or cracks in rocks. When rain falls, the first water that enters the soil replaces water that has been evaporated or used by plants during a preceding dry spell.

Between the land surface and the water table is a zone that hydrologists call the



How ground water occurs in rocks.

unsaturated zone in which there is usually at least a little water, mostly in smaller openings of the soil and rock. The larger openings in the rocks of the zone at times contain mostly air instead of water. After a significant rain, the zone may be almost saturated; in a long dry spell, it may become drained and almost dry. In this zone, some water is held in the soil and rocks by *molecular attraction*, and it will not flow toward or enter a well. Similar forces hold enough water in a wet towel to make it feel damp after it has stopped dripping.

After the thirsty plants and soil have had enough water and if rain continues to fall, the excess water will drain to the *water table*—the top of the zone in which openings in rocks are saturated. Below the water table, all the openings—crevices and pores—are full of water. The raindrops have, at last, become ground water, and this water is free to move from the saturated rocks to a nearby stream or into a well being pumped. A well, in simple concept, may be regarded as nothing more than an extra large pore into which gravity forces new water as water is removed from

volume of the aquifer. If the grains, however, are poorly sorted, the spaces between larger grains may be filled with smaller grains instead of water. Poorly sorted rocks, therefore, do not hold or transmit as much water as well-sorted rocks.

If water is to move through rock, the pores must be connected to one another. If the rock has a great many connected pore spaces big enough that water can move freely through them, the rock is said to be *permeable*.

A rock that is a good source of water must contain many interconnected pore spaces or cracks. A compact rock almost without pore spaces, such as granite, may be permeable if it contains enough sizable cracks or fractures. Nearly all consolidated rock formations are broken by parallel systems of cracks, called *joints* by geologists. These joints are caused by stresses in the Earth's crust similar to those that elevate mountains, cause earthquakes, and cause other earth movements. At first many joints are hairline cracks, but they tend to enlarge through the action of many physical and chemical processes. The ice crystals formed by water that freezes in rock crevices near the land surface will cause the rocks to split open. Heating by the Sun and cooling at night cause expansion and contraction that produce the same result. Water will enter the joints and may gradually dissolve away the rock or flush out weathered rock and thereby enlarge the openings.

As ground water moves through permeable rocks, it moves around and between neighboring impermeable ones; thus, like surface water, it takes the paths of least resistance. Although it moves slowly, it may travel for miles before it emerges as a spring, seeps unseen into a stream, or is tapped by a well.

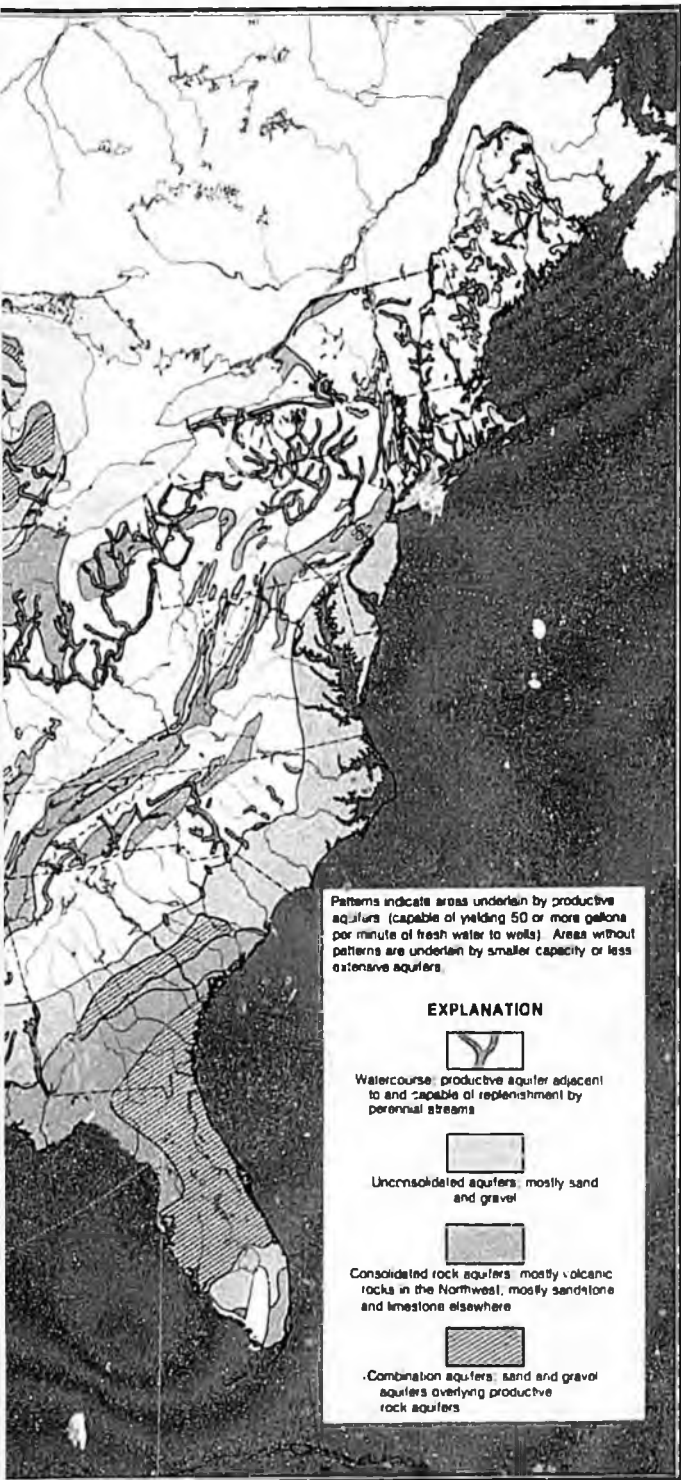
A relationship does not necessarily exist between the water-bearing capacity of rocks and the depth at which they are found. A very dense granite (poor aquifer) may be found at the Earth's surface, as in New England, whereas a porous sandstone (better aquifer) may lie hundreds or thousands of feet below

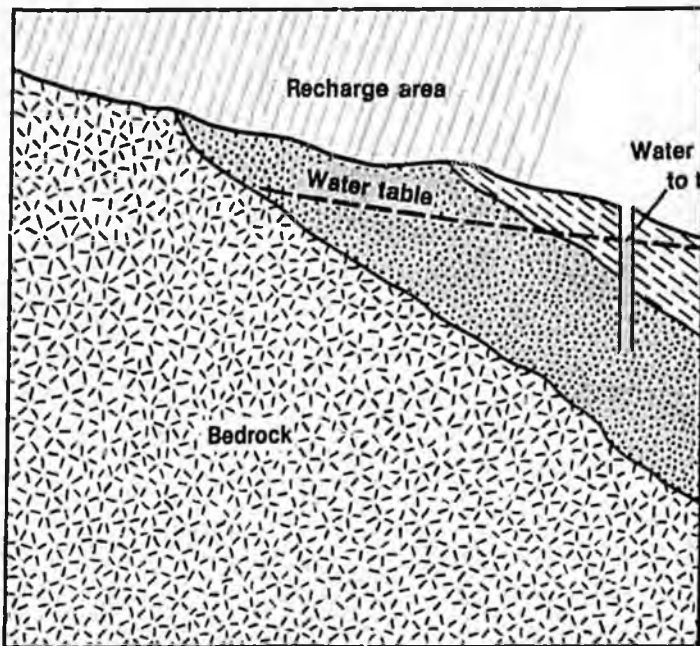
the surface, such as the Dakota Sandstone mentioned previously. Rocks that yield fresh water have been found at depths of more than 6,000 feet, and salty water has come from oil wells at depths of more than 30,000 feet. On the average, however, porosity and permeability decrease as depth increases; the pores and cracks in the rocks at great depths are virtually closed because of the pressure of overlying rocks.

After entering an aquifer, water moves toward lower lying places of discharge from the aquifer. Ground water also can move *upward* when it is confined under pressure between layers of impermeable rock, such as clay or shale. If an aquifer confined under such pressure is pierced by a well, water will rise above the top of the aquifer and may even flow from the well onto the land surface. Water confined in this way is said to be under *artesian pressure*, and the aquifer is called an *artesian aquifer*. The word *artesian* comes from the town of Artois in France, the old Roman city of Artesium, where the best known flowing artesian wells were drilled in the Middle Ages. The imaginary level to which water will rise in tightly cased wells in artesian aquifers is called the *potentiometric surface*.

Deep wells bored into rock to intersect the water table and reaching far below it are often called artesian wells in ordinary conversation, but this is not necessarily a correct use of the term. Such deep wells may be just like ordinary, shallower wells; great depth alone does not automatically make them artesian wells. The word *artesian*, properly used, refers to situations where the water is confined under pressure below layers of impermeable rock.

Where ground water is not confined under pressure, it is described as being under *water-table* conditions. For practical reasons, hydrologists need to know whether they are dealing with water under artesian or water-table conditions. For example the two kinds





Artesian aquifer and recharge area.

of aquifers—artesian and water-table—respond differently to pumping. Generally, it is assumed that artesian water is continuous for some distance under the confining layer of rock, and that it is replenished some distance away. However, replenishment to artesian aquifers may be derived locally by leakage from adjacent confining rocks. Under water-table conditions, an aquifer also may be recharged locally and is therefore more immediately responsive to precipitation.

A *spring* is the result of the natural discharge from a ground-water reservoir filled to overflowing. There are different kinds of springs and they may be classified according to the geologic formation from which they come, such as limestone springs or lava-rock springs; or according to the amount of water they discharge (large or small); or according to the temperature of water (hot, warm, or cold); or by the forces causing the springs (gravity or artesian flow).

Thermal springs are ordinary springs except that the water is warm, or, in some places, hot. Many discharge in regions of

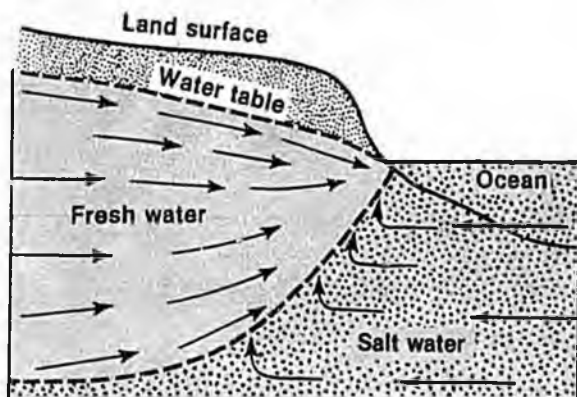
for plants in small amounts but is toxic to some plants in only slightly larger concentrations.

Water that contains a lot of calcium and magnesium is said to be *hard*. The hardness of water can be expressed in terms of the amount of calcium carbonate (the principal constituent of limestone) or equivalent minerals that would be formed if the water was evaporated. Water is considered soft if it contains 0 to 60 mg/L of hardness constituents, moderately hard if between 61 to 120 mg/L, hard if between 121 and 180 mg/L, and very hard if more than 180 mg/L. Very hard water is not desirable for many domestic uses; for example, it will leave a scaly deposit on the inside of pipes, boilers, and tanks. Hard water, however, can be made soft at a fairly reasonable cost, and it is not always desirable to remove all the minerals that make water hard. Extremely soft water is likely to corrode metals but is suitable for laundering, dishwashing, and bathing. Water for a municipal supply commonly strikes a reasonable balance between hardness and softness.

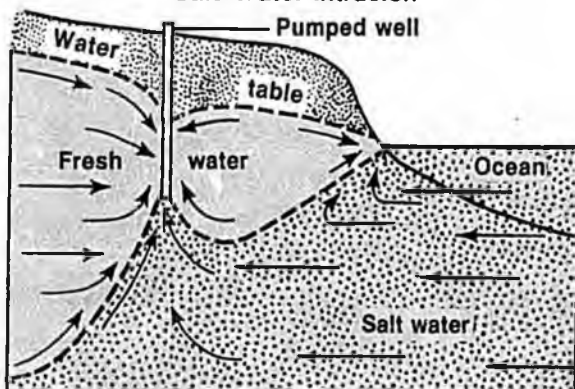
Ground water, especially acidic ground water, in many places contains excessive amounts of iron. This iron causes reddish stains on plumbing fixtures and clothing. Like hardness, excessive iron content can be reduced by treatment.

Another characteristic that must be considered in water, whatever its source, is pH which is a measure of the hydrogen-ion concentration. The pH scale ranges from 0 to 14. A pH of 7 indicates neutral water; above 7, the water is basic; below 7, it is acidic. A one-unit change in pH represents a 10-fold change in hydrogen-ion concentration. For example, water with a pH of 6 has 10 times more hydrogen-ions than water with a pH of 7. Basic water can form scale; acidic water can corrode. According to U.S. Environmental Protection Agency criteria, water for

Natural Conditions



Salt-Water Intrusion

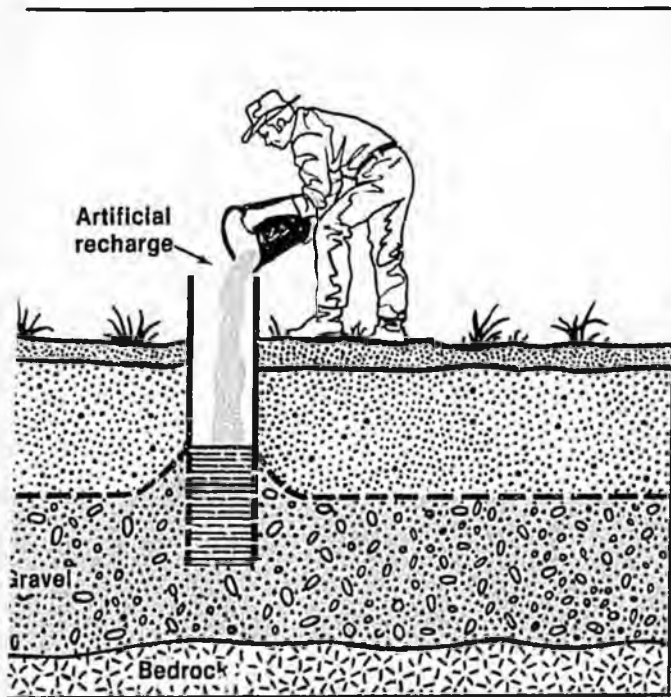


How intensive ground-water pumping can cause salt-water intrusion in coastal aquifers.

domestic use should ordinarily test between a pH of 5.5 and 9.

In recent years, the growth of industry, technology, population, and water use has increased the stress upon both our land and water resources. Locally, the quality of ground water has been degraded. Municipal and industrial wastes and chemical fertilizers and pesticides, not properly contained, have entered the soil and filtered downward to threaten ground-water quality. Other contamination problems include sewer leakage, incorrect septic-tank operation, and landfill leachates. Along some coastal areas, intensive pumping of ground water has caused salt-water intrusion into fresh-water aquifers.

In recognition of the potential for contamination, chemical analyses are made routinely



supplies. The Survey's Water Resources Division, in cooperation with other Federal, State, and local agencies, maintains a nationwide hydrologic-data network and carries out a wide variety of water-resource and hydrologic investigations, and develops new methodologies for studying water. The results of these investigations are indispensable tools for those involved in water-resource planning and management. Numerous inquiries concerning water resources and hydrology are directed to the Survey and to State water-resources and geological agencies.

Some water underlies the Earth's surface almost everywhere. To locate ground water accurately, however, as to depth, quantity, and quality, several techniques must be used, and a target area must be thoroughly tested and studied to determine hydrologic and geologic features important to the planning and management of the resource. To start with, the landscape may offer clues to the hydrologist about the occurrence of shallow ground water. Conditions for large quantities of shallow ground water are more likely under

valleys than under hills. In some regions—in parts of the arid Southwest, for example—the presence of “water-loving” plants, such as cottonwoods or willows, indicates ground water at shallow to moderate depth. Any area where water persists at the surface as springs, seeps, swamps, or lakes reflects the presence of ground water, although not necessarily in large quantities or of usable quality.

Rocks are the most valuable clues of all. As a first step in locating favorable conditions for ground-water development, the hydrologist prepares geologic maps and cross sections showing the distribution and positions of the different kinds of rock both on the surface and underground. Some sedimentary rock formations may extend many miles as aquifers having fairly uniform permeability. Other formations may be cracked and broken and contain openings large enough to carry water. Types and orientation of joints or other fractures may be clues to useful amounts of ground water. The rocks may be so folded and displaced, however, that they can be traced underground only with difficulty.

Next, the hydrologist obtains information on the wells in the target area—their locations, depth to water, amount of water pumped, and kinds of rocks they penetrate. This information is then processed and analyzed.

If there are no wells in the area, or if not enough information is available on the ones that are there, the hydrologist may contract with a well driller to drill some test wells, which he will use in pumping or aquifer tests. These tests will help to determine the amount of water moving through the aquifer, the volume of water that can enter a well, and the effects of pumping on water levels in the area. Because water quality is as important as water quantity, the hydrologist will take samples of water from different wells and samples of the rocks through which the water flows and have them chemically analyzed.

underground, but it is only within recent decades that hydrologists, geologists, and engineers have learned to estimate just *how* much and have begun to document its vast potential for use.

One million cubic miles of the world's ground water is estimated to be stored within one-half mile of the land surface. Although only a fraction of this reservoir of ground water in storage can be practicably tapped and made available on a perennial basis through wells and springs, the amount of water stored underground is more than 30 times larger than the volume in all the fresh-water lakes (nearly 30,000 cubic miles) and more than 3,000 times larger than the estimated volume of water (about 300 cubic miles) in all the world's streams at any given time.

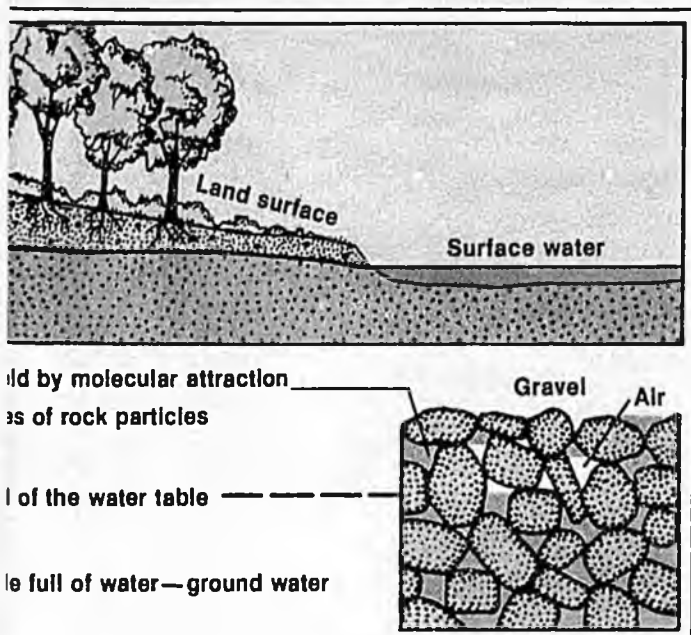
According to water-resource specialists of the U.S. Geological Survey, the United States was using about 415 billion gallons of water a day in the mid-1970's for public supplies, commerce, industry, irrigation, and other urban and rural uses. About 20 percent of this water was water from wells and springs, and in several States the use of ground water equaled or exceeded the use of water from streams and lakes.

Comparison of ground-water use with total water use in the United States, 1975

| | Total use (Bgal/d)* | Ground-water use (Bgal/d) | Ground water (Percent of total water use) |
|---------------------------------|------------------------|---------------------------------|--|
| Public supplies | 29 | 11 | 37 |
| Rural domestic and livestock | 5 | 4 | 80 |
| Irrigation | 140 | 57 | 40 |
| Industrial | 241 | 11 | 4 |
| TOTALS | 415 | 83 | 20% |

Source: Geological Survey Circular 765—Estimated use of water in the United States, 1975.

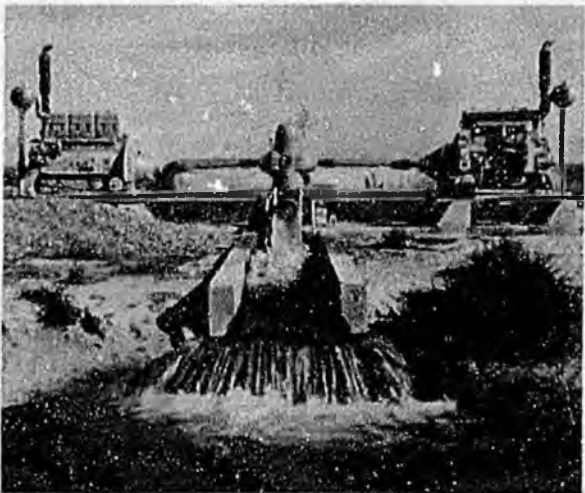
* billion gallons per day



the pore. Thus, a well drilled into water-saturated rocks will fill with water approximately to the level of the water table. If the well is pumped, gravity forces water to move from the saturated rocks into the well to replace the pumped water.

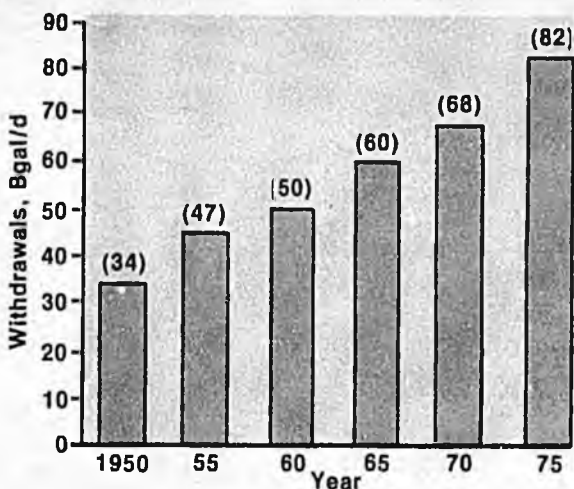
This leads to the question: Will water be forced in fast enough under pumping for a continuing water supply? A tight rock, such as clay or solid granite, having only a few hairline cracks may restrict movement of water to the well. Obviously, such a rock would be a poor water bearer. On the other hand, a rock having large openings will permit water to move more freely, and such a rock would be a good water bearer. The amounts yielded to a well that justify calling a rock water bearing, an aquifer, may range from a few hundred gallons a day where a small domestic supply is needed, to as much as several million gallons a day where large supplies are needed for industry, agriculture, or municipalities.

The word *aquifer* comes from the two Latin words, *aqua*, or water, and *ferre*, to bear or carry. The aquifer literally carries water



This water is called *ground water*. It is stored in, and moves slowly through, moderately to highly permeable rock strata called *aquifers* and represents, in terms of instantaneous storage at any one time, the largest single source of fresh water available to and commonly used by man.

Ground-water reservoirs have been known to man for thousands of years. Scripture (Genesis 7:11) on the Biblical Flood states that "the fountains of the great deep (were) broken up," and Exodus, among its many references to water and to wells, refers (20:4) to "water under the Earth." Many other chronicles show that man has known from ancient times that much water is contained



Increase in fresh ground-water utilization, 1950—75

underground. The aquifer may be a layer of gravel or sand, a layer of sandstone or cavernous limestone, a rubbly zone between lava flows, or even a large body of massive rock, such as fractured granite, that has sizable openings.

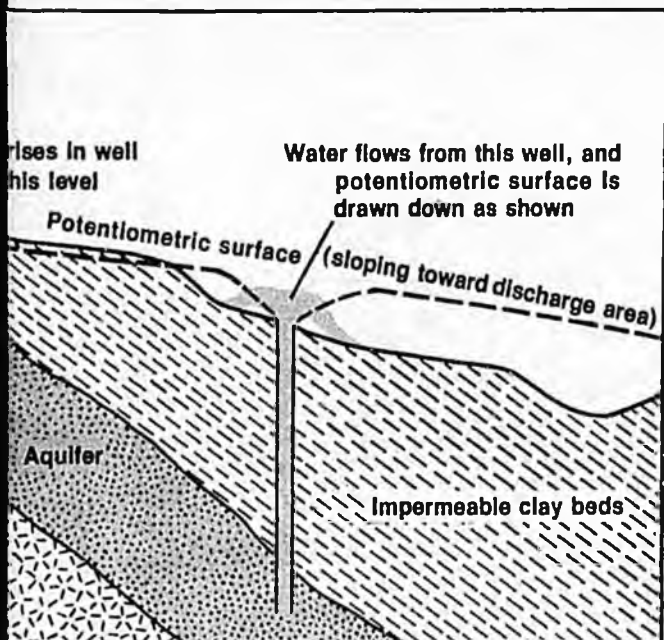
An aquifer may be only a few or tens or hundreds of feet thick. It may lie just below the surface or thousands of feet below. It may underlie a few acres or thousands of square miles. The Dakota Sandstone in the West, for example, carries water over great distances beneath many States (including North Dakota, South Dakota, southeastern Montana and eastern Wyoming, eastern Colorado, Nebraska, Kansas, northeastern New Mexico, and northwestern Oklahoma). Many aquifers, however, are only local in extent (such as the deposits of permeable sand and gravel accumulated irregularly in the central and northeastern parts of the United States during and following the Glacial Period).

The quantity of water that a given rock can contain depends on the rock's *porosity*—the total measure of the spaces among the grains or in cracks that can fill with water. If the grains of a sand or gravel aquifer are all about the same size, or "well sorted," as geologists say, the spaces between them account for a large proportion of the total



Ground-water areas in the United States.





recent volcanic activity and are fed by water heated by contact with hot rocks far below the surface. Such are the thermal springs in Yellowstone National Park. Even where there has been no recent volcanic action, the rocks become warmer with increasing depth. In some such areas, water may migrate slowly to considerable depth, warming as it descends closer to the heated regions deep in the Earth. If it then reaches a large crevice that offers a path of less resistance it can rise more quickly than it descended. Such water does not have time to cool before it emerges, and a thermal spring results. The famous Warm Springs of Georgia and Hot Springs of Arkansas are of this type. *Geysers* are thermal springs that erupt intermittently and to varying heights, some of which are spectacular and world famous, such as Old Faithful in Yellowstone National Park.

Quality of Ground Water

For the Nation as a whole, the chemical and biological character of ground water is

good. The quality of ground water in some parts of the country, however, particularly shallow ground water, is changing as a result of man's activities. Ground water is usually more free of bacterial contamination than surface water because the soil and rocks through which ground water percolates screen out most of the bacteria. Bacteria, however, occasionally find their way into ground water, sometimes in dangerously high concentrations. But freedom from bacterial contamination alone does not mean that the water is fit to drink. Many unseen dissolved mineral and organic constituents are present in ground water in various concentrations. Most are harmless or even beneficial; though occurring infrequently, others are harmful, and a few may be highly toxic.

Water is a solvent. Spring water may contain dissolved minerals and gases that give it the tangy taste enjoyed by many people. Without these minerals and gases, the water would taste flat. The most common dissolved mineral substances are calcium, magnesium, sodium, potassium, chloride, sulfate, and bicarbonate. In natural water chemistry, these substances are called *common constituents*.

Water is not considered desirable for drinking if the quantity of dissolved minerals exceeds 1,000 milligrams per liter (mg/L). Water with a few thousand mg/L of dissolved minerals is classed as slightly *saline*, but it is used routinely in areas where less-mineralized water is not available. Some well and spring water contains dissolved-mineral constituents in even greater concentration and cannot be tolerated by human beings, plants, or animals. At depth, many parts of the country are underlain by highly saline ground water which has only very limited uses.

In high concentrations, certain dissolved mineral constituents can cause special troubles; for example, too much sodium in the water may be harmful to people who have heart trouble. Boron is a mineral that is good

and regularly on municipal and industrial water supplies. Federal, State, and local agencies are taking steps to increase water-quality monitoring and have refined analytical techniques so that early warning can be given, and plans can be implemented to mitigate or prevent water-quality hazards.

Appraising the Nation's Ground-Water Resources

A widespread popular notion is that the water table has progressively declined all over the country. Although there are sizable areas where ground water is being withdrawn at rates causing water levels to decline persistently, as in parts of the dry Southwest, this is not true throughout the country. For the Nation as a whole, there is neither a pronounced downward nor upward trend. Water levels rise in wet periods and decline in dry periods. In areas that are not "over-pumped," particularly in the humid central and eastern parts of the country, water levels average about the same as they did in the past.

Aquifers are recharged by rain or snowmelt percolating downward or by seepage from overlying lakes or streams. An area of recharge, where rainwater or seepage enters the aquifer, may be nearby or many miles from wells or springs. Natural refilling of ground-water reservoirs at depth is a slow process because ground water moves slowly through aquifers. It has been estimated, for example, that if the ground-water reservoir of the High Plains of Texas and New Mexico, an area of slight precipitation, was emptied and all pumping was to cease, it would take centuries to refill at the present estimated small rate of recharge. In contrast, a shallow aquifer that is in an area of heavier precipitation or one in direct contact with streams and lakes and receiving water from them may be recharged rapidly.

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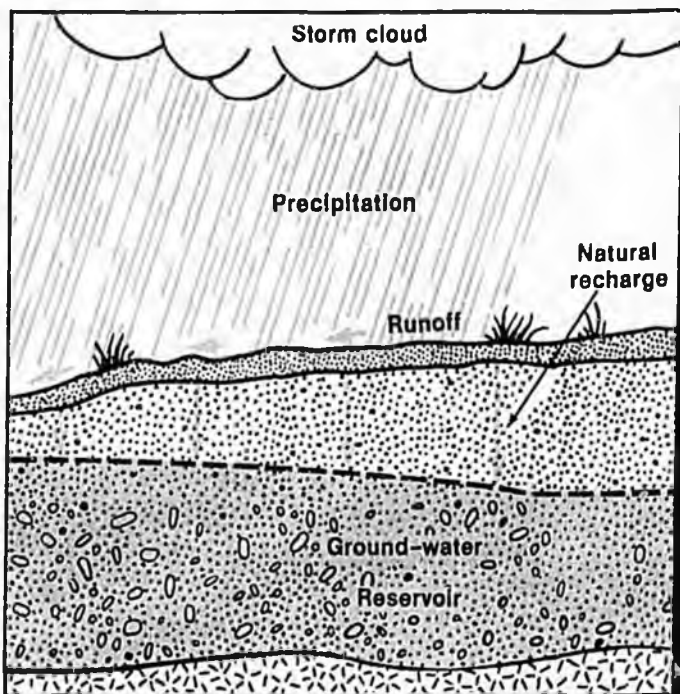
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Natural and artificial recharge of a ground-water reservoir.

Ground-water reservoirs can be recharged artificially. For example, considerable ground water used for air conditioning is returned to aquifers through recharge wells on Long Island, N.Y. Ground-water reservoirs may be recharged in two main ways: one way is to spread water over the land in pits, furrows, or ditches, or to erect small dams in stream channels to detain and deflect surface runoff, thereby allowing it to infiltrate to the ground-water reservoir; the other way is to inject water directly into recharge wells constructed for the purpose as simulated above by a man pouring water into a well. The latter is a more expensive method but may be justified where the spreading method is not feasible. Although some artificial-recharge projects have been successful, many have been disappointing, and there is still much to be learned about different ground-water environments and their receptivity to artificial-recharge practices.

One of the major responsibilities of the U.S. Geological Survey is to assess the quantity and quality of the Nation's water

The hydrologist's report, with its geologic and hydrologic maps, will show where water can be found, its chemical composition, how it moves underground, and, in a general way, how much is available. Although described simply, this is the scientific approach used by the U.S. Geological Survey, State resource agencies, and consulting engineers, hydrologists, and hydrogeologists in studying ground-water resources.

In the past, locating ground-water supplies was the main problem facing hydrologists and well drillers. Now, with years of experience and a large information base available, finding water is no longer the main problem; evaluating the ground-water resource in developed areas and prudent management of the resource, once it is found, and protection of its quality are the current problems. Thus, prediction of the capacity of the ground-water resource for long-term pumpage, the effects of that pumpage, and evaluation of water-quality conditions are among the principal aims of modern-day hydrologic practice in achieving proper management of ground water.

Ground water, presently a major source of water, is also the Nation's principal reserve source of fresh water. Thus, every individual, well owner or not, has a stake in its wise use. The public will have to make decisions regarding water supply and waste disposal—decisions that will either affect the ground-water resource or be affected by it. These decisions will be more judicious and reliable if based upon knowledge of the principles of ground-water occurrence. Even the simple facts contained in this leaflet can help people make wiser judgments about the use of our ground-water resource.

This publication is one of a series of general interest publications prepared by the U.S. Geological Survey to provide information about the earth sciences, natural resources, and the environment. To obtain a catalog of additional titles in the series "Popular Publications of the U.S. Geological Survey," write:

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Water in the Urban Environment Erosion and Sediment



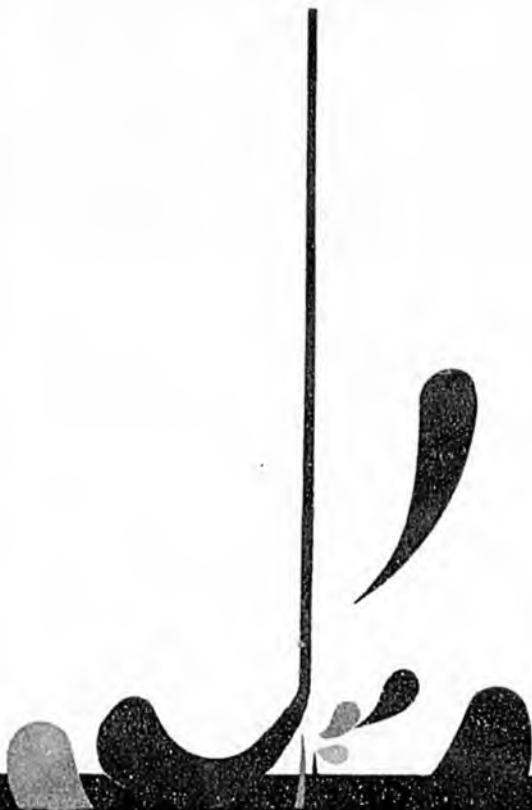
Department of the Interior/Geological Survey

Water in the Urban Environment: Erosion and Sediment

by William J. Schneider

Water: Resource and Hazard

Water is both an urban resource and a potential hazard. As a resource, it supplies our daily needs, sustains our industries, adds beauty to the landscape, and provides recreational opportunities. As a hazard, water can cause flooding and accumulate pollution. This leaflet discusses the problem of erosion and sediment.



Sediment—the mud and other solids washed off the land surface—is one of the major pollutants of our waterways. For every pound of municipal and industrial waste dumped into our rivers, lakes, and streams, erosion usually adds several pounds of sediment. Although perhaps not as dangerous to health as waste pollution, sediment pollution is indeed costly. Each year we spend more than \$125 million to dredge some 38 million cubic yards of sediment from our harbors and waterways—enough sediment to fill almost 2 million railroad cars. In addition, we lose more than \$100 million in reservoir capacities each year from the deposition of stream-borne sediment. Added to this are the less tangible losses from sediment damage to the water environment and to its recreational and esthetic qualities.



Sediment deposition can reduce a lake to mud flats.

Sediment: The Sources

The sediment in our streams and rivers is derived almost entirely from the erosion of soil. Although rural and forest areas contribute some sediment to our waterways, by far the greatest source is from land undergoing urbanization. When exposed to rainfall, earth laid bare during construction erodes easily and contributes sediment to our waterways at rates that may approach 20,000 to 40,000 times the erosion rate of farms and woodlands. Furthermore, such land commonly remains bare for as much as 3 months during construction of a single residence unit and for more than a year during construction of large housing and apartment developments. Hydrologists of the Geological Survey have documented the magnitude of this sediment problem, particularly in the fast-growing Washington, D.C. metropolitan area. Their studies indicate clearly the tremendous amounts of sediment that can be eroded during construction:



Sediment also impairs recreational uses of our water resources.



Erosion from bare soil during housing construction is one of the sources of sediment.

- Lake Barcroft, in northern Virginia, originally served as a water-supply reservoir for the surrounding area. As encroachment by urban development forced its abandonment as a water-supply source, the lake became the focal point of high-priced suburban development. The continued urban expansion resulted in even greater accumulation of sediment from the construction and development. Eventually more than 235,000 tons of sediment were deposited in the lake; that is more than 40 tons of silt for every acre under development in the basin. During 1961 and 1962, when construction in the basin was at its peak, residents of the area spent more than \$200,000 to dredge sediment from the lake in order to maintain its recreational and esthetic qualities.
- In Montgomery County, Md., Geological Survey hydrologists have determined erosion and sediment production rates at an actual construction site. Here, more than 3,800 tons of soil were eroded during construction of 89 houses on a 20-acre site. This amount of erosion is equivalent to the removal of $1\frac{1}{4}$ inches of soil over the entire area. A single storm on August 4, 1960, removed more than 256 tons of soil in less than 2 hours.



Erosion from highway construction also contributes significant sediment loads.

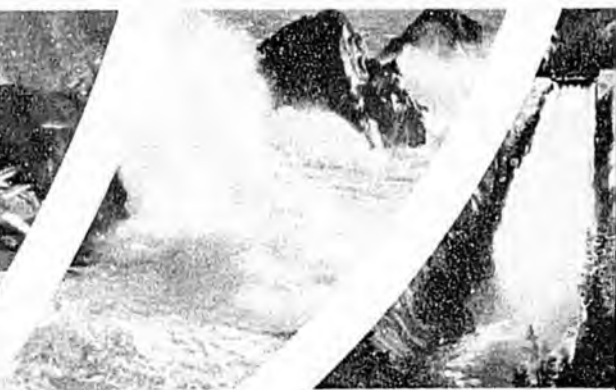
- Highway construction—another form of urban development—also contributes huge sediment loads to our waterways. In the Scott Run watershed in Fairfax County, Va., over 69,000 tons of sediment were eroded from the land laid bare during highway construction. More than half the sediment, some 37,000 tons, was carried by Scott Run to the Potomac River, where it contributed to siltation of the estuary in the Washington, D.C. area. Although the area of highway construction covered only 11 percent of the land area in the basin, it contributed 94 percent of the total sediment load carried by Scott Run to the Potomac River during the 3-year construction period.

Erosion: Its Control

How can this erosion and sedimentation be controlled? The easiest way to prevent sediment problems in streams and rivers is to control the erosion at its source. By inhibiting or preventing the erosion of soil during construction, production of sediment is restricted.

Numerous techniques can be used for controlling the erosion and sedimentation caused by urban development. They range from selecting the proper season for construction to the building of engineering

Water of the World



WATER OF THE WORLD

by Raymond L. Nace

DISTRIBUTION OF MAN'S LIQUID ASSETS IS A CLUE TO FUTURE CONTROL

Most people know that water is unevenly distributed over the Earth's surface in oceans, rivers, and lakes, but few realize how very uneven the distribution actually is. It is instructive to consider the total inventory of water on the planet Earth, the areas where the water occurs, and the long-term significance of the findings.

The world ocean—139 million square miles of it—contains 317 million cubic miles of saltwater. The average depth of the ocean basins is about 12,500 feet. If the basins were shallow, seas would spread far onto the continents, and dry land areas would consist chiefly of a few major archipelagoes—high mountain ranges projecting above the sea.

Considered as a continuous body of fluid, the atmosphere is another kind of ocean. Yet, in view of the total amount of precipitation on land areas in the course of a year, one of the most astonishing world water facts is the very small amount of water in the atmosphere at any given time. The volume of the lower 7 miles of the atmosphere—the realm of weather phenomena—is roughly four times the volume of the world ocean. But, the atmosphere contains only about 3,100 cubic miles of water, chiefly in the form of invisible vapor, some of which is transported overland by air currents. If all vapor were suddenly precipitated from the air onto the Earth's surface it would form a layer only about 1 inch thick. A heavy rainstorm on a given area may remove only a small percentage of the water from the airmass that passes over. How, then, can some land areas

receive, as they do, more than 400 inches of precipitation per year? How can several inches of rain fall during a single storm in a few minutes or hours? The answer is that rain-yielding airmasses are in motion, and as the water-depleted air moves on, new moisture-laden air takes its place above the area of precipitation.

The source of most atmospheric water is the ocean from which it is derived by evaporation. Evaporation, vapor transport, and precipitation constitute a major arc of the hydrologic cycle—the continuous movement of water from ocean to atmosphere to land and back to the sea. Rivers return water to the sea along one chord of the arc. In a subterranean arc of the cycle, underground bodies of water discharge some water directly into rivers and some directly into the sea.

Estimated average annual evaporation from the world ocean is roughly 39 inches. The conterminous United States receives an average of 30 inches of precipitation every year, or about 1,430 cubic miles in total volume. Evapotranspiration returns approximately 21 inches of this water to the atmosphere (about 1,000 cubic miles). Obviously, some rain is water that was vaporized from the land areas and is being reprecipitated. Evidently the global hydrologic cycle, which sends water from sea-to-air-to-land areas and back to the sea again, has short circuits. These are called subcycles.

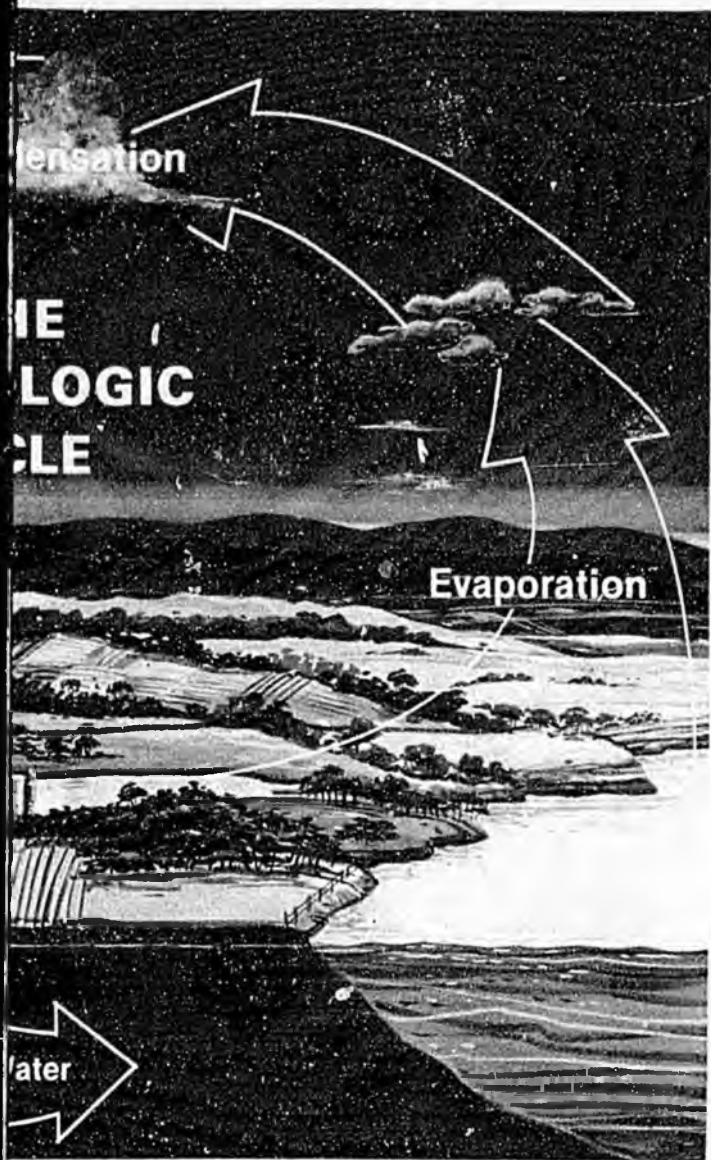
There are many complexities and variations in the fate of water that falls as rain or snow. For example, high in the central Rocky Mountains of North America, the Yellowstone River heads in Yellowstone National Park just east of the Continental Divide. The river water discharges through the Missouri and Mississippi Rivers into the Gulf of Mexico about 1,600 airline miles distant from the head.

On the west side of the Continental Divide, not far from the Yellowstone, rises the Snake River which flows across Idaho to join the Columbia near Pasco, Washington. Its water eventually reaches the Pacific Ocean about 700 airline miles from the source and about 2,200 miles from the mouth of the Mississippi.



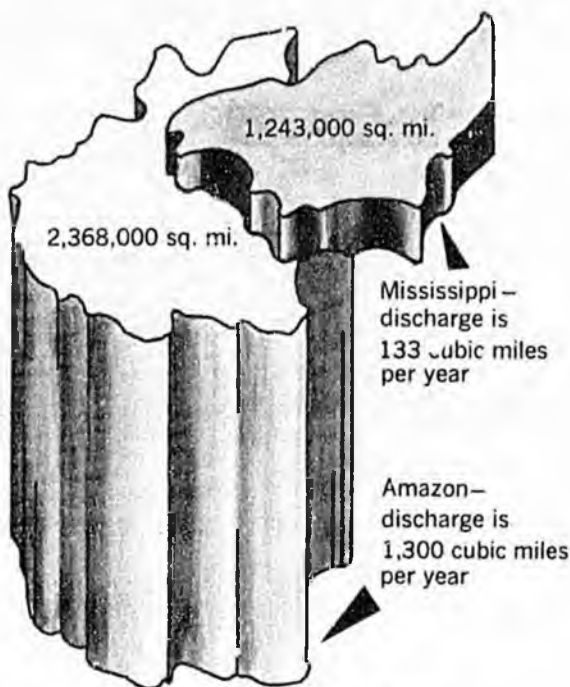
All water comes from the ocean and is returned to the ocean in a continuous hydrologic cycle.

This is a good example of the continuous movement and transfer of water in the hydrologic cycle. An air mass moving eastward across the Rocky Mountains contains water evaporated from the Pacific Ocean. Some of the water falls as rain to the west and some to the east of the Continental Divide. Thus, two drops of rain fall side by side along the continental backbone.



end up, one in the Pacific, the other in the Atlantic Ocean, although both were derived from the Pacific.

No one knows how much water moves from the Pacific to the Atlantic Ocean by vapor transfer, precipitation, and runoff, but we do know a great deal about runoff itself. Estimated total flow into the sea from rivers in the 48 adjacent States takes place at the rate of about 1,803,000 cubic feet per second (a cubic foot is about 7.48 gallons), which amounts to approximately 390 cubic miles per



Amazon vs. Mississippi drainage.

year. Values for runoff (390 cubic miles) plus evaporation (1,000 cubic miles) do not quite equal the precipitation (1,430 cubic miles) because none of these values is precise. Moreover, some water is discharged into the sea directly from ground-water sources without passing through streams. The missing 40 cubic miles of water, roughly 10 percent of the value for streamflow, might represent direct ground-water discharge.

Hydrologists have not generally considered that direct ground-water outflow to the sea is so large, but there is really no good basis that can be used to dispute or support what the computations seem to indicate. At any rate, the data are sufficiently accurate for the present purpose which is to show the relative magnitude of water volumes involved in the annual water cycle.

Some more specific data give a good idea of the relative importance of large and small rivers in maintaining continental water balances.

The Mississippi, North America's largest river, has a drainage area of 1,243,000 square miles (about 40 percent of the total area of the 48 conterminous States) and discharges at an aver-

ate of 620,000 cubic feet per second. This amounts to some 133 cubic miles per year, or approximately 34 percent of the total discharge of all the rivers of the United States.

Columbia, nearest American competitor of the Mississippi, discharges less than 75 cubic miles per year. Relatively speaking, the great Colorado River is a dwarf, discharging only about 10 cubic miles annually.

On the other hand, the Amazon, the largest river in the world, is nearly 10 times the size of the Mississippi. It discharges about 4 cubic miles per day and some 1,300 cubic miles per year—about 10 times the flow of all United States rivers.

Africa's great Congo River, with a discharge of approximately 340 cubic miles per year, is the continent's second largest. The estimated annual discharge of all African rivers is about 510 cubic miles.

Measurements of only the few principal streams on the continent afford a basis for reasonable estimates of the total runoff item in a general water balance. The small streams are

controlled by the Hoover Dam on the Colorado River. Franklin D. Roosevelt estimated that it discharges nearly 2.8 cubic miles of water.



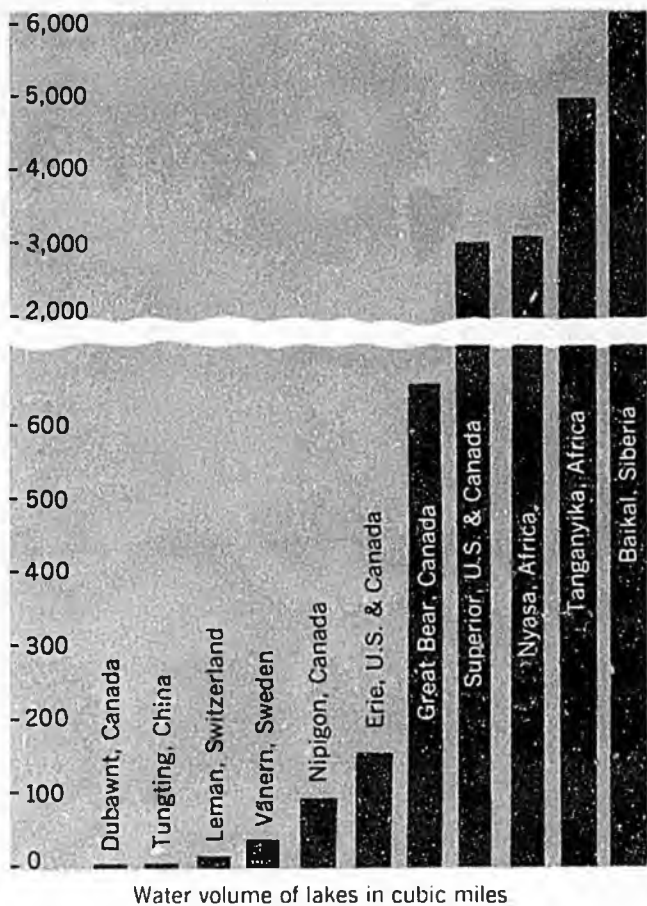
important locally, but they contribute only minor amounts of the total water discharged. Thus it is possible to estimate the total runoff of all the rivers of the world, even though many of them have not been measured accurately. Sixty-six principal rivers of the world discharge about 3,720 cubic miles of water yearly. The estimated total from all rivers, large and small, measured and unmeasured, is about 9,200 cubic miles yearly (25 cubic miles daily).

Crude estimates have indicated that the total amount of water that is physically present in stream channels throughout the world at a given moment is about 300 cubic miles. Evidently, river channels on the average contain only enough water to maintain their flow for about 2 weeks. Some have much more water, others much less, but it seems to be a fair average. How, then, do rivers maintain a flow throughout the year, even during rainless periods much longer than 2 weeks? The answer to that question will appear later in the discussion of ground water.

After oceans and rivers come lakes, which can be called wide places in rivers. This is certainly true of the many small lakes that are impounded by relatively minor and geologically temporary obstructions across river channels. But no single oversimplified metaphor accurately describes all lakes, which are widely varied in their physical characteristics and the geologic circumstances under which they occur. The handsome little tarn occupying an ice-scooped basin in a glaciated alpine area is radically different from the deep and limpid Crater Lake of Oregon, which fills the crater of a now-extinct volcano. Lake Okeechobee in Florida is totally different from any of the North American Great Lakes, which occupy huge basins formed in a complex manner by glacial excavation at some places, moraine and outwash deposition at others, isostatic subsidence of that whole region of the Earth's crust, and other factors. The Great Lakes of North America, in turn, bear no resemblance to Lake Tanganyika in the great Rift Valley of Africa. Processes that are poorly understood created the rift by literally pulling two sections of the Earth's crust apart, leaving a deep, open gash part of which is occupied by the lake. And these are only a few examples of wide

variations in the nature of lakes.

The Earth's land areas are dotted with hundreds of thousands of lakes. Wisconsin, Minnesota, and Finland contain some tens of thousands each. But these lakes, important though they may be locally, hold only a minor amount of the world supply of fresh surface water, most of which is contained in a relatively few large lakes on three continents.



Whether a lake contains freshwater or saltwater makes a considerable difference in its usefulness to man, so the Earth's greatest lakes are considered in both of the categories, fresh and salt.

The volume of all the large freshwater lakes in the world aggregates nearly 30,000 cubic miles, and their combined surface area is about 330,000 square miles. "Large" is a relative term that requires explanation. For this article, a lake is called large if its contents are 5 cubic miles or more.

Location

SURFACE WATER



Freshwater lakes



Saline lakes and inland seas



Average in stream channels

SUBSURFACE WATER



Vadoso water (includes soil moisture)



Ground water within depth of half a mile

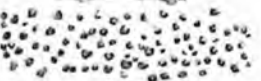


Ground water—deep lying

OTHER WATER LOCATIONS



Icecaps and glaciers



Atmosphere (at sea level)



World ocean

TOTALS (rounded)

* A cubic mile of water equals 1.1 trillion gallons

D WATER SUPPLY

Surface area (square miles) Water volume (cubic miles) Percentage of total water

| | | |
|-------------|-------------|-------|
| 330,000 | 30,000 | .009 |
| 270,000 | 25,000 | .008 |
| — | 300 | .0001 |
| 50,000,000 | 16,000 | .005 |
| | 1,000,000 | .31 |
| | 1,000,000 | .31 |
| 6,900,000 | 7,000,000 | 2.15 |
| 197,000,000 | 3,100 | .001 |
| 139,500,000 | 317,000,000 | 97.2 |
| | 326,000,000 | 100 |

Thus the listing includes Dubawnt Lake, Canada (about 6 cubic miles), but excludes the Zürichsee of Switzerland (about 1 cubic mile). The range of volume among the large lakes is enormous, from a lower limit of 5 cubic miles to an upper one of 6,300 cubic miles in Lake Baikal in Asiatic Russia, the largest and deepest single body of freshwater in existence. Some appreciation of its volume may be gained from the realization that Lake Baikal alone contains nearly 300 cubic miles more water than the combined contents of the five North American Great Lakes. The Great Lakes loom large on a map, but their average depth is considerably less than that of Baikal.

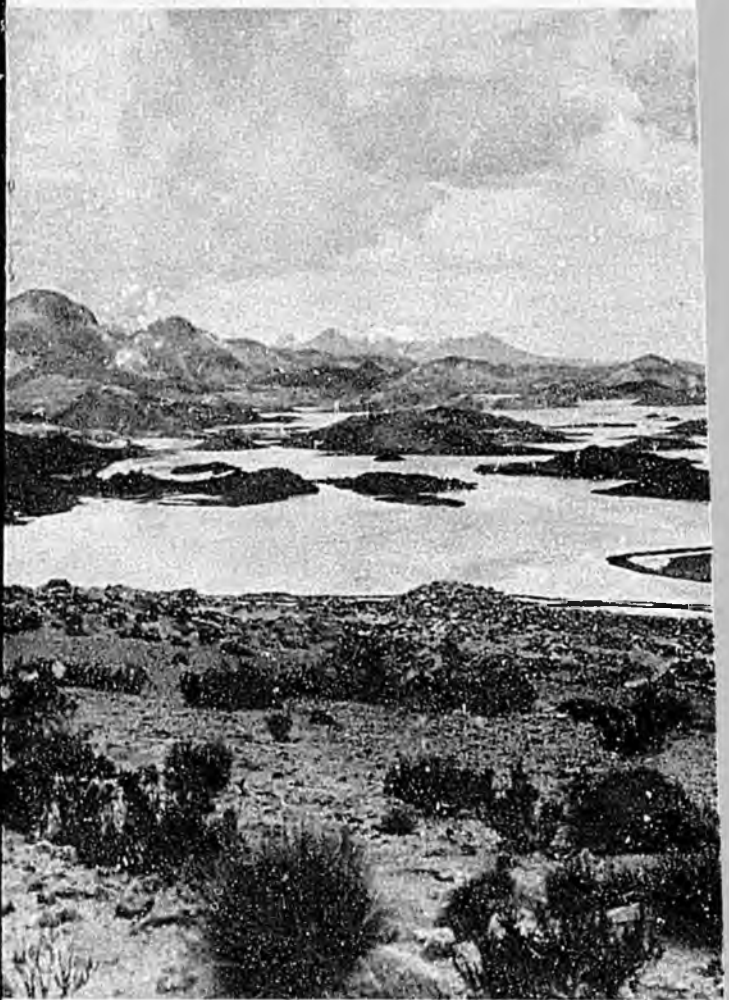
Nevertheless, North American lakes are a major element in the Earth's water balance. The Great Lakes, plus other large lakes in North America (chiefly in the 48 States and Canada) contain about 7,800 cubic miles of water—26 percent of all liquid, fresh, surface water in existence.

Similarly, the large lakes of Africa contain 8,700 cubic miles, or nearly 29 percent of the total freshwater supply. Asia's large lakes contain about 6,400 cubic miles, or 21 percent of the total, nearly all of which is in Lake Baikal.

Lakes on these three continents account for roughly 75 percent of the world's fresh surface water. Large lakes on other continents—Europe, South America, and Australia—have only about 720 cubic miles, or roughly 2 percent of the total. All that remains to fill the hundreds of thousands of rivers and lesser lakes that are found throughout the world is less than one-fourth of the total fresh surface water.

Saline lakes are equivalent in magnitude to freshwater lakes. Their total area is 270,000 square miles and their total volume is about 25,000 cubic miles. The distribution, however, is quite different. About 19,240 cubic miles (75 percent of the total saline volume) is in the Caspian Sea, and most of the remainder is in Asia. North America's shallow Great Salt Lake is comparatively insignificant with 7 cubic miles.

All these water sources we have discussed are the obvious ones. There is another—soil moisture—that may be the most significant segment of the world's water supply because of the key role played by plants in the food chain. Some



Laguna de Cotacatani, a morainal-dammed lake, in the Andean region of northern Chile.

plants grow directly in water or marshy ground, but by far the greater mass of vegetation on Earth lives on "dry" land. This is possible because the land is really dry at just a few places, and often only temporarily. How dry is dust? The dust of a dry dirt road may contain up to 15 percent of water by weight. However, plants cannot grow and flourish with so little water because the soil holds small percentages of moisture so tenaciously that plant roots cannot extract it. Aside from desert plants, which store water in their own tissues during infrequent wet periods, land plants flourish only where there is extractable water in the soil. Inasmuch as a quite ordinary tree may withdraw

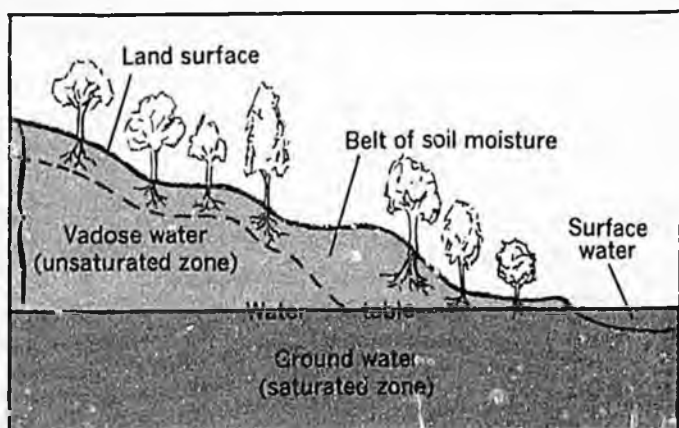
and transpire about 50 gallons of water per day, frequent renewals of soil moisture, either by rain or by irrigation, are essential. The average amount of water held as soil moisture at any given time is on the order of 6,000 cubic miles for the world as a whole—an insignificant percentage of the Earth's total water, but vital to life. Relatively little vegetation receives artificial irrigation, and practically all of it depends on natural soil moisture, which, in turn, depends on orderly and timely operation of the hydrologic cycle.

Another little-considered water reservoir has been known to man for thousands of years. Scripture (Genesis 7:11) on the Noachian Deluge states that "the fountains of the great deep (were) broken up," and Exodus, among its many references to water and to wells, refers (20:4) to "water under the earth." Many other chronicles show that man has known from ancient times that there is much water underground. Only recently has he begun to appreciate how much.

Beneath most land areas of the world there is a zone where the pores of rocks and sediments are completely saturated with water. Hydrologists call this ground water, and the upper limit of the saturated zone is called the water table. The water table may be right at the land surface, as in a marsh, or it may lie hundreds of feet below the land surface, as in some arid areas. Water in the unsaturated zone above the water table is called vadose water and includes the belt of soil moisture. Water in the intermediate part of this zone has passed through the soil and is percolating downward toward the water table.

The world volume of that part of the vadose water below the belt of soil moisture is probably somewhat more than that of soil moisture—say 10,000 cubic miles. It is highly important because, although it is not extractable by man, it is potential ground-water recharge, and ground water is extractable. Each influx of water from precipitation on the land surface, followed by percolation through the soil, provides an increment of recharge to the ground water.

Below the water table, to a depth of half a mile in land areas of the Earth's crust, there is about 1 million cubic miles of ground water. An equal if not



Relation of the water table to saturated and unsaturated zones.

greater amount is present at a greater depth down to some 10,000 to 15,000 feet, but this deeper water circulates sluggishly because the rocks are only slightly permeable. Much of the deep-lying water is not economically recoverable for human use, and a good deal of it is strongly mineralized.

Ground water flows through moderately to highly permeable strata, which are called aquifers, at rates of a few inches to perhaps several hundred feet per day; 40 to 50 feet per day would be a rather high rate of flow.

Depending on how far the ground water must travel to reach a surface discharge area, water in shallow to moderately deep zones may remain underground from a few hours to 100 years or longer. Water at great depth may take tens or hundreds of thousands of years to pass through an aquifer, and some is completely stagnant.

The volume of ground water in the upper half mile of the continental crust probably is about 3,000 times greater than the volume of water in *all* rivers at any one time, and nearly 20 times greater than the combined volume of water in all rivers and lakes. It is easy to see, therefore, that ground-water reservoirs have tremendous importance as equalizers of streamflow. Under natural conditions, most ground-water reservoirs are full to overflowing, and the overflow water provides what is called the base flow of surface streams enabling them to flow even during long, rainless periods and after winter snows have melted.

According to calculations, the volume of ground water in storage in the United States to a depth of half a mile is equivalent to the total of all recharge during the last 150 years. This estimate is crude, but it helps to emphasize the important fact that ground-water reserves, although immense, are not wholly self-renewing annually. At places where they have been depleted by pumpage, they might take many decades to recover even if pumping were stopped completely.



Consider, for example, a location in the dry Southwestern United States where annual recharge to an aquifer is only two-tenths of an inch of water. In such areas, it is not uncommon to pump 2 feet or more of water per year for irrigation or other uses. In this over-simplified example, if the entire aquifer were pumped at that rate, yearly pumpage would be equivalent to 120 years' recharge, and 10 years of pumping would remove a 1,200-year accumulation of water. Recharge during the pumping period would be negligible. Mechanical problems and economic factors would prevent complete emptying of an aquifer, but the example is valid in principle.

The next big items on the water-balance sheet are icecaps and glaciers. They may seem unimportant in the water cycle because, although the ice masses alternately shrink or grow a little from time to time, new ice is added about as fast as old ice melts. The polar ice masses, however, have a great influence on weather, and everything that happens in the polar regions indirectly affects everyone throughout the world (NATURAL HISTORY, October 1963). Moreover, if a shift in climate led to extensive melting of icecaps, there would be a rise in sea level with important effects.



Vast expanse of the Antarctic ice sheet, shown in relief model, represents 85 percent of all the ice in the world.

in all low-lying coastal areas.

Mountain glaciers, such as those of the Alps in Europe (after which alpine glaciers are named), the Himalayas of Asia, and the Cascades of North America, are like average rivers in some respects. They are important locally, but they contain an insignificant fraction of the world's water. The total volume of all alpine glaciers and small icecaps in the world is only about 50,000 cubic miles (comparable to the combined volume of large saline and fresh lakes).

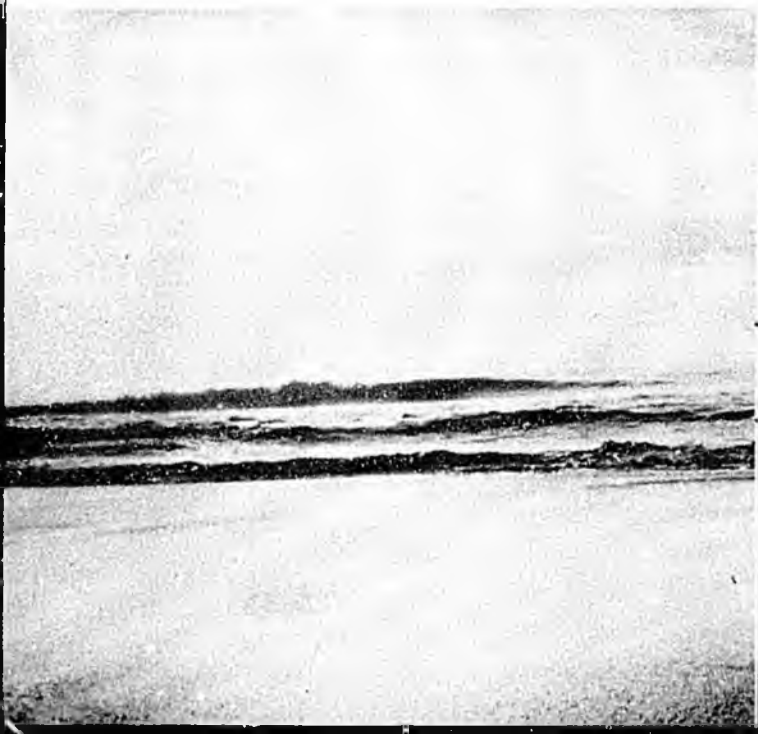
An alpine glacier is one that rises in mountainous uplands and, by plastic deformation, flows along a valley. A continental glacier, or icecap, is one that is plastered over the landscape, mountain and valley alike. Icecaps tend to flow radially outward from their center of accumulation. Wastage occurs by sublimation from the surface and by melting or calving away around the periphery. Average icecaps, like those on Novaya Zemlya, Iceland, and Ellesmere Land, are analogous to average lakes. They are locally important, but hold an insignificant share of the world's water and only a small part of the total volume of perennial ice.

The Greenland icecap is an entirely different matter. About 667,000 square miles in area and averaging nearly 5,000 feet in thickness, its total volume is about 630,000 cubic miles. If melted, it would yield enough water to maintain the Mississippi River for somewhat more than 4,700 years. Even so, this is less than 10 percent of the total volume of icecaps and glaciers. The greatest single item in the water budget of the world, aside from the ocean itself, is the Antarctic ice sheet.

Since the advent of the International Geophysical Year, 1957, considerable information has been accumulated about Antarctica. Data on the thickness of the ice sheet are relatively scarce, but there is enough information to permit an approximate estimate. The area of the ice sheet is about 6 million square miles, and the total volume, therefore, is between 6 and 7 million cubic miles, or some 85 percent of all existing ice and about 64 percent of all water outside the oceans.

The hydrologic importance of the continent and its ice may be illustrated briefly. If the Antarctic icecap were melted at a suitable uniform rate it could feed:

1. The Mississippi River for more than 50,000 years;
2. All rivers in the United States for about



17,000 years;

3. The Amazon River for approximately 5,000 years; or

4. All the rivers in the world for about 750 years.

The statistics about water given here are rather simple, but they are sufficiently important to tabulate in order to get them more clearly in mind. The table on pages 10 and 11 gives a comparative view of the world's water.

About 97 percent of all water in the world is in the oceans. Most of the remainder is frozen on Antarctica and Greenland. Thus, man must get along with the less than 1 percent of the world's water that is directly available for freshwater use. Obviously, he must find much more effective ways of managing if he is to prosper.

Water is a global concern. The water cycle recognizes no national boundaries. Man has become so numerous and his activities so extensive that he has begun to affect the water cycle—certainly on a regional scale and very likely on a global scale. To learn more about the world's water and how to use it, many countries have joined together in a program—the International Hydrologic Decade—aimed at overcoming on a global scale the now-existing critical deficiency in hydrological knowledge.





As the Nation's principal conservancy agency, the Department of the Interior has the responsibility for most of our nation's owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and people who live in Island Territories under U.S. administration.

works, from temporary procedures to permanent installations. Basically, these techniques are aimed at (1) reducing the area and duration of exposure of soils to erosion, (2) covering exposed soils with mulch or vegetation, (3) mechanically retarding the rates of storm runoff, (4) trapping the sediment carried by the storm runoff, and (5) planning land-clearing operations to coincide with periods of minimum rainfall.

Reduction of the area and duration of exposure of bare soils is fundamentally a planning process. Proper planning can insure that large areas are not cleared of cover and left bare for extended periods of time. Land cleared for highway construction and housing subdivisions commonly lies exposed to intensified erosion from one construction season to the next. Ideally, only short sections of highway or individual lots should be



Sediment traps can be used on land undergoing construction to inhibit the movement of sediment to streams.

cleared, developed, and then rapidly provided with erosion-retarding cover. Economically this is not always feasible; clearing of large areas must be done while equipment is available and at the site. Proper planning, however, can minimize the time during which the cleared land is exposed to the erosional effects of storm runoff.

During the construction period following the grading of the land, erosion can be inhibited by mulching or by planting temporary vegetative cover. Natural and artificial mulches, such as straw and plastic-based sprays, are both in use. Straw, or other similar material, provides a ground cover that breaks the force of the falling rain and thus protects the underlying soil. Plastic and chemical sprays and soil additives bind together the soil particles, making them more resistant to the erosional force of the rain. Temporary seeding with grass improves appearance and provides protection from the erosional force of the rainfall.



Hydro-mulching prevents erosion of bare soil.



Sediment traps fill rapidly with sediment during periods of construction.

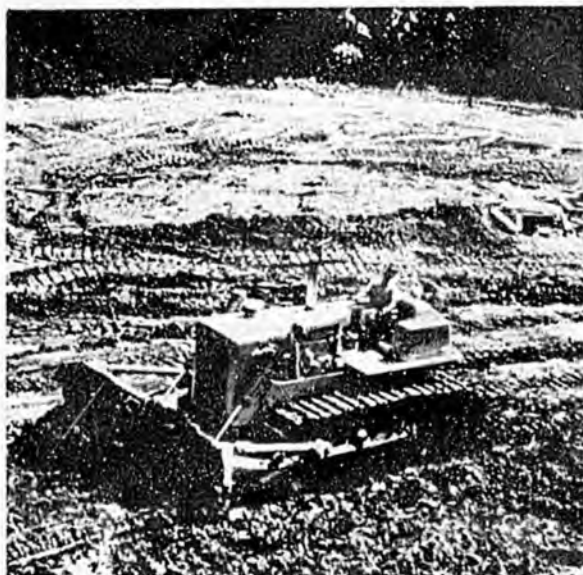
Temporary sediment traps can be constructed. These are essentially small reservoirs that detain the sediment-laden runoff at the construction site and permit the coarser sizes of eroded soil to settle out behind the dam, rather than move into the streams and rivers. Such sediment traps generally are temporary measures, installed during clearing of the land and maintained during construction. Usually they are eliminated during the final grading and landscaping when their usefulness in retarding sediment has diminished.

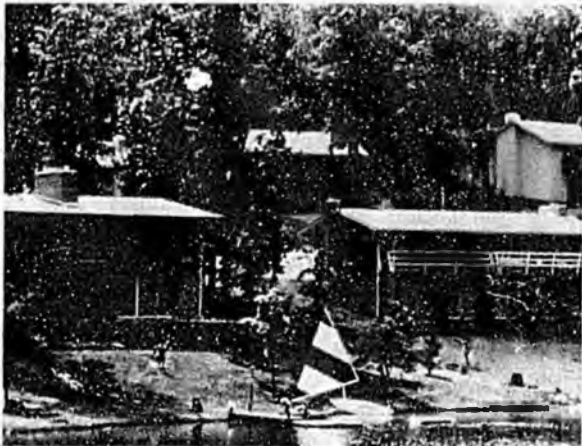
Another approach to controlling erosion and sediment production is the development of zoning based upon potential erodibility of the landscape. By considering land slope, soil characteristics, rainfall intensities, and other factors, regional planning can make density of development commensurate with acceptable sediment levels.

Erosion and Sediment: A Local Responsibility

Preventing erosion is basically a local responsibility. Many local governments now have ordinances or zoning regulations requiring adequate controls over sediment production during construction. The experiences of Montgomery County, Md., in the Washington metropolitan area, are typical. In the early-to-mid 1960's, Montgomery County began to feel the impact of burgeoning urban growth. In 1965, aware of the problems caused by the excess sediment produced during urbanization, the Montgomery County Council adopted a resolution soliciting voluntary cooperation of the construction industry. Experience, however, indicated the need for improved compliance if sediment loads of streams were indeed to be reduced. Thus, in 1967, the voluntary policy became mandatory when zoning regulations were adopted requiring erosion and sediment control procedures as part of construction activities.

Erosion and sediment control measures do add to the cost of construction, but in the long run this cost may be considerably less than the potential damage to streams and rivers from excessive sediment. By far the





Proper land-use planning not only reduces sediment, but can provide esthetic benefits as well.

most economical and effective sediment control measure is careful planning to minimize disturbance of the natural ground cover over the shortest period of time.

* * *

For additional information:

Geological Survey Water-Supply Paper 1591-E, "Sediment Movement in an Area of Suburban Highway Construction, Scott Run Basin, Fairfax County, Va., 1961-64," by R. B. Vice, H. P. Guy, and G. E. Ferguson, \$0.70. Geological Survey Circular 601-E, "Sediment Problems in Urban Areas," by H. P. Guy, without charge. Both may be obtained from the Alexandria Branch of Distribution listed below.

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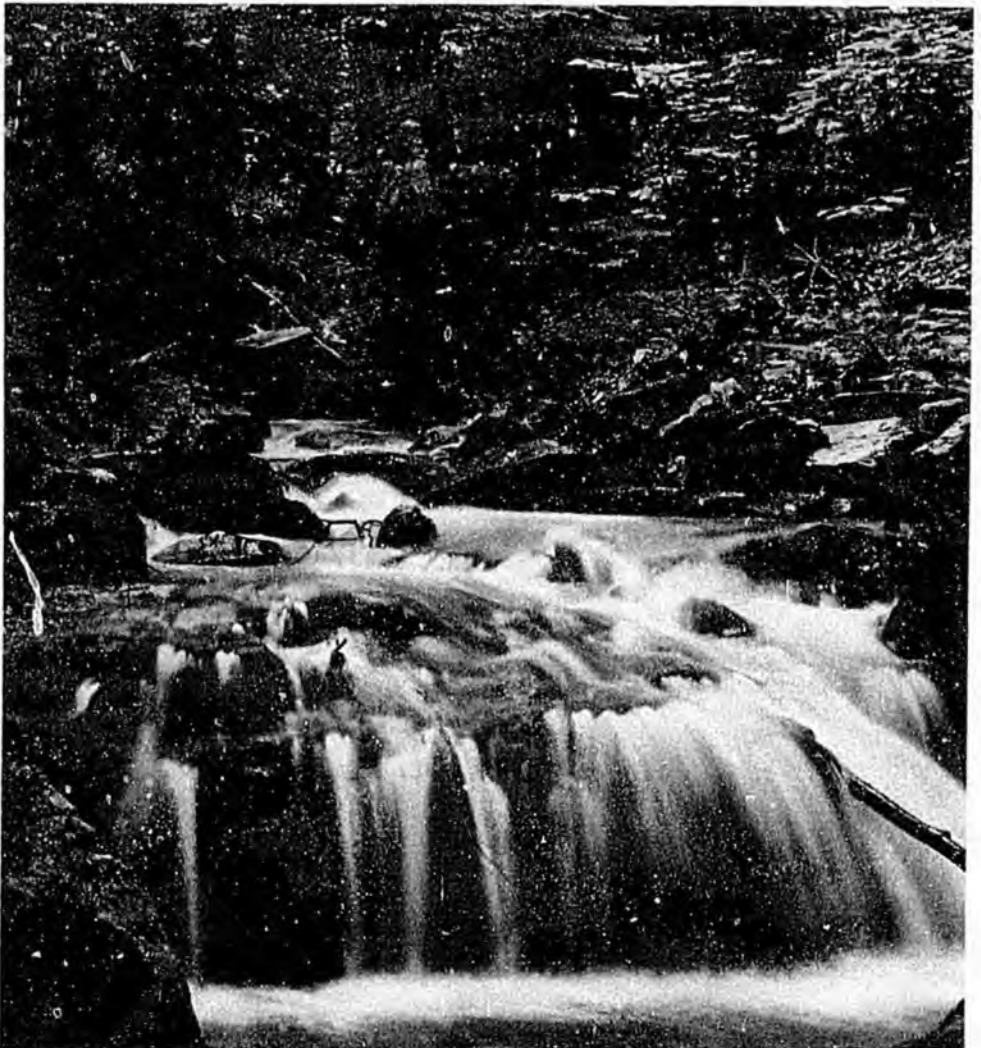
As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.



Reprint from: USGS Annual Report, Fiscal Year 1976

How Much Water in a 12-ounce Can?

A Perspective on Water-Use Information



U.S. Department of the Interior/Geological Survey

How Much Water in a 12-ounce Can?

A Perspective on Water-Use Information

by I. C. James II, J. C. Kammerer, and C. R. Murray

*A pint a day,
is all I say,
to keep my whistle wet.
But so much more,
I have to pour,
before my table's set!*

B. L. Anon.

Water Use and Its Variations

On a hot afternoon after mowing the lawn, or after returning home from a round of golf, or when just resting from your daily toil, have you ever gone to the refrigerator to satisfy your thirst with a 12-ounce (355-milliliter) can of your favorite beverage? You want to relax and reflect on the activities of the day, but your act of consuming the contents of that 12-ounce can is the culmination of a long chain of processes requiring energy, materials, water, labor, and management. Let us consider your effect as a consumer on the water resources of the Nation and try to answer the question, "How much water is in a 12-ounce can?"

Twelve ounces, of course—three-eighths of a quart, or, in the metric system, 0.355 liter (0.000355 cubic meter). But wait a minute; let's rephrase the question to "How much water did it take to manufacture the 12-ounce can?" Doesn't it take water to clean the can before it is filled, water to produce the steel or aluminum used in the

can, water to mine the coal that is used in converting iron ore to metallic iron in making steel used in the can, and water for cooling in the thermal electric plants that supply these industries with electric energy?

Let us use that can from which you were about to pour your 12-ounce drink as an example for exploring the ramifications of one of our simple daily water-consumption decisions. The fabrication of metal cans requires a small quantity of water for a variety of in-plant purposes such as cooling and washing. In 1968, nationwide water withdrawals for this industry

Cooling-water intake.



totaled 7 billion liters (7.4 billion quarts). The average in-plant water use per can is about 0.2 liter of water withdrawn. This small direct use of water is an obvious consequence of your consumption of a beverage in a 12-ounce can. But what of the indirect uses of water necessary to sustain the industries that directly supply the can manufacturers with goods and services?

Using 1967 data, it is estimated that supporting industries directly supplying the metal-can fabrication industry withdraw about 23 liters (24.3 quarts) of water per can produced. Each of these supporting industries, in turn, must purchase goods and services from still other industries. As those purchases "ripple out" through our economy, additional economic sectors become involved. The accumulated water withdrawals for all the indi-

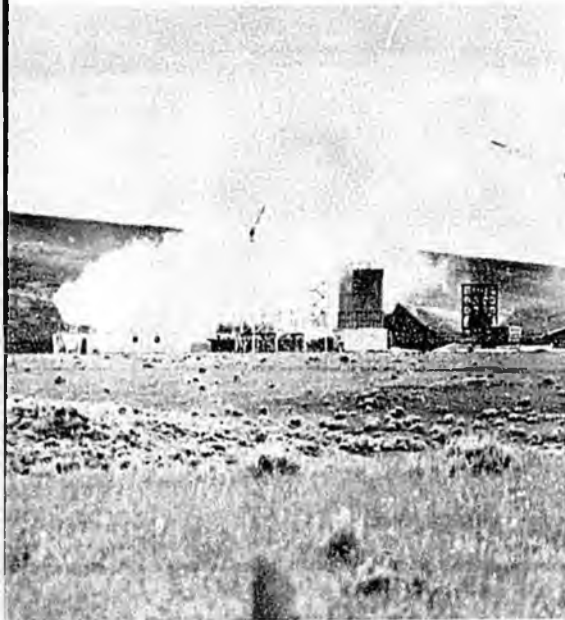
rect suppliers total 40 liters (42.3 quarts) per can, thus increasing water withdrawals by both direct and indirect suppliers to about 63 liters (66.6 quarts) per can.

You might question the need for this type of information; certainly, your individual decision to consume the contents of one can has little impact on water use. In the aggregate, however, the water-use decisions of a large group of individuals, or national policy decisions on water use that affect many individuals, may have a considerable impact. Also, the accumulated indirect effects of an industrial water use are often more significant than the direct water use in that industry, as in the example where an additional 63 liters (66.6 quarts) per can is withdrawn by direct and indirect suppliers to a can manufacturer.

ELECTRIC POWERPLANT NEAR HAYDEN, COLO.

Powerplant and cooling towers.

Cooling-water discharge.

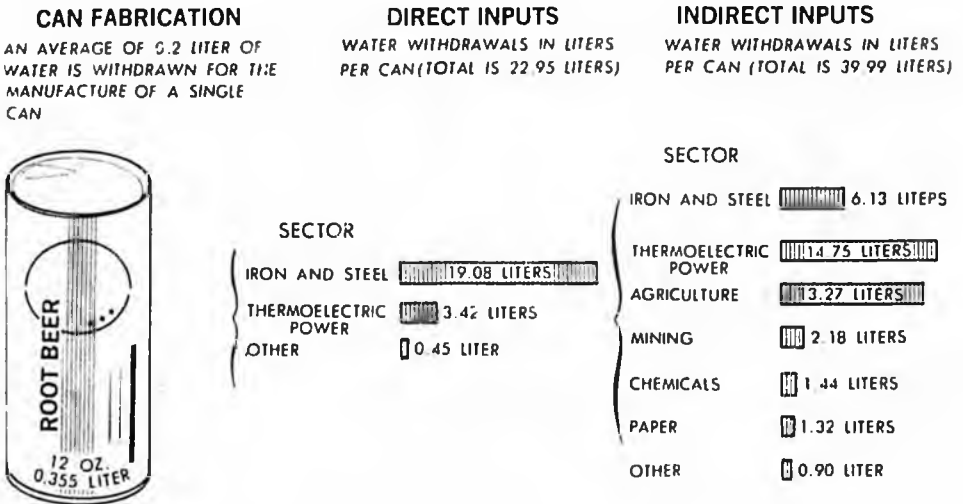


Estimates of indirect water-use effects are made by utilizing a technique known as input-output analysis. For this type of analysis, a table is constructed to show the value of direct input from each economic sector in the United States that goes into a unit value of output for all the other economic sectors. By applying mathematical procedures to the information in the table, a new table can be constructed to show total direct and indirect inputs from each economic sector for a unit value of output in each of the other economic sectors. Multiplying these values by the average water use per unit value of output in all of the economic sectors gives the water use for a unit value of output from any particular economic sector. Figure 1 shows in simplified form how this concept may be developed and applied to estimate

the water use required to produce one 12-ounce container.

As the total amount of water used by both direct and indirect suppliers for the production of a 12-ounce can was found to be about 63 liters (66.6 quarts), many times the direct use, so may indirect water use for the support of production in other economic sectors be estimated, using similar methods. For example, an estimate can be made of the amount of water used for the production and shipment of \$10 billion worth of grain, as can an assessment of water-use effects of national legislation concerning highways, housing, energy, and environmental measures. Possibly too often the prescribed solution to a national problem has been proposed without a thorough evaluation of the impacts of that solution. Would a legislative ban on nonreturnable containers alleviate

FIGURE 1.—Water withdrawals by direct and indirect suppliers for the fabrication of a 12-ounce beverage can. (1 liter equals approximately 1 quart.)



solid-waste disposal problems? And how would that ban affect costs, energy use, water use, and mineral use? Because almost all regulations have negative as well as positive effects, it is desirable that all effects be expressed in specific numbers, if possible, and then debated before a legal or policy commitment is made so that water-use changes can be estimated.

A beverage can may be made entirely of aluminum, or it may be bimetallic, having a steel bottom and steel sides and an aluminum top. The steel industry and the aluminum industry differ from each other in their requirements for water, energy, minerals, and other economic inputs. The aluminum-reduction industries (converting ore to metal), for instance, require a relatively large amount of electric energy; therefore, traditionally, aluminum-reduction plants have been located in areas where hydroelectric power is plentiful and relatively inexpensive. The production of one aluminum can requires the equivalent of 10 cubic meters (about 11 short tons) of water going through turbines in a 15-meter (50-foot) high dam. This also is a water use, but the water is not withdrawn from the river channel; therefore, the quantity and the quality of the water are not perceptibly affected.

Water for steel: Wide variations

The largest direct water use in the example of the 12-ounce can is in the iron and steel industry. A more detailed look at this industry

illustrates some interesting water-use facts that must be considered in producing water-use information.

Steel-industry data have often been used to show the wide range in water use that occurs within a single industry. Inasmuch as more than 95 percent of gross water use in steel plants is for cooling, comparisons of quantities used for cooling are very significant. Data (gross use, including reuse) compiled by Walling and Otts (1967, p. 364) for 25 integrated steel plants and steel-processing plants showed ranges of 14 to 409 cubic meters (3,750 to 108,000 gallons) required to produce 907 kilograms (1 short ton) of ingot steel. As these authors pointed out, some factors that affect cooling-water requirements are the age and condition of a plant, procedures of operation, and quality of cooling water. Costs of water withdrawal also significantly affect the amount withdrawn. Russell and Vaughan (1976) estimated that a change in the price of water from \$0.0044 to \$0.01 per cubic meter would reduce water withdrawals by more than 80 percent; further price increases, however, would have little additional effect. The quantity of water actually consumed would remain about the same or increase slightly with price increases.

Water uses in the home and per capita use

Household uses of water also vary greatly in magnitude. Household uses are internationally expressed in terms of liters (1 liter

equals 1.0567 quarts) per day per person, and depend upon such characteristics as climate, accessibility (connected or not connected to a public water-supply system), water quality, water pressure, cost, outdoor needs (lawn, garden, pool),

and whether or not the water supply is metered. Although a person needs less than 2 liters (2.1 quarts) of water a day (from liquid and solid foods) to survive, in the United States the actual daily household use (indoor and outdoor) ranges

TABLE 1.—Anticipated daily domestic uses of water by a family of four. (Adapted from Reid, 1965, p. 18.)

| Family use of water | Liters per day per family | Liters per day per capita | Gallons per day per family | Gallons per day per capita |
|---|---------------------------|---------------------------|----------------------------|----------------------------|
| Drinking and water used in kitchen | 30 | 7.6 | 8 | 2 |
| Dishwasher (3 loads per day) | 57 | 14 | 15 | 3.75 |
| Toilet (16 flushes per day) | 363 | 91 | 96 | 24 |
| Bathing (4 baths or showers per day) | 303 | 76 | 80 | 20 |
| Laundering (6 loads per week) | 129 | 32 | 34 | 8.5 |
| Automobile washing (2 carwashes per month) | 38 | 9.5 | 10 | 2.5 |
| Lawn watering (180 hours per year) | 379 | 95 | 100 | 25 |
| Garbage disposal unit (1 percent of all other uses) | 13 | 3 | 3 | 0.75 |
| Total | 1,312 | 328 | 346 | 86.5 |

TABLE 2.—Estimated daily per capita use of freshwater in the United States.

| | Gallons per person per day | Liters per person per day |
|---|---|---------------------------|
| Water required for survival | Less than ½ | Less than 2 |
| Average personal consumption of water (liquids and water in foods). | About 1 | About 4 |
| Domestic uses of all kinds (indoor and outdoor uses), 1970; home connected to public water-supply system. | 75 | 280 |
| National averages in 1975 | | |
| Public water systems, including public-supply water for domestic, industrial, commercial, and public (fire-fighting, parks, etc.) uses and water-system losses (population ¹ served in 1975: 175,000,000). | 168 | 636 |
| Self-supplied industrial use (total population ¹ in 1975: 217,000,000). | 783 | 2,960 |
| Combined public, rural, industrial, and irrigation uses (excluding hydroelectric power). | 1,600 | 6,000 |
| Water for hydroelectric power | (If saline water use is added, per capita use is 1,930 gallons, or 7,310 liters.) | |
| | 15,200 | 57,500 |

¹ Includes Puerto Rico and Virgin Islands (U.S.).
Source of data for 1975: Murray and Reeves, 1977.

from less than 40 liters (42.3 quarts) per capita in some homes without plumbing to several hundred liters per capita in affluent homes with watered lawns. Lawn watering and toilet flushing are the two largest household uses of water. Table 1 shows a hypothetical example of average daily water use in the future by a family of four (assuming that family has two bathrooms, a garbage-disposal unit, a dishwasher, an automatic laundry, and two automobiles).

Daily per capita water use in the United States is sometimes expressed as a nationwide average for a given year. The average daily per capita *household* use for 1970 (Kammerer, 1976) was about 280 liters (297 quarts) per person for homes connected to public water-supply systems; however, the total average daily per capita use of freshwater for *all* withdrawal uses—for agricultural irrigation, self-supplied rural homes (domestic and livestock uses), self-supplied industries, and public supplies—was about 5,900 liters (6,235 quarts) per capita for the same year, and 6,000 liters (6,340 quarts) in 1975 (table 2).

Water as a Commodity: History and Legal Concepts

One of the most significant trends in our water-use picture is the change since colonial times, when water was considered an essentially free resource, to the present, when water has become a very expensive commodity in

some locations.

English common law regarded water as a common-property resource for those who owned land along streams (riparian owner) to use freely. The only large uses were for power in milling and manufacturing processes, and those uses were not consumptive or otherwise detrimental to water used by other riparian owners. This doctrine was brought by the colonists to the Eastern United States where it still strongly influences the water laws of the Eastern States. On the other hand, water legislation in most of the Western States was more influenced by Spanish law and custom, and it was generally adapted to meet the particular needs of miners, farmers, and ranchers in arid regions. The appropriation doctrine which evolved as a key element of western water law held that the person who first diverted water and put it to a beneficial use had a right to maintain that diversion and use. Any subsequent upstream diverters could only operate on the condition that prior rights were being satisfied. This was a doctrine that recognized water rights as real property, but it frequently did not provide for marketing arrangements, and the concept of setting a price for water still had not been developed. The idea of free water for those who would develop and use it fit well with the concepts of westward expansion; the natural resources of the West were presumed to be available for those with the initiative to exploit them.

As water needs of the public increased for such purposes as fire

protection, dust control, sanitation, disease eradication, and domestic consumption, there was a significant increase in the extent of water-supply systems, leading to a general transition from private to public ownership of water companies. In the West, the simple irrigation systems on individual farms gave way to large irrigation districts that required the capital and efforts of many. User charges to recover the capital costs and provide for operating and maintenance costs became accepted, but the mechanisms for pricing and marketing water rights developed slowly.

As increases in water use deplete the easily developable supplies, more costly additional supplies are being sought. As the costs of water go up, water resources become more and more like other economic commodities for which there are supplies, demands, and a pricing and marketing structure to balance the supply and demands. The influences and concepts of economists are being utilized in the study of water use. More commonly, water is being thought of as another input to a production process for which substitutions can be made. In the case of industry, treatment and recycling of water can substantially reduce withdrawals, but only with the expense of additional capital investments and increased energy and chemical costs. To be able to predict water use, some knowledge of the options for substitution that the factory, farm, or home manager has available is necessary so that the impacts of their decisions

can be anticipated as the prices of water and other commodities change.

These few examples of water use and its variations and economic ramifications illustrate only some of the complexity and importance of water-use information. U.S. Geological Survey programs that define the time and space availability of the Nation's water supplies provide information, which—when compared to the water demands of industrial, agricultural, and municipal users—provide an assessment of our abilities to meet these current and future demands. However, studies and assessments of water use have not achieved the detail or degree of accuracy that is now found in water-supply information. Because water use is substantially affected by variables—economics, technology, and custom—much different than those affecting water supply, the methods and techniques for measuring and projecting water use must be developed from concepts and technical disciplines that go beyond the natural and physical sciences. The U.S. Geological Survey is cognizant of these needs and, in cooperation with State and local governments, is developing programs to acquire water-use data that are of the same order of accuracy as its water-supply data.

Simply stated, in the hydrologic cycle, water moves from the atmosphere to the land and sea and back again into the atmosphere. Water use—both natural and controlled—occurring during the land-sea part of the hydrologic cycle includes

(1) evapotranspiration from irrigated, nonirrigated, and wild vegetation, (2) evaporation from water surfaces, (3) withdrawal of water from streams, lakes, reservoirs, and wells, (4) dilution, assimilation, and transport of wastes, and (5) occupancy of surface waters as a habitat (by fish, wildlife, and so forth), a transport route (navigation), and a recreational facility.

For purposes of estimation and measurement, these water uses are grouped into three principal categories:

1. Withdrawal (or "off-channel") uses, such as withdrawal from a well or diversion from a stream, for public supplies, irrigation,

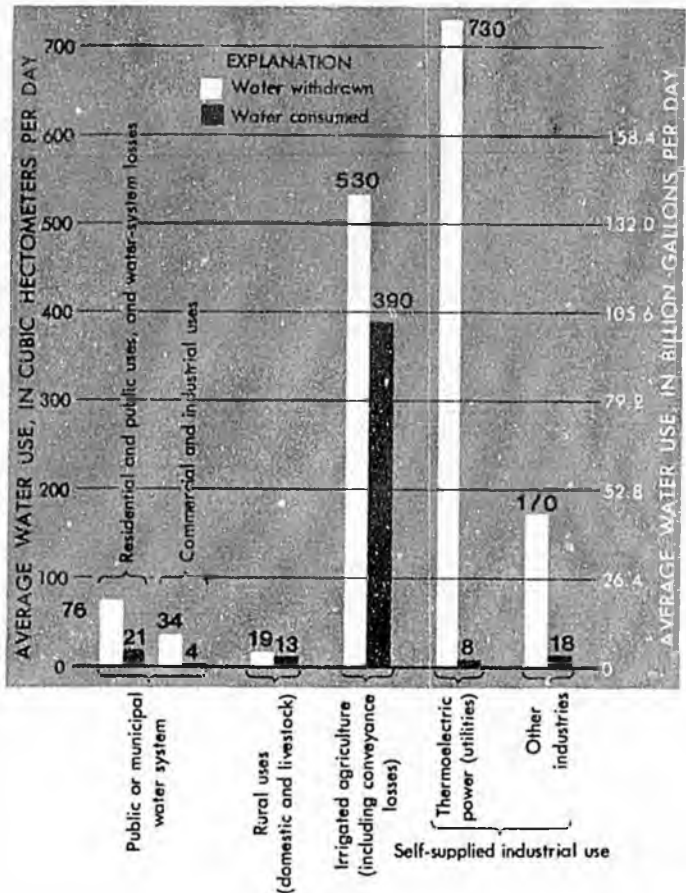
and industry;

2. Nonwithdrawal (or "instream") uses, such as for hydroelectric power, navigation, recreation, preservation of wildlife and sport fishing habitat, salinity control, waste dilution, and transport;

3. Nonsupply uses (also sometimes referred to as "water losses" or "preemptive consumptive use"), such as evaporation from lakes and reservoirs and evapotranspiration from nonirrigated food and fiber crops.

Withdrawal uses are the most measurable and measured of the three categories of use, but they

FIGURE 2.—Estimated water withdrawn and water consumed in the United States in 1975. Totals above each bar are in metric units; 1 cubic hectometer = 1 million cubic meters = 264 million gallons. (Adapted from Murray and Reeves, 1977.)



are measured far less frequently and systematically than water supplies (for example, the flow of water in streams). Figure 2 compares a few of the national water-use statistics for 1975 with respect to average quantities withdrawn and the part of the withdrawals consumed.

Nonwithdrawal uses (water uses that are not dependent on diversion of water from ground- or surface-water sources) may be categorized as flow uses and onsite uses. Navigation, hydroelectric power, sport fishing habitat, freshwater sweetening of saline estuaries, and the disposition and dilution of waste water are commonly classified as flow uses; all these uses are accomplished by free-flowing water moving in a defined channel. Onsite uses are of two principal types: (1) water use which occurs in a watercourse, lake, reservoir, or other body of water, and (2) water use resulting from improvement of natural conditions, a use that is sometimes called "preservation use." Stream evaporation from an increased heat load is an example of the first type of onsite use, and water lost from improvements to swamps, wetlands, and fish hatcheries are examples of the second type. Many of the nonwithdrawal uses cannot be readily measured, thus presenting a hydrologic challenge for more accurate determination and for evaluation of their effect on the quantity and quality of water resources available for other uses.

Perhaps surprisingly, about 8 times as much water is used consumptively—in the category, "non-

supply uses"—by the naturally occurring processes of evaporation and transpiration in the growth of vegetation (forests, grasses, and nonirrigated crops) in the United States than is supplied nationwide for all withdrawal uses. The "non-supply" water returned to the atmosphere by this natural process is also referred to as a "consumptive and preemptive use," or sometimes as "water losses"; it is the remainder after runoff (streamflow) has been subtracted from precipitation. The sustained availability of large quantities of this nonsupply water—most of which occurs as soil moisture—constitutes a major natural resource. Without significant amounts of local soil moisture,

TABLE 3.—Estimated water supply versus water demand—regional (eastern, central, and western) water use in the conterminous United States in 1975. (Adapted from Murray and Reeves, 1977.)

| Region |
|--|
| 31 Eastern States ¹ (8 eastern regions) |
| 10 Central States ² (parts east of Continental Divide; 5 central regions) |
| 7 Western States (parts west of Continental Divide; 5 western regions) |
| 48 States (conterminous United States) |

commercial agriculture, as well as public parks and residential lawns and gardens, would not be possible unless there were major importation of water from other locations. Another nonsupply use is the evaporation of water from large water surfaces, such as lakes, rivers, and snow and ice fields. An extremely rough estimate of average nonsupply water use in the conterminous United States is 16,000 cubic hectometers per day (20 inches per year times 3 million square miles), most of which is evapotranspiration from vegetation. Nace (1967, p. 4) has pointed out that actual daily per capita water use for all purposes in an advanced society amounts to "many thou-

sands of gallons, drawn chiefly from soil moisture."

Supply Versus Demand (Water Use) in 1975

In the general terms of average nationwide water supply (based on streamflow), the United States has a great abundance of water—3 times as much as was withdrawn in 1975 and more than 12 times as much as was consumed during usage and therefore unavailable for reuse. Table 3 shows some supply-versus-demand relationships for the aggregated eastern, central, and western parts of the Nation as well as for all the 48 conterminous States. What these data do not

The water we have . . .

Average flow of streams in the 48 conterminous States

(Includes ground-water component of base streamflow)

The water we use . . .

Water withdrawn and water consumed

| Area | | Stream discharge | | Population in 1975 | Withdrawals in 1975 | | Water consumed in 1975 | |
|-------------------------|--------------------|---------------------------|--------------------------------|--------------------|---------------------------|-------------------------|---------------------------|-------------------------|
| 1,000 square kilometers | 1,000 square miles | Cubic hectometers per day | Thousand cubic feet per second | Million people | Cubic hectometers per day | Billion gallons per day | Cubic hectometers per day | Billion gallons per day |
| 2,713 | 1,047 | 2,800 | 1,100 | 151 | 860 | 230 | 55 | 15 |
| 2,980 | 1,150 | 640 | 260 | 30 | 290 | 78 | 130 | 35 |
| 2,132 | 823 | 1,100 | 460 | 32 | 390 | 100 | 170 | 46 |
| 7,825 | 3,020 | 4,500 | 1,800 | 213 | 1,500 | 410 | 360 | 96 |

¹ Excludes some parts of Arkansas, Iowa, Louisiana, Minnesota, and Missouri.

² Includes parts of an additional 5 States.

NOTE: Stream-discharge and water-use data rounded to 2 significant figures.



those circumstances, might be as little as one-third of the average runoff in some parts of the Nation because of wide variations in flow from season to season and from year to year and because of topographic, geologic, hydrologic, ecologic, and economic constraints on the construction of reservoirs.

FIGURE 3.—Water withdrawn (used) in 1975 as a percentage (first number) of annual runoff (long-term average), and water consumed in 1975 as a percentage (second number) of annual runoff, in each water-resource region in the conterminous United States. (Adapted from Murray and Reeves, 1977, p. 19.)

| Date | Lowest flow since October 1960 | | Average runoff 1941-70, in cubic meters per day per square kilometer | Average runoff 1975, in cubic meters per day per square kilometer |
|-------------------|---|--|--|---|
| | Discharge, in cubic hectometers per day | Runoff, in cubic meters per day per square kilometer | | |
| Oct. 31, 1963 .. | 2.89 | 165 | 1,550 | 2,130 |
| Sept. 10, 1966 .. | 1.47 | 49.1 | 825 | 1,150 |
| Aug. 2, 1965 ... | 12.5 | 52.9 | 1,140 | 1,680 |
| Nov. 8, 1962 ... | 14.9 | 335 | 1,190 | 1,800 |
| Dec. 23, 1963 .. | 14.8 | 10.8 | 137 | 158 |
| Jan. 8, 1964 ... | 308 | 104 | 466 | 649 |
| Oct. 11, 1961 .. | 14.9 | 271 | 867 | 1,050 |
| July 18, 1961 .. | 18.9 | 105 | 243 | 315 |

[The flow of streams (and therefore the supply of surface water) varies not only from place to place, but also from year to year, season to season, month to month, and day to day. For example, on the eight large streams listed at left, the highest flow of a given stream since 1960 was from 9 to nearly 600 times greater than the lowest flow on the same stream.]

What Are Some of Our Information Needs?

Water-use information is needed at all levels of water-resource planning—from the designing of an individual household's self-supplied water system to planning for the development of our largest river basins. The analyses of the effects of potential legal or policy water decisions also require water-use information whether the issue at hand is a temporary ban on lawn watering or a national policy on nuclear-powerplant siting.

The past few years have demonstrated how rapidly radical changes in resource availability can affect the directions of some sectors of the U.S. economy and can affect the national pattern of water use. The growth in energy demand had been mostly satisfied by increasing oil imports during the 1960's and early 1970's. However, with the realization of possible interruptions of oil imports and their subsequent momentous increases in price, national attention has been focused on developing our extensive reserves of coal as a less expensive,

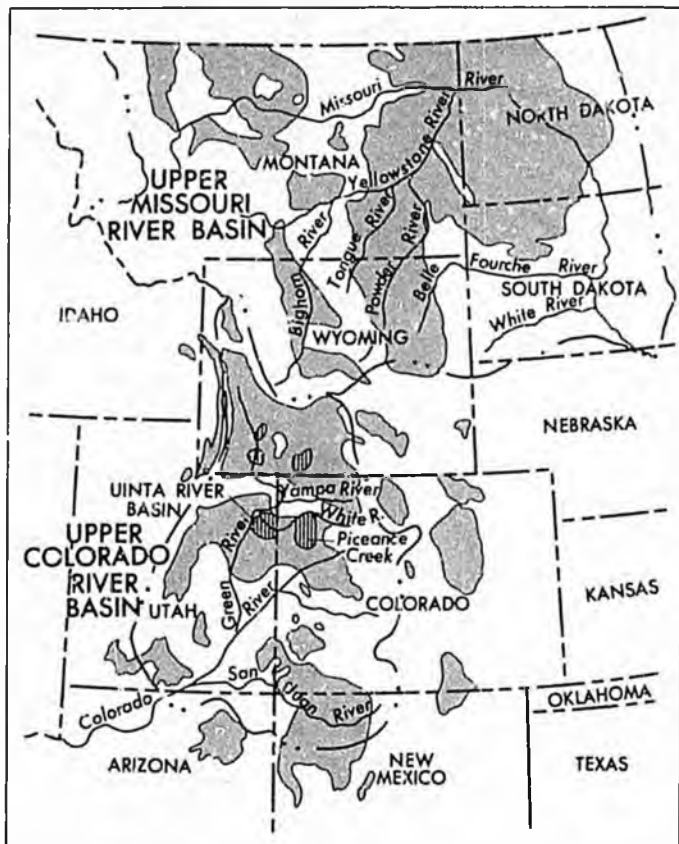


FIGURE 4.—Location of coal fields and oil-shale deposits in upper Missouri River and upper Colorado River basins, West-ern United States.

SOURCE: U.S. GEOLOGICAL SURVEY



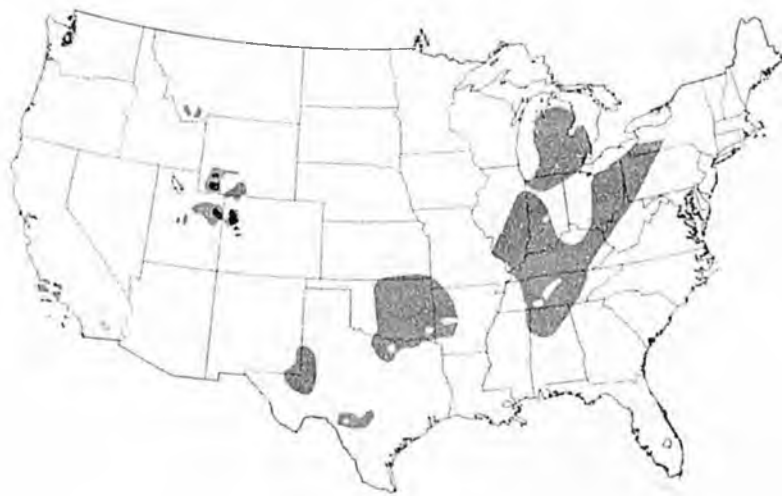
more secure alternative to oil imports.

Most of this attention is now being directed toward the development of surface-minable (strip-minable) coal reserves in the water-short Western United States. Surface-minable coal is the only energy resource that can be brought into production rapidly, and it is usually less costly to produce than underground coal. The semiarid Western States have 63 percent of the demonstrated reserve base of coal suitable for stripping in the United States, and much of this has a desirably low sulfur content. Figure 4 shows the location of some of the principal western deposits of coal, including those minable by surface methods. Comparing this with the existing water uses in figure 3, it can be seen that the coal deposits occur in areas in which the existing water use is large in comparison with supply of water available.

Direct water requirements for surface coal mining are not large; the modest demands for sanitary and dust-control purposes can usually be met locally. Irrigation of spoils undergoing reclamation in arid areas may require more water than is available on a mine site but only in amounts that will not cause significant water-use problems. In contrast to these relatively modest water needs for mining and reclamation, the conversion of coal to secondary forms of energy such as gas, oil, or electricity for transportation, distribution, and consumption will constitute a significantly large water use. These secondary industries will also generate associated industrial and commercial growth that will also increase the water use.

The preponderance of high-grade oil-shale deposits are also located in the semiarid West (fig. 5). In addition to water used for processing and cooling in

FIGURE 5.—Principal reported oil-shale deposits in the conterminous United States. Darker areas in Colorado, Utah and Wyoming are known to contain high-grade deposits. (Adapted from Duncan and Swanson, 1965, p. 11.)



shale-retorting operations, water is used for compacting spent shale material.

The very great demands that will be made on water and environmental resources for energy conversion are only "the tip of the iceberg" compared to the ensuing demands that will be made for industrial, residential, and commercial development. These increased water-use needs cannot be met by the already overcommitted available water supply; rather, they must come from a transfer of water rights from one type of use to another.

This will often mean that water which up to now has been used for agricultural purposes will subsequently be sold to industrial users. If the water was used to irrigate hay and feed-grain crops, its loss might considerably change the character of ranching and, hence, change the ambience of the area. Most water users, especially industrial users, have options for using less water, but these options require higher capital investments and operating costs. If a user can legally buy water from other users, he will do so, but if water transfers are not permitted, the costs of reducing water use will eventually be passed on to consumers. To thoroughly evaluate the social, environmental, and economic effects of energy development, detailed information on water-use options and their costs must be developed for the energy-conversion industries and for other major water users who will be directly or indirectly involved in energy production and development. Also to

be considered are industries that are purposely located near energy-conversion industries in order to utilize products or byproducts of energy-conversion processes.

Detailed analyses of plant-level options for converting coal to gas, oil, and electricity and the effects of these options on water use have been undertaken, and some are near completion. Methods for projecting water use for secondary development resulting from increased energy development and for relating these water demands to supply capabilities and environmental resources are being studied.

How Are Water-Use Information Systems Developed?

It is necessary for a planner or designer of a new water-supply system to study other similar systems in order to estimate water demands for the new system, but, because this type of information is often scattered throughout thousands of reports from towns, cities, public-health agencies, and engineering firms, it is not always easy to find. Aggregate water-use information for a region or an industry is even more difficult to assemble because some companies are hesitant to disclose information about their operations that might be useful to competitors.

The need for a more centralized source of water-use information has led to the development of some data-collection and data reporting systems. These have usually been based on periodic assessments

made by conducting many interviews and canvasses, collecting data from secondary sources, and estimating to fill the gaps. The quality of water-use information ranges from the accuracy obtained for metered uses to the uncertainty of hydrologic estimates of irrigation conveyance losses. In fact, a major proportion of existing water-use data consists of estimates that are of such limited accuracy as to be useful only in very general assessments of water problems.

The economic fact that consumers usually use less of a commodity as it becomes more expensive, but use more of it as their incomes increase, indicates that information on income and water prices, as well as a number of related items of information about household size, house-lot size, and property values, may be helpful in estimating variations in water use. Equations can be developed to make these estimates, but statistical analyses must be based on data that include economic and demographic information as well as water-use information.

For estimating the effects of changing prices and technology on industrial water use, another type of detailed analysis can be made on an industry-by-industry basis for industries that use large amounts of water. These plant-level analyses of the processes involve detailed engineering-economic studies of how existing plants are operated or how new plants should be designed and operated in order for the company operating the plant to maximize profits under current prices and regulations. Existing

plants often cannot significantly change their rate of water use without extensive retrofitting. New plants, however, have a much wider range of process technologies to choose from for minimizing production costs under changed economic conditions. For cooling purposes, one of the largest uses of industrial water, a decrease in water use (withdrawal) can usually be achieved at a cost of increased water consumption, and the converse is also usually true. The recent increases in energy prices relative to water costs may alter the historical trend toward less water-intensive cooling systems. Plant-level analyses of the total costs of various cooling systems can be used to determine the directions that future changes in water use will take.

Summary and Conclusions

We can estimate past and present water uses, but total water needs for most withdrawal uses are changing; water use is responsive to prices, technology, customs, and regulations. Although inventory systems for estimating water use are good indicators of past and present uses, such systems are not as accurate or as frequently reported as we would like, and they do not show us future water-use trends.

Providing more complete and accurate water-use information will involve the work of many hydrologists, engineers, and economists. It will require more detailed and complete water-use data and a

wider knowledge of local factors. Much of the information can be collected by State or local agencies, and a well planned, nationally consistent effort can produce data that will serve many purposes. However, providing water-use information for *all* purposes will require additional comprehensive statistical-data and engineering analyses of water-use options at the plant level. These analyses can provide information on changing conditions, and, with this knowledge, it will be possible to construct computer models for regional assessments of water use in relation to water supply.

For most of our Nation, the period of free and easily developed water supplies has ended; in some areas, water use is approaching or exceeding the available supply. We are, however, not running out of water. Much still remains to be done toward modifying the occurrence of water to better fit regional demands, and, more importantly, many options for modifying water use and reuse remain to be explored. The development of new water supplies will take more time than the development of methods for better utilizing water through reuse, conservation, and new technologies.

Sometime in the future, the manufacture of a 12-ounce beverage can will have considerably different water-use effects. We must prepare for these effects if that 12-ounce can is to continue to be available to us.

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As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.



STATE OF ALASKA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF FOREST, LAND AND WATER MANAGEMENT

OFFICE USE ONLY

ADL

APPLICATION FOR WATER RIGHT

Instructions: You will need (1) a map showing the location of your source of water and the area of use, (2) a copy of your property ownership document, i.e. deed, patent, lease agreement or an easement agreement if you do not own the property involved, (3) a copy of your driller's well log, if application is for an existing well, (4) Statement of Beneficial Use Of Water (Form 10-1003A) if this is an existing water use, and (5) Application for Permit to Construct or Modify Dam (Form 10-1015) if you will be constructing a dam over 10 feet high or over 50 acre feet of storage. Please type or print in ink.

1. Full legal name of Applicant(s) _____

2. Mailing Address _____

Home Phone _____ Business Phone _____

3. Source of Water Supply:

(a) Well

Drilled Hand Driven Dug Other _____

If existing well, attach copy of driller's well log.

If existing well, and no log, supply all known information

Total depth _____ Drawdown _____

Intake Depth _____ Screened Yes ___ No ___ Unknown ___

Static level _____

(b) Surface Water

Stream River Lake Spring

Give geographic name (if unnamed, state so) _____

If "No," MUST obtain an easement or right-of-way and supply copy. Give name, mailing address and phone number(s) of legal owner.

Name _____

Mailing Address _____

_____ Zip _____

Home phone _____ Business Phone _____

6. Type of water use and Quantity of water needed: Please fill in the attached Water Use Chart indicating the quantity of water and months of use for each type of water use. Standard quantities and definitions are provided for your convenience. If water use is for a Commercial/Industrial purpose or Other Use not on the Water Use Chart, refer to question 7.

7. Commercial/Industrial and Other Uses:

Explain in detail the basis for quantity of water requested. Use additional sheet of paper if needed. Indicate type of operation including structures and methods used. Include a sketch or engineering drawings. Enter quantity requested and months of use on attached Water Use Chart.

8. Date when water use began or is expected to begin _____ . If water use is existing, fill out Statement of Beneficial Use of Water (Form 10-1003A).

HAVE YOU ATTACHED?

- | | |
|---|---|
| <input type="checkbox"/> Deed, patent, lease, etc. | <input type="checkbox"/> Driller's log (if existing well) |
| <input type="checkbox"/> USGS or Subdivision map | <input type="checkbox"/> Diversion sketch and plans |
| <input type="checkbox"/> \$25 Filing fee (checks payable to State of Alaska) | <input type="checkbox"/> Dam sketch and plans |
| <input type="checkbox"/> Water Use Chart | |
| <input type="checkbox"/> Statement of Beneficial Use of Water (Form 10-1003A) (if existing water use) | |

Statements appearing herein are to the best of my knowledge true and correct.

 SIGNED _____ DATE _____
(Applicant)

| | | | | |
|-----------------------|-----|-----|-------------------|-------|
| OFFICE USE ONLY | x,y | RMI | Location check | Other |
|-----------------------|-----|-----|-------------------|-------|

Water will be taken from surface water source by:

- Pumping
- Gravity Flow System
- Diversion (Altering a watercourse) - Attach sketch and plans giving dimensions and specifications.
- Damming - Attach sketch and plans giving dimensions and specifications. If dam is over 10 feet high or over 50 acre feet storage, MUST file Application for Permit to Construct or Modify Dam (Form 10-1015).
- Other _____

4. Location of point of WITHDRAWAL, DIVERSIGN, or IMPOUNDMENT:

MUST attach copy of map or subdivision plat and indicate location

- (a) Fractional part _____ Section _____
Township _____, Range _____, _____ Meridian.
- (b) If applicable, Lot, Block, Subdivision; U.S. Survey No. _____

- (c) Does applicant own or lease the property at point of water withdrawal and over which water is transported? Yes No

If "Yes," MUST attach copy of ownership document (i.e. deed, patent)

If "No," MUST obtain an easement or right-of-way and supply copy. Give name, mailing address and phone number(s) of legal owner.

Name _____

Mailing Address _____

_____ Zip _____

Home phone _____ Business Phone _____

5. Location of point of USE: If same as question 4, check and go to question 6.

MUST attach copy of map or subdivision plat and indicate location.

- (a) Fractional part _____ Section _____
Township _____, Range _____, _____ Meridian.
- (b) If applicable, Lot, Block, Subdivision; U.S. Survey No. _____

- (c) Does applicant own or lease the property at point of water use? Yes No

If "Yes," MUST attach copy of ownership document (i.e. deed, patent)

WATER USE CHART

| Office Use SIC | Type(s) Of Use | Standard Quantities | Quantity Requested | Months of Use From To (Inclusive) | |
|-------------------|---|------------------------|-----------------------|---|--|
| 8800 | (1) Single Family | Per Household | | | |
| | (a) Fully plumbed | 500 GPD | GPD | | |
| | (b) Partially plumbed | 250 GPD | GPD | | |
| | (c) Unplumbed | 75 GPD | GPD | | |
| 6514 | (2) Duplex | Per Duplex 1000 GPD | GPD | | |
| | (3) Multi-Family | Per Unit 250 GPD | GPD | | |
| 7011 | (4) Motel, Resort | Per Room 100 GPD | GPD | | |
| 0241 | (5) Livestock | Per Head | | | |
| | Dairy Cows | 30 GPD | GPD | | |
| | Hosing dairy barn | 35 GPD | GPD | | |
| 0212 | Range Cattle | 15 GPD | GPD | | |
| 0272 | Horses | 15 GPD | GPD | | |
| 0214 | Sheep | 2 GPD | GPD | | |
| | Goats and Hogs | 3 GPD | GPD | | |
| | Poultry, Rabbits, etc. | 1 GPD | GPD | | |
| | Livestock Total | | GPD | | |
| | (6) Irrigation (Type of Crop: _____) | Per Acre 0.5 AFY | AFY | | |
| | (7) Commercial/ Industrial | | | | |
| | (8) Other: _____ | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

DEFINITIONS:

GPD - gallons per day

AFY - acre feet per year

CFS - cubic feet per second

- (1) SINGLE FAMILY - Water use necessary for a single household and the irrigation of up to 10,000 sq. ft. of yard and garden.
 - (a) Fully plumbed - Water piped into the residence for domestic uses. Hot water heater and water flush toilet included.
 - (b) Partially plumbed - Water piped into residence for limited domestic uses. Generally no hot water heater and no water flush toilet included.
 - (c) Unplumbed - No water piped into the residence. Water is hand carried for limited domestic use.
- (2) DUPLEX - Water use necessary for two single households and the irrigation of up to 20,000 sq. ft. of yard and garden.
- (3) MULTI-FAMILY - Water use necessary for three or more households. Apartment units included.

ALASKA

Ground-Water Resources

Alaska has abundant surface-water resources, but many of the streams and lakes are frozen for most of the year and most of the larger streams transport glacial silt that makes the water unacceptable for many uses. These factors lend special significance to ground water as a source of supply, even though permafrost (perennially frozen ground) profoundly affects the occurrence and availability of ground water in all but the south coastal regions (Williams, 1970; fig. 1). Permafrost forms a virtually impermeable layer that restricts recharge, discharge, and movement of ground water, functions as a confining layer, and decreases the volume of unconsolidated deposits and bedrock in which water may be stored (Zenone and Anderson, 1978, p. 1).

Ground water constitutes 22 percent of total water use in the State. Aquifers provide water to 276,000 people (69 percent of the population), of which 172,000 rely on public water-supply systems and 104,000 on rural (private) systems. Ground-water withdrawals for various uses in 1980 and related statistics are given in table 1.

GENERAL SETTING

Major landforms of Alaska include three great mountain ranges—the Coastal, the Alaskan, and the Brooks—from south to north; a broad interior lowland that is drained by large rivers and contains scattered highlands and plateaus; and large coastal plains, valleys, and river deltas (Wahrhaftig, 1965). The principal mountain ranges have cores of igneous and metamorphic rocks, which are overlain by younger sedimentary and igneous rocks. In most of the State, the bedrock is covered by unconsolidated deposits of glacial and alluvial origin.

Because of its large geographic area, climatic conditions differ considerably across the State. Average annual temperatures range from 10°F in northern Alaska to 45°F in the southeastern coastal areas; extremes range from -80° to 100°F, which occur in the interior lowland. Recorded annual precipitation ranges from about 5 inches (in.) on the north slope of the Brooks Range to 300 in. along the southeastern coast. A large amount of precipitation and relatively low temperatures in the coastal mountains of southeastern and south-central Alaska favor the formation and persistence of glaciers and perennial snowfields, which now cover nearly 30,000 square miles (mi²), or about 5 percent of the State. Melting snow and ice in glaciated areas provide a water source not directly related in time to local precipitation. The meltwater has a regulatory or moderating effect on streamflow variability and, in turn, on ground-water recharge along alluvium-filled glacial valleys (Zenone and Anderson, 1978, p. 2).

Table 1. Ground-water facts for Alaska

[Withdrawal data rounded to two significant figures and may not add to totals because of independent rounding. Mgal/d = million gallons per day; gal/d = gallons per day. Source: Solley, Chase, and Mann, 1983]

| Population served by ground water, 1980 | |
|--|-----|
| Number (thousands) - - - - - | 276 |
| Percentage of total population - - - - - | 69 |
| From public water-supply systems: | |
| Number (thousands) - - - - - | 172 |
| Percentage of total population - - - - - | 43 |
| From rural self-supplied systems: | |
| Number (thousands) - - - - - | 104 |
| Percentage of total population - - - - - | 26 |
| Freshwater withdrawals, 1980 | |
| Surface water and ground water, total (Mgal/d) - - - - - | 220 |
| Ground water only (Mgal/d) - - - - - | 49 |
| Percentage of total - - - - - | 22 |
| Percentage of total excluding withdrawals for thermoelectric power - - - - - | 26 |
| Category of use | |
| Public-supply withdrawals: | |
| Ground water (Mgal/d) - - - - - | 23 |
| Percentage of total ground water - - - - - | 47 |
| Percentage of total public supply - - - - - | 43 |
| Per capita (gal/d) - - - - - | 134 |
| Rural-supply withdrawals: | |
| Domestic: | |
| Ground water (Mgal/d) - - - - - | 11 |
| Percentage of total ground water - - - - - | 22 |
| Percentage of total rural domestic - - - - - | 99 |
| Per capita (gal/d) - - - - - | 105 |
| Livestock: | |
| Ground water (Mgal/d) - - - - - | 0 |
| Percentage of total ground water - - - - - | 0 |
| Percentage of total livestock - - - - - | 0 |
| Industrial self-supplied withdrawals: | |
| Ground water (Mgal/d) - - - - - | 14 |
| Percentage of total ground water - - - - - | 31 |
| Percentage of total industrial self-supplied: | |
| Including withdrawals for thermoelectric power - - - - - | 9 |
| Excluding withdrawals for thermoelectric power - - - - - | 11 |
| Irrigation withdrawals: | |
| Ground water (Mgal/d) - - - - - | 0 |
| Percentage of total ground water - - - - - | 0 |
| Percentage of total irrigation - - - - - | 0 |

PRINCIPAL AQUIFERS

Principal aquifers in Alaska consist of unconsolidated alluvium and glacial deposits, and consolidated clastic and carbonate sedimentary rocks. The aquifers are described below and in table 2; their areal distribution is shown in figure 1.

Table 2. Aquifer and well characteristics in Alaska

[Mgal/d = million gallons per day; gal/min = gallons per minute; ft = feet. Note: Permafrost restricts availability of ground water, especially in rocks of little permeability. Sources: Reports of the U.S. Geological Survey, Alaska Department of Environmental Conservation, and the Alaska Department of Natural Resources]

| Aquifer name and description | Water withdrawals (Mgal/d) | Well characteristics | | | Remarks |
|---|----------------------------|----------------------------|---|--|---|
| | | Depth (ft) Common range | Yield (gal/min) Common range May exceed | | |
| Unconsolidated aquifers: Alluvial and glacial outwash deposits. Confined to unconfined. | 48 | 50 - 200 | 5 - 10 | | Individual private-supply wells in thin alluvium or mixed glacial deposits. |
| | | 100 - 400 | 50 - 1,000 3,000 | | Major supply wells in thick alluvium, glacial outwash deposits. Provides public supply at Anchorage and Fairbanks, industrial supply for Kenai Peninsula. |
| Bedrock aquifers: Igneous metamorphic, and sedimentary rocks. Generally unconfined. | 1 | 50 - 500 | 1 - 10 25 | | Source for most private wells in upland areas, particularly near Anchorage and Fairbanks. |

UNCONSOLIDATED AQUIFERS

The greatest volume of ground water in Alaska is stored in alluvium of river valleys, including flood plains, terraces, and alluvial fans of major valleys and smaller mountain and upland valleys. Alluvial deposits in the valleys of the Yukon, the Tanana, the Kuskokwim, the Kobuk, and the Susitna Rivers have a large recharge potential because they are connected hydraulically to the extensive surface-water system. In the lower Tanana River basin, for example, the maximum known thickness of alluvium is 2,000 feet (ft) (Anderson, 1970), and wells less than 200 ft deep may yield as much as 3,000 gallons per minute (gal/min).

Coastal basins and valleys are filled by glacial till and fine-grained glaciolacustrine materials that are interbedded with more permeable, water-worked deposits of sand and gravel. The largest and best-known ground-water system of this type is that of the Cook Inlet lowland, particularly in the Kenai and Anchorage areas, where alluvium of glacial outwash origin that is confined by glacial, lacustrine, and estuarine deposits yields as much as 1,500 gal/min to wells.

Alluvium-filled coastal valleys along the Gulf of Alaska (such as those in the Seward area) and in mountainous southeastern Alaska (such as that of the Mendenhall River near Juneau) probably contain large, but as yet not fully explored ground-water supplies. However, freshwater aquifers in these areas may be connected hydraulically to the ocean, and extensive ground-water development potentially could cause saltwater intrusion.

Because most ground-water development in Alaska is from unconsolidated aquifers, virtually all available water-quality data are for those aquifers. Known dissolved-solids concentrations of water from unconsolidated aquifers range from about 25 milligrams per liter (mg/L) in shallow stream-channel alluvium to 64,000 mg/L in shallow coastal wells, but most sampled ground water contains less than 250 mg/L of dissolved solids and is suitable for most uses (Feulner, Childers, and Norman, 1971, p. 39). Very mineralized ground water occurs in the Copper River basin (reported dissolved-solids concentrations of 2,400 mg/L in a well and 14,500 mg/L in a spring, both near Glennallen) and in many parts of the continuous permafrost zone (fig. 1). Iron is present in objectionable concentrations (more than about 0.3 mg/L of

iron causes staining of laundry and plumbing fixtures) in a large percentage of shallow wells in most areas of the State. Other constituents that are present locally in undesirable concentrations include nitrate as nitrogen (as much as 60 mg/L) and arsenic (as much as 10 mg/L) at Fairbanks (Johnson and others, 1978).

BEDROCK AQUIFERS

Glacial and alluvial deposits are either very low in permeability, thin, or absent in approximately 75 percent of Alaska. In such areas, appreciable amounts of ground water are present only in consolidated rocks. Carbonate rocks in the northeastern Brooks Range in northern Alaska provide extensive reservoirs for ground water. Individual springs in these rocks discharge as much as 16,000 gal/min. Sandstone and alternating strata of sand, silt, and clay are widespread throughout the State, but such rocks have been explored for water only in the western Kenai Peninsula with poor aquifers because of low permeability. Presently, the most intensive development of bedrock aquifers is in the uplands near Fairbanks (fractured schist) and in a few places in southeastern Alaska. These rocks generally provide only modest amounts of water (well yields of 10 gal/min or less) that are adequate for single household needs.

GROUND-WATER WITHDRAWALS AND WATER-LEVEL TRENDS

Much of the ground-water withdrawal in Alaska occurs within the municipality of Anchorage (location 4, fig. 2), where more than one-half of the State's population resides. About 50 other communities rely solely on ground water for their supply. The only areas outside Anchorage with large-scale ground-water use are the Tanana River valley in interior Alaska (locations 1, 2, fig. 2), and the industrial complex on the Kenai Peninsula (location 5, fig. 2).

The withdrawal and use of ground water are increasing with the growth of population and continuing industrial and commercial development. Analysis of observation-well data from the Anchorage, Fairbanks, and Kenai areas, however, indicates that past and present pumping has not resulted in such adverse effects as saltwater encroachment in coastal areas or excessive drawdown.

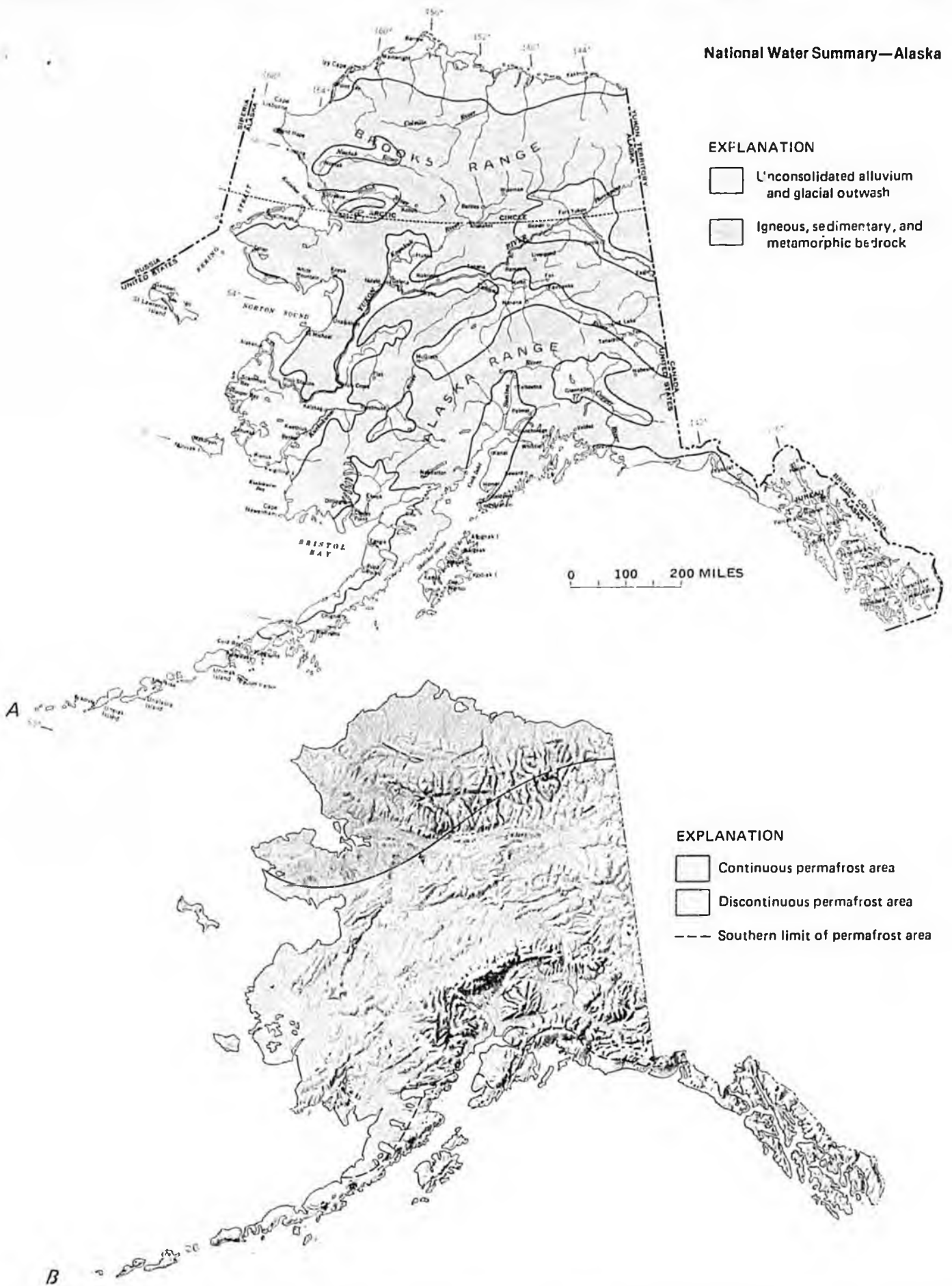


Figure 1. Principal aquifers in Alaska. A, Geographic distribution. B, Geographic distribution of permafrost areas. (See table 2 for a more detailed description of the aquifers. Sources: A, Wahrhaftig, 1965. B, W. Iliams, 1970.)

GROUND-WATER MANAGEMENT

The Alaska Water Use Act, Alaska Statutes 46.15.010-270, was enacted in 1966 to regulate appropriation and use of water in the State. This Act gave statutory definition to the doctrine of prior appropriation (first in time, first in right) authorized by the State Constitution. The Act also established a procedure for maintaining existing rights and providing new rights to ground and surface waters of Alaska. The original regulations implementing the Water Use Act were amended extensively on December 29, 1979, and incorporated as 11 AAC 93, Water Management. Those of particular interest relate to the appropriation of water, water-well standards, and temporary water use. The latest amendments to the Alaska Water Use Act include legislation relating to geothermal development and reservation of water (Alaska Department of Natural Resources, 1981).

Alaska's Water Quality Standards, established in Title 18, Chapter 70 of Alaska Administrative Code, identify the uses of the State's waters and set criteria, which limit man-induced pollution, to protect these water uses. Procedures and criteria for changing the identified uses of a water body are included in the standards (Alaska Department of Environmental Conservation, 1979).

The Alaska Department of Natural Resources (ADNR), Division of Geological and Geophysical Surveys (DGGS) is the designated State agency responsible for water-data collection. The DGGS, in cooperation with the U.S. Geological Survey and other State and Federal agencies, has developed and implemented an Alaskan Water Resources Evaluation (AWARE) Plan to coordinate water-data collection and water resource study activities in the State (U.S. Geological Survey and Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys, 1984).

The ADNR's Division of Forest, Land and Water Management, Water Management Section, is responsible for plan-

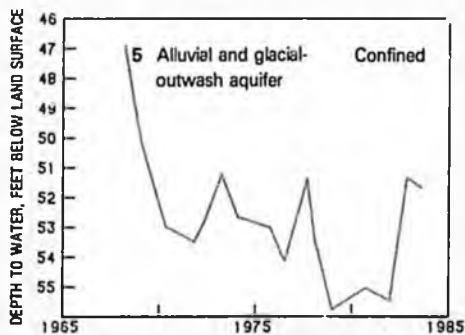
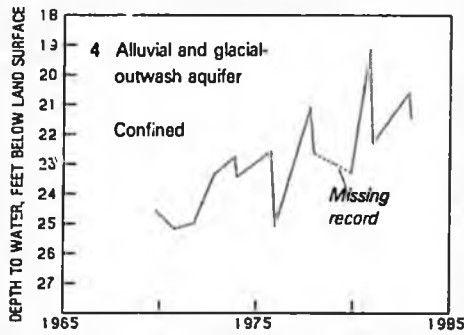
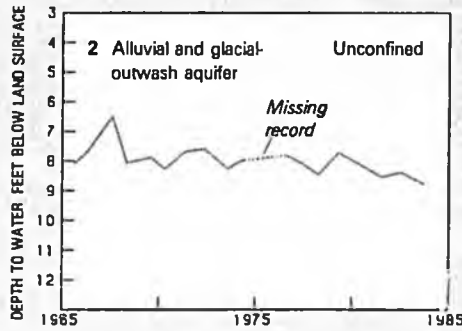
ning and administering the appropriation of water in the State, and the Department of Environmental Conservation is responsible for implementation of the provisions of Alaska's Water Quality Standards. Future development, protection, and conservation of the State's water resources depend on these important functions.

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EXPLANATION

Ground-water withdrawals, 1980
(million gallons per day)

- 2.0 – 5
- 5.1 – 10
- 10.1 – 15

Location number

- 2 Withdrawal site

| WITHDRAWAL SITES | | | |
|------------------|---------------------|--|----------------|
| No. on map | Geographic area | Aquifer | Principal uses |
| 1 | Fairbanks | Alluvial and glacial-outwash | Public supply. |
| 2 | Eielson | do | Industrial. |
| 3 | Clear | do | Do. |
| 4 | Anchorage | do | Public supply. |
| 5 | Kenai | do | Industrial. |
| 6 | Juneau | do | Rural supply. |

Figure 2. Areal distribution of major ground-water withdrawals and graphs of annual greatest depth to water in selected wells in Alaska. (Sources: Withdrawal and water-level data from U.S. Geological Survey files.)

AHTNA, INCORPORATED
Drawer 6
Copper Center, Alaska 99573
Ph. No.: (907) 822-3476

Frank

July 29, 1985

Mr. Tom Hawkins, Director
State of Alaska
Department of Natural Resources
Division of Land and Water Management
355 Cordova Street
Rm 7-003
Anchorage, Alaska 99510

Re: Navigability

Mr. Hawkins:

In July 16, 1985 you sent a letter, along with maps of the Ahtna Region, asking Ahtna, Inc., to review all waterbodies or portions of water within our land conveyance areas and to indicate what Ahtna, Inc., thinks should be found navigable based upon use or susceptibility to use. This letter is in response to the above and other interests which Ahtna, Inc., feels a need to be addressed.

First of all, Ahtna, Inc., opposes any determination regarding the issue of navigability in our region. With the exception of the Copper and Chitina Rivers, we strongly disagree with your letter, regardless of whether the waterbodies are a lake, pond, stream or river. Secondly, with our State navigability efforts we appear to be in a position where we do not see any reason why we should identify and identify waterbodies for public access, public recreation and the likes. Thirdly and lastly, while the State of Alaska wishes to classify water bodies for public and recreational use within the Chitina region, it has erroneously taken the idea that Ahtna, Inc., would consent to such. Ahtna, Inc., at this time has not completed studies on a greater part of its lands, therefore, Ahtna, Inc., feels that there are no navigable waters within our region with the exception of the Copper and Chitina Rivers only! For your information, our interest on our lands, be it village or regional, supercedes the State of Alaska interests.

Ahtna, Inc., has been working extensively on the issue of navigability. We have done research into this subject and even to the point of assessing our rights in court. By way of your letter, we again feel encroached upon, without justification. These encroachments, in dealing with the State to name a few (excluding navigability), are as follows: A) Subsistence; B) R.S. 2477's; C) Native Sovereignty; D) A.L. 280; and E) Native Allotments, etc. We totally disagree with your definition of navigability and see it as only an excuse to win back (lands) what was taken when ANCSA was passed. In actuality, the only people who had a right of ownership to the lands were the Alaska Natives.