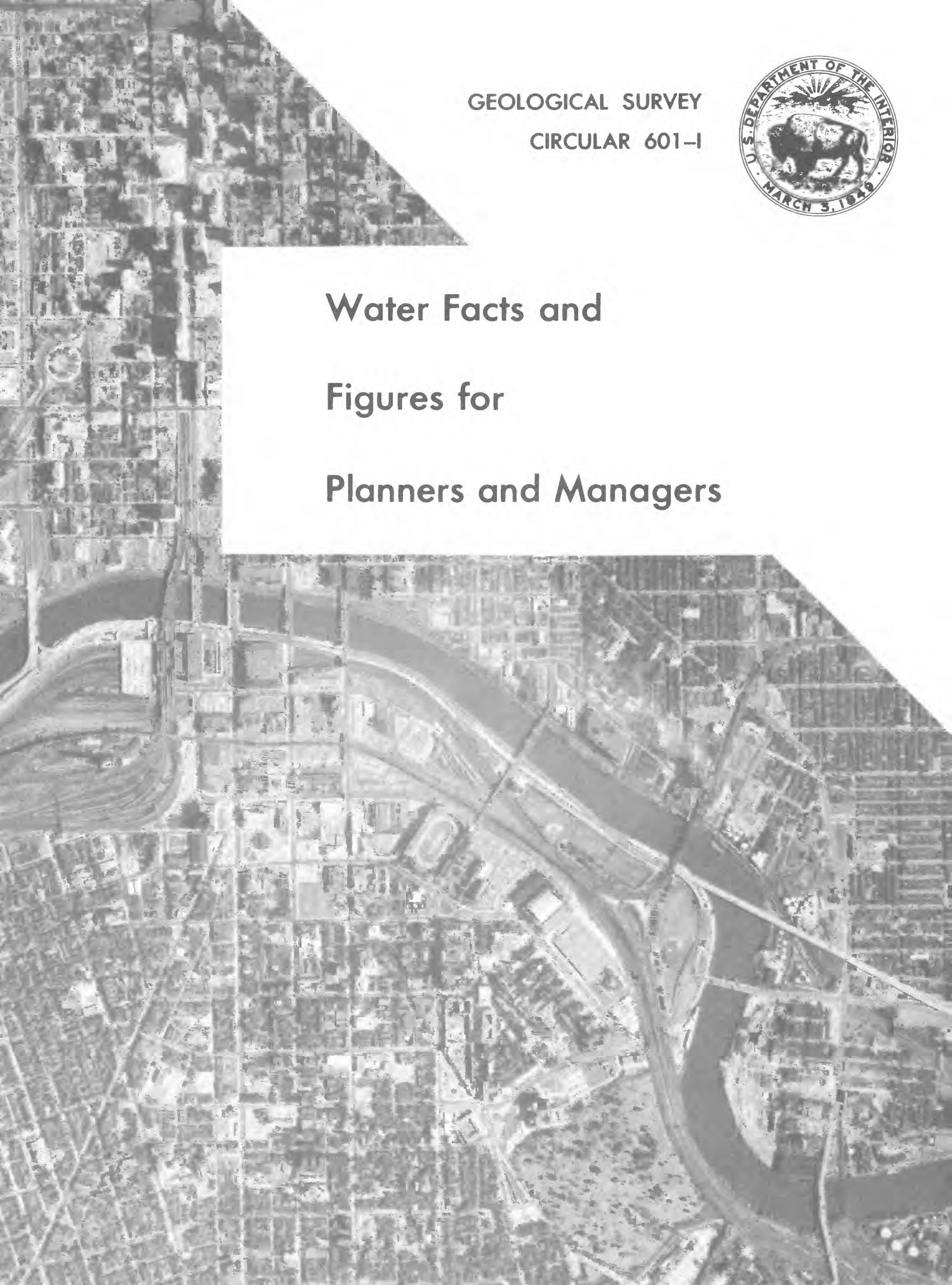
GEOLOGICAL SURVEY

CIRCULAR 601–I

Water Facts and Figures for Planners and Managers



Water Facts and Figures for Planners and Managers

By J. H. Feth

WATER IN THE URBAN ENVIRONMENT

GEOLOGICAL SURVEY CIRCULAR 601-I

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FOREWORD

Urbanization—the concentration of people in urban areas and the consequent expansion of these areas—is a characteristic of our time. It has brought with it a host of new or aggravated problems that often make new demands on our natural resources and our physical environment. Problems involving water as a vital resource and a powerful environmental agent are among the most critical. These problems include the maintenance of both the quantity and quality of our water supply for consumption, for recreation, and general welfare and the alleviation of hazards caused by floods, drainage, erosion, and sedimentation.

A prerequisite to anticipating, recognizing, and coping intelligently with these problems is an adequate base of information. This series of reports is intended to show the relevance of water facts to water problems of urban areas and to examine the adequacy of the existing base of water information.

E. L. Hendricks

E. L. Hendricks,
Chief Hydrologist

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By J. H. Feth

ABSTRACT

Water is defined in terms of its chemical composition and dominant physical properties, such as expansion on freezing and high surface tension. Water on the earth is about 97 percent in the seas, 2 percent in glacier ice, principally Greenland and Antarctica. Man is left with less than 1 percent as liquid fresh water to sustain his needs. This is possible under good management because water moves cyclically. Conjunctive use of surface and ground water is advocated, as is reuse of wastewater. Water needs for domestic and light industrial use can be reasonably forecast for planning purposes. Heavy-industry needs must be determined on a site-by-site basis.

The units commonly used by hydrologists with respect to quantities and quality of water are defined; their significance in water management is outlined, and metric-english equivalents are given for many. A glossary of terms concludes the report which is intended as a reference work for use by planners and managers.

INTRODUCTION

Because water is such an ever-present, pervasive substance in our lives we are constantly concerned with it. Any plan for land use requires consideration of water—how to get it, how to use it, how to dispose of it. Every new subdivision must have domestic water and facilities to dispose of wastewater. Every industrial site must have provision for potable water, for process or cooling water or both, and for disposal of wastes. A city or rural park? We need water for visitors to drink, water for waste disposal, and often water for a lake or pond that will serve the recreational purposes for which it is intended. Solid-waste disposal? Unless the planning is correct, water seeping through the wastes can carry pollutants to streams, lakes, or bodies of ground water that someone else wants to use. The problems are inescapable.

Not everyone wants to, or needs to, be an expert on water. But—especially today when environmental concern is great and growing—the private citizen, the planner, the politician, and the manager and decision-maker need to know enough to listen and respond with understanding and intelligence to the consultant and staffer.

The planner and decision-maker must constantly compromise. The dedicated preservationist may suggest solutions ideal for him; the developer may suggest uses and solutions ideal for him. The planner and decision-maker must weigh these against the feasible, with quality of life for everyone in mind, and find or devise the land-use compromise, the master plan, the grading ordinance, the modified-use permit that in his studied judgment provides the best land-use pattern.

Water is so all-pervasive that it enters into virtually all such decisions one way or another.

This circular is intended to provide the basic information that goes into considerations of water. It is concerned mostly with the language used in dealing with water. It is long on terminology, numbers, and equivalents and correspondingly short on theory and principles. It is a handbook where one finds the meaning of many water terms all packaged together with a suggestion of their significance and interrelations. Not all terms are easy to understand, even when digested and capsulized as well as possible. But water itself is complex in its behavior. I hope the user will find this circular handy at his elbow when he reads a consultant's report, a staffer's briefing—or just browses in publications concerned with water and water problems.

HOW IT'S PRESENTED

The circular is organized into four main parts. First there is a section telling a little about water and our demands for it—not exhaustively, but enough to remind us what water is, how it occurs, and how much we need. Second is a section on water-quantity terms. The third section considers water-quality terms—the physical, chemical, and biological terms most often encountered in discussions of water quality as related to use. And finally there is a glossary which provides a condensed summary of definitions pertaining to the technical terms that are discussed just a bit more fully in the other sections of the circular. The glossary, then, is the dictionary section. Reference citations appear here and there in the text—as (Leopold and Langbein, 1960), for instance. The full citation will be found at the back of this circular in "References."

A BIT ABOUT WATER

WHAT IS WATER?[1]

What is water? Water is a common liquid. We see it as rain, snow, and fog and in the seas, lakes, streams, springs—and what comes gushing out of the tap when we turn it on.

Water is made up of countless molecules, each consisting of two atoms of hydrogen and one of oxygen. Hydrogen and oxygen under many conditions are gases, but when combined in these proportions they form water.

In 1934, Dr. Harold Urey discovered minute portions of a third component in water. He called the material deuterium, which is a heavier isotope of hydrogen. Later another hydrogen isotope, tritium, was found to be a part of water. Deuterium and tritium are special hydrogen atoms that weigh more because they contain extra neutrons.

Water can appear as solid, gas, or liquid (fig. 1). In fact, water is the only substance on earth that appears in three distinct forms of matter within the normal range of climatic conditions. The form it takes depends on the vigor of motion of its molecules. At low temperature, the molecules are relatively quiet, literally because they have less energy. This is the condition that produces ice, the solid form of water. When frozen, the water molecules form in hollow circles, as shown. At moderate temperatures, when the molecules are activated by the extra heat energy, water is liquid. The molecules are close together, yet they slip around freely. This is what gives liquid its flowing motion. At high temperatures, the molecules move about violently, colliding with one another and forming vapor, an invisible gas.

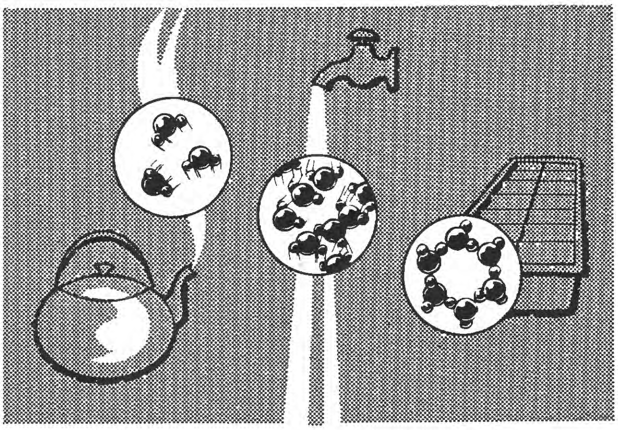

FIGURE 1.—Water as a gas, liquid, and solid.

Most substances shrink as they get colder until they finally freeze, but water expands slightly just before it freezes and during the freezing process. Because of this expansion, ice is lighter than water, whereas almost all other compounds are heavier when frozen. This is fortunate, because if ice were heavier than liquid water, lakes and streams would freeze from the bottom up instead of from the top down. They would become solid ice and in cold climates the deepest layers might not melt even in the summer. Solid freezing would have a disastrous effect on fish and water plants, which could not live through the winter at all.

Another remarkable fact about water is its heat capacity. Heat capacity is the ability of a substance to absorb a great deal of heat without itself becoming extremely hot. Water's heat capacity is the highest of all substances in nature except ammonia. For instance, an empty

[1] Condensed and modified from a U.S. Geological Survey pamphlet of the same title, available on request from Information Officer, U.S. Geological Survey, Washington, D.C. 20244.

pan on a gas flame will very quickly become red-hot and then burn black. But if some water is placed in the pan over the same flame, the water will absorb heat from the pan. The pan will become hot, but not red-hot, and the temperature of the water will rise only a few degrees, comparatively speaking.

The heat capacity of water enables the oceans to be huge reservoirs of solar warmth and to keep our weather from going to great extremes of either heat or cold. The moderating effect of water is noticeably lacking in the desert where days tend to be very hot and nights chilly to downright cold.

Water has an extremely high surface tension. Surface tension is the ability of a substance to stick to itself. A drop of water falling from a spout clings to the tap and stretches very thin before finally letting go. Immediately it forms a sphere and this sphere resists deformation. To split water apart and make it form two new surfaces, tremendous force is necessary.

Because of its high surface tension, a water surface can support objects heavier than itself—a needle, for instance, or insects that "skate" around on the water.

But perhaps water's most remarkable property is its action as a solvent. Given enough time, water can and does dissolve everything exposed to it.

Water is a great mover and doer. It is constantly modifying the landscape, generally very slowly, but now and again catastrophically as in times of floods and mudslides. Each drop of rain is an independent sphere, like a tiny bullet, which can break away minute fragments of even the hardest rock provided the rock surface has been weakened by chemical breakdown (also engineered by water) of the mineral grains of the rock. As they strike the earth and become a flowing liquid, the raindrops surround and move fine particles of soil. Water carries the soil particles into streams and finally down to the flood plains, deltas, and the sea.

All these striking aspects of water depend on a process called chemical bonding. All molecules have an electronic cohesiveness tending to hold their atoms together. In the case of water this force is relatively great and makes for an extremely tight structure. This force results from the fact that an atom of oxygen has two unpaired electrons, whereas the two hydrogen atoms lack an electron each. The hydrogen atom with its single electron is eager to obtain another one. The mutual need of the atoms for paired electrons draws them irrestably together, and the bond thus formed is extraordinarily strong. You can see from the diagram (fig. 2) that the hydrogen and oxygen atoms share two unpaired electrons.

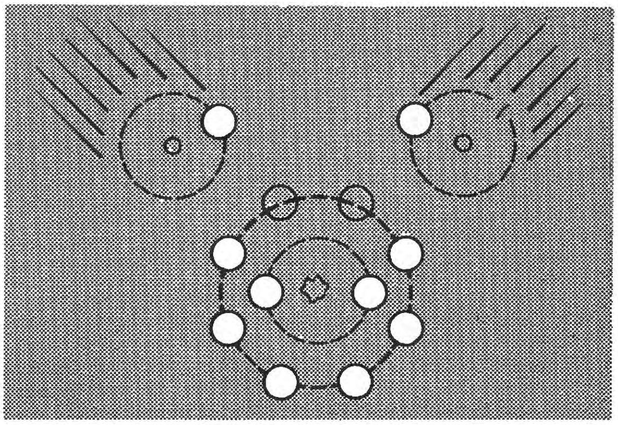

FIGURE 2.—Diagram of water molecule showing one atom of oxygen and two of hydrogen.

Strong chemical bonding accounts for water's remarkable ability to adhere to substances (or "wet" them, as we ordinarily say), and thus eventually to dissolve them. Bonding also effects the boiling point of water and is responsible for its freezing process. The importance of this bonding to life processes is great indeed, for without it water would not have the unique properties already described.

WHERE IS WATER?[2]

Most of the world's supply of water—the estimate is more than 97 percent—is in the oceans. Most of the rest is locked up in the ice caps of Greenland and Antarctica—more than 2 percent. So man is left with something less than 1 percent of the supply to work with—except insofar as he has begun to tap the oceans for industrial cooling water and is beginning to desalinize a little ocean water for his use. Even so, there seems to be enough fresh, liquid water on the earth to supply

[2] This discussion is abridged and modified from the U.S. Geological Survey pamphlet "Water of the World" available from the Information Officer, U.S. Geological Survey, Washington, D.C. 20244.

present and projected needs far into the next century at least, *provided* we will bear the cost of making it clean, keeping it clean, storing and transporting it, and increasingly recycling it for use more than just one time.

It is rather convenient, and quite accurate, to look at the total supply of fresh water on the earth as recycled sea water—water that has evaporated from the surface of the oceans leaving the salt behind; water that is in the atmosphere and in lakes and rivers; or water that is in the soil or deeper in the aquifers (water-bearing strata) that underlie the land in many places and supply water to wells and springs. Wherever it is, and though it may take awhile to get there, the fresh water is enroute back to the sea again. The cycle is illustrated in figure 3.

GROUND WATER

Table 1 shows an estimate by the U.S. Geological Survey of the distribution of the world's total supply of water. Notice that of the liquid fresh water, an overwhelming proportion is ground water—that is water in layers of rocks beneath the land surface. The deep-lying ground water is commonly salty, costly to extract and use, and doubtfully renewable in any reasonable time span because water underground moves slowly at best and to recharge (refill) the deep aquifers would take centuries.

Ground water in shallow aquifers ("within a depth of half a mile," as shown in table 1) is commonly fresh and moves more rapidly than the deeper ground water. Its movement, however, is general throughout the broad rock formation and not in underground lakes and rivers as is sometimes said. In areas of heavy precipitation, shallow ground water is rather rapidly recharged, and the ground-water system is analogous to a surface reservoir that can be drawn upon with assurance that the supply will be renewed in a reasonable time when the rains come. In semiarid areas, the ground-water supply may represent the accumulation of recharge from hundreds or even thousands of years. There, the renewal rate is very slow, and as far as man's life span is concerned, the ground-water supply is a one-time-only source. In such areas, when the ground water is depleted, alternative sources of supply must be found, usually at great cost.

The quantities of ground water used reach sizable proportions, although estimates are inexact because the records are incomplete. But the U.S. Geological Survey estimated ground-water use in southern Arizona to be nearly 5 million acre-feet per year—about 1½ trillion gallons. For the San Joaquin Valley, California, the estimate for 1966 was 9½ million acre-feet—nearly twice that in Arizona, and equal to about 3 cubic miles of water.

Not all the water stored underground can be extracted for use. Earlier, we saw that one of its outstanding characteristics is that of wetting surfaces. The same property causes some of the water to cling to the surfaces of whatever rock materials it is stored in, and there-

TABLE 1.—*World's estimated water supply*

Location	Surface area (square miles)	Water volume (cubic miles)[1]	Percentage of total water
Surface water:			
Fresh-water lakes	330,000	30,000	0.009
Saline lakes and inland seas	270,000	25,000	.008
Average in stream channels	----------	300	.0001
Subsurface water:			
Water in unsaturated zone (includes soil moisture)	50,000,000	16,000	.005
Ground water within a depth of half a mile		1,000,000	.31
Ground water—deep lying		1,000,000	.31
Other water locations:			
Icecaps and glaciers	6,900,000	7,000,000	2.15
Atmosphere (at sea level)	197,000,000	3,100	.001
World ocean	139,500,000	317,000,000	97.2
Totals (rounded)	----------	326,000,000	100

[1] A cubic mile of water equals 1.1 trillion gallons.

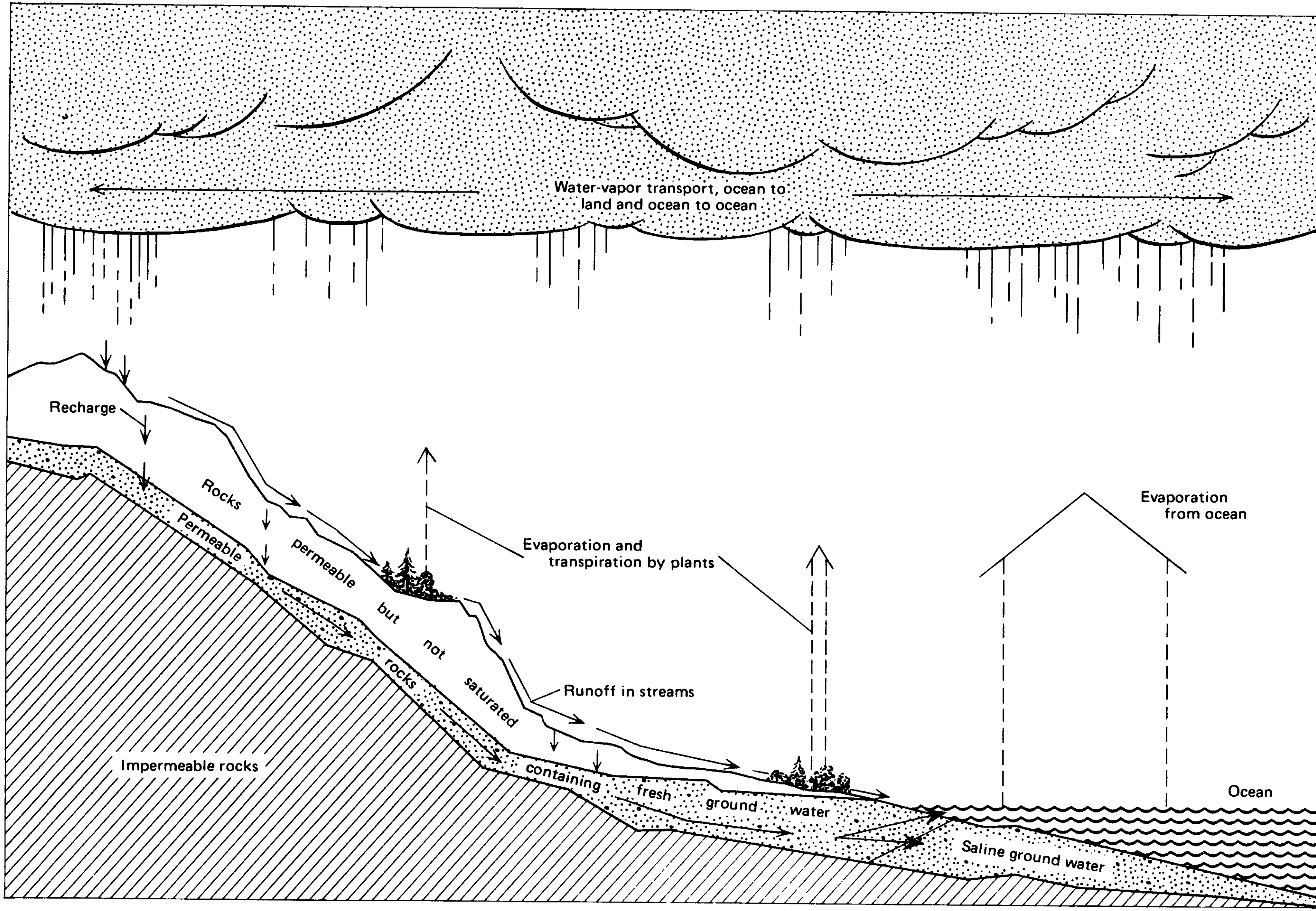

FIGURE 3.—Sketch of some elements of earth's water cycle.

fore, it cannot be removed completely. Also, as ground water moves slowly, a pumping well dewaters the aquifer in its vicinity first and water from other parts of the aquifer moves slowly to refill the dewatered zone around the well. Therefore, wells would have to be spaced uneconomically close to one another to extract in a reasonable time all the water that was not clinging to the rock materials.

All the foregoing says that ground water is a large and highly valuable resource for man. But its modes of occurrence and movement must be understood so that the resource can be used and managed advantageously. More on this subject will be said in the section "Conjunctive Use."

SURFACE WATER

Surface water is what first comes to mind when "water supply" is mentioned. It is the water we see in ponds, lakes, reservoirs, or flowing in streams. It is the water historically first used except in those arid areas where there are few or no streams and where what lakes may exist are brackish or highly saline.

Surface water originates as rain or melting snow—locally as melting glacier ice. The processes involved, however, are not simple.

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 over land 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 air mass 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 air masses are in motion, and as the water-depleted air moves on, new moisture-laden air takes its places above the area of precipitation.

The basic 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 discharges some water directly into rivers and some directly to the sea.

Estimated average annual evaporation from the world ocean is roughly 39 inches. The conterminous 48 United States receive 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, and its waters eventually reach the Pacific Ocean about 700 airline miles from their source and about 2,200 miles from the mouth of the Mississippi.

This is a good example of the continuous mixing 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 or snow to the west and some to the east of the Continental Divide. Thus, two drops of rain falling almost side by side along the continental backbone may end up, one in the Pacific, the other in the Atlantic Ocean, although both were derived from the Pacific.

No one known 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 conterminous United States takes place at the rate of about 1,803,000 cubic feet per second (a cubic foot is about 7½ gallons), which amounts to approximately 390 cubic miles per year.

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. The world's river channels themselves contain on the average 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 is that during rainless periods the flow in streams generally is from ground water. Aquifers adjacent to streams will, if full, discharge water from underground storage and augment—or sustain— streamflow. However, if water levels in aquifers are lower than levels in adjacent streams, water tends to move from the streams into the aquifers. Together, the streams and aquifers really constitute one, interlocking system. At those times when nearly all water in a stream is from ground-water sources, hydrologists say the stream is at baseflow. Although baseflow period normally represents the lowest period of streamflow, the mineral content of the stream water is commonly (but not always) at its highest. Determination of quantities and quality of baseflow is, therefore, a necessary step in planning to use and manage flow in streams.

The earth's land areas are dotted with hundreds of thousands of lakes. Wisconsin, Minnesota, and Finland contain some tens of thousands each. Some Alaskans claim that their State alone has a million lakes. If so, quite a few small ponds must be included in the count. These lakes, important though they may be locally, hold only a minor part of the world supply of fresh surface water, most of which is contained in a relatively few large lakes on three continents.

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 fresh-water surface 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 fresh-water 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.

TO RECAPITULATE

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 fresh-water use. Obviously, he must find much more effective ways of management if he is to prosper.

Water is a global concern, and 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.

CONJUNCTIVE USE

Surface water and ground water—and precipitation, for that matter—are all part of a single, closely interrelated resource, fresh water. What is damaging to part of the system, damages the whole system. The idea behind conjunctive use is to manage all components of the system, insofar as possible, in such a way as to use the whole resource to maximum advantage (fig. 4). In times past, the tendency has been to develop and use surface water without regard to its interrelation with ground water; or to develop a ground-water supply without much regard for its relation to surface supply in the region. Consideration was rarely if ever given to wastewater as part of the total supply.

Conjunctive use can be looked at as a carefully planned and managed system of tradeoffs.

For instance, in some areas of the West, precipitation is highly seasonal—heavy in winter, sparse the rest of the year. We've long ago learned to manage part of the system by storing water in surface reservoirs when it was abundant, and releasing the stored water during the rest of the year. But we are running out of surface-storage sites and still have (1) increasing demands for water, and (2) locally seasonal surpluses that flow unused to the sea.

In those circumstances, one answer is deliberately to put water in storage underground through the process of artificial recharge. In some places, surplus water is put underground through recharge wells. In parts of Long Island, N.Y., and southern California, treated wastewater is put down recharge wells to build a water barrier against sea-water intrusion of used aquifers. Elsewhere, seasonally surplus surface water is recharged through spreading grounds or ponds underlain by sand and gravel that allow the water applied to infiltrate readily and to percolate rapidly downward and become recharge to ground water.

Such programs of water management have several aims—protection of aquifers as mentioned, stopping land subsidence, and storing water in aquifers where it is virtually free from loss by evaporation. The processes of artificial recharge are basically simple, but management is often complicated by complex aquifers geology, siltation of the spreading surfaces, clogging of wells, and, in some places, the incompatible quality of the recharge water with respect to water already in subsurface storage or to the mineralogy of aquifer materials.

In ideal situations, conjunctive use may involve putting seasonally surplus water underground and using surface supplies, then as surface water becomes scarce, using water from wells. This is the simplest and most direct trade off. Again, conjunctive use is a management concept and process, designed to use to optimal advantage both surface and subsurface components of the water resource. In a few places, and somewhat sporadically so far, attempts have been made, and continue, to modify the timing and quantities of precipitation by cloud seeding.

HOW MUCH WATER?

Good, hard facts with wide transfer value are hard to come by for per capita, or other unit, use of water. This dilemma stems from variations in demand imposed by variations in climate, income, tradition, and industrial processes. There may be other factors as well.

It is widely recognized that patterns of industrial water demand are changing as it becomes more economical to recycle and reuse process water than to use and discharge water on a once-through basis. The change reflects both the increasing cost of supplying new process water and the rapidly growing demand that industry clean up its wastewater before discharging it.

The following survey is not intended to be exhaustive. The use data cited have been gleaned from a variety of available sources and represent a state-of-the-art evaluation.

DOMESTIC DEMANDS

Strictly in-home use tends to be fairly modest, ranging from perhaps 10 gpcd (gallons per capita per day) to 80 gpcd. The low values are found in home not served by electricity. Higher values appear to be representative of rural, suburban, and urban use in homes that are served by electricity. Suburban use may be larger than urban if water for yard irrigation is included (Leopold and Langbein, 1960). A

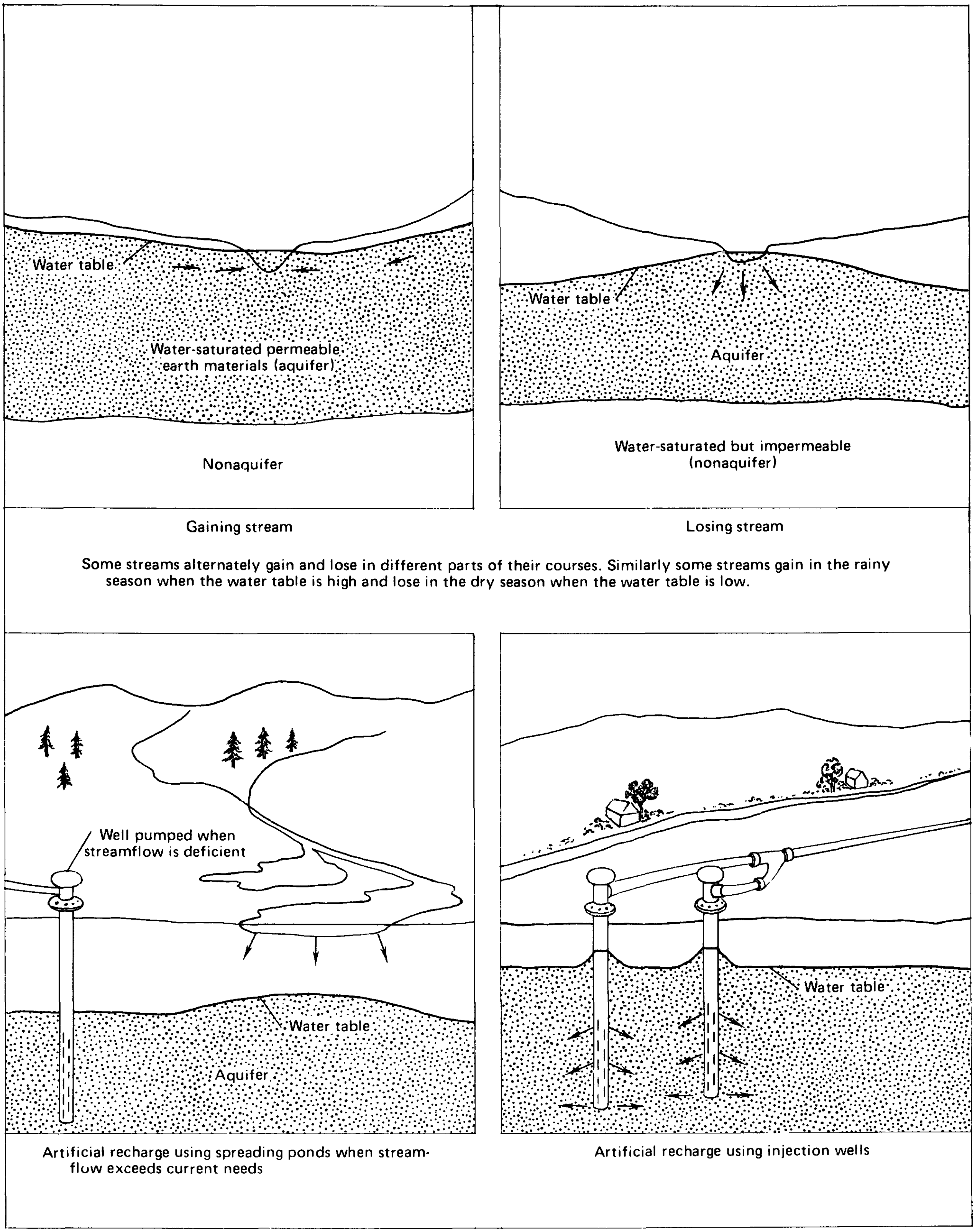

FIGURE 4.—Concepts of surface water-ground water relations and conjunctive use including artificial recharge.

few specific use factors cited by those authors (p. 32) are as follows:

Use	
Flush a toilet	6 gallons (revised est. 1973)
Tub bath	30–40 gallons
Shower bath	20–30 gallons
Wash dishes	10 gallons
Run washing machine	20–30 gallons
Wastes	
Dripping faucet	One drop per second= 4 gallons per day
"Humming" toilet leak	1½ gallons per hour= 13,000 gallons per year
Water the yard	
Humid areas—6 inches per year 8,000 sq ft=30,000 gallons per year	
Semiarid areas—20 inches per year 8,000 sq ft=100,000 gallons per year	
Desert areas—36 inches per year 8,000 sq ft=180,000 gallons per year	

Peak-use rates diverge markedly from the average rate, and need to be accommodated in design of municipal water systems. Leopold and Langbein (1960, p. 33) sketched the pattern as follows:

> Water use varies during the day and during the week in a way to reflect most interesting details of American home life. Use is, of course, low during the night but increases rapidly to a maximum between 8 and 9 o'clock in the morning. Another peak use occurs at suppertime between 6 and 8 o'clock in the evening. Though there is variation in maximum peak between cities, this difference is interpreted to mean that more people take baths in the morning than at bedtime. Also, an extra heavy peak occurs on Saturday night in many cities; so it appears that the Saturday night bath is still a reality.

A more graphic indication of variation in load is shown in the accompanying graphs (fig. 5) compiled by M. P. Hatcher and cited by Savini and Kammerer (1961, p. A–13).

COMMERCIAL AND INDUSTRIAL USE

The graphs (fig. 5), of course, introduce the commercial and industrial demands that may be imposed on municipal water systems. At this stage of the game, a separation needs to be made of those industries that draw fairly modest quantities of water from municipal systems and industries whose needs for water are so large that it is economical for them to develop their own supplies. That distinction should be kept in mind and thoroughly ironed out between planners and industrialists anytime a new industry seeks to move into a site within a land-use planner's purview. The intricate physical, economic, and legal problems involved in such decisions go far beyond the scope of this discussion.

In 1960, average use by commerce and industry in the United States was about 70 gpcd. Public use on top of that, use for firefighting, street cleaning, public-building use, and maintenance of public parks was some 10 gpcd. And leaks from water mains, unmeasured leaks from faucets, and errors in measurement account for an additional—and seemingly almost irreducible—20 percent of the total municipal supply. In sum, the average per capita use of water in American cities was about 150 gpcd (Leopold and Langbein, 1960, p. 33). In 1970, per capita use from public water supplies was about 180 gpd (Murray and Reeves, 1972, fig. 8). Total use including water withdrawn for irrigation and industry was about 1,800 gpcd. McKinney (1962, p. 167) confirmed these general values in his estimates of sewage discharge as follows:

> 50 gpcd—domestic sewage, purely residential area.
>
> 75 gpcd—as above, but heavy concentration of electrical appliances.
>
> 100 gpcd—residential community with business and light industry.

Special problems in planning for commercial use in the growing numbers of places in the country that depend on special-interest uses and tourism, are indicated by the following paragraph from Flack (1971, p. 757).

> A special word may be in order with respect to seasonally occupied areas. The unsteady loading of water systems in tourist oriented locations creates severe problems in terms of water supply and in terms of waste water disposal. High impact loading in winter in the ski areas and in the summer season in mountain and seaside resort areas can create extreme supply and treatment problems. Populations that increase from several hundred to the thousands and ten thousands for a short season can wreak havoc on a water and wastewater system. This area of specialized water use requires specialized water design and probably different sorts of criteria for design than are customarily used. A different kind of design criteria is needed for a community that goes most of the year with a couple of hundred people and suddenly jumps to several thousand, than for a similar city that has a stable population all year around.

Light industrial use of water is accommodated in previous paragraphs—use such as might typically come from municipal supplies. Heavy industry is another story, and a few facts may demonstrate the magnitude of its

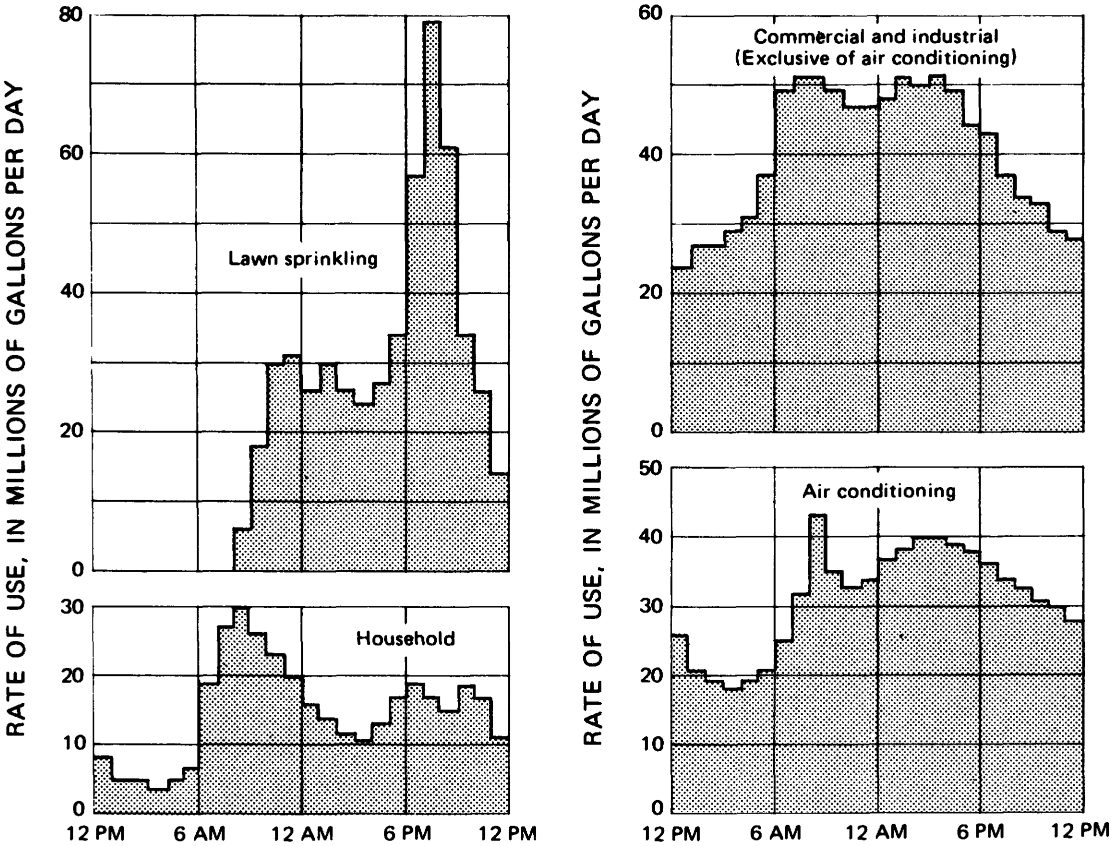

FIGURE 5.—Hourly trends in water use on maximum day (July 12) of use in 1954 of public water supply of Kansas City, Mo. Based on data prepared by M. P. Hatcher for 1955 conference of American Water Works Association (from Savini and Kammerer, 1961, p. A13).

needs. Ninety-four percent of water used by industry is used for cooling, and most of this can be used again. But repeated reuse for cooling may have drastic effects on receiving streams, as is shown by the example of the Mahoning River, Ohio. Several steel mills use. the Mahoning, and in July 1941 a stream-water temperature of 117°F (47°C) was measured. Even in winter, a temperature of 84°F (29°C) was recorded. The importance of water temperature is discussed in the section of this report on physical quality of water.

The electric-power industry presently uses by far the largest amount of cooling water in its fuel-powered generators. (The large use of water in hydroelectric turbine generation is disregarded as that is flow-through use and has no, or negligible, effect on water quality for reuse.) The chemical industry is second but uses only about one-tenth as much water as does power-generation cooling.

Some of the major industrial uses of water are shown in (table 2). Note that the use ranges from 79 gped (gallons per employee per day) for furniture and fixtures to 25,157 gped for petroleum and coal products and that from 67 to 95 percent of the intake water reappears in the wastewater stream (right-hand column, table 2).

Geographic distribution seems to offer no valid clues as to per capita use of water. The results of a survey (Durfðr and Becker, 1964, p. 74–77) are shown graphically (fig. 6). The per capita use ranges from 65 to 370 gpd, Spokane, Wash., having the highest and Fresno, Calif., the next highest. About 100 miles north of Fresno, but under almost identical climatic conditions, Sacramento, Calif., showed about 100 gpcd less use than Fresno. Seattle, Wash., showed a use of 140 gpcd, and neighboring Tacoma 290 gpcd. Chicago reported use of 230 gpcd and adjacent Gary, Ind., only 100

TABLE 2.—*Quantity of water used by manufacturers*

[Data gathered for manufacturing establishments with 6 or more employees. Adapted from Reid, 1971, p. 250–251]

Industry Group	Number of employees	Annual water intake (billions of gal)	Gallons per employee per day (thousands)	Intake water appearing as waste-water (percent)
Processing Industries:				
SIC				
20 Food and kindred products	1,589,380	812	1.400	91
24 Lumber and wood products	489,354	161	1.146	82
26 Paper and allied products	583,234	2,078	9.762	94
28 Chemicals and allied products	734,261	3,899	14.584	94
29 Petroleum and coal products	152,470	1,400	25.157	94
30 Rubber and plastic products	406,777	168	1.439	95
32 Stone, clay, and glass products	550,451	264	1.434	88
33 Primary metal industries	1,122,911	4,587	11.196	94
Weighted average	--------	----	6.507	--
Fabricating Industries:				
SIC				
21 Tobacco products	76,989	4	.168	67
22 Textile mill products	854,543	158	.644	91
25 Furniture and fixtures	360,882	8	.079	94
31 Leather and leather products	322,747	20	.215	94
34 Fabricated metal industries	1,058,954	76	.249	93
35 Machinery, except electrical	1,424,432	172	.421	95
36 Electrical machinery	1,502,324	114	.264	87
37 Transportation equipment	1,593,285	252	.551	95
38 Instruments and related products	301,650	31	.363	90
39 Miscellaneous manufacturing	371,858	19	.175	93
Weighted average	--------	----	.378	--

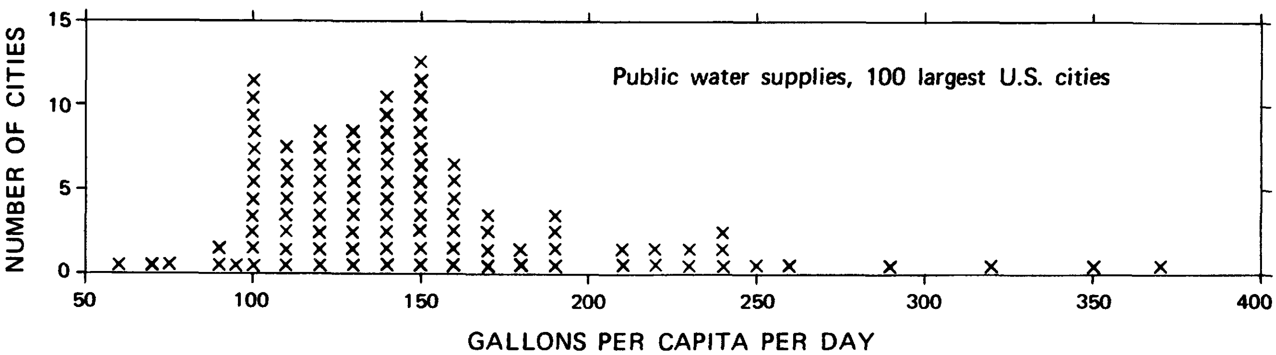

FIGURE 6.—Range in per capita use of water in 100 largest cities of the United States, 1962.

gpcd. Although the graph shows a strong enough central tendency, there is broad spread in the data. The only apparent explanation is that municipal systems that show high per capita use values are tapped to a considerable degree by industry. The lower use values—including Gary, for instance—seem to imply that industrial water is self-supplied.

The foregoing data, sketchy as they are, indicate the general magnitude of domestic and commercial water-supply needs. The load on municipal water-supply and sewage-disposal systems imposed by industry is highly variable and not amenable to averaging. The planner thus must plan on a site-by-site basis in terms of the foreseeable types of industry involved, their size, and their impact on supply and disposal facilities. No easy job. But there are no shortcuts in sight.

PATTERNS OF CHANGE

For all the variations in detail with location, climate, land forms, natural resources, and natural hazards, there is a general pattern that relates urbanization and its parallel changes in land and water use, to the hydrologic systems that operate in any given region. Before considering water units, their significance, and the wonderously varied terms in which they are expressed, it is well to bear the overall pattern in mind. Savini and Kammerer (1961, p. A6–A7) tabulated the hydrologic effects of progressive urbanization (table 3), and defined several stages in the process.

In the early-urban stage, city-type homes are built on large plots and are interspersed here and there with schools, churches, or shopping centers. Water supply is usually obtained by pumping from individual wells, the rubbish is burned, the garbage buried, and sewage is disposed of in septic tanks or cesspools. The middle-urban stage is characterized by large-scale housing developments, more schools and shopping centers, some industrial buildings, and enlarged networks of streets and sidewalks. Municipal systems to supply water of acceptable purity and sewers to dispose of sewage may be built. However, some domestic sewage may still be discharged to septic tanks and subsurface disposal systems. Domestic food wastes may be collected by truck or discharged through kitchen-disposal units to septic tanks or sewer systems. The late or advanced, urban stage is characterized by a large number of homes, apartments, commercial and industrial buildings, and streets and parking lots. A large part of the area is roofed or paved. Sanitary sewers and large, but frequently inadequate, storm sewers remove human and industrial wastes and provide drainage. The smallest streams are eliminated entirely and the slightly larger streams are confined to artificial channels and canals and may be obstructed by bridge piers. Buildings and other structures encroach upon the natural stream floodway and even into the channel. The hydrologic and hydraulic effects of these changes are quite severe.

We have now looked at what water is, how and where it occurs, how much is needed, and man's impact on water. Now let's go on to consider the language used by hydrologists, engineers, and chemists when they discuss quantity and quality of water.

WATER-DATA UNITS AND EQUIVALENTS

Those who use, distribute, analyze, and evaluate water speak in many tongues. There are cfs (cubic feet per second), m^3/sec (cubic meters per second), mgd (million gallons per day), miners' inches, and acre-feet.

In water-quality terms, there are such units as ppm (parts per million), mg/l (milligrams per liter), and MPN (most probable number)—not to mention picocuries per liter, grains per gallon, and degrees Fahrenheit or Celsius. Confusing? Of course!

The purpose of this section is to introduce and define many of the diverse units of measurement of quantity and quality of water that are used. Where appropriate, a little bit is said about the interpretation and significance of data reported in the several units. And an attempt is made to show how the units relate one to another. This section is to be browsed in, or more often, consulted as a capsule reference when an unfamiliar term crops up.

The sources of information are given in parentheses. They provide much more authoritative information on the subjects than is given in this section.

THIS METRIC BUSINESS

One symptom of the increasing use in the United States of the nearly worldwide metric system is the increasing frequency with which chemical quality of water is discussed in terms of milligram per liter, rather than in parts per million, the units that used to prevail. Another sign is the growing use of degrees Celsius (centigrade) along with, or in place of, degrees Fahrenheit. These matters are discussed in a later section on chemical-quality units.

We have yet to "go metric" in this country in terms of volume units. Meanwhile, the scientific and planning literature from overseas and from Central and South America commonly uses metric units. So, in the section on quantity, some equivalents that may be useful are included.

WATER-QUANTITY DATA

How much water is there? How good is it?

These are the questions that must be answered in evaluating the suitability of a water supply for any planned use. This section deals

TABLE 3.—*Hydrologic effects during a selected sequence of changes in land and water use associated with urbanization*

Change in land or water use	Possible hydrologic effect
Transition from preurban to early-urban stage:	
Removal of trees or vegetation, Construction of scattered city-type houses and limited water and sewage facilities.	Decrease in transpiration and increase in storm flow. Increased sedimentation of streams.
Drilling of wells	Some lowering of water table.
Construction of septic tanks and sanitary drains	Some increase in soil moisture and perhaps a rise in water table. Perhaps some waterlogging of land and contamination of nearby wells or streams from overloaded sanitary drain system.
Transition from early-urban to middle-urban stage:	
Bulldozing of land for mass housing; some topsoil removal; farm ponds filled in.	Accelerated land erosion and stream sedimentation and aggradation. Increased flood flows. Elimination of smallest streams.
Mass construction of houses; paving of streets; building of culverts.	Decreased infiltration, resulting in increased flood flows and lowered ground-water levels. Occasional flooding at channel constrictions (culverts) on remaining small streams. Occasional over-topping or undermining of banks of artificial channels on small streams.
Discontinued use and abandonment of some shallow wells.	Rise in water table.
Diversion of nearby streams for public water supply.	Decrease in runoff between points of diversion and disposal.
Untreated or inadequately treated sewage discharged into streams or disposal wells.	Pollution of streams or wells. Death of fish and other aquatic life. Inferior quality of water available for supply and recreation at downstream populated areas.
Transition from middle- to late-urban stage:	
Urbanization of area completed by addition of more houses and streets, and of public, commercial, and industrial buildings.	Reduced infiltration and lowered water table. Streets and gutters act as storm drains creating higher flood peaks and lower base flow of local streams.
Larger quantities of untreated waste discharged into local streams.	Increased pollution of streams and concurrent increased loss of aquatic life. Additional degradation of water available to downstream users.
Abandonment of remaining shallow wells because of pollution.	Rise in water table.
Increase in population requires establishment of new water-supply and distribution systems, construction of distant reservoirs diverting water from upstream sources within or outside basin.	Increase in local streamflow if supply is from outside basin.
Channels of streams restricted at least in part to artificial channels and tunnels.	Increased flood damage (higher stage for a given flow). Changes in channel geometry and sediment load. Aggradation.
Construction of sanitary drainage system and treatment plant for sewage.	Removal of additional water from area, further reducing infiltration recharge of aquifer.
Improvement of storm drainage system	
Drilling of deeper, large-capacity industrial wells	Lowered water-pressure surface of artesian aquifer; perhaps some local overdrafts and land subsidence. Overdraft of aquifer may result in salt-water encroachment in coastal areas and in pollution or contamination by inferior or brackish waters.
Increased use of water for air conditioning	Overloading of sewers and other drainage facilities. Possibly some recharge to water table, owing to leakage of disposal lines.
Drilling of recharge wells	Raising of water-pressure surface.
Wastewater reclamation and utilization	Recharge to ground-water aquifers. More efficient use of water resources.

with the first question; a following section deals with the second.

In talking about "how much" we must first look at the complex of units used in defining "how much." For starters, let's browse a little.

One gallon per minute doesn't sound like a lot. But that much flow from a spring or well provides 1,440 gpd (gallons per day)—enough for a family of five with lawn watering thrown in, or for 10–15 people otherwise. At least 100 people could survive awhile on that amount, provided the water is all caught and stored for use as needed.

We have just used two quantitative terms, gallons per minute and gallons per day. Let's look at these and other terms in common use, and compare one with another, starting with the exotic.

Back when the West was young, and in places where gold could be had for the taking, hydraulic miners established their water rights in terms of the *miner's inch.* The miner's inch is defined as the quantity of water that will flow through an orifice 1 inch square under a stated pressure head that ranges from 4 to 6½ inches in different places. The variance led, naturally, to confusion. So the value of the miner's inch has been set by statute in most of the Western States as follows:

50 miner's inches = 1 cfs (cubic foot per second) in Idaho, Kansas, Nebraska, New Mexico, North Dakota, South Dakota, Utah, Washington, and northern California.

40 miner's inches = 1 cfs in Arizona, Montana, Oregon, and southern California.

38.4 miner's inches = 1 cfs in Colorado.

Clearly, the miner's inch is an unhandy unit of measure and is nearly obsolete. It is of historic interest and is the basis of various water rights still in existence in the West.

In irrigation practice, the *acre-foot* is a common unit of volume. It is the quantity of water that will cover 1 acre to a depth of 1 foot and is equal to 43,560 cubic feet or nearly 326,000 gallons. An acre-foot equals about 1,230 m^3 (cubic meters) and 3.07 acre-feet make up 1 million gallons.

Flow rates in public water-supply systems are commonly reported in *gallons per minute* (gpm) or *millions of gallons per day* (mgd). Flow rates in rivers are commonly stated in *second-feet* (=cfs=cubic feet per second; the British call this unit the "cusec"). Flow at the rate of 1 cfs=449 gpm=0.645 mgd. Also, 1 cfs=28.3 l/s (liters per second)=0.0283 m^3/s (cubic meters per second).

Precipitation, whether as rain or as snow, is generally reported in this country in inches of depth per year. Precipitation intensity may be expressed as inches per hour. Elsewhere, the common measure of precipitation is the *millimeter* (mm=thousandth of a meter). There are 25.4 mm per inch.

Some of the equivalent units are shown in the following nomograph (fig. 7) and tables 4 and 5.

TABLE 4.—*Round-number conversions, English and metric units*

[Prepared by H. E. Thomas]

Length

	Symbol	*mm*	*m*	*km*	*in*	*ft*	*mi*
Millimeter	mm	1	0.001	----	0.039	0.003	------
Meter	m	1,000	1	0.001	39.4	3.28	------
Kilometer	km	----------	1,000	1	39,400	3,280	0.621
Inch	in	25.4	.0254	----	1	.083	------
Foot	ft	305.8	.305	----	12	1	------
Mile	mi	----------	1,610	1.61	63,360	5,280	1

Area

	Symbol	*m^2*	*ha*	*km^2*	*ft^2*	*acre*	*mi^2*
Square meter	m^2	1	--------	----	10.76	0.000247	------
Hectare	ha	10,000	1	----	107,600	2.47	0.00386
Square kilometer	km^2	1,000,000	100	1	10,760,000	247	.386
Square foot	ft^2	.093	--------	----	1	-----------	------
Acre	acre	4,050	.405		43,560	1	.00156
Square mile	mi^2	2,590,000	259	2.59	------------	640	1

TABLE 4.—*Round-number conversion, English and metric units*—Continued

Volume	
1 km^3 (cubic kilometer)	=811,000 acre-ft (acre-feet)
	=1,000,000,000 m^3 (cubic meters)
1 m^3 (cubic meter)	=35.3 ft^3 (cubic feet)
	=264. U.S. gallons
	=1,000 l (liters)
1 l (liter)	=0.0353 ft^3 (cubic foot)
	=0.264 U.S. gallon
1 mg (million U.S. gallons)	=3.07 acre-ft (acre-feet)
1 acre-ft (acre-foot)	=1,233 m^3 (cubic meters)
	=43,560 ft^3 (cubic feet)
	=325,900 U.S. gallons
1 ft^3 (cubic foot)	=0.0283 m^3 (cubic meters)
	=7.48 U.S. gallons
	=28.3 l (liters)
1 gal (U.S.)	=0.134 ft^3 (cubic foot)
	=3.78 l (liters)

Flow Rate	
1 km^3/yr (cubic kilometer/year)	=811,000 acre-ft/yr (acre-feet/year)
	=723 mgd (million U.S. gallons/day)
	=31.7 m^3/s (cubic meters/second)
1 mgd (million U.S. gallons/day)	=694 gpm (U.S. gallons/minute)
	=1.55 cfs (cubic feet/second)
	=0.044 m^3/s (cubic meter/second)
1 gpm (U.S. gallon/minute)	=0.063 l/s (liter per second)
1 m^3/s (cubic meter/second)	=22.8 mgd (million U.S. gallons/day)
	=15,800 gpm (U.S. gallons/minute)
	=35.3 cfs (cubic feet/second)
	=1,000 l/s (liters/second)
1 cfs (cubic foot/second)	=0.645 mgd (million U.S. gallons/day)
	=449. gpm (U.S. gallons/minute)
	=0.0283 m^3/s (cubic meter/second)
	=28.3 l/s (liters/second)
1 l/s (liter/second)	=15.8 gpm (U.S. gallons/minute)
	=0.0353 cfs (cubic feet/second)

TABLE 5.—*Miscellaneous equivalents*
[Prepared by H. E. Thomas]

1 inch of rain yields about 27,200 gallons per acre.
1 inch of rain yields about 100 tons per acre.
1 gallon of water weighs 8.34 pounds.
1 cubic foot of water weighs 62.43 pounds.
1 liter is nearly equivalent to 1¾ pints or ⅕ gallon.
1 imperial gallon (in the United Kingdom and Canada, for instance) = nearly 1⅕ U.S. gallon.
1 million gallons per day=1.547 cubic feet per second.
1 cubic mile=3,379,200 acre-feet=1×10^{12} (1 followed by 12 zeros) gallons.
1 cubic foot per second=1.98 (nearly 2) acre-feet per day.

WATER-QUALITY UNITS

What with chemical quality, biological quality, physical quality, radiological quality, there is a plethora of units used to discuss water quality. Atop all that, there are some units fading from use (grains per gallon), and a transition well along toward the use of metric units.

In this section we'll try to (1) make units useful by pointing out their origins and limitations, and (2) give indications of how units in one system relate to those in another system or to show that conversion from one system to another cannot be made. The discussion takes up the more common physical, chemical, biological, and radiological units.

PHYSICAL UNITS

WATER TEMPERATURE

Water temperature is of concern to just about everyone from the industrialist seeking cooling water, through the swimmer or fisherman (one likes it warm, one likes it cold), to the commercial ice manufacturer or the bon vivant, for despite folk tales to the contrary, block ice and ice cubes freeze faster from cold water than from warm. Temperature exercises major control over solubility of oxygen in water, so sanitarians are concerned. And, by now, we are all concerned with "thermal pollution," or "thermal enrichment," depending on local circumstances and personal point if view. Measurement of water temperature at one point in a water body and one moment in time is easy—just dunk in a thermometer or thermistor and read it off.

SAMPLING

However, planners and managers should always keep in mind the fact that a single read-

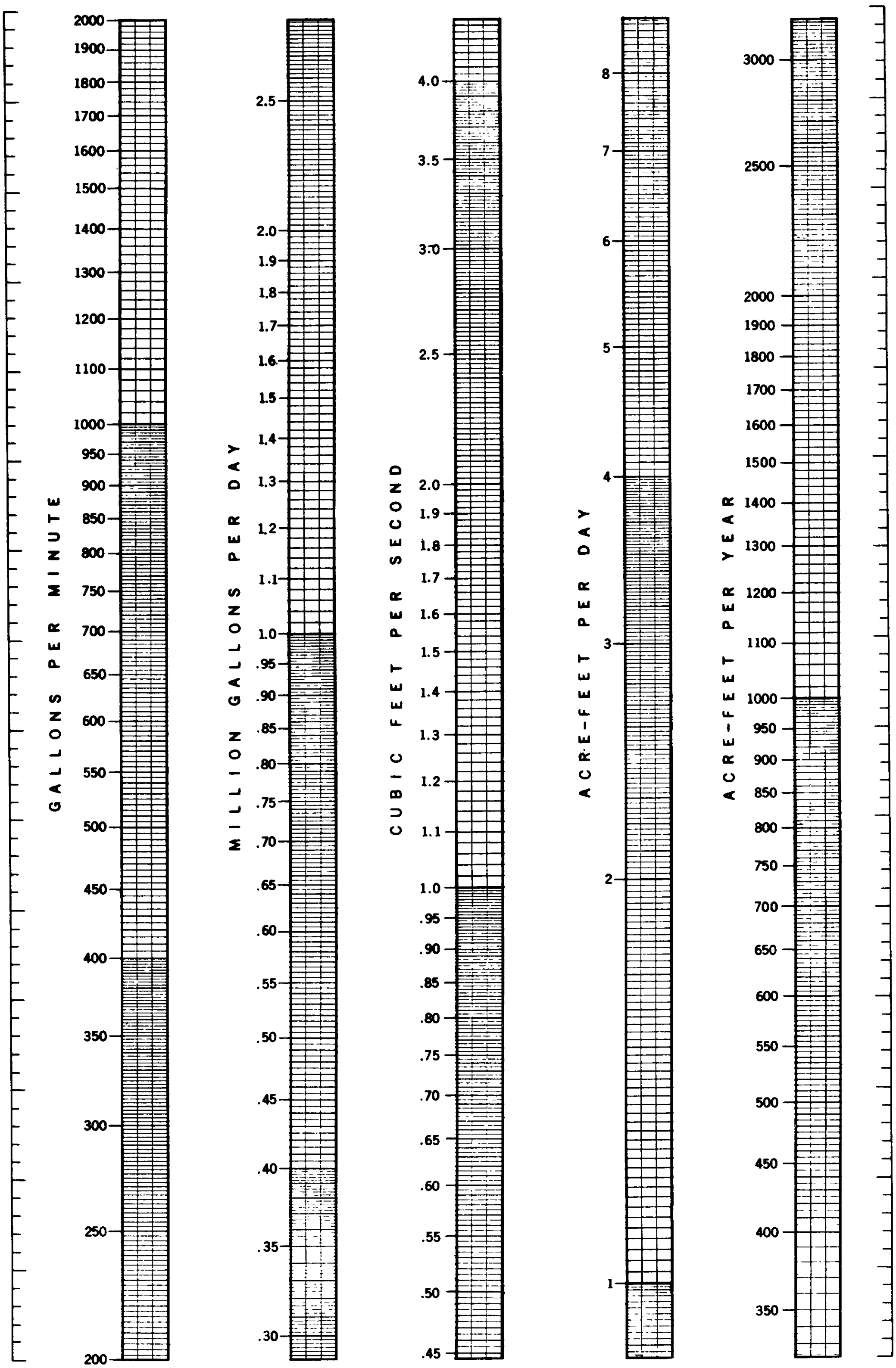

FIGURE 7.—Nomograph for converting water-measurement units (by William Back).

ing is not a sound basis for planning or decision. Water-temperature measurements, like all water-quality determinations, are samples that may or may not represent conditions in the whole water body. More likely there are variations with depth and laterally across and throughout the stream or lake. And there are changes with time—hourly often, seasonally for sure. Hardware is now available to monitor water temperature and other properties either continuously or at selected time intervals. If the relations between temperature at the sampling point and throughout the water body of interest are known, such continuous records can be used to great advantage in water management.

SCALES

The water cooler in an office puts out water at 8°C—sounds tooth-chilling, doesn't it? But 46°F, which it is, is just nice, cool, and refreshing. Lake trout spawn in water at comparable temperatures; salmon and stream trout in water a bit warmer but not higher than 13°C; but largemouth bass, bluegill, and the like, spawn when water temperatures approach 32°C, which is 90°F.

What are °C? They make up the metric temperature scale, of course, in which 0° is the freezing point of water and 100° (at sea level) the boiling temperature. Long called "centigrade," because of the 100-degree span from freezing to boiling, the scale now is frequently called the Celsius scale, after Anders Celsius, an 18th century Swedish astronomer who devised it. Like other metric measures, the Celsius scale is being used more and more in this country. Table 6 gives the temperature equivalents for the Fahrenheit and Celsius scales for the normal range of natural water temperatures.

SPECIFIC CONDUCTANCE

A common way to express general mineral content of water is by its *specific electrical conductance*—that is, its capacity to conduct an electric current. Truly pure water has almost no such capacity. Dissolved substances that ionize (form electrically charged particles) in water increase its capacity to conduct a current. So as dissolved-solids concentrations increase, the specific conductance (sometimes called *electrical conductivity*) also increases.

TABLE 6.—*Temperature conversion*

[To nearest °C]

°F	°C	°F	°C	°F	°C	°F	°C
32	0	55	13	78	26	101	38
33	1	56	13	79	26	102	39
34	1	57	14	80	27	103	39
35	2	58	14	81	27	104	40
36	2	59	15	82	28	105	41
37	3	60	16	83	28	106	41
38	3	61	16	84	29	107	42
39	4	62	17	85	29	108	42
40	4	63	17	86	30	109	43
41	5	64	18	87	31	110	43
42	6	65	18	88	31	111	44
43	6	66	19	89	32	112	44
44	7	67	19	90	32	113	45
45	7	68	20	91	33	114	46
46	8	69	21	92	33	115	46
47	8	70	21	93	34	116	47
48	9	71	22	94	34	117	47
49	9	72	22	95	35	118	48
50	10	73	23	96	36	119	48
51	11	74	23	97	36	120	49
52	11	75	24	98	37	121	49
53	12	76	24	99	37	122	50
54	12	77	25	100	38		

The ratio DS:Sp.cond. (dissolved solids to specific conductance) varies a bit but is generally in the range 0.6 to 0.7—dissolved-solids concentration (in mg/l) is six-tenths to seven-tenths the value of specific conductance (in micromhos) determined in a standard conductance cell. So, specific conductance of 1,000 suggests dissolved-solids concentration of 600–700 mg/l; 400 sp.cond. suggests 240–280 mg/l, and so on.

Conductance is the reciprocal of resistance so conductance is reported in reciprocal ohms, called mhos. Natural waters have specific conductance so much less than 1 mho that they are reported in *micromhos*, the observed value in mhos multiplied by one million.

For more detail on these subjects, see Hem (1970, p. 96–103).

pH

The *pH* of a solution (such as water) is defined as the negative logarithm, to the base 10, of the hydrogen-ion activity. That's a fact that you can file and forget. But what pH can tell about the usefulness of water is critically important to the user and manager of water.

The pH scale runs from 0–14. And pH is generally determined with a meter hooked up to two electrodes that are immersed in the water being tested. On the scale, 7.0 is neutral and is the pH of pure water. A pH less than 7 indicates an acidic solution, and a pH greater than 7 a basic solution.

The pH scale and some of its areas of significance are illustrated in figure 8. The pH scale is logarithmic—that is, each unit change in pH represents a 10-fold change in hydrogen-ion concentration.

Partly because the pH is sensitive to many environmental influences, this property of water is a very useful index to the balance of chemical forces in the water in its natural state. The reactions of water with various substances, as a function of pH, depend on the thermodynamic properties of those substances. Though the reactions indicated toward the upper and lower limits of the pH scale may appear anomalous, they can be explained in chemico-physical terms, although not simply.

A Warning

Although pH can be, and often is, precisely determined to two decimal places, many—probably most—reported pH values should not be taken exactly at face value. This is because the pH of a solution changes, sometimes drastically and very rapidly with exposure to air, with changes in temperature, with biological activity in the sample bottle, and in response to many other influences. Therefore, a pH determination made in the laboratory may not represent very well the pH of water in a river or lake, underground in an aquifer that supplies water to a well, or in a municipal water-distribution system for that matter. Where pH cannot be measured in place, it should be determined in the field just as soon as the water sample is taken. If a water supply is corrosive, but the lab reports show normal pH values, a field pH check may help to locate the trouble.

pH Ranges

Figure 8 shows that unpolluted natural waters tend to have a narrow pH range not far from neutrality. Narrow ranges, near neutrality, are the rule for most beneficial uses of water. The range in water used for public supply is surprisingly wide, a testament again to man's great adaptability—he can tolerate a wider pH range than most fish, for instance. Perhaps recognizing that, the U.S. Public Health Service (1962) did not set pH limits in its drinking-water standards.

The vast pH range of untreated wastewaters illustrates their potential impact on receiving waters. In addition to high organic loads, toxicity, content of heavy metals, and other characteristics that may be present, the extremes in pH of some wastewaters impose damaging conditions on sewage-treatment plants. The microorganisms die off or become ineffective in sewage treatment when pH becomes either too high or too low. Discharge of untreated waste may, of course, change the pH of lakes, streams, and estuaries to ranges outside the tolerance of some or all organisms present.

So, as said before, the technical definition of pH may be of little interest to planners and managers, but the relation of pH to use of water must be recognized.

TURBIDITY

Turbid water looks muddy. Actually, *turbidity* is defined as capacity to scatter light, and is measured by passing a beam of light through a tube containing a water sample and measuring the intensity of light scattered to a sensor set at right angles to the path of the beam.

Turbidity is expressed in arbitrary JTU (Jackson turbidity units), and the limits for water for domestic use are variously set at 1 to 5 JTU by different authorities. According to some criteria (FWPCA, 1968), wastewater discharges should not cause turbidity in receiving water greater than 50 JTU in warm-water streams, 25 JTU in warm-water lakes, or 10 JTU in cold-water streams or lakes. Turbidity is controlled by coagulation, sedimentation, and filtration.

The determination is not exact because the particles of clay, microorganisms, and other materials that cause turbidity have different capacities for scattering light.

SEDIMENT

Sediment consists of those particles of solid matter—mostly mineral—that are transported by flowing water. In size, the particles may range from grains of clay virtually invisible to the naked eye to huge boulders, but generally when we speak of sediment we refer to suspended sediment—those particles of clay, silt, and sand small enough to be transported throughout the water body rather than those

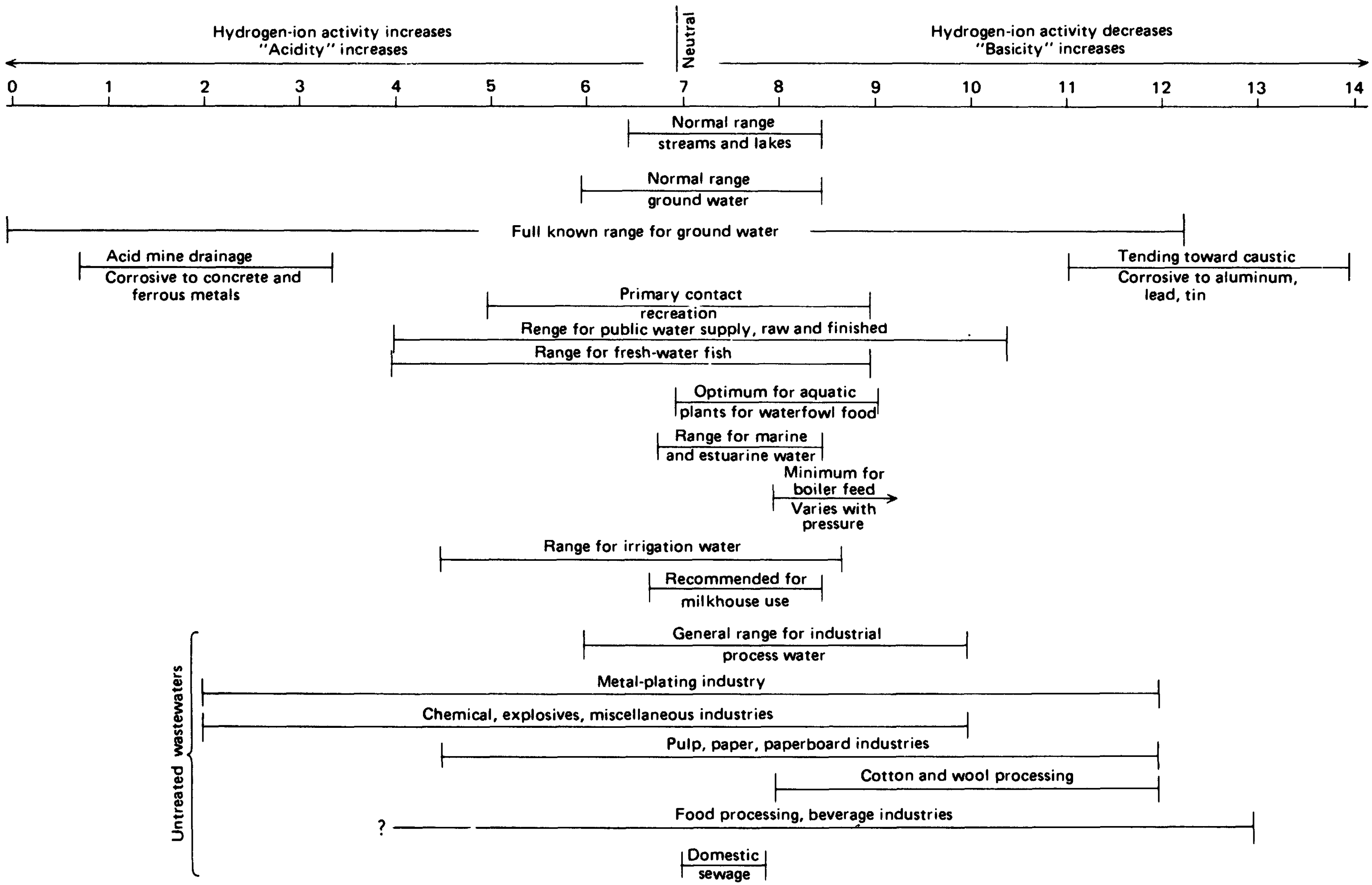

FIGURE 8.—pH ranges in relation to use. References: White, Hem, and Waring (1963), FWPCA (1968), Hem (1970), Rudolfs (1953), Ciaccio (1971), and Comp (1963).

moved along in contact with the bed of the stream (those are called bedload).

"Drinking Water Standards" says nothing about sediment. It is assumed that public water supplies are adequately filtered. Any tiny particles that might get through are then included in "turbidity" as far as "Standards" goes. Sediment, however, and the processes that produce it are important factors in overall water quality and in planning. In 1968–69, for instance, landslides and mudflows cost individuals and taxpayers at least $25 million in the San Francisco Bay region alone (Taylor and Brabb, 1972).

H. P. Guy (1970, p. E3–E4) summarized urban erosion and sediment problems. Following are some of the major concerns of sediment to the urban planners and managers. According to Guy (1970), sediment may affect public health as harmful bacteria, toxic chemicals, and radionuclides tend to be adsorbed and concentrated on sediment particles; sediment may also clog drainage ditches and form favorable spots for mosquitos to breed. Sheet, rill, and gully erosion is promoted in newly graded areas; undesirable changes in those areas may result, and the load of sediment may cause damage when deposited downstream. Raindrop impact on bare soil seals the land surface, reducing infiltration, increasing stream runoff, and decreasing ground-water recharge. Streams and other bodies of water are made unsightly by heavy loads of sediment. Their recreation potential is materially diminished. Water-treatment costs are increased as sediment concentrations go up. Erosion or deposition of sediment may cause bridge or culvert failure as well as serious ecological changes by alteration or destruction of the original habitat on the bed of the stream or lake. Sediment deposition during floods increases maintenance costs for streets, highways, and other public facilities. But perhaps the most serious urban sediment problem is the general deterioration of the total environment.

Areas with steep slopes are especially susceptible to erosion when the surface cover is disturbed, as during construction. The underlying materials—whether rock or sand or clay—of course strongly influence the erosibility. It is desirable—when feasible—to plan construction for periods when little intense rain is to be expected. Prompt restoration of cover of one kind or another over soil bared by erosion also is always a requisite.

POWERS OF TEN

Powers of ten are a handy and much-used device for expressing very large and very small numbers. A few "power" expressions are scattered through this circular, especially in the sections immediately following. Therefore, for ready reference, table 7 lists the powers of ten equivalents.

TABLE 7.—*Powers of ten*

One billion	1,000,000,000	1×10^{9}	
One million	1,000,000	1×10^{6}	
One thousand	1,000	1×10^{3}	
One hundred	100	1×10^{2}	
Ten	10	1×10^{1}	
One	1	1×10^{0}	
	0.1	1×10^{-1}	One tenth
	0.01	1×10^{-2}	One one-hundredth
	0.001	1×10^{-3}	One one-thousandth
	0.0001	1×10^{-4}	One ten-thousandth
	0.00001	1×10^{-5}	One hundred-thousandth
	0.000001	1×10^{-6}	One one-millionth
	0.000000001	1×10^{-9}	One one-billionth

Note that the value of zero cannot be expressed in powers of ten. As examples of the use of the table, $3.4\times10^{3}=3,400$; $4.9\times10^{5}=490,000$; $2.3\times^{-3}=0.0023$; and $5\times10^{6}=0.000005$.

CHEMICAL UNITS

ppm VERSUS mg/l

Parts per million (ppm) and *milligrams per liter* (mg/l) are not exactly the same, for 1 ppm is one part by *weight* in 1×10^{6} (one million) parts by *weight* (see fig. 9 and table 7), and 1 mg/l is one part by *weight* in 1×10^{6} parts (1 liter) by *volume*. Luckily, up to concentrations of about 7,000 mg/l, substances in solution generally don't change the density of water (specific gravity=1.0) enough to matter; so 1 liter of solution still weighs very close to 1×10^{3} g (1,000 grams). To that limit, then, ppm and mg/l are numerically interchangeable. Beyond the limit, a liter of solution weighs enough more than 1×10^3 g that density-correction factors are needed. But in planning we seldom have to deal with water having concentrations that exceed 1×10^3 or 2×10^3 mg/l (except for cooling water), so we can omit further complications.

μg/l TO pg/l

Most of the common ions and non-ionized constituents in water are found and reported in concentrations of a few tenths of one mg/l to a few hundred mg/l in waters we are concerned with. However, as trace constituents such as chromium, zinc, mercury, and the like become of more interest, another scale comes into play, and we have units such as:

μg/l (*microgram per liter*)

$$= \frac{mg/l}{1 \times 10^3} = 10^{-6} g = ppb = \text{part per billion.}$$

ng/l (*nanogram per liter*)

$$= \frac{mg/l}{1 \times 10^6} = 10^{-9} g = ppt = \text{part per trillion.}$$

pg/l (*picogram per liter*)

$$= \frac{mg/l}{1 \times 10^9} = 10^{-12} g = \text{(not used).}$$

The term "parts per trillion" has pretty much dropped out of use; nanogram is holding its own—an increasing number of analytical procedures achieve that sensitivity. Both ppb and its equivalent μg/l are used in reporting trace constituents, both metallic and those of organic nature such as pesticides.

BIOLOGICAL UNITS

INTRODUCTION

"The coliform count * * * is the only commonly used parameter that bears any direct relation to the public health" (Camp, 1963, p. 209–210). Accepting that premise, we shall here talk almost solely about the coliform group of bacteria that includes *fecal coliform* bacteria (until recently called *Escherichia coli* and earlier *Bacillus coli*), and the coli-aerogenes group of microorganisms that are considered to be *indicators* of fecal pollution. The coliform bacteria are not of themselves known to be harmful. But they occur in great numbers, and many are found in the gut and feces of warm-blooded animals—these are fecal coliform bacteria. Currently, methods are available (APHA, 1971, p. 635–636) for determination of fecal streptococci and enteric viruses, among which are major pathogens (disease-causing organisms), but the methods remain largely provisional. Hence the bacteriological acceptability of water for domestic use, shellfish culture, water-contact sports, and the like is still judged largely by the detectable content of coliform bacteria.

The rationale behind that judgment is the fact that fecal coliform bacteria, fecal streptococci, and enteric viruses all are discharged with animal feces. Therefore, the presence of any coliform organisms (fecal used to be hard to test for separately) was taken to suggest that the pathogenic organisms (streptococci and viruses) might also be present. And that brings us to the terms "MPN" and "colonies per 100 ml."

MPN

Before going on, let's recognize two warning flags. One was hoisted by McKinney (1962, p. 129) who said: "The MPN value is not an absolute number, but it has been so abused by sanitary engineers that the MPN value has almost taken absolute significance. A single MPN value suddenly becomes an absolute number." The second flag is from "Standard Methods" (APHA, 1971, p. 637), which states: "Bacteriologic results must be considered in the light of information available concerning the sanitary conditions surrounding the source of any particular sample." In other words, don't read a test result and then shoot from the hip.

MPN INDEX

The *MPN* (most probable number) is that number of coliform bacteria statistically most likely to produce the test results observed. The *MPN index* per 100 ml is assigned within 95 percent confidence limits. Both the index and the limits vary with the size of sample portions used and with test procedures followed. In essence, the MPN index is a manufactured number—a statistical likelihood analogous to a number on an actuarial table—and not a hard and fast fact. "Standard Methods" (APHA, 1971, p. 672–676) gives tables from which test results can be converted to the MPN index.

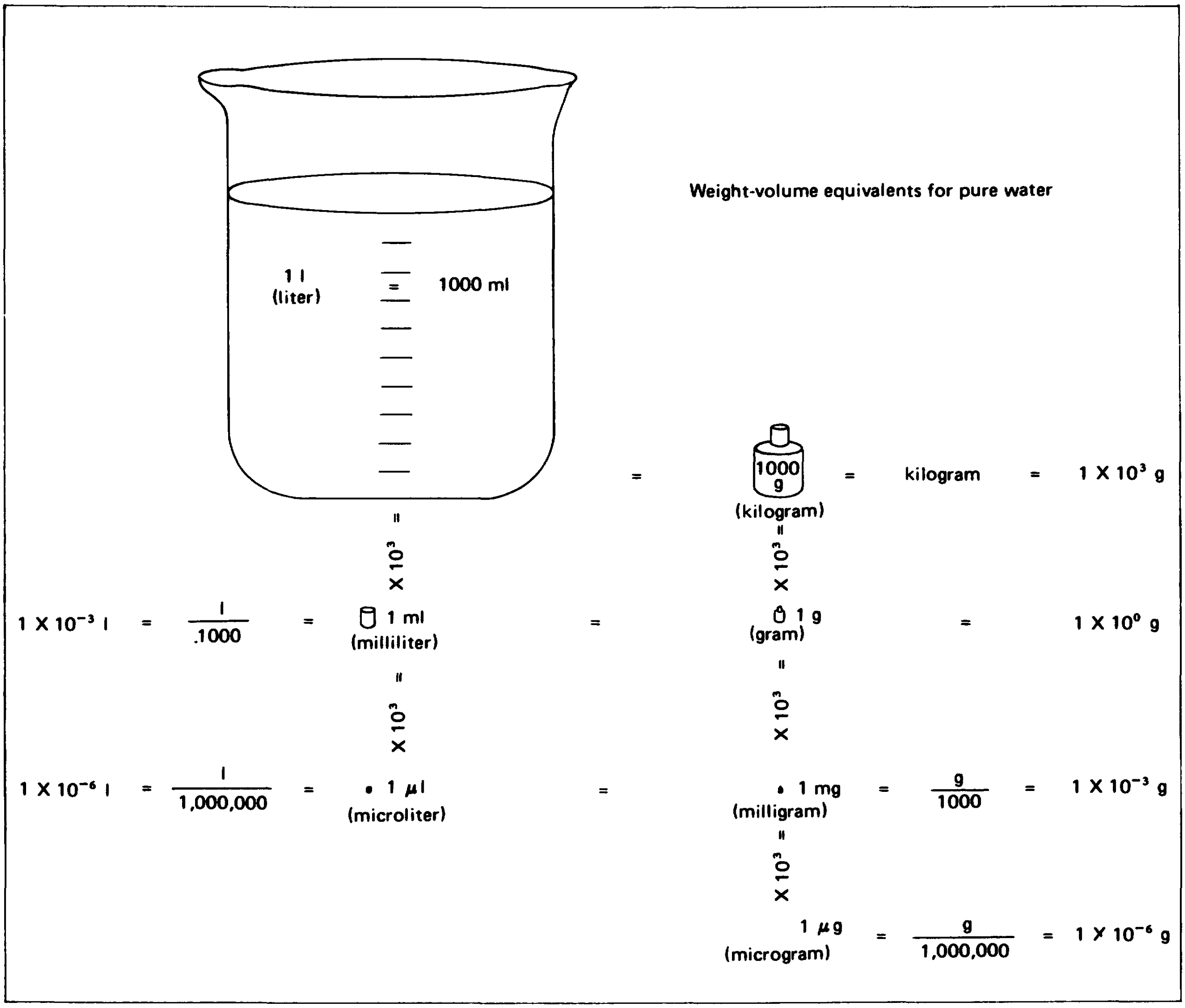

FIGURE 9.—Weight-volume equivalents for pure water.

COLONY COUNT

In recent years, another method for coliform determination has gained increasing acceptance. Briefly, this method involves passing a portion of water sample—with proper precautions to insure sterility of equipment—through a paper filter. The filter is transferred to a base of nutrient in a petri dish and incubated. After 22–24 hours the coliform colonies that develop are counted, and the count is calculated, if necessary, to the number appropriate to 100 ml by the equation:

$$\text{Coliform colonies per 100 ml} = \frac{\text{coliform colonies counted} \times 100}{\text{ml of sample filtered}}.$$

Results are reported as total coliform colonies per 100 ml. Because in this method colonies of bacteria are observed, there is no ready way in which to estimate (or determine) the number of individual bacteria. "Standard Methods" (p. 678–685) discusses the membrane-filter (colony count) method, including a modification specific for fecal coliform bacteria.

CAVEAT EMPTOR

"Let the buyer beware" is heard normally with reference to commerce and the marketplace. But translated as "let the user beware," the warning is not inappropriate.

The colony count and the MPN index are not interchangeable, nor can one result be translated to an equivalent in the other units.

For reasons stated and suggested above, the U.S. Public Health Service (USPHS, 1962, p. 3–6) set bacteriological-quality standards for drinking water "used by carriers subject to the Federal Quarantine Regulations" with a flexibility that recognizes the uncertainties inherent in methods now available for coliform determinations.

Most planners and managers may want to rely on public-health consultants for advice in interpreting MPN-index and colony-count data.

DO BOD TOC COD?

This is neither a request for fish, written in medieval English, nor an incantation in some exotic language. It's a composite of four characteristics of water, closely related to one another, and all related to what's called the "health" of lakes, streams, and estuaries.

DO (dissolved oxygen) is, strictly, a chemical-quality term and is reported in mg/l or ppm or in percentage of saturation. The concentration is determined by chemical methods or by use of a special electrode. The ability of water to retain oxygen in solution is strongly dependent on temperature as, at sea level, saturation at 10°C is 11.33 mg/l, but at 30°C only 7.63 mg/l. In "healthy" warm-water lakes or streams, DO should not fall below 5 mg/l, and in cold-water lakes or streams, not much below 7 mg/l. Normally, natural water does not hold in solution more oxygen than the saturation limits indicated above.

The term "oxygen sag" appears frequently in discussions of polluted streams. It refers to a marked reduction in dissolved-oxygen content that may occur in response to various influences. Normal water bodies show an oxygen sag daily as the water warms up in the sun. Remember that the warmer the water, the less oxygen it can hold in solution. The "sag" disappears as the water cools off at night and redissolves oxygen from the air. Such sags normally are small and do no damage.

More serious sags occur in response to introduction of loads of oxygen-consuming waste— or of heated water. Such sags are dissipated downstream from the waste discharge. But in moderately extreme and sudden loadings, the sag may become so severe that fish kills result, even though the oxygen depletion may last only a short time.

In streams and lakes where nutrient concentrations are high — commonly polluted waters—there is a tendency for algae to multiply into what may be "nuisance blooms." In those circumstances, and even where algae are abundant but not to the "nuisance" level, the traditional oxygen-sag pattern is reversed. In sunlight the algae, being plants, produce oxygen by photosynthesis and the daylight hours in consequence are hours of high oxygen content. At night, respiration (the reverse of photosynthesis) occurs, the algae take oxygen back from the water, and concentrations diminish progressively until daylight restores photosynthetic activity. Eventually, the algae die off and the processes of their decay impose a heavy oxygen demand on the water, so a long-lasting, serious, and sometimes deadly oxygen sag is formed.

BOD (biochemical oxygen demand) is a laboratory assay of the consumption of DO in water samples by oxidation of organic materials—or use by microorganisms in metabolic processes. The common procedure requires incubation of sample plus oxygen-saturated water for 5 days. BOD is, therefore, often reported as "5-day BOD." The units are mg/l. The BOD is determined by analyzing for the DO remaining in the sample after 5 days of incubation. BOD determinations are most useful when applied to wastewaters. Values of BOD for stream and lake waters are hard to interpret because of large differences between the laboratory environment of the test and the natural environment from which the samples came. However, in broad terms, a high BOD suggests a water burdened with organic wastes and therefore likely to be deficient in oxygen— therefore a water in which only certain plant and animal life can survive.

TOC (total organic carbon) is recognized in the 1971 edition of "Standard Methods" as a tentative procedure that involves oxidation of organic carbon in the water to CO_2 (carbon dioxide) and determination of CO_2 in a gas analyzer. Results are reported in mg/l of carbon. At present, there is no automatic way to interpret TOC in terms of BOD or other related measures of organic pollution. In a study of a particular water body, it may be possible to develop by trial and comparison, a relation between TOC and BOD that is appropriate to that particular study, but the relation cannot be transferred to other environments across the board.

COD (chemical oxygen demand) provides a quick, rough measure of the loads of pollution or oxidizable materials in water. The COD test is based on the fact that organic compounds, with few exceptions, can be oxidized by strong oxidizing agents under acid conditions. Samples are heated with strong oxidizing agents, the organic material is oxidized, and the amount of oxygen required for this oxidation is calculated in terms of mg/l. COD tests give a general estimate of organic loading in water, but cannot be used interchangeably with BOD values.

RADIOLOGICAL UNITS

Threat to health and life from radiation has haunted us at least since Hiroshima and Nagasaki. Physicians, public health officials, and biologists are concerned with units such as the "r" (roentgen), "rad" (radiation absorbed dose), and "rem" (roentgen equivalent man). These and others are defined and discussed by McKee and Wolf (1963, p. 343–354).

Although the rads, rems, and so on are really what we care about for reasons of personal and public health, the "RBE" (relative biological effectiveness) of the several types of radiation emitted by radioactive substances effectively precludes easy interpretation of their concentrations in water supply. The varying responses to radiation in different parts of the body—and from individual to individual—further fog the view.

Consequently, limiting concentrations have been set by different agencies at different levels. The controversy continues.

The occurrence of radioactivity in water also is reported in several ways. The reporting units may be based on various assumptions (McKee and Wolf, 1963, p. 343–354; Hem, 1970, p. 209–215).

Uranium, commonly thought of as *the* radioactive element, actually is a sluggard because of its slow rate of radioactive disintegration (long half-life). In water analyses, uranium is commonly reported in micrograms per liter. Uranium is sparingly soluble. Hem (1970, p. 212) cited concentrations of 0.1 to 10 μg/l as the normal range in natural water.

Other radioactive substances are present in water in smaller quantities that are extremely hard to measure directly. Some, however, are much livelier than uranium, and disclose their presence by radioactivity. Their "concentrations," therefore, are commonly expressed in water analyses by *activities* in μc/l (microcuries per liter) or pc/l (picocuries=micromicrocuries per liter). Activities are measured by mechanically sensing and counting (as with a Gieger counter) radioactive emissions.

A c (curie) is a measure of rate of decay of a radioactive substance and is defined as 3.70×10^{10} disintegrations per second (McKee and Wolf, 1963, p. 343). A μc (microcurie) is one one-millionth of a curie or 3.70×10^{4} disintegrations per second, and a picocurie is one one-trillionth of a curie or 3.70×10^{-2} disintegrations per second—say 2–3 counts per minute, in round numbers.

Health standards are expressed in MPC (maximum permissible concentration) which takes into account such things as the degree to which the human body accumulates and stores the element in question, the element's half-life, the average daily intake of water by people, and sources of the element other than water. The complexity is compounded by our rather scanty knowledge of some of the factors just named and confounded further by differences of opinion among people setting MPC values. No wonder MPC's are not the same worldwide.

Among 18 radionuclides tabulated by McKee and Wolf (1963) table 8–1), four are emitters of alpha particles—but of those, only radium-226 is important. So, commonly, water analyses for radioactive elements assign all alpha activity to radium-226 and report radium in terms of pc/l (picocuries per liter, remember?). U.S. Public Health Service (1962, p. 58) cited 3 pc/l as a limit for radium-226, and 10 pc/l as a limit for strontium-90 activity, where separable. The World Health Organization, playing it conservatively, has indicated a limit of 1 pc/l alpha as surely safe, but went on to say "Higher figures * * * may be safe" if absence of dangerous radionuclides can be demonstrated (McKee and Wolf, 1962, p. 348).

The same source shows a level of 10 pc/l as safe for beta (and presumably gross beta-gamma) activity. Beta-gamma activity is reported in either microcuries or picocuries per liter.

These, then, are a few (but not all) of the problems in understanding reports of radioactivity in water. Most planners and managers may want to leave interpretation of radiological hazards to their public-health consultants.

WATER-QUALITY STANDARDS AND CRITERIA

The Federal Water Pollution Control Act amended by the Water Quality Act of 1965 authorized—indeed required—all States and the Federal Government to estabilsh water-quality standards for interstate streams and coastal waters. The law included a requirement that standards to be set should "protect the public health or welfare, [and] enhance the quality of water * * * ." The "enhance" provision proved to be controversial as many States felt maintenance of the status quo was enough to ask. However, in the end, the 50 States complied, and water-quality standards were established.

In addition, various river-basin commissions, regional water-pollution control boards, international treaties, and other governmental bodies have their own sets of standards or criteria. It is infeasible to assemble them all—or even to find a representative series of examples. Their numbers are too many and their purposes—hence requirements—too diverse.

There is a good deal of confusion in use of the terms "standards" and "criteria." The Federal Water Pollution Control Administration (now the Environmental Protection Agency) reported (FWPCA, 1968, p. v) the following definitions:

Standard—a plan that is established by governmental authority as a program for water pollution prevention and abatement.

Criteria—a scientific requirement on which a decision or judgment may be based concerning the suitability of water quality to support a designated use.

McKee and Wolf (1963, p. vii) said in this connection:

> * * * the use of the word "standard" has been avoided * * * for its signifies "any definite rule, principle, or measure established by authority." Instead "criterion" has been chosen for it designates "a means by which anything is tried in forming a correct judgment respecting it."

Putting those ideas together, one may conclude that a set of criteria are assembled, usually experimentally, that tell you what is known about the behavior of substances in water—whether they are harmful or beneficial, and in what concentrations the harm or benefit is likely to occur. Then, on the basis of those data, an agency with authority to do so, sets guidelines or rules (see below) as water-quality standards.

The most widely quoted—and sometimes misquoted—set of water-quality standards in the United States most likely is the Drinking Water Standards, 1962, published by the U.S. Public Health Service (1962) of the Department of Health, Education, and Welfare. Those standards (rules, regulations, limits) have been widely accepted by local health agencies which have modeled their own accordingly—or adopted the USPHS standards across the board. The standards have been widely quoted in the literature on water quality and used to evaluate potential supplies in terms of their acceptability for drinking water.

And in the process, an important distinction has sometimes been overlooked, which is why the reference was made to misquotation. There are two types of limits in the standards, carefully defined in the book (USPHS, 1962, p. v). The two are:

> (a) Limits which, if exceeded, shall be grounds for rejection of the supply. Substances in this category may have adverse effects on health when present in concentrations above the limit.

Type (a) limits are often referred to as the *mandatory* limits.

> (b) Limits which should not be exceeded whenever more suitable supplies can be made available at reasonable cost.

Type (b) limits are the *recommended limits.* In effect, those limits are desirable because, if exceeded, the water may be esthetically displeasing or may cause nonlethal but unpleasant reactions in the more susceptible users of the water. It's nice not to exceed the recommended limits—but an excess is not necessarily grounds for rejecting the supply if you can't do better. A case in point involves the commonly quoted "limit" of 500 mg/l dissolved solids (or 1,000 mg/l when better water is not available) that appears in the USPHS Standards. Many a water report implies that water having a higher dissolved-solids concentration cannot be used for public supply. But USPHS Standards (1962, p. 33) itself says, "More than 100 public supplies in the United States provide water with more than 2,000 mg/l of dissolved solids. Newcomers and casual visitors would certainly find these waters almost intolerable * * * [but] many are able to tolerate if not to enjoy these highly mineralized waters."

The moral of this story is: know the Federal, State, and local regulations that apply to your own circumstance. And bear in mind the critical difference between mandatory and recommended limits.

The USPHS standards (abbreviated) and those of WHO (World Health Organization) are shown in table 8.

TABLE 8.—*Comparison of chemical constituents in the drinking water standards of the World Health Organization and the U.S. Public Health Service*

Chemical Constituent	Concentrations in milligrams per liter			
	WHO International (1971)		U.S.P.H.S. (1962)	
	Highest desirable level	Maximum permissible level	Recommended limit	Maximum allowable
Anionic detergents	0.2	1.0	0.5	---
Arsenic	---	.05	.01	0.05
Barium	---	---	---	1.0
Cadmium	---	.01	---	.01
Calcium	75	200	---	---
Carbon chloroform extract	---	---	.2	---
Chloride	200	600	250	---
Chromium (hexavalent)	---	---	---	.05
Copper	.05	1.5	1.0	---
Cyanide	---	.05	.01	.2
Fluoride	Same as USPHS	---	[1] 0.8–1.7	[1] 1.6–3.4
Iron	.1	1.0	.3	---
Lead	---	.1	---	.05
Magnesium	[2] 150	150	---	---
Manganese	.05	.5	.05	---
Nitrate (as NO_3)	---	45	45	---
Phenolic compounds (as phenols)	.001	.002	.001	---
Selenium	---	.01	---	.01
Silver	---	---	---	.05
Sulfate	200	400	250	---
Total solids	500	1,500	500	---
Zinc	5.0	15	5.0	---

[1] Recommended limits and maximum allowable concentrations vary inversely with mean annual temperature.
[2] If there are 250 mg/l of sulfate present, magnesium should not exceed 30 mg/l.

GLOSSARY

Acre-foot. The quantity of water needed to cover 1 acre to a depth of 1 foot. Equals 43,560 cubic feet=1,233.4 cubic meters=325,851 gallons=1,233,000 liters.

Activity. Here used as measure of rate of decay of a radioactive element. Each departure of proton, neutron, etc., from an atom of an element is a disintegration, an event that can be recorded instrumentally. So activity is an expression of the rate of radioactive disintegration, registered by counts, as on a Geiger counter.

Aquifer. A subsurface water-bearing unit that transmits water rapidly enough to supply useful quantities to springs and wells. Sand and gravel aquifers are characterized by innumerable spaces around and among the grains. Water is stored in and moves through those spaces. Limestone may have intergranular spaces but commonly stores and transmits water in small to cavernously large openings formed by solution. Lavas, especially basalt, store and transmit water in cracks and in bouldery zones of rubble between successive flows of lava.

Baseflow. Low flow in streams; occurs typically during long periods between rains when streamflow is maintained mostly or entirely by ground-water discharge.

Biochemical oxygen demand (BOD). A measure of the living and nonliving organic demand for oxygen imposed by wastes of various kinds. A high BOD may temporarily, or permanently, so deplete oxygen in water as to kill aquatic life. The determination of BOD is perhaps most useful in evaluating impact of wastewater on the receiving water bodies.

Celsius, degrees (°C). A temperature scale based on 100 equal divisions (degrees) between the freezing temperature of water (taken as 0°C) and the sea-level boiling temperature (taken as 100°C). Named for Anders Celsius, an 18th century Swedish astronomer who devised the scale.

Chemical oxidiation demand (COD). A quick (and only approximate) measure of loads of oxidizable matter in water. Results cannot be used interchangeably with BOD values. However, COD can quickly identify water with very low or very high BOD potential.

Coli-aerogenes group. See Coliform bacteria.

Coliform bacteria. A large and varied group of bacteria. The fecal coliform bacteria flourish in the guts and feces of warm-blooded animals, including man. *Escherichia coli* (*E. coli*) is largely of fecal origin and has been the indicator organism most commonly cited as indicating sewage or feedlot pollution. The coliforms apparently do not themselves cause disease, but their presence in water suggests that disease-causing organisms (pathogens) may also be present. Coliform bacteria are used as indicators of pollution because they are abundant and their presence is fairly easy to detect. The coli-aerogenes group is also among indicator organisms and is not usually distinguished from other fecal coliforms. Fecal streptococci and enteric viruses are pathogens found in animal wastes. Methods for their identification in water remain provisional. The presence of fecal coliform bacteria suggests that streptococci and viruses *may* be present—hence the concern over danger of infection whenever large numbers of fecal coliform bacteria are detected in water. (See Most Probable Number.)

Conjunctive use. Planned management of surface- and ground-water resources as a single, interlocking system.

Cubic foot per second (cfs). A flow rate=28.32 liters per second=448.831 gallons per minute. Same as *second-foot* or British cusec.

Curie. See Activity.

Cusec. See Cubic foot per second.

Dissolved oxygen (DO). DO concentration of unpolluted water depends pretty much on atmospheric pressure and temperature. Therefore it is greater at sea level and when water is cool than at high altitudes or when water is warm.

Nonliving organic matter (especially its content of carbon in any form) and various chemicals react with oxygen in water, depleting the oxygen and causing stress from lack of oxygen on fish and other aquatic life. In extreme depletion, water may become anaerobic (literally without air), stagnate, and stink.

Electrical conductivity. See Specific conductance.

Enteric viruses. See Coliform bacteria.

Fahrenheit, degree (°F). The familiar thermometer scale in which freezing temperature of water is 32°F and boiling at sea level is 212°F. Named for Gabriel D. Fahrenheit, an 18th century German physicist.

Fecal coliforms. See Coliform bacteria.

Fecal streptococci. See Coliform bacteria.

Ground water. Subsurface water that completely fills (saturates) all available space within an aquifer and below the top of the zone of saturation. Contrast with *Water in unsaturated zone.* Ground water does not occur in subsurfaces "lakes" nor move in subsurface "rivers" except those in a few caves in limestone.

Half-life. See Radioactivity.

Ion. An electrically charged particle of matter dissolved in water. For instance, common table salt has no chemical charge. In water, salt "dissociates;" each molecule of salt (NaCl) forms one ion of sodium (Na^{+1}) with a positive charge, and one ion of chloride (Cl^{-1}) with a negative charge. (Chlorine is a gas; each molecule consists of two atoms of the element chlorine. In water, the atoms travel alone, are electrically charged, and are called chloride ions.)

Kilogram (kg). A unit of weight=1,000 grams= weight of 1 liter of pure water.

Liter (l). Metric measure of volume=1,000 ml (milliliters). For pure water, 1 liter weighs 1 kilogram= 1,000 grams.

Maximum permissible concentration (MPC). A standard intended to govern the concentration of a radioactive substance allowable in drinking water. Standards—and only a few have been suggested—differ from place to place. The MPC for any element is set on the basis of variables such as sources other than water from which the element may be absorbed, degree to which element accumulates in the body, estimated daily intake of water, and half-life of the element.

Microcurie. See Activity.

Microgram (μg). One one-millionth of a gram= 1×10^{-6}g.

Microgram per liter (μg/l). One one-millionth of a gram of substance in 1 liter of water. Equals *part per billion* (ppb) because 1 liter of pure water weighs 1,000 grams, so we have 1 one-millionth of 1 gram in 1,000 grams, or 1 ppb by weight. Used in identifying and reporting trace concentrations of heavy metals or of pesticides.

Micromhos. See Specific conductance.

Milligram per liter (mg/l). One part *by weight* of dissolved chemical, or suspended sediment, in 1 million parts *by volume* (=1 liter) of water. Numerically equivalent to *parts per million* (ppm) between 0 and about 7,000 mg/l.

Milliliter (ml). One one-thousandth of a liter=the volume of 1 gram of pure water.

Miner's inch. Obsolete unit of measure in western States; variously, 38.4, 40, and 50 miner's inches= 1 cubic foot per second, as set by law in different States. Still the basis for some old water rights.

Most Probable Number (MPN). A statistical evaluation of degree of water pollution based on presence of coliform bacteria. It is not feasible to identify the exact concentration of coliform bacteria in a water sample. The MPN interprets test results in terms of results observed. (See Coliform bacteria.)

Nanogram per liter (ng/l). One one-billionth of a gram of substance in 1 liter of water. Equals *part per trillion* (ppt) because 1 liter of pure water weighs 1,000 grams, so we have 1 one-billionth of one gram in 1,000 grams, or 1 ppt *by weight.* Trace concentrations of heavy metals or of pesticides are reported in nanograms per liter. "Parts per trillion" has pretty much dropped out of use.

Part per billion (ppb). See Microgram per liter.

Part per million (ppm). One part by weight of dissolved chemical, or suspended sediment, in 1 million parts *by weight* of water. Numerically equivalent to *milligrams per liter* (mg/l) between 0 and about 7,000 ppm.

Part per trillion (ppt). See Nanogram per liter.

pH. Measure of hydrogen-ion activity in solution. Expressed on a scale 0 (highly acid) to 14 (highly basic). pH 7.0 is a neutral solution, neither acid nor basic.

Pathogens. See Coliform bacteria.

Picocurie. See Activity.

Powers of ten. A convenient notation based on multiples of 10—ten raised to a positive or negative exponent. The number 1.0 is 1 times 10 to the zero power (1×10^0). Positive exponents (powers) are numbers greater than 1.0. Negative exponents express numbers (decimal fractions) smaller than 1.0. Each increase of 1 in the exponent (power) is equivalent to moving the demical point one place—positive to the right, negative to the left. By convention, the number expressed as a power of 10 is stated as one whole number to left of decimal, plus whatever is needed to complete the number, times 10 to the appropriate power. For instance:

365 million $=3.65\times10^8$

365 millionths $=3.65\times10^{-6}$, which is handier (once you're used to it) than its equivalent 0.00000365, or even $\frac{365}{1{,}000{,}000}$.

Radiation absorbed dose (rad). A measure of the radiation dose absorbed by matter (as human tissue, for example). The rad is about equivalent to the absorption of 1 roentgen (r) of X-rays.

Radioactivity. The property of some elements of giving off particles or rays or both. The rays are gamma or X-rays. The particles are alpha particles (like the nucleus of a helium atom), neutrons, or protons. The process is called radioactive decay. Decay rate is measured by the *half-life*—that is, by the time it takes for one-half the available particles to be given off. Uranium decays slowly and has a half-life of about 4.5 billion years. Strontium-90 has a half-life of 28 years. Tritium (radioactive hydrogen) has a half-life of about 12.5 years. Some man-made radioactive elements have half-lives of tiny fractions of a second.

Radionuclide. A radioactive atom having (1) a specified number of protons and neutrons (therefore a specified mass), and (2) the property of giving off protons, neutrons, or rays at a specified time rate.

Recharge. Addition of water to an aquifer. Occurs naturally from infiltration of rainfall and of water flowing over earth materials that allow water to infiltrate below land surface. *Artificial recharge* through injection wells, or by spreading surface water where it will infiltrate is widely practiced in some places such as southern California and Long Island, N.Y., both to store water where it won't evaporate and to protect ground-water bodies from intrusion of sea water into aquifers.

Relative biological effectiveness (RBE). A measure of the relative effect on man of various types of radiation. One rad of alpha particles or of neutrons or protons has 10 times the RBE of 1 rad of beta particles or gamma or X-rays. Heavy recoil nuclei are estimated to be 20 times as damaging as X-rays on the same scale.

Roentgen (r). A measure of radiation (as X-rays= gamma rays). One r produces in 1 cubic centimeter of air, ions that carry one electrostatic charge.

Roentgen equivalent man (rem). The quantity of radiation of any kind that has the same effect on man as does absorbing 1 roentgen (r) of X-rays. The various kinds of radiation considered are gamma and X-rays, beta particles, alpha particles, neutrons and protons, and heavy recoil nuclei.

Second-foot (cfs). See Cubic foot per second.

Specific conductance (Sp. cond.). Literally *specific electrical conductance* (or *electrical conductivity*); a measure of the capacity of water to conduct an electrical current under standard test conditions. Increases as concentrations of dissolved and ionized constituents increase. Actually measured as resistance (in millionths of an ohm) but reported usually as micromhos (reciprocal of millionths of an ohm). As a rule of thumb, dissolved-solids concentration (in mg/l) is 60–70 percent of specific conductance (in micromhos).

Surface water. The water we see on the land surface, as in lakes, ponds, and streams.

Total organic carbon (TOC). A newly developing test for the one constituent, carbon, in wastewater that perhaps most influences BOD. Relations between TOC and BOD must still be determined by trial and error in specific studies before TOC alone can be used as an index of organic pollution of a waterbody.

Turbidity. Defined as capacity of materials suspended in water to scatter light. Measured in arbitrary Jackson turbidity units (JTU). Highly turbid water is often called "muddy," although all manner of suspended particles contribute to turbidity.

Water in unsaturated zone. Water, including soil moisture, below land surface but above the zone of saturation where all available space is filled by water. This water may percolate down to the zone of saturation to become ground water, or may, as soil moisture does, return to the surface by capillary attraction or in roots of plants.

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