A layman's look at . . .

Water in ALABAMA

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Report based mainly on work accomplished cooperatively with the Geological Survey of Alabama, the Alabama Highway Department, and other State, Municipal, and Federal agencies

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CONTENTS

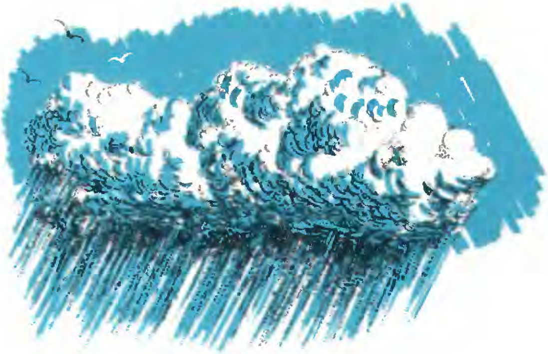
FIGURES

Introduction

?Do forests reduce floods?
?Where does my well water come from?
?What is the temperature of the water that will be found in a well on my farm?
?Will salt or fresh water be found if I drill a well?
?Is the water table falling in my State?

These and similar problems are discussed in this book. The section on "The supply of water" concerns the occurrence of water in Alabama, and some aspects of climate and land which affect the supply of water. The section "The use of water" is about the use of water in Alabama, and problems associated with water supply and flood control. The "Tomorrow's water" section discusses opportunities for further development.

The three authors are a geologist, an engineer, and a chemist of the U.S. Geological Survey. Together, they have devoted half a century to the technical and scientific study of water resources. Their work in Alabama has been supported cooperatively by the U.S. Geological Survey, the Geological Survey of Alabama, and several Federal, State, and local agencies.



THE SUPPLY OF WATER

The Water Cycle

Our water comes from the ocean, as shown on figure 1, and returns to the ocean in a never-ending cycle. Water evaporates from the ocean and becomes vapor in the air. Carried overland by winds, it condenses and falls as rain or snow, part of which is absorbed by soil, part evaporated, and part used by trees and plants. The remainder returns to the ocean through streams that drain the land. During its journey, water modifies the face of the earth by erosion and other processes. The cycle moves at a varying pace (sometimes there is drought, occasionally flood), but move it does and thus replenishes the supply for land and people.

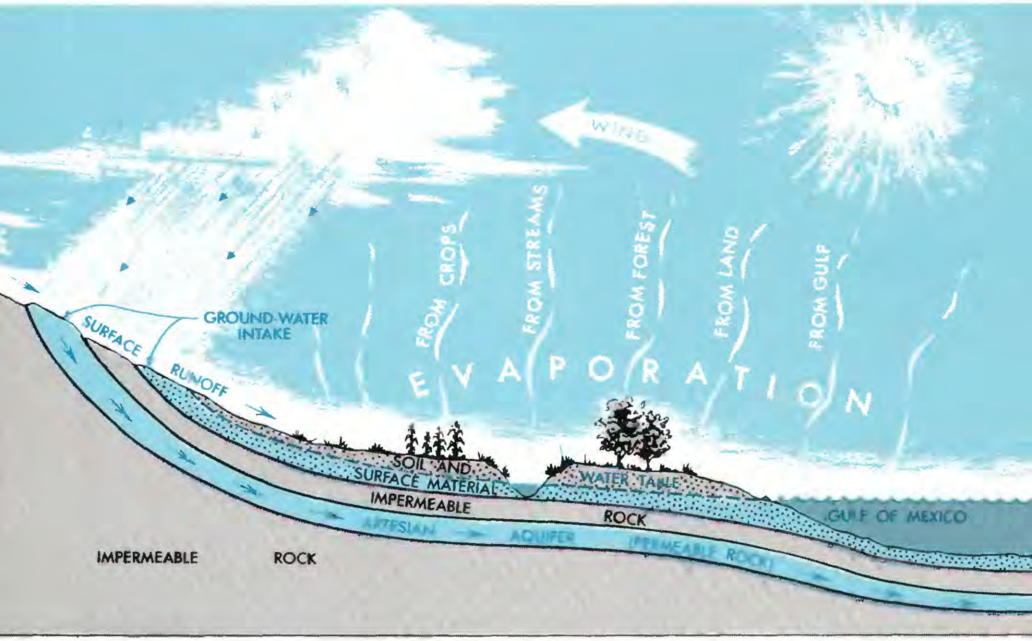


FIGURE 1.—Water, a renewable resource. Moisture from the Gulf of Mexico is carried by winds over the land and falls as rain. Part is absorbed by the ground, part is used by vegetation, part again evaporates, and part runs back to the Gulf in streams.

The total amount of water in and on the earth changes but little, if at all. Some is in the oceans, rivers, and lakes; some is in openings in soil and rock; some is frozen in polar icecaps and in glaciers; some is in the tissues of plants and animals; and some is held as vapor in the atmosphere. Most of the vapor that condenses into rain is evaporated from the sea. If the polar icecaps melted, the sea would rise and cover sections of Alabama, as it did many times long ago in the geologic past.

Most rain that falls on Alabama is moisture that evaporated earlier from the Gulf of Mexico. The nearness of the Gulf is thus a major reason for plentiful rainfall in Alabama. Rains come at intervals as the air moves back and forth and as contact between warm air with colder air causes the moist air to release part of its water as rain. Climatic forces change with the seasons, but the directions and velocity of the winds do not vary greatly from season to season; thus, there are no major seasonal differences in the amount of rainfall in Alabama (fig. 2). There is, however, a seasonal difference in the type of rainstorms: the more intense rains usually occur during warmer months.

General or average conditions obscure variations. Variations of weather must be considered because they can be very great and extremes are important in relation to water supply. Long-time trends in climate may exist, but there is little evidence of any significant trend in Alabama within recent decades or even centuries. We are, however, interested in those changes that occur from year to year and during periods of a few years.

Rainfall at Tuscaloosa in most years differs greatly from the long-time average (fig. 3). During some periods, series of wet years or of dry years tend to occur together. At other times wet years and dry years occur entirely independently of each other. Evidently lack of repeated order or pattern in annual rainfall is a characteristic of weather.

An even greater range in variability is evident if single months are studied instead of years. At Montgomery, for example, rainfall was less than 0.01 inch in October 1904, but more than 20 inches in November 1948. In some years when total annual rainfall is near normal, seasonal amounts may be abnormally high or low.

FIGURE 2.—Average annual rainfall in Alabama.

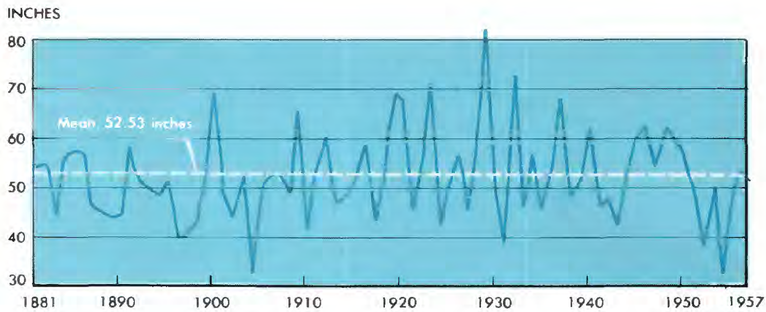


FIGURE 3.—Annual rainfall at Tuscaloosa.

If we consider individual storms, extreme variations are evident: First, the amount of rain can vary from a mere trace to a great deal; about 30 inches fell at Elba in the great storm of 1929. Second, the area covered by a storm may be very small or it may be many thousands of square miles.

About 15,000 cubic miles of water evaporates each year from the lakes and land surfaces of the continents. Water evaporates

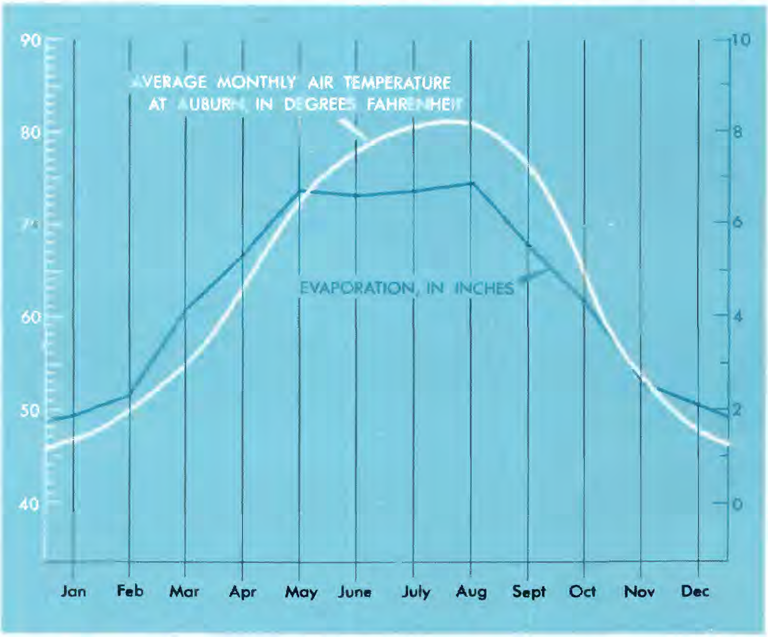


FIGURE 4.—Monthly evaporation from a pan at Lake Martin and air temperature at Auburn.

from lakes and rivers, from wet soil and other wet surfaces, from the leaves of plants and trees, and from bodies of snow and ice. The amount that evaporates from a given area depends in part on the areal extent of the supply available for evaporation and in part on the area's climate.

Direct measurement of evaporation from all sources is difficult or impossible, but some idea of potential evaporation can be obtained by measuring the amount of water evaporated from a pan. Figure 4 shows relation of evaporation to air temperature.

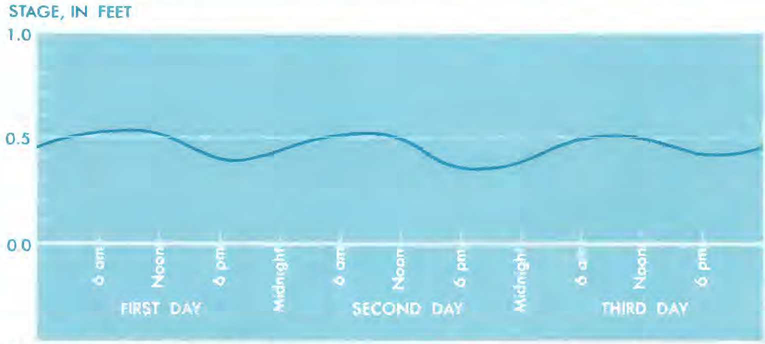


FIGURE 5.—*Variation in the stage of Indian Creek near Troy. The amount of water used by vegetation produces daily decrease in the creek level.*

Rapid seasonal changes occur in spring and fall, but more water evaporates in the spring than in the fall because days are longer, more heat is available, and wind velocities are higher. The rate of evaporation is controlled principally by the amount of heat received from the sun and the rate of movement of air. If our index had allowed for length of day (to apply a heat factor) and for wind movement, the points plotted on the figure would form regular lines. Additional factors play an important rôle in evaporation from lakes or reservoirs.

Evaporation from wet surfaces and from trees and plants cannot be measured directly. We are sure that the amount of evaporation from each is very great at times and at other times much less, and varies as the supply is plentiful or scarce. Use of water by vegetation is illustrated in figure 5.

The stage of Indian Creek near Troy varies with amount of water used by riparian (bank-side) vegetation. Withdrawal is small at night and greater during the day, but time lag causes the stream to flow more just before noon and less in the early evenings.

During warmer months of the year, trees draw large quantities of water through their root systems. The water moves through the trunk and branches to the leaves, where it is transpired. How much returns to the atmosphere in this way? We do not know accurately, but as much as 1,000 pounds of water may be transpired by a tree for each pound of wood produced. Trees cover two-thirds of Alabama and other water-using vegetation occupies other land, so the amount of water involved is very large indeed.

Although the exact amount of water evaporated from each source is not known, together the different sources return to the atmosphere over Alabama an amount of water equal to three-fifths of all that is received as rain. In a normal or average year, the amount evaporated covers the State to a depth of 32 inches. In a drier year the amount is less; in a wet year, more. The amount also varies with location and land use.

The sky gives us water and takes some of it back again. That which remains—about two-fifths of the amount received as rain—is with us for a time as water in the ground or water in the streams and lakes. This is the part that man can aspire to control or put to use.

How ground water occurs

The supply of water in the ground varies with the seasons of the year, it varies from year to year as rainfall varies, and it varies from place to place as the soil and the rocks that make up the land vary. In respect to ground water, the variations that occur from place to place are more important than those that occur with time, and to understand them requires study of the land, its origin, and its makeup. The science concerned with the history and makeup of the earth is called geology.

Geologists read the history of the earth by observing the nature of rocks and their location. Many rocks provide evidence of extensive seas of an earlier time. Parts of the area that is now Alabama were under water during long periods of time, and other areas have been subjected to alternating periods of inundation and emergence. Long exposure to the forces of weather cause rocks to partially rot or decompose to a substantial depth. Other rocks, such as limestone and dolomite, can be altered internally as well as at the surface. Channels and caverns are left as chemical waters attack, dissolve, and erode along fractures in the rock mass. In some rocks, cracks and fissures are formed by changes in temperature or by mechanical action associated with movement of the crust.

The working of external forces can be observed. Alternate freezing and thawing breaks up rocks at the surface. The roots of trees help the process. Water alone dissolves some material, and chemicals in water attack, alter, and modify other earth materials. Rain beats upon the land and helps wear it away. Water runs over the land and carves channels to carry water and sediments to the sea and deposit them there. Eventually they form sedimentary rocks. Then the mountains and highlands are eroded in their turn and reduced to plains and lowlands.

All together, these forces and events have worked to create the surface and subsurface of our present world. Knowledge of the subsurface is the key to understanding the water in the ground.

Water from rains and from surface streams sinks into the ground. Some is retained in the soil near the surface and we call that part soil moisture. Some continues to seep downward until it can go no farther. At that point it joins other water in the ground which has filled up or saturated all the open spaces in the earth material. Water in the saturated zone is called "ground water." The upper surface of the saturated zone is the water table.

The amount of open spaces in the earth material can be small or large, depending on the type of material. In fine-grained material like clay, the open spaces or pores are small. Figure 6 shows the makeup of rocks common to Alabama and how they vary in porosity, or water-holding, ability. Limestone solution channels, which can gradually become caves many feet in diameter, are capable of holding large quantities of water. Many other sedimentary rocks can also store large quantities of water. In hard or consolidated rocks, openings usually occur as cracks caused by the breaking or fracturing of the rocks, but occasionally such rocks also contain solution channels. Thus the occurrence of ground water varies with the characteristics of the type of material and the structure of the rock. Porous rocks that store and (or) transmit water are called "aquifers."

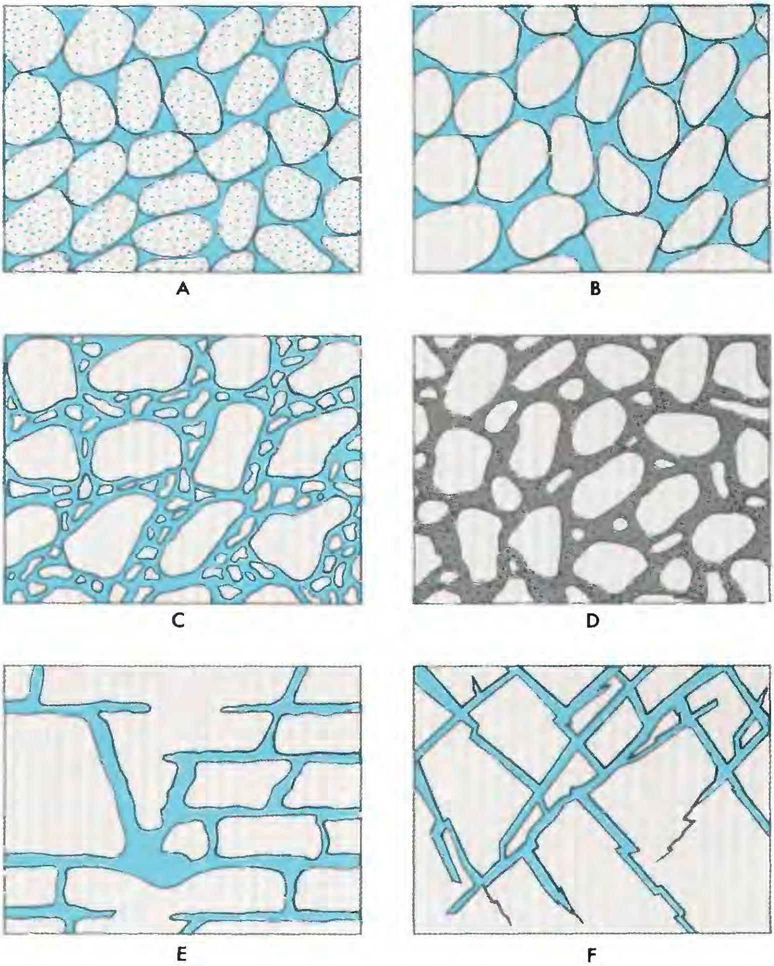


FIGURE 6.—Typical rocks and their porosity or water-bearing capacity. A, rock of very high porosity: sand or gravel of uniform porous grains and uniform intergranular space; B, rock of high porosity: sand or gravel of uniform grain size and intergranular space, but the grains themselves being imporous; C, rock of low porosity: sand or gravel having grains of different sizes and lacking uniform intergranular space; D, rock of very low porosity: sand or gravel of different grain sizes in a cemented mixture; E, rock made porous by solution channels (as in limestone or marble); F, rock made porous by fractures (as in granite or other dense impermeable rock).

Water seeks its own level, as the old saying goes. As the water in a stream flows toward a lower level, so does water in the ground. Water circulates freely in some rocks, and this type of rock is called "permeable." The opposite type of rock is impermeable. Unconsolidated materials like sand and gravel usually permit water to move in any direction. The movement of water in fractures or in solution channels of consolidated materials is more restricted and must follow the course of the fracture or the channel.

Sedimentary rocks may have both permeable and impermeable layers. Water in a permeable layer between impermeable ones can only move laterally along the course of the permeable layer. Under such conditions, the water is "confined" by the impermeable layers and is under "pressure" of the water in that part of the layer at a higher elevation (fig. 7). If a hole or well were drilled through the upper confining layer, the water would rise in that hole to the level made possible by the pressure. An artesian well is one in which the water is under pressure. At places where the land surface is low enough and the pressure is great enough, the water flows freely at the level of the ground. All artesian wells, however, do not flow.

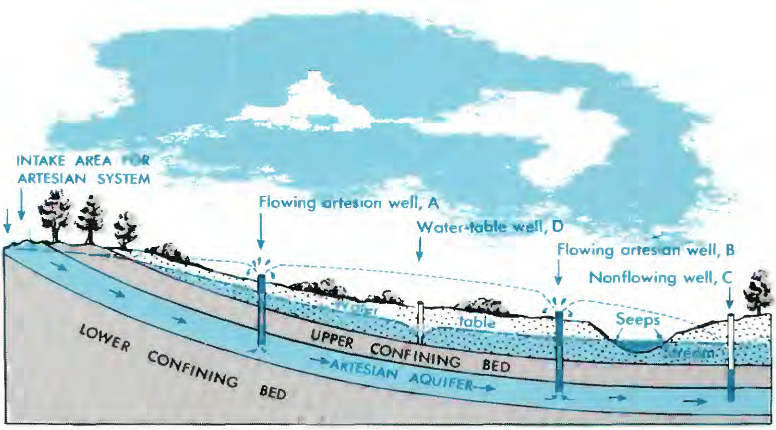


FIGURE 7.—Conditions necessary for an artesian system. Rain, falling on the intake area, moves downward into the water-bearing bed and is confined under pressure. Water levels in wells rise toward the surface and, where the land-surface is low enough as in wells A and B, the wells flow. Well C is a nonflowing artesian well. Well D is a shallow water-table well. Seeps occur where the shallow water table intersects the land surface along streambeds or in ravines.

The water table rises as it is replenished (or recharged) by rain or falls as water slowly drains to a lower level. The lowest natural outlet level for most ground water is a nearby stream channel. Water in some sedimentary rocks follows a permeable formation to great depths below the earth's surface. Because some of these formations extend under the Gulf of Mexico, some ground water returns to the Gulf by this route, but the amount is relatively small.

The shape of the water table is partly controlled by the topography of the land and tends to conform, in a general way, to the shape of the land surface. Depressions in the land are sometimes below the water table; ponds may be formed in which water stands at the level of the water table. However, if fine sediments seal the bottom and sides of the pond, the movement of water between pond and ground is prevented. Therefore, the water level of the pond does not necessarily reflect the level of the water table.

The amount of water held in limestone channels tends to vary greatly throughout the year. At the end of the wet winter season, it is at a maximum. In the spring and summer months, the demand of trees and crops for water increases and less water is available to sink into the ground; the water level in the ground slowly declines and usually reaches its lowest point by late fall or early winter.

Ground water in Alabama's three major land divisions

The rocks in Alabama range in age from a few million to more than 500 million years. Alabama has three major physiographic divisions, based on type and age of rocks: the Piedmont, the Plateau, and the Coastal Plain (fig. 8). The similarity of the rock types within each area implies a similarity of occurrence of ground water within each area. Because that implication is true, broadly speaking, it provides a convenient basis on which to discuss and define the occurrence of ground water in the State.

However, a word of caution is in order. Within each area the major similarities in the age and makeup of the rocks are pronounced, but there are also local variations. When they occur,

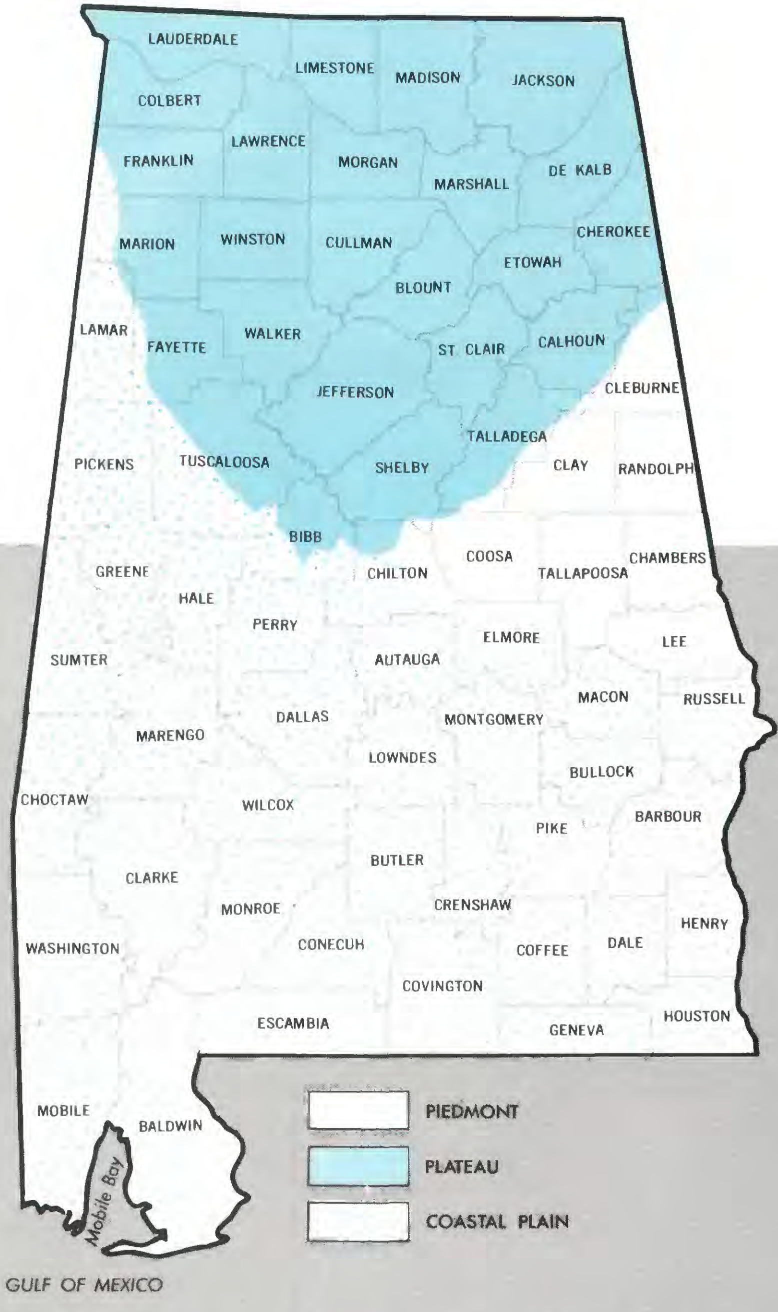


FIGURE 8.—Three major physiographic divisions of Alabama, based on type and age of rocks.

the local variations can modify the occurrence of ground water, and at places they all can be important.

The rocks in the Piedmont are the oldest in Alabama. The more recent ones were formed over 200 million years ago, and many are older than 500 million years. Some are sediments of an ancient time and have been uplifted, distorted, and folded into a very complex arrangement. Others are igneous intrusions caused by molten masses migrating along ancient openings in the crust. Through long exposure to the elements, the rocks have weathered to great depths. In some areas, the weathered material remains in place and forms a relatively flat elevated surface. In other areas it has been deeply eroded by the streams which drain the land. Here we find granite, schist, gneiss, quartzite, slate, phyllite, and marble. These are hard rocks, they contain some cracks, crevices, and solution channels, but, in general, the openings extend downward only 200 to 300 feet. The largest openings are found in marble.

The water table is sometimes in the weathered material and sometimes in the bedrock. Generally, in upland areas it is in the bedrock and in lowland areas in the mantle overlying the bedrock. Water in the mantle can be obtained from a dug well, but drilled wells are needed to tap the supply in the bedrock.

About 70 percent of the domestic wells in the area are dug. In general, dug wells have low yields and many go dry during droughts (fig. 9). The yield is limited by the very low rate at which water can flow through the fine, tightly packed material in the weathered zone. Wells fail in dry times when the water table declines below the bottom of the well.

Drilled wells yield larger supplies, but the average drilled-well yield in the Piedmont is only about 30 gallons per minute. The yield of a well is usually expressed in gallons per minute. One gallon per minute is equal to 1,440 gallons per day, and 694 gallons per minute equals 1 million gallons per day. A successful drilled well must penetrate a sufficient number of openings in the bedrock to provide the desired yield of water. Some wells penetrating solution channels in marble yield as much as 900 gallons per minute, but the occurrence of marble is chiefly limited to Talledega County.

Springs in the Piedmont are numerous but generally have small yields. They occur where the water table intersects the land sur-

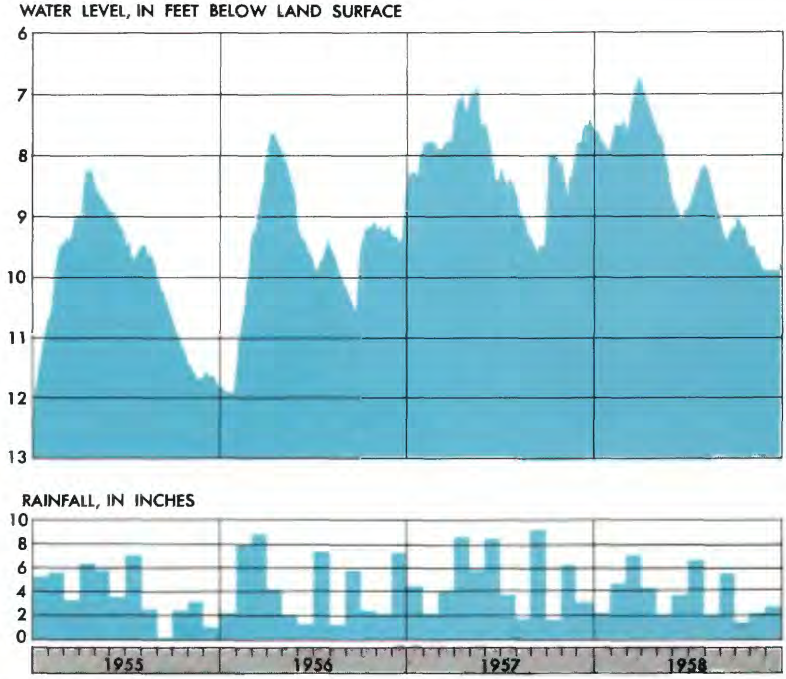


FIGURE 9.—Water levels in a well at Eclectic, Ala., showing fluctuation in response to rainfall.

face and are most numerous at the heads of steep valleys where bedrock commonly crops out. Large springs in the Piedmont flow chiefly from solution cavities in marble.

The choice of a well site in the Piedmont area is often a matter of convenience, little attention being given to factors controlling the occurrence of ground water. In addition to convenience of location, the choice of a well site should be determined by quantity and quality of water needed, type of rock, location of fractures and openings in the rock, thickness of soil zone, geologic structure, topography and surface drainage, and the danger of pollution.

The configuration of the land (called "topography") is the most important factor in locating a successful well in the Piedmont area. Wells in valleys have the highest average yield, about 40 gallons per minute. The yield from wells on slopes averages 26 gallons per minute. The wells having the lowest average yield, 13 gallons per minute, are on hilltops (fig. 10).

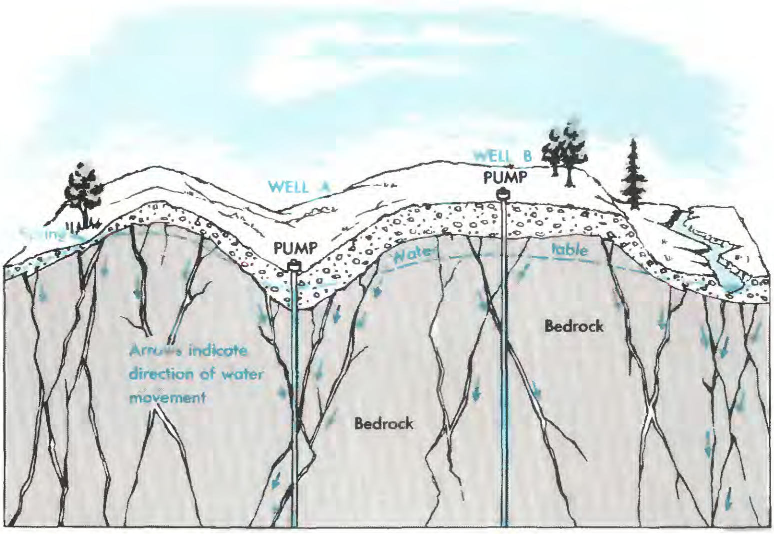


FIGURE 10.—Wells in the Piedmont. Well A, drilled in a small valley, intersects many fractures and has a shallow water level. Well B, drilled on a hill, intersects few fractures and has a deep water level.

Water obtained from wells and springs in the Piedmont is relatively free from mineral matter. Sometimes the iron content may be high enough to stain clothing and utensils, but generally the water is low in total dissolved solids and is not highly corrosive.

The Plateau can be subdivided roughly as follows: limestone valley, coal measures, valley and ridge (fig. 11). The rocks in the Plateau were deposited in a sea that covered all the State but the Piedmont from about 125 to about 500 million years ago. The material was laid down horizontally, and some of the layers (or "beds," as the geologist calls them) are thick and massive. The beds in the area bordering the Piedmont were later subjected to pressure from disturbances in the earth's crust. The long northeast-trending parallel folds that form the valleys and ridges at the eastern edge of the Plateau are evidence of these disturbances.

The rocks of the Plateau include limestone, sandstone, shale, and coal. The first three are sedimentary deposits; the last is organic material. Coal occurs in seams from a few inches to a few feet thick and is to be found to some extent in all the area except a portion of the Tennessee Valley. Interlayered with the

FIGURE 11.—Subdivisions of the Plateau province.

coal are sandstone and shale. Limestone beds are found at the surface in the Tennessee Valley and in the areas where disturbances have occurred.

Ground-water conditions in the area of the Coal Measures are much like those of the Piedmont. Here water is found in cracks and crevices and in the mantle overlying the rock. Here both dug wells and drilled wells are used; their yield varies from a few gallons to 300 gallons per minute. As in the Piedmont, topography is an important factor in locating a successful well. It is sometimes necessary to drill one or more test wells to find openings in the bedrock capable of supplying the desired quantity of water. Wells intersecting faults or large fracture zones can furnish substantial quantities of water.

In the limestone area of the Tennessee Valley, ground water is developed from wells intersecting solution channels and cavities in the limestone and from large springs issuing from the limestone. Solution channels are formed in the limestone by the chemical and abrasive action of water which enlarges fractures and joints in the bedrock (fig. 12). These tubelike openings range in size

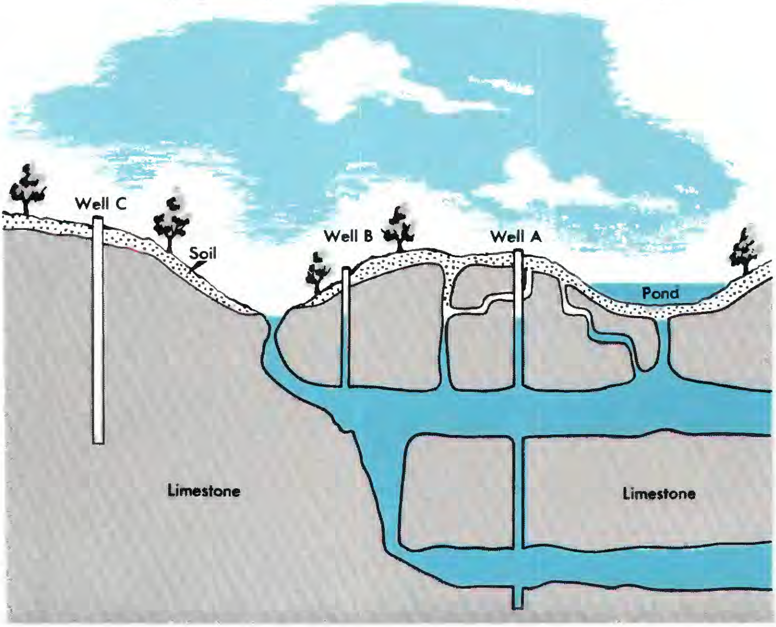


FIGURE 12.—Three hypothetical wells, tapping ground water in solution channels in limestone: Well A, successful and yields water throughout the seasons; Well B, only partly successful because it would be dry during prolonged droughts; Well C, unsuccessful because it penetrates no solution channels.

from a few inches in diameter to large caves. A network of solution channels extending over a large area forms a huge underground reservoir for the storage of water. Sometimes solution channels intersect the soil zone at the top of the bedrock and sink holes are formed by the inflow of surface water. In such areas the water can move rapidly from the surface to the underground channels. Polluted surface water may reach the channels and move considerable distances underground in a short period of time. However, recharge is chiefly from precipitation which filters through the soil zone and into the solution channels in cavernous areas. Springs occur at places where solution channels intersect the land surface near the base of hills and in the valleys. The flow from springs varies with the seasons of the year as shown in figure 13. Limestone reservoirs below the level of spring outlets stay full, or nearly so, at all times.

Success of wells in cavernous limestone is best assured by putting down test wells to locate solution channels and to determine their size. If many wells are needed in an area, a

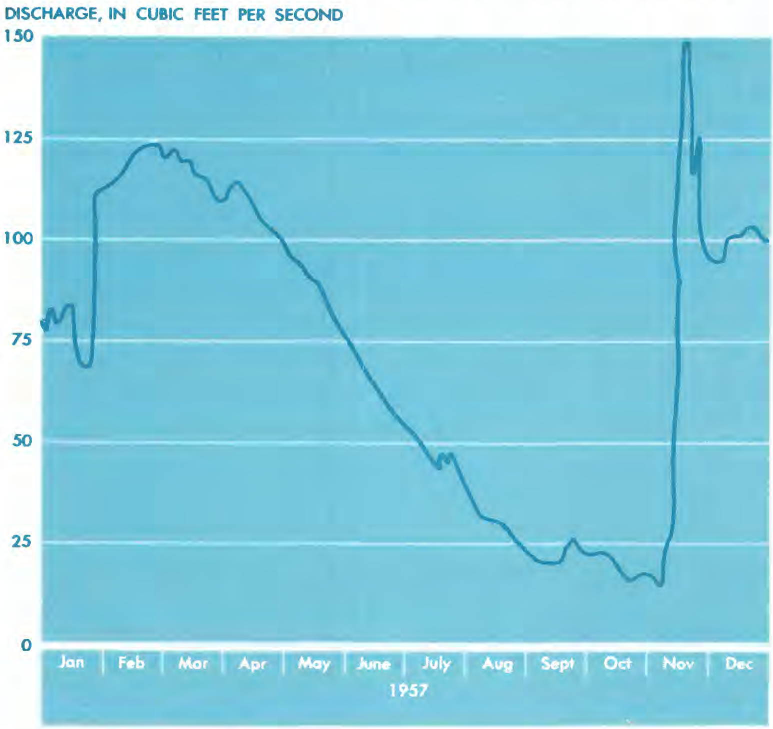


FIGURE 13.—Flow of Tuscumbia Spring, 1957. Note that flow varies from season to season.

general study of the area should be made to insure that pumping at one well will not adversely affect the yield of another. Wells penetrating solution channels in limestone sometimes yield large quantities of water; one at Huntsville, for example, can supply 7,000 gallons per minute. Many are capable of producing several hundred gallons per minute.

Water in the rocks of the Plateau is generally of good quality, though water developed in sandstone and shale sometimes contains objectionable amounts of iron. Water developed from limestone is moderately hard and requires additional soap when used for washing, but seldom requires special treatment to lessen the hardness.

The rocks of the Coastal Plain are the most recent in Alabama. About 125 million years ago, the sea began to recede. The present Alabama-Florida shoreline was established about 1 million years ago. All rocks in the Coastal Plain are of sedimentary origin; some are now mostly sand and gravel, others are clay, chalk, marl, and soft limestone. Originally the beds were nearly horizontal, but they now dip southward toward the Gulf of Mexico at a rate of about 40 feet per mile. Each layer is thus exposed to the surface at its northern terminus and is overlain downdip by beds of later sedimentary rock.

Water can enter rock formations where they are exposed, or "crop out," at the surface. Water can also enter through overlying formations which are permeable. Many formations are mostly unconsolidated sand and gravel and are capable of storing and transmitting large quantities of water. At greater depths the formations can collect and retain oil and gas. For example, a sand bed containing water at Tuscaloosa and Eutaw contains oil and gas at Gilbertown and Pollard.

Although individual wells at places in the Piedmont and on the Plateau yield more water than individual wells in the Coastal Plain, the Coastal Plain generally is more abundantly supplied with water. The consistent occurrence of good water-bearing sand and gravel beds through large areas of the Coastal Plain make the development of large-capacity wells relatively easy (fig. 14).

The problem of finding water is principally one of locating the permeable formation capable of supplying the water needed. The water-holding and transmitting characteristics of the formations are generally known to geologists. Each formation can be identified by its place in the successive layers of formations, and

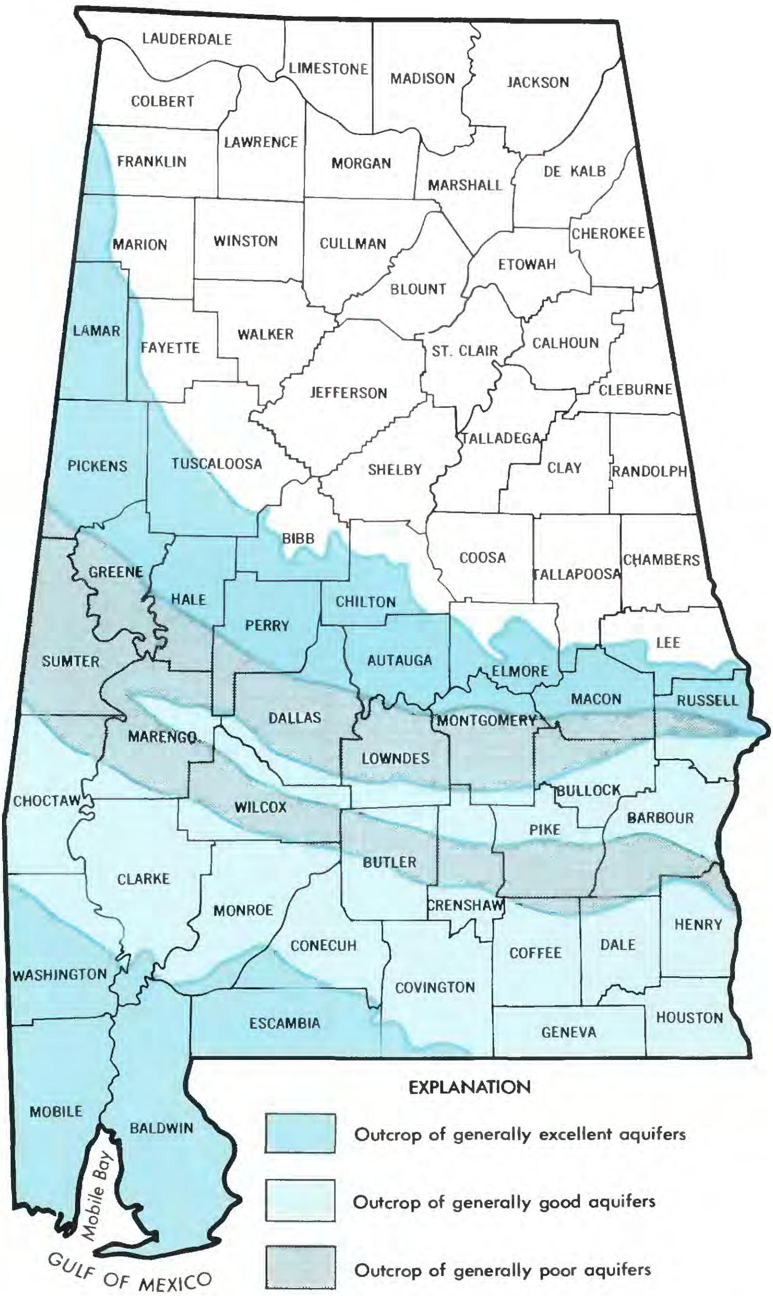


FIGURE 14.—Map of Alabama showing a general classification of the aquifers of the Coastal Plain and their areas of outcrop.

by the fossil remains of ancient sea life that are peculiar to each bed.

Clay, claystone, and chalk are not permeable and yield very little water to wells and springs. Limestone sometimes yields large quantities of water to wells penetrating solution cavities in the formation. Shallow wells, usually less than 100 feet in depth, can be developed in good sand and gravel beds. Along the coast and elsewhere, surface sands are developed simply by driving well points and sand screens to depths as much as 30 feet.

Drilled wells, ranging in diameter from 4 to 18 inches and in depth from a few feet to as much as 1,500 feet, are the most efficient and practical means of developing ground water from the better water-bearing sands and gravels in the Coastal Plain. These wells range in yield from the small domestic or farm well pumping 5 to 10 gallons per minute to the large municipal or industrial well producing as much as 1,000 gallons per minute. The Coastal Plain has been an area of extensive development of artesian flowing wells. In lowland areas along major streams, wells will flow when they penetrate confined sand beds whose recharge areas are at elevations higher than the well site. The discharge from these wells ranges from a few gallons per minute to as much as 2,500 gallons per minute. Some farmers and ranchers have developed several flowing wells on the same farm for stock use because construction of additional wells was more economical than providing pipelines.

In the Coastal Plain, ground water is generally of good quality. In some areas, only highly mineralized water is available, but in most areas it is possible to obtain water low in mineral content by drilling to a selected formation.

Quality of ground water

Water is a mineral. Gold, iron, and salt are also minerals. Each of these solid minerals responds on contact with water in a different way. For example, gold rings are not affected by contact with water. Iron rusts as it comes in contact with water and ultimately the rust will consume the iron. If a teaspoon of salt is put into a pitcher of water, it immediately disappears. Each substance has reacted in a different way, but the water appears unchanged. However, by performing certain tests we learn that the water has also reacted. The water was unchanged by contact with the gold, but it absorbed some of the iron and all the salt.

The mineral content of water changes in its journey through the cycle from the sea to the sky to the land and back to the sea. The more common dissolved minerals in water are the chlorides, bicarbonates, and sulfates of calcium, magnesium, and sodium. Very minor amounts of what are commonly called trace elements in water, such as copper, manganese, lead, and zinc, are also present, for almost any known mineral is slightly soluble in water. Some of the materials are organic, that is, they have originated from plant or animal life.

The amount of minerals that will be dissolved depends on the type of minerals and their resistance to chemical and physical attack, the length of time the minerals are in contact with water, and the chemical composition and temperature of the water itself. Once the minerals are in water, their concentrations can be changed by the influence of rainfall, the topography which controls the rapidity with which the rain runs off into the streams and the ocean, and the amount of materials added or removed by the continued action of the water on soluble materials or by man's activities. Thus, the mineral content of water reflects the environment of the water.

The formations in the earth from which we obtain our water, because of the manner in which they were laid down, usually consist of rocks and minerals of similar chemical composition. It would be expected then that water from a particular place in a particular formation would have the same characteristics for long periods of time, and in general, it does. However, the characteristics of the water at distant points in the same formation may be different. This difference may result from the presence of rocks of slightly different composition in the formation, or the water may have passed through several formations during its journey.

It has already been noted that after the rain falls on the surface of the earth, it percolates downward through the soils and rocks until it reaches the water table. If we examine the rainwater for its mineral content during this journey, we will note that it is almost pure but that small quantities of gases it contains increase its ability to dissolve materials from the earth's crust. In addition, contact with plants and bacteria within the top few inches of the soil increases the carbon dioxide content considerably—as much as 10 to 1,000 times the amount found in the atmosphere. The presence of this gas causes one mineral, calcium carbonate, to be 100 times more soluble in water. If, then, the water percolates through limestone, it picks up a considerable amount of calcium and carbonate. There is a limit, however, to the amount of dissolved calcium and carbonate the water can carry, and this limit is dependent not only on the solubility of the limestone but also on the presence of other minerals in the water.

If the rain falls on an area of resistant rocks such as granite or on insoluble quartz sands, very little material will be dissolved by the water. However, as it comes in contact with more soluble materials, these will be picked up and carried along. Thus, water passing from one formation to another will vary in mineral content and concentration and will affect the chemical composition of the formations through which it passes.

Figure 15 shows graphically the composition and amounts of the more common minerals dissolved in ground water in various sections of the State. The mineral concentrations are considered to be generally representative of the composition of the water of the formation at these points, although they may vary within the general area.

In addition to the mineral content, the temperature of ground water is also often considered in determining its worth for use. For many industrial uses, temperature is considered as important a property as the mineral composition. The temperature of ground water is relatively stable in comparison to that of surface streams or impoundments in the same area. The temperature of shallow ground water which is between 30 and 60 feet below the land surface is generally 2° to 4°F above the mean annual air temperature of the area. Water nearer the surface will vary about 10° to 20°. Below 60 feet the temperature of the water increases with depth at the rate of about 1°F for each additional 100 feet.

Streamflows as water resources

The Alabama River flows ceaselessly to the sea, and so do many other streams in spite of long periods of little or no rain. From where, then, did the water come? It came from the ground. During periods between rains, the flow of streams is maintained

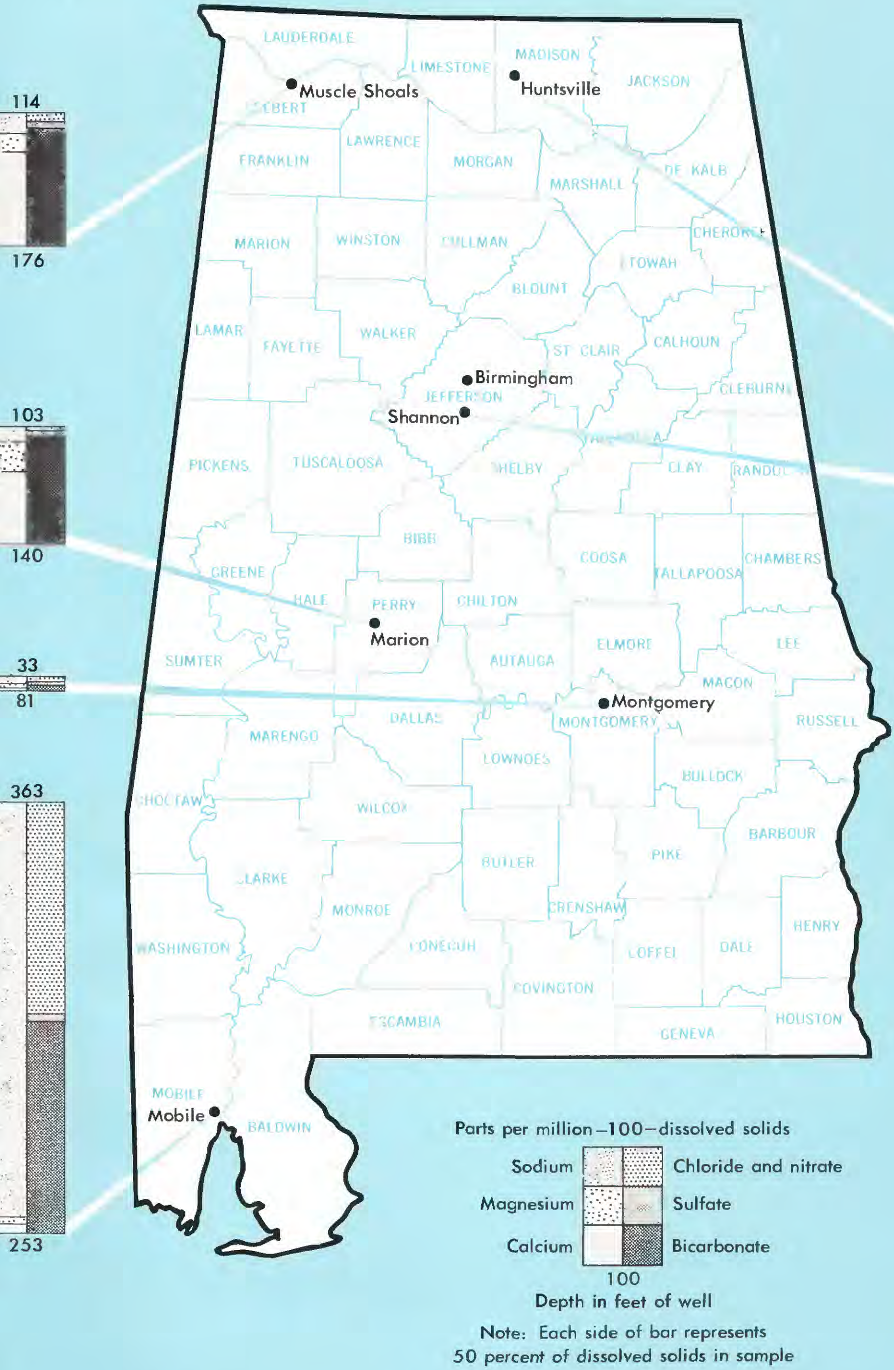


FIGURE 15.—Composition of the dissolved solids in ground water in Alabama.

by water already in the stream channels or by water seeping from the ground or flowing from springs. If dry weather persists, ultimately all streamflow will be from water stored in the ground. When the water table is below the level of a stream, water moves from the stream to the ground, but when it is above, ground water feeds the stream. Because of this relation, shallow headwater streams will at times cease to flow while nearby deeply intrenched streams continue to flow (fig. 16).

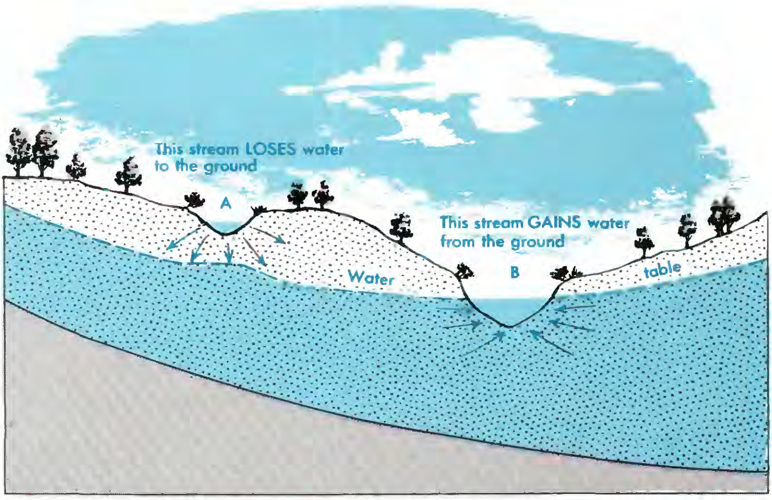


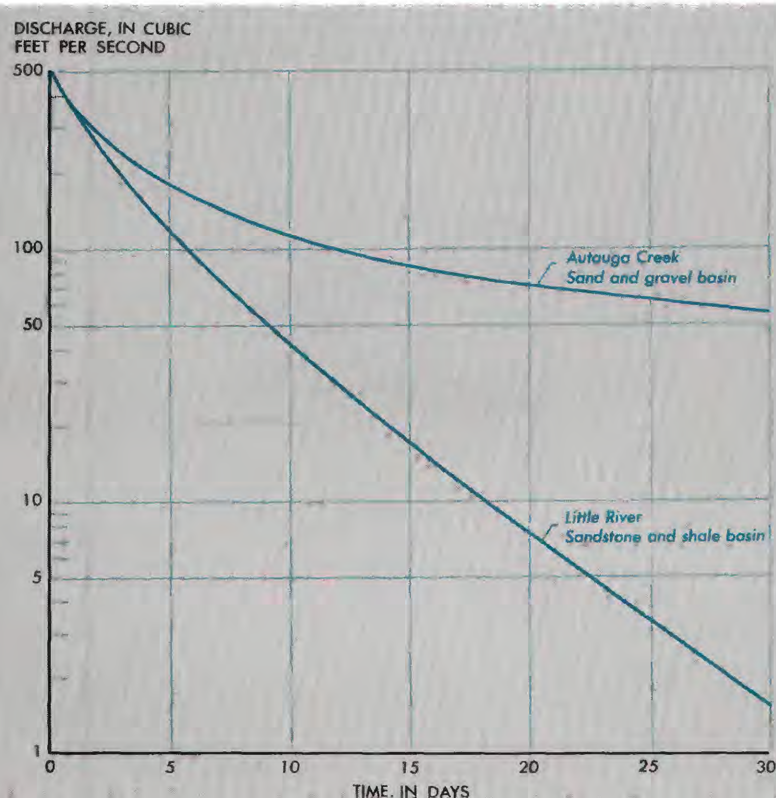
FIGURE 16.—How the position of the water table affects the flow of a stream. Stream A is above the water table and loses water to the ground; it may not flow during droughts. Stream B is below the water table and receives water from the ground; it will flow until the water table declines below the bed of the stream.

We have seen how water in the ground varies from place to place, being plentiful in some places and scarce in others. The minimum or low flow of streams varies in a similar manner: the flow is well sustained in some places during droughts and poorly sustained in others. The dry-weather flow of two streams which drain contrasting geologic areas is shown in figure 17. The flow of each stream diminishes but each at a different rate. The rate depends on the ability of the ground to hold and release water to the stream. The Autauga Creek basin (being underlain by unconsolidated sand and gravel) can hold much water, but the basin of Little River (being in sandstone and shale) can hold little.

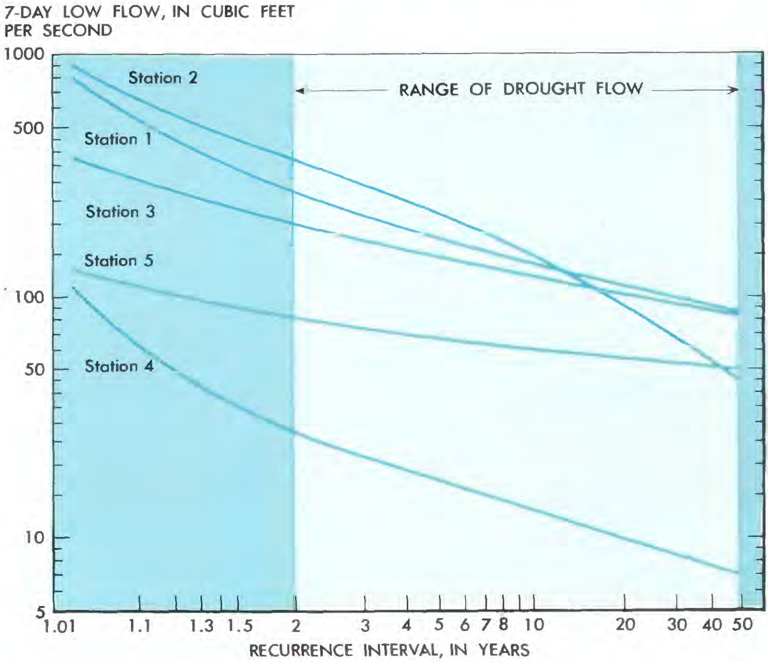
In figure 17 we have introduced a factor which requires a few words of explanation. The flow or discharge of the stream is shown as discharge in cubic feet per second (cfs). It is equivalent to approximately 450 gallons per minute or two-thirds of a million gallons per day. Note also that the discharge scale is of the logarithm type, in which the pattern of horizontal lines is repeated in cycles. The scale used here has three cycles. The values of the second cycle are 10 times those of the first, and those of the third cycle are 10 times those of the second. If this simple relationship is remembered, it is easy to determine the value of other lines on the scale which are not marked, and to interpret information plotted on this type of scale.

A study of the records of the flow of a stream as it varies from day to day over a period of years shows that the low flow of each year usually differs from that of other years. If these low flows are listed in order of magnitude, the smallest and the largest are immediately obvious, but the relation of these extreme values to the others is not so clearly seen. If we now go a step farther and compute by certain mathematical procedures the frequency

FIGURE 17.—How dry-weather flow of streams varies with basin geology. Autauga Creek basin is in sand and gravel. Little River flows over sandstone and shale.



of occurrence of the various flows and plot that information on a suitable graph, we can better understand the meaning of all the values in the list. Figure 18 was derived in that manner. Low flow is the average discharge during the week of lowest discharge in each year, 1900–54, values for some years being estimated. Figure 18 shows how the flows are related to each other and how they plot on a time scale. Half of the values in the list would plot along the portion of the curve to the left of the line for the 2-year recurrence interval, and half to the right of that



Station	Drainage area (sq mi)
1. Pea River near Samson	1,187
2. Tallapoosa River at Wadley	1,660
3. Cahaba River at Centreville	1,029
4. Locust Fork at Trafford	625
5. Flint River near Chase	342

FIGURE 18.—The frequency of low flow of five Alabama streams. The frequency of low flow of streams may be predicted from past records. For example: The 2-year recurrence flow is considered normal low flow. The Locust Fork at Trafford could be expected to reach a low flow of about 110 cfs each year, but to reach a low flow of 7 cfs only once in 50 years.

line. The 2-year line is thus the line at which the median weekly low flow will be found. We can term this "normal low flow." All flows to the right of the 2-year line can be classed as flows during periods of drought. Values of flow at 10-, 20-, 30-, and 50-year recurrence intervals are progressively smaller and will occur with decreasing frequency. For example, we would expect the 50-year discharge to occur only twice in a century, on the average. At other times in that century the flow would normally be larger.

Figure 18 shows the normal low flow of Locust Fork at Trafford to be 29 cubic feet per second. Records of flow of the Locust Fork have also been obtained at other sites along the stream. From those records we can determine the normal low flow, and by comparing the several values can learn how the flow varies along the stream (fig. 19).

At places the Locust Fork discharge is suddenly increased by water from sizable tributary streams. At other places the flow is gradually increased by water from springs or seeps or from smaller tributaries.

The normal low flow for many streams and sites in the State has been determined. Adjustment of such flows to represent

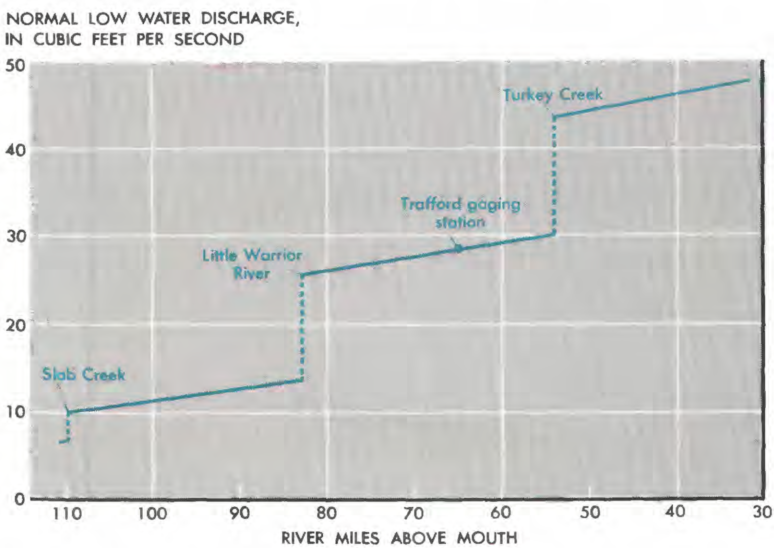


FIGURE 19.—How the low flow of Locust Fork varies from place to place along a reach of the stream.

FIGURE 20.—Normal low flows of Alabama streams. Figures are adjusted to represent runoff from 1 square mile so that each can be compared with the others. Normal low flow is that calculated to recur every 2 years.

runoff from only 1 square mile permits comparisons that show the variation of flows from stream to stream and from area to area. Figure 20 gives that information for many small streams, but not for the larger rivers. Values of normal low flow in cubic feet per second per square mile for tributary streams are shown on the map at sites where information was obtained; they represent the low-water yield of the basin above that point. Because yield is stated in discharge per square mile of stream basin, each figure can be directly compared to all others on the map. Flows vary greatly from stream to stream in some areas and are more uniform in others.

Figure 20 shows values ranging from no flow to 0.98 cubic foot per second per square mile. Some of the values can be related to and explained by the geology of the basin which the stream drains; others cannot be adequately related to properties of the land. Precise values can be obtained only from records of flow.

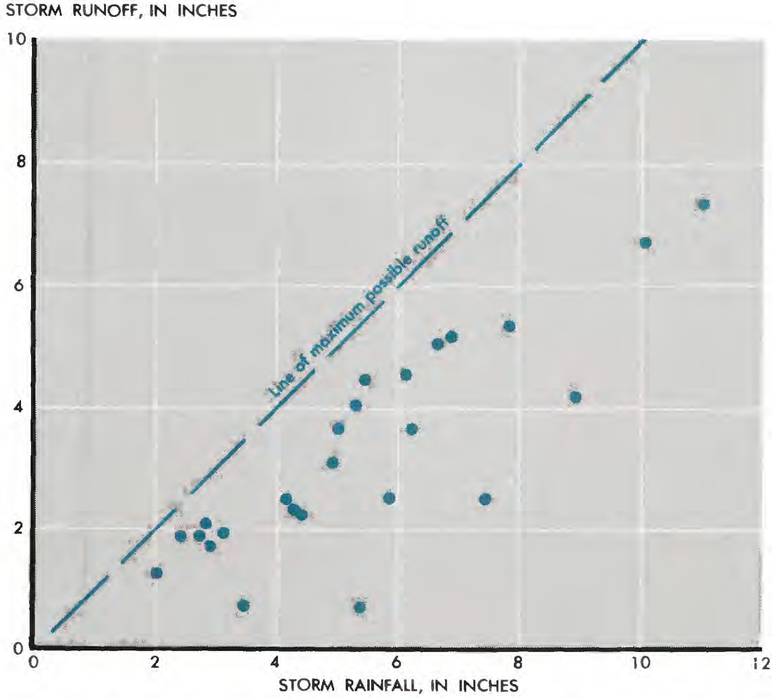


FIGURE 21.—Runoff of Mulberry Fork near Garden City compared to the storm rainfall which caused it.

Flows of the larger streams—those that drain basins of about 1,000 or more square miles—are subject to annual variations but are less subject to variations caused by local land properties, for they commonly drain more than one type of land.

Heavy rains occur several times annually in Alabama. Some cover small areas, some large ones; some last for minutes and others for days. If the ground is wet at the start of the rain, most of the water will run off over the ground and into the streams. If the ground is dry, a larger part will seep into the ground and a smaller part will run off (fig. 21).

Infiltration will vary also with the type of soil or rock in a basin. Some soils are deep, sandy, and porous and can absorb large quantities of water. Other soils are shallow and can hold but little water, or, like clay, are very impermeable and can absorb water only at a slow rate. In nearly all soils the capacity for infiltration is greatest at the start of a rain and becomes less as the rain continues.

On a bare clay soil, the splashing and churning of the raindrops tend to seal or cut off the pores at the surface of the ground and thereby reduce the capacity for infiltration. In forests, the trees partially shield the ground from the impact of the rain, and litter on the ground conditions the soil to absorb the maximum amount of rainfall. Thus forests tend to promote infiltration and indirectly to reduce direct runoff and the size of floods in the streams.

When a stream overflows its banks, water spreads over the bottomland. As the stream continues to rise, a broad lake is formed as if there were a dam downstream. Because flow over bottom lands and flow into a lake are very much alike in appearance and in effect on the discharge of a stream, engineers speak of such flow as "water going into storage" if the lake level is rising, and "water coming from storage" if the lake level is falling. Water going into storage reduces the flow downstream from the place of storage.

It has been shown that the relation of rainfall to runoff varies widely and is affected by topography (fig. 22), the rate and the amount of rainfall, the porosity of the soil, and the condition of the ground (whether wet or dry, barren, or forested). If we had

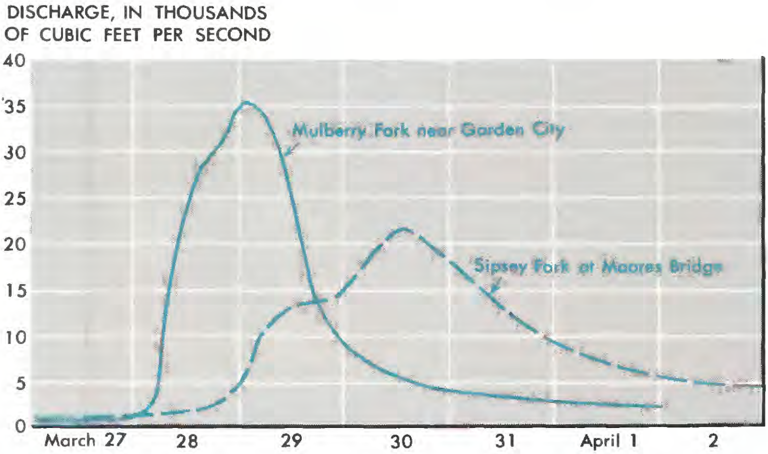


FIGURE 22.—How topography affects the flow of a stream. Mulberry Fork near Garden City flows in an area of rugged topography. The Sipsey Fork at Moores Bridge flows in an area of flat topography.

to determine flood flows by considering all these things, the task would be impossible or nearly so. Fortunately we can measure flood flows directly, and get the information we seek from the streams themselves.

In 1929 the people of Elba and Brewton and elsewhere in south Alabama saw their cities and their lands engulfed by flood-swollen rivers. Streams that normally are a few feet to a few hundred feet wide rose out of their banks and kept rising until at some places they became miles wide. And as they rose, they washed out roads and bridges and dams, ruined crops and drowned cattle, and covered the streets of some towns to the second floor of buildings. The damage was counted in millions of dollars.

The height of the water in the channel and the size of the area inundated are important, but do not provide a good basis for judging floods for they are related to conditions that vary greatly from place to place. The engineer appraises floods by the amount of flow during the flood period and by the stage and rate of flow at the peak of the flood. The Geological Survey collects data on the volume of flow. This information is required for proper design and operation of dams and reservoirs for flood control. Information on peak stage and rate of flow is used in designing spillways, bridge openings, and levees, in improving the carrying capacities of channels, in locating buildings above flood water, for flood-warning services, and for other purposes.

Volumes of flow are conveniently obtained from graphs similar to those showing flow on Sofkahatchee Creek (fig. 23). Peak discharges are appraised by plotting the magnitude of flow on a scale of frequency. Methods similar to those explained in the discussion of low flows are used. Values for two river basins are shown in figure 24; they differ because storm-runoff characteristics differ in the two basins.

As mentioned earlier, many factors affect the rate of runoff from the land and thus the rate of flow of water in a stream. Further study has shown that the effect of some factors is closely

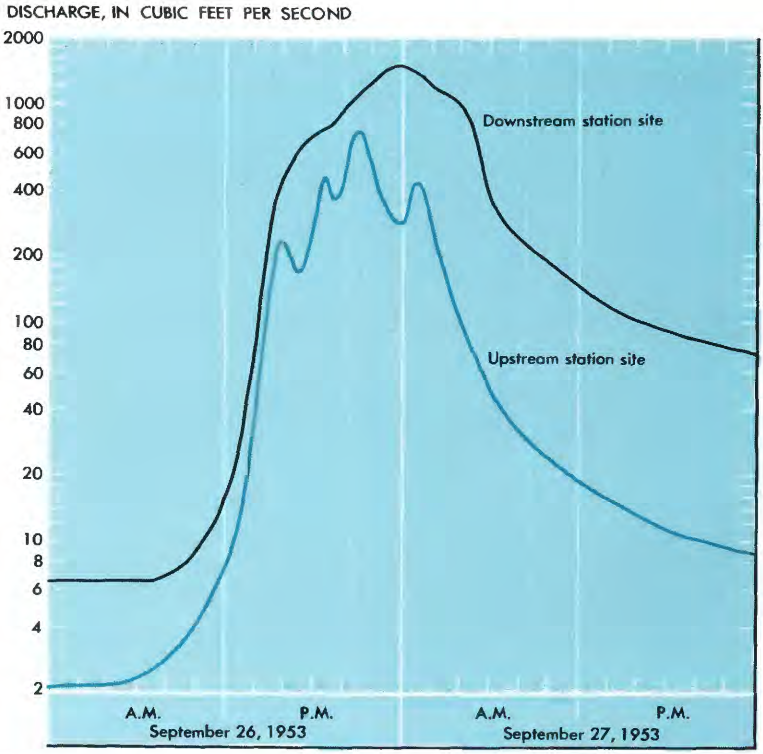


FIGURE 23.—Flood on Sofkahatchee Creek near Wetumpka, September 26–27, 1953. Rains associated with a tropical hurricane caused the flood. Flows are much larger at the downstream station because of the increase in drainage area.

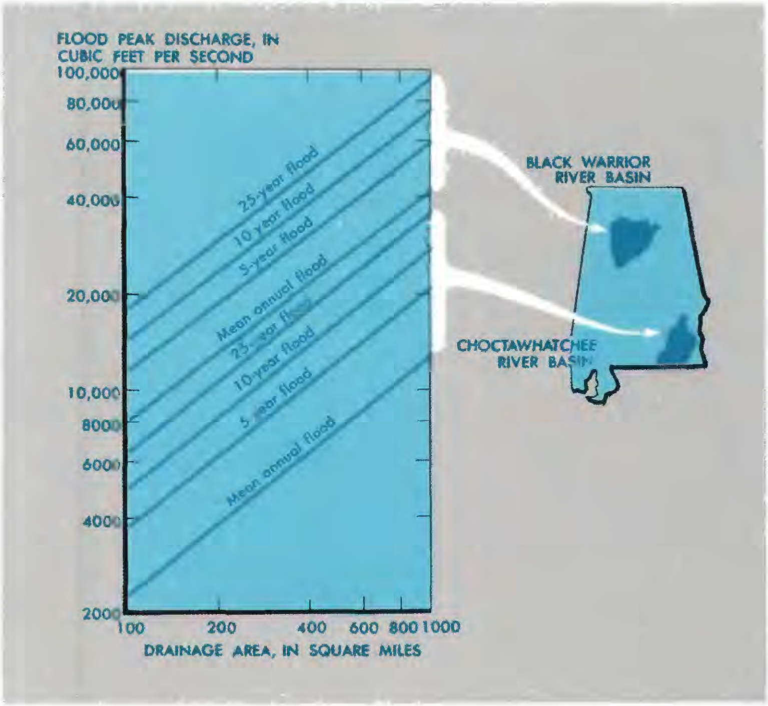


FIGURE 24.—Peak flood flows of two river basins in Alabama for various recurrence intervals. Size of drainage basin is one of many factors that affect the rate of runoff of a stream.

related to the area of the watershed. This relation simplifies the problem of finding an easily defined index to use in appraising peak flood flows in different streams. Our index is size of drainage area. Values of runoff for two stream basins are compared to size of drainage area in figure 25. The values for the two basins differ greatly and that difference reflects the impact of the variables not explained in the area index. The flood-producing characteristics of other basins in Alabama are generally in the range of values shown on the figure.

On the Great Seal of Alabama, a small map outlines the boundaries of the State. The only information shown within these boundaries is the location of the larger rivers in the State. We like to think that the seal's designer recognized the value of the streams to the people of the State. The land, the water, the forests, and the minerals are valuable to the people and are termed "natural resources." Sometimes there are droughts or floods, and at such times the supply of water is a problem. If, however, all the flows could be merged into an average value, it would eliminate the extremes that cause most of our water problems. For example, suppose that we lived on the bank of a stream in which the water never rose to a flood level nor receded to the low flows of a drought. That stream would indeed be a blessing to those who lived beside it. The average supply of water in the streams and in the ground is a blessing to the people of the State and is considered by many to be our most important natural resource.

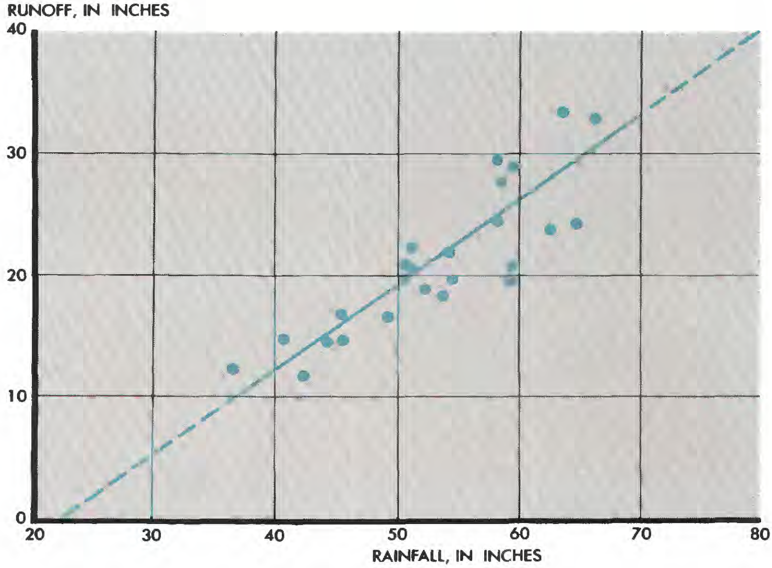


FIGURE 25.—Annual runoff of the Tallapoosa River at Wadley compared to the amount of rain falling on the basin. The straight line shows the relation of average annual rainfall to average annual runoff.

When all the flows in a stream for a year are merged into a single value, the result would be the average flow for that year. If this data were collected for a number of years, the long-time average annual flow for the stream could be found. Let us take a closer look at these yearly and long-time values.

In figure 25 the line that represents the average relation of rainfall to runoff has been extended upward and downward. The extension indicates that no runoff would occur from an annual rainfall of 23 inches and that runoff would be 40 inches if annual

FIGURE 26.—How annual runoff, in cubic feet per second per square mile, varies over the State.

rainfall were 80 inches. By deduction, figure 25 also shows that water loss (the difference between rainfall and runoff) would range from 23 to 40 inches and would increase with more rainfall.

If the average annual flows over a period of years were determined for many streams, they could be compared as they varied from stream to stream or from basin to basin. Such a comparison (fig. 26), would show differences that are in part associated with the rainfall pattern shown in figure 3. The differences would also reflect certain properties or characteristics of the land.

Runoff near the Gulf is the greatest in the State (fig. 26), because it is related to the heavier rainfall of that area. The reasons for variations in other areas are less clearly understood. Probably, however, runoff is least in a belt through the center of the State because, in the western part of that belt, the soils are permeable and an above-average amount of water seeps deep into the ground. The water is then discharged through ground-water aquifers instead of running off into the surface streams. In the eastern part of the belt, the low level of runoff results from a high level of loss by evaporation. Large evaporation in this case is associated with a land that readily yields its moisture to the atmosphere and in doing so leaves extensive voids or cracks which catch and store subsequent rainwater which is in turn evaporated.

Information presented in figure 26 makes possible a rough estimate of the average flow of a stream. The estimate can be made as follows: First, determine the area (in square miles) of the drainage basin. Next, locate the stream on the map. Determine from the map the runoff for the location and then multiply that value by the area of the drainage basin. The resulting figure is the stream's average discharge in cubic feet per second.

Because larger streams drain many runoff areas and because some originate out of the State, it is difficult or impossible to compute their runoff from figure 26. Figure 27 shows how flows of the larger rivers increase as they cross Alabama on their way to the sea.

Quality of surface water

The mineral content of Alabama's surface water is derived from many sources. A small amount is carried in by rainfall. The major amounts come from the soils and rocks with which the water has been in contact. Some minerals come from sewage and waste disposals of municipalities and industries, some come

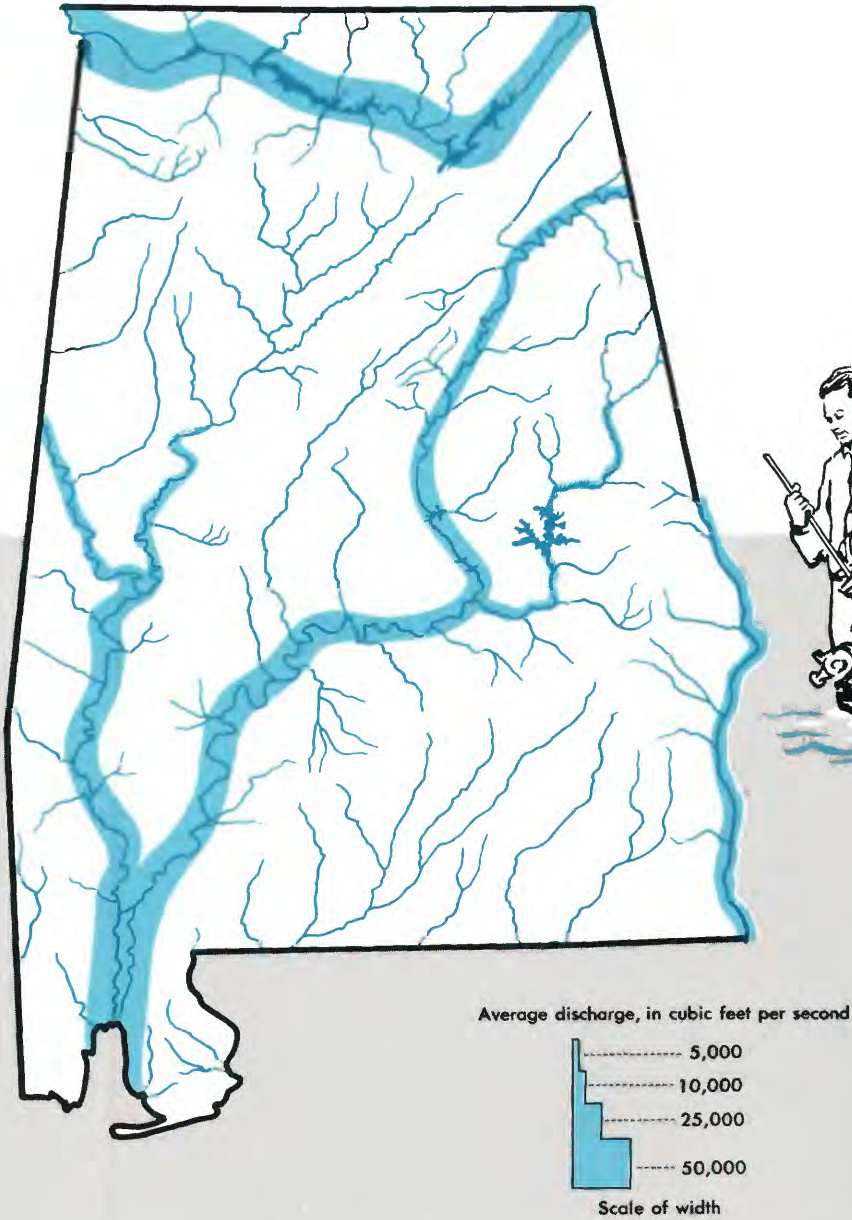


FIGURE 27.—Average annual discharge of Alabama's larger rivers.

as direct runoff from lands that have been fertilized heavily, and in certain places part of the mineral content is carried into the stream by ground waters flowing from the underground formations.

As we have already learned, ground water feeds the streams during periods of little or no rainfall; the mineral content of the streams during these periods will therefore resemble closely that of the ground water coming into the stream. This water may be feeding back into the stream from what is known as "in bank" storage; that is, water that has entered the ground laterally from the stream during floods. Part of the water may come from the deeper formation under artesian pressure and issue from the streambed as springs. We will make comparisons later between the quantity of mineral matter carried in the streams during minimum flows and at flood flows. At the moment, however, we indicate only that the concentrations of the minerals carried in the streams are usually higher during low flows than during high flows.

As the amount of water increases in the stream because of rainfall and runoff, changes in the mineral content occur. The initial runoff may have fairly high concentrations of chemicals resulting from the contact with weathered material at the surface, but the major effect of water running off directly over land as a result of rainfall is a dilution of the stream concentration. This water has not had time to dissolve much material and is, therefore, low in concentration. Longer contact of part of the rainfall with rocks permits more solution of soluble materials and concentrations rise. As more rain falls, the river floods, and the mineral concentration is diluted throughout the high stages. This, then, is the general pattern: diluted waters during high stages, more concentrated waters during low stages. Day to day changes occur as well as changes from season to season. The average composition of the dissolved solids of several streams is shown in figure 28.

We have been discussing the unseen dissolved materials in surface waters and how they vary. Let us look now at the visible materials transported by streams. Sand, gravel, silt, and clay are carried in suspension in water as long as velocity and turbulence of the stream are sufficient to keep the particles in motion.

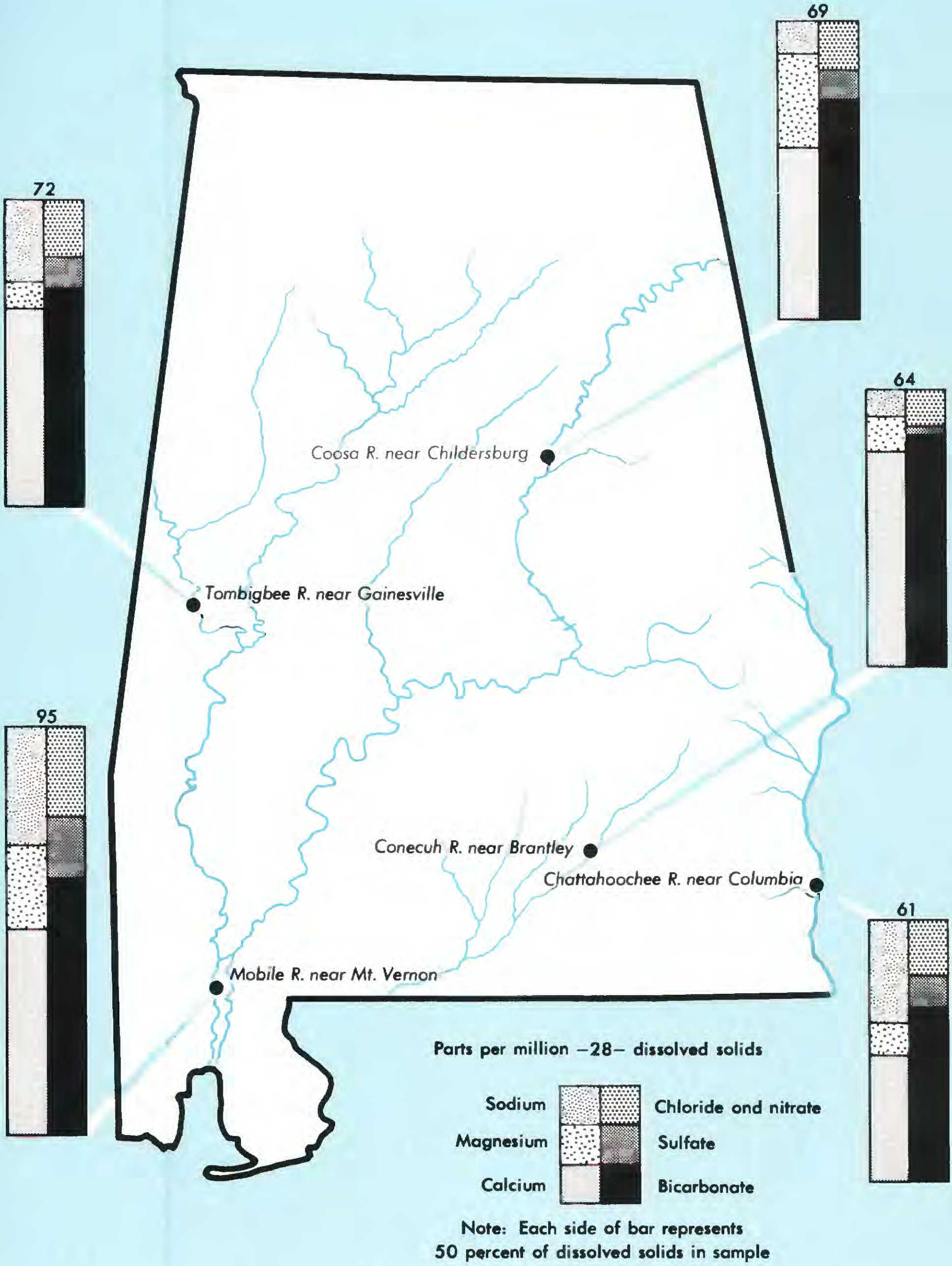


FIGURE 28.—Composition of the dissolved solids in water from some Alabama streams.

These materials are called sediment and may be either suspended or may be traveling along the bed of the stream. The effect of sediment makes the water muddy and unsightly, renders it unsuitable for some purposes prior to clarification, and shortens the useful life of reservoirs by deposition.

Sediment comes from the land surface and from the beds and banks of streams. It is present in larger quantities during the rainy season, when the velocity of the runoff is high, than during periods of low flow. Although a stream may be perfectly clear, there is some movement of the heavier materials along the bottom, even during low flow, and for many of the streams which have their drainage areas in forest or grasslands, the material rolling along the bottom may be the major load transported.

How much of this material is being moved is difficult to determine merely by looking at the stream. Although very fine particles (the clays) make a stream appear extremely muddy, they may be only a very small part of the total amount of material being moved. These small particles are retained in suspension even at lower velocities, and sluggish streams receiving them remain muddy for long periods of time.

The temperature of surface water, unlike that of ground water, varies from season to season, day to day, and sometimes from hour to hour. For some streams, the temperature of the water may vary as much as 15°F in any one day. In general, the temperature of streams fluctuates with the air temperature, although not to the same extent (fig. 29). Movement of the water, the proximity to the ground, the amount of water in the stream, and the direct influence of ground water have a stabilizing effect on surface-water temperatures.

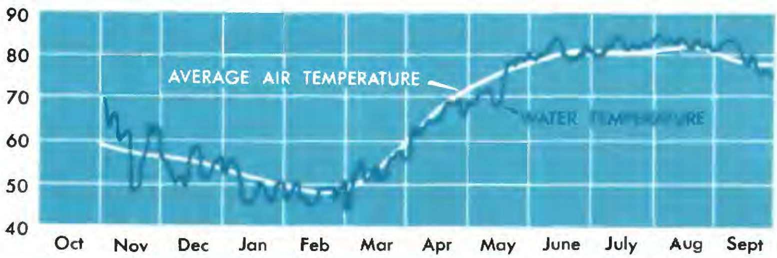


FIGURE 29.—Daily temperature, in degrees Fahrenheit, of water in the Chattahoochee River at Columbia, Ala., and monthly average temperature of air at nearby Dothan, Ala., 1940–41.

Natural influences—climate, topography, and geology—contribute to the variability of the mineral content of surface waters. Man's activities can have an even more pronounced effect upon the mineral content and, through use or misuse of the water, he can introduce material greatly in excess of that occurring naturally. He may also introduce materials that make the water unsuitable for many uses, or his activities may increase the temperature of the water. Alabama has recognized the importance of preserving the quality of the water resources, and the State Water Improvement Commission has taken steps to minimize present stream pollution and to prevent future pollution of the State's water supplies.

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THE USE OF WATER

If you stood on a street corner and asked those who passed, "How is water important to you?" nearly all would mention water for drinking and water for bathing. Beyond these, the answers would be many and varied. They could include water for chickens and cows and horses, water for washing dishes and clothes and automobilies, water for lawns and gardens and crops, water for making ice and for use in some air-conditioning systems, water to turn the wheels of grist mills and the turbines of hydroelectric plants, water in boilers to make steam, water to cool the steam of steampower plants, water in industry—a great many uses, water for the pleasures of fishing and boating, and water for putting out fires.

Each person uses water each day for drinking and bathing. The housewife uses additional water for cooking and washing dishes and clothes. Others use water for washing the family car or watering the roses or the lawn. For these things the average town family uses about 40 gallons each day for each of its members. These uses are clearly seen, but other uses of water for the general benefit may be forgotten. Each time an electric light is used, water is also being used indirectly, water which had earlier been used to wash coal or cool steam or turn a turbine. Nearly everything that is manufactured or processed has at some stage required a supply of water. Thus, the real supply for each person is not the 40 gallons individually used in the home, but many times that amount.

Water for the Farm

Rural residents of Alabama use about 50 million gallons each day for domestic use and for watering livestock. During dry periods, additional water is used to irrigate crops and pastures.

It is estimated that rural families use about 20 gallons per person each day as compared to 40 for members of city families. Ninety percent of the farms in Alabama use electric power, but only 40 percent of farm families have running water in their homes. Other families continue to draw their water by hand from a well or spring, and this practice tends to reduce the use of water and largely accounts for the smaller per capita use of water by rural people. The total rural domestic use is estimated to be 30 million gallons daily, and the total stock use is about 20 million gallons daily. For example, a sheep drinks about 1 gallon a day, a hog 2 gallons, a horse or mule 8 gallons, and a cow about 10 gallons.

Nearly all the domestic supply for rural families is obtained from wells or springs. In the Piedmont area, most supplies come from dug wells. These wells range in depth from about 10 to 80 feet and can usually supply only a few gallons of water a minute. Elsewhere in the State, drilled or jetted wells are more commonly used and the yields of the wells are much larger. Such wells range in depth from about 25 feet to several hundred feet and in size from about 2 to 6 inches. Many wells tap artesian aquifers and, if located in lowland areas such as river valleys, commonly overflow from the pressure of water confined at higher elevations (fig. 30). Other wells are pumped. Many pumped wells yield several hundred gallons per minute, and a few produce more than a thousand gallons per minute.

Alabama farmers have constructed about 21,600 farm ponds which range in size from one-fourth acre to 400 acres. Ponds are used for irrigation, for watering cattle, and for fishing. Most ponds are near places where the flow of water is intermittent. During periods of clear weather, the water level of the pond is lowered by evaporation. Some ponds are on ground which is relatively permeable, and a large amount of water is lost by seepage. Farm ponds not infrequently fail during droughts.

Abnormally dry summers during recent years have caused a few farmers to procure and use irrigation systems to provide additional water for their crops. Water added by these systems has greatly increased the yield of the irrigated crops and pastures. About 460 systems are used to irrigate 27,000 acres of crop and pasture land. Nearly all use lightweight portable aluminum pipe and distribute the water over the land by sprinklers. Most systems are moved from place to place on a farm and obtain their supply of water from more than one source. The 460 irrigaiton systems in Alabama are supplied at one time or another by water from 138 wells, 251 streams, 251 ponds or lakes, and 11 springs. When operating, the average irrigation system uses about 500 gallons of water a minute.

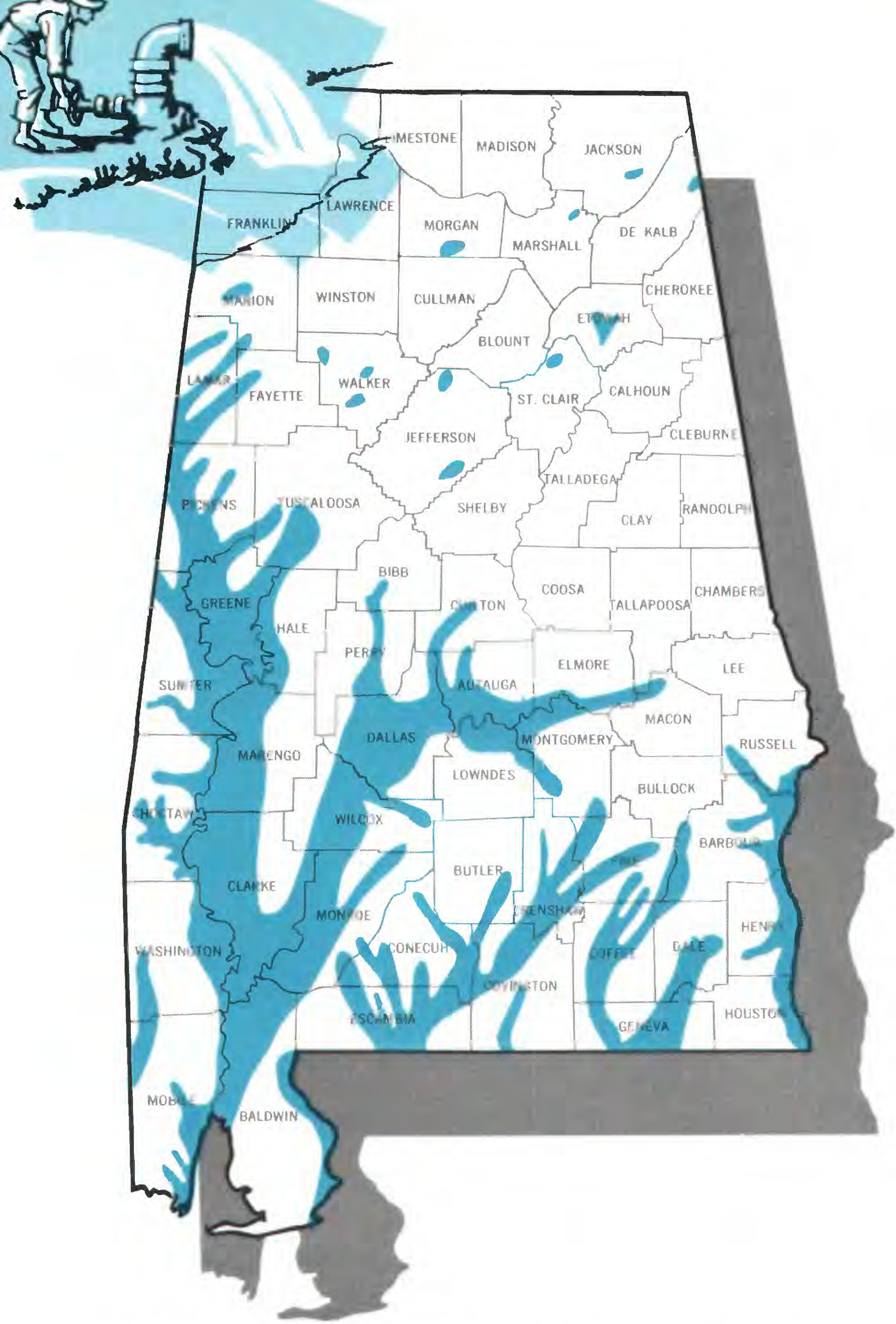

FIGURE 30.—Areas of artesian flow in Alabama. Artesian wells will flow if developed in the lowlands of the flood plains of the Coastal Plain streams and in some valleys in north Alabama.

Water for cities and towns

According to the State Health Department, 287 public water-supply systems serve 330 communities in Alabama. Fifty communities get their water from springs or shallow wells, 166 communities from deep wells, and 71 communities from streams or reservoirs. In some places the supply of water is obtained from more than one source. Sylacauga, Eufaula, and Talladega are the only cities in the State that have both a surface- and a ground-water supply. Most of the smaller communities get their supply from wells or springs. The following table shows the source of supply for municipal systems which serve more than 5,000 people and the estimated number of people supplied by each. Communities served by the system of an adjoining community are not listed in the table.

Accurate records of the number of people supplied by all municipal systems are not available. It is estimated, however, that 1.7 million people in Alabama obtain about 190 million gallons daily from such systems.

The initial selection of a source of supply depends upon many factors. Where water in the ground is plentiful and of satisfactory quality, that source may be preferred. There are excellent reasons for this preference. As water seeps into the ground, impurities are removed by the filtering action of the ground. Thus ground water is usually clear and relatively free of contamination by bacteria. There are other advantages in obtaining water from a well or spring. The supply in the ground, generally, remains constant, and once the level of that supply has been determined the user knows with some assurance the capability of his source of supply. Another advantage is the uniform quality and small variation of temperature over long periods of time.

Surface water usually contains impurities washed from the surface of the basin drained by the stream. Water from surface sources and from some wells must be filtered and treated before it can be used for municipal and some industrial supplies (fig. 31).

Some water is hard because it contains excessive amounts of calcium and magnesium which have been dissolved from limestone or dolomite. Such water can be softened by adding chemicals; lime and soda ash are commonly used for this purpose. By other commonly used methods, material such as iron, manganese, and silica can also be removed. Unpleasant tastes and odors are removed by oxidation, aeration, and by the addition of chlorine.

Municipal water supplies serving 5,000 people or more

Municipality	Estimated number of people served	Source of water		
		Spring	Well	Stream
Albertville	6, 000		X	
Alexander City	13, 000			X
Andalusia	11, 000		X	
Anniston	60, 000	X		
Athens	8, 000	X	X	
Atmore	5, 800		X	
Auburn	15, 000			X
Birmingham	450, 000			X
Brewton	5, 300		X	
Childersburg	6, 000	X	X	
Clanton	5, 800			X
Cullman	9, 900			X
Decatur	26, 000			X
Demopolis	5, 000		X	
Dothan	28, 000		X	
Enterprise	9, 000		X	
Eufaula	8, 000		X	X
Fayette	5, 000			X
Florence	28, 000			X
Fort Payne	7, 600			X
Gadsden	65, 000			X
Greenville	10, 000		X	
Guntersville	5, 800			X
Hartselle	5, 500			X
Huntsville	40, 000	X	X	
Jasper	10, 000			X
Leeds	5, 500	X		
Mobile	150, 000			X
Montgomery	150, 000		X	
Opp	6, 000		X	
Ozark	7, 400		X	
Phenix City	25, 000			X
Piedmont	5, 000			X
Prichard	40, 000			X
Roanoke	5, 800			X
Russellville	6, 000			X
Selma	23, 000		X	
Sheffield	13, 000			X
Siluria	5, 000	X		
Sylacauga	14, 000		X	X
Talladega	13, 000		X	X
Tallassee	8, 000			X
Troy	12, 000		X	
Tuscaloosa	65, 000			X
Tuscumbia	8, 500	X		
Tuskegee	7, 000			X
Wetumpka	5, 000			X

FIGURE 31.—Reservoir on Tallaseehatchee Creek. Sylacauga obtains part of its water from this reservoir. The water is filtered and treated at a plant near the dam. Deep wells furnish the remainder of the supply. (Photograph furnished by J. W. Goodwin Engineering Co., Birmingham, Ala.)

Some chemicals are not easily removed; sodium, chloride, and fluoride are examples, and their removal usually is not economically feasible. Knowledge of the minerals in water is an early point of concern for any who would develop a new source of water supply. Most of the surface and ground water of Alabama is free of objectionable amounts of minerals.

Water from most wells can be used without treatment but, because of concern for bacterial contamination, chlorine is commonly added. Efforts are also made to remove those constituents which tend to settle on pipes and clog up distribution systems. Depleted oxygen can be restored by aeration.

Water systems for four of the large cities in Alabama—Birmingham, Montgomery, Mobile, and Huntsville—are of interest because of the number of people they serve and because of the variability of source of supply.

Birmingham is on the divide separating the Coosa and Warrior basins, and no large streams flow by the city. The small streams nearby cannot furnish enough water for the city unless their surplus flow is caught and stored for later use. Two reservoirs were built for this purpose—Inland Reservoir and Lake Purdy. Each is capable of storing a volume of water equal to many months of natural flow. From each the city draws water at a near-uniform rate. The supply in the reservoirs is replenished during rainy periods.

Birmingham's water system was organized as a private company in 1885. The company originally developed Fivemile Creek, but that source soon became inadequate, and since 1891 water has been diverted from the Cahaba River. A dam on Little Cahaba River, impounding Lake Purdy, was constructed in 1910, and raised in 1928 and again in 1938 to provide additional storage. The present capacity of Lake Purdy is 5.7 billion gallons. The filter plant for this system is on Shades Mountain and has a capacity of 55 million gallons per day. In 1951 the waterworks facilities were purchased by the city of Birmingham. The system now serves Birmingham and the nearby communities of Bessemer, Homewood, Mountain Brook, Fairfield, Tarrant City, Graysville, Woodward, and some smaller places.

In 1938, the Birmingham Industrial System built Inland Reservoir on Blackburn Fork, a tributary of Locust Fork, to supply industrial water to Birmingham. The maximum dependable supply for a dry year from Inland Reservoir is estimated to be 50 million gallons per day. Present diversion from the reservoir is about that amount.

Since 1940, Birmingham Waterworks has obtained additional water from the Industrial System. Water from that source is treated at the Birmingham Station Filter Plant, which has a capacity of 12 million gallons per day.

The demand for water, however, continues to grow. The existing sources of supply are nearing the upper limit of their capabilities. Plans have been formed to obtain additional water from Sipsey Fork at a site 30 miles northwest of the city. Upstream from that site, a large storage dam and powerplant are being built by the Alabama Power Co. This reservoir, when completed, will have sufficient capacity to provide a dependable regulated flow of about 600 million gallons daily.

Water from Inland Reservoir is of slightly better quality than water from Lake Purdy, being low in mineral content and extremely soft. Water from Lake Purdy is low in mineral content and only moderately hard. The principal chemical constituents of the Lake Purdy supply are calcium and bicarbonate.

The seasonal changes in temperature of water in Inland Reservoir are of interest. During winter months a near-uniform temperature exists throughout the reservoir, but with the coming of warmer weather, the upper layers of water are warmed and

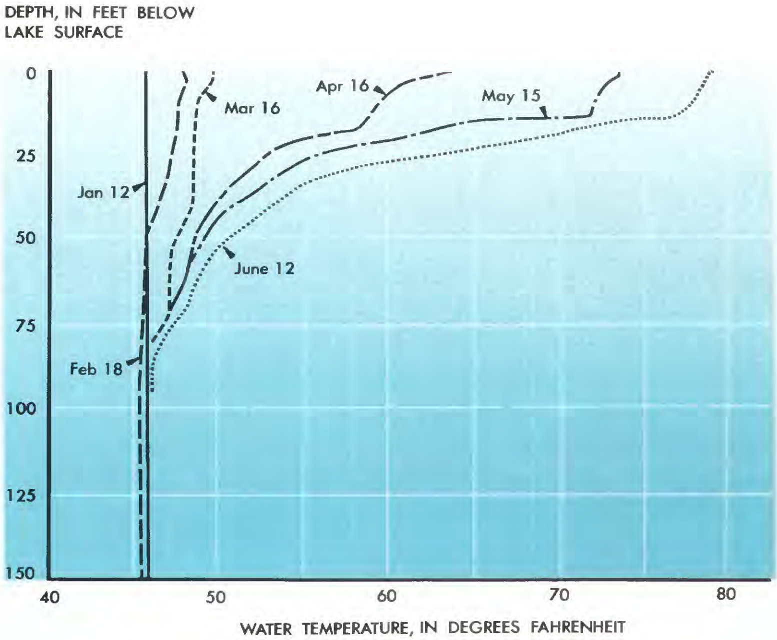

FIGURE 32.—Temperature of water in the Inland Reservoir. Temperature varies with depth and with the season of the year. A cool supply is obtained in all seasons by diverting water from near the bottom of the reservoir.

the temperature profile varies (fig. 32). Through spring and summer, the variation in temperature becomes more pronounced until the colder weather of late fall arrives and once again restores the condition of uniformity.

The mineral content of the water also is changed or modified by its passage through the pool or retention in the pool. Through mixing, the mineral content is made more uniform, and the sudden changes sometimes found in unregulated streams become less pronounced in the flow of streams below dams. Some less desirable changes can also take place. In large lakes, mixing is not complete and highly mineralized water, which is slightly heavier than pure water, tends to remain near the bottom during the warmer months of the year.

The city of Montgomery was incorporated by the first State Legislature in 1819. The early settlers and citizens used shallow wells and springs as a water supply until 1885. The first public water-supply system for the city was organized in 1884 by a private corporation. Water was obtained from six wells drilled in the waterworks lot in what is now the city's North well field along North Court Street in the northern part of Montgomery. All these wells are reported to have had natural flows when they were drilled in 1885, and one of them, drilled to a depth of 837 feet, is reported to have flowed at a rate of 200 gallons per minute. Many private wells in the Montgomery area also had natural flows. As more and more wells were drilled, without regard for proper spacing and the amount pumped from each, water levels in the wells declined, and by 1899 most of the wells in Montgomery had ceased to flow (fig. 33).

In 1895 the city acquired the private water system. In 1899, 12 new wells were drilled and equipped with airlift pumps. The combined capacity of these wells, all located in the North well field, is reported to have been 5 million gallons per day. As demands for water increased, additional wells were drilled in the North well field and, in 1941, 12 test wells were drilled southwest and west of the city to determine the thickness and areal extent of the water-bearing sand and gravel beds.

FIGURE 33.—Montgomery's West and North well fields. The close spacing of the municipal wells has contributed to a declining water level in the area.

By 1949 the municipal water system included 31 wells having a total daily capacity of 17 million gallons. In 1958 the water system included 32 wells in the North well field (17 operative) and 31 wells in the West well field having a combined daily capacity of about 31 million gallons.

The Montgomery area is underlain by crystalline rocks at a depth of about 1,100 feet below land surface. These rocks are overlain by Coastal Plain sediments, which consist of alternating beds of sand and clay. Along the Alabama River, the Coastal Plain strata are overlain by a deposit of river alluvium consisting of 20 to 80 feet of sand, clay, and gravel.

Relatively large quantities of ground water occur under artesian conditions in the Coastal Plain sediments. Test drilling has defined four water-bearing zones in these formations.

The alluvium (soil, sand, or gravel deposited by running water) along the Alabama River is the source of many domestic supplies and is tapped by a few of the municipal wells of largest capacity in the North well field. The water in the alluvium is generally unconfined and is replenished by local precipitation.

Records of water levels in observation wells indicate that water levels in wells that draw from the deeper Coastal Plain sands are declining at the rate of about 9 feet per year, whereas those in wells that draw from the upper sands are declining only about 1 foot per year. Withdrawals of large quantities of water from these sands have created relatively large cones of depression in the water table.

Ground water from water-bearing sand and gravel in the Montgomery area is generally of good quality, being soft and low in chloride, but in some places contains excessive amounts of iron. The temperature of the water averages about 68°F.

Some ground-water problems in the Montgomery area have resulted from improper spacing of wells and others from excessive pumping. The recharge area for the artesian systems is only a short distance to the north of the city. Concentrated development has caused excessive lowering of the water level in some areas (fig. 34).

In early years, water for Mobile was hauled from creeks north of the city. In 1840 a privately owned waterworks was constructed on Three Mile Creek, from which Mobile was supplied water until 1898. In 1886 a second private system was constructed on Clear Creek and was operated separately from the first. The city of Mobile acquired the first system in 1898 and the second in 1907. Since 1907 the city has operated the waterworks. In 1952 a reservoir on Big Creek was constructed which now supplies most of the water used by the city and supplies some water to industries.

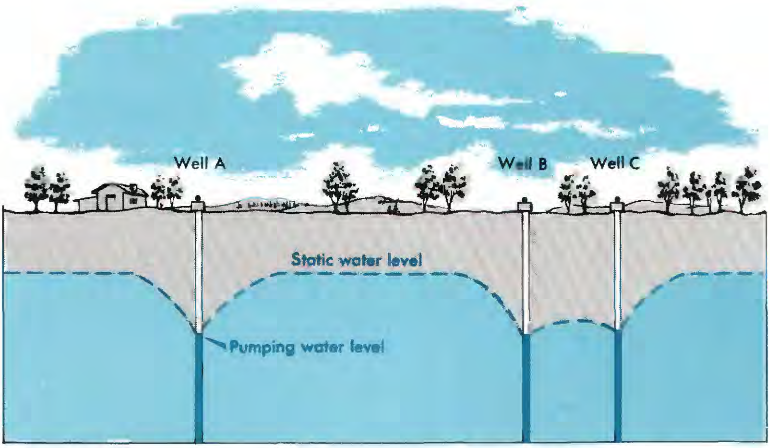

FIGURE 34.—Three pumping wells. Well A is properly spaced in relation to wells B and C. The cones of depression around wells B and C overlap and cause a decrease in yield and an increase in pumping cost in each well.

The dependable yield of Big Creek Reservoir was appraised on the basis of a 15-year record of streamflow. The most adverse drought-flow conditions between 1939 and 1954 occurred during the summer and fall of 1954. Computations show that during this time a release of 100 million gallons per day would have depleted the reservoir by about 84 percent of its usable capacity before the drought eased. A release of 110 million gallons per day would have required the entire usable capacity of the reservoir. Big Creek Reservoir was designed to insure a safe yield of 100 million gallons per day, of which 30 million gallons per day is reserved for domestic use, the remainder being available for industrial use.

Although the city has supplied the greater part of water for domestic and industrial needs, many shallow and a few deep wells are in use by individuals in the area. Ground water has been used commercially since before 1900 by breweries and for the manufacture of ice. Air-conditioning units utilizing water from shallow wells were installed in many of the downtown business houses around 1937.

The shallow sands which are 25 to 90 feet deep in the downtown area of Mobile have been overdeveloped. Pumpage of ground water for air conditioning and to permit construction of Bankhead Tunnel lowered the water table several feet below sea level and has resulted in the encroachment of salt water from the Mobile River. This lowering of the water table causes salt water to enter the shallow water-bearing sands in the entire downtown well field (fig. 35). Whether fresh water can be restored to these shallow sands is questionable.

Deeper sands, from 700 to 800 feet below the surface, presently supply considerable quantities of water. Inasmuch as this use has caused but little decline of artesian pressure, the sands appear to offer further opportunities for development. The water has a chloride content that ranges from 1,400 to 2,500 parts per million, but its use in industrial cooling systems has proved to be satisfactory.

Huntsville's public water-supply system, the South's first and the Nation's second, was established in 1823; it utilized Big Spring, now an emergency source of the present supply. Water from Big Spring flows from a solution channel in limestone and supplied almost all the needs of the city until 1950 (fig. 36).

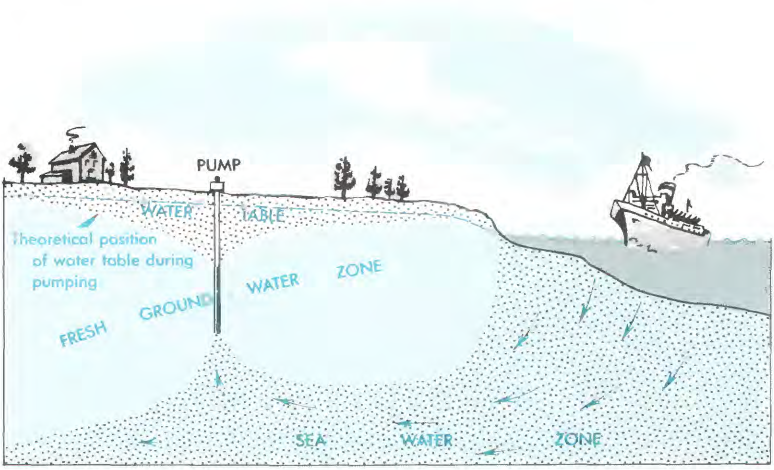

FIGURE 35.—Salt water encroaches into a fresh-water zone as a result of improper well spacing or excessive pumping or both.

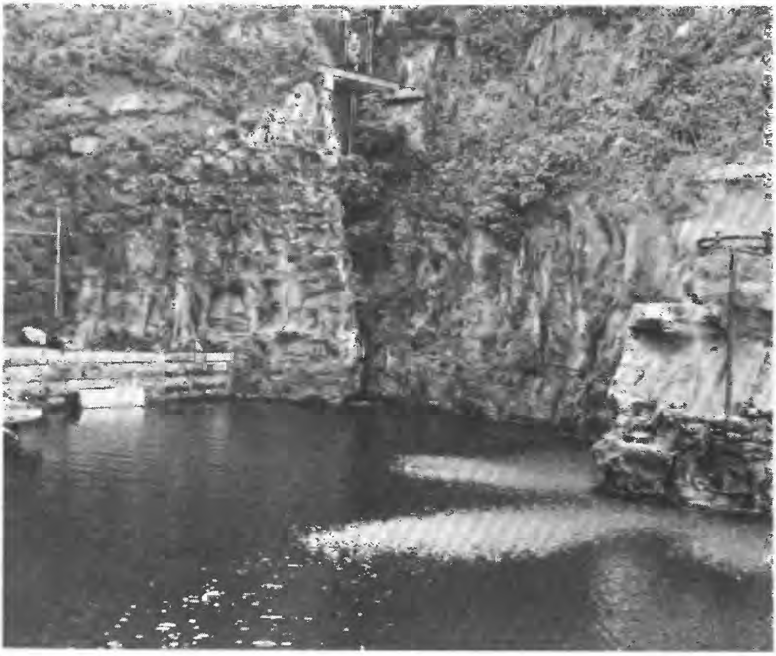

FIGURE 36.—Huntsville Big Spring, which flows from solution channel formed along fracture in limestone.

Paced by rapid industrial expansion and population increase, the demands for water by the city grew from about 2.5 million gallons per day in 1943 to about 6 million gallons per day in 1954, and is now 10 million gallons per day. Throughout the winter, spring, and early summer, the flow of Big Spring is more than adequate to meet this demand. In late summer and fall, when demands on the water system are greatest, the discharge of Big Spring has been as low as 1.5 million gallons per day, which is approximately the estimated minimum flow.

To meet the growing demands for water, the city in 1950 purchased Brahan Spring and all its facilities from the Huntsville Manufacturing Co., which had earlier developed the spring to supply its cotton mill and mill village. Brahan Spring can supply about 1 million gallons per day to the city.

In a short while even more water was needed and is now being obtained from four wells. As long as a sufficient quantity of water can be developed from wells, the city plans to maintain Big Spring as a standby source to be used in emergencies.

The Huntsville area is underlain by massive beds of limestone that dip gently to the southeast. Ground water occurs in extensive joint, bedding-plane, and fracture systems in the limestone. These openings where developed by wells or springs yield large amounts of ground water.

Ground water in the Huntsville area is soft to hard, moderately low in dissolved solids, and low in sulfate and chloride content.

Water for industry

It is estimated that rural areas in Alabama require about 50 million gallons daily, and Alabama cities and towns require about 190 million gallons daily. Large as those figures are, they appear small when compared to figures for water used by industry. A single industrial enterprise, the Tennessee Coal, Iron and Railroad Co., uses nearly twice as much water each day as is used by all the city, town, and rural people of the State combined. The exact amount of water used by all industries in the State is not known but that amount is very large indeed.

There are two general categories of water use: consumptive and nonconsumptive. Water that is used for waterpower, navigation, or recreation is not removed from the stream or lake. Such use is nonconsumptive. Water that is used for industrial or domestic purposes, however, is actually subtracted from the supply and is returned in a degraded condition. This is consumptive use of water.

An industrial user may need a large supply of water. Sometimes, however, he is more concerned with the quality of the supply. The suitability of a supply is directly related to how the user makes use of it. The following table shows the water requirements of typical industries.

Industrial uses and water requirements

Process or product	*Water requirement, in gallons*
Meat packing	3,600 per ton of meat
Vegetable canning	500 per case
Dyeing cotton yarns	26 per pound
Paper and paper products	20,000–80,000 per ton
Dynamite	7 per pound
Sulfuric acid	16,000 per ton
Ammonium nitrate fertilizer	150,000 per ton
Washing coal	100 per ton
Making brick	20–250 per 1,000 brick
Gypsum board	3,000 per 1,000 square feet
Pig iron	1,400 per ton
Iron pipe	500 per ton

The table contains only a few uses by Alabama industries, but shows that the requirements of industry are great and varied. The requirements change from time to time as new methods of manufacturing are devised and as economic conditions change. For instance, in the 7 years from 1952 through 1958, Alabama has moved from far down the list to fourth place among the states in commercial production of broiler chickens. In 1958 Alabama produced 130 million birds. Six gallons of water are required for the processing of each bird for market. Thus in Alabama a new water-using industry has developed in the last few years.

The industrial demands on our water resources are always growing. No one has a record of all current uses, and the older records are now out of date. Available records indicate that total industrial demand is about 5,000 million gallons per day.

Water delivered to homes for domestic consumption sometimes contains material which would make that water unsuitable for certain industrial purposes. The quality required, of course, is directly related to the water's intended use. If the water is to be used for processing of foods, it obviously must not contain harmful bacteria. For other uses, certain mineral constituents are desirable in that they enhance the quality of the finished product. For example, too little hardness in water used for baking will result in soggy bread.

Limitations of the amount of impurities in water for industrial use differ for each purpose. The dissolved salts in sea water do not restrict its use for cooling purposes. At the other extreme, there are very exacting requirements for water used in the manufacture of certain electronic tubes; not only is the water completely demineralized for this use, but the air and the entire plant must be completely free of dust, smoke, and other impurities.

The uses of water in industry are for drinking and sanitary purposes, for boiler feed water, for cooling, and for process water incorporated into the product. By far the greatest volume used in industry is for cooling purposes.

When electricity is produced by burning coal, oil, or gas, water in a boiler is turned to steam and that steam is used to turn a turbine which drives the generator producing the electricity. After passing through the turbine, the steam is cooled before being returned to the boiler to start again on its journey. The steam is

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cooled by water circulating through pipes in a condensing chamber. For every pound of coal burned, about 500 pounds of cooling water is required. About 3,500 million gallons of cooling water is required each day at the steampower plants in Alabama. Water is used for this one purpose at the rate of more than 1,000 gallons each day for each of the State's inhabitants.

Figure 37 shows one step in use of cooling water by another industry. Quite obviously, the temperature of water used for cooling would be an important quality.

Any water that is not corrosive or does not produce slime is suitable for cooling purposes. It is also desirable that the water have low turbidity and hardness, and contain little iron and manganese. The water may be treated to remove suspended materials or reduce corrosive action. However, the tremendous quantities of water required for cooling dictate the selection of the source of supply requiring the least treatment.

FIGURE 37.—Industrial reuse of water. Water is cooled by spraying and then reused at blast furnace to obtain economy in operation. This system has a capacity of 30,000 gallons per minute. (Photograph furnished by U.S. Pipe and Foundry Co., Birmingham, Ala.)

The source of boiler water must be selected more carefully because of undesirable minerals, particularly that for boilers operating at high pressures. The undesirable effects of improper boiler water are scale, corrosion, and embrittlement of the boiler plate. Scale forms in boilers by deposition of calcium, magnesium, and silica from the highly concentrated dissolved solids. This hard insulating deposit reduces the efficiency of the boiler and requires more fuel. Excessive deposit can lead to failure of the boiler parts where heat produced by the fires is not transmitted readily to the water.

Corrosion is caused by dissolved gases—oxygen or carbon dioxide—or by the presence of certain chemicals, principally the chlorides or nitrates of calcium and magnesium or free acids. The gases in the boiler feed water or in the condensed steam being returned can be removed in a deaerating heater. In the deaerating heater, the temperature of the boiler feed water is raised and, because dissolved gases are less soluble in water at high temperatures, they are released from solution. The chemicals that would cause corrosion are usually removed by prior treatment of the water. Even so, over a period of time the concentrations of these materials will build up, and internal treatment of the water becomes necessary to insure that conditions leading to corrosion are absent.

Embrittlement, or cracking of the boiler plate, is caused by failure to maintain the proper alkalinity or by the presence of considerable amounts of certain chemicals, such as sodium bicarbonate or sodium carbonate. Proper control of the alkalinity in the boiler and the use of materials such as sodium nitrate or quebracho tannin and phosphates prevent embrittlement.

If industrial users were questioned about the characteristics they could not tolerate in their process water, each one would give a different answer. Some would be concerned with the appearance of the final product; some would be concerned with the difficulties in the intermediate steps of manufacturing because of the presence of certain materials. Each user would place certain limitations on the amount of dissolved or suspended materials in the water. Some industries require water safe for human consumption, and they would then treat this water to satisfy their particular requirements. Some of the properties of water that are particularly critical are: turbidity, color, hardness, iron and manganese content, alkalinity, odor, taste, and dissolved gases. For any particular process, one or possibly several of these properties would be undesirable. Food and drink processing plants, for instance, find iron and manganese, color, odor, taste, and sometimes hardness adversely affect the quality of the finished product.

For the pulp and paper industries, the process water should be practically free of suspended matter, color, iron, and manganese. The presence of these materials causes either a reduction in the brightness of the finished product or a discoloration of the product. Hardness in the water is objectionable because it contaminates the pulp and the final product. The amount of these materials that may be present is more restrictive for the manufacture of fine paper than for the manufacture of kraft paper. Where a final treatment, such as bleaching, is given to the product, the requirements for purity are less stringent.

At aluminum reduction plants, the principal use for high-quality water is the boiler water makeup. The major use of water is in the gas scrubbers, and for this purpose there are no limiting restrictions on presence of materials in the water. In the gas scrubbers, fumes from the reduction pots are washed with a water spray to absorb fluorine gas and fine particles of aluminum oxide and carbon. Fluorine gas has a toxic effect on vegetation and, for this reason, must be removed before the fumes are released to the atmosphere.

The particular requirements for purity of process water in various chemical industries depend upon the particular product and the process used in its manufacture. No attempt will be made, therefore, to set up specifications for purity of the water for chemical industries.

Within recent years, the use of atomic reactors to produce electricity has brought about requirements for very pure water for use in these plants. The problems encountered if extremely pure water is not used are twofold:

1. Corrosion within the system could lead to weakening and failure of system components, and
2. Excessive radioactivity could be built up by irradiation of impurities in the water.

Corrosion, particularly troublesome at the high temperature and pressure used, would be caused by the presence of dissolved oxygen and certain dissolved materials, such as chloride; these materials should be completely absent. The purity required for the water used in these reactors perhaps can be visualized from this comparison: If a piece of table salt the size of a matchhead is dissolved in a pool of water 40 feet long, 40 feet wide, and 10 feet deep, the concentration obtained would be an average of the dissolved salts permissible in the water to be used in the reactor. The average concentration of the Mobile River near Mount Vernon, Ala., is almost 1,600 times that of the water to be used in the reactors.

It is recognized, then, that for industrial users the mineral quality of the water is extremely important and that for some purposes the presence of even minute amounts of impurities in the water restricts its use.

As was earlier stated, the amount of water diverted each day for industrial purposes has been estimated to be about 5 billion gallons a day. Some of this supply is diverted from the waterway only momentarily, as at a steamplant, for instance. Water diverted from the ground is seldom, if ever, returned to the original source but is carried off by streams. At some industrial plants the same supply is used for more than one purpose, and at other plants water is used many times before it is discarded.

Small industrial water supplies are usually obtained from a municipal system. Industries which use large quantities of water usually have their own private system.

Falling water produces power

A cubic foot of water weighs 62.4 pounds. If that weight of water fell 8.81 feet, it would produce 550 foot-pounds of energy, which if done in a second would equal 1 horsepower. The fact that falling water can be put to useful work has long been known. The concept of what constitutes a desirable and efficient water power has changed from time to time.

In 1900 there were 897 waterpower plants in use in Alabama. Only three of these had a capacity in excess of 1,000 horsepower, most of them being rated between 5 and 50 horsepower. The majority were for grinding wheat and corn and were called flour mills or grist mills. Others were used to saw and plane lumber, to card wool, to gin cotton, to weave cloth, or to make twine and rope; many served several purposes. The history of one waterpower plant is interesting enough to quote (The Waterpowers of Alabama, by B. M. Hall: Alabama Geol. Survey Bull. 7, 1902):

"The waterpower at Prattville was first developed about 1830 when it was used by a man named May to operate a small sawmill. About 1833 this waterpower and the adjacent lands were purchased by Mr. Daniel Pratt, who then erected a cotton gin factory which was driven by the waterpower. The dam at that time was about 8 feet high. A number of years after the purchase of this property by Mr. Pratt, he increased the dam so that it now has a height of 16 feet, and is built of brick. At present it is used jointly by the Prattville Cotton Mills and Banking Company and the Continental Gin Company, the former using about 255 horsepower and the latter about 100 horsepower."

To add a sequel to the story, the waterpower developed at Prattville was mechanical power in that it was put to use by means of shafts, pulleys, and belts. As the need for power at Prattville increased beyond the capacity of the local development, electric power was obtained from an outside source and some machines were then driven by individual electric motors.

As the 19th century ended, ideas on waterpower began to undergo a change. The day of mechanical power in which the user of a waterpower had to locate his mill on the bank of the stream drew to a close. The day of power through the generation of electricity had already dawned.

How many of the 897 waterpowers of 1900 are still in use is not known, but most are now abandoned or destroyed. Many have been washed away by floods. The pools of others have long since been filled with sediment. Changes in agriculture and in laws governing milling made the operation of some unnecessary and of others uneconomical. A few remain—as do covered bridges—to serve our time and future generations in a very picturesque way.

Late in the last century, a hydroelectric plant was built on the Tallapoosa River at Tallassee to supply electricity to the city of Montgomery. In the early years of this century, other plants were built to supply Talladega, Sylacauga, Goodwater, Speigner, Centreville, Troy, and Elba. These were located on streams near the towns they served, the individual plants having capacities of a few hundred to a few thousand horsepower. The plant supplying Elba was washed out in the 1929 flood, but was rebuilt. The one at Tallassee was replaced by a larger development. The others are no longer used.

New ideas and needs have led to changes in the pattern of elective power development. The capacity of early waterpower plants was set near the level of the minimum flow of the stream. Larger flows were not used—they were wasted over the dam or

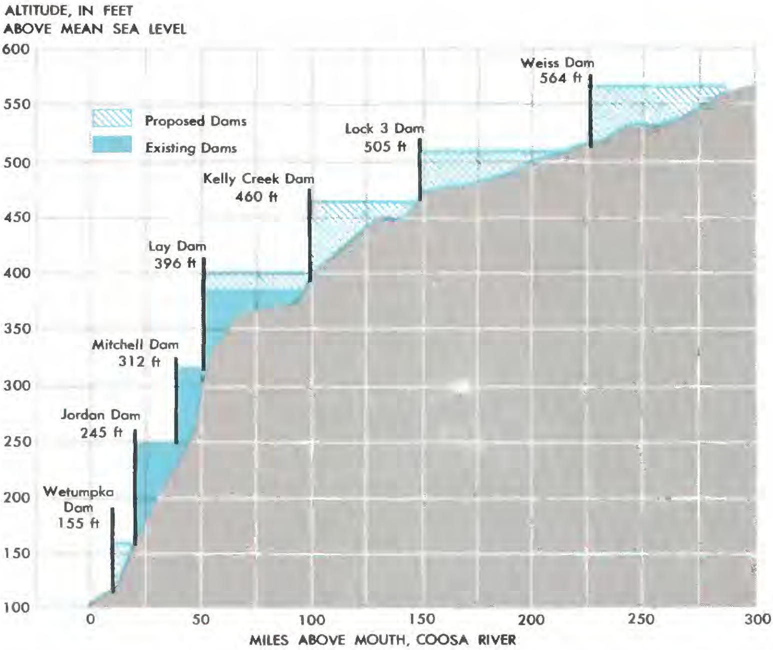

FIGURE 38.—Profile of the Coosa River showing location of existing dams and places where other dams are to be built.

spillway and did no work. It was easy to see that the plant capacity could be greatly increased if the rate of flow could be controlled by storing water in wet periods for release in dry periods—now a common practice. Early experience in the operation of individual plants showed that such operation was inefficient in comparison with the possibilities of an integrated system to serve many communities. Studies showed that large plants were more efficient than small ones, and that a combination of steampower and waterpower was better than either type alone. To gain these several advantages required the joining of efforts and the expending of large sums for capital improvements, which in turn led to the formation of the integrated power company to serve a large area.

The Alabama Power Co. completed its first major unit, a plant on the Coosa River, in 1914. Two other hydroelectric plants were built on the lower Coosa River in succeeding years along with plants on the Tallapoosa. Martin Dam and Reservoir on the Tallapoosa River effectively control the runoff from an area of about 3,000 square miles. Waterpower there and at other plants down the Tallapoosa River is thus closely related to the average flow of the river. The dams on the Coosa River have only limited ability to control the flow and are spoken of as run-of-river plants. A dam on a headwater stream near Cartersville, Ga., does store wet-weather flow and the Coosa plants benefit from that storage. The Cartersville Dam was built by the U.S. Corps of Engineers.

The Alabama Power Co. has recently embarked on an ambitious program of building other dams and power-generating facilities. Figure 38 shows the plan of development of the Coosa River. The Lewis Smith Dam is also being built on the Sipsey Fork, a tributary of the Black Warrior River, and other plans call for installation of generating facilities at two Federal navigation dams on the Black Warrior River.

Water stored above the Lewis Smith Dam will produce power but will also provide other benefits. Water released at the dam will provide both larger flows and cooler water for the steampower generating facilities of the company downstream at Gorgas, and will thus increase the efficiency of those facilities. Those releases will also provide additional flow for the operation of navigation locks downstream on the Black Warrior and Tombigbee Rivers. The city of Birmingham is constructing a pipeline to a site on the Black Warrior River below the Lewis Smith Dam to tap an assured supply of cool water of good quality.

At Florence, Ala., the Tennessee River carries the runoff from nearly 31,000 square miles, and the flow is at all times substantial. In a shoal section upstream from Florence, the river drops 140 feet. This combination of large flows and steep stream gradient is everywhere recognized as offering near-ideal possibilities for development of waterpower. Plans for a development near Florence were envisioned long ago. During World War I, the need

FIGURE 39.—Wilson Dam and powerhouse. This dam makes possible hydroelectric power, flood control, and navigation on the Tennessee River. (Photograph furnished by Tennessee Valley Authority.)

for nitrogen for explosives was great and a method for obtaining nitrogen from the air by using electric current had been perfected. To supply the power for this use, the construction of a dam and powerplant near the lower end of the shoal was begun. Today that plant is called Wilson Dam in honor of President Woodrow Wilson. The present capacity of Wilson Dam is 610,000 horsepower.

In dry weather, all flow at the Wilson Dam is used to generate power or to operate the navigation lock. Flood flows are discharged over the dam, the rate of flow being controlled by gates on the crest of the dam (fig. 39).

The Tennessee Valley Authority was created in 1933. Since then, it has constructed many dams on tributaries of the Tennessee River to store water, to control flood flows, and to generate power, and has built other dams on the Tennessee itself to make further use of the water for navigation and power. Pickwick, Wheeler, and Guntersville Dams were completed in the first decade of TVA construction. These dams, together with Wilson, create a series of pools for the 200-mile reach of the river in Alabama. At these dams, power is generated from a flow which rarely falls below 20,000 cubic feet per second through an aggregate combined fall of about 240 feet. For capacity operations, flows of about two and a half times the minimum are required.

The U.S. Corps of Engineers has completed two plants on the Chattahoochee River, one near the mouth and one in the headwaters. They are presently building another at a site east of Abbeville. All these plants furnish power and provide other benefits.

Small waterpower plants have been built on the Pea and Conecuh Rivers in south Alabama for the benefit of nearby towns and farms.

The major rivers carry the runoff from large areas. Because their flows are large, they offer the greatest opportunity for developing large waterpowers, and an active program is underway (fig. 40). Flows can be improved by the construction of reservoirs on tributary streams, and in time projects of this type will be undertaken.

Rivers are also highways

Long before the white man came to this continent, the Indians used the rivers to move themselves and their belongings from place to place. When the white man came and explored the continent, he too used the streams as highways. As the land was settled and goods were produced for market, some of these goods were carried to the marketplace on rafts or flatboats propelled by manpower or floated down the creek and rivers. This use of streams was developing at the time when dams were being built for small mills, and the use for one purpose soon came into conflict with the use for the other.

As early as 1821, 2 years after Alabama became a State, the legislature recognized the conflict over use of streams and passed the first law dealing with the problem. In that year an act was passed in which a reach of Mulberry Fork—"from its junction with Sepsie Fork to Ballimore"—was declared to be a public highway. Between that time and 1861, a total of 50 such acts was passed by the legislature. It is of interest to note that no act referred to a larger river, an indication that no conflict of use had yet developed in regard to those larger streams.

FIGURE 40.—Sites of proposed and existing dams for development of the major rivers. Many other dams have been built on tributary streams.

The early rafts and flatboats had one great drawback: mostly they could only travel with the current. Those who rode them downstream had to make the return journey on foot or on horseback. Robert Fulton changed this situation when he built the *Clermont* and steamed up the Hudson River in 1807. By 1812 a steamboat had appeared on the Mississippi, and by 1821 the steamboat *Osage* had been put in service between Florence, Ala., and New Orleans. Thus, very early in the history of Alabama as a State, cotton and other goods were being sent to the gulf port of New Orleans by way of the Tennessee, Ohio, and Mississippi Rivers.

Those who navigated boats on rivers faced many obstacles. Shallow water, sand bars, and snags were bad, but the really formidable obstacle was the shoal reach of a stream. Muscle Shoals at Florence was an effective barrier, and how to get around it was a problem as early as 1810. In 1828, Congress granted the State of Alabama 400,000 acres to be sold, the proceeds to be used to construct a canal around Colbert and Muscle Shoals. A canal around part of the shoal was built and put in use in 1836. But, poorly engineered, it was a failure.

Many things seemed to block the way toward improving the streams for navigation. These included: the Indians, the bordering Spanish province of Florida, sectional jealousy, money panics, the years of the Confederacy and of Reconstruction, the coming of the railroads, records of projects which failed, and aversions to governmental construction of internal improvements.

To improve navigation on the Coosa River, a plan was made to build 31 locks between Greensport and Wetumpka. Three sites were improved in 1890, and two others plus a site near Rome, Ga., were improved in the period between 1914 and 1917. This work was undertaken during and after the period when railroads were being built in the area; need for navigable waterways was considered less pressing and further work on the plan was stopped. The locks are not now used.

Funds for planning improvements on the Black Warrior and Tombigbee Rivers first became available in 1884. By 1915, the last of the 17 dams and locks from tidewater to near Birmingham had been built by the U.S. Corps of Engineers. By the time the last structure was started, improvements were already underway—lock 17 was built to a much greater height than the original

FIGURE 41.—A tug and barge train being raised to the level of the upper pool at Demopolis Lock and Dam on Tombigbee River. Another tow stands by, awaiting its turn to be locked through to the lower pool. (Photograph furnished by Corps of Engineers, U.S. Army.)

plan called for. This change eliminated the need for additional dams upstream. Other higher dams have since been built to take the place of from two to four of the earlier low dams, and work at other sites is underway or planned. When all improvements are completed, the five newer dams, known as Jackson, Demopolis, Warrior, Oliver, and Holt, will have replaced the lower 16 old dams. Each will be equipped with a lock chamber measuring 110 by 600 feet. Larger and fewer locks will greatly reduce the travel time of boats using the waterway. About 3 million tons of cargo are annually carried by vessels on this waterway (fig. 41).

The Chattahoochee River is presently being improved for navigation and power. The Jim Woodruff Lock and Dam near the Florida line has been completed, and work is rapidly progressing on the Walter F. George Lock and Dam east of Abbeville. These dams, together with one planned for Columbia, and dredging of the lower river will provide a navigable waterway from tidewater to Phenix City.

Improvement of navigation on the Tennessee River was one of the objectives of the TVA act. The river is now navigable from its mouth at the Ohio River to Knoxville, Tenn., including, of course, the 200-mile stretch in Alabama. At Wilson Dam the Tennessee Valley Authority is presently building a lock which will lift boats 100 feet, the highest lock lift in the world. At and below Wilson Dam, the locks are 110 by 600 feet, but upriver they are generally 60 by 360 feet. When conditions warrant, the upriver locks will be enlarged. About 8 million tons of goods move through this waterway each year.

When all the power dams planned for the Coosa River are built, the river will be a series of pools from Wetumpka, Ala., to Rome, Ga. If locks were placed in those dams, boats could then navigate that stretch of the river. A long-range plan for the Coosa and Alabama Rivers calls for building three dams and locks; when and if this is done, navigation from Wetumpka to the Gulf will be possible (fig. 42).

As early as 1807, routes to connect the Tennessee River to the Gulf by way of an arm of the Mobile River were being proposed. A route from a prong of the Hiwassee in the Tennessee basin to a headwater stream of the Coosa was surveyed in 1827, this route being a common portage for the Indians and for the early settlers. Other routes were surveyed and studied in later years. The present consensus seems to favor the Tombigbee route shown on the map (fig. 43). It is argued that if this waterway is developed, boats that ply the waters of the Ohio, Cumberland, and Tennessee Rivers would use it to advantage. For some, the journey to the Gulf would be made shorter by 400 miles. It is further argued that the port of Mobile would flourish, and that all of Alabama would benefit.

The State Docks and other facilities at Mobile handle about 15 million tons of goods each year. The principal products and tonnage figures for 1958 were: petroleum, 3.5 million tons; iron ore for shipment to Birmingham, 3.3 million tons; bauxite for shipment to Alcoa, Tenn., 2.1 million tons. Many shiploads of bananas are unloaded each year from the "Great White Fleet" of the United Fruit Co. Inland waterways are important to Alabama and, if developed further, could be of much greater importance.

FIGURE 42.—Inland and coastal navigable water routes. The proposed Tombigbee route would link the Warrior and Tennessee River systems.

Water for fun and recreation

It was mentioned that Alabama farmers have built about 21,600 ponds. Many of these ponds are stocked with fish and are open, for a fee, to the public for fishing or are enjoyed by the members of a club. Seventeen lakes built in various sections of the State by the State Department of Conservation are stocked with fish and are open to the public.

Although the ponds and small lakes are locally important, the major vacation playgrounds are either at the Gulf coast or at the lakes behind the large dams. At those locations, people enjoy many types of water sports, including fishing, water skiing, boat racing, and sail boating. Along the backwaters above Lake Martin, Lake Jordan, and the dams of the TVA, many vacation cottages have been built, and other cottages are found in the Gulf areas of Mobile and Baldwin Counties. As other dams are built, the day approaches when all sections of the State will be within 50 miles of some large water body. When that day comes, Alabama could, with good reason, claim to be a vacation paradise.

Toward clean streams

Water is used on the farm, in the home, or in the factory, and then discarded. Water diverted to condense steam in a steam-power plant is warmed in the process but is otherwise unchanged as it returns to the stream after having done that work. Most diverted water is changed by use, and, when returned to a stream after use, is in less desirable condition than before that use.

Until about 1950, some industries and cities attempted to improve the quality of the used water before returning it to the stream, but many others did not make that effort. Groups of responsible citizens became concerned with the growing pollution of streams. Through their effort a public agency known as the Water Improvement Commission of Alabama was created in 1947. The commission works toward improving the purity of the water in the streams by decreasing the amount of impurities conveyed to the streams.

In the years since its creation, personnel of the commission have worked with many communities and industries on programs for reducing pollution. In the last 10 years, about 30 plants have been built to treat sewage before it is returned to the stream.

Municipal and industrial wastes are treated to prevent bacterial contamination, the killing of fish and other aquatic life, deterioration of stream quality, and the nuisance of foul-smelling, unsightly streams. The materials that bring about these conditions in water are dissolved and suspended inorganic and organic substances, along with the bacterial contamination. Organic materials in sewage are the products of living organisms, whereas some inorganic wastes result from manufacturing processes. The inorganic materials may be any chemical substance produced as a byproduct of manufacturing; they include such contaminants as acids, alkaline materials, iron, brine, or any number of other chemicals which may be toxic to fish and aquatic life, and even to man. Bacterial contamination, of course, comes mainly from the disposal of sewage that has received no treatment or only partial treatment.

Usually there is no visible measure of the amount of pollution or contamination in a stream insofar as the bacterial content is concerned. However, streams polluted by organic wastes can be recognized by their appearance and odor. These conditions are brought about by the action of bacteria in converting the dissolved or suspended decomposable substances to stable mineral compounds. The floating and suspended debris in the stream is broken down into smaller particles that settle out. The foul odors that are a byproduct of the life cycle of the bacteria no longer exist when the materials being decomposed have reached a stable state, for these materials are the food supply for the bacteria.

The same process of the decomposition of organic materials by bacteria occurs in streams that do not receive sewage or industrial wastes. All streams receive organic material in the form of vegetable matter and these are acted upon by bacteria in the same manner as in heavily polluted streams. During dry periods, when the water is not flowing and where large amounts of leaves and other vegetable matter are present, the water becomes stagnant and the gases released by the bacteria resemble, to a small degree, those released by streams that are heavily polluted.

The ability of the stream to purify itself is dependent on the amount of dissolved oxygen available in the water. As long as this oxygen is in excess of the requirements of the aquatic life and of the bacteria, we have a clean stream insofar as putrefaction is concerned. We may still have bacteria harmful to man occurring in the stream, but other forces tend to destroy these, as will be explained later.

If excessive loads of sewage or other wastes are placed into a stream, an immediate change takes place in the number and kinds of bacteria living in the water. An almost explosive multiplication of the bacteria occurs in response to the availability of food. The bacteria, as do all living organisms, require oxygen

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for survival and, because they are present in enormous numbers, the naturally occurring oxygen supply in the stream is depleted. When these bacteria die off from lack of oxygen, another type, capable of obtaining their oxygen supply from the organic materials they feed on, multiplies rapidly and completes the decomposition of the organic materials to a stable state. In turn, when the food supply of the second group of bacteria is exhausted, they too die and the stream returns to a pure condition.

As previously mentioned, bacteria that are harmful to man occur in the streams, but they, too, seem to diminish in the same way that organic materials diminish owing to bacterial action. The reduction of bacteria in clean waters can be attributed to shortage of food supply and to competitive life in the stream. Those intestinal bacteria that are harmful to man appear to be adversely affected by the presence of other bacteria and do not appear to thrive for long periods of time in highly polluted streams. In clean streams and in those undergoing purification, the tendency is for all bacteria, including those harmful to man, to die off at a constant rate from starvation, destruction by competitors, high acidity, or from other causes; that is, a given percentage of the remaining bacteria die for each successive increment of time.

Though it is true that a polluted stream will in time purify itself, continuous pollution may overload the stream to a point where it could never recover. The stream would then have been destroyed for most uses other than as an open sewer. Because of the importance of water, streams must be retained in a condition suitable for many uses, and we have, therefore, focused increasing attention on the treatment of sewage and industrial wastes. Waste materials of many industrial plants receive some treatment before being placed in streams or in mains leading to municipal sewage treatment plants. For wastes of some other plants, the treatment given at the municipal plants is sufficient to prepare the water for return to streams.

Many cities give only primary treatment to their wastes. The purpose of primary treatment is removal of most of the solids. The sewage is detained in tanks for a short period of time to permit the materials that will settle to be removed and to skim off the materials that float on top of the water. This type of treatment is sufficient where the effluent from the treatment is released in large streams having a great capacity for self-purification. Secondary treatment further removes the solids through use of living organisms to break down the suspended substances. The secondary treatment usually must be followed by filtration if water of high clarity is desired.

During the primary and secondary treatment, 75 to 99 percent of the bacteria will be removed along with the solid materials. The effluent from the plant is usually chlorinated to ensure the complete destruction of bacteria.

The treatment process will remove almost all the solid materials in the wastes. We must recognize, however, that many dissolved materials are not effectively removed by this process, although some may be acted upon by the bacteria to a certain degree. Within recent years the use of synthetic detergents in the household has become troublesome to treatment-plant operators. Detergents are not destroyed by the treament in modern plants, and when discharged into the streams may be picked up in the water many miles downstream.

It has been said previously that storage of water in a reservoir has the beneficial effects of reducing the sediment and color. The reduction of color requires a long time and is due to the exposure to the sun's rays. There are disadvantages, too, in storage where conditions are ideal for the development of plant and animal life that impart tastes and odors to the water and, in some cases, can cause an increase in the color. The production of these tastes and odors, because of the abundant aquatic life, occurs usually in newly filled reservoirs, where there is an abundant supply of food for the organisms. Sometimes the organisms can be controlled by a chemical treatment of the reservoir waters.

The tendency in present-day reservoir construction and management is to live with these problems rather than go to the expense of removing all the vegetation and the layer of top soils from the area to be flooded. After a few years of operation, even if none of the vegetation has been removed, the food supply for these organisms will have been reduced to that amount replaced by each summer's growth. There still will be certain periods when tastes and odors will occur in the water, but they are usually susceptible to removal in water-treatment plants.

Another, sometimes troublesome, condition exists in deep reservoirs where the bottom layers of water and the mud itself are devoid of dissolved oxygen. Under these conditions, certain bacteria thrive and are instrumental in bringing iron and manganese into solution from the muds. Aeration and other treatment are necessary to remove these materials.

Where the waters from deep in the reservoir are released to the stream, the destruction of fish and other aquatic life occurs owing to the lack of oxygen in the released water. The speed with which oxygen from the atmosphere is redissolved in the water is influenced more by turbulence of the stream than by any other factor. If a series of riffles or shoals are present to increase turbulence, the aeration will be much more rapid.

Floods are a problem

The first settlement in Alabama was established in 1702 by the French at Twenty-Seven Mile Bluff on the Mobile River. The settlement consisted of a fort and houses for 400 people. In March 1711, a great flood destroyed many of the houses and at its crest was several feet deep in the fort which was on the highest ground in the area. Following this flood, the settlement was moved to the present site of Mobile.

When Alabama became a State in 1819, the Congress allotted to it certain lands, including 1,620 acres which could be sold to pay for construction of a Capitol building. A site for the capital city was selected at the confluence of the Alabama and Cahaba Rivers. It was named Cahaba and work on building the Capitol and other buildings and houses was immediately undertaken. The town was first occupied in 1820. The site was poorly chosen, for it was subject to flooding. On one occasion the members of the legislature entered the Capitol through second floor windows, having gotten there by boats. In the legislative session of 1825–26, the members voted to move the Capitol, and in a short time the town was abandoned. A present-day visitor to the site can find no evidence of these original buildings.

The flood of 1929 and the destruction caused by it were discussed earlier (p. 33). Many other floods could be described. After each big flood, there comes the cry of "Do something so that flood destruction will not occur in the future." The most sensible of the "Do something" alternatives is to avoid building on the flood plain.

Stream channels carry the flow most of the year. Most streams also have flood plains over which water flows at times. Some streams overflow several times each year and other streams overflow rarely. But regardless of how often or how seldom the stream overflows, the flood plain should be regarded as part of the waterway. Obviously, the waterway is not a suitable place for building a house or store or barn or factory.

Unfortunately, our people have not always followed the paths of wisdom in selecting building sites, and others have erred as did those who first settled Mobile and Cahaba. The principal difference between the history of those settlements and some others is that some sites have been used for long periods before they have been flooded. To abandon them is not easy because of the great investments in the buildings and facilities of towns and factories. What can be done at such places?

Floods can be controlled in two ways. The flow can be made to fit the channel or the channel can be made to fit the flow. The alternatives can be simply stated. The work involved and the cost of such work are often difficult and frequently too expensive to undertake.

The channel is sometimes made to fit the flow by dredging and straightening it. The channel of Black Creek at Gadsden was straightened and increased to a width of 50 feet for a 2-mile section through the town. The capacity of a stream channel can also be increased by building levees. At Collinsville and at Prattville, improvements consist of a combination of channel straightening and enlarging and of levees built along the banks of the stream. Elba has been protected by levees built between the streams and the town. Much farmland bordering creeks in the Tennessee River basin has been protected by levees.

Making the flow fit the channel is often possible but is seldom economically feasible. Some benefits can be obtained by planting trees, by plowing on contours, and by some other land-treatment practice. Good land-treatment practices help anchor the soil in place and reduce erosion. These measures do help reduce runoff in the summer, but are less effective in winter and spring, which are the seasons when most of the greater floods occur in Alabama. The positive and certain method for controlling flood runoff is to impound the flow behind a dam. There are in Alabama no major projects of this kind devoted solely to this purpose.

The dams of the TVA system are operated for three purposes—for control of floods, for navigation, and for production of power. At the start of the usual flood season of January to March, the reservoirs are lowered to provide an area to store flood runoff. Water caught behind the dam reduces flooding of the streams below the dam. After the end of the season of widespread floods, the reservoirs are filled, if there is sufficient rain, so that they can provide more water for power and for navigation.

Floods on the Alabama River are sometimes reduced because water is stored behind Martin Dam on the Tallapoosa River. The reservoir is not operated for flood reduction and when that happens it is simply a fortuitous benefit. Dams on the Coosa, Warrior, and Tombigbee Rivers do not provide any appreciable flood-control benefits.

Some work is now being done to control the flooding of agricultural lands by constructing small reservoirs on headwater streams. Such reservoirs will reduce flooding of bottom lands below them, but will not necessarily prevent the larger streams from flooding.

We have said that the most sensible approach to the flood problem is to avoid building on the flood plain. Yet sometimes there is no choice but to encroach on the river's domain.

The bridge builder of earlier times did not have a major problem. For him, a knowledge of the highest flood stage of a stream would suffice. He built his bridge from bank to bank and a little above the stage of the highest flood and successfully did his job. The larger floods flowed both over and around the bridge. But in times of high water, travel on the road would be delayed until flood waters receded to the level of the banks. In time people became impatient of this delay and demanded that the roadways approaching the bridges also be put above high water so their journeys would not be interrupted.

The problem of today's bridge builder is more complicated. He has to know the height of flood waters, and in addition, he has to know the quantity of flood flow and how it is distributed in the channel and over the bank. He needs that extra information so that he can better locate his bridge or bridges and determine the correct lengths. The length of a bridge is closely related to the quantity of flow. For good design the bridges need to be placed and sized in keeping with the distribution of the flow. The modern bridge engineer designs his bridges to pass a once-in-25- or 50-year flood and the traveling public is seldom inconvenienced.

TOMORROW'S WATER

The preceding discussion of water use was mostly concerned with present use. However, it is apparent that the need for water is increasing and at a rapid rate. Projection of the past rate of growth gives an approximation of the level of use to be expected in the future. Such a projection indicates a greatly expanding volume of use a few decades from now. How will those future needs be met? Some answers to that question will be attempted along with a brief discussion of water law.

Supply and demand

Alabama is an area of plentiful water supplies, but the supply varies. It has been noted that ground water is scarce in some areas and plentiful in others, and that streamflows are scarce at times and plentiful at other times. The average supply is indeed plentiful, but at some places or at some times that average is not available. Therein rests the problem. Increasingly the local natural supply in time or place will be outgrown and something must be done to improve the nearby supply or to find a more distant source. How can the nearby supply be improved?

New sources of water

Water in the atmosphere tends to form around a particle such as dust. It then grows in size as it comes in contact with other water vapor. As it grows, it gets heavier, and when of sufficient size and weight, will fall as rain. Knowledge of this beginning of a raindrop led to the belief that rain could be induced by providing particles for the raindrop to build on, if cloud formations were favorable. The process is commonly termed "cloud seeding." Many have tried it, and much has been written of their efforts. Opinions as to the worth of the effort differ widely because the results obtained can be variously interpreted as to cause and effect. Evidence indicates that a measure of success is sometimes obtained, but the method will probably not be used to any appreciable extent in Alabama.

At a few places in the world, a fairly large supply of fresh water is obtained from sea water to supply a town or city. The salt in sea water can be removed in several ways. All are relatively expensive. The Federal Government is attempting to find an inexpensive method of removing salt from sea water or brackish water. Pilot projects that make use of the several alternate methods are to be constructed at five sites in the United States. If any are successful to the extent of making possible the development of large quantities at low cost, the coastal areas could be freed of water-shortage problems. The sea certainly contains an inexhaustible quantity of water, but inexpensive conversion of large supplies at low cost is not to be expected in the immediate future.

Much water that has been warmed through use is cooled by spraying into the air as shown in figure 38. This water has been used and will be used again. Another practice is to use the water first for one purpose and later for another that does not require first-quality water. Because water can be reused in many industrial applications, a small supply can do the duty of a large supply. The practice of reusing water is already common in Alabama in some areas and in some industries, and will probably increase in the future.

Large amounts of water are contained in aquifers in the southern and western parts of the State. The supply is large and because the aquifers remain full at nearly all times, they can with some justice be termed "nature's reservoirs." The total volume of water in these aquifers is enormous, and the better ones provide a major source of supply for the future.

In other sections of Alabama underlain by limestone, extensive caverns and channels have been developed in the limestone. These openings, where interconnected, form huge reservoirs for the storage of ground water. Large springs occur where the reservoirs overflow. Some of the largest springs are at Athens, Huntsville, and Tuscumbia. Wells penetrating these reservoirs have been developed for municipal and large industrial water supplies.

The yield of wells and springs developed in limestone varies from season to season and depends closely on the amount and frequency of rainfall. Cities and industries using large amounts of ground water must key their developments to the periods of low flow and water levels. In periods of extreme drought, however, the underground reservoirs are the last to reflect the effects.

In some States, nature also provides many surface reservoirs in the form of natural ponds or lakes. Almost none exist in Alabama. Some large streams and all spring-fed streams contain an increment of storage in their minimum flows, which frequently make them favorable sources of supply. The flow of other streams during low-water periods is commonly a small fraction of the average flow. To make much use of the flow of such streams requires storing a part of the flow during wet periods for later use in dry periods.

How much flow can be stored depends upon the shape of the land. Where unusually favorable conditions exist, it is possible to store all flow and release it at something approaching a uniform rate. A development to this extent is seldom feasible, and a more realistic goal would be to provide storage capable of producing a sustained yield equal to about two-thirds the average flow of the stream.

Storing water requires building dams at places where the volume of storage is great in proportion to the height and length of dam. Streams in the hilly and mountainous sections of the State are most suitable for development of reservoirs.

Water laws

Alabama has few laws related to water rights, and those few are mostly related to conditions of a past time that are not now important. Not many conflicts have developed at local levels; those that do develop are settled in courts using common-law procedures as influenced by a doctrine known as "riparian right." According to this doctrine, only those who possess land bordering a stream have any right to use water in that stream, but that water use must be reasonable and not detrimental to the needs of others. The need for diverting water to nonriparian lands or purposes is not recognized or provided for.

In recent drought years, a substantial amount of the flow of some small streams has been diverted for irrigation. Water so used is consumed and is not returned to the stream channels, as water diverted for other purposes commonly is. The extent of flow depletion has brought forth some conflicts between users. These new conflicts created a sense of anxiety on the part of some, and set in motion a movement to appraise the situation in regard to water use and water laws. Representatives of various water-using interests met and discussed the subject. They concluded that a State-sponsored study should be made and advised the legislature of that conclusion. About the same time, another group attempted to obtain legislation which would require capping of overflowing wells where the water was not being used. The effort was not successful. The history of the attempts to obtain legislation indicates that the water situation is not yet judged to be sufficiently acute to require action. This judgment may be accurate as of now, but excessive delay would appear to be unwise, for uncertainty about water rights may tend to discourage developments which could profitably be undertaken.

Toward better water management

The construction of a dam at Sipsey Fork will produce several benefits—waterpower, water for a municipality, water for navigation, and cool water for increasing the efficiency at a steam-power plant. Most reservoirs constructed today include the multiple objectives of navigation, flood control, and electric power.

The potential value of water moving in a stream is recognized by many. For some the stream is an artery of commerce. Others see it as a source of electric power. Still others see it as a source of water for a town or mill or farm, or as a convenient outlet for disposing of wastes from a town or mill. A few look on the stream as an enemy which sometimes floods their lands and buildings and which they would like to see tamed. Thus men aspire to put water to use, but occasionally are at cross purposes with each other.

The satisfaction of all interests should be sought in all developments and should be obtained to the extent required to satisfy the public interest. The degree to which the public interest can be satisfied is obviously related to economic justification, but that should not be the sole criterion for judging worth. It is difficult or impossible to place a price on the values inherent in recreation or conservation, for instance.

Good water management implies some understanding of alternatives and also of the possible long-term effects of plans for water development. There is a certain finality in most water projects that is not easily altered to meet changing needs arising at a later date. To choose wisely for the present, and at the same time to plan for a changing future, requires a good deal of knowledge about water. This account of Alabama's water resources and water problems was written to provide some of that knowledge, and to help the State's citizens make informed choices on questions of water policy, now and in the future.

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