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· SPRINGS ·

THEIR ORIGIN, DEVELOPMENT, AND PROTECTION

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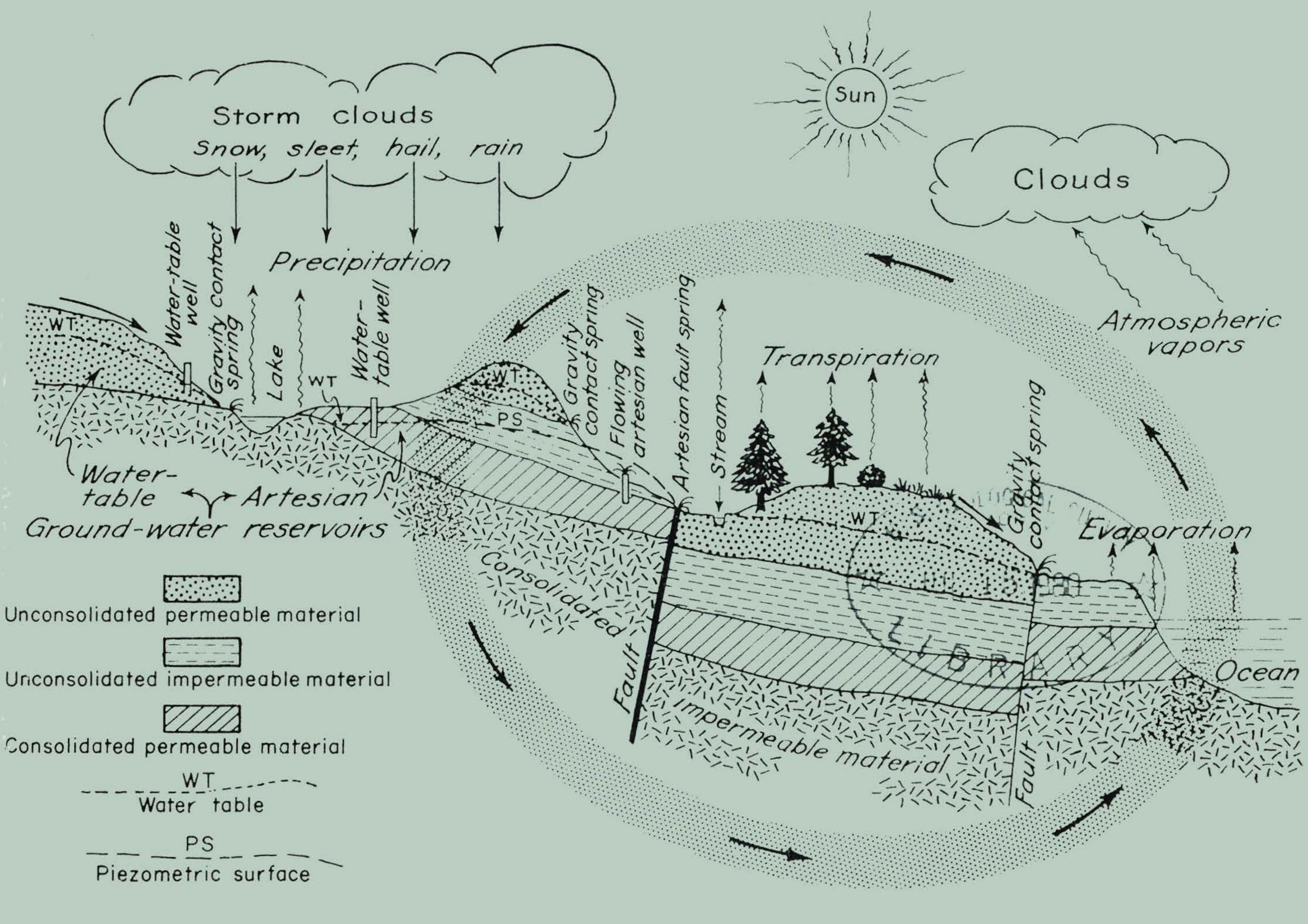

THE HYDROLOGIC CYCLE

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INTRODUCTION

This paper has been prepared to describe springs briefly, to give some suggestions about developing and protecting them, and to list selected reports and books that contain more detailed explanations of springs and that describe how to develop and protect them from contamination.

THE HYDROLOGIC CYCLE

Most everything contains water. Water is present in the atmosphere above the earth. Sometimes we can see that water in the form of clouds, but generally it is in vapor form and is invisible. When air contains nearly all the water it can hold, we say the "humidity" is high. When the air is dry--contains much less water than it can hold--the humidity is low. Warm air will hold more invisible water than cold air. If air that is holding all the water it can becomes colder, clouds are formed. Then, if the clouds are cooled more and if certain other conditions are just right, the water is dropped from the air as rain, snow, sleet, or hail. The snow, sleet, and hail are eventually converted to water in liquid form or into water vapor, in which form it again enters the atmosphere. Water that falls on the land surface runs off in streams or into ponds and lakes, is used (transpired) by vegetation, is evaporated from the soil, or sinks into the ground.

Water on the surface of the earth is called "surface water." It is the water we see in streams, ponds, lakes, and oceans. Water that sinks into or is absorbed by the earth is called either "soil moisture" or "ground water." Atmospheric water, rainwater, surface water, soil moisture, and ground water are not different waters. They are one and the same water. The different names indicate only the location. Of course, water in the different locations generally contains different chemicals and organic particles.

Of the water that sinks into the soil, some may be absorbed by the soil. Some of the soil water is used by plants and some is evaporated back to the atmosphere. If more water sinks into the ground than the soil can hold, the surplus moves deeper. Finally, this water comes to a geologic formation, perhaps a dense clay or a hard, dense rock, through which it cannot move or can more only very slowly. The water gathers on top of this tight formation and fills the pore spaces in the overlying, more porous rock, sand, or gravel. Thus, a body or reservoir of water is formed beneath the land surface. If water can be pumped or otherwise withdrawn from this reservoir, it is called an "aquifer;" the water in it is called "ground water." The surface of the water in the reservoir is called the "water table." The reservoir may be only a few feet thick (or deep), or it may be many tens or even hundreds of feet thick. It may underlie an area of a few hundred square feet, or it may underlie many square miles. The water table may be at or just below the land surface, or it may lie many feet--perhaps hundreds of feet--below the land surface.

Perhaps contrary to popular belief, the surface of a ground-water reservoir, or the water table, is seldom if ever flat. The water table nearly everywhere has a shape something like that of the land surface overlying it, although more subdued. Over the years, most ground-water reservoirs become filled to overflowing. The ground water then moves to low points to be discharged through seeps and springs into streams or other bodies of surface water. A hydraulic gradient, or slope of the water surface, is always required to make water move naturally. In other words, the water table must always have a slope if water is being discharged from the ground-water reservoir. Water will then move from the higher to the lower levels.

In some places permeable water-bearing material is confined between layers of tight materials--that is, between materials that are impermeable or relatively so, such as clay or shale. Water in the confined, more permeable material is then said to be under "artesian pressure." Water enters the confined aquifer where it approaches or is at the land surface and at some high elevation or level. The difference in water level, or the hydraulic gradient, between that place and lower level where a spring emerges or a flowing artesian well is drilled causes the water to move toward the spring or well.

Ground-water movement is relatively slow except through large underground openings such as those in highly fractured rocks, or in cavernous rocks such as some limestones and lava rocks. In fine-grained unconsolidated materials, such as silt and fine sand, the movement may be only a small fraction of an inch per day. In coarse gravel the movement may be as much as a few hundred feet per day. Thus, years may be required for ground water to move a mile or more. Moving at the relatively high rate of 100 feet per day, the water would move only abour 7 miles in a year.

Ground water is removed from an aquifer by evaporation if the water table is at or near the land surface; it may be removed also by plants whose roots act like little pumps that raise the water to the part of the plant above the land surface. Here the plant transpires, or breathes, the water through its leaves and back into the air.

When a hole or well is dug or drilled in the ground deep enough to penetrate an aquifer, ground water will appear in the well. If the aquifer is a water-table aquifer, the ground water in the well generally will stand at the level where it was found. This level is essentially the same as the water table, or top of the ground-water reservoir.

Where the aquifer is confined between less permeable materials as described previously, water in a well dug to the aquifer will rise above the level at which it was found and sometimes will flow from the well at the land surface. This water is called "artesian ground water." If a large number of holes should be drilled into an artesian aquifer and cased, if necessary, so that water would not flow from them, the water would stand in each hole at a level above the aquifer. These levels are called the "hydrostatic," or "static," level of water in the aquifer. The imaginary surface that everywhere coincides with these levels is called the "piezometric surface" of the artesian aquifer. It corresponds to the water table in an unconfined aquifer. Some artesian wells do not flow naturally at the land surface. This is because the piezometric surface is below the land surface. Thus, we have both flowing and nonflowing artesian wells.

In some places, the water table will rise high enough to form ponds or lakes in low spots in the land surface. These are called "ground-water lakes" and the level of the lake surface is essentially the same as the level of the water table beneath the land adjacent to the lakes. If the lake has an outlet, it will tend to drain to a level below that of the adjacent water table, and ground water will move slowly toward and into the lake through seeps and springs. The same thing applies to streams that are cut below the level of the water table. Thus, much ground water enters the lakes and streams. In fact, ground water supplies most of the water in our streams except during periods of heavy rainfall or snowmelt.

Thus, we come to the definition of a "spring." It is a place where there is natural discharge at the land surface of water from a ground-water reservoir that is filled to overflowing.

In the preceding paragraphs we have described in a simplified way how water is formed and falls from the atmosphere, is deposited on the earth's surface, and is returned to the atmosphere by evaporation and transpiration, there again to be formed into clouds and returned to the earth's surface. Water is thus continually "going around in circles," and the entire process is called the "hydrologic cycle." The process is, however, more complicated than the preceding description may indicate. The figure on the cover page of this paper shows the process diagramatically in a little more detail. It may be seen from this illustration that springs are created by the water that appears in only one very small part of the hydrologic cycle.

KINDS OF SPRINGS

Springs may be divided into many different types or classes based upon various characteristics. For example, they may be classified in accordance with the type of geologic formation from which they issue, such as limestone springs or lava-rock springs. Or, they may be classified according to the amount of water discharged (large or small; or of the first, second, etc., magnitude), the temperature of the water (hot, warm, or cold), or the forces causing the springs (gravity or artesian flow).

Although the type or class to which a spring belongs will often be a controlling factor in its development, a thorough discussion of the classes of springs would be too long for this paper. More comprehensive discussions can be found in several of the bibliographic references given at the end of this paper, especially in those numbered 2 and 6.

THE DEVELOPMENT OF SPRINGS

Springs are "developed" to collect and distribute their flow from a central location, to increase the flow from them, and to protect the water from contamination. Many springs are in use, but only a small proportion are developed to yield the greatest amount of water. This is especially true in humid regions. Even in arid and semiarid regions, where water is especially valuable, many springs are undeveloped or only partly developed. The water from some is allowed to be wasted by evaporation or by transpiration from nonbeneficial plants. Some drain into mudholes and swamps where the water is contaminated by men and animals.

A fully developed spring will yield the greatest amount of water possible. All the flow will be recovered and collected at one or more places. Storage space will be provided for the water not used immediately. And that part of the water to be used for human consumption will be protected from contamination or, in some instances, purified by chemical or other treatment. Proper development may convert useless seepage areas into concentrated flows or appreciable amounts of usable water.

If a spring is to be developed so that the water can be used for human consumption, special attention should be paid to its bacteriological and chemical quality. Is the water polluted and dangerous to drink? If it is, can the cause of the pollution be removed? If not, can the water be purified to make it safe to drink or suitable for other desired use? Does the water contain too much mineral matter, and if so can some of it be removed? Water for drinking should contain some minerals to make it taste good, however. Water without some minerals in it tastes "flat."

Even the clearest, coolest, and most sparkling water may be unsafe to drink or unsuitable for certain uses. Many springs issuing from sand, sandstone, and other rocks containing only very small openings are not contaminated. However, contaminating matter may penetrate through large cracks and fissures. Such pollution is quite likely to occur where houses, barns, sewers, cesspools, or septic tanks are located on higher ground near a spring. It is especially likely to occur in or near cities or towns. The water from limestone springs, lava-rock springs, or fracture springs is sometimes contaminated by sources of pollution that are long distances, even miles, away from the spring. It is a good safety practice to have spring water tested by a competent bacteriologist and chemist for contamination before it is used for human consumption.

The water should also be tested for contamination at periodic intervals as long as it is being used by human beings, or a positive method of continuous purification should be provided.

Spring water to be used for human consumption should not be exposed to the open air after it flows from the rock, sand, or gravel until it is withdrawn from the collecting or the storage reservoir. Also, the water should be withdrawn from the reservoir through pipes, not in buckets.

Many aquifers act as filters and remove organic pollution from water passing through them. The distance that water must move through these materials before pollution is removed varies widely. It depends in part upon the character of the water-bearing material--that is, the size and shape of the openings through which the water moves. Also, the amount of polluting material that has entered the water has a great effect upon the distance the water must move through the water-bearing material before it is purified.

Bacteria may be completely removed from water traveling only a few feet or tens of feet through clay, silt, or fine sand. In medium-grained sand, the distance of movement may need to be a hundred feet or more. In coarse sand or gravel the necessary distance may be a thousand feet or more. If the water moves to the spring through large cracks, or through solution channels such as those in cavernous limestone, it may travel for miles from a source of pollution and still be highly polluted. Because of the difficulties in determining the type of material through which water moves before arriving at a spring and of determining any possible source of pollution, the safest procedure is to have the water tested before developing or using it.

Developing and diverting the water from a single large spring usually requires little in the way of preliminary geologic investigation. The engineering work may need to be only that necessary to improve the spring opening and to provide the necessary facilities to store, distribute, and protect the water. The amount of investigation and improvement needed may depend largely upon the use to which the water is to be put and upon the desired elaborateness of the collection, storage, and distribution facilities. In any case, the water should be tested for possible pollution if it is to be used for human consumption or for recreational uses such as swimming.

The amount of geologic investigation and engineering work needed for the full development of a seepage area or of a group of small springs also will depend in part upon the use to be made of the water. The type of the spring--that is, its geologic and hydrologic characteristics--may be the principal factor governing the investigational and construction work needed. The work involved may include a geologic investigation to determine the source of the water, the route or routes it travels before emerging at the land surface, and possible sources of contamination; an estimate of the amount of water available; and application of drainage engineering methods to collect the water and convey it to its point of use. The maximum amount of water available from a seepage area will often exceed the amount that flows naturally from the area, because proper development may save considerable water that is being lost from the area by evaporation and by transpiration from plants.

HOW TO DEVELOP SPRINGS

Because of the many different conditions under which springs occur, no one method of development or type of construction is suitable for all springs. If extensive use is to be made of water from a spring, the advice and services of professional people should be obtained. These would be engineers, geologists, bacteriologists, and chemists who are experts or specialists in water.[1] If the water is to be used for drinking or swimming, the very minimum of professional help sought should be that of competent persons to check the bacteriological and chemical quality of the water.

Development and protection of springs generally can be done satisfactorily by nonprofessional persons, however, if the amount of water involved and its use is small and if certain precautions and standards are observed. The following paragraphs will give a few sample development methods of the simpler types.

Gravity Depression Springs

The simplest method to develop springs and seeps of the gravity type in unconsolidated materials on gentle slopes is to sink tile, concrete pipe, or concrete or wooden boxes at the point where the water emerges most freely from the ground. These structures should have open joints or other openings through which water may enter.

They should be large enough, perhaps 5 by 10 feet or more, to capture a large part of the flow. They should be sunk as far into the ground as is practical, perhaps so that 2 to 4 feet of water will stand in them. They should be placed so that the longer dimension rims along rather than down the slope of the land surface. To prevent contamination, the sides of the structure should be built up a foot or more above the land surface and be provided with a tight cover having an inspection lid. Ditches should be made around the structure to carry surface water away from the spring. The site should be fenced to keep animals at least 15 to 25 feet away from the spring. Pipes should be provided to convey the water from the collecting structure to the point of use. Provision should be made to dispose of any surplus water by conveying it to a nearby stream, pond, or storage tank. In some places the surplus water may be spread on adjacent lands to irrigate crops or can be used to recharge a ground-water reservoir at a lower level.

Some springs emerge on valley floors subject to intermittent flooding. In these places, it may be best to sink a large-diameter well on the bank or slope above the spring and to extend its casing or curbing above flood height. The bottom of the well should extend below the elevation of the spring. Pumping from the well will capture all or part of the water that is flowing from the spring, or if conditions are right a discharge pipe may be let into the curbing below the water level, so that the water can be conveyed by natural flow.

The flow from springs on steeper slopes, as on talus slopes or the steeper parts of alluvial fans, often can be increased by digging a tunnel from which laterals are extended at intervals. Beginning at the spring or seep, the tunnel is dug into the unconsolidated material with a slight upward slope. The amount of water needed, or the amount available, will determine the number and length of the laterals. The tunnel should be shored with heavy timbers and perhaps refilled with cobbles and boulders to prevent possible eventual caving of the unconsolidated material.

Large-scale development of depression springs in consolidated rocks generally is not feasible, especially if the rocks are hard. The simplest way to develop water issuing from a large number of small openings, as in massive sandstone, is to excavate a basin as large as practicable at the point or in the area of the greatest flow. Water flowing from other nearby openings in the rock may be led to the central excavation by shallow trenches or ditches. Be sure the trenches and central excavation are covered to prevent contamination of the water.

Contact Gravity Springs

Contact gravity springs are those whose water flows to the surface in permeable material because the aquifer is underlain by less permeable material that retards or prevents the downward percolation of the ground water and deflects it to the surface. Most springs of this type occur in stratified materials in which the ground water forms a relatively thin sheet over a large area. The water usually reaches the surface along a zone of seepage on the face of a more or less steep slope. This seepage zone often can be recognized as a band of damp soil or as a line of unusually dense vegetation.

Development of contact springs consists principally of collecting the widely distributed water at one or more central points. This may be done by tunnels as described previously for depression gravity springs. Or, one or more trenches may be dug along the line of seepage and the water led to a central point. If only a small amount of water is desired, it may be more feasible to sink a large-diameter well upslope from the seepage zone and to the top of the impermeable material. Pumping the well will then intercept some of the water before it reaches the land surface at the line of seepage.

In some places the material that contains the water is consolidated and the underlying material is unconsolidated. This is the case where permeable lava rock overlies volcanic ash or soft shale. To develop springs under these conditions, a tunnel should be excavated below rather than above the contact, and as much of the consolidated water-bearing material exposed in the roof of the tunnel as is possible.

Artesian Springs

The water from artesian springs is brought to the land surface by artesian pressure. They generally issue through a fissure in the tight confining material overlying the water-bearing material. Artesian springs occur only in areas of artesian flow and usually in areas of consolidated rocks. If the area in which the water emerges is small, a covered reservoir may be built around the spring. Or, covered ditches or trenches may be built to collect the water emerging from a number of fissures.

There are many other types of springs. Geysers are special types of intermittent springs in which the flow is caused by highly heated steam expanding at depth below the land surface. Some springs ebb and flow because of changes in atmospheric pressure. The development of each spring is an individual and separate problem that varies in detail with the type of spring.

BLASTING OF SPRINGS

Some persons will think first of blasting to enlarge a spring opening and obtain more water. Blasting a spring is a practice that should be considered cautiously and all factors carefully considered before it is undertaken. A good spring can be permanently impaired, or even destroyed, by blasting.

In unconsolidated materials, the work generally can be done as cheaply and more safely by more conventional methods. Blasting unconsolidated material may compact the material more tightly and cause the water to seek escape elsewhere.

Blasting a spring or spring area in consolidated rocks probably will create additional fissures in the rocks. These may, if the blasting is properly planned, tend to divert more water to the spring. However, the new cracks and fissures might permit the water to drain away and emerge at a lower elevation or at some other point, thus causing loss of a spring.

In any case, blasting a spring should never be undertaken by a person inexperienced in the handling of explosives.

SELECTED REFERENCES

U.S. Geological Survey water-supply papers may be purchased for a nominal sum from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C. At the time of preparing this bibliography, Water-Supply Papers 255 and 557 were out of print; however, copies can be consulted at many University libraries, at some large public libraries, and at most offices of the U.S. Geological Survey.

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2. Meinzer, O. E., 1923, Outline of ground-water hydrology, with definitions: U.S. Geol. Survey Water-Supply Paper 494, 71 p., 35 figs.

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4. ______ 1939, Ground water in the United States: U.S. Geol. Survey Water-Supply Paper 836-D, p. 157-232, 1 pl., 31 figs.

5. Todd, D. K., 1959, Ground water hydrology: New York, John Wiley & Sons, 336 p. (A textbook.)

6. Tolman, C. F., 1937, Ground water: New-York McGraw-Hill 593 p. (A textbook.)