COLORADO'S GROUND-WATER PROBLEMS

BULLETIN 504-S

GROUND-WATER IN COLORADO

COLORADO STATE UNIVERSITY EXPERIMENT STATION
FORT COLLINS

Contents

This publication is one of a series of three bulletins covering the physical, legal and economic aspects of ground water use, by Morton W. Bittinger, Assistant Civil Engineer, Civil Engineering Section; Edward J. Farmer, Assistant Economist, Economics Section, and Irving F. Davis, Jr., Assistant Economist, Economics Section, of the Colorado Agricultural Experiment Station, Colorado State University. Copies of the others can be obtained from the Bulletin Room, Colorado State University, Fort Collins, or from County Extension Agents.

Acknowledgment

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GROUND WATER IN COLORADO

Morton W. Bittinger[1]

Introduction

Are you interested in Colorado's ground water, its use and conservation? Many Coloradoans are, and more of us should become so. In eastern Colorado we are approaching maximum use of surface-water supplies, making us more and more aware of ground water's importance to everyone. We need to know how to make the best use of this resource. In order to do this, we should understand why and where ground water occurs, where and how fast it moves, and how it is replenished.

You may feel that ground water is too difficult and mysterious a subject for you to understand. You are not alone in this. The occurrence and movement of ground water have been clothed in mystery since the first wells were dug thousands of years ago. However, the science of ground-water hydrology has developed greatly in recent years. We know now that the occurrence and movement of water underground can be explained by natural laws.

We believe that mystery and superstition have no place in this science any more than in any other scientific field. The modern ground-water hydrologist now has sufficient tools and techniques at his disposal to remove the guesswork and mystery that have been previously associated with water underground.

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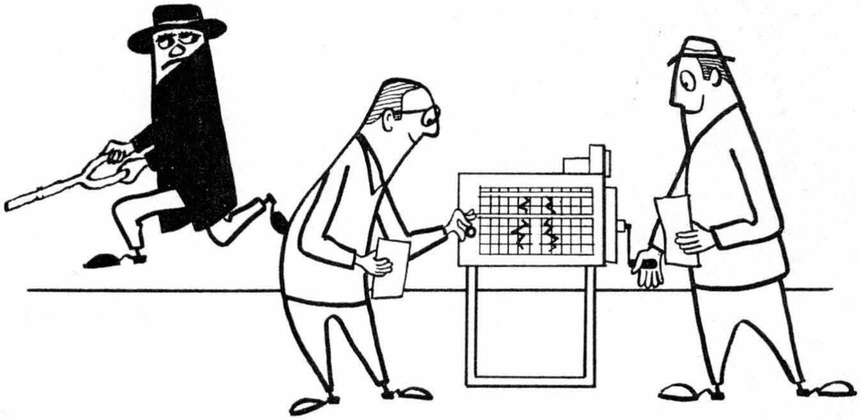


Modern ground-water hydrologists have tools and techniques that do away with guesswork and superstition.

Getting Together on Terminology

Understanding our ground-water problems in Colorado requires that we know the basic factors that govern the occurrence and movement of ground water. We will discuss these factors and how they relate to the development of Colorado's underground water resources. But before we do, we should get on common ground by explaining a few terms that are often misused and misunderstood.

It is generally understood that the water which fills the voids, pores, or crevices in the rock or other materials beneath the earth's surface is called "ground water." It may be found several hundred feet below the surface, or as near as a few inches. However, names for various kinds of ground water have developed through the years. For instance, you may have been told that your well is tapping an "underground river or lake," "percolating water," "tributary water," or "artesian water."' Let's see what these terms mean.

Underground River or Lake

Long before much scientific knowledge was available concerning the occurrence and movement of ground water, courts found it necessary to make rulings on its use and ownership. Thus, a lot of terminology commonly used today was developed by lawyers and judges to serve their purposes at the time. The terms "underground river" and "underground lake" are such terms. They represent a logical attempt to speak of ground water in the same manner as we do of surface water.

However, the analogy between surface water and ground water can be easily carried too far. It is true that ground water may be contained in a buried river channel or valley. It is also true that the ground water may flow faster in one place than another.

But, the normal rate of flow underground is considerably less than in a surface river or stream. For instance, a drop of water in the South Platte River could travel from Denver to the Nebraska line (approximately 210 miles) in less than a week. The same drop of water flowing underground probably would move less than 50 feet during the same time.

But the implication of a stationary body of water by the term "underground lake" is also unrealistic. Nearly all ground water is moving, even though it may be extremely slow. We should stop using the terms "underground river" and "underground lake" because they are misleading. Unfortunately, due to established legal precedent, these terms will continue to be heard in the court room.

The geologist's term for a formation capable of furnishing water to wells is "aquifer." Another term that also is more appropriate than those discussed above is "ground-water reservoir." The word reservoir infers some type of storage which (1) allows us to withdraw water, (2) may be filled after the level has been lowered, and (3) may overflow when it reaches a certain level. This is the concept we should have if we are to make the best use of our underground water resources.

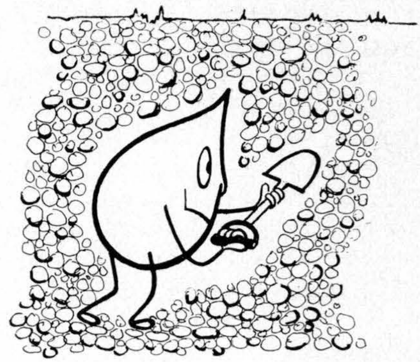
Percolating Ground Water

Another term which originated before the science of ground-water hydrology was developed is "percolating ground water." Courts have defined percolating ground water as water which "oozes, seeps and percolates under the surface in no discernable direction and without calculable volume." The present day ground-water hydrologist objects to this type of definition which infers mysterious and unknown factors influencing the movement of ground water. By mak-

"The going is pretty slow, especially when these openings get too small."

ing the proper physical measurements he is able to determine the direction, velocity, and volume of ground-water flow.

The term "percolating water" is still in use by the hydrologist, but only to describe the slow movement of water through the ground. We refer to the movement of water vertically downward from the ground surface as "seepage." Both types of flow are relatively slow.



"I'll get out somehow, I've got connections."

Tributary Ground Water

The term "tributary ground water" is particularly important in Colorado due to several recent court decisions. The following sentence, taken from one of these decisions,[2] sums up the significance of tributary water:

> "In Colorado, it is the presumption that all ground water situated in the basin or watershed of a stream is tributary to the stream and subject to the appropriation of the waters of the stream; and the burden of proof to the contrary is one asserting that such ground water is not tributary."

Therefore, the pumping of tributary ground water might be prohibited if surface rights are harmed since nearly all surface decrees are many years senior to beginning of pumping.

Most of our ground water is moving toward streams and thus would be considered tributary; however, a matter of reasonableness should enter here. Ground water extremely remote from the stream to which it is a tributary may not show up as surface flow for hundreds of years. In addition, a sizable portion of that water may leave the ground through evaporation and plant use before it has a chance to become stream flow. Therefore, to be practical and most efficient in the use of our water, we need to recognize the difference in pumping tributary water where it will have an effect upon surface rights compared to areas where it may have very little effect upon stream flow. Techniques are available for estimating these effects.

Artesian Water

There is much misuse of the word "artesian." To some, the word infers only a deep well—or water from a deep well. To others the thought of a flowing well immediately comes to mind. Artesian water is sometimes thought of as being better water

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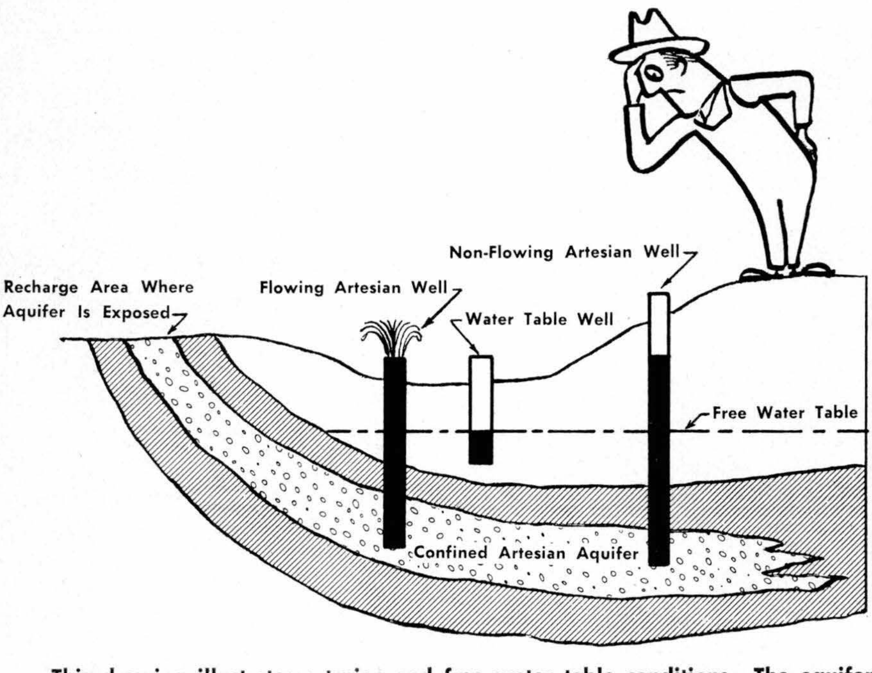
[2]Safranek vs. Town of Limón (1951) 123 C. 330, 228P, 2d 975.

than other kinds. Each of these concepts may be true in some cases, *but not always.*

Artesian merely means water under pressure. If you drill a well into a formation and water rises in the well higher than the point at which it was first encountered, you have drilled into an artesian formation or aquifer. The amount of rise of water is an indication of the amount of pressure in the aquifer. We sometimes refer to this as "confined water." If the water does not rise in the well we say it is "unconfined" or that there is a "free water table."

An artesian situation requires a stratum of water-bearing material (aquifer) bounded on the top and bottom by less permeable materials. To develop enough pressure in the aquifer to cause the well to flow the intake end of the aquifer must be at a higher elevation than the top of the well, and the flow in the aquifer must be restricted sufficiently so that the easiest escape route is through the well.

The conception that artesian water is always good quality is not accurate. The quality depends upon the source of the water and the type of formation



This drawing illustrates artesian and free water table conditions. The aquifer intake has to be higher than the top of an artesian well so pressure can force the well to flow. A pump is needed to obtain water from a water table well or a non-flowing artesian well.

through which it has been flowing. This is true with all ground water.

Changes in pressure travel rapidly in an artesian aquifer. You may see a reduction in discharge of a flowing artesian well the instant a neighboring well is turned on. This sometimes leads people to believe that water travels with that high a velocity.

However, this only represents a pressure change in the aquifer. We see the same thing occurring in a household plumbing system when flow from one faucet is reduced immediately upon the opening of a second faucet at another location.

Permeability and Transmissibility

The nature of the aquifer determines the ease with which it may transmit water. The term that refers to this ability to transmit water is "permeability." A clean, coarse gravel has a high permeability, whereas a fine sand may have a much lower permeability.

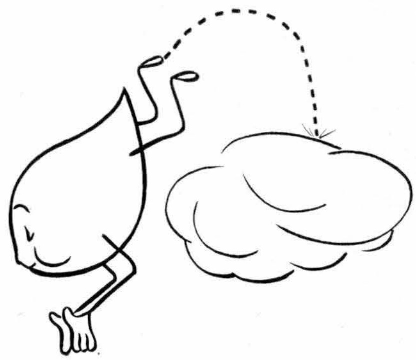
The term "transmissibility" is related to permeability and to the size of the aquifer. It is a measure of the water-carrying capacity of the aquifer and is calculated by multiplying the permeability by the thickness of the water-bearing formation. Thus two aquifers of 50- and 100-foot thicknesses may have the same permeability, but the transmissibility of the thicker aquifer would be twice that of the thin one.

The ground-water hydrologist can measure these characteristics of an aquifer by means of pumping tests on wells. Knowing the permeability and the slope of the water table, the rate of movement of the ground water may be calculated.

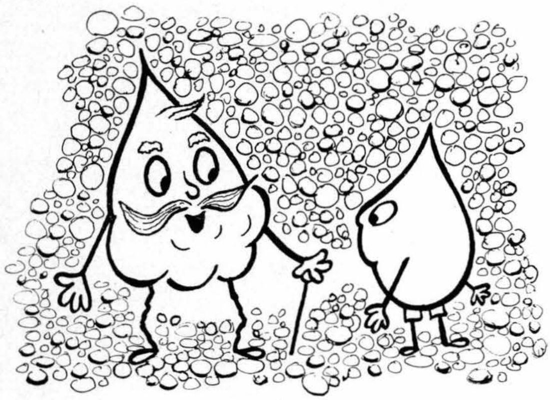
What Is the Source of Ground Water?

Water underground is a part of the complex drama in which water everywhere is involved in its constant movement through cycles of precipitation and evaporation. Because it is out of sight and not as dynamic in its actions we tend to isolate ground water in our thinking from other forms of water.

Certainly thunderstorms, snows, floods and the like are the prominent characters. They receive the headlines and dominate the everyday conversation. But it is important to remember that



"Sure hope I'll get to see my underground friends again. I spent the best 1,000 years of my life there."

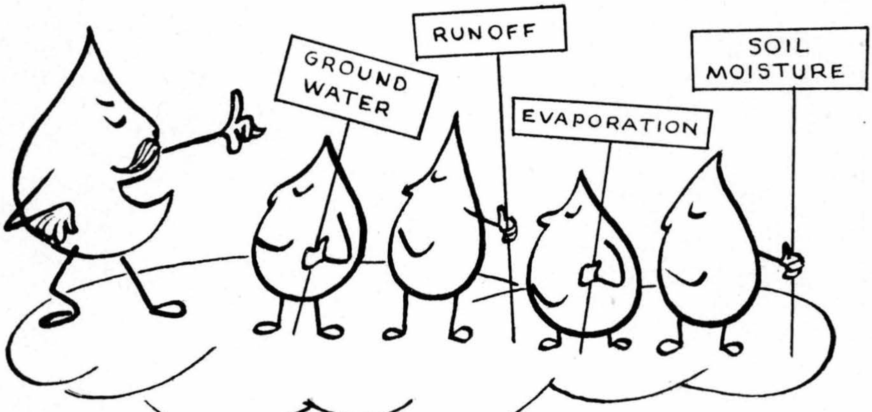


"Yes, sir, sonny, I arrived here during the Gold Rush."

ground water also is a part of nature's play we call the "hydrologic cycle."

Part of the water you are pumping today may have fallen as rain or snow hundreds of years ago. Probably some of it was above ground only a short time ago. In fact, nearly all ground water was precipitation at one time.

But, over all, only a small fraction of the rain or snow becomes ground water. That fraction which does join the ground water is the part that escapes several other possible fates. A large part of the precipitation runs off the land surface, finding its way into streams and rivers and finally to the oceans. Another fraction is evaporated back



"You have all been assigned your jobs. Remember to get back here as soon as you can."

into the atmosphere. Still another part may become soil moisture that will be used later by vegetation.

How Does The Water Get Underground?

The fraction of the precipitation which becomes ground water does so only where soil and geologic conditions are favorable. Under some conditions water may move directly downward from the surface on which it fell.

However, the major natural supply to many ground-water reservoirs occurs where streams and rivers flow over porous beds of sand and gravel. Also, man's irrigation activities have added new opportunities for water to get underground through seepage from canals, reservoirs and excess irrigation.

Considerable progress has been made in some states and in other countries in developing ways of purposely putting water underground or artificially "recharging" the ground water. But whether it be natural or artificial, success of ground-water recharge is largely dependent upon favorable geologic conditions.

Once Underground, Where Does The Water Go?

The force of gravity acts upon water underground just as it does above ground. We find that the aquifers usually slope in the same general direction as the land surface above. They also generally slope towards an outlet, such as a stream.

Thus, ground water is usually moving in the direction of general land slope and towards an outlet. The exact route the water may take is determined by the geology of the underground formations. Underground water seeks the easiest route the same as surface water. But because it cannot be seen, there are often considerable differences in opinion as to the movement of ground water. As studies of our reservoirs progress, many of these differences are being cleared up.

Why Does Ground Water Move So Slowly?

Ground water moves slowly because water table slopes are generally small and the resistance to flow quite large. Imagine a difference in water levels of only one-fourth of an inch forcing water through ten feet of sand and gravel. If the water table under your land slopes no more than ten feet per mile (not uncommon) this is about the situation you have. This slope would cause more water to flow through clean coarse gravel (high permeability) than through fine sand (lower permeability), but the velocity would still be relatively small.

However, although the movement may be slow, the total volume of water that may move through an aquifer in a period of a year may be quite large. This, of course, depends not only on the rate of movement but also on the size of the aquifer.

What Causes Differences in Yield Between Wells Taking Water From The Same Reservoir?

If we could look underground, the answer to this question would be apparent. The difference lies in the *geology* of the underground formations if other things such as well construction and pump efficiencies are comparable.

In Colorado, our principal ground-water reservoirs were formed from sand and gravel laid down by running water. Differences in water currents and velocities caused large differences in the type of material deposited. Some places received a liberal quantity of clean coarse gravel, whereas other areas immediately adjacent may have received much finer material, possibly sand intermixed with clay.

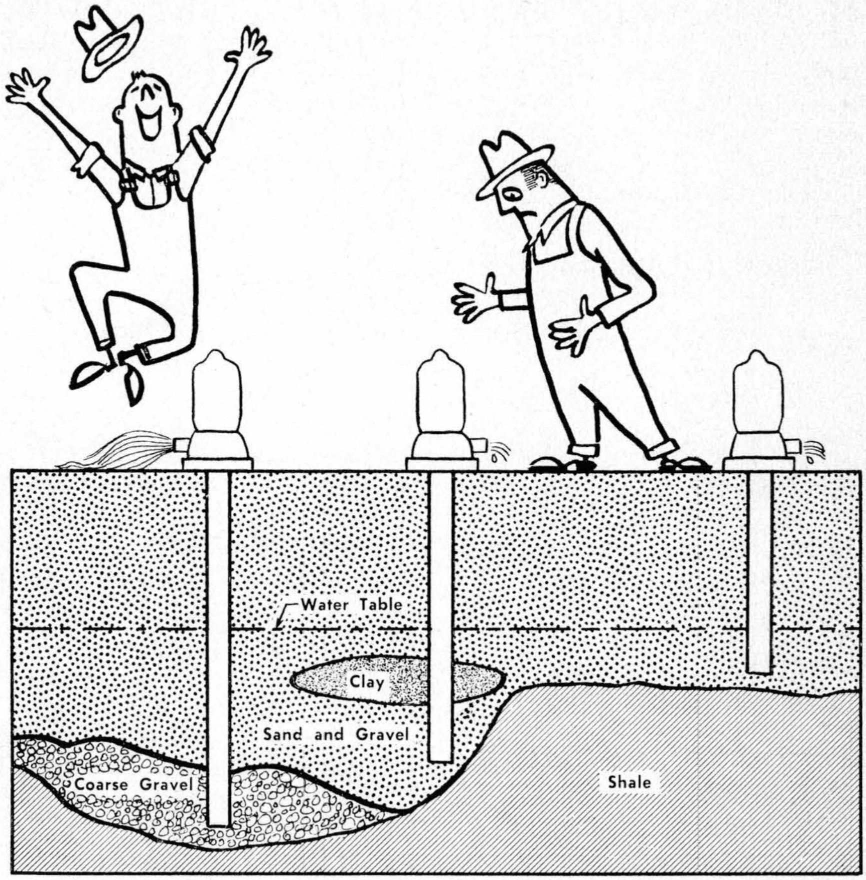
Such differences in material result in large differences in permeability, and consequently in the yield of wells.

The depth or thickness of the underground reservoir may also vary. Again, this is due to geological differences. The production from a well is influenced greatly by the depth of the saturated aquifer that it penetrates. That is, other things being equal, a well penetrating 100 feet of water-bearing material should produce nearly twice that of a well with only 50 feet of aquifer. These factors point up the desirability of drilling test holes before locating a new well.

But not all troubles are due to geological differences. Poor well construction may also be a cause. Providing adequate perforations or screen opposite the water-bearing formations is extremely important. The size of the openings should be determined *after* the sizes of the sands and gravels in the formation are observed. This information should be obtained when the test holes are drilled.

Careful development of the well after construction is also an important part of getting a good well. The development process removes the fine sand from the formation around the well, leaving the more permeable coarser material next to the screen.

Contracting with a reputable and experienced driller is good insurance for obtaining a properly constructed well.



These three wells withdrawing water from the same reservoir have greatly different capacities because of differences in the thickness of the water-bearing formations and in the permeability of the materials surrounding the wells. Such differences may affect wells only a few hundred feet apart. Test drilling and proper well construction are important considerations in obtaining the best possible well on your land.

Contrary to common belief, the diameter of the well is not of great importance. Doubling the diameter of a well increases the cost considerably, but may increase the production only slightly. It is more important to penetrate as much water-bearing material as is possible than it is to drill a large-diameter well.

Developing A Ground-Water Reservoir By Pumping

Let's now take a look at what happens within a ground-water reservoir when it is being developed by wells. Before wells are drilled, the reservoir is probably in equilibrium. This means that over a period of years the amount of water flowing into the reservoir is balanced by that leaving the reservoir. Under these conditions the water-table level will tend to be steady for extensive periods.

Changes Due to Pumping

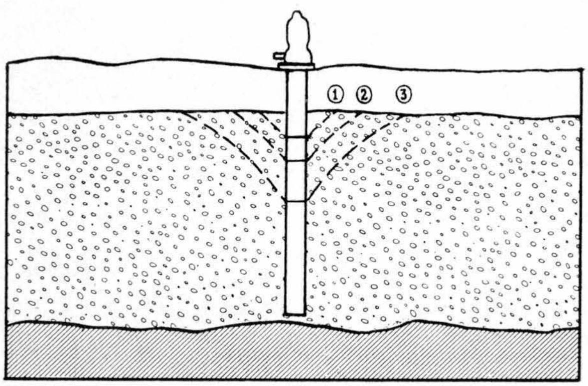
Suppose that you are the first to drill a well in this reservoir. The first revolutions of your pump will draw water out of the well casing and lower the level in the well. This difference in water level between the inside and outside causes water to flow into the well. Assuming that this is not an artesian aquifer, the sands and gravels surrounding the well become unwatered. As pumping continues, the water must come from greater and greater distances. To supply the force necessary for bringing the water from farther away, the water in the well must continue to lower.

The unwatered area around the well is called the "cone of depression." The amount of lowering or drawdown necessary to keep the pump supplied with water depends upon the permeability of the aquifer.

A cone of depression is also formed about a well in an artesian aquifer. However, instead of representing an unwatered area, it refers to an area of lowered pressure in the aquifer. It is this difference in pressures that forces water into the well.

If no water is added to the formation, the cone of depression will continue to grow as long as pumping continues or until it reaches the limits of the formation. Usually, though, the cone of depression will become distorted by natural features such as a barrier created by relatively impermeable materials, or by a source of supply.

In the one case a part of the water source to the well is cut off, causing the drawdown to increase in order to keep the pump supplied. In the other case the cone of depression may extend under a flowing stream or river. If the water table is in contact



Cone of depression after (1) one hour of pumping; (2) one day; (3) one week.

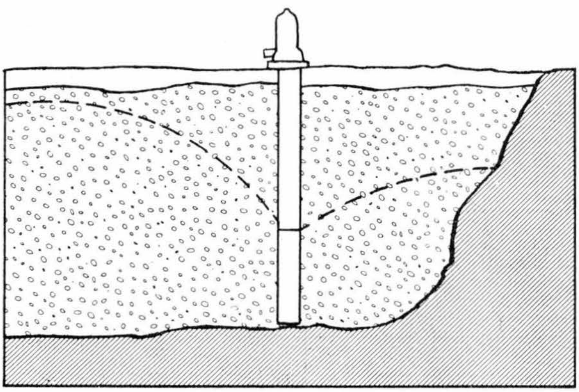
with the stream bed, dewatering of the materials underneath will tend to induce seepage from the stream. If conditions are such that the seepage can maintain the underlying formation full of water, the cone of depression will not grow any larger.

What Happens When Several Wells Are Drilled in the Same Vicinity?

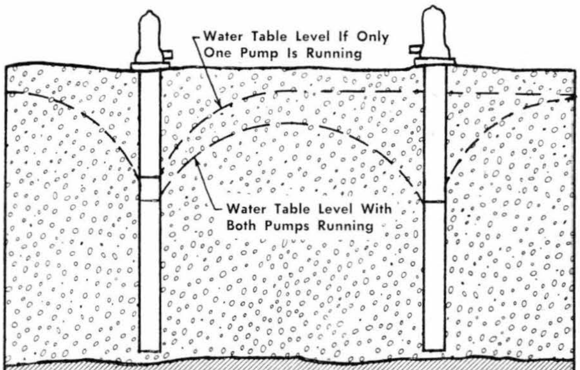
Each well that is pumped will develop a cone of depression about it. As pumping continues and these cones of depression enlarge, they may come into contact with one another. When this occurs it is similar to that of a barrier, in that the source of water is reduced to each well. Consequently, when wells are spaced too closely, greater drawdown is needed to produce a given quantity of water. The minimum distance between wells to obtain satisfactory performance of each can be determined from an analysis of pumping tests.

How Can We Know How Much Should be Pumped from the Reservoir?

Before any pumping there was a certain amount of average annual recharge to each ground-



Distortion of the cone of depression due to an impermeable barrier.



Wells too close together reduce each others' supply.

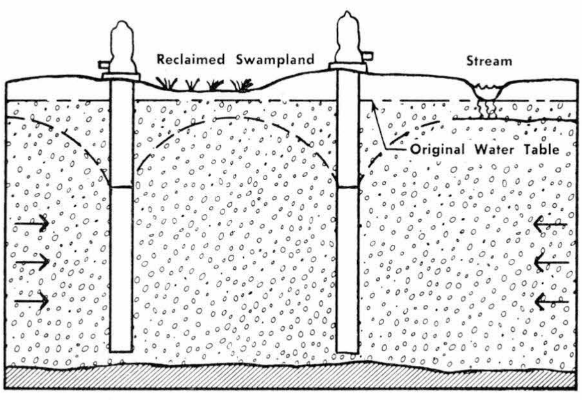
water reservoir. From this we might easily reach the conclusion that the amount pumped each year should not exceed the natural recharge.

However, there are several reasons why it may be possible to increase pumping beyond this point. First of all, if the pumping is for irrigation, a part of the water applied may return to the ground water. Also, the possibilities of developing new recharge to the pumped area increase as the water table is lowered. This is because more water may be drawn in from around the area and from surface bodies of water. In addition, by lowering the water table in areas where it was close to the surface, water may be salvaged that was normally wasted by useless vegetation and by evaporation from the soil.

For these reasons it is difficult to predict in advance how much pumping a reservoir can safely support. However, a study of the behavior of the water table or artesian pressures under various degrees of development enables the hydrologist to estimate a safe pumpage rate.

After your pump is shut off in the fall, the ground water will continue to move towards your well in an effort to fill up the cone of depression. If the supply is sufficient, the water level should be back up to normal by the following spring. But if each year the water table is lower than it was the previous spring, there is more water being pumped out of that immediate area than is being replaced.

For maximum use of our ground-water reservoirs, we should expect the water table to lower during periods of low precipitation and heavy pumping. Thus, lowering of the water table is not always to be frowned upon. It may be desirable if possibilities of recharge during wet years are good. But, if your water table lowers each year, and does not recover during periods of wet weather and less pumping, it indicates you may soon be in trouble.



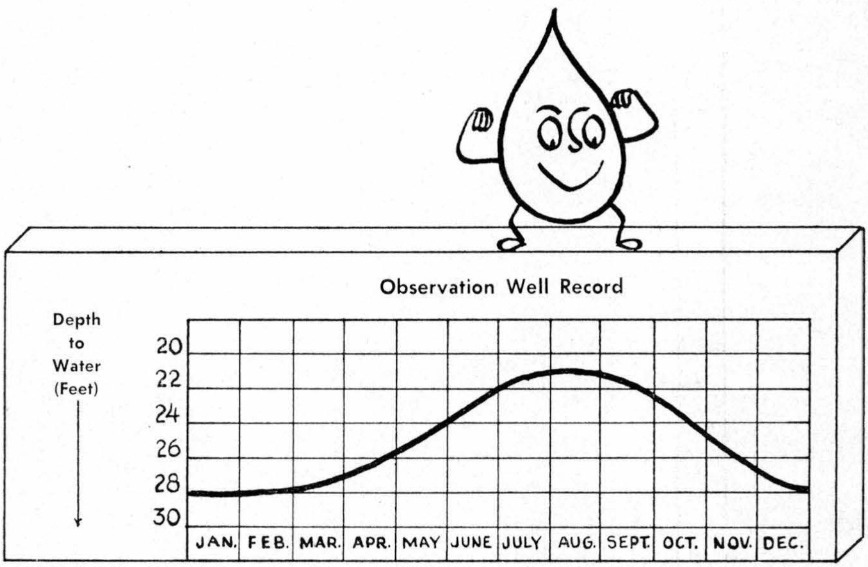
Pumping often develops new recharge to the ground water in an area.

If the water table continues to recede, a point may be reached when such a small flow of water can be pumped that it will be impractical to irrigate.

Colorado State University Experiment Station and the Ground Water Branch of the U. S. Geological Survey are cooperating in measuring the depth to water in obervation wells located in different parts of the state. Records dating back to the early days of pumping are available and give a good index of how our reservoirs are reacting to development. The following sections illustrate typical water-table fluctuations under various conditions of pumping and recharge.

High Recharge, Moderate Pumping. Much can be learned from a study of water-level fluctuations. The chart below shows a yearly cycle of water table fluctuation in a reservoir receiving a good supply of recharge water during the summer months. Strange as it may seem, the water level rises during the pumping season and lowers through the winter. This pattern is typical of those in areas of Colorado where replenishment by irrigation is high, such as along the main stem of the South Platte and Arkansas Rivers. Lowering during the winter is caused by a leveling off of the water table and drainage to the river.

Low Recharge, Moderate Pumping. Areas without surface water for irrigation generally have the type of pattern shown on page 15. The water table



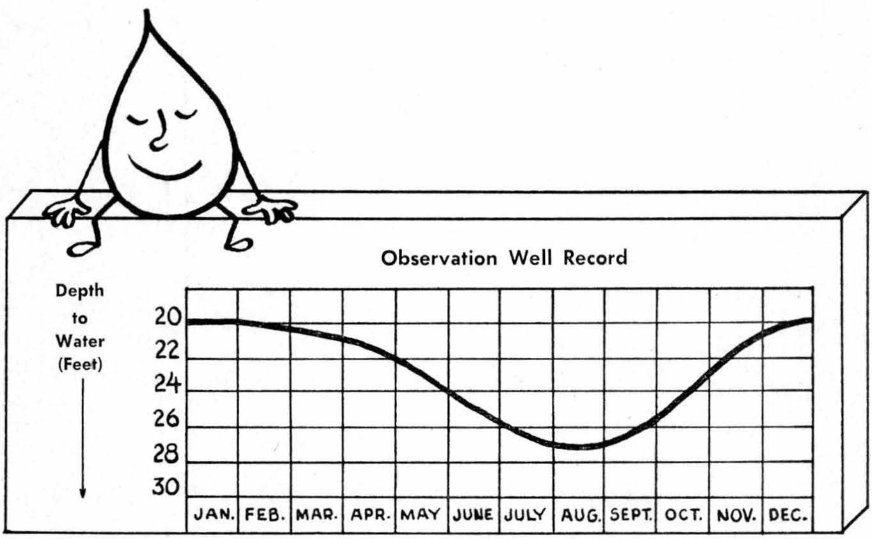
Nothing bothers this fellow. He gets a good boost every summer—a typical pattern of water-table fluctuation in a reservoir which receives recharge water during the spring and summer months.

is drawn down during the pumping season and recovers while the pumps are not operating. If the recovery does not equal the lowering, the water table will not reach the level of the previous spring. A good indication of the general trends can be obtained by comparing successive spring water-table levels.

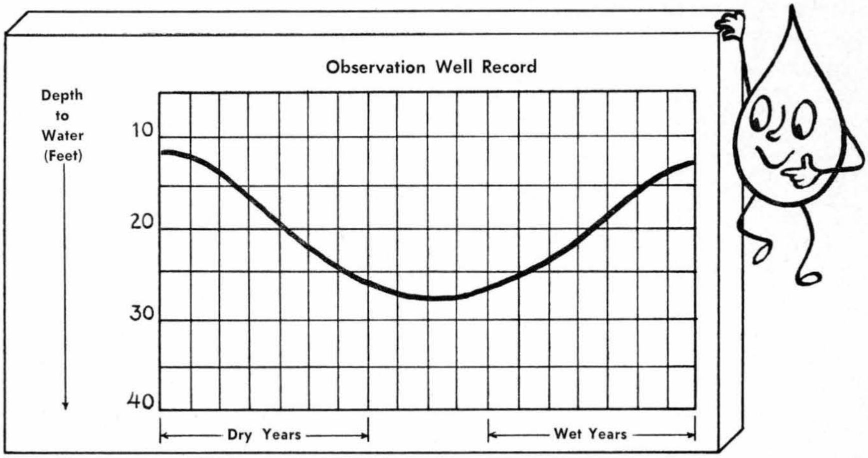
Optimum Development. The top chart on page 16 pictures water-table fluctuations in an underground reservoir developed to an optimum level. The water level is lowered in dry years, but recovers in wet years when recharge is greater and pumping less. Such a situation is parallel to the operation of a surface reservoir. Here, storage is used to carry through dry periods, but the opportunities for replenishment are sufficient to refill the reservoir during periods of surplus water. One can see why a long record of water-table levels is valuable, as only a few years might give an erroneous impression.

Overdevelopment. The bottom chart on page 16 shows water-table levels in an area of overdevelopment. No recovery occurred even during wet years. Reduction in pumping and, if possible, a means of artificially replenishing the ground water are needed to avoid depletion of the resource.

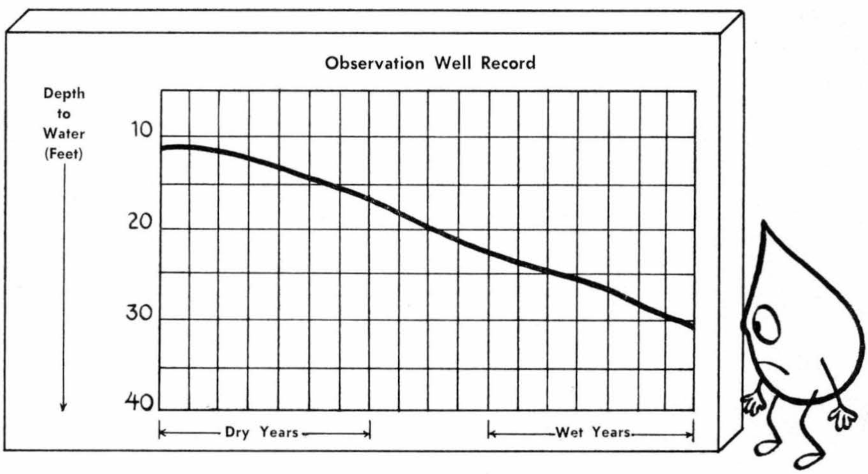
It is important to note at this



This fellow recovers pretty well when he's not working—a typical pattern of water-table fluctuation in an area of low recharge and moderate pumping.



Ground water can be replenished—typical water-table fluctuations in an area of optimum pumping development.

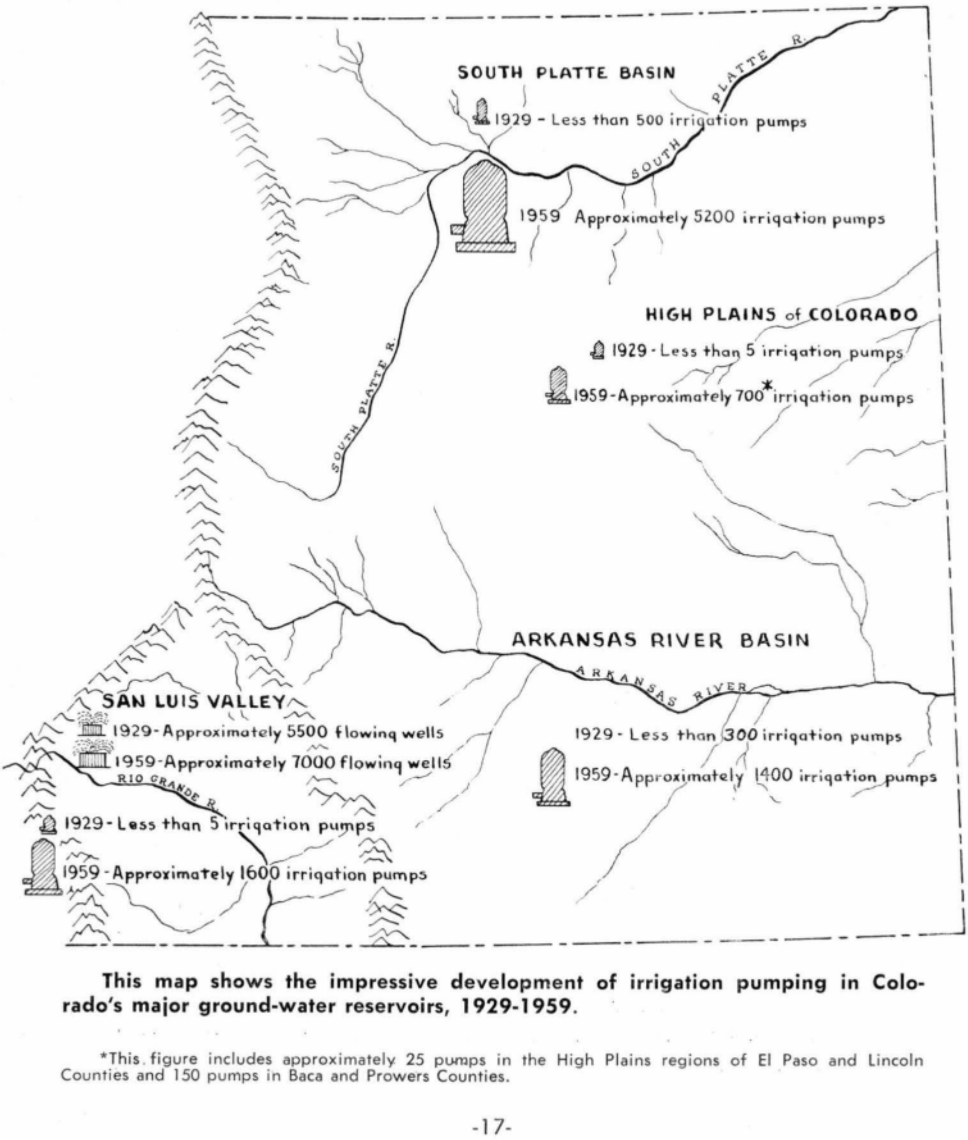


Things are getting serious, better find an answer—typical water-table fluctuations in an area of overdevelopment.

point that the above situations of development and recharge can and often do occur simultaneously in various parts of the same reservoir. Unlike a surface reservoir, withdrawal or addition of water at one point does not immediately, and sometimes may never, affect the water level over the entire reservoir.

Colorado's Ground-Water Reservoirs

Geologic developments in centuries long past formed the ground-water reservoirs we use today. Colorado was dealt with quite favorably by receiving four reservoirs of large storage capacity. These are (1) the South Platte, (2) the Arkansas, (3) the High Plains, and (4) the San Luis Valley. These reservoirs are located under our major agricultural areas, therefore ground-water development has been principally for irrigation. In fact, irrigation accounts for 90% or more of all ground water with-



This map shows the impressive development of irrigation pumping in Colorado's major ground-water reservoirs, 1929-1959.

*This figure includes approximately 25 pumps in the High Plains regions of El Paso and Lincoln Counties and 150 pumps in Baca and Prowers Counties.

drawn. Many other smaller ground-water reservoirs exist in Colorado and are important to the areas they serve. However, we will discuss only the four major reservoirs in this bulletin.

The South Platte and Arkansas River Reservoirs

More than two-thirds of Colorado's residents live within the basins of the South Platte and Arkansas Rivers. Also, a high percentage of our irrigated farm land lies within these basins. The valleys of these rivers and their major tributaries contain two of Colorado's most highly developed ground-water reservoirs.

At least 6,600 irrigation pumps, three-fourths of the state's total, operate in these two areas (1959). Since these two reservoirs are similar in their history of formation and development, we will discuss them together.

How Were These Reservoirs Formed?

During the time when the Rocky Mountains were lifting, swift rivers eroded large valleys or channels in the formations of shale and sandstone that were then on the surface. Later, possibly because of changes in slope and climate conditions, these channels were filled with sands and gravels deposited by the streams. These permeable materials deposited in channels carved in the impermeable bed rock make up the ground-water reservoirs. In general the buried channels are wider and deeper in the South Platte Basin than in the Arkansas Basin.

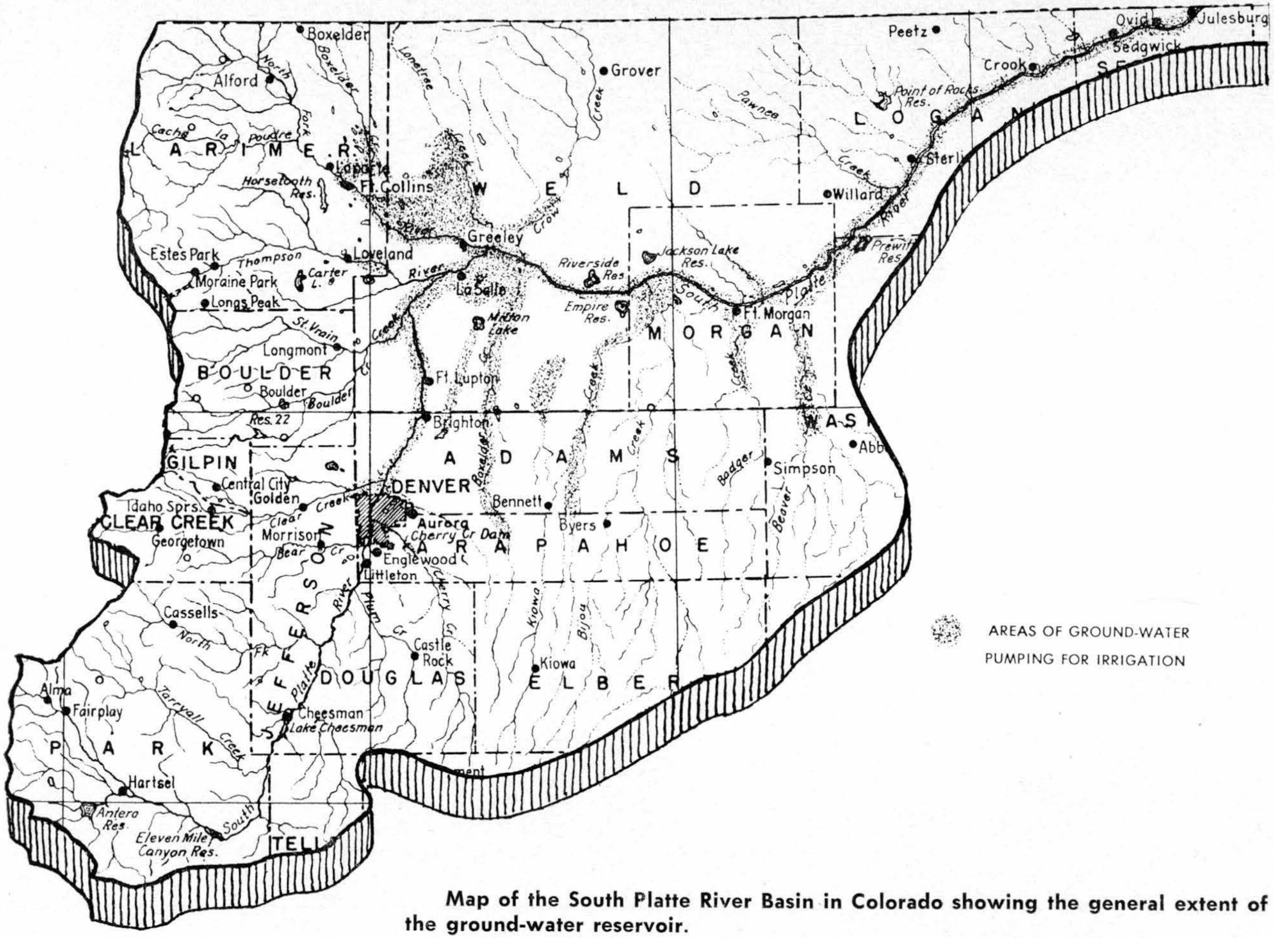
How Are They Filled?

The rivers and tributary streams of modern times follow about the same routes as the buried channels. In addition, a few buried channels were left isolated and do not now have active surface streams above them.

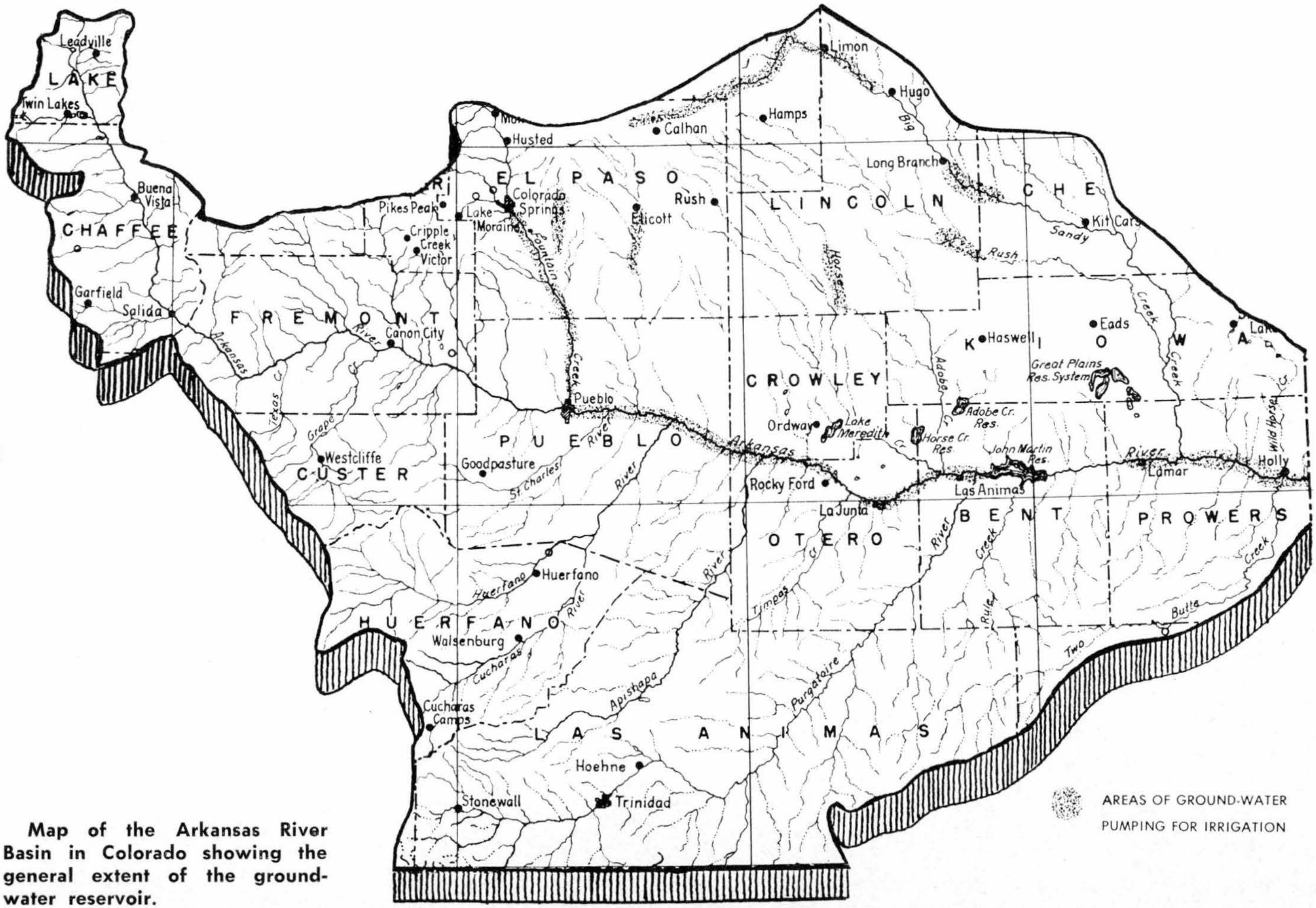
For centuries, water from the rivers and streams has seeped downward into the under-ground reservoirs. Before man entered the picture, both the South Platte and Arkansas Rivers were typical arid region streams in which the flow diminished as it progressed downstream because of this seepage. The stream beds were often dry, especially at greater distances from the mountains.

Over the centuries, a small amount of ground-water storage was gradually built up. In time, an equilibrium was established in which the water flowing away underground about balanced the replenishment water from above.

Some 100 years ago, when farmers first started irrigating, this equilibrium was greatly disturbed. By diverting the stream flow as it came out of the mountains and spreading it over their lands, they induced more water into the underground reservoirs. Seepage from surface reservoirs,



Map of the South Platte River Basin in Colorado showing the general extent of the ground-water reservoir.



Map of the Arkansas River Basin in Colorado showing the general extent of the ground-water reservoir.

canals and surplus irrigation water built up the water table much faster than Nature was doing.

Within a short time the water table became higher than the river bed. Instead of the river losing water it began to gain from the ground-water reservoir. In one way of looking at it, the reservoir was filled and beginning to spill. The water returning to the river from the underground developed the main stems of both rivers into year-round streams, and downstream farmers filed for rights to use this water.

In the case of both the South Platte and Arkansas Rivers, the irrigation in the lower reaches is almost entirely dependent upon "return flow." The amount of return flow increased as irrigation increased, and, in the case of the South Platte, appeared to level off by about 1930. Thus another balance was established.

Since 1930 another factor has entered into the picture. That factor is the increased withdrawal of ground water to supplement surface irrigation water. This development has played a very important part in the economy of both areas. Pumping of the ground water has helped carry crops through drouths and maintain high production where otherwise there may have been extensive crop failures. Pumping has also been beneficial in areas where the ground water would otherwise have been too high and caused waterlogging of the soil.

Thus, ground water pumping has proved to be a profitable and complementary partner of surface water irrigation. Use of ground water has also made irrigation possible in areas where surface water is not available.

Ground-Water Problems

Overdevelopment—The areas within the South Platte and Arkansas basins in which we need to be concerned about overdevelopment are the tributaries which do not have surface water supplies and therefore have limited recharge possibilities. South Platte tributaries in which irrigation depends largely or entirely upon wells include Crow, Box Elder, Kiowa, Bijou, Badger and Beaver Creeks.

Ground water replenishment is dependent upon rainfall and upon seepage from the creeks during floods. Withdrawals in excess of natural replenishment can easily occur in these areas.

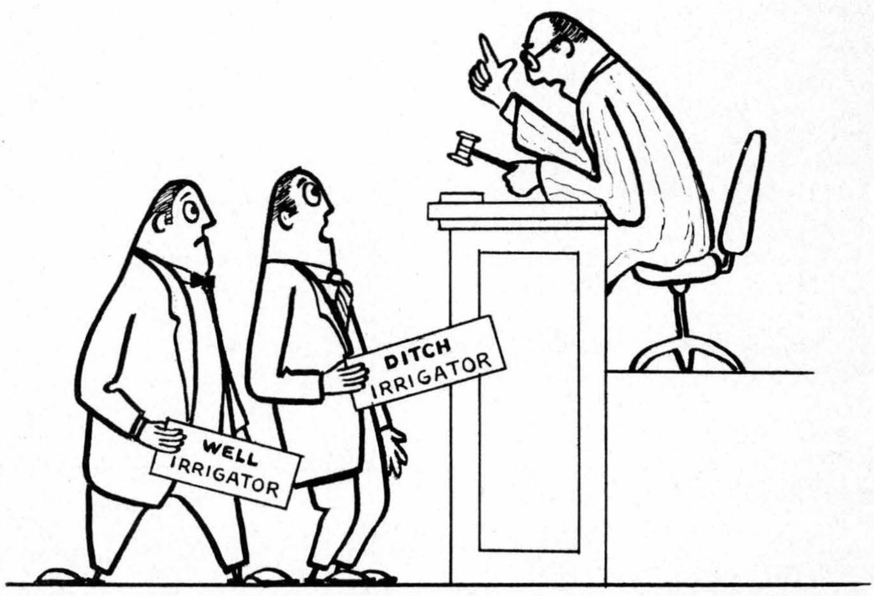
Other areas that are in some danger of overdevelopment are generally those with limited surface supplies for irrigation. Such areas include the Box Elder Creek Valley (tributary to Cache La Poudre River) near Wellington, Prospect Valley and the Box Elder Creek valley in southern Weld County. Parts of Fountain Creek in the Arkansas Basin also fall into this category. These areas have a greater potential recharge than those above canals, but may be seriously overpumped during periods of inadequate surface supplies.

Water-bearing formations in the South Platte and Arkansas Valleys are quite thin, much less than 100 feet in most places. Thick shale underlying these reservoirs eliminates the feasibility of deepening wells to counteract falling water tables.

Therefore, in the areas of probable overdevelopment, the two logical solutions for protecting the present investment and assuring permanent irrigation farming are (1) controlled pumping, and (2) improved ground-water recharge. The opposite alternative is to continue depleting the resource with the realization that a time will come when insufficient supplies will be available for irrigation.

Surface Diverters vs. Pumpers—A basinwide problem confronting both river systems is that of the proper relationship between use of surface water and ground water. Irrigators dependent upon surface water suspect that ground-water pumping along the river valleys diminishes stream flow and imposes upon their rights. Those using pumps often feel that the water under their land is their own and that they may use it as they please.

This conflict of interests should not be allowed to obscure the mutual advantages that both sides have under a dual system of surface- and ground-water use. If pumping were stopped in favor of surface diverters, much



A proper balance of surface- and ground-water use could benefit everyone concerned and lead to the most efficient use of a valuable natural resource.

Knowledge and planning are the answers to our ground-water problems.

land would become waterlogged and require expensive drainage systems to retain production. On the other hand, the pumpers should realize that the canals and reservoirs of the surface-water systems play an important part in recharging their ground-water reservoirs.

Should the courts have to decide the relationship of ground water to surface water? A decision in favor of one or the other would be extremely unfortunate. Rather, the surface diverters and pumpers should take advantage of their mutual benefits and work out a plan of coordinated surface and ground-water use.

A proper balance of surface and ground-water use could benefit everyone concerned and lead to the most efficient use of this valuable natural resource. Such a plan would need much thought and careful study, but it is not impossible.

The High Plains Ground-Water Reservoir

The Kansas River basin in eastern Colorado contains the High Plains ground-water reservoir. A part of the High Plains ground-water reservoir also extends into the Arkansas Basin (Lincoln, El Paso and Kiowa Counties) and in Baca County. Unlike those of the South Platte and Arkansas basins, this reservoir does not occur in relatively narrow strips along the rivers and streams. This ground-water reservoir underlies more than 12,000 square miles in eastern Colorado and has a storage capacity of several times that of the South Platte and Arkansas reservoirs combined.

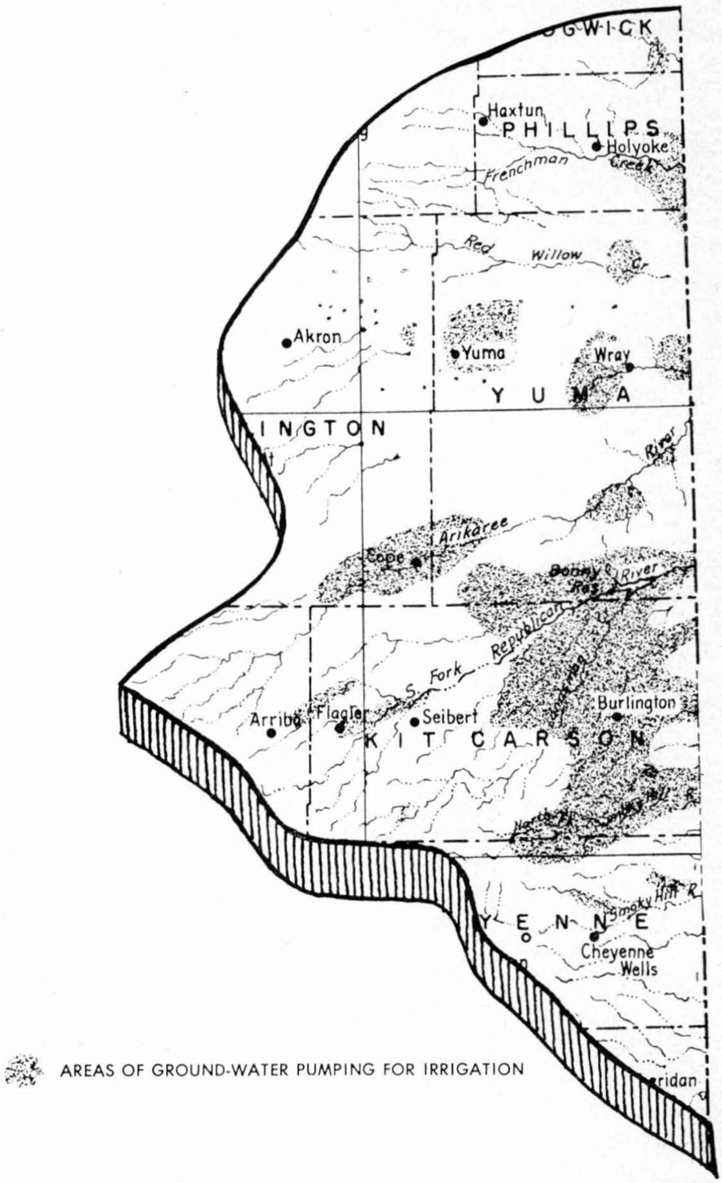
It is part of a much larger reservoir reaching north to the Black Hills, east under large areas of Nebraska and Kansas, and south to the southern part of the Texas panhandle. The water-bearing formation has been given the name "Ogallala" by geologists. The Ogallala formation is variable in thickness and in its water-yielding properties.

About 700 irrigation pumps were in use in the High Plains area of Colorado in 1959.

How Is the Reservoir Filled?

The principal and possibly only way that water enters this reservoir is from precipitation on the land surface above. The amount which becomes ground water varies depending upon the character of the land surface and the amount of precipitation. On the average, however, the annual contribution is very small—possibly averaging only one-half inch of water per year over the Colorado High Plains area. But, since this has been taking place for thousands of years, a vast amount of ground water has accumulated.

The amount of recoverable water in storage in the Ogallala formation in Colorado may be at least 100 million acre-feet.



Map of the High Plains of Colorado in the Kansas River Basin. The shaded areas show the general location of irrigation well development. Concentration of wells within the shaded areas is considerably less than for the other major ground-water reservoirs.

Ground-Water Problems

Individual — If you farm in this region and wish to use ground water for irrigation, your immediate problems are that of obtaining a good well and the amount of lift involved. The Ogallala formation is made up of a conglomeration of silt, sand and gravel, cemented together in varying degrees by calcium carbonate. Permeable gravels and sands are found in discontinuous beds. Location of your well in the more permeable zones is desirable. Extensive test drilling may be required to find the best location.

The depth to water varies from less than 50 feet to more than 200 feet in the High Plains. Under present conditions you will want to carefully examine the costs of irrigation if you will have to lift the water more than 100 feet. You should remember that as more wells are drilled the water table will lower and your lift will increase. Economic considerations are likely to play an important part in the development of the High Plains ground-water reservoir.

Basin Development—A basin-type problem exists in the High Plains also. We have already noted that natural replenishment of this reservoir is small, possibly averaging only one-half inch a year. If we would want this supply to last forever, well development would have to be drastically restricted. For instance, one well pumping at the rate of 500 gallons per minute would withdraw the equivalent of one-half inch of water from under a section of land in less than two weeks.

Thus, restricting pumping to the average annual recharge might allow only a few acres to be irrigated for each section of land, an impractical situation. Also, the water table would decline even under these conditions for the natural flow of the ground water to the east across the state line would continue in much the same volume as prior to pumping development.

It may be argued that the large volume of water already stored in this reservoir is of no value unless it is used. Development of the reservoir would produce wealth for the area that otherwise would be unobtainable. We know that when we take other mineral resources from the ground such as coal, oil and ores, we will eventually reach exhaustion and abandon the enterprise.

Should the same philosophy hold here? If so, those investing money and labor in irrigated agriculture in this area should be aware of the expected life of the resource, and of the consequences upon depletion. To be economically sound, development should be controlled to the extent that the resource will last long enough to repay the investment in irrigation facilities.

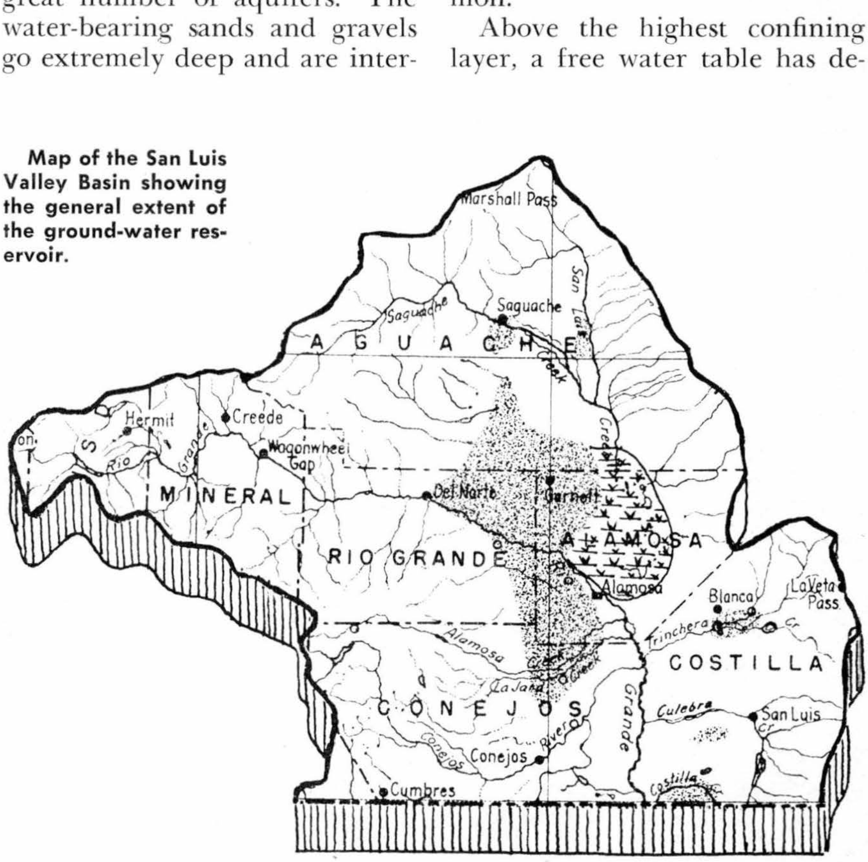
In consideration of the welfare of our country as a whole, it may be sound policy to delay development of the High Plains ground-water reservoir. This delay could be until a time when there is more demand for increased production. For instance, use of the resource during an emergency period when high production is needed may be of considerably more value to the nation than when surpluses are still on hand.

The San Luis Valley Ground-Water Reservoir

The San Luis Valley ground-water reservoir involves the most complex geology of the four being discussed. It is made up of a great number of aquifers. The water-bearing sands and gravels go extremely deep and are inter-fingered with layers of less permeable materials. The lower aquifers are under artesian pressure, and flowing wells are common.

Above the highest confining layer, a free water table has de-

Map of the San Luis Valley Basin showing the general extent of the ground-water reservoir.



AREAS OF GROUND-WATER PUMPING FOR IRRIGATION

"SUMP AREA" IN WHICH WATER LOGGING AND ALKALI CONDITIONS HAVE RESULTED IN ABANDONMENT OF AGRICULTURAL OPERATIONS TO A LARGE DEGREE.

veloped. In fact, the water table is purposely raised and held close to the ground surface for subirrigation.

Filling the Reservoir

Recharge of the lower artesian aquifers is accomplished principally by surface streams flowing over the exposed ends of the aquifers at the edges of the valley. Recharge of the water-table aquifer takes place largely from irrigation activities and artesian flows.

Ground-Water Problems

Pumping vs. Subirrigation—Since the water table must lower around a pumped well, pumping from the water-table aquifer conflicts with the practice of subirrigation. However, in periods of deficient surface-water supply when subirrigation cannot be maintained, the ground-water reservoir can save the Valley from extensive crop failure. When a good supply of surface water again becomes available a quick recharge is possible.

This was demonstrated very vividly when water tables recovered as much as 30 feet in 1957, after an extensive drouth. The San Luis Valley also is an area in which a coordinated and balanced use of surface and ground water is highly desirable.

Wastage — Uncontrolled flow of artesian wells has existed in the San Luis Valley for a long time. Many wells, although closed off at the surface, continue to leak water into the upper water table. Control of old wells with leaky or no casings is difficult and it would be virtually impossible to eliminate all the waste. However, good construction of new wells can prevent adding to the problem.

Drainage—Pumping of ground water to lower the water table in areas of poor drainage has promise in the San Luis Valley. Research is being conducted by the Colorado Agricultural Experiment Station in the "sump area" where land has become unproductive due to a high water table and salty soil. Results show that it is feasible to reclaim this land by combining pumping with good soil management practices.

Ground Water in Our Future

Possibly you haven't thought of it in this way before, but development of ground-water resources differs from development of surface-water supplies in one important aspect. Surface-water supplies are nearly all developed and distributed through the efforts and financing of groups of people, such as irrigation companies, municipalities and federal agencies. Ground-water development, however, is accomplished largely by individual effort and private funds.

Thus, the idea of basin-wide

plans for surface-water development is not new to us. But that idea in regard to ground water may be. However, if we take a realistic look at the growth of population and industry in Colorado, and the resultant increasing demands for water, we must conclude that basin-wide planning of ground water use is in our future. It is already obvious that the lack of water will set the limit on Colorado's growth.

We already have seen how intimately ground water is associated with surface-water supplies in Colorado. It follows that consideration of one is not complete without consideration of the other. The heaviest demands for water are in eastern Colorado, where all surface waters except floods are fully appropriated. It seems logical that we should start thinking about making use of our ground-water reservoirs to greater advantage, for the time may not be too far away when such action will be a necessity.

Our ground-water reservoirs are already in existence and the recharge areas are all within the state. The water stored in these reservoirs is practically evaporation-free and there is no problem in reduction of capacity by siltation. The volume of storage is many times that of existing surface reservoirs in Colorado, and no land needs to be taken out of production to use them. We need to learn how to manipulate and operate these ground-water reservoirs in relation to our surface supplies.

Accomplishment of this will benefit all water users—but will also require their full cooperation. Considerable technical knowledge is available, but a great deal more study, investigations and research are needed to develop and implement a workable plan of coordinated surface and ground-water use.

Knowledge and planning are the answers to our ground-water problems.