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GROUND WATER RESOURCES INSTITUTE QUARTERLY

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TABLE OF CONTENTS

The GWRI QUARTERLY invites the submission of original articles and speeches. Material should be suitable for a layman's audience, including government legislators and administrators, educators, business leaders, and others with a voice in national water management policies.

The editors reserve the right to decide on editorial content. Extracts or digested material shall be approved by the author, and shall be so identified. Unused manuscripts will be returned.

Address all correspondence to:

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ON OUR COVER: Governor Winthrop Rockefeller (third from right) introduces dignitaries participating in GWRI's 5th Annual Seminar. Guests included: Senators John McClellan (Ark.) and Henry Bellmon (Okla.); Representatives William Alexander, John Paul Hammerschmidt and David Pryor (Ark.), and Don Clausen (Calif.); Nils Boe, in charge of the White House Office on Intergovernmental Relations; and L. A. Heindl of the National Academy of Science.

NOT IF - BUT HOW

Natural fluctuations in water level play a prominent role in the hydrologic cycle. Long-term water level declines reflect the withdrawal of water for use; levels will continue to decline so long as discharge (natural and man-made) exceeds recharge. A rise in water level represents an increase in the water stored in the ground — storage which drains out to sustain the low flow of rivers in humid regions. Thus, ground water storage is a natural regulator of river flow as well as a direct source of water to wells.

There is reason to believe, however, that ground water storage could be an even more efficient regulator of streams than it is at present, through *artificial* recharge and discharge of the natural ground water reservoir. Water would be withdrawn to compensate for decreased streamflow during droughts and then replenished during the next wet period.

Unfortunately, though the technology of withdrawing ground water is highly developed, the technology of artificial recharge still requires research. Our management of ground water is still one of "capture" — diversion of water before it gets to its natural outlet — rather than planned sowing and a harvest. The storage capacity of the ground is an asset brought into use only through variations in the water level. Our ability to manage this resource will be advanced through better understanding of ground water hydrology and the technology of recharge. The GWRI QUARTERLY is dedicated to communicating this story.

Winrock Farms, Ark.:

GROUND WATER AND GOVERNMENT

In welcoming guests to the 5th Annual GWRI Seminar, Arkansas Governor Winthrop Rockefeller summarized the program's purpose as reflecting a deep and growing concern about the nation's water resources. "This conference," he noted, "is designed not only to appraise you but, through the news media, all people — of the urgency of the problem." The productive two-day session brought together experts in the field of hydrology and representatives of both Federal and state governmental agencies in exploring the various aspects of the problem — with particular emphasis on the related responsibilities of government at all levels. The two talks presented here capture the flavor of that meeting.

PROTECTING OUR WATER SUPPLY– WHO AND HOW

BY CHARLES F. LUCE

Urgencies of pollution control, intelligent regulation of water withdrawals and constant research demand the cooperative action of state and Federal agencies.

The findings of experts studying the Nation's ground water resources have brought into sharp focus a number of problems which must be solved if this great resource is to be used efficiently.

In some areas, for example, the ground water has been very rapidly exploited since the introduction of the electric pump. Valuable deposits of ground water have been literally "mined out," giving rise to serious economic and social dislocations.

An extremely complex and difficult problem arises when it becomes necessary to regulate the distribution of the underground water among all those having a legal right to utilize it. This creates a need for governmental regulation of use under laws which are in accord with correct physical principles.

Interstate problems are beginning to appear and we do not yet have tested ways for working out solutions to such problems.

In a few places, the ground water is being polluted and many more pollution problems may develop in the future if steps are not taken to forestall them.

State laws and court decisions governing the utilization of ground water differ widely and, unfortunately, some of them have been based upon misinterpretations of the basic nature of ground water and of the physical laws which govern its movements and its relationships with surface water supplies.

We have learned relatively little about making efficient use of aquifers for the underground storage of surface water, and thus have not taken advantage of a potential means of reducing the great evaporation losses attendant upon storage in surface reservoirs — losses which are particularly large in the arid zone.

There is an urgent need for comprehensive plans, embracing both surface and subsurface waters, scientifically designed to insure that the Nation's water needs are met both wisely and economically.

If we are to develop such plans, we must have two kinds of information: utilitarian data on the extent and nature of the specific aquifers to be embraced by each plan; and a better understanding of fundamental principles.

All of this serves to point up the urgent need for public entities empowered to carry out such plans. In order to establish such entities, and to provide the powers and policy guidance they require, there must be adequate state legislation — and this presents still another problem of major significance.

Finally, there is a real need for better public understanding of the true nature of the ground water resource, and of the problems which must be solved if that resource is to be used to its fullest potential.

Some Major Policy Issues

Inherent in these problems are significant policy issues which must be resolved by the various levels of government.

One major issue involves reaching decisions on whether a particular ground water deposit should be "mined" and, if so, when and at what rate the resource is to be used to produce optimum gains for the Nation, the region, and the locality.

When a deposit of ground water becomes exhausted, there arises the question of the degree to which government is obligated to cushion the shock to the local economy resulting from termination of the mining process.

To what extent is the public, through its various levels of government, obligated to "bail out" those who bear the brunt of the exhaustion of a resource? What are the alternatives? Should, for example, some provision be made to set aside profits during the period in which the resource is exploited?

These are only a few of the issues with which governments must come to grips as they attempt to solve the problems outlined earlier.

The Role of Governments

In this context, then, what is the proper role of governments in the development, use and conservation of the ground water resource?

First, it is evident that there is a need for basic research. Obviously, the Federal and state governments must assume primary responsibility for meeting these research needs.

The enactment of the Water Resources Research Act of 1964 constituted a giant step toward meeting such needs. Grants now being made by the Office of Water Resources Research from appropriations authorized by that Act are enabling the Nation's scientists to carry out many fundamental studies that were previously impossible.

Another need which requires both Federal and state programs is that of delineating and evaluating the important underground fresh water reservoirs, or aquifers. The major effort here is the admirable program of investigations being carried out cooperatively by the states and the U.S. Geological Survey.

It has been estimated that during fiscal 1969 approximately $12 million was expended to carry out this cooperative program, of which slightly less than half was provided by the Federal government. In the neighborhood of $6 million additional was spent for straight Federal investigations, making the total Federal expenditure roughly $12 million.

This would have seemed a large sum only short years ago. But today an investment on the order of $12 million appears rather puny, particularly in light of the demand for information which has accompanied the striking rate of increase in the use of ground water.

Governments also have an obligation to broaden the investigational program now underway. It is not enough to map and determine the capabilities of the fresh water aquifers. We need to know a great deal more about the potentialities of geological formations for the storage of surface waters, and more about the methods that may be used to introduce water into these formations.

Treated waste water is already being injected into the sands of Long Island to combat the encroachment of salt water, and the use of this practice will undoubtedly become common during the next several decades.

In California artificial recharge of aquifers has been practiced on a large scale for some time, and much has been learned through this experience. In particular, it has demonstrated that the storage of surface waters in underground reservoirs is both physically and economically feasible under certain conditions.

We also need to learn how to utilize the crust of the earth as a depository for wastes that cannot safely be released to surface streams. This means that we will need to know more about deep-lying formations from which injected wastes cannot escape to aquifers man may someday wish to utilize as a source of water.

It is imperative that we broaden present investigations of aquifers to include those containing saline water. Methods for removing the salt from such waters are being perfected, and we can already foresee a time when it will be possible to utilize saline ground water as a source of municipal and industrial supply.

Next, of course, various governmental entities — both Federal and state — must cooperatively formulate the comprehensive plans required if we are to make optimum use of the ground water resource. The Water Resources Planning Act of 1964 provided a sound basis for such planning, and Congress appears to have provided an adequate charter. To date, however, there has been a tendency to emphasize the development of surface waters and to give less than full consideration to subsurface waters.

Control of withdrawals from aquifers is another function that can only be exercised by government. Here the principal burden must fall upon the states and upon the public entities which they establish to manage the resource. The states must, of course, provide the basic policies under which such entities operate. Consequently, there is a real need for state laws which: (1) establish the basic principles and policies which are to govern the development, the utilization (including control) and the conservation of ground waters within the State, and (2) authorize the establishment of the public entities required to insure that aquifers are managed in accord with an optimum plan.

There remains one further function in which both Federal and state governments must play a leading role: pollution control. The necessity for intelligent pollution control measures is increasing rapidly as greater use is made of the Earth's mantle as a repository for industrial wastes, such as brines. Fortunately, the pollution of subsurface waters is not yet widespread, and the Nation is, therefore, afforded an opportunity to prevent the development of the type of serious problem it now faces with surface water.

The responsibilities I have mentioned in this quick inventory will place a heavy load upon the governmental agencies concerned, and it is incumbent upon all of us here to give them such assistance as we may find it within our power to render.

THE ROLE OF GOVERNMENT IN GROUND WATER DEVELOPMENT

The areas in which Federal, state, and local public agencies must assume major responsibilities are:

☐ *In financing much of the basic research on ground water.*

☐ *In delineating and evaluating the important deposits of ground water so that they may be developed, used, and conserved in accordance with optimum plans. These investigational programs must be broadened to provide a basis for storing surface waters underground, to learn how to safely use deep-lying formations for the storage of wastes, and to collect the information on the saline aquifers we shall be turning to in the not too distant future.*

☐ *In developing the comprehensive, balanced and coordinated plans required to insure optimum development and control of important aquifers in proper combination with the development of surface waters.*

☐ *In controlling withdrawals from these aquifers. This key function rests with the states and with any local public entities they may establish for the purpose. It calls for bringing state laws into harmony with sound principles, and also providing therein for the establishment of public entities capable of exercising control at local levels.*

☐ *In preventing the pollution of important deposits of ground water.*

Charles F. Luce is Chairman of the National Water Commission, and also serves as a member of the Board of Directors of United Air Lines, the New York Urban Coalition, and Resources for the Future.

The National Water Commission

The newly-formed National Water Commission, of which I have the honor to serve as Chairman, was formed to offer such assistance.

The Commission is made up of seven citizens who, having no other connection with the Federal government, are in a position to weigh the Federal programs and policies objectively, and to furnish the Congress and the President impartial findings and recommendations.

We have developed a tentative program of 31 studies and have submitted this program to the Federal Departments, the states, and numerous organizations concerned with water, with a request for their views and suggestions.

We have initiated a series of seven conferences, six regional and one national, to obtain the views of the state and regional agencies, as well as of national non-governmental organizations. The Commission is also meeting separately with the agencies which carry out the present Federal water programs.

We are being assisted in our work by a panel of well-known consultants, and have assembled ad hoc advisory panels of ecological experts and outstanding economists.

At present, we plan to complete a report early in 1973.

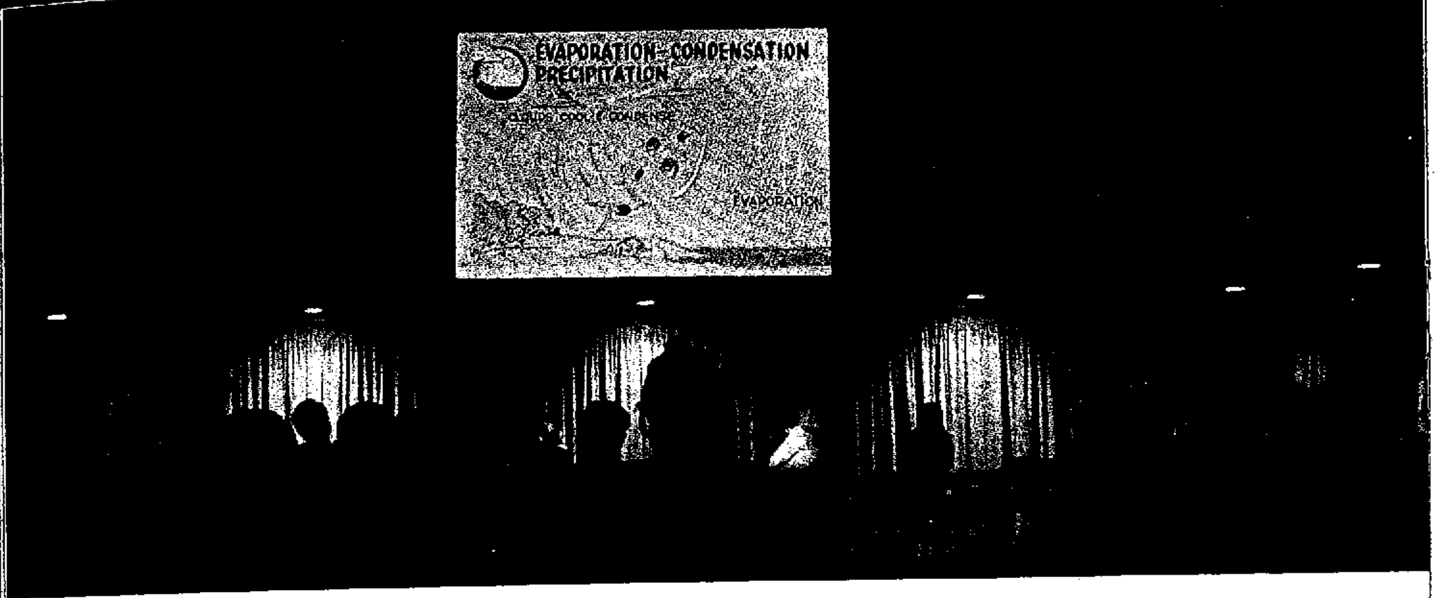
It is certain that our studies will give careful consideration to the development, utilization and conservation of the ground water resource. In fact, our tentative program provides for:

(a) A study of the ways in which the Nation's future water demands may be met, including the development of underground supplies.

(b) A study of water laws, including the Federal and state laws concerned with the development and use of ground waters.

(c) A study of the methodology of developing comprehensive plans for optimum development and use of the Nation's water resources.

The results of these studies, fortified by the assistance we expect to receive from the states, the Federal Departments, interested non-governmental organizations, consultants and advisers will, I am sure, enable the Commission to deal meaningfully with the ground water problems.



Seminar guests view slide series which accompanied Richard Sniegocki's talk on the "Physical Behavior of Ground Water."

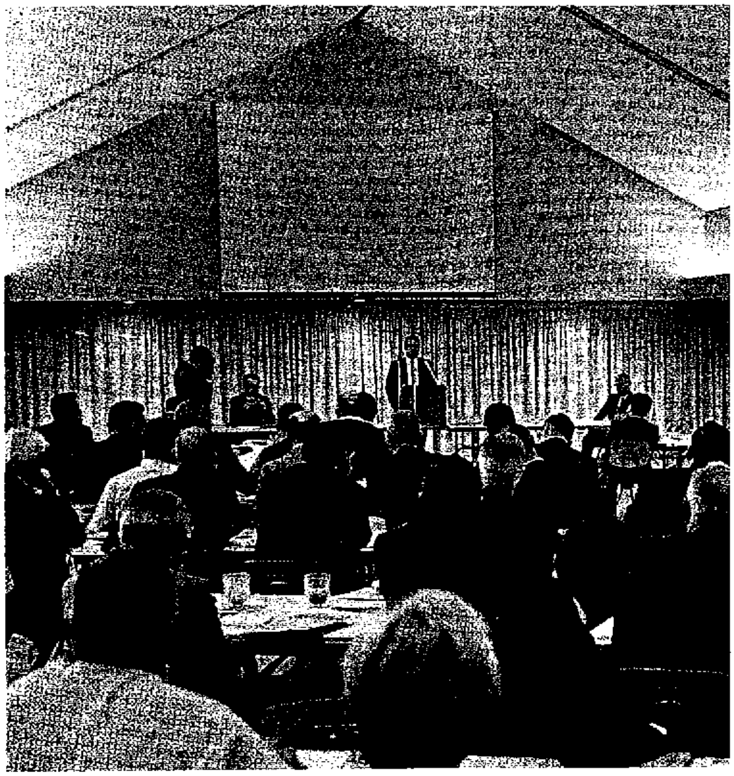
THE GWRI SEMINAR IN RETROSPECT

Last September 7 and 8, Governor Winthrop Rockefeller opened his Arkansas home, Winrock Farms, to participants in the Institute's 5th Ground Water Seminar. Over 150 persons, including water decision-makers from government, industry, and education, attended.

The Seminar centered around the theme "Ground Water and Government," and included presentations on "The Future of Ground Water Development," "Physical Behavior of Ground Water," "Ground Water and Economics," and "Ground Water and the Law."

"What we are trying to accomplish here," said retiring president Leslie Mack, "is to stimulate an awareness among our lawmakers of the social, administrative, legal and judicial aspects of ground water management. We hope, too, to serve as a vehicle for promoting closer communication among the various administrative agencies that deal with water."

Above, Governor and Mrs. Winthrop Rockefeller entertain seminar participants during a reception at Winrock Farm.



Among the Seminar speakers were Richard Sniegocki (left), district chief, U.S. Geological Survey, and Fred B. Hout (below), President of Barnes Manufacturing Company. Mr. Hout spoke on the subject of "Ground Water and Economics."

Opening the program, Governor Rockefeller introduces speakers (from left) Sniegocki, Klein, Mack, Luce, and Hout.

Dignitaries arrive at Winrock airport. A charter flight brought Seminar participants from Washington, D. C.

Though seemingly secure beneath the earth's crust, our ground water supplies are seriously threatened by pollution. The same pollutants that taint surface supplies will eventually also affect ground water — with greater impact and longer-lasting results. The dual specter of dwindling supply and doubled demand gave rise to . . .

GOVERNMENT'S NEW HARD LINE POLICY ON POLLUTION

BY CARL L. KLEIN

Only in the past few years have we begun to care about the quality of our environment — about preservation of those precious resources which always seemed somehow limitless and now so suddenly are almost gone. And even now the work is too often stalemated by apathy and indifference.

Carl L. Klein, former Illinois Congressman, is Assistant Secretary of the Interior for Water Quality and Research.

Yet the need for control is critical. And the ability to stem pollution may mean the ability to insure man's continued survival on this planet. It's as clear-cut and as urgent as that.

Look around you. At the Calumet River in Illinois. Or the Passaic in New Jersey. At Lake Erie slowly dying in Ohio, in Pennsylvania and New York State. At the devastation of Galveston Bay. Then consider the arithmetic that tells us the world's population may double by the year 2000.

The plain fact is that we need pollution abatement now. That is the essence of my message — and my mission.

Ground Water Problems

Our fresh ground water resources, for example, seem vast. They far exceed our surface supplies and are available almost everywhere in the United States. The absence of sediment and bacteria in most ground water means it can usually be used with little or no treatment. It is potentially of extreme importance in industrial, agricultural and urban development.

In most parts of the country, ground water use is increasing and will continue to increase with population growth and greater per capita use of water.

One of our problems, however, is recharging the ground water. A case in point. The ground water supply for metropolitan Chicago started 200 miles away at the Wisconsin River — 1000 years ago. Chicago is gradually depleting that supply by failing to recharge. And Chicago is not alone. This failure is a national phenomenon which seriously threatens our total supply of ground water.

Surface disposal of domestic and industrial waste, seepage from septic tanks, mine drainage, feedlot concentrations, deep well disposal

— the same types of pollutants that affect surface water will eventually also affect ground water, with greater impact and longer-lasting effects.

Clearly, though the supply seems vast, ground water is a limited resource and, unless we take precautions *now* to prevent pollution, we may deny ourselves full use of this resource in the future.

The Federal Government and Water

"The central race in the world today," President Nixon said recently, "is neither an arms race nor a space race. It is the race between man and change." Government must focus "not only on tomorrow, but on the day after tomorrow."

Our job, then, is water quality — today, tomorrow, and the day after tomorrow. We cannot allow our ground water to deteriorate to the same extent as our surface supplies before we act.

The Federal government is working not just on an overview but on many fronts. We are developing an all-out effort to enforce present anti-pollution laws. We are looking for new sources of water and new ways to purify used water. We are searching for new and better ways to combat pollution at all levels. We are looking for ways to insure an adequate supply of water for this nation in the years ahead.

Chemical-physical treatment, the most promising technological development in the last 50 years, may provide the breakthrough for which we have been searching. My scientists and engineers were sufficiently impressed to give the go-ahead for a 100,000-gallon-per-day physical-chemical plant at Blue Plains on the Potomac.

Essentially the process involves adding lime to raw sewage to precipitate the phosphates and coagulate the solids. The effluent is then filtered through activated carbon. The lime is recycled and the resultant ash made into sterile fill. We expect to start testing the process for general use shortly and to have the results in about 12 to 18 months.

This is a new project for the District of Columbia and is properly a Federal concern, but the Federal government cannot and will not do the job everywhere. Pollution is basically a local and state responsibility.

Most states have had their water quality standards approved. But because of the relative newness of the concern, some states have experienced difficulty in securing the necessary implementing legislation. Others have done so but, for a variety of reasons, have had problems in bringing these laws to bear on a particular problem. Most often, such delays are the product of small but vocal groups with special anti anti-pollution interests.

Basically the Federal role is to bring home the necessity for action. But if local enforcement procedures are ineffective and pollution continues, then the Federal government must and will step into the situation.

My orders are to abate pollution — and the orders are for abatement now.

Secretary of the Interior Hickel has stated unequivocally that the government intends to "prosecute those who pollute."

Improving Water Quality

Pollution is not one of the great inevitables of civilization. Water quality *can* be improved on a massive scale. The "Times" of London, for example, recently noted fish returning to the lower Thames for the first time since the 1920's thanks to pollution control.

We already have within our hands the technical skills necessary to solve the pollution problem. But we have not as yet solved it. Why?

Technical know-how is not enough. Programs are ineffective without implementation, without action. Pollution, after all, is a public problem and cannot be solved without public support. Lethargy, apathy and aimlessness must be overcome.

That is the job before us, and that is the Federal view of our nation's water problem.

We must match our research and technology with the will to get this job done, to encourage those responsible for pollution to do the job.

Whatever the obstacles, that job will be done. Whatever is called for — whether it be assistance in terms of providing technical advice, or seed money for construction or enforcement — the Federal government stands prepared to offer.

For as Secretary Hickel said recently: "The people of America have made it abundantly clear that they will no longer tolerate pollution of their environment. This administration believes this is a reasonable demand and one which we have a mandate to satisfy quickly and thoroughly."

ECONOMIC GROUND WATER WITHDRAWAL

Noted hydrologist reviews the principles involved in tapping ground water resources.

When properly designed and constructed, wells permit the economic withdrawal of water from a water-bearing formation. How adequately any well will accomplish this purpose depends on:

- Intelligent application of the principles of hydraulics in the analysis of well and aquifer performance.
- Skill in drilling and well construction that insures taking best advantage of the geologic conditions.
- Selection of materials that will insure long life.

Nature of Converging Flow

When pumping is begun, the water level in the vicinity of a pumped well is lowered. Water moves from the surrounding water-bearing formation into the well to replace that being withdrawn by the pump. The pressure that drives that water toward the well is the head, represented by the difference between the water level in the well and at any place outside the well.

As the water moves closer to the well, it must move through successive cylindrical sections that are progressively smaller in area. Accordingly, the velocity of the water must increase as it approaches the well.

In Figure 1, A_1 represents the area of a cylindrical surface 100 ft. from the center of the well, and A_2 represents the area of a similar surface 50 ft. from the center. It is readily seen that A_1 is twice A_2. But the same quantity of water is flowing toward the well through both areas, so the velocity V_2 must be twice V_1.

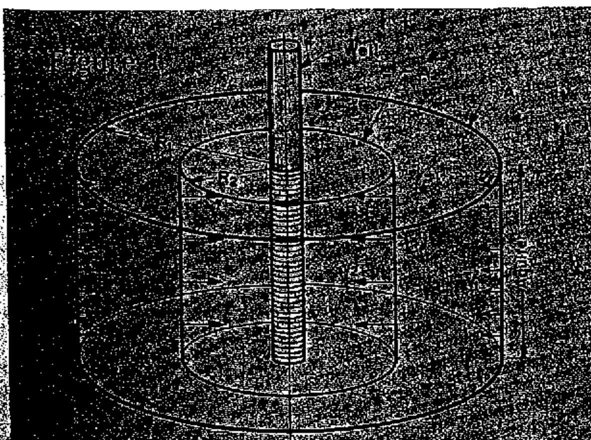
With increasing velocity, the hydraulic gradient increases as flow converges toward a well. As a result, the lowered water surface develops a continually steeper slope toward the well. The form of this surface is described as the *cone of depression*.

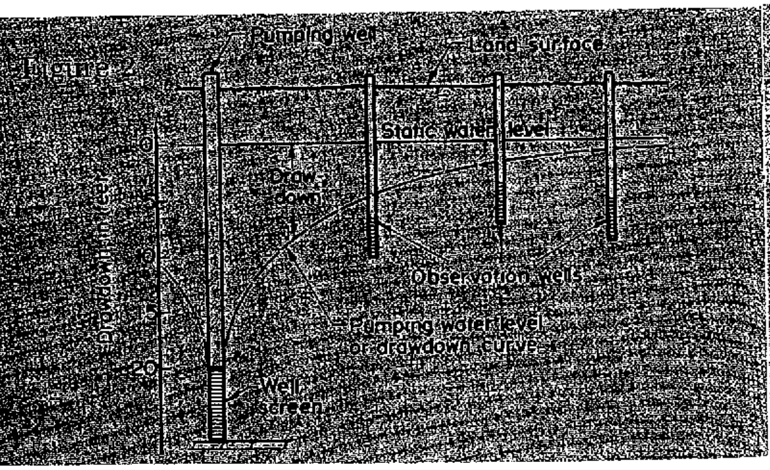
Any well, when pumped, is surrounded by such a cone. Each differs in size and shape depending upon the pumping rate, length of pumping period, aquifer characteristics, slope of the water table, and recharge within the zone of influence of the well.

Cones of Depression

In a formation with low transmissibility, the cone is deep and has a small base with steep sides. In a high transmissibility formation, the cone is shallow and has a large base with flat side slopes. The amount the original water level, or pressure surface, is lowered on the base of the cone and within the well itself is called the drawdown at that point.

Figure 2, representing a transverse section of the cone, shows how the drawdown is distributed within the cone on one side of a pumping well. The curve shows the levels at which water would be found in observation





BY GERALD F. BRIGGS

This article is based on information in the book, "Ground Water and Wells."

wells drilled at various distances from the pumped well. This is sometimes called the drawdown curve. In a water-table aquifer, it represents the water surface within the aquifer as the well is being pumped. In an artesian aquifer, it represents the hydrostatic pressure in the aquifer. The difference between the water level indicated by the curve and the static water level is drawdown at any given point.

Head loss is a term used to represent the force required to overcome the resistance to flow. The head losses from point to point along the pumping water-level curve in Figure 2 are the changes in drawdown between these points.

Suppose, for example, the well is being pumped at a constant rate of 200 gpm. At a distance of 20 ft. from the well the drawdown is about 6 ft.; 6 ft. of head are required to force 200 gpm through the formation from the outer limit of the cone of depression to within 20 ft. of the well. It requires another 6 ft. of head to move the 200 gpm from 20 ft. to within about 5 ft. of the well. At this point the drawdown is about 12 ft. The remainder of the total drawdown, or head loss, is used in pushing the water through the last 5 ft. of formation and through the well screen.

The total drawdown of 20 ft. measured in the well is the head in feet required to move 200 gpm through the aquifer and into the well.

When water is pumped from a well, the quantity discharged initially is derived from aquifer storage immediately surrounding the well. As pumping continues, more water must be derived from storage at increasingly greater distances from the well bore. This means that the cone of depression must expand, increasing the radius of influence of the well. Drawdown also increases as the cone deepens to provide the additional head required.

Initial Flow From Aquifer To Well

The cone expands and deepens at a decreasing rate with time, however, because with each additional foot of horizontal expansion a larger volume of stored water is available than from the preceding one. (See Figure 3)

Assume that after one hour of pumping the radius of the cone is 400 ft. and its depth 6 ft. at the well bore. At the end of the second hour, the cone's radius has expanded to 570 ft. and its depth increased to 6.3 ft. In the second hour, therefore, the cone has extended outward an additional 170 ft. and deepened by 0.3 ft.

The third hour of pumping produces an additional radial expansion of only 130 ft. and an increase in depth of only 0.2 ft. Calculation of the volume of each of the cones would show that C_2 has twice the volume of C_1, and C_3 has three times the volume of C_1.

After some hours, the deepening or expanding

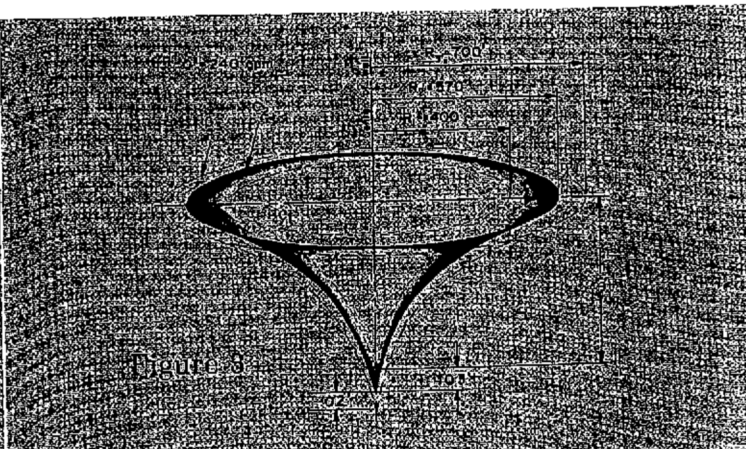


Figure 3

Well Diameter vs Yield Ratio, in %

Well Diameters						
6"	12"	18"	24"	30"	36"	48"
100	110	117	122	127	131	137
—	100	106	111	116	119	125
—	—	100	104	108	112	117
—	—	—	100	104	107	112
—	—	—	—	100	103	108
—	—	—	—	—	100	105

Figure 4

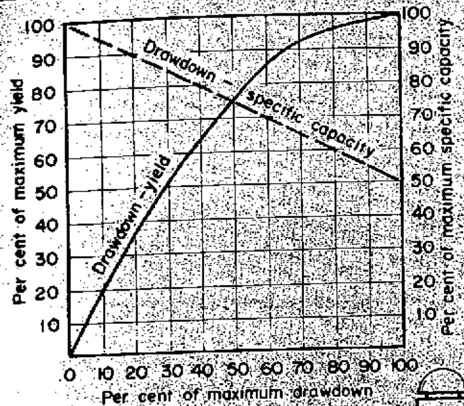


Figure 5

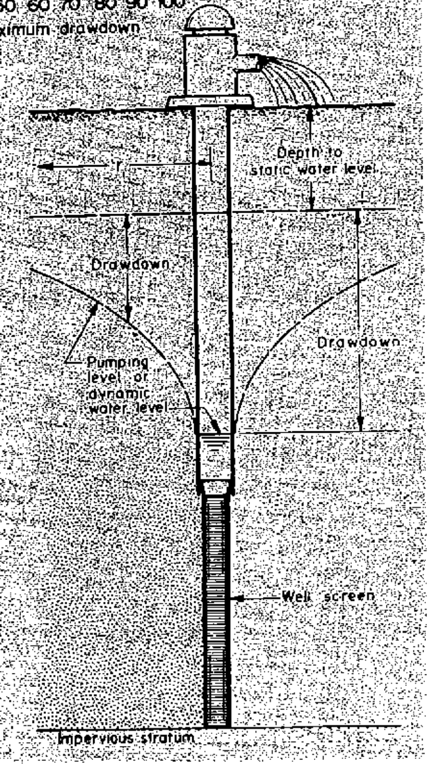


Figure 6

of the cone during short time intervals is not always noticed, which often leads observers to conclude that the cone has reached a stabilized position. The fact is, however, that the cone continues to enlarge until aquifer recharge occurs in an amount equal to the pumpage.

When the cone stops expanding, a condition of equilibrium exists. There is no further increase in drawdown with increase in pumping time. In some wells, this occurs within a few hours; in others it never occurs, even though the pumping period may be extended for years.

Relation of Well Size to Yield

Many persons assume that doubling the diameter of a well doubles its yield. This is untrue.

Figure 4 shows the figures obtained when R = 400 ft. — a typical value for water-table conditions. As indicated on the table, if a 6-in. well will yield 100 gpm with a certain drawdown, a 48-in. well constructed on the same spot will yield 137 gpm, or 37 percent more water at the same drawdown.

These ratios apply both to specific capacity and total yield. For example: if a 12-in. well is producing 20 gpm per foot of drawdown, then a 24-in. well in the same location would provide 111 percent as much, or 22.2 gpm per ft. of drawdown. Thus, doubling the diameter of a water-table well will increase its yield about 11 percent.

For artesian wells, where *R* is much larger, the percent increase resulting from doubling the well diameter is smaller — generally about 7 percent.

Relation of Drawdown to Yield

For a well operating under artesian conditions the yield is directly proportional to the drawdown, as long as the drawdown does not exceed the distance from the static piezometric surface to the top of the aquifer. Theoretically, this means that if the drawdown is doubled, the yield is doubled. Or, the specific capacity of the well is constant at any pumping rate as long as the aquifer is not unwatered.

For a well in a water-table aquifer, the part of the formation within the cone of depression is actually unwatered during pumping, thus changing the ratio of drawdown to yield. When the drawdown is doubled, the well yield is less than doubled. The specific capacity decreases proportionally with increased drawdown.

Figure 5 shows the relation between drawdown, yield, and specific capacity for a water-table well. The solid curve shows the relationship between drawdown and yield.

Maximum drawdown means lowering of the water level to the bottom of the well; 50 percent drawdown means lowering the water level to a point halfway between the static water level and the well bottom.

Maximum yield is the quantity the well will produce at maximum drawdown. As an example, suppose that a well 120 ft. deep has a static level of 20 ft. and that the saturated thickness of the formation is 100 ft. During a test, the well is pumped at 100 gpm and the pumping level stabilized at 40 ft., or at a drawdown of 20 ft. How much will the yield be with 40 ft. of drawdown and the pumping level at 60 ft.?

Here, 100 percent drawdown is 100 ft.; thus the 20-ft. drawdown during the test was 20 percent of the total possible drawdown. The solid curve in Figure 5 shows that at 20 percent drawdown, the yield is 36 percent of the well's maximum yield. A drawdown of 40 ft. is 40 percent of the total possible and would provide 64 percent of the maximum yield. If 100 gpm is 36 percent of maximum, then 64 percent would be:

64/36 x 100 = 178 gpm

The well can be expected to yield 178 gpm at 40 ft. of drawdown.

The broken line in Figure 5 shows how specific capacity varies with drawdown. Theoretically, maximum specific capacity corresponds to zero drawdown because there is no reduction in the saturated thickness. The minimum occurs when drawdown and yield are maximum. Note that the minimum specific capacity is 50 percent of the maximum. In the previous example, 90 percent of the maximum specific capacity would be obtained with 20 ft. drawdown and 80 percent with 40 ft.

Optimum well operating characteristics are obtained when the product of yield and specific capacity is largest. This occurs at about 67 percent of the maximum drawdown.

At 70 percent of maximum drawdown, 92 percent of the maximum yield is obtained — so the well is yielding within 8 percent of its maximum. To obtain that remaining 8 percent would require an additional 30 percent drawdown. Clearly, then, it is uneconomical to operate a well with a drawdown greater than 70 percent.

Objectives of Tests

The usual purpose in testing a water well is to obtain information about its performance and efficiency. Taken under controlled conditions, data reflecting yield, observed drawdown, and calculated specific capacity give a measure of the well's productive capacity and provide data on which the selection of pumping equipment can be based.

Well testing may also be conducted to obtain data from which the principal factors of aquifer performance can be calculated. However, a test set-up for this purpose is more properly called an "aquifer test."

Briefly, aquifer tests consist of pumping one well at a constant rate and recording both the drawdown in the well and the drawdown caused by this pumping in nearby observation wells. At the instant of each measurement, the time interval of pumping is also recorded. These data can be analyzed to show the hydraulic characteristics of the aquifer.

Gerald F. Briggs, vice president of engineering for UOP-Johnson Division, is a member of the Ground Water Resources Institute's Technical Advisory Committee.

DEFINITIONS . . .

of a number of the terms used in discussing the hydraulics of wells are given here.

□ **Static Water Level** is the level at which water stands in a well when no water is being taken from the aquifer, either by pumping or free flow. It is generally expressed as the distance from the ground surface to the water level in the well.

For a well which flows at the ground surface, the static level is above ground and is often referred to as the shut-in head. If a well is said to have a shut-in head of 10 ft., this means that the artesian pressure is such that water would rise 10 ft. above the measuring point in a pipe extended above that point.

□ **Pumping Level,** also called the "dynamic water level," is the level at which water stands in a well when pumping is in progress. In the case of a flowing well, it is the level at which water may be flowing from the well.

□ **Drawdown** is the difference, measured in feet, between the static water level and the pumping level. It represents the head that causes water to flow through the aquifer material toward a well at the rate that water is being withdrawn.

□ **Residual Drawdown.** After pumping is stopped, water levels rise and approach the static water level. During this period, the distance that the water level is found to be below static water level is called residual drawdown.

□ **Well Yield** is the volume of water per unit of time discharged from a well, either by pumping or free flow.

□ **Specific Capacity** of a well is its yield per unit of drawdown. Dividing the yield by the drawdown gives the value of the specific capacity.

□ **Radius of Influence (R)** is the distance from the center of the well to the limit of the cone of depression.

□ **Coefficient of Storage (S)** of an aquifer is the volume of water released from storage, or taken into storage, per unit of surface area of the aquifer per unit change in head. In water-table aquifers, **S** is the same as the specific yield of the material unwatered during pumping. In artesian aquifers, **S** is the result of two elastic effects — compression of the aquifer and expansion of the contained water — when the head or pressure is reduced during pumping. The coefficient of storage is a dimensionless term. Values for **S** for water-table aquifers range from 0.01 to 0.25; for artesian aquifers, from 0.00001 to 0.001.

□ **Coefficient of Transmissibility (T)** of an aquifer is the rate at which water will flow through a vertical strip of the aquifer one foot wide and extending through the full saturated thickness, under a hydraulic gradient of 1.00 or 100 percent.

Values of the coefficient of transmissibility range from less than 1,000 to over 1,000,000 gpd per ft.

THE CRITICAL BALANCE: SUPPLY VS DEMAND IN WATER USE

BY C. RICHARD MURRAY

Current water supply problems can — and undoubtedly will — be solved. But more planning and ingenuity will be needed and higher costs can be expected.

If the nature of water use permits most of the water to be returned in a reusable condition, then a demand of several times the supply can be met. But in 1965 (the last year for which we have hard figures) 85 percent of U.S. water consumption took place in the relatively arid 17 Western states — where only a quarter of the country's supply is found.

The practical relationships between supply and demand are further complicated by other important factors such as time, location, and economics.

The broader the geographic area under consideration, the more uniform and amenable to treatment the problems appear. In a specific drainage basin, however, deficiencies in precipitation and runoff can produce a serious imbalance between supply and demand.

Water Management

Fortunately, increased dependability of supply generally can be obtained through investment in water control measures, such as constructing reservoirs, controlling evaporation, or artificially recharging ground water aquifers. Thus water-supply management may play an important role in meeting demands.

Withdrawal of fresh ground and surface water in the 48 conterminous states in 1965 was 310 bgd, or approximately three-fourths the dependable fresh supply. Consumption was 77 bgd, about one-fifth the estimated dependable supply.

The critical nature of the supply vs demand situation over the 17 Western states is shown in Figure 1. All fresh water withdrawals for off-channel uses in these 17 states amounted to about 130 bgd, compared to about 150 bgd for the estimated dependable supply. Consumption amounted to about 66 bgd — 45 percent of the dependable supply.

Comparing dependable supplies with withdrawals and water consumption in the water resource regions west of the Mississippi Valley (Table 1), it is apparent that only the Pacific Northwest has a very favorable supply-demand ratio.

With increasing aridity, a larger percentage of the water withdrawn is consumed and the withdrawals approach or may exceed the dependable supply. If the regions shown in Table 1 are further subdivided, the supply may be inadequate to meet demands in the subregions, such as the Upper Missouri and Upper Arkansas, or in individual river basins and, therefore, chronic water shortages are experienced.

Except for areas of local overdraft, increased

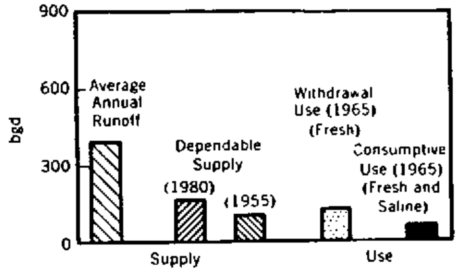
Table 1

Supply Compared with Demand in Western United States—bgd

Region	Estimated Dependable Supply, 1980	Total Withdrawal 1965	Water Consumed 1965	Fresh Surface Water Withdrawn 1965
Missouri	33	21	10.2	16.5
Arkansas	20	10.4	5.7	5.0
Western Gulf	20	30	14	10
Colorado	15	17	8.4	12
Great Basin	9	6.9	3.8	5.3
South Pacific	28	38	15	14
Pacific Northwest	70	29	10	24

C. Richard Murray is affiliated with the U.S. Geological Survey Water Resources Div. of the Department of the Interior.

Figure 1



development in most parts of the country is still possible. However, the cost of increasing the dependable supply compared to the added benefits that may be derived will exercise a restraining influence on the extent of development.

When the demand exceeds the supply from all available sources, changes will then be largely conversions from one type of use to another offering greater economic benefits. Low consumptive use and suitability of discharge water for reuse are important factors in determining to which use the water will be put as the competition for available supply increases.

Trends In Withdrawal Uses

In general, estimates of both ground and surface water withdrawals (Table 2) show fairly uniform increases over each 5-year period. The estimates for surface water used for irrigation declined from 1950 to 1960 and changed little for 1965. However, estimates of ground water use for irrigation increased from 30 bgd in 1960 to 42 bgd in 1965.

No definite trend in the use of ground water in industry is noted. Industry will probably increase ground water withdrawals as competition for sources of surface water becomes greater.[1]

In industrial plants using fresh water for cooling, particularly those located in arid regions, more emphasis will be placed on repeated use of the water. In many parts of the West, water scarcity has already led to the adoption of conservation measures, particularly in thermoelectric power plants.

Current water supply problems can — and undoubtedly will — be solved. But if they are to be solved, more planning and ingenuity will be necessary and increased costs can be expected.

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[1]*Excluding thermoelectric plants, ground water amounted to 24 percent of all water withdrawals for industry in the West and 13-1/2 percent in the East. However, ground water furnished 42 percent of the fresh water withdrawals for industry in the Western states and 15-1/2 percent in the East.*

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STATEMENT OF PURPOSE

The purpose of the **Ground Water Resources Institute** is to stimulate public awareness of ground water, which comprises most of the available fresh water supply in the United States and the world.

Underground water has long been used for private and public supply. But in comparison to surface water sources, too little is known by our leaders and citizens about the intrinsic value and benefits of this great resource. Only when the benefits of ground water are fully understood can it fulfill its rightful role in total water management programs.

The Institute is a non-profit educational organization striving for broader ground water use and conservation of this vital resource.