Ground Water:
An Undervalued Resource

U.S. Department of the Interior/Geological Survey
Introduction

During the coming decades, the increased pumpage of ground water to supplement surface supplies is expected to increase dramatically throughout the country. Economic growth of cities, particularly in the water-short Southwest, and the prime contributing factor to the desire to develop water supplies capable of weathering a prolonged drought will be another. Large amounts of water will be needed for new energy-producing industries, particularly in the transport of power and the operation of slurry pipelines. Irrigation systems are becoming a routine consideration in virtually all agricultural practice even in areas. The development of pivot equipment, in which the sprinkler pipe rotates around a central well and irrigates...
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by Gordon D. Bennett

Introduction

During the coming decade, pumpage of ground water to supplement surface supplies is expected to increase dramatically throughout the country. The rapid growth of cities, particularly in the water-short Southwest, will be a prime contributing factor; the desire to develop water supplies capable of weathering extended drought will be another. Large amounts of water will be required for new energy-producing industries, particularly in the generation of power and the operation of coal slurry pipelines. Irrigation is fast becoming a routine component of agricultural practice even in humid areas. The development of center-pivot equipment, in which a moving sprinkler pipe rotates around a central well and irrigates a circular area, has caused a rapid increase in irrigated acreage and a growing emphasis on ground water as a source of irrigation supply. Finally, environmental objections to large surface reservoirs are forcing planners to consider ground water as an alternative source of supply for all applications.

This increasing use of ground water is certain to have varied and widespread impacts. From a strictly hydraulic point of view, all pumpage must result in a lowering of ground-water levels, and this in turn would affect all users of ground water in the area. In addition, pumpage tends to reduce the available surface-water supply by reducing natural accretion of ground water to streams and, in some cases, by inducing direct seepage from streams to the ground-water system. In some instances, the pumped ground water is returned to the stream system or...
directly to the ground-water regime through artificial recharge, irrigation field seepage, or certain forms of waste disposal after a cycle of use. The result may then be degradation in water quality rather than diminished supply. Finally, pumpage may have an impact on the structure of the Earth. Sustained withdrawals from some types of aquifers can cause compaction of the geologic column and subsidence of the land surface.

In the development of ground water, as in the development of any resource, well-informed management can make a great difference. The consequences of pumpage will depend to a large extent on the way in which it is implemented. If the results of various courses of development are understood in advance, planners will be in a position to choose the course for which the ratio of benefit to real cost is most favorable. Even where no planning authority exists that can guide and influence the development of ground water, an understanding of the consequences of various patterns of withdrawal is necessary if society is to be prepared to meet those consequences.

The prerequisite to any kind of successful management is information—particularly on the hydrologic impacts of various development alternatives. The requirement is for a predictive capability through which the planner can estimate in advance what will happen if this or that scheme of withdrawal is implemented. For a number of years, ground-water investigations inside and outside the U.S. Geological Survey have focused on the development of such predictive capabilities. In general, these efforts have been at a local scale because the state of the science has been limited and because the interest of planners has been largely at the local level. The anticipated increases in withdrawal over the next decade, however, will produce impacts which are regional in scope. To provide management information at a regional scale, including predictive capabilities, the Geological Survey has initiated a new series of hydrologic investigations—the Regional Aquifer-System Analysis (RASA) Program.

The Role of Ground Water in the Economy

The significance of ground water to economics can best be illustrated through one or two examples. In California’s Central Valley, pumpage for irrigation was curtailed prior to 1977 and was replaced with surface water in an effort to stem the land subsidence which had accompanied earlier heavy withdrawals. The drought of 1977 caused a failure of surface-water supplies, and there was widespread concern that the agricultural production of the valley, a vital factor in the economy, would fall seriously. Surface-water supplies have, however, pumped irrigation wells were reactivated thousands of new wells. Irrigation supplies were maintained throughout the dry season, and the impact of the drought on food production in the valley was greatly reduced. As the passing of the drought water has again become a source of irrigation.

The experience illustrated the importance of ground water. An irrigating state is the total water supply and the value of integrating management of ground water to meet current demand.

Another example of the economic significance of ground water can be found in the Great Plains States, where ground water and shallow ground water resources are already being used for irrigation and new sources are needed to supply the energy demands of energy development. The Madison aquifer is vast but deep-lying and, largely unutilized for water, has been proposed as a source of power for future generations, coal slurry plant, and power generation. The question of utilizing the Madison is currently the subject of investigation. Whatever outcome of these investigations, competition between related uses and other...
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omy, would fall seriously short. As
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sands of new wells were drilled.
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tained throughout the growing
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Another example of the eco-

nomic significance of ground water can be found in the northern
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The Madison aquifer, an extensive
but deep-lying and, therefore,
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ations, coal slurry pipelines, and
power generation. The feasibility of
utilizing the Madison in this way is
currently the subject of intensive
investigation. Whatever the results
of these investigations are, the
competition between energy-
related uses and other water de-
mands will probably be a factor in
the regional economy for many
years to come. This situation will
be repeated in other parts of the
country as the effort toward greater
domestic energy production
intensifies, and, in many instances,
ground-water development will
be proposed as the solution.

The examples illustrate the
management questions facing the
planner are basically economic
issues. Some are clear cut; for
example, any new draft on the
ground-water system must in-
fluence the pumping lift, flow rate,
or quality of the supply to existing
installations, and each of these
factors has an influence on cost.
The economic implications of other
management questions may be less
clearly defined, but they are real.
Certain environmental impacts of
pumpage, for example, may not
usually be thought of in terms of
dollars. However, if a development
scheme is abandoned because of
environmental considerations, a
decision has implicitly been made
to place a higher value on main-
tenance of the environment than
on the benefit of the pumpage to
the economy. This decision, inten-
tionally or not, attaches a minimum
dollar value to the environmental
issue.

The need for management in any
case is an economic need. Hap-
 hazard development of ground
water will cost the Nation much
more than well-managed develop-
ment. Successful management of
any resource depends upon
adequate information, and ground
water is no exception. An understanding of the natural flow system and of the way in which it will respond—hydraulically, chemically, and structurally—to imposed stresses is a necessary prerequisite to ground-water development planning.

The nature of ground-water flow systems

The ground-water regime is a dynamic system in which water is continuously in motion from areas of recharge to areas of discharge. In a typical ground-water flow system, this movement occurs through an extensive heterogeneous but interconnected geologic framework. This framework generally includes permeable units, normally thought of as water-bearing zones or aquifers, and less permeable units, which were formerly considered confining zones (aquicludes) but are now more commonly thought of as semiconfining zones (aquitards). The chemical quality of ground water is recognized to be a function of the processes, particularly interaction with the geologic framework, that have occurred along the path of flow. Thus, chemical quality normally varies from one point to another in the flow pattern.

Prior to development in a given region, the flow regime is presumably in hydrologic equilibrium, having total recharge to the system equal to total discharge from it. Pumpage disrupts this equilibrium, causing a withdrawal of water from storage and a concurrent decline of water levels. As water levels fall, natural discharge from the system is reduced, and recharge may be increased. In time, these changes in natural inflow and outflow may be sufficient to balance the withdrawal; if this occurs, a new equilibrium is achieved in which recharge is balanced by the sum of natural outflow and pumpage, and depletion of storage no longer occurs. Such an equilibrium, however, may not always be possible at a given rate of withdrawal. If the pumpage from a given system exceeds the reductions in natural outflow and the increases in recharge which can be induced, wells will continue to draw from storage until depletion of the supply forces a reduction in withdrawal rate.

It is important to recognize that the reduction in natural outflow described above implies that withdrawal of ground water ultimately must have an impact on surface-water resources. If, for example, a ground-water flow system originally discharges to a stream, development of ground water will ultimately bring about a reduction in streamflow equal to the pumpage, provided a new equilibrium is achieved. In some applications, of course, much of the pumpage is returned to the stream system after use. As noted earlier, the impact on the stream is then largely one of degradation in quality rather than quantity of flow. The sign of ground water is that it is both part of and a product of the geologic regime. It reflects the stress in either direction and has been a source of conflicting issues throughout history.

The methods of simulation of ground-water flow systems

During recent decades, development and advances have been made in the field of computer simulation of ground-water flow. These methods are based on advances that have been achieved in our understanding of the potential for the movement of ground water through rock and soil and in management of these resources.

Briefly, simulation is a process by which we can predict the results of different actions (and perhaps natural events).
An underground flow system is characterized by a natural flow regime, which is a balance of inflow and outflow. In this regime, water in storage is replenished by recharge, while water is withdrawn by discharge. Ground-water flow occurs in permeable units, such as aquifers, and in impermeable units, such as confining layers. Ground-water flow systems are complex due to the heterogeneity of geologic formations, which can vary from place to place. The flow of water in these systems is influenced by factors such as topography, geology, and land use.

Pumpage disrupts the natural equilibrium in ground-water flow systems. Pumping from wells causes a withdrawal of water from storage, which can affect the natural flow regime. As water levels fall, natural recharge from the system is reduced, and recharge may be increased. In some cases, a new equilibrium is achieved in which recharge is balanced by the sum of natural outflow and pumpage, and depletion of storage no longer occurs. Such an equilibrium, however, may not always be possible at a given rate of withdrawal. If the pumpage from a given system exceeds the reductions in natural outflow and the increases in recharge, wells will continue to draw from storage until depletion of the supply forces a reduction in withdrawal rate.

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The total volume of water in storage as ground water is extremely high relative to the rate of flow through the system. This high ratio of storage to flow rate tends to encourage development of ground water from storage; it also means that the ground-water system is a far more drought-resistant supply than most surface sources and that conjunctive management of ground water and surface water is an effective method of weathering fluctuations in surface supplies.

The method—computer simulation of ground-water flow systems

During recent years, rapid strides have been made in the field of computer simulation of ground-water flow systems. These advances have had far-reaching effects on the techniques of ground-water investigations and on the potential for intelligent management of ground-water resources.

Briefly, simulation refers to the process by which the hydraulic (and perhaps other) characteristics of the flow system are represented by a set of equations which can be solved on a digital computer. The set of equations, the computer routines required for its solution, and the input data (specifying the properties of the geologic framework and of the ground water itself and outlining the problem to be solved) collectively constitute the "model" of the flow system. Hydrologic effects are addressed in all ground-water models; more sophisticated simulations may also treat corollary effects, such as land subsidence or solute transport. An example of the use of simulation is provided by the Geological Survey's work on Long Island, where a three-dimensional model of the flow system has been used to predict declines in water level and streamflow that would be caused by various development alternatives.

Initially, simulation was regarded by many primarily as an aid in hydrologic prediction. The normal sequence of operations involved hydrogeologic investigation, construction of a model based on the results, and use of the model as a planning tool to predict the effects of various proposed schemes of pumping. With the continued development of simulation technology, however, there has been a growing realization of the contribution the method can offer to the process of hydrogeologic investigation itself. Increasingly, models are thought of as investigative tools to be used in the study of existing ground-water flow systems.
variety of ways, ranging from simple trial-and-error to sophisticated statistical approaches, simulation allows the investigator to test his hypotheses, to check the sensitivity of his results to various assumed conditions, and to generate a reasonable reconstruction of the flow system on the basis of available field data. In this sense, it has made the analysis of regional hydrology a much more realistic goal than it was a few years ago.

It is relatively uncommon for hydrologic investigation to precede ground-water development altogether in a given region. As a rule, hydrologic investigations are initiated in response to problems that normally arise only after pumping has been in progress for several years. Thus, the hydrologist rarely has a firsthand look at the undisturbed or natural condition of the system that he is studying. Rather, he sees it in some intermediate condition, disturbed by a certain level of development but not yet subject to the full stresses which are to be imposed. An understanding of the original flow system is a prerequisite to an analysis of many other facets of the hydrogeology, particularly those relating to water chemistry. Simulation has proven particularly useful in this aspect of hydrologic investigation. When a model has been developed that offers a satisfactory representation of present conditions, it can be used to simulate the prepumping situation, thus providing an analysis of the original flow pattern.

The use of simulation as an investigative tool has not diminished its significance in terms of hydrologic prediction. The development of a predictive capability for planning purposes remains the ultimate goal of most hydrogeologic work today; the only real difference is that simulation itself now plays a large role in the investigations leading to that goal.

The hydraulic investigations of the RASA Program represent a systematic effort to study a number of extensive regional ground-water systems that together cover much of the country and represent a significant element of the national water supply. Twenty-five systems have been identified for study, although the list is not necessarily in its final form. In general, the study areas transcend political subdivisions to which hydrologic investigations have often been limited in the past.

A regional aquifer system may be defined as an extensive set of aquifers within a given geographic region and made up of units that are hydraulically interconnected or that share some common characteristics that it is efficient to study them in a single exercise.

The hydraulic investigations of the RASA Program may be within the ground-water systems or may be external to them, in the case of a number of studies linked to a common subject network.

Needless to say, the definition and allocation of a wide range of system studies. The project candidates have been selected on the basis of further criteria, the most important of which (1) the significance of the system as a potential source of supply of water—particularly to the economy, or, at least, to a region of more than one state; (2) the severity of the water problems facing the project area; and (3) potential water needs or area—particularly those associated with energy projects, irrigation, and industrial development. Although the project areas are subject to state nature, this is not a requirement.

Three studies were conducted during fiscal year 1978, in the California Central Valley, the Western Great Plains, and the Northern Plains. The important area is the water in the Central Valley, in the northern Great Plains, and in the northern Great Plains. A study of the northern Great Plains has been mentioned. The Central Valley Study will continue with evaluating effects of expanded irrigation. The expanded use of groundwater is an adjunct to surface water irrigation system. A study of the northern Great Plains presents an expansion of the head of the Madison aquifer.
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Analysis of Regional Aquifer Systems

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activities. They will also provide a means of predicting the hydraulic effects of stress, such as pumpage, artificial recharge, or waste disposal. In some studies, associated effects, such as land subsidence, changes in water quality, or costs of pumping, may be incorporated in the models. The simulations will be based on a full assemblage of existing data and on such new data as are required to fill critical gaps in the available information. In some cases, collection of this new data will require extensive field operations.

Simulation will be initiated early in each project to study the overall nature of the flow system, to identify sensitive parameters and data needs, and to determine what segments of the system, if any, can be treated independently in further work. As additional data are assembled, the simulation of the regional system will be refined progressively, and detailed models of local problem areas will be developed. The regional model, apart from contributing to an understanding of the overall hydrologic system, will provide the boundary conditions for experiments on the local models, thus tying the local simulations into the regional analysis.

Each study will address water quality as well as hydraulics. The present water-quality distribution throughout the study area will be described, and an effort will be made to interpret this distribution in terms of the original flow pattern, the changes in response to development, and the associated geochemical processes.

The products of these investigations will vary according to the needs of the area, although, again, some common patterns will be followed. In particular, results will be released continuously during each study through a series of data reports and short papers, and the full results of the investigation will be summarized in a comprehensive final report.

The studies are designed to complement the Survey’s continuing program of cooperative ground-water investigations. As a general rule, investigations initiated under the cooperative program are of local nature, and, frequently, they are oriented to the solution of specific problems. Because the RASA studies are designed to look at the regional picture, they will serve to tie together local investigations, whether past, present, or future; in terms of simulation, they will provide boundary flows for detailed local models. Thus, the RASA Program is expected to act as a stimulus to other hydrologic investigations rather than as a replacement for any existing program.
As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.