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Aquifer/Stream Relationships
and Aquifer Recharge

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**Uncovering the Hidden Resource:
Groundwater Law, Hydrology, and Policy in the 1990's**

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I. Introduction

Man continues to increase his demand for fresh water to satisfy his domestic, municipal, industrial, irrigation, commercial and recreational uses. This means even greater competition for the limited ground and surface water supplies. Problems which need to be addressed in the 1990's include: ground/surface water conflicts, better management of our total water resources, operating to prevent injury to vested water rights, impact of conservation measures on both ground water quantity and quality, maintenance of dominion and control for artificially recharged waters, sharing costs and benefits of artificially recharged water, and reduction of litigation costs.

This presentation will illustrate some of the problems which need to be solved. Questions will be posed which may be addressed by later speakers at the conference. The need for better management to minimize water shortages and prevent injury to vested water rights will be stressed. Example of specific situations will be drawn from Colorado, Idaho, Mississippi, and Florida. Some discussion of water quality issues will be included.

II. Definitions

A. Surface Water - Surface water is that water which in its free state occurs on the surface of the earth. Examples would include rivers, streams, lakes, reservoirs and the ocean. Surface water moves under the influence of gravity and can move with a velocity of several miles per day. Depending on the degree of accuracy needed, it generally can be measured quite accurately and it is possible to see and observe its direction and rate of flow. Man has built structures to divert, store and spread this resource and put it to beneficial use.

B. Ground Water - Ground water is that water which exists beneath the land surface. It is stored and is often transmitted through interconnected pore or void spaces. A geologic formation which will both store and transmit ground water is called an aquifer. Groundwater may exist in both a fully saturated and partially saturated state. For todays presentation the comments will generally be in reference to the fully saturated state although some further reference on how the partially saturated zone controls the rate and movement of recharge or discharge will be made.

Ground water in fully saturated aquifers will move in a direction and at a velocity controlled by the gradient of hydraulic head and the aquifer's permeability. The equation which is used to calculate ground water flow rates is called Darcy's Law and is represented in a general form as:

Q = KA

Q = rate of flow (L^3/T)

K = aquifer permeability (L/T)

A = Cross sectional area of aquifer through which the flow occurs ($L^{2)}$

= hydraulic gradient which is the difference in hydraulic head per unit length (Dimensionless)

Generally groundwater will move in response to the force of gravity. The velocity is much slower than surface water and may only be a few thousand feet per year. For confined, artisan, aquifers the pressure change due to a hydrologic event will be much faster than for an unconfined aquifer.

It is nearly impossible to accurately measure the total volume of water which is stored in an aquifer and the principal goal is to try and estimate the volume of water which could be removed due to gravity drainage. It is also difficult to determine the quality of ground water because it can change due to solution, deposition or absorption of salts between the geologic formation and the ground water.

Man has learned how to develop ground water and it is most often withdrawn by pumps from wells. Ground water has also been produced by gravity drains, tunnels, and other subsurface structures. Men have developed artificial recharge structures to place surface water into an underlying aquifer.

C. Hydrologic Cycle - The generalized hydrologic cycle illustrates the many physical processes which occur in nature. For the most part men's need for fresh water relies upon precipitation in the form of rain or snow as the source. Significant quantities of fresh water have been stored in aquifers and are currently being pumped, sometimes at rates which exceed the natural recharge thus mining the groundwater. An example of an aquifer where withdrawals exceed recharge is the Ogallala aquifer.

Generally water moves through the hydrologic cycle under the influence of gravity. Streams flow from higher to lower elevations and water is stored in natural lakes and man made reservoirs. The infiltration of rainfall through the soil naturally recharges underlying aquifers and deep percolation of irrigation water below the root zone is a major factor for recharging alluvial aquifers.

Water is generally considered a conservative material in that it generally is neither created or destroyed in large quantities even though it may change from the liquid to vapor or ice and snow state under natural processes. The continuity or mess balance equation is most important in calculating or understanding how water moves through the hydrologic cycle. That equation has the form:

$$\text{Inflow} - \text{Outflow} = \text{Change in Storage}$$

In studying how the hydrologic cycle works or when making water investigation studies one would expect to write such mass balance equations for each of the various components including: the stream, each reservoir or lake, each ground water aquifer, soil moisture storage, etc.

Many of our computer models which will be discussed later at this conference are primarily based upon a series of mass balance equations and the use of Darcy's Law for groundwater flow. Models which misrepresent the physical systems or which violate the continuity principle generally provide misleading information. Some assumptions are usually needed to simplify or approximate the real world conditions. Litigation often results from differences in assumptions, approximations or representation of the real system.

Data are needed to quantify the state of each part of the hydrologic cycle and the natural processes or system parameters. One can not estimate how ground water will flow unless you have knowledge about the geology and soils. As man continues to increase his demands for fresh water, it is imperative that he improve his understanding of the many natural and physical limitations and that he develop techniques and procedures so that he can be provided information needed to make wise management decisions. Computers are essential to capture, and analyze data and model the complex hydrologic system. These computers can also be used to answer "what if" scenarios and are now being used extensively to estimate or quantify the amount of injury which has occurred to other vested water rights, example: U.S. Supreme Court Case, Kansas v. Colorado, No. 105.

III. Ground/Surface Water Interaction

A few examples will help illustrate how mans use of ground and surface water has modified the natural hydrologic system.

A. Alluvial aquifers - Both the South Platte and Arkansas Rivers in Colorado flow through alluvial material which were deposited in an erosion channel. These alluvial materials function as an unconfined aquifer which is hydraulically connected to the river. It is this interconnection of the stream and aquifer which complicates water administration or management decision. Pumping of ground water from the wells could impact stream flows and a change in how surface water has been historically used could change the rate and location of recharge to the aquifer which could impact the rate and timing of ground water return flows to the stream.

The pumping of wells could influence stream flows by actually lowering the water table below the stream so that water would flow from the stream into the aquifer. A more likely scenario is that well pumping, will intercept water which would have otherwise have flowed into the river as ground water return flows.

History books document that both the South Platte and Arkansas Rivers in Colorado flowed only intermittently prior to the development of irrigation. As a result of deep percolation from irrigation the ground water levels rose and the return flows caused the two rivers to become perennial streams. Ground water levels near Fort Morgan rose as much as 70 feet during the late 1800's.

The ground water observation well network data base maintained by Colorado State University, the U.S. Geologic Survey and the State Engineers office contains data which shows how the water levels fluctuate from year to year and seasonally. Specifically wells beneath the highest irrigation canals have their highest water levels in the fall at the end of the irrigation season showing the significant impact of deep percolation of irrigation water and canal leakage on the aquifer's recharge. In contrast wells located above the highest canal have their lowest water levels in the fall showing that pumping has exceeded natural recharge and water has been removed from storage.

The observation well network also showed significant rise in the ground water levels in the Boxelder Creek Alluvium northeast of Fort Collins, Colorado when the USBR Big Thompson Project started to deliver additional surface water to that area in the early 1950's. That area had experienced ground water level deadlines as wells were being installed to provide a supplemental supply for the insufficient surface canal flows used for irrigation. Following a period of rising ground water levels the levels have now stabilized at the prewell development level.

B. Bedrock Aquifer/Stream Impact - The Denver Basin aquifers are in hydraulic connection with the South Platte River and its tributaries. Robson (1987) studied these bedrock aquifers and concluded the steady state ground water outflow into the South Platte surface streams amounted to as much as 41 cubic feet per second, 30,000 acre feet per year. He further stated that due to pumping from the bedrock aquifer wells the water levels are declining and this has all ready reduced the return flows and they will be further reduced as the water levels in the bedrock aquifers decline further. Observation well data from the State Engineers Office, Romero (1989), show in the Arapahoe aquifer wells near the Denver Tech Center to be declining at a rate of 40 - 60 feet per year, at this time.

These declines in water levels are changing the historical ground water gradients. Not only has there been a reduction in the ground water outflow, but there has been a charge in direction and velocity of ground water flow. There is concern that the direction of flow of contaminated ground water beneath the Rocky Mountain Arsenal could change and begin to move toward centers of heavy pumping.

C. Idaho's Basalt Well Pumping - A large number of irrigation wells withdraw groundwater from the extensive basalt aquifers north and west of the Snake River from Idaho Falls downstream to Twin Falls. It is alleged that the pumping from those wells has lowered the ground water levels in the Basalt reducing the ground water gradients which has reduced the spring outflow which accounts for a large part of the Snake River flow downstream from Burley, Idaho.

D. Mississippi Well Pumping Dries Yazoo River - During recent years a large number of new irrigation wells have been drilled to provide water for rice irrigation in the Yazoo River Basin. This has lowered the ground water levels by as much as 100 feet and the result has been an almost total dry up of the Yazoo River during certain reaches during the peak pumping season.

E. Florida Pumping Impacts Lake Levels - Pumping in Florida from wells has lowered the ground water levels reducing ground water flow into some of the lakes resulting in falling lake levels. Extensive studies have been undertaken to obtain a better understanding of the hydrologic system and the ground/surface water interaction. Some regulation of well pumping has been implemented.

IV. Colorado Augmentation Plans Prevent Injury

Colorado experienced significant irrigation well development during the 1950's and early 1960's. Senior vested surface rights became concerned that well pumping was impacting their rights. The Colorado legislature passed the "Ground Water Management Act" in 1965 which required the State Engineer to evaluate each new well permit application to see if there was unappropriated water available and that there would not be injury to other rights. If he could not find that there was unappropriated water and non injury then the permit was denied. Between 1967 and 1969 further engineering studies were made which concluded that well pumping could deplete stream flows, but that if the stream could be compensated by an equal amount to the depletions, there wouldn't be injury to vested rights. The Colorado Legislature in 1969 passed what was known as the "Water Right Determination and Administration Act" which set up the provisions for court approval augmentation plans to allow junior wells to continue to pump when senior surface decrees would have been injured, absent the augmentation water. New appropriations were also allowed if they had a court decreed augmentation plan to prevent injury. Even depletions from pumping of Denver Basin bedrock Aquifer wells that are not nontributory must have an augmentation plan.

An augmentation plan will replace to a senior vested right, ground or surface water right, sufficient water in time, place and amount to prevent injury. The purpose of the court to decree such plans was to take testimony and include provisions to make sure injury would not occur. In most cases an extensive period of retained jurisdiction is included to assure the plan does in fact prevent injury.

V. Litigation

There has been and probably always will be extensive litigation concerning ground/surface water conflicts. These cases are usually very extensive and complex involving significant technical material, data, assumptions, computer modeling and expert witnesses with different opinions. The fact that groundwater hydrology is not an exact science and that it is difficult to observe or quantify "cause and effects" is responsible for litigation complexity.

Recent or ongoing cases in Colorado of major magnitude which involve ground/surface water conflicts include:

- U.S. Supreme Court Case - Kansas v. Colorado No. 105. Claim wells have decreased stateline stream flow.
- AWDI - Division III 86CW46 claim for nontributory water which was found to be tributary and well pumping would injure other rights.
- Castle Meadows - Division I - 92SA163, 89SA64, 86CW281. Case deals with need for augmentation water in order to pump not nontributory ground water.

A challenge for the 1990's would be to reduce litigation time and costs. Items to be considered include: collection and sharing of hydrologic and geologic data so that a stipulation on factual issues can be made, use of standerdized and documented groundwater models, agreement on how to model the ground and surface water systems with appropriate assumptions, agreement on what other water rights need to be evaluated for protection, how to treat wetlands, and minimum stream flow decrees, whether water quality should be considered and who does it impact, could the proposed new or amended water rights be administered and who should pay for any special provisions, should there be retained jurisdiction and for how long, who could re-open a case and for what grounds.

The more that can be resolved outside the courtroom there is greater likelihood that all parties will benefit in a more workable solution with reduced litigation costs. Extended complex water court trials significantly impact a courts trial docket.

VI Aquifer Recharge

The ground water aquifer received natural recharge as part of the hydrologic cycle. In addition the deep percolation of irrigation waters contributes significantly to many aquifers. One issue that is now becoming very important is the potential deteriation of ground water quality due to deep leaching of pesticides, herbicides, insecticides and fertilizers. The danger is there to transport soluble contaminates downward into the ground water. Extensive research is underway to demonstrate best agricultural management practices to minimize the chance of ground water contamination. Some water quality data indicates higher concentrations of nitrate in groundwater due to deep leaching of fertilizer however contamination from insecticides or herbicides is not well documented.

As a means to replenish depleted groundwater aquifers, artificial recharge using spreading basins, pits, ponds and wells is an accepted practice. Even water rights have been decreed recognizing artificial recharge and subsequent withdrawal as a beneficial use. There is need for more research and demonstration projects on artificial recharge facilities to develop needed economic and engineering data. This has become an accepted practice to store ground water in an aquifer where is can later be pumped and put to a beneficial use.

There are several unanswered questions concerning artificial recharge which must be addressed in the 1990's. They are: Must one be able to demonstrate dominion and control of artificial recharged ground water before being allowed to pump it back for later use? Who benefits from artificially recharged water and who should pay the cost? In whose name should a water right for artificially recharged water be sought? What type of public or private entities should be allowed to artificially recharge water and what powers should those agencies have? What precautions need to be taken to make sure that the aquifer is not contaminated with polluted recharge water? How can artificial recharge be included into an integrated ground and surface water management system?

There is one other term which is often used, "induced recharge". This term is sometimes included as a means of artificial recharge in that is generally is associated with ground water pumping which reduces the water in storage, changes the hydraulic gradient and causes surface water to enter the aquifer at a rate greater that what would have happened under natural conditions. An example would be well pumping which causes a cone of depression such that stream flow infiltrates out through the river bottom recharging the underlying aquifer.

VII Management and Operational Decisions

It is becoming more and more difficult to make good operating or management decisions. It requires the availability of good and adequate data to document the state of the complex hydrologic systems. Because of the magnitude of data and complexities of analyses it generally involves the use of computers and some type of numeric model. Good well trained staff with a through understanding of the hydrologic system, assumptions in the model, data limitations and overall management objective in mandatory.

Where both ground and surface water are available to supply a need it is often desirable to implement what is called conjunctive use. Use of both ground and surface water in a conjunctive use plan will often minimize water shortages and will provide a timely supply to meet expected needs at a reasonable cost. This concept is most applicable to area wide service or use areas with a variety of uses with varying types of water rights. Conservancy districts or management districts are the types of agencies which could coordinate both the surface and ground water uses coupled with artificial recharge so as to minimize water shortages and also reduce total project costs. For the person with the most senior surface water decree it does not make sense for him to consider conjunctive use unless he could benefit by having an extended water supply by pumping ground water where his surface right would normally be dry. Groundwater users have much to by gained by considering conjunctive use.

There are a number of new technologies for obtaining optional optimal operating decisions. The word optimal is often in the eye of the beholder and what is optimum for one person may not be optimum for another. The problem is how do you describe legal and economic constraints or objective functions. Optimization routines should be used sparingly to assure they are truly providing correct answers and they should be regularly reviewed to assure all the assumptions and objectives are still valid with time.

VIII. Water Quality Issues

A strict use of only ground water will generally result in a deterioration of ground water quality with time, because any consumptive use will leave the salts behind which will return to the aquifer as deep percolation or natural recharge. A salt balance must be calculated for each ground and surface water system and it is time to realize that decisions such as implementation of conservation measures can significantly impact both the quantity and quality of recharge water to an aquifer. Depending on how the aquifer may be connected to an adjacent stream system, then the impact of conservation could adversely affect the quantity and quality of surface stream flows. Some application or use of good quality surface water may be necessary to maintain a salt balance for the soil root zone, the underlying aquifer and the stream.

Every effort should be made to prevent contamination of both the aquifers and streams by excessive or inappropriate applications of fertilizer, insecticides or herbicides.

IX Summary

Ground/Surface water conflicts will continue and will probably intensify as man continues to develop and use our limited ground and surface water supplies. As we gain a better understanding and knowledge of our aquifers and how they are connected or respond to surface water usage, maybe management decision can be made within the physical and natural constraints so as to reduce or hopefully minimize litigation and conflict between users.

The water administration or management decision will become more complex requiring the availability of well trained and dependable people. Adequate data must be available to make the decisions and increased use of computers and models should be anticipated. Long range plans or objectives need to be developed and reviewed on a regular basis.

Water quality will become a bigger issue. Decision can no longer be made on quantity alone. The impact on changing historic practices must be evaluated because it might minimize water shortages, but completely change the water quality regime. Consideration of how to solve water quality issues as well as water quantity is not an insurmountable task, but it will add significantly to the complexity of management or operating decisions.

Bibliography

Robson, S.G. (1987) Bedrock Aquifers in the Denver Basin, Colorado - A Quantitative Water Resources Appraisal. U.S. Geological Survey Professional Paper 1257, 73p.

Romero, John C and Howard C. Bainbridge (1989) Water Levels in the Bedrock Aquifers of the Denver Basin, Colorado 1989. Office of the State Engineer Division of Water Resources, 21p.