USES AND MISUSES OF AQUIFER DATA AND MODELS

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Introduction

Many erroneous predictions have been made on the availability of groundwater. Errors have been made in both over-estimating water availability and grossly under-estimating the available supply. Dire predictions of saltwater intrusion have been made when, in fact, no such condition exists.

Aquifer models are often very unreliable in the hands of the inexperienced. Many hydrogeologists do not understand the variable nature of T and S, transmissivity and storativity, or the impact of aquifer boundary conditions.

Many engineers look at observation well hydrographs, making future projections without understanding all of the factors that influence water levels.

Public decisions regulating or restricting the use of groundwater must be based on extensive hydrologic study with due consideration to all input parameters, not fragmentary points of data that are unrelated. The appropriate data base includes estimates of total annual pumpage with corresponding water level measurements taken in a short period of time, over several years, and long-term water quality monitoring from wells of known condition. Even newly constructed wells can be drilled near old abandoned boreholes whose location was lost in time and give uncharacteristic data for the area.

Aquifer Yield

The yield available from a stream-connected aquifer may be grossly over estimated. The common assumption is that stream bed conductivity is a constant and will stay the same as initial test conditions. Fine sands and silt are induced into the river bed material by pumping activity, reducing the stream bed conductance or permeability. Often channel dams are constructed down-stream to increase the recharge head, but fine sand and silt drop out of the streamflow, further decreasing the river bed conductance which requires dredging to restore the well field yield.

In stream-connected aquifers, often the long-term streamflow characteristics are not properly evaluated. Annual streamflow is gradually decreasing throughout the country, especially in midwest and western states. Groundwater pumpage from stream-connected aquifers has eliminated the stream base flow or surplus groundwater discharge from natural precipitation. Further, agricultural soil conservation practices are reducing runoff from the frequent, low intensity storm systems. The construction of reservoirs and watershed structures store runoff and increase evaporation loss to the atmosphere. The consistency of streamflow from many of our rivers for water supply is now unreliable.

On the other side of this issue, the availability of groundwater can be underestimated. The initial decline in groundwater levels due to pumping are often very rapid, especially when total pumpage is increased. The decline in head or depression of water level is necessary to induce water flow through the aquifer system to the pumpage center. The rate of flow through the aquifer is a linear function in accordance with Darcy's Law.

However, an aquifer cannot be recharged until the water levels have declined, otherwise there is no storage capacity available. When large quantities of water are pumped from aquifers, such as exist in Hinds County, Mississippi, two things happen. One, the cone of depression may expand until leakage of water from the shallow overlying aquifer equals the average pumping rate. Second, the effective coefficient of storativity increases with drawdown, reducing the rate of water level decline. The drawdown trends observed for Hinds County (See Figure 1) and vicinity are normal to develop the leakage and recharge to support the area pumpage.

The U.S. Geological Survey conducted a regional aquifer system analysis (RASA) of the Gulf coast area, including Mississippi, in which the system was modelled using regional water level data, pumpage estimates, and aquifer test data. It was found that no major overdraft of the aquifers existed in the region and that pumpage and recharge were in equilibrium (Williams 1990). Increase in pumpage was capturing additional recharge and intercepting some of the discharge from the aquifers outcrop and subcrop areas.

Aquifers have tremendous yield potential from the storage of water in the pore space of unconsolidated geologic materials (silts, sands, and gravel). For example, in the Ogallala aquifer in southwestern Kansas during the 1960's, water levels declined 2 to 3 feet per year for many years. Both the number of wells pumping increased, as did the areal influence expand. In more recent years, irrigation pumpage has stabilized and the coefficient of storativity has increased with delayed drainage from aquifer storage. The result is that water levels decline less than 1 foot per year or even recover during years of above normal precipitation due to reduced pumpage.

The same scenario was observed for the Ogallala Aquifer in the 36,000 square mile area of the Texas High Plains in the panhandle of Texas. It was recently calculated that the aquifer contains 417 million acre feet of water in 1990. This volume is 32 million acre feet more than expected, based upon computer models operated by the Texas Water Development Board staff in Austin (Anon 1991).

In aquifers of large areal extent, when the specific yield of an aquifer reaches 15 percent, pumpage in excess of natural recharge can exist for many decades before serious dewatering occurs. In the case of the Las Vegas valley aquifer, by the 1940's, groundwater withdrawals exceeded the perennial yield (Morros and Katzer 1990). For the decade prior to 1971, the rate of decline ranged between 10-12 feet per year; since then the rate has slowed to about 2-3 feet per year with reduced pumpage from the basin. The storage component of an aquifer can support an over draft situation for 50 years and still maintain a viable water supply.

Water Quality

For fresh water to occur in an aquifer, there must be a source of recharge, an area or place of discharge, and a circulation of fluid through the system. The velocity of ground water movement may vary from a few feet per year to a few hundred feet per year under natural gradients.

The age of fresh groundwater varies with the recharge mechanism and circulation system. Age of water refers to the elapsed time water was precipitated from the atmosphere to being withdrawn from the aquifer and may vary from a few days to a few thousand years in most aquifers.

Since water is the universal solvent, its quality is influenced by the geological environment and local recharge circulation system. Waters of vastly differing quality characteristics can occur in different layers in the subsurface. In coastal areas, highly brackish or salt brine can occur at shallow depth with fresh water aquifers at deeper depths. This is due to differences of permeability of the formation and the water flow system from its recharge area.

Dire predictions of saltwater intrusion have been made along the Gulf Coast when in fact no such condition exists. About 10 years ago, the author was personally involved in the investigation of brackish water supply wells on Sanibel Island, Florida. The total dissolved mineral and chloride content has been increasing slowly in several of the wells. First impression of review of the water quality data would easily lead one to conclude that saltwater intrusion was occurring and was so reported by the other geologists. However, a more detailed investigation of the well construction and formation log revealed these wells were constructed by cable tool drilling equipment with no cement grout and penetrated an intermediate formation of low permeability containing brine of 50,000 mg/l TDS. The casing corrosion pattern was such that ever increasing amounts of this high TDS water was mixing with the aquifer water in the well casing and being pumped to the electrodialysis plant. This was a well casing failure problem, not saltwater intrusion.

A very similar situation was recently observed in Pascagoula where one well was pumping water from a formation with about 120 mg/l of chloride and a few hundred yards away another well from the same aquifer was pumping water with 500 mg/l of chlorides. The second well is experiencing casing failure through the shallow sand aquifer containing brackish tidal water. This second well should have a liner cement-grouted inside the present casing or be plugged and abandoned and a new replacement well drilled 50 to 100 feet away with a double casing grouted through the shallow brackish aquifers in this vicinity.

In another situation on an island along the Florida Panhandle, a municipal water supply well was drilled and tested and found to be of acceptable quality. After a few weeks of pumping, the chloride content exceeded 350 mg/l. After much fumbling around, an "old timer" remembered that an old 4-inch well used to exist about 300 yards from the well site. The abandoned well was finally located, drilled out, and properly plugged. Within days, the new well water quality returned to the background level of other wells from the same formation on the island. It is easy to jump to a false conclusion when there is insufficient investigation.

The pumping rate and induced chemical activity in a well can cause a change in water quality. Water enters the well bore at the beginning of turbulent flow from the aquifer opposite the termination of the pump suction or if located in the well casing, the pump energy is transmitted downward until dissipated by the formation permeability or it causes the pump to break suction. If a zone of high permeability exists in the upper part of the well, little or no water may be produced from the bottom aquifers open to the well (Nuzman 1989). If in time the flow from the highly permeable zone is reduced by calcification or bacteriological plugging, then a gradual shift of flow to the lower portion of the aquifer will occur. Should the lower portion of the well open to the aquifer be of higher salinity, a gradual increase in water salinity will be observed from the pump discharge. This phenomena was observed to have occurred in a well in the Fernandina Beach, Florida, area.

Aquifer Models

Aquifer models are often very unreliable in the hands of the inexperienced. One of the most difficult piece of data to obtain is a reliable water level or piezometric head map of an area for a given or known condition of pumping. Often, published water level maps are made from a composite of water level measurements made over a period of several years. Then pumpage must be estimated by some indirect method based on population living in the area or other methods. These data may be better than nothing but can be very misleading. In a regional aquifer simulation model, a great deal of time and money must be spent in getting representative data of permeability or transmissivity, water level or piezometric head data, and water quality for each aquifer layer present in the region. Consistency and reliability of aquifer data is required to correctly assess the perennial aquifer yield and impact of future pumpage.

Many hydrogeologists do not understand the variable nature of "T", the aquifer transmissivity. The coefficient of transmissivity obtained from a pumping test not only reflects the formation permeability but also may reflect well losses due to drilling problems, negative boundaries due to horizontal limits of the aquifer, leakage from overlying or underlying aquifers, and recharge from a surface water source. If one installs pairs of observation wells around the test well, the up-gradient wells usually give a lower than normal "T" value and the down-gradient observation wells a higher than normal "T" value due to the hydraulic gradient across the site.

Usually the time drawdown data collected in the first few hundred minutes of pumping best fit the theoretical assumptions upon which the evaluation is based. A review of those assumptions for the non-equilibrium equation or Theis formula follows:

1. The water-bearing formation is uniform in character and permeability in both horizontal and vertical directions,
2. The formation has uniform thickness,
3. The formation has infinite areal extent,
4. The formation receives no recharge from any source,
5. The formation has no hydraulic gradient,
6. The pumped well penetrates and receives water from the full thickness of the water-bearing formation and is 100 percent efficient, and
7. The water removed from storage is discharged instantaneously with lowering of the head. If, for example, recharge is occurring from a surface source, the pumping test transmissivity value may be twice the true value for the formation. If the aquifer is modelled and the recharge boundary is again impressed on the aquifer, the computed available yield may be more than twice the actual yield available from the aquifer.

One of the more difficult features to identify in a pumping test is leakage from an underlying or overlying aquifer. The leakage may be a direct function of the head differential and may not always be apparent in the drawdown data. The "T" value obtained overestimates the true value of the formation and model results may be overly optimistic.

Conversely, faults or shifts in the aquifer formation may develop a partial negative boundary that gives conservative values for "T". A model analysis may underestimate the perennial yield of the system.

Obviously, several aquifer tests need to be conducted in the same hydrogeologic unit to correctly assess the real value of transmissivity and formation permeability.

The coefficient of storativity in a model setting is a most difficult situation to handle. Based on the assumptions previously cited, the coefficient would be a constant. In actual practice, the coefficient of storativity may be a variable. Because of this feature, estimates of the average or apparent storativity must be made for model analysis. This phenomenon was first recognized by Hantush and Jacob in 1955 and later improved upon by Hantush (1964). About this same time, Boulton (1963) identified the typical sag in the time drawdown curve as delayed yield from storage. Curve fitting procedures were given to evaluate this leakage effect from aquifers.

The significance of the coefficient of storativity is that this value greatly affects the drawdown over time from the aquifer. Since this coefficient is essentially a variable, estimates of average value should be made for specific increments of time. For example, in a confined aquifer of tertiary sand or similar formation S = .0001 would be a reasonable value for the initial pumping for about 15% drawdown of the initial head above the aquifer. The value may then increase to S = .001 for the next 50% decline in head. S can increase to about S = .01 for the next 25% of the head decline above the top of the aquifer. At this point, the coefficient makes the transition to specific yield or that portion of the aquifer that will drain water by gravity flow. Specific yield for graded sands (of variable size particles) is approximately 0.15, or 15 percent of the aquifer mass, to 0.20 or more for a coarse gravel or uniform size sand particles. The effect of this phenomena is that as drawdown in an aquifer occurs, there is an ever increasing volume of water released from the internal storage component of the aquifer. Therefore, aquifers must be modelled in time drawdown segments to realistically predict the yield from aquifer storage. A water table aquifer, once dewatered, will assume a near constant value of specific yield for subsequent recharge and discharge cycles.

Well Hydrographs

Many engineers look at observation well hydrographs (see Figure 1) and make future projections without understanding all the factors that influence water levels. When a series of wells are examined in a regional area with a decline in water level of 80 to 100 feet over 50 years, the straight line projection assumes that increases in pumping rates will continue into the future in the same manner as the past. When average daily pumpage increased from less than 5 mgd to nearly 17 mgd in the past 50 years in the Hinds County planning area (Waggoner 1990), then pumpage should increase to 29 mgd average day by the year 2040 with an additional 80 to 100 feet of water level decline (linear projection). Water levels would still be well above the top of the Sparta formation at all observation points shown in the report. Should pumpage not increase due to water conservation efforts, then the increase in storage yield and leakage from overlying aquifers would show a leveling off trend approaching equilibrium with the system. If pumpage increased faster than the historical rate indicated (expotential projection), then the rate of decline would increase until pumpage stabilized at a new level.

Water level decline can occur rapidly in an area where wells are closely grouped and pumpage exceeds the transmission rate of flow of the aquifer. This phenomena has occurred in the Prattville, Alabama area where the city wells and an industrial plant's wells all pump from the same aquifer (Gordo) in close proximity. Interestingly, when drawdown reached the top of the aquifer, water level declines leveled off but less water could be pumped from the wells. The well construction used in the area with small diameter screens prevented further lowering of the pumps and the aquifer became self regulating. Additional groundwater supply was readily available from the aquifer with additional wells located 2 to 3 miles away from this pumping center.

Public Relations

Laws governing groundwater withdrawals have been adjusted to reflect the desire and need to prevent resource depletion and conflict among users. Courts today are inclined to regard groundwater more as a shared public resource that is subject to management and regulation than as private property with rights of unlimited use (Bowman 1990). State legislatures are passing comprehensive ground-water-management statutes to provide appropriate technical evaluation rather than relying on the Courts to settle disputes. Ground-water-management areas are one of a number of means of addressing groundwater supply problems and, in some cases, groundwater quality problems.

Public decisions regulating or restricting the use of groundwater should be based on extensive hydrologic study with due consideration to all input parameters, not fragmentary points of data that are unrelated. Inventory of all pumpage from each aquifer on an annual basis must be made. Non-pumping water levels in wells must be measured in a relative short period of time (1 week) at approximately the same time (usually in the winter) each year. The aquifer geologic deposition characteristics should then be correctly identified (aquifer transmissivity). This may require several pumping tests throughout the aquifer. Given the field distribution (transmissivity), the potential distribution, piezometric head or water level map for a specific condition of pumpage, then aquifer models can uniquely calculate the boundary flow conditions (aquifer recharge) for the hydrologic system. Calibrating the aquifer model to two or more historic known conditions provides a reliable tool to predict the effects of pumpage management and regulation.

Summary

In summary, appropriate regulations on well construction, well re-placement, pump setting standards, water use metering, regular water level measurements, and periodic water quality sampling are all necessary data elements needed for proper evaluation and management of groundwater source aquifers.

Appropriate management mechanisms that allow reasonable development and regulation of groundwater resources exist. Moreover, the technology to properly evaluate the perennial yield of groundwater basins exists. Some overdraft may be desirable to fully use the groundwater resource for beneficial purposes.

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