Water Management:

Making Sure Everyone Gets a 'Reasonable' Share

Several complementary strategies can be optimized to alleviate the enormous strain now placed on our nation's underground water supplies.

Richard C. Peralta

Effective strategies for managing water resources are becoming more and more important to reconcile competing uses for underground supplies. For engineers in agriculture, there is a desire to ensure the long-term availability of ground and surface water for agricultural areas. But today's strategies must also take into account the other uses for water within a region. In addition, it should be possible to accommodate change from one regional objective to another target condition.

Several different modelling techniques are helping to resolve these conflicting requirements. For example, one technique is proving effective in simulating groundwater use in Arkansas. Other analytical tools show considerable promise for optimizing regional strategies without unduly compromising local needs. Moreover, these techniques are gaining acceptance in planning studies conducted for both state and Federal agencies.

Basis for Concern

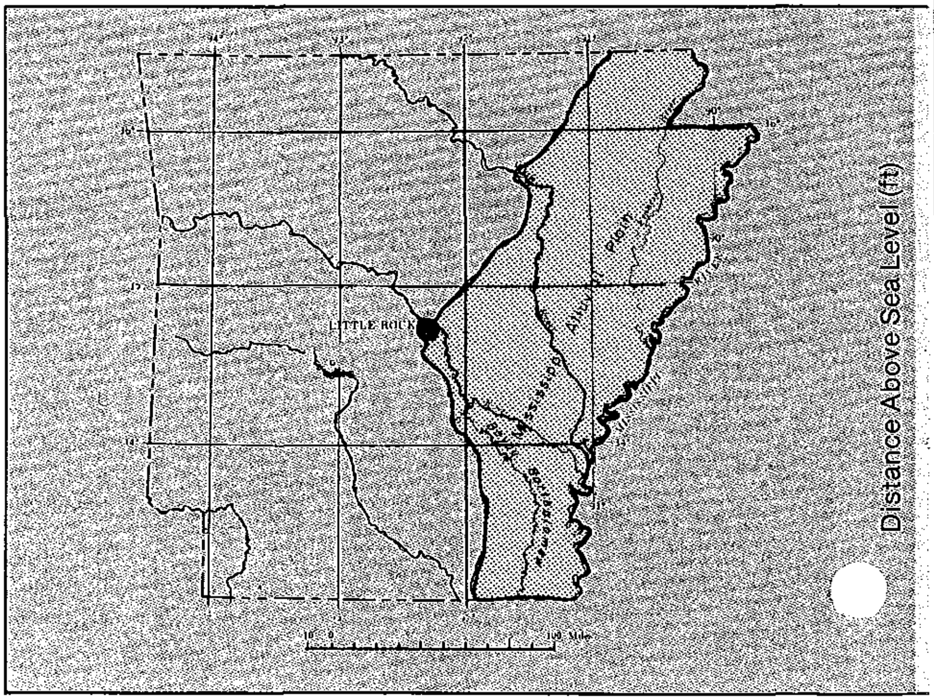
About 80% of the water consumed in Arkansas is pumped from underground water-bearing geologic formations called aquifers. In recent years, pumping by agriculture, industry, and municipalities has caused groundwater levels to reach an alarming point in some areas. Where the water level nears the base (or bottom) of an aquifer, the saturated thickness — distance between the water level and the aquifer's base — may become too thin to allow wells to yield their designed discharge volume.

Landowners in Arkansas are entitled to the reasonable use of groundwater pumped from aquifers underlying their property. However, no one is allowed to pump so much water that it deprives another landowner of his reasonable use. That's because pumping from one well causes a decline in water levels at other nearby wells. As a result, water users in areas with dangerously thinning saturated thicknesses may confront a dilemma whereby they must make one of three tough choices: 1. Reduce water use and production. 2. Procure an alternative source of water. 3. Continue to deplete the supply, becoming increasingly vulnerable to drought and risk successful litigation by injured groundwater users.

The long-term solution for the problem is to develop and implement water-use strategies that maintain an adequate saturated thickness while

Water Level Drop Poses Irrigation Threat

High-yielding aquifers underlie this 16,400 mi² study area in eastern Arkansas (map). Rice and soybean production in the area's northern part make extensive use of irrigation, prompting concern over long-term availability of groundwater. This concern is justified according to declining water levels (1981 vs '59 vs '39) in the Quaternary aquifer beneath Arkansas' Grand Prairie (graph). An increasingly thin "gap" between the water table and aquifer base in one location can mean dry pumping wells during the summer. Pumping also lowers the levels for nearby wells, making some landowners vulnerable to lawsuits. Therefore, optimal water-use strategies for this area seek to protect against drought and litigation, ensure groundwater availability, and sustain an irrigated agriculture.



ensuring the perennial availability of groundwater. This task can be difficult for areas where recharge to an aquifer cannot possibly replace current pumping rates from the aquifer. In such cases, the strategies may require the combined or coordinated use of groundwater and diverted surface water in order to maintain current production levels.

Strategies Take Shape

A groundwater pumping strategy that maintains groundwater levels at fairly constant levels over the long-term is called a sustained yield strategy. An advanced concept and methodology for developing a sustained yield strategy that maintains a predetermined regional set of groundwater levels (potentiometric surface) and satifies saturated thickness constraints is called the Target Level Approach (TLA).

The TLA is significant for two major reasons. First, a TLA computer model calculates a sustainable pumping strategy that will maintain specific levels. In contrast, traditional groundwater models predict the effect of known pumping rates on water levels.

Second, the TLA is a hydrologically and legally integrated approach to groundwater use that has potential for use in a large variety of environments. The approach is especially attractive for riparian rights/reasonable-use states like Arkansas because it can be implemented without making radical changes in the basic water-rights system.

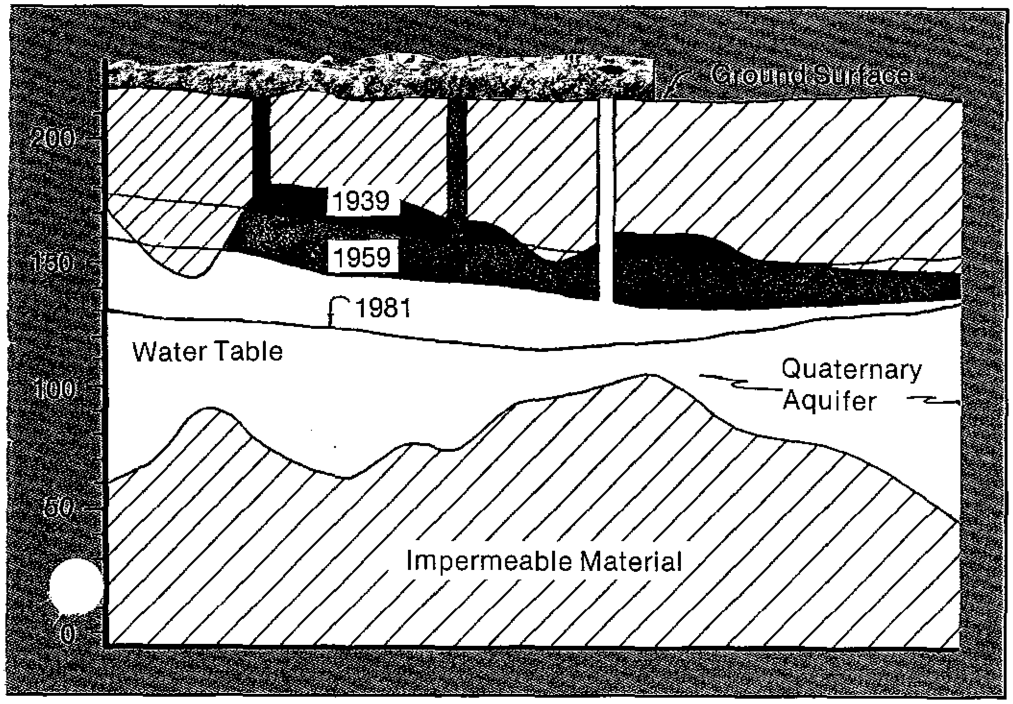
There are an infinite number of possible sustained yield strategies for any aquifer system. Moreover, each particular strategy will cause the evolution and maintenance of a different regional potentiometric surface.

Critical Choices

The question is naturally asked, "Which strategy and 'target' surface is most desirable?" A technique called the Target Objective Approach (TOA) addresses that issue. Basically, the TOA involves the development of sustained yield strategies and 'target surfaces' that maximize attainment of a particular predetermined regional policy within a framework of appropriate constraints.

The TOA is a management-oriented tool that allows an *a priori* analysis of alternative water management policies. It has been used to demonstrate that if all agricultural and industrial water users in the Grand Prairie were to reduce pumping by a common proportion in order to achieve a sustained yield, less the 20% of current pumping volume could be continued.

On the other hand, a more hydrologically sound sustained-yield pumping strategy has been designed that permits 50% of current pumping to continue. Most interestingly however, a strategy has been developed that will ensure a sustained yield and perennially satisfactory saturated thicknesses in all parts of the region, and will replace all but about 10% of current groundwater use by a combination of groundwater and diverted river water.



Analytical Techniques

To date, several computer simulation/optimization models have been developed for both the TLA and TOA at the Water Resources Management Laboratory, which is affiliated with the agricultural engineering department at the University of Arkansas.

For the TLA, these models combine the use of linear or quadratic goal programming techniques with embedded equations describing porous media flow.

TOA models, also containing embedded flow equations, have been devised that use linear optimization to determine maximum feasible sustainable groundwater pumping. In addition, these models can either minimize unsatisfied demand or minimize the common proportion that all water users would need to reduce their current pumping in situations where recharge cannot keep pace with current demand.

Quadratic TOA models minimize the cost of attempting to satisfy current water demand from combined water supplies and simultaneously accomplish multi-objective optimization. These models have proved useful in evaluating the water supply problem of the Grand Prairie area and the Boeuf-Tensas Basin in Arkansas.

Finetuning the Results

Several valuable methodologies have been developed to ensure that individual water users are affected as favorably as possible under optimal regional strategies. For example, Target Modification Methods (TMM) permit refinement of a regionally optimal strategy to better satisfy local (or quarter-township-sized) needs. This capability stems from TMM provisions for interactive modification of optimal linear or quadratic strategies, modification of a strategy to constrain contaminant movement in groundwater, and for selection of a compromise strategy from a pareto optimum of conflicting objectives.

In addition, dynamic Target Attainment Methods (TAM) and Optimal Mining Methods (OMM) have been developed to enhance water-use strategies. Both methods are based on using embedded porous media flow equations, linearized influence coefficients describing the dynamic effect of pumping on transient water levels, and optimization techniques.

The chief aim of TAM is to create regional strategies that maximize the evolution of a particular 'target' potentiometric surface within a specific planning period. Alternatively, OMM is used to create strategies that maximize either the volume of groundwater that can be mined (pumped without being replaced by recharge), or maximize the net economic return to be derived from such mining.

Multi-Tool Approach

Altogether, a comprehensive group of tools has been developed to aid in the systematic planning and evaluation of policies for using regional water resources. Th techniques are applicable for many regions where the coordinated use of groundwater and surface water is desirable. They are currently being used in developing strategies that best assure the sustained availability of water for users in two multi-county regions in Arkansas. ■

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Techniques on Tap for Shaping Water Strategies

Various mathematical and graphic techniques help to optimize regional strategies for groundwater use. For example, an area-wide grid clarifies potential conflict between regional objectives and local needs. Topographical fluctuations within cells provide decision variables when working out compromises that accommodate water-user needs on a quarter-township basis. Other techniques are employed to reconcile differing regional water objectives (Z). In this case, several utility (U) functions are assigned in a procedure that yields a "best compromise solution." An overall strategy thus reflects a combination of hydrologic constraints, social/economic values, and adminstrative rules and laws.