Arkansas Groundwater Management Via Target Levels

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ABSTRACT

AN approach to groundwater management by maintaining "target" groundwater elevations is presented. A finite difference form of the Boussinesq equation is proposed as a means of determining the groundwater withdrawals that will maintain those levels in the long term. This spatially distributed pumping can represent a sustained yielding pumping strategy. A sample pumping strategy is presented for the Arkansas Grand Prairie. Such a strategy is applicable under a variety of legal systems. It represents an especially attractive alternative for riparian rights states (like Arkansas) where effective groundwater management without radical changes in the basic water rights system is desired.

INTRODUCTION

Large scale water management systems and problems are complex. Successful management of such systems requires that both physical and legal constraints be satisfied. As many engineers, legislators, judges, attorneys and administrators can testify, this is not easy. Management is especially difficult for groundwater because it is an obscure resource. The development of laws governing groundwater has often preceded a technical understanding of its movement. As a result, and possibly because a detailed description has not historically been available for most aquifers, the legal right to use groundwater frequently has had little relation to the ability of an aquifer to provide that water in the long term. In some "water-rich" states, the abundance of water has created a reluctance to formulate solutions to water quantity problems (as distinct from water quality issues). Nevertheless, as increased use has made it obvious that groundwater is a limited resource, various efforts to secure its future availability are being made. This paper represents a physically and legally integrated approach to groundwater management in Arkansas, a riparian rights/reasonable use state.

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Groundwater is the source of about 80% of water consumptively used in Arkansas (Holland and Ludwig, 1981). Significant groundwater pumping is concentrated in areas of agricultural and industrial production. In this paper "pumping" refers to groundwater withdrawals. In some of these areas, average annual withdrawal from the aquifer exceeds recharge. As a result of this mining, groundwater levels are dropping. This drop in the groundwater level can accelerate salt water intrusion in an aquifer, cause aquifer compaction, or make irrigation economically unfeasible and disrupt an economy dependent on groundwater. Generally, these problems can be prevented or limited by maintaining groundwater levels at appropriate elevations.

Once target groundwater levels are determined, the question is, how can they be maintained? Maintaining groundwater levels requires that, on the long term, as much water enters the aquifer, and each part of it, as leaves it. The term "sustained yield" refers to a volume of annual withdrawal which is on the average balanced by an equivalent volume of annual recharge. The spatially distributed pattern of pumping that will maintain specific groundwater levels can be referred to as a sustained yield pumping strategy. The first objective of this paper is to present a simple approach for developing a sustained yield pumping strategy. To accomplish this, the Arkansas Grand Prairie is used as an example. Groundwater levels in the Prairie in 1982 are used as hypothetical target levels and the pumping strategy that will maintain those levels is presented. In practice, such information is useful for estimating where and how much supplemental surface water may be needed to meet water requirements. The second objective is to address the legal feasibility of using a sustained yield pumping strategy to maintain target groundwater levels. A review and analysis of pertinent water law is followed by an examination of the possibility of utilizing the target level approach in Arkansas with minimal legal changes.

DEVELOPING A SUSTAINED YIELD PUMPING STRATEGY TO MAINTAIN TARGET LEVELS

Introduction and Background

Traditional quantitative groundwater models are used to predict the water levels that result from known or estimated groundwater withdrawals. They are not designed to determine the groundwater pumping that will maintain preselected target levels. Another modeling approach is needed to calculate the pumping values which will maintain those levels. To paraphrase Hall and Dracup (1970), models should be **conceptualizations** of actual systems which have the **essential features** or characteristics of the system, **for specific purposes.** The

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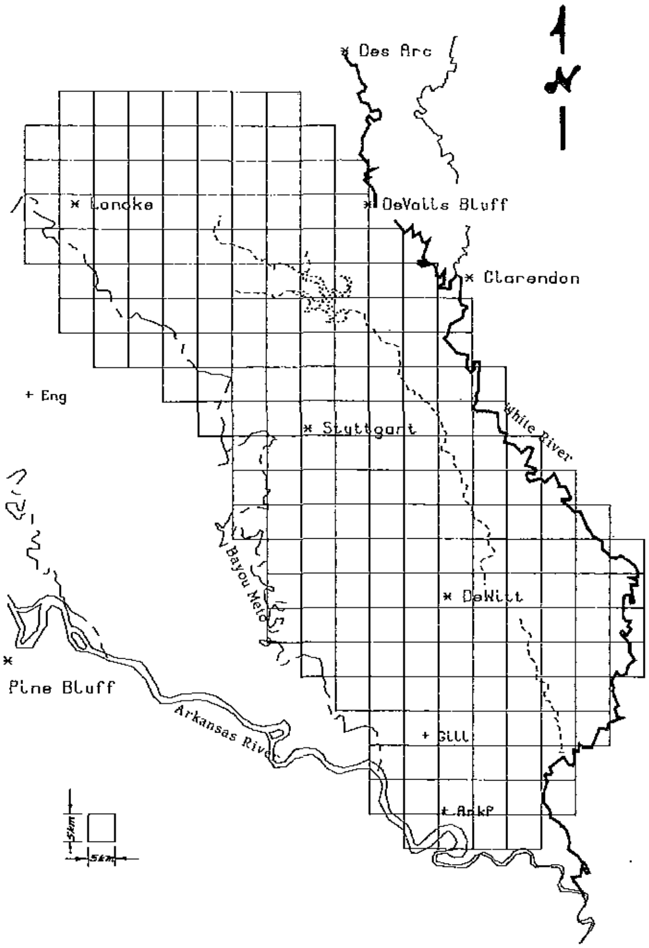

Fig. 1—The Arkansas Grand Prairie (Griffis, 1972).

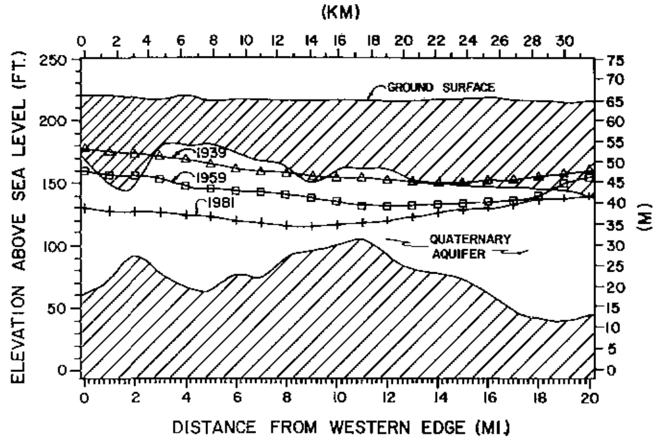

Fig. 2—Groundwater level changes in a West-East cross-section of the Grand Prairie.

approach presented is designed to develop sustained yield pumping strategies that will maintain target groundwater levels. Its application is demonstrated for the Grand Prairie.

The Grand Prairie is in that portion of eastern Arkansas lying within the Gulf Coastal Plain. It and much of the plain are underlain by an extensive Quaternary aquifer. The study area in this paper (Fig. 1) encompasses most of the Grand Prairie and corresponds closely to the borders of a newly formed irrigation district. Project and computer limitations prevented a much larger area from being included in the study. A relatively impermeable clay layer overlies the aquifer in most of the area. The volume of percolation moving from the ground surface into the aquifer is thought to be very small (Engler et al., 1945), and no streams penetrate to the aquifer in the interior of the study area. Simulation based upon 1915 (pre-development) water levels indicated that it is best to assume no deep percolation for the area's interior. The study area is bounded by the White River on the east, the Arkansas River on the south and a bayou on the west. Along these borders, only the White River is thought to penetrate to the aquifer at some locations (Engler et al., 1945). Thus recharge to the aquifer within the study area comes primarily from parts of the aquifer outside the area. Fig. 2 shows a west-east cross section of the study area near its center and the potentiometric surfaces which existed in the spring of 1939, 1959, 1981. The top line is the ground surface and the clear area in the center is the Quaternary aquifer. Shaded areas are idealized representations of relatively impermeable clay layers. In its natural state the aquifer was probably confined throughout the area. Extensive pumping however, has made the central portion completely unconfined and saturated thicknesses are alarmingly thin.

Griffis (1972) successfully calibrated a digital model of the Quaternary aquifer and predicted the effect on groundwater levels of recharging by injection wells. Estimates of aquifer characteristics similar to those utilized by Griffis were used in validating a different simulation model (AQUISIM) for the area (Verdin et al., 1981; Peralta et al., 1983). In that study the area was divided into cells which were 5 km by 5 km (3 miles by 3 miles) in size. Developing a sustained yield pumping strategy for the area involves calculating the volume of groundwater which can be pumped out of each cell during a specified time period without causing resulting groundwater levels to be below target elevations. Because groundwater levels in the Grand Prairie are measured by the U.S. Geological Survey every spring, a time period of one year was considered most practical. The ideal goal of a sustained yield pumping strategy is for water levels to return to the target elevations each spring.

Since the described approach is based upon the use of target water levels, constant head cells are used on the study area's periphery. Naturally, the rivers and groundwater levels which actually exist in these cells vary in elevation every spring and throughout the year, and would do so without any pumping whatsoever. No information is available concerning the degree of stream-aquifer connection along the borders of the study area. For this reason, groundwater levels are used as the basis for constant head cell elevations. Validation with AQUISIM verified that the use of 10-year average groundwater elevations for the constant head cells was satisfactory for predicting water levels in the area for at least ten years into the future (Peralta et al., 1983). In summary, for purposes of this paper, the study area is treated as a groundwater system, rather than as a stream-aquifer system.

Theory

In a water management scenario, target water levels are relatively fixed from year to year (except as changing goals or management techniques require). Therefore, the simplest means of linking them with pumping rates is with a steady state equation. Fig. 3 shows a cross section

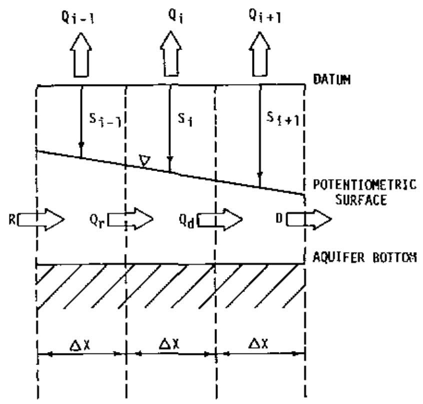

Fig. 3—Cross-Section of a three-cell groundwater flow system.

of a three-cell system. R and D are respectively the horizontal recharge and discharge between the system and the surrounding aquifer. Q_r and Q_d, respectively, are the horizontal recharge and discharge between cell i and adjacent cells. Q_{i-1}, Q_i and Q_{i+1} represent the net volumes being withdrawn from the three cells during the time period. Each is the sum of all vertical discharge and recharge to the aquifer for each cell. The drawdowns, S_{i-1}, S_i and S_{i+1}, are the distances from a datum to the groundwater level in the center of each cell. As long as the volume entering the system (R) equals the volume leaving the system ($D + Q_{i-1} + Q_i + Q_{i+1}$) during the period, the drawdowns will not change. Similarly, for cell i, as long as $Q_r = Q_d + Q_i$, S_i will not change.

Darcy's law has long been used in evaluating flow in porous media. It may be used to calculate Q_r. Assuming that each cell is square (Δx by Δx in size):

$$Q_r = T_{i-1/2}\,(S_i - S_{i-1}) \quad\ldots\ldots\ldots\ldots [1]$$

where

Q_r is the recharge to cell i from an upgradiant cell, L^3/T

$T_{i-1/2}$ is the geometric mean intercell transmissivity between cell i-1 and cell i, L^2/T, calculated by $\sqrt{(T_{i-1})(T_i)}$.

S_i is the drawdown from a datum in the center of cell i, L

The transmissivity of each cell is the product of the hydraulic conductivity and the saturated thickness at the center of the cell. The saturated thickness is the distance between the bottom of the aquifer and either the top of the aquifer or the water table for confined and unconfined cells, respectively.

Since $Q_i = Q_r - Q_d$, it follows that:

$$Q_i = T_{i-1/2}(S_i - S_{i-1}) - T_{i+1/2}\,(S_{i+1} - S_i) \quad\ldots\ldots\ldots\ldots [2]$$

Using the same approach in two dimensions, the steady state net pumping for any cell (i,j) is:

$$Q^{ss}{}_{i,j} = -\,T_{i-1/2,j}\,S_{i-1,j} - T_{i+1/2,j}\,S_{i+1,j}$$
$$+\,[T_{i-1/2,j} + T_{i+1/2,j} + T_{i,j-1/2} + T_{i,j+1/2}]\,S_{i,j}$$
$$-\,T_{i,j-1/2}\,S_{i,j-1} - T_{i,j+1/2}\,S_{i,j+1} \quad\ldots\ldots\ldots\ldots [3]$$

where

$Q^{ss}{}_{i,j}$ = the steady state pumping rate for cell i,j, L^3/T

$T_{i-1/2,j}$ = the intercell transmissivity between cell (i,j) and cell (i+1,j), $= \sqrt{[(T_{i,j})(T_{i+1,j})]}$, L^2/T

$T_{i,j+1/2}$ = the intercell transmissivity between cell (i,j) and cell (i,j+1), $= \sqrt{[(T_{i,j})(T_{i,j+1})]}$, L^2/T

$S_{i,j}$ = the drawdown in cell (i,j), L

The same equation was previously derived from the linearized Boussinesq equation for steady state conditions (Illangasekare and Morel-Seytoux, 1980). For consistency their terminology and means of estimating intercell transmissivity were adopted. They used the equation as part of an innovative technique of reinitializing groundwater simulation and reducing computer storage requirements (Morel-Soytoux et al., 1982; Verdin et al., 1981). In that application there was no need for constraining the magnitude or sign of the resulting pumping values. As a result, they were artificial values and did not represent sustained yield pumping values.

Groundwater levels are generally monitored in randomly spaced observation wells. Gridded estimates of observed groundwater elevations are obtained from the random data by either hand or automated interpolation. Universal punctual kriging is a commonly used automated method of preparing gridded elevations from random observations because it retains the observed value at an observation point and because it provides a standard error of the estimate for each gridded value (Delhomme, 1978; Sophocleous, 1983). Numerous sets of observed spring water levels in the Grand Prairie have been kriged to provide gridded estimates of groundwater levels. Experience has shown that when these levels provide the basis for estimating a steady-state pumping value by using equation [3] the pumping is somewhat unrealistic. Negative pumping (recharge) will sometimes be calculated for cells where no recharge can be occurring. This occurs generally where a cell's kriged groundwater elevation represents a localized high. The occurrence of a high is a result of several characteristics of the data. The randomness of the initial observation points is one factor. Another factor is that punctual kriging treats the observed values as if they were accurate. In reality, they are not accurate because the water levels were obtained by subtracting the distance between the potentiometric surface and the ground surface from the ground elevation, which was estimated from topographic maps. As a result of these factors, the standard error of the estimate of the gridded groundwater elevations in the Grand Prairie varies generally between 4 and 11 ft.

A computer program (TARGET2) was developed to create realistic target levels and their attendant pumping strategies for the Grand Prairie. The program requires a global estimate of hydraulic conductivity. As input, the program accepts for each cell: the gridded groundwater elevations, the elevation of the top and bottom of the aquifer, the minimum desirable saturated thickness and the minimum and maximum desirable pumping volumes. For cells at which no recharge can physically occur, the minimum pumping volume is zero. For purposes of this paper, a realistic upper limit on pumping is the current volume being pumped in the cell.

The program begins by using equation [3] to determine the recharge needed at each constant head cell to maintain gridded water levels precisely as they are input. The calculated recharge value is used as a default upper limit on recharge at the particular constant head cell. This constraint can be relaxed or tightened by a user-specified volume or separately specified if sufficient hydrogeologic information is available to make that determination. Beginning at either the northwest or the southeast corner of the area, the program then compares each cell's water level and steady state pumping volume with the present limits. If necessary, its water level is lowered (and transmissivity recalculated) until the selected criteria are satisfied. The solution is of course limited by Darcy's Law and the fact that the total discharge from all cells cannot exceed the sum of the **maximum** recharge for all constant head cells. The mathematical formulation assures that the sum of the positive pumping values (discharges) equals the sum of the negative values (recharges).

The approach is a simple one, with obvious limitations. Two conditions must be met for the steady state pumping strategy which it calculates to be a sustained yield pumping strategy. The first condition is that recharge which is calculated for a constant head cell must be physically feasible. In other words, sufficient water must **be available** to enter that cell from outside the study area's aquifer and the water must **be able** to enter the aquifer when the groundwater level in the constant head cell is at its specified elevation. Constant head cells receive recharge from outside the system in two ways. The first is by seepage from a river or surface water body. To estimate this movement of water from the surface water resource to the aquifer requires specific hydrogeologic information or field data. If this is available, the physical feasibility of the recharge calculated in the pumping strategy can be judged. Constant head cells can also receive water by movement from the aquifer outside the study area. Darcy's law can be used to evaluate the physical feasibility of the recharge required by the pumping strategy. This requires predicting water levels and flow patterns outside the study area. In some cases accurate prediction requires that a groundwater management strategy exist for an entire aquifer system. A realistic alternative to having one strategy for the whole area is to coordinate the pumping strategies of adjacent areas.

The second condition that must be met arises because the steady state pumping strategy assumes steady flow and pumping throughout the year. This is obviously not the case. Water needs are not constant. Groundwater pumping is neither continuous nor uniformly distributed in time. The major portion is pumped during the summer. The cessation of pumping and continuation of recharge during the fall and winter must occur in such a way as to allow water levels to regain their initial elevations by spring. The degree to which the actual temporal distribution of pumping affects the resulting water levels must be determined for each situation. Verifying that a particular pumping strategy will not cause unexpected results requires the use of a dynamic simulation model.

Development of a Hypothetical Pumping Strategy

An arbitrary management objective was used to demonstrate how a pumping strategy can be developed. Assume that the goal was to maintain groundwater levels as they were in the Grand Prairie in the spring of 1982. In that year observations were made in about 150 randomly distributed wells in the Grand Prairie. Universal kriging was used to interpolate and estimate the water level at the center of each cell from the observed elevations. These represented the input water levels to TARGET2. The aquifer was assumed to be homogeneous and isotropic. Based on previous work by Engler, et al. (1945), Sniegocki (1964), Griffis (1972) and Peralta, et al. (1983), a hydraulic conductivity of 270 ft/day was assumed. Recharge in constant head cells was limited to that calculated by the input levels, except in a few cells with possible stream-aquifer connection. The upper limit on pumping from any internal cell was set equal to current pumping in that cell. The resulting target levels are shown in Fig. 4. On a cell by cell basis, the difference between the target elevations and the input elevations is less than the standard error of the estimate of the input levels. In other words, the target levels are about the same as the input levels, with their pumping strategy being physically realistic. The pumping strategy is displayed in Fig. 5. Negative values represent recharge, positive values represent withdrawal. Each of these is a net value, i.e. the sum of all discharges and recharges.

Examining the contour lines in Fig. 4 lead one to expect groundwater to move from the periphery to the central portion of the study area. The positive values for southeastern boundary cells in Fig. 5 indicate that some water is discharging at that location. The second cell from the top of the left hand column in Fig. 5 also has a positive value. This is the result of the steep slope of the groundwater level between this cell and the one north of

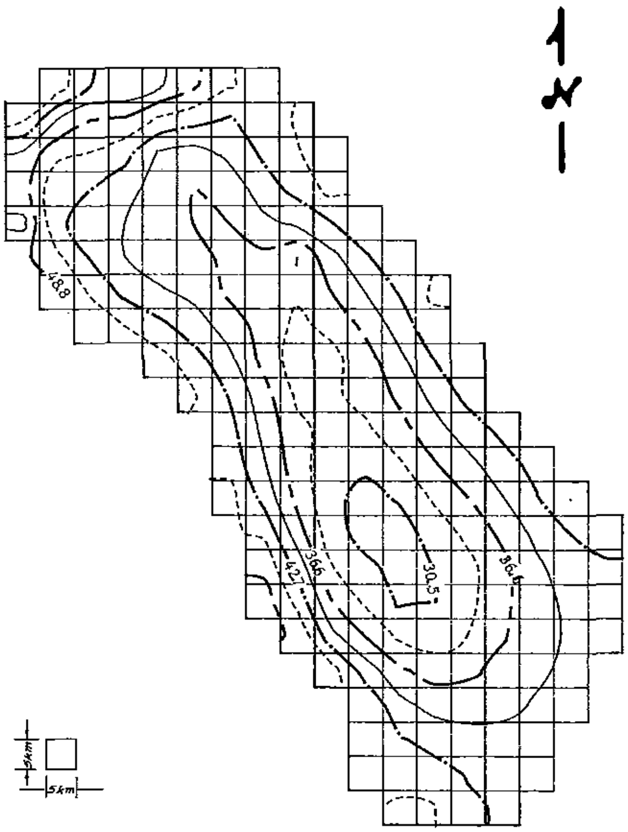

Fig. 4—Target groundwater levels based on Spring 1982 water levels (m above sea level).

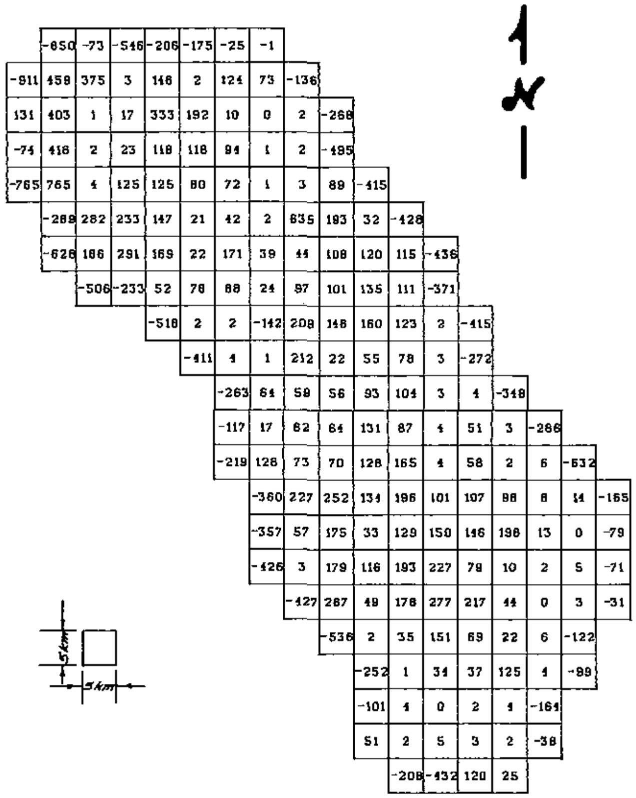

Fig. 5—Sustained yield pumping volumes which will maintain the target elevations (ha-m/yr/25 km^2).

it, which in turn is primarily the result of extensive pumping for aquaculture. Fig. 5 shows that water must be pumped from that cell for it to maintain its groundwater level in relation to its neighbors.

The values in Fig. 5 represent a sustained yield pumping strategy as long as the two previously mentioned conditions are met. Absolute verification of the physical feasibility of the recharge to each constant head cell is beyond the scope of this paper but, simple analysis was made of the entire area. The sum of all values in constant head cells is approximately 14,800 ha-m (120,000 ac-ft). This is an estimate of the net volume of recharge to the study area's aquifer, at the constant head cells, needed to maintain target levels. Engler, et al (1945) used a volumetric balance approach to estimate an average annual recharge rate of 16,900 ha-m (137,000 ac-ft) between 1929 and 1943, a period of dropping groundwater levels. As water levels in the center of the Prairie have continued to drop, and the steepness of the gradient has increased, annual recharge rates have exceeded 16,900 ha-m. It is probable then, that the annual rate of 14,800 ha-m is sustainable over the long term. It is recognized however, that this is dependent upon the continued maintenance of the selected constant head cell elevations by the regional groundwater flow pattern.

Dynamic simulation required estimating what percent of each cell's annual pumping volume could realistically be used in each month. Reference was made to the results of daily water balance simulation and irrigation scheduling, which had been performed for rice and soybeans using fifteen seasons of daily climatological data (Peralta and Dutram, 1982). Monthly irrigation requirements were calculated as a percentage of annual needs. Similarly, monthly values of water use per aquacultural acre and for each municipality were estimated as percentages of annual use. Based on the types of **users** of waters in a particular cell, the percentage of the annual water use which would occur in the cell, in each month, was estimated. This composite percentage varied from cell to cell and from month to month. These percentages were used to divide the annual sustained yield pumping values for each cell into twelve unequal monthly pumping volumes (April to March). For any cell, the sum of its twelve monthly values is its annual sustained yield pumping value. The group of twelve pumping volumes for each cell were duplicated ten times to create hypothetical pumping data for 120 consecutive months of simulation. Other input data were created as follows. The initial water levels were the same as the target levels and transmissivities were the same as those used in the steady-state formulation. An effective porosity of 0.3 was assumed (Engler et al, 1945; Sniegocki, 1964; Griffis, 1972; Peralta et al, 1983) for the dynamic simulation. One hundred and twenty consecutive months of response to the hypothetical pumping were simulated beginning in April and ending in March, using the AQUISIM model (Verdin et al, 1982).

After 120 months of simulation, the greatest difference between target and simulated groundwater elevations was 0.2 m (0.6 ft). This occurred in a cell with aquacultural water use. Aquacultural water demand is high in late winter and one would not expect water levels in such cells to have returned to target levels by the end of March. In almost all other cells, the difference between simulated and target water levels were less than 0.1 m (0.4 ft). The very small difference between target and simulated values are comparable to those which have been obtained in other unpublished tests of this method on hypothetical situations. Fig. 6 shows the differences between target and simulated water levels which occurred in August, after 113 months. This month, immediately following the irrigation season, displays the greatest difference between simulated and target levels. Even then, the average elevation in the worst cell is within 0.3 m (1.1 ft) of the target elevation.

In summary, the pumping strategy shown in Fig. 5 can be assumed to be a sustained yield pumping strategy. There are many possible sustained yield pumping strategies and sets of target levels for any study area. Target levels and their pumping strategies have also been designed to more uniformly meet water needs over the entire area and to assure that a minimum acceptable saturated thickness exists. A current effort involves determining the spring target levels that will insure that sufficient saturated thicknesses exists even during droughty growing seasons when all or most water needs may need to be met by groundwater.

Depending on how target levels differ from current levels, a number of years of management might be required for actual water levels to evolve to target levels. During that period, during the sustained yield era, and during a period of recovery from drought, pumping in some cells would be less than present pumping. To insure the continued availability of sufficient water to meet water requirements, surface water would need to be diverted to those areas. Fortunately, in the case of the Grand Prairie, preliminary indications are that adequate surface water resources exist nearby to provide the

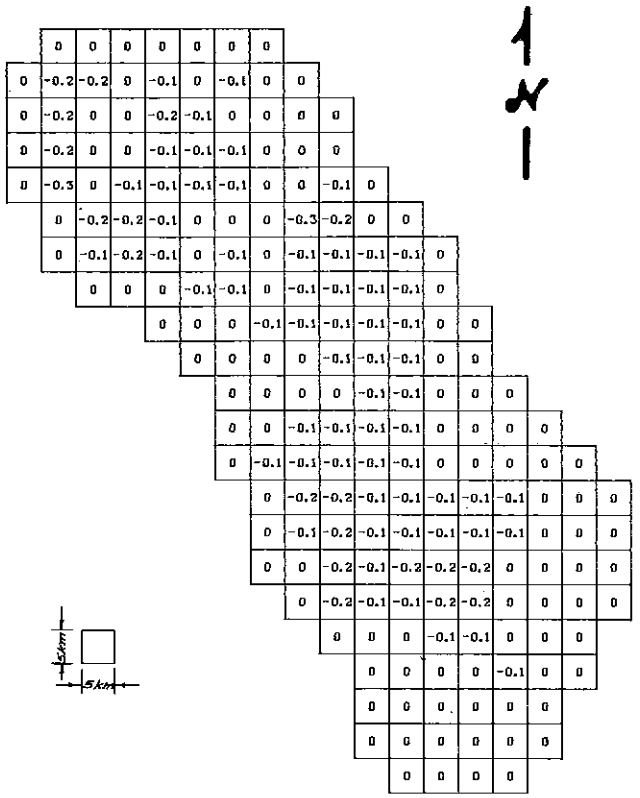

Fig. 6—Simulated - target elevations in August, after 113 months (m).

required supplemental water (Peralta and Dutram, 1982).

GROUNDWATER MANAGEMENT AND REASONABLE USE

Arkansas Water Law

No matter how equitable and efficient a particular engineering solution to a problem may be, legal constraints must be considered. A detailed discussion of the legal feasibility of implementing the target level approach in Arkansas is presented elsewhere (Peralta and Peralta, 1984) and is beyond the scope of this paper. A brief overview of pertinent Arkansas water law is presented to facilitate evaluation of the legality of the approach by water managers in other states and countries.

As is true in most of the humid Eastern states, Arkansas water rights are based on the old English common law(1)* and have been defined on a case by case basis (Peralta, A., 1982). Under the common law, the right to use surface water is incident to ownership of "riparian" land—land abutting surface water—and is an actual part and parcel of the soil.(2) Likewise, the right to use groundwater is incident to ownership of land overlying groundwater. Riparian rights are usufructuary, rights to use the water, not actual ownership (Hutchins, 1974), but are protected by constitutional due process like other property rights.(3)

The "reasonable use rule" applies to both surface and groundwater use in Arkansas.(4) Riparian or overlying owners share a coequal right (with other similarly situated riparian or overlying owners) to make reasonable use of the water as long as such use does not unreasonably interfere with the rights of others.(5) The Arkansas Supreme Court has ruled that "no proprietor has priority in use of water in derogation of another's rights."(6) Protection from "unreasonable use" extends to quality as well as quantity.(7)

An owner of land overlying groundwater in Arkansas has the right to use the water to the "full extent of his needs if the common supply is sufficient, and to the extent of a reasonable share of thereof, if the supply is so scant that the use by one will affect the supply of other overlying users."(8) In times of scarcity, the California correlative rights doctrine governs, allowing each overlying landowner a proportionate or pro-rated share of the available supply.(9)

The court has ruled that among riparians, domestic users have precedence.(10) Arkansas statutory law delineates priority of use during times of scarcity as: (a) sustaining life; (b) maintaining health; and (c) increasing wealth.(11) In harmony with the law governing surface water use, the Arkansas Supreme Court has considered industrial use of groundwater which halted domestic use "unreasonable."(12) Agriculture, like industry, must yield to the priority given to domestic use. As groundwater levels decline, large nondomestic water users become increasingly vulnerable to successful litigation.

The Arkansas Supreme Court has stated that unreasonable use is "largely a matter of the discretion of the court after an evaluation of the conflicting interests of each of the contestants before the court."(13) The court considers such factors as the purpose, extent, duration, and necessity of use, the nature and size of the water supply, the extent of injury versus the benefit accrued from pumping and any other factors that come to the attention of the court.(14) Two alternatives for dealing with "unreasonable" users have been recognized: (a) restraining further use; or (b) ordering payment to extend the affected well(s) to a greater depth.(15)

The concept of reasonable use is evolving as the court addresses more complex water problems. The court recently reversed a previous restriction requiring overlying owners to use water only on overlying lands. The court rules that a city could legally buy land, drill wells, remove the water to a distant point, and sell it to its customers.(16)

Reasonable Use and the Target Level Approach

The use of target levels by the appropriate state agency or water management district to achieve or maintain a safe sustained yield is not incompatible with the reasonable use/correlative rights doctrine which regulates groundwater use in Arkansas. The reasonable use/correlative rights doctrine takes into consideration the amount of pumping compatible with protection against "unreasonable use." Pumping that interferes with domestic use, for example, has consistently been ruled to be "unreasonable." From that point of view, the courts already employ an informal sort of "target level" approach to determine the reasonableness of disputed water uses. The logical extension of the court's reasoning in this example is the formal recognition of target levels (by whatever name) protecting domestic use. The use of either informally determined or formally established target levels in future decisions is likely as the court applies the correlative rights doctrine of shared reductions to resolve the inevitable conflicts over water

*Numbers in parenthesis as superscripts refer to appended list of cases.

from aquifers being depleted by mining.

The court's decision to weigh the "extent of injury versus the benefit accrued from the pumping"[17] lends itself well to the designation of appropriate target levels (as needed) by the governing water management agency. Such levels are established to protect existing rights by: reducing the incidence of injury and assuring the continued availability of the resource for beneficial use. Users complying with a prescribed target level strategy should enjoy a degree of protection from successful litigation over water use.

Political realities in Arkansas make the availability of supplemental surface water essential. Any plan calling for reduced use of groundwater by some water users must provide for adequate surface water to meet needs. There is presently no specific case approving nonriparian use of surface water. However, the rules governing municipalities and the meshing of ground and surface water laws set some precedent for approving such use under special circumstances.

First, Arkansas municipalities currently transport and distribute both surface and groundwater to nonriparian and nonoverlying domestic and industrial users. Distribution of supplemental surface water to agricultural and other users by a water management agency is not inconsistent with the rules now governing cities. Secondly, the Arkansas Supreme Court has ruled that off-site use of groundwater can sometimes constitute legal reasonable use.[18] Coupled with the court's ruling that the same standard of law should be applied to ground and surface water use[19], acceptance of off-site use of surface water seems likely.

SUMMARY AND CONCLUSIONS

A groundwater management tool which utilizes a finite difference form of the Boussinesq equation is presented. It permits estimation of the annual spatially distributed pattern of pumping which will maintain groundwater levels at desired (target) elevations. This pumping pattern is a sustained yield pumping strategy. The target level approach to developing a sustained yield pumping strategy is attractive from a management perspective because it uses a forward linkage between desired water levels and the pumping rates needed to maintain those levels.

The target level approach is compatible with the reasonable use/correlative rights doctrine which presently governs Arkansas groundwater use. Application of this approach to groundwater management by an appropriate water management agency would not violate the fundamental facets of Arkansas groundwater law (although legislative and/or judicial action is necessary for its use). In order to supply adequate supplemental surface water to those forced to reduce groundwater use under a sustained yield pumping strategy, some modification of current surface water law to allow nonriparian use is required. An attempt to implement a sustained yield pumping strategy in Arkansas without providing for the supply of adequate supplemental water would be politically unfeasible.

Some of the goals attainable by using the target level approach to achieve a sustained yield of groundwater in the Arkansas Grand Prairie are:

1. to prevent groundwater levels from continuing to decline;
2. to increase assurance that a certain volume of groundwater will be available year after year;
3. to protect existing water rights; and
4. to lessen the likelihood of successful water litigation against users who comply with the pumping strategy.

In summary, the target level approach is designed to be compatible with both the physical system and the legal realities governing water use in the area. With minimal changes in existing Arkansas water law, it can be a useful and integrated groundwater management tool. It has potential applicability in a number of different legal settings, but is particularly attractive for riparian rights states seeking ways to guarantee continued beneficial use of their groundwater resources without resorting to a radical restructuring of the basic water rights system.

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