# USING TARGET LEVELS TO DEVELOP A SUSTAINED YIELD PUMPING STRATEGY IN ARKANSAS, A RIPARIAN RIGHTS STATE

By

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# INTRODUCTION

Groundwater is the major source of water for consumptive use in Arkansas. Significant pumping is concentrated in areas of agricultural and industrial production. In a number of these areas, including much of the Grand Prairie region of Arkansas, average annual withdrawal from the aquifer exceeds recharge. As a result of this groundwater mining, water levels are dropping. Mining which leads to excessive declines in the water level can accelerate salt water intrusion in an aquifer, cause aquifer compaction, make irrigation economically unfeasible, and eventually disrupt an economy based upon groundwater. Generally, these problems can be prevented or limited by maintaining groundwater levels at appropriate elevations and thereby maintaining favorable hydraulic gradients.

Once desired target groundwater levels are agreed upon, how can they be maintained? Basically, maintaining groundwater levels over the long term requires that as much water moves into 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 which will maintain specific groundwater levels can be referred to as a sustained yield pumping strategy.

This report presents a simple approach for developing a sustained yield pumping strategy for the Grand Prairie. Using 1982 groundwater levels as hypothetical target levels, the pumping strategy which will maintain those levels is presented. It should be emphasized that there are an infinite number of possible sustained yield pumping strategies for any area. The example given in this report is for demonstration purposes only and is not being proposed for implementation.

In practice, knowing how much groundwater should be pumped to maintain specific groundwater levels in certain areas is useful for estimating where and how much supplemental surface water is needed to meet water requirements beyond the amount that the aquifer can supply year after year. The target level approach is a tool designed to aid water users to obtain maximum beneficial use from the available water resources while protecting existing rights.

Accordingly, the second objective of the report is to evaluate the legal feasibility of implementing a sustained yield pumping strategy to maintain and/or achieve target groundwater levels in Arkansas. A brief overview of applicable water law is followed by an analysis of the legal modifications necessary to implement the target approach in Arkansas.

# DEVELOPING A SUSTAINED YIELD PUMPING STRATEGY TO MAINTAIN TARGET LEVELS

## Introduction and Background

A computer model is a representation of a physical system which describes the essential elements of the system for a particular purpose (Hall and Dracup, 1970). Traditional quantitative groundwater models are used to predict the water levels which result from known or estimated groundwater withdrawals. They are not designed to determine the pumping which will maintain preselected target levels. A different modeling approach is needed to calculate the pumping values which will maintain specific levels. The approach presented here is designed to develop sustained yield pumping strategies capable of maintaining target groundwater levels. Its application is demonstrated for the Grand Prairie region of Arkansas.

The Grand Prairie is in the Gulf Coastal Plain (See the report cover). It and most of the Plain are underlain by an extensive Quaternary aquifer. The study area encompasses most of the Grand Prairie and includes most of the Grand Prairie-White River Irrigation District (Figure 1). A relatively impermeable clay layer overlying the aquifer in most of the area is responsible for the comparatively small volume of deep percolation moving from the ground surface into the aquifer (Engler, et al, 1945). Simulation based upon 1915 (pre-development) water levels indicates 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 Post Canal

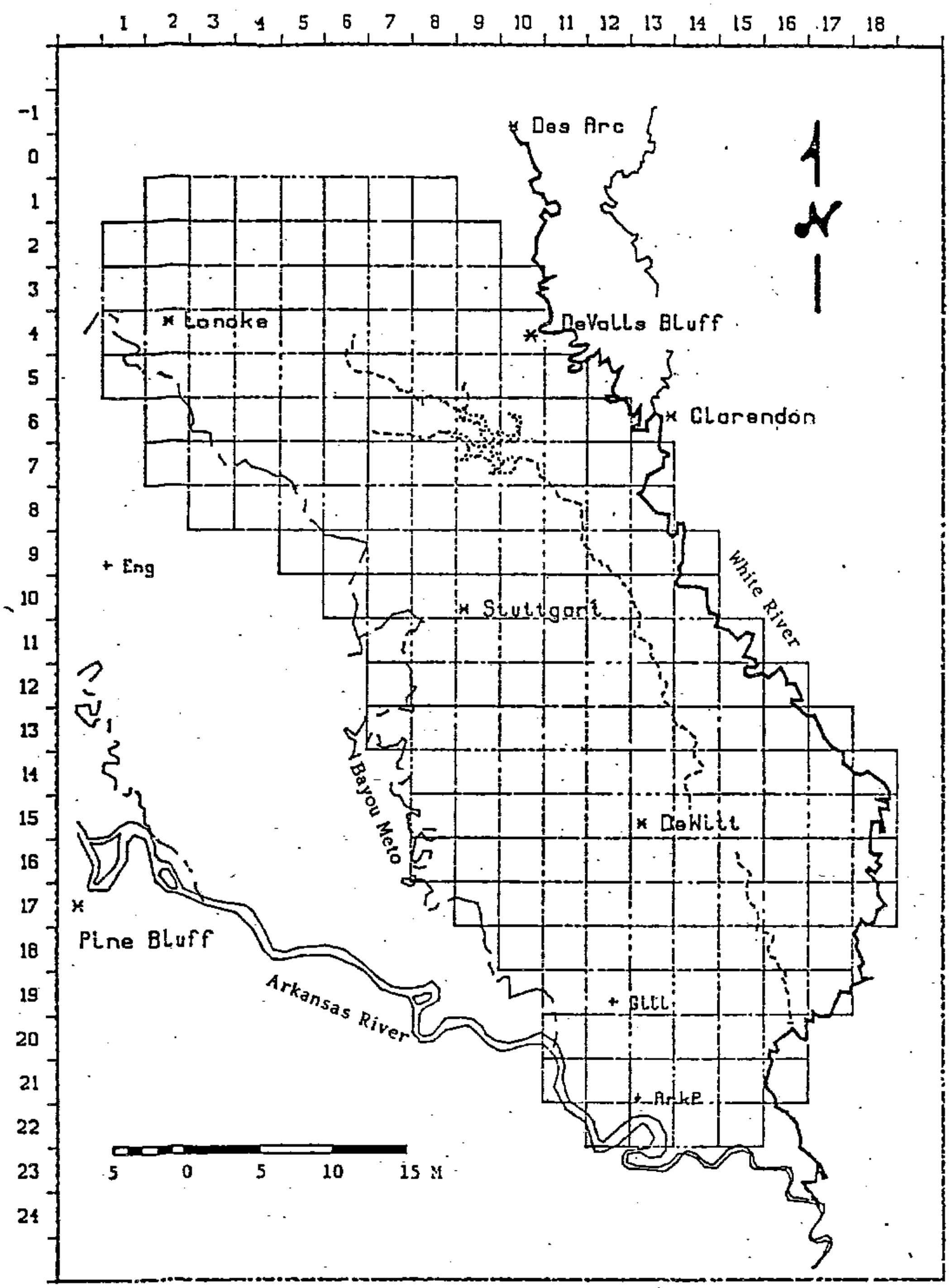



Fig: 1 Grand Prarie study area.

Numbering of the study area.

on the south and the Bayou Meto on the west. In some locations, these boundary waters may penetrate to the aquifer. Recharge to the aquifer from streams in the interior of the study area is minimal. Thus recharge to the aquifer within the study area comes primarily from parts of the aquifer lying outside the study area.

A west-east cross section of the study area near Stuttgart and the potentiometric surfaces which existed in the springs of 1939, 1959 and 1981 are shown in Figure 2. The potentiometric surface is "an imaginary surface connecting points to which water would rise in tightly cased wells from a given point in an aquifer. It may be above or below the land surface" (Lohman, 1979). Water will rise to the potentiometric surface within a well of its own accord.

In Figure 2, the top line represents the land 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. (The aquifer is confined wherever the potentiometric surface is above the top of the aquifer.) Extensive pumping has made the central portion completely unconfined and saturated thicknesses are dangerously thin.

A number of studies of the available water supply in the Grand Prairie have been conducted. One by Griffis (1972) successfully calibrated a digital model of the Quaternary aquifer and predicted the effect of recharging by injection wells on groundwater levels. Approximations of aquifer characteristics similar to those utilized by Griffis were used in validating a

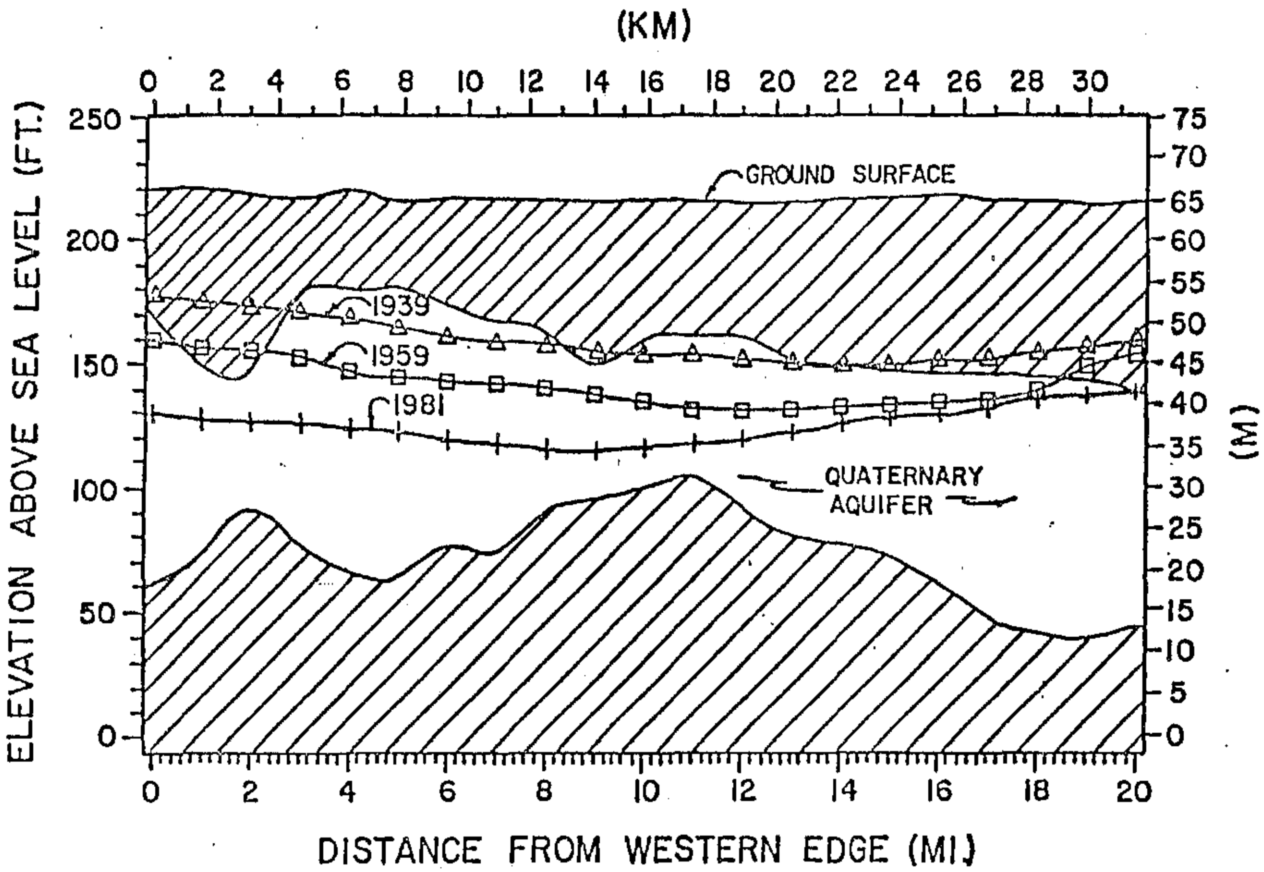



Fig: 2 Cross-section of the Quaternary aquifer near Stuttgart and historic groundwater levels. (Interpolated from USGS data and records of water-well construction) different simulation model (AQUISIM) for the area (Verdin et al, 1981; Peralta, et al, 1983). The study area was divided into 3-mile by 3-mile cells. Developing a sustained yield pumping strategy 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 Prairie are measured by the U.S. Geological Survey each spring, a time period of one year is most practical. The ideal goal of a sustained yield pumping strategy is to return water levels to target elevations spring after spring.

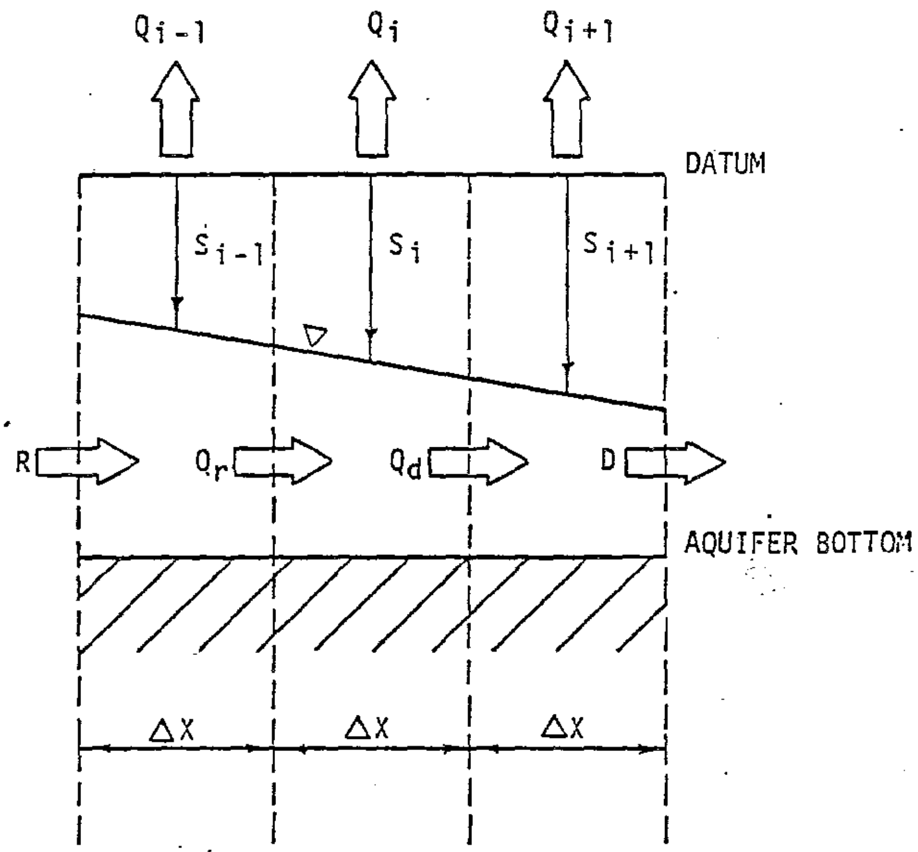
Groundwater simulation models must have defined boundary conditions about the periphery of a study area. Since the approach described in this paper is based on the concept of target groundwater levels, it utilizes constant groundwater elevations in its peripheral cells (constant head cells). The model's purpose is to calculate the steady-state groundwater levels and physically feasible pumping rates which satisfy certain predetermined criteria. For the pumping rates to be feasible, the model must assure that the recharge which is simulated to occur at constant head cells is not greater than that which can physically occur in the field. Our approach addresses the problem of recharge feasibility by permitting the model user to employ an upper limit on the simulated recharge volume which can occur at any of the constant head cells per unit time. Under steady state conditions the rate of recharge into a constant head cell is the same as the rate of movement out of the cell. The rate of movement out of a cell is a function of the hydraulic gradient between the cell and adjacent cells. Thus, within the program, control over the recharge (flux) rate to constant head cells is exercised by constraining the range of feasible hydraulic gradients between constant head and interior cells.

The ground and surface water levels which exist in the constant head cells naturally vary, and would do so without any pumping whatsoever. Besides the natural variation in levels, there is no information available concerning the degree of stream-aquifer connection along the borders of the study area. Therefore, average spring groundwater levels in the constant head cells are used throughout the study. Validation with AQUISIM verifies that the use of ten-year average groundwater elevations for the constant head cells is satisfactory for predicting water levels in the area for at least ten years into the future (Peralta, et al, 1983).

## Theory

In a water management scenario, target water levels are relatively fixed from year to year (except as changing goals or management techniques require) and may be directly linked to pumping rates via a steady state equation. Figure 3 shows a cross-section of a three-cell groundwater flow system. The potentiometric surface (groundwater level) is shown sloping down from left to right. Groundwater moves from areas with higher water level elevations to areas with lower elevations, so water enters the system from the left and leaves to the right. R

FIGURE 3




Cross-section of a three-cell
groundwater flow system

and D are, respectively, the horizontal recharge and discharge between the system and the surrounding aquifer. $Q_r$ and $Q_d$ represent the horizontal recharge and discharge between cell i and adjacent cells. The net vertical discharges from the aquifer underlying the cells during the time period are designated as $Q_{i-1}$, $Q_i$, and $Q_{i+1}$. Each net value is the sum of the pumping and any vertical recharge which exists at the particular cell. If there is no vertical recharge then it represents pumping. For purposes of this report, the steady-state drawdowns, $S_{i-1}$, $S_i$, and $S_{i+1}$, are defined as the distance from a datum ( reference elevation) to the groundwater level in the center of each cell. Under steady-state conditions, the volume entering the system (R) during the time period equals the volume leaving the system ($D + Q_{i-1} + Q_i + Q_{i+1}$) during the period and the drawdowns do not change. Similarly, for cell i, as long as $Q_r = Q_d + Q_i$, $S_i$ does not change.

Darcy's law, which has long been used to evaluate regional flow patterns, is used to calculate $Q_r$. Assuming that each cell is square ($\Delta x$ by $\Delta x$ in size), Darcy's law may be stated as:

(1) $Q_r = \sqrt{(T_{i-1})(T_i)}\ (S_i - S_{i-1})$

where the following definitions apply (the letters L and T refer to units of length and time respectively):

$Q_r$ is the recharge to cell i from the upgradient cell, ($L^3/T$)

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

$(S_i - S_{i-1})$ is the hydraulic gradient

$T_i$ is the transmissivity in the center of cell i, ($L^2/T$)

and

$\sqrt{(T_{i-1})(T_i)}$ is the geometric mean transmissivity between cell i-1 and cell i. It is used, instead of the arithmetic mean, as an estimate of the midpoint transmissivity because its value will be zero if either of the cell transmissivities is zero.

The transmissivity of each cell is the product of the hydraulic conductivity and the saturated thickness at the center of the cell. For a cell in which the potentiometric surface is above the top of the aquifer (confined conditions) the saturated thickness is the distance between the aquifer bottom and the top of the aquifer. For a cell in which the water level is below the top of the aquifer (water table or unconfined conditions), the saturated thickness is the distance between the aquifer bottom and the groundwater level.

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

$$(2)\quad Q_i = \sqrt{(T_{i-1})(T_i)}\,(S_i - S_{i-1}) - \sqrt{(T_{i+1})(T_i)}\,(S_{i+1} - S_i)$$

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

$$(3)\quad Q_{ss}(i,j) = -DTR(i-1,j)S(i-1,j) - DTR(i,j)S(i+1,j) + [DTR(i-1,j) + DTR(i,j) + DTU(i,j-1) + DTU(i,j)]S(i,j) - DTU(i,j-1)S(i,j-1) - DTU(i,j)S(i,j+1)$$

where $Q_{ss}(i,j)$ = the steady state pumping rate for cell (i,j), $(L^3/T)$.

DTR(i,j) = the midpoint transmissivity between cell (i,j) and cell (i+1,j) $=\sqrt{T(i,j)\ T(i+1,j)}$, $(L^2/T)$.

DTU(i,j) = the midpoint transmissivity between cell (i,j) and cell (i,j+1) = $\sqrt{T(i,j)\ T(i,j+1)}$ , (L2/T).

S(i,j) = the drawdown in cell (i,j), (L).

The same equation was previously derived from the linearized Boussinesq equation (Illangasekare and Morel-Seytoux,1980). For consistency, their terminology and means of estimating midpoint transmissivity have been adopted. The equation was used as part of an innovative technique of reinitializing groundwater simulation and reducing computer storage requirements (Morel-Seytoux, et al, 1982; Verdin, et al, 1981). In that application there is no need for constraining the magnitude or sign of the resulting pumping values. As a result, they are artificial values and do 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 statistically based automated method of preparing gridded elevations from random observations. It is used because it retains the observed value at an observation point and because it provides a standard error of the estimate for each gridded value (Sophocleous, 1983). Numerous sets of observed spring water levels in the Grand Prairie have been kriged to provide gridded estimates of groundwater levels. The steady state pumping rates which will maintain the gridded groundwater levels can be determined using equation 3. However, these pumping values can be physically unrealistic.

For example, a negative pumping value, which means recharge, will sometimes be calculated for cells where no recharge can be occurring. This happens in cells where the kriged groundwater elevation represents a localized high. The high may result because of characteristics of the data, such as the random spatial distribution of the initial observation points. In addition, punctual kriging treats the observed values as if they were absolutely accurate. In fact, the elevation of the ground surface was estimated from topographic maps and the water levels were obtained by subtracting the distance between the potentiometric surface and the ground surface from the ground elevation. As a result of these factors, the standard error of the estimate of the gridded groundwater elevations in the Grand Prairie generally varies between 4 and 11 feet.

A computer program (TARGET2) was developed to create physically realistic target levels and attendant pumping values for the Grand Prairie. The program requires an estimate of hydraulic conductivity. As input, the program accepts for <u>each</u> cell: initial gridded groundwater elevations, the elevation of the top and bottom of the aquifer, the <u>minimum</u> saturated thickness <u>acceptable</u> in the design set of target levels, and minimum and maximum desired pumping values for the steady state pumping value which will maintain the target level. Since the program uses hydraulic conductivity and the elevations of the top and bottom of the aquifer in each cell, it is appropriate for confined as well as unconfined aquifer conditions. For cells at which no recharge can physically occur, the minimum pumping volume is zero and the value is forced to be either zero or a positive value. For purposes of this report it is assumed that the current pumping in the cell represents a realistic upper limit and that needs in excess of current pumping are met from other sources of water.

Initially, the program determines the recharge needed at each constant head cell to maintain gridded water levels precisely as they are input. The resulting recharge values are used as a default upper limit on recharge at each individual constant head cell. This constraint may be relaxed or tightened by a user-specified volume if desired.

Next, beginning at either the northwestern or southeastern corner of the study area, the program compares each cell's water level and the steady state pumping volume with the input limits. If required, the water level is lowered and the transmissivity recalculated until the selected criteria are satisfied. The solution is of course limited by Darcy's law and the fact that total pumping cannot exceed total maximum recharge. The mathematical formulation assures that the sum of the positive pumping values (discharges) equals the sum of negative values (recharges).

The approach is a simple one, with some obvious limitations. Two conditions must be met for the calculated steady state pumping strategy to be a sustained yield pumping strategy. First, the calculated recharge for a constant head cell must be physically feasible. In other words, sufficient water must be available to enter the cell from outside the study area and the water must be able to enter when the groundwater level in the constant head cell is at its specified elevation. TARGET2 assures that the calculated recharge is not greater than the predetermined upper limit on recharge for any constant head cell. Constant head cells receive recharge from outside the system by seepage from a river or surface body lying in the cell and/or from parts of the aquifer extending beyond the study area. Determining the upper limit on recharge (i.e. the maximum physically feasible recharge for a particular constant head cell at a particular ground water elevation) requires specific hydrogeologic field data.

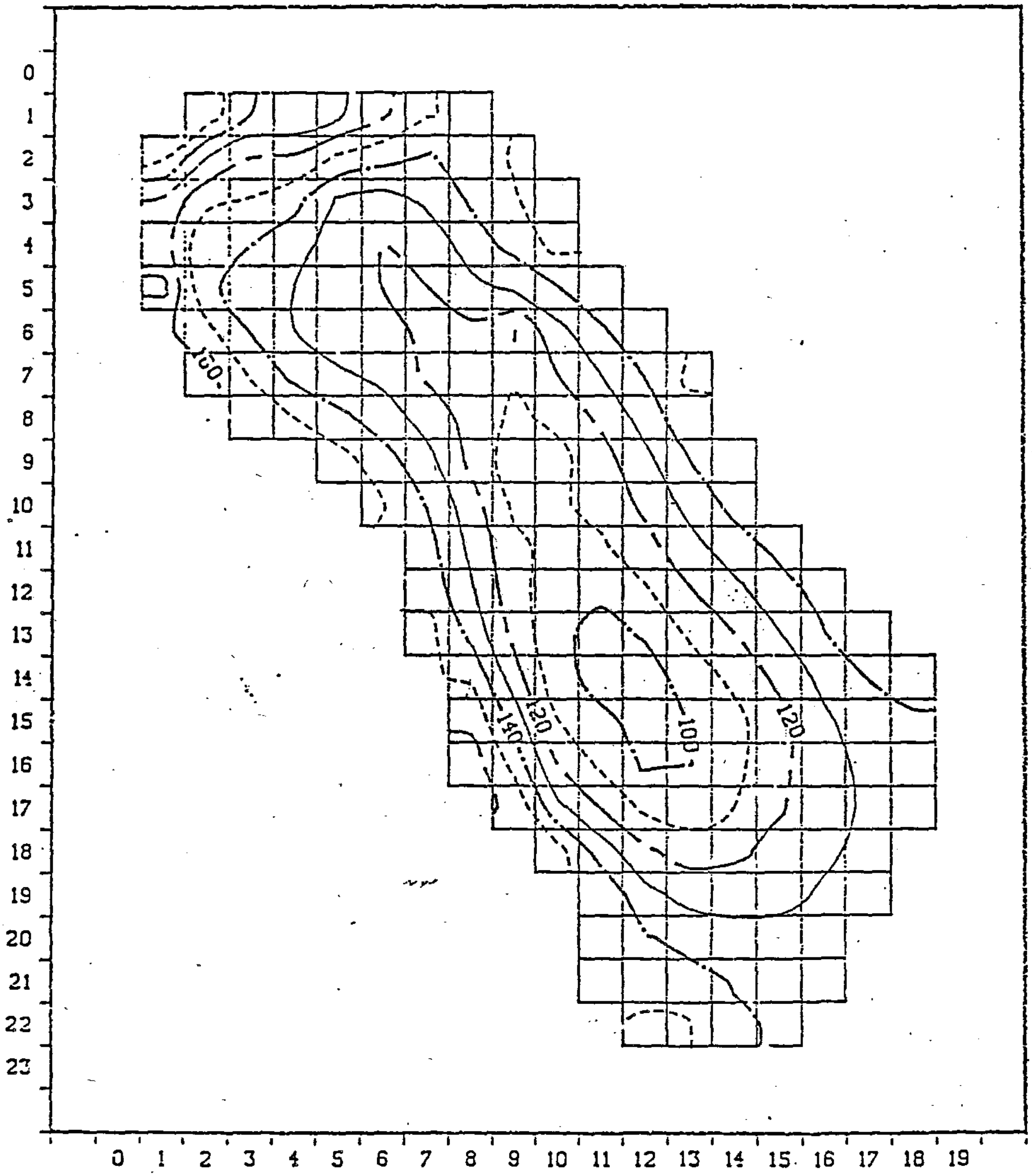
The second condition which must be met for the calculated steady state pumping strategy to be a sustained yield pumping strategy is verification (using a dynamic simulation model) that the steady state pumping strategy will not cause unexpected results. The requirement arises because the steady state 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 for irrigation during the summer. As a result, water levels decline during the summer. The cessation of pumping and continuation of recharge during the fall and winter must occur in such a way that water levels are allowed 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. An example and elaboration of the dynamic verification process is described in the next section.

## Development of a Hypothetical Pumping Strategy

An arbitrary management objective is selected to demonstrate how a pumping strategy can be developed. For this example, spring 1982 groundwater levels for the Grand Prairie are used as the basis for developing target levels. Observations in the spring of 1982 from about 150 randomly distributed wells in the Grand Prairie are utilized. Universal kriging is used to interpolate and estimate the water level at the center of each three mile by three mile cell from the observed water levels. These estimated water levels serve as input levels for TARGET2, a steady state groundwater simulation model. 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 is assumed. The upper limit on recharge in constant head cells is the recharge calculated by Darcy's law using the input levels. Except in a few cells with a possible stream-aquifer connection, the upper limit used for pumping from any internal cell is set at the estimated volume currently being pumped from the Quaternary aquifer in that cell. The resulting target water levels are shown in Figure 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, but the resulting pumping strategy (see Figure 5) is physically realistic.

The volumes shown in Figure 5 are net values (the sum of all discharges and recharges between the aquifer underlying the cell

FIGURE 4




Sample set of target groundwater elevations (ft above sea level)

FIGURE 5

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | -6591 | -595 | -4423 | -1667 | -1418 | -201 | -10 | | | | | | | | | | |
| -7350 | 3718 | 3037 | 29 | 1181 | 15 | 1002 | 593 | -1098 | | | | | | | | | |
| 1062 | 3263 | 11 | 136 | 2697 | 1558 | 85 | 1 | 14 | -2173 | | | | | | | | |
| -602 | 3368 | 13 | 183 | 954 | 1112 | 764 | 4 | 19 | -3769 | | | | | | | | |
| -6197 | 6201 | 30 | 1011 | 1017 | 644 | 558 | 7 | 21 | 723 | -3360 | | | | | | | |
| | -2146 | 2235 | 1690 | 1194 | 168 | 339 | 15 | 5144 | 1560 | 259 | -3471 | | | | | | |
| | -5096 | 1509 | 2351 | 1370 | 178 | 1338 | 315 | 357 | 878 | 973 | 929 | -3531 | | | | | |
| | | -4100 | -1556 | 418 | 630 | 709 | 191 | 784 | 816 | 1091 | 899 | -3006 | | | | | |
| | | | | -4201 | 13 | 17 | -1153 | 1694 | 1180 | 1295 | 998 | 14 | -3367 | | | | |
| | | | | | -3334 | 31 | 11 | 1718 | 176 | 446 | 631 | 28 | -2206 | | | | |
| | | | | | | -2133 | 523 | 475 | 455 | 756 | 840 | 24 | 30 | -2821 | | | |
| | | | | | | -945 | 137 | 504 | 516 | 1060 | 707 | 29 | 416 | 25 | -2319 | | |
| | | | | | | -1775 | 1033 | 593 | 542 | 1034 | 1340 | 31 | 469 | 16 | 45 | -5122 | |
| | | | | | | | -2919 | 1839 | 2083 | 1036 | 1590 | 823 | 870 | 795 | 64 | 116 | -1340 |
| | | | | | | | -2896 | 466 | 1418 | 268 | 1045 | 1212 | 1182 | 1605 | 105 | 4 | -642 |
| | | | | | | | -3453 | 21 | 1648 | 944 | 1564 | 2245 | 641 | 84 | 16 | 39 | -573 |
| | | | | | | | | -3459 | 2165 | 396 | 1446 | 2247 | 1755 | 356 | 2 | 20 | -250 |
| | | | | | | | | | -4348 | 19 | 284 | 1223 | 556 | 180 | 46 | -988 | |
| | | | | | | | | | | -2041 | 4 | 277 | 301 | 1017 | 30 | -797 | |
| | | | | | | | | | | -822 | 32 | 0 | 18 | 31 | -1324 | | |
| | | | | | | | | | | 417 | 13 | 42 | 26 | 14 | -311 | | |
| | | | | | | | | | | | -1687 | -3423 | 974 | 200 | | | |

Steady state pumping values which will maintain the target elevations (ac-ft/yr) and the world outside the study area's aquifer.) One may notice that some cells have a very small annual pumping volume while other adjacent cells have pumping volumes which are several orders of magnitude larger. This is partially the result of the uneven nature of the bottom of the aquifer, as well as the limits placed on desirable saturated thicknesses while inputting data to the program. The steady state target levels of Figure 4 and the attendant pumping values of Figure 5 represent merely one out of an infinite number of possibilities. No effort was made to present an example that would be socially acceptable to all users--that is beyond the scope of this report. TARGET2 has however been used to develop strategies in which groundwater usage was more equitably distributed. This was accomplished by changing the lower limit on acceptable pumping for most cells.

To iterate, the pumping values shown in Figure 5 represent a sustained yield pumping strategy as long as the two limiting conditions (physical feasibility and consideration of impact of temporal distribution of pumping) are met. The contour lines in Figure 4 and the positive values for southeastern boundary cells in Figure 5 demonstrate movement of groundwater from the northwestern part of the study area to the southeast. The second cell from the top of the left hand column in Figure 5 has a positive value because of the steep slope of the groundwater level between this cell and the one north of it (the direct result of extensive pumping for aquaculture). Water must be pumped from that cell for it to maintain its groundwater level in relation to its neighbors.

Absolute verification of the physical feasibility of recharge to each constant head cell is beyond the scope of this study, but a simple analysis was made of the entire area. The sum of all values in constant head cells is approximately 120,000 acre-feet, an estimate of net recharge to the aquifer required to maintain target levels. Engler,et al (1945), using a volumetric balance approach, estimated an average annual recharge rate of 137,000 acre-feet between 1929 and 1943, a period of dropping groundwater levels. Recharge is often greater during an era of declining water levels than during a period of sustained yield. As water levels in the center of the Prairie have continued to drop, the steepness of the gradient has increased and annual recharge rates have increased above 137,000 acre-feet. The annual rate of 120,000 acre-feet, then, can probably be maintained over the long term under a sustained yield strategy as long as the selected constant head cell levels are maintained by the regional groundwater flow pattern.

Dynamic simulation requires estimating the percent of each cell's annual pumping volume which is realistically needed for use each month. To accomplish this, daily water balance simulation and irrigation scheduling was performed for rice and soybeans using fifteen seasons of daily climatological data (Peralta and Dutram, 1983). Monthly irrigation requirements per acre of these crops were calculated as percentages of annual use. Similarly, monthly values of water for aquaculture and for each municipality were estimated as percentages of total annual use. Based on the types of users of water in a particular cell, the percentage of annual water use occurring in each cell for each month was estimated. This composite percentage varied from cell to cell and from month to month. The calculated percentages were used to divide the annual sustained yield pumping value 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 value. The twelve pumping volumes for each cell were duplicated ten times to create hypothetical pumping data for 120 consecutive months. 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. This value was reported or used as the storage coefficient by earlier researchers (Engler, et al, 1945; Sniegocki, 1964; Griffis, 1972) and was used in validating the use of AQUISIM for the Grand Prairie (Peralta, et al, 1983).

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. After 120 months of simulation, the greatest difference between target and simulated groundwater elevations was 0.6 feet. This occurred in a cell with aquacultural water use. In almost all other cells, the difference between simulated and target levels was less than 0.03 feet. The very small differences between target and simulated values are comparable to those obtained in other upublished tests of this method. Figure 6 shows the differences between target and simulated water levels which occurred in August after 113 months of simulation. This month, immediately following the

FIGURE 6

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | | | | | | | | | |
| 0.0 | -0.5 | -0.7 | -0.1 | -0.3 | -0.1 | -0.3 | -0.1 | 0.0 | | | | | | | | | |
| 0.0 | -0.8 | -0.1 | -0.1 | -0.7 | -0.4 | -0.1 | -0.0 | -0.0 | 0.0 | | | | | | | | |
| 0.0 | -0.7 | -0.1 | -0.1 | -0.2 | -0.3 | -0.2 | 0.0 | -0.1 | 0.0 | | | | | | | | |
| 0.0 | -1.1 | -0.1 | -0.3 | -0.3 | -0.2 | -0.2 | -0.1 | -0.1 | -0.2 | 0.0 | | | | | | | |
| | 0.0 | -0.6 | -0.5 | -0.3 | -0.1 | -0.1 | -0.1 | -1.1 | -0.5 | -0.1 | 0.0 | | | | | | |
| | 0.0 | -0.4 | -0.6 | -0.4 | -0.1 | -0.4 | -0.1 | -0.2 | -0.3 | -0.3 | -0.2 | 0.0 | | | | | |
| | | 0.0 | 0.0 | -0.1 | -0.2 | -0.2 | -0.1 | -0.3 | -0.3 | -0.3 | -0.2 | -0.0 | | | | | |
| | | | | 0.0 | -0.0 | -0.1 | -0.3 | -0.4 | -0.3 | -0.4 | -0.2 | -0.1 | 0.0 | | | | |
| | | | | | 0.0 | -0.0 | -0.0 | -0.1 | -0.1 | -0.2 | -0.2 | -0.1 | 0.0 | | | | |
| | | | | | | 0.0 | -0.1 | -0.1 | -0.1 | -0.2 | -0.3 | -0.0 | 0.0 | 0.0 | | | |
| | | | | | | 0.0 | -0.1 | -0.2 | -0.2 | -0.3 | -0.2 | -0.0 | -0.1 | -0.0 | 0.0 | | |
| | | | | | | 0.0 | -0.3 | -0.2 | -0.2 | -0.3 | -0.4 | -0.1 | -0.1 | -0.1 | 0.0 | 0.0 | |
| | | | | | | | 0.0 | -0.5 | -0.6 | -0.3 | -0.4 | -0.3 | -0.3 | -0.2 | -0.0 | 0.0 | 0.0 |
| | | | | | | | 0.0 | -0.2 | -0.4 | -0.2 | -0.3 | -0.3 | -0.4 | -0.4 | 0.0 | -0.1 | 0.0 |
| | | | | | | | 0.0 | -0.0 | -0.5 | -0.3 | -0.5 | -0.6 | -0.2 | -0.1 | -0.0 | -0.0 | 0.0 |
| | | | | | | | | 0.0 | -0.5 | -0.2 | -0.4 | -0.6 | -0.5 | -0.1 | 0.0 | 0.0 | 0.0 |
| | | | | | | | | | 0.0 | -0.0 | -0.1 | -0.3 | -0.2 | -0.1 | -0.0 | 0.0 | |
| | | | | | | | | | | 0.0 | 0.0 | -0.1 | -0.1 | -0.3 | -0.0 | 0.0 | |
| | | | | | | | | | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | |
| | | | | | | | | | | 0.0 | 0.0 | -0.1 | -0.0 | -0.0 | 0.0 | | |
| | | | | | | | | | | | 0.0 | 0.0 | 0.0 | 0.0 | | | |

Simulated - target elevations in August,
after 113 months of simulation (ft)

irrigation season, displays the greatest difference between simulated and target levels. Even then, the average elevation in the "worst" cell is within 1.1 feet of the target elevation.

In summary, the pumping strategy shown in Figure 5 may be considered to be a sustained yield pumping strategy. There are, of course, many possible sustained yield pumping strategies and sets of target levels for any given area. Depending upon the water management goals to be met, users may find it desirable to provide for sufficient saturated thicknesses to protect domestic use or to provide for use during times of drought. Target levels and pumping strategies to more uniformly meet groundwater needs over an area and to assure the existence of a minimum acceptable saturated thickness have been designed. A current effort involves determining the set of spring target levels for the Grand Prairie which can insure sufficient saturated thicknesses even during drought when all or most water needs must be met by groundwater.

Depending on how different the chosen target levels are from current levels, a number of years of management might be required for actual and target water levels to coincide. During that period, during the sustained yield era, and during periods 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 be required to supplement groundwater supplies. Fortunately, in the case of the Grand Prairie, preliminary indications are that adequate surface water resources exist nearby to provide the necessary supplemental water.

## GROUNDWATER MANAGEMENT AND THE RIPARIAN RIGHTS/REASONABLE USE DOCTRINE

### Arkansas Water Law

No matter how equitable and efficient a particular engineering solution to a problem may be, legal constraints must be taken into account. Arkansas' system of water rights has evolved over time and is dependent upon both statutory (legislator-made) and case (judge-made) law. Relatively few statutes governing the right to use water have been passed by the Arkansas General Assembly. With the exception of pollution control measures which are largely mandated by federal law, most water rights issues have been settled in the state courts. As a result, Arkansas water law has evolved primarily on a case by case basis (Peralta,A.,1982).

Understanding how Arkansas' current water law came into being is important, both in ascertaining whether the target level method is legal now, and in evaluating trends that might impact groundwater management efforts in the foreseeable future. For this report, applicable Arkansas water law is briefly reviewed to assess the feasibility of implementing a sustained yield pumping strategy to maintain or achieve target water levels. (For a more comprehensive look at Arkansas water law, see Arkansas Water Law by Paul Douglas Mays, Arkansas Soil and Water Conservation Commission, 1981.)

Arkansas is blessed with an average of forty-nine inches of rainfall annually, some 2,700 miles of surface streams and substantial groundwater reserves (U.S. Geological Survey, 1969).

Most water disputes in the past have concerned disposal of excess surface water rather than the right to use water (Dewsnup and Jensen, 1973). As is true in most of the humid Eastern States, Arkansas water rights are based on the old English common law. With the passage of the Reception Statute, Arkansas law received the common law of England and all statutes of the British Parliament "made prior to the fourth year of James the First ... of a general nature... and not inconsistent with the Constitution and laws of the United States or the Constitution and laws of Arkansas".1 Under the common law, the right to use surface water is incident to ownership of "riparian" land--land abutting surface water. The right to use groundwater is incident to the ownership of land overlying groundwater.

The riparian rights doctrine (as opposed to the doctrine of prior appropriation) has long been recognized as the governing doctrine for both ground and surface water in Arkansas.2 Riparian proprietors share a coequal right to use the water they hold in common. The Arkansas Supreme Court has ruled that "no proprietor has priority in use of water in derogation of another's rights."3 The right to use water under riparian rights is attached to the land as an actual part and parcel of the soil.4 Like other property rights, riparian rights are protected by constitutional due process.5

Riparian rights are usufructuary rights -- rights to use water without damaging the source--not actual ownership (Hutchins,1974). The maxim, "sic utere tuo ut alienum non laedas," was applied in the reasoning of the early Arkansas cases. Basically, this means to "use your property in a manner which will not injure others."

Arkansas groundwater law is subject to the law of surface waters (6) so a fundamental understanding of surface water law naturally precedes an understanding of Arkansas groundwater law. The legal use of surface water in the state was originally governed by the "natural flow" rule which basically limited water use to domestic use. Artificial uses such as irrigation were not legally permissible.7 Under the natural flow rule, each riparian owner was "entitled to the usual flow of a stream in its natural channel over his land, undiminished in quantity and unimpaired in quality."8 The natural flow rule required that the stream remain virtually unchanged.

As has been done in most riparian states, the Arkansas Supreme Court has modified the natural flow rule to allow "reasonable use" of water by riparian land owners.9 Such reasonable use must not unreasonably interfere with reasonable beneficial use of the water by other riparian landowners.10 Protection from "unreasonable use" extends to quality as well as quantity.11 In Harris v. Brooks, the landmark case for reasonable use in Arkansas, the Court stated that:

> "the purpose of the law is to secure to each riparian owner equality in the use of water as near as may be by requiring each to excercise his right reasonably and with due regard to the rights of others similarly situated."12

The court has ruled that among riparians, domestic users have precedence, and after domestic use, all other uses are equal.13 Arkansas statutory law delineates priority of surface water use during times of scarcity as: (1)sustaining life; (2)maintaining health; and (3) increasing wealth.14

Because of the hidden nature of groundwater, the old English common law did little to regulate its use. Groundwater was considered to be mysterious and its appearances and disappearances to be almost magical. Accordingly, early groundwater law recognized "absolute ownership" by the overlying landowner. Any groundwater an overlying owner could capture was legally his to use, regardless of how such capture affected the underground water supply of his neighbor.

As knowledge about groundwater has increased, most states have replaced absolute ownership with a more realistic rule. The Arkansas Supreme Court has chosen to apply the riparian rights doctrine and reasonable use standard governing surface water to ground water use as well.15 In Jones v. Oz-Ark-Val Poultry Co., the court stated that the reasonable use rule should apply to all underground waters--whether a "true subterranean stream" or "subterranean percolating waters."16

An owner of land overlying groundwater 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 thereof, if the supply is so scant that the use by one will affect the supply of other overlying users."17 The Arkansas high court has favorably recognized the California correlative rights doctrine as set forth in Hudson v. Dailey.18 Under correlative rights, the reasonable use rule is modified in times of scarcity to entitle each overlying landowner to a proportionate or prorated share of the available supply.19

In harmony with case and statutory law governing surface water use, the Court has, in general, called industrial use of groundwater which interferes with domestic use "unreasonable."20 (Here, it must be noted that the legal merit or utility of an activity which produces harm is weighed against the legal gravity of the harm on a case by case basis and that the decision is based on the court's judgement, so no absolutes can be stated.) Agricultural and industrial users alike are increasingly vulnerable to the possibility of successful litigation as groundwater levels decline and domestic use is disrupted. In fact, in the Grand Prairie, a number of wells have already become unusable and as water levels continue to decline, more will follow.

In Arkansas, "only when a riparian proprietor's use of water is unreasonable can another who is harmed by it complain even though the harm is intentional."21 It is the reasonableness of the interference with other riparians that is decided when conflicting uses are brought before the court. In that sense, the reasonable use rule might be called the "reasonable interference rule." In <u>Scott</u> v. <u>Slaughter</u>, quoting from <u>Harris</u> v. <u>Brooks</u>, the Arkansas Supreme Court states that:

> "It recognizes that there is no sound reason for maintaining our lakes and streams at a normal level when the water can be beneficially used without causing unreasonable damage to other riparian owners."22

The Arkansas high court has stated that unreasonable use is "largely a matter for the discretion of the court after an evaluation of the conflicting interests of each of the contestants before the court."23 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.24 Two alternatives for dealing with "unreasonable" users have been recognized: (1) restraining further use; or (2) ordering payment to extend the affected well(s) to a greater depth.25

The Arkansas Supreme Court has avoided rigidly defining reasonable use. In Harris v. Brooks the court ruled "that we are not necessarily adopting all the interpretations given it by the decisions of other states, and that our own interpretation will be developed in the future as occasions arise."26 The concept of reasonable use is evolving as the Court addresses more complex water problems. The court recently removed a previous restriction requiring overlying owners to use water only on overlying lands. In Lingo v. The City of Jacksonville, the court ruled that "It is permissible for a riparian owner to move subterranean and percolating waters and use it away from the lands from which it was pumped if it does not injure the common supply of other riparian owners."27

The court has consistently used the maximum beneficial use of the State's water as a standard. In Harris v. Brooks the court elucidated:

"In all our consideration of the reasonable

> use theory as we have attempted to explain it we have accepted the view that the benefits accruing to society in general from a maximum utilization of our water resources should not be denied merely because of the difficulties which may arise in its application."28

To summarize, Arkansas water law is based on a riparian rights reasonable use rule for both surface and groundwater (whether percolating or flowing). Riparian or overlying owners have a right to make reasonable beneficial use of the water "with due regard to the rights of others similarly situated."29 Protection against "unreasonable" use extends to quality as well as to quantity. The courts decide which uses are reasonable and which are unreasonable on a case by case basis as conflicts arise.

Domestic use is preferred over other uses of both ground and surface water. In times of scarcity, surface water use is allowed in the following order: (1) sustaining life; (2) maintaining health; and (3) increasing wealth. The correlative rights rule (giving overlying owners a proportionate or pro-rated share) modifies the reasonable use rule for groundwater use when the supply is insufficient to meet needs.

As a general rule, the Arkansas Supreme Court has sought to insure maximum beneficial use of the State's water resources. In order to promote maximum beneficial use, the court has modified the common law on several occassions and appears willing to make further changes as the need arises.

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 and correlative rights doctrine which regulates groundwater use in Arkansas. The reasonable use and correlative rights doctrine takes into consideration the amount of pumping compatible with protection against "unreasonable use" or "unreasonable interference". Pumping which 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 protecting domestic use because the court has consistently applied greater knowledge about the true nature of groundwater as such knowledge has become available. 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 from aquifers being depleted by mining.

The court's decision to weigh the "extent of injury versus the benefit accrued from the pumping"(30) 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.

To avoid unnecessary economic hardship to users, the availability of supplemental surface water is essential. Any plan calling for reduced use of groundwater by some water users must provide for adequate surface water to meet needs. There is, at present, no case specifically approving nonriparian use of surface water. However, the meshing of ground and surface water law in the state and the rules governing municipalities set some precedent for approving such use. In the first place, the Arkansas Supreme Court has ruled in Lingo v. City of Jacksonville that off-site use of groundwater can, at least in some circumstances, constitute legal reasonable use.31 Combined with the court's decision in Jones v. Oz-Ark-Val Poultry Co.(32), that the reasonable use rule should be used to determine the rights of riparian owners whether they have surface waters, subterranean streams or percolating underground waters, Lingo makes it likely that the court will recognize the legality of off-site application of surface water.

Secondly, 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. Similar statutory authority might, therefore, be extended to a water management agency.

Action by the Arkansas General Assembly to facillitate use of the target level approach is needed. Legislatures in Florida, Nebraska and elsewhere have created substate level districts empowered to capture, conserve, develop, purchase, transport and deliver ground and surface waters to users within the district. Application of the substate district concept (where needed) appears well-suited for conjunctive management of ground and surface water in Arkansas.

## SUMMARY AND CONCLUSIONS

A sub-state level groundwater management tool is presented utilizing a finite difference form of the Darcy Equation to estimate the annual pumping rates which will maintain groundwater levels at desired elevations. The spatially distributed pumping rates can constitute a sustained yield pumping strategy when considered on an annual spring to spring basis. Proper selection of the target water levels can insure that they also represent a safe sustained yield, providing sufficient saturated thickness to protect domestic or agricultural users even in times of drought. Thus, the target level approach is particularly attractive from a management point of view.

The target level approach is attractive from a water user's viewpoint as well. Some of the possible benefits to users employing the target level approach include:

(1) the advantages of a workable and effective sub-state groundwater management technique with minimal changes in existing Arkansas water law;

(2) the assurance that a certain volume of groundwater can be available for use year after year;

(3) the assurance that groundwater can be available for use in times of drought when supplemental surface water is limited or unavailable;

(4) the protection of aquifer/groundwater quality from degradation by maintaining appropriate water levels;

(5) the achievement of a measure of protection from litigation charging unreasonable use;

and

(6) the protection of existing water rights.

The target level approach is not incompatible with the reasonable use and correlative rights doctrine which presently governs Arkansas groundwater use. Application of the target level approach by the appropriate water management agency violates none of the fundamental facets of Arkansas groundwater law, although legislative and/or judicial action is necessary for its utilization. For example, formal recognition of the legality of nonriparian use of supplemental surface water is needed. Any attempt to implement a sustained yield pumping strategy without provisions for supplying adequate supplemental surface water would be inequitable and economically unsupportable.

The target level approach is not meant to be used in isolation. It is but one element of the overall management strategy needed to reasonably and equitably meet current and future water requirements for the Arkansas Grand Prairie. The target level approach may be adapted for appication in other areas of Arkansas and in other states as well.

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