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SUSTAINED GROUNDWATER YIELD AND CONJUNCTIVE USE VIA TARGET LEVELS IN A REASONABLE USE STATE

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Assuring the sustained availability of water of adequate quality and quantity in a stream-aquifer hydrologic system frequently requires coordinating the use of groundwater and surface water. Since, without the use of reservoirs, it is difficult to assure that available river water will be adequate at a particular time and place, providing an assured supply requires reliance on groundwater.

Regional sustained yield groundwater withdrawal strategies can be calculated using specialized computer programs. Each such strategy consists of a set of volumes that can be withdrawn from different portions of an aquifer system, year after year, without causing undesirable changes in groundwater levels (the potentiometric or piezometric surface). In fact, pumping in compliance with such a 'safe yield' strategy will eventually cause the evolution of a particular, unique, steady-state potentiometric surface. The first objective of this paper is to provide a brief overview of methods for designing desirable or optimal regional steady-state potentiometric surfaces.

Conjunctive water management refers to coordinating the use of groundwater and surface water resources that may or may not be in hydraulic connection. Causing the evolution and maintenance of a desirable potentiometric surface by systematic water use is an appropriate planning approach for either situation. The second objective of this paper is to describe two applications. The first application develops sustained yield strategies that maintain legal in-stream water requirements by controlling the potentiometric surface elevations and hydraulic gradient in the vicinity of the streams. This example also illustrates the usefulness of the approach in maintaining necessary groundwater flow across institutional boundaries. The second application determines the time-varying requirement for diverted river water to supplement sustainable groundwater use.

Assessment of the chances of implementing a sustained yield-conjunctive use strategy in Arkansas requires consideration of existing water laws. The legal feasibility of maintaining a 'target' potentiometric surface in Arkansas, without considering conjunctive use or stream-aquifer interaction, has been previously analyzed in detail as a Special Report in the Arkansas State Water Plan (Peralta and Peralta, 1984b). The third objective is to present the salient features of that analysis and to discuss possible steps toward utilization of the target level approach for conjunctive water management.

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The development of pumping strategies to maintain, as closely as possible, a predetermined 'target' steady-state surface has been termed the Target Level Approach (TLA) (Peralta and Peralta, 1984a). Similar to the TLA is the Target Objective Approach (TOA), in which optimization is used to calculate the target steady-state potentiometric surface and sustained yield pumping strategy that maximizes achievement of a predetermined regional policy objective (Peralta and Killian, 1985). The TOA is useful because many statutes and case law couch directions for water use in objective-oriented terms. A legal mandate to "maximize beneficial use of groundwater" or to "minimize cost of supplying supplemental surface water" can be translated by the Target Objective Approach into specific spatially distributed pumping strategies to achieve the objective. Instead of predicting the result if pumping continues at a particular rate, the TOA allows water users to know the sustainable rate of pumping that will achieve particular goals (Peralta, A., et al, 1985).

Aguado et al. (1974) pioneered the use of steady-state approaches by showing how to minimize the cost of dewatering a construction site. Other approaches to optimizing groundwater management have been developed although few applications to actual large systems have been reported. Gorelick (1983) provides an excellent review of some of these. The TOA differs from most other applications of optimization in groundwater management in its intent to ultimately achieve a 'safe' target steady-state potentiometric surface. Furthermore, pumping that causes an existing surface to evolve into the target surface is sustainable, while pumping that is optimal for a limited planning period may not be.

The idea of systematically causing the evolution of a desirable steady-state potentiometric surface in regions dependent on groundwater is gaining popularity (Knapp and Fienerman, 1985). Computer models for determining optimal 'target' regional potentiometric surfaces and groundwater pumping strategies have been developed for several regional policies. These policies include: maximizing sustained groundwater yield (Peralta et al., 1985), minimizing the cost of attempting to satisfy water demand from conjunctive water resources (Peralta and Killian, 1985), maximizing the degree to which a current potentiometric surface is maintained (Yazdani and Peralta, 1986), maximizing net economic return from groundwater use (Knapp and Fienerman, 1985) and multiobjective optimization (Datta and Peralta, 1986). It should be mentioned that most of these models have been successfully applied to regions of 4660 or 8285 sq. km. (1800 or 3200 sq. mi.) in size.

Methods that allow the modification of a regionally optimal strategy to better satisfy local goals have also been demonstrated (Killian and Peralta, 1985). 'Local' refers to 'cells' 23.3 sq. km. (9 sq. mi.) in size which comprise the 'regions'. These Target Modification Methods (TMM) are important because most water users may (understandably) be reluctant to sacrifice their immediate economic well-being for the long-term regional benefit afforded by implementing a regionally optimal strategy. In other words, TMM allow a water management district to use a numerically optimal regional strategy as a starting-point from which to develop a strategy that is as socially and politically acceptable as possible.

Additional modification methods have been developed to enhance protection from drought and successful litigation charging unreasonable use (Peralta et al, 1986) and groundwater contamination (Datta and Peralta, 1987). Also, application of the Surrogate Worth Trade-off Method (Maimes and Hall, 1974)a for aiding a group of decision makers to select a 'compromise' strategy from a pareto optimum in a multiobjective situation has been demonstrated (Datta and Peralta, 1986). In summary, a fairly comprehensive group of techniques is available for designing desirable regional potentiometric surfaces and sustained yield groundwater withdrawal strategies. These techniques are

applicable for conjunctive water management in stream-aquifer systems.

It should be noted that most of the procedures mentioned above utilize steady-state flow equations to derive annual groundwater withdrawal rates. As a result they do not consider the additional capture of water that may be caused by time varying pumping. Thus, actually sustainable time varying groundwater withdrawals along recharge sources may be somewhat greater than sustainable groundwater pumping calculated by steady-state approaches. This weakness exists to some extent for any model, depending on the length of the time steps utilized in the simulation.

In some situations, transmissivities change significantly with time during the period in which a steady-state surface is evolving. This means that, in actual implementation, pumping strategies must change somewhat with time during that evolutionary period.

Applications of Target Surface Approaches to Conjunctive Water Management

Maintaining appropriate streamflow in a stream-aquifer system is an important capability of any conjunctive water management methodology. For example, streams in the 8285 sq. km. Bayou Bartholomew Basin (Area A in Fig. 1) flow from Arkansas into Louisiana. Water management strategies developed for that area must assure that reasonable streamflow will continue. Strategies developed using an optimization model can be formed to comply with such a requirement. When developing a strategy for the Bayou Bartholomew Basin using the SSTAR model (Peralta et al., 1985), a limit on recharge to the aquifer from each stream was imposed. Assuming average inflow to the stream and average diversion by riparian users, implementation of a sustained yield strategy that causes no more than average recharge to the aquifer would assure at least average streamflow.

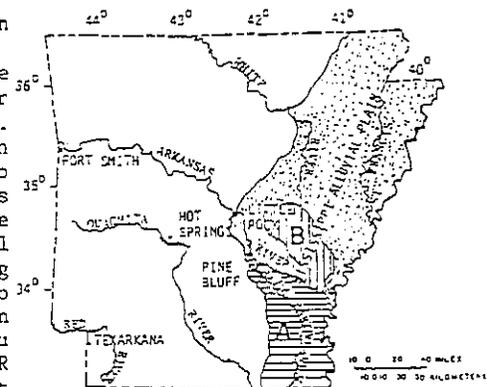


Figure 1. Mississippi Plain Alluvial Aquifer underlies all shaded areas. Target surfaces and sustained yield pumping strategies have been developed for Area A (Bayou Bartholomew Basin) and Area B (Grand Prairie Region).

Table I shows maximum sustainable groundwater pumping for four scenarios. These differ in a) how much annual recharge to the aquifer from the streams is acceptable, and b) the direction and volume of annual groundwater movement between Arkansas and Louisiana. Clearly, as one permits less recharge and more streamflow from streams, sustainable groundwater pumping decreases. Similarly, a hypothetical interstate agreement to maintain at least 3700 cubic decameters (3000 ac-ft) of annual groundwater flow to Louisiana would reduce sustainable groundwater pumping from that achievable if up to 6800 cubic decameters (5500 ac-ft) could enter from Louisiana.

Table I. Maximum Sustainable Annual Groundwater Pumping in the Bayou Bartholomew Basin, (cubic decameters/yr)

Upper Limit on Aquifer Recharge from Streams Flowing to Louisiana, (cubic decameters/yr) †	Upper Limit on Groundwater Flow from Louisiana, (cubic decameters/yr)	Lower Limit on Groundwater flow to Louisiana
	6,800	3,700
95,800	192,300	181,500
15,400	109,500	107,100

† These streams include the Bayou Bartholomew, Bossut, Tensas River and Bayou Macon. Recharge from the Arkansas River and Mississippi River is not included.

The ability to evaluate the temporally and spatially varying need for water from different sources is also important for conjunctive water planning. In one project, an agency needed to know when, where and how much river water would need to be diverted to supplement available groundwater if irrigated crop production were maximized for the 4660 sq. km. Arkansas Grand Prairie (Figure 1) (Yar et al., 1985). It was assumed that a sustained yield pumping strategy would be implemented which would assure at least 6 m (20 ft) of saturated thickness in all cells while approximately maintaining current groundwater levels. The resulting conjunctive use strategy is summarized in Table II.

The first step in strategy development was to determine for each cell, the maximum potential annual and monthly irrigation water requirement based on soil type, suitable crops, irrigation scheduling, and average climatic conditions. These annual water requirements were considered to be upper bounds on acceptable annual groundwater withdrawal in the cells. They were used in SSTAR to calculate the desired annual sustained yield pumping strategy. Simple subtraction of annual groundwater availability from annual water need provides annual need for diverted river water in each cell.

Table II. Monthly Percentages of Potential Crop Water Needs and the Need for Groundwater and Diverted River Water in the Grand Prairie

Month	Monthly Percentage of Potential Seasonal Water Needs	Percentage of Potential Needs Which Can Be Met By Groundwater	Percentage of Potential Needs Which Will Require Surface Water
April	5	1	99
May	7	1	99
June	29	2	98
July	25	4	96
August	32	36	64
September	2	1	99
Entire Season	---	14	86

The second step involved consideration of the monthly variation in water use from the two sources. This was accomplished by assuming that one would want to minimize surface water use during periods of low river flow. Since streamflow diminishes between April and August, and crop water needs are greatest and most critical during August, it was reasonable to plan to use as much groundwater as possible during August. The monthly potential need for diverted river water was estimated by assuming that as much of the annual allotment of groundwater as possible would be used in August. If annual groundwater availability exceeded the August water requirements of a cell, the remaining available groundwater was utilized consecutively in July, June, May, April and lastly in September.

Clearly, river water would need to be the dominant source of supply. Available groundwater is inadequate to support potential irrigated acreages over the long-term. This analysis does not address the potential availability of surface water. If surface water availability is insufficient, then the assumed potential irrigated acreages are not sustainable.

Legal Feasibility and Needed Legal Changes for Implementing a Sustained Yield/Conjunctive Water Use Strategy in Arkansas, a Reasonable Use State.

Conjunctive use, for the purposes of this discussion, includes both stream/aquifer interaction and the coordination of surface and groundwater to meet water requirements. The examples presented have outlined the utility of some of the technical tools available for achieving conjunctive use. The question, then, is whether the legal means to apply these tools is available in the state of Arkansas. Minimum legal requirements for achieving conjunctive use goals must include: (1) a single legal system governing both ground and surface water use; (2) legislative and judicial willingness to adapt the basic riparian rights doctrine to accommodate changing needs; (3) the ability of riparians and non-riparians to use surplus surface water transferred from other basins; and (4) coordinated state agency oversight. A brief overview of pertinent Arkansas water law and analysis follow.

Arkansas, like most of her eastern neighbors, is a riparian rights state. The riparian rights doctrine, based on the old English common law, has long been recognized as the governing doctrine for the legal use of water in Arkansas. (a) Under the riparian rights doctrine, 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.

In Arkansas, the riparian rights doctrine has been modified to allow "reasonable use" of the ground and surface waters of the state by overlying and riparian land owners. (b) In *Harris v. Brooks*, the landmark case for reasonable use case in Arkansas, the Arkansas Supreme Court ruled 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 exercise his right reasonably and with due regard to the rights of others similarly situated." (c)

In *Jones v. OZ-ARK-VAL Poultry Co.*, the court stated that the reasonable use rule applied to all underground waters, in addition to surface waters, whether a "true subterranean stream" or "subterranean percolating waters." (d) The Arkansas high court further favorably recognized the California correlative rights doctrine as set forth in *Hudson v. Dailey*. (e) Under correlative rights, the reasonable use rule is modified in times of scarcity to allow each overlying land owner a proportionate or prorated share of the supply. The court ruled that an overlying groundwater user 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." (f)

What constitutes "unreasonable use" has been ruled "largely a matter of the discretion of the court after an evaluation of the conflicting interests of each of the contestants before the court." (g) The court considers such factors as the purpose, extent, duration, 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. (h) The court has recognized two alternatives for dealing with "unreasonable users", depending upon "all the facts and circumstances of a particular case": (1) declaring the interfering use "unreasonable and, as such, enjoined"; or (2) making a "reasonable and equitable adjustment." (i) For example, in a groundwater case, ordering payment to extend affected wells to greater depths or limiting the number of hours per day that the interfering well(s) may legally be used. (j)

Both case and statutory law have consistently given domestic use precedence over other uses of surface water. (k) In harmony with the laws governing surface water use, the court has ruled industrial use of groundwater which

interferes domestic use to be "unreasonable."(l) In such cases, the legal utility of an activity which produces harm is weighed against the legal gravity of the harm on a case by case basis by the court.

The court's policy of weighing "the extent of injury versus the benefit accrued" from the pumping" lends itself well to the designation of appropriate target groundwater levels by the governing water management agency. Target levels are established to protect existing rights by: reducing the incidence of injury and by assuring the long-term availability of the resource for beneficial use. Indeed, the Arkansas Supreme Court has previously used a sort of "target level" approach to settle water disputes.(m) For example, in Harris v. Brooks, the court ruled that the appellees should be enjoined from pumping water out of Horseshoe Lake when the water level reached 189.67 feet, and stated: "We make it clear that that this conclusion is not based on the fact that 189.67 is the normal level and that appellees would have no right to reduce such level. Our conclusion is based on the fact that we think the evidence shows this level happens to be the level below which appellants would be unreasonably interfered with."(n)

In a groundwater case, Lingo v. City of Jacksonville, the court restricted pumping by the City of Jacksonville "to the extent that it would damage the plaintiffs." Saying that "It is difficult at this time to find with any confidence the exact amount of water that may be removed without damage to the landowners," the court concluded that "the pumps individually may not be operated during any one twenty-four hour period for more than eight hours."(o) An optimization method like the Target Objective Approach may well be used in future cases to increase the degree of certainty with which the court can predict the permissible pumping rates to protect existing legal usages. Peralta, et al. (1986) demonstrate how a target level can be designed to provide a degree of protection from depletion for individual well users in a critical cell.

The court has openly stated 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 that may arise in its application."(p) The Arkansas high court has declared that it is "not necessarily adopting all the interpretations given it by the decisions of other states."(q) The Arkansas Supreme Court has consistently based its decisions on the best available hydrologic data, and has not refused to modify the riparian rights doctrine to accommodate beneficial uses of water in the state.

Several proposed water codes have been considered (and rejected) by the Arkansas legislature. The rejections have not apparently been because of a lack of commitment, but because of an apparent lack of general public support for sweeping changes in the existing water rights system. The Arkansas General Assembly has modified the riparian rights doctrine a number of times. In Act 81 of 1957, the legislature made provisions for the lead state water agency (Arkansas Soil and Water Conservation Commission) to allocate surface water in times of shortage. In Act 180 of 1968, the ASWCC was given authority over registration of legal diversions from streams. Finally, in 1985, the legislature passed Act Act 1051, providing for interbasin transport of waters under the jurisdiction of the ASWCC. Regulations governing such transfers are currently being drafted.

The Arkansas Soil and Water Conservation Commission can provide oversight for conjunctive use in the state. Both ground and surface water matters fall under the jurisdiction of this single state agency.

Summary

Groundwater and surface water regional models can be created to develop water use strategies that maximize achievement of predetermined regional objectives. In addition, the water use strategies developed by such planning models can:

- assure the sustained availability of groundwater;
- make best use of surface water resources while they are available for recharge to an aquifer or for diversion to riparian or nonriparian lands; and
- successfully coordinate the use of groundwater and surface water resources that hydrologically interact with each other.

Implementing a sustained yield groundwater management strategy that can sustain approximately the same amount of pumping year after year at each pumping location will ultimately result in the development of a 'steady-state' water table, piezometric or potentiometric surface. Let 'potentiometric surface' refer to the water table or piezometric surface. This steady-state potentiometric surface is a 'target' surface that, when properly designed, assures:

- adequate saturated thicknesses for existing or planned wells;
- adequate saturated thickness to permit additional groundwater pumping in time of drought; and
- movement of an 'appropriate' amount of water between the district's aquifer and connected aquifers or streams.

In summary, water users adhering to such a groundwater management strategy should enjoy some degree of protection from successful litigation charging 'unreasonable use'. Furthermore, the use of diverted river water can be coordinated with the sustainable use of groundwater to maximize the total use of available water. There is not now any major legal impediment to conjunctive use of groundwater and surface water in Arkansas. It is hoped that future acts of the legislature, courts and administrative agencies will preserve presently existing options.

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