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Water for the 21st Century, Will it Be There?

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WATER MANAGEMENT BY DESIGN

BY

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Abstract

One of Arkansas' major water management goals is to provide adequate water for agriculture, the economic mainstay of the state. Effective water management requires inputs from engineering, economics, law, administration, and environmental concern, all in a matrix of public education, participation and communications.

Groundwater levels in eastern Arkansas have been dropping for decades as irrigation for rice, other row crops, and fish farming have increased substantially. Additional surface water supplies are available from the adjacent rivers but there are competition, conflict of use, and jurisdictional problems involved.

A critical path sequence chart was designed to include all the research steps necessary to accomplish the goal of assuring adequate agricultural water. The paper discusses each of the steps involved, the status of research on each step, its source of funding, and how it will be used.

Introduction

The Mississippi alluvial aquifer is a Quaternary deposit underlying much of eastern Arkansas. Overlying a small part of that aquifer is the Grand Prairie (Fig 1), a fairly flat region long famous for intensive production of irrigated rice and soybeans.The major source of irrigation water in the prairie has been Quaternary groundwater. In the prairie, the aquifer is overlain by a relatively impermeable clay layer. The area is especially well-suited for rice production because the clay restricts the downward movement of water and thus limits deep percolation losses. Another less favorable result is that the aquifer in that vicinity is recharged only in locations of stream-aquifer connection. Consequently, recharge has not kept pace with discharge and groundwater levels have been dropping for most of this century. Saturated thicknesses are dangerously thin in some parts of the prairie and wells are becoming inoperable. This trend is projected to continue and the difficulty in obtaining adequate water to increase.

The efforts described in this paper were undertaken to provide a way to meet the long range water needs of users in the Grand Prairie. Because of the area's heavy reliance on groundwater, it is assumed that assuring a sustained yield of groundwater (ie achieving steady state conditions) is desirable. Steady-state conditions imply groundwater levels which are stable over time. Determination of desirable spring groundwater levels and the pumping which will maintain those levels (the target level approach to groundwater management) is an important part of the development of a water management strategy for the area. In order to meet needs in excess of feasible groundwater recharge, it is also assumed that supplemental diverted surface water will be made available from nearby rivers.

The purpose of the paper is to describe the procedure being undertaken to achieve the long term availability of adequate water supplies for the Grand Prairie. A flow-chart of the most significant steps in developing a customized water management strategy for the Grand Prairie is found in Figure 2. The number found with each step is the same number specified in the Procedures section where each step is discussed. The letter above the step signifies its status: C for complete, -C for almost complete, U for underway and F for future. The external funding agency and completion report, if any, is also specified for each step.

Since no single source of funds was available for the entire project and funding had to be sought from outside sources for each step , no firm deadlines for the accomplishment of sequential steps were developed and no time-scale is shown in the figure. The first proposal for a part of the study was funded in 1981.

Procedure

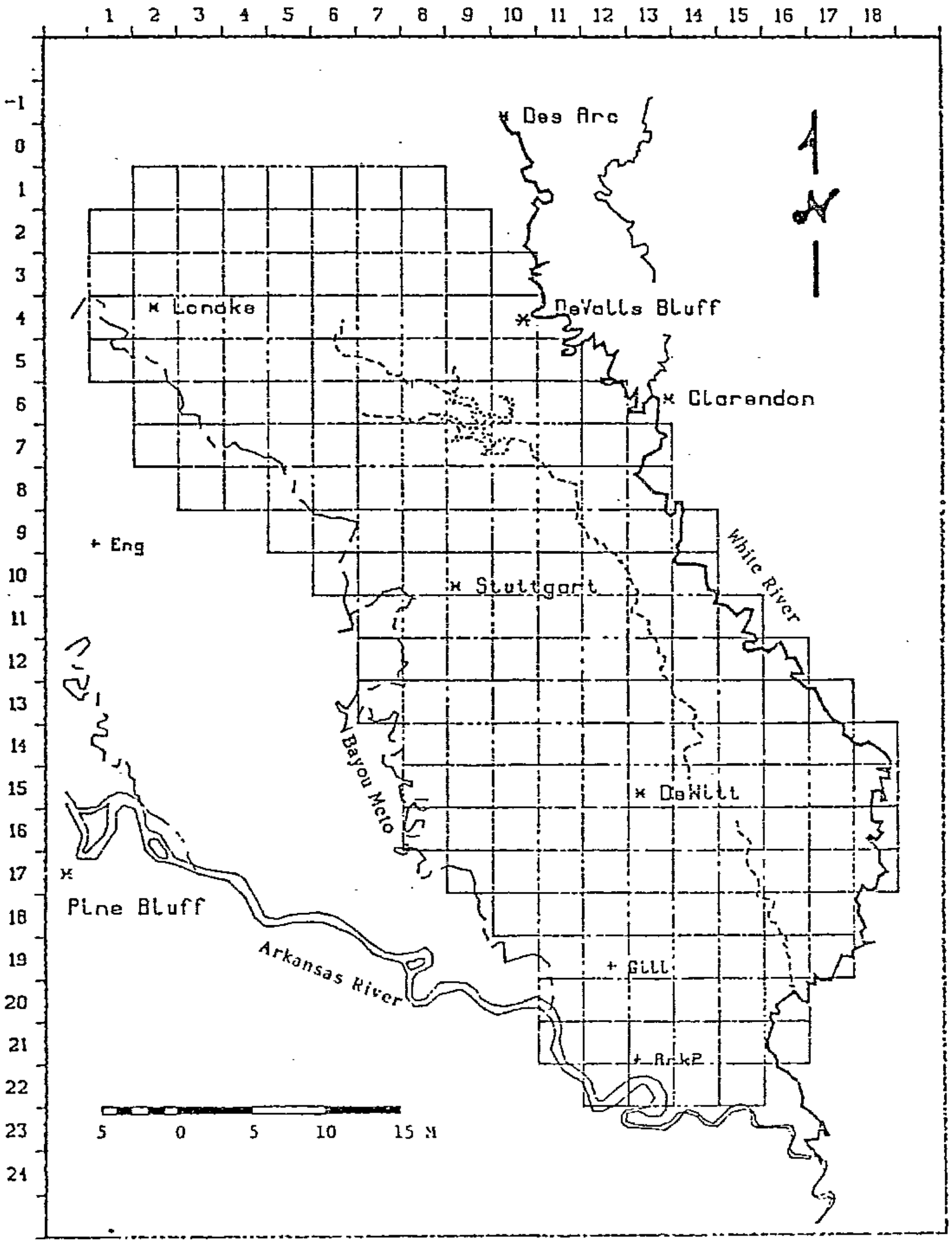

Fig. 1. Grand Prarie Study Area

Development of a successful water management strategy or plan involving groundwater requires the availability of a well validated groundwater simulation model. The Arkansas Soil and Water Conservation Commission, (the state's primary water resources agency) funded the validation of a groundwater model of the area. AQUISIM, a generalized two-dimensional flow model, was chosen for this effort (Verdin, et al, 1981). A uniform 3 mile by 3 mile grid was selected (Fig 1). Determination of the availability of suitable data and/or the creation of data for use in this model was a necessary preliminary step (step #1 in Figure 2) (Peralta et al, 1983a). Because of the earlier groundwater modeling work of Griffis (1972) and work by federal and state agencies, adequately accurate geologic information was already available. For this reason, and because sufficient pumping and groundwater level data was not available prior to the early 1970's, a model calibration step was omitted and only validation was performed. The limited availability of USGS groundwater level data prior to the early 1970's limited the validation period to that between 1972 and 1982. Algorithms were developed which used USGS land use data bases and USDA crop reporting service data to proportionately assign irrigated rice and soybean acreages to each cell in the study area for each year of the validation period. Agricultural, aquacultural and municipal water use were estimated on a cell by cell basis for the same years.

Other programs were written to demonstrate changes in groundwater levels and groundwater storage (#2). For consistency and to provide an unbiased estimate of observed water levels, universal kriging, a statistical techniques, was used to provide gridded estimates of observed elevations. The model was validated using a history matching procedure (#3) (Peralta et al, 1983b). The model- predicted change in storage was five percent greater than the observed change in storage after 10 years of simulation.

Concurrently, the Corps of Engineers began a reconnaissance level study of the feasibility of importing surface water to the Grand Prairie. For consideration in the channel design process, an upper limit on the potential amount of surface water which may someday be needed was desired. Rather than utilizing projected acreages over a planning horizon the Corps preferred to use a potential water need based on soil capability. To provide this data we made use of both county soil surveys and USDA's Master Source File of soil types. The former provides a list of crops which are recommended for each soil type. The latter provides the soil type in the center of each quarter of a square kilometer cell for much of eastern Arkansas. Assigning the most water-intensive practical crop to each of these sub-cells results in the development of a very water-intensive cropping pattern.

Use of the average and extreme irrigation water requirements based on 16 years of climatological data provides estimates of maximum potential irrigation water needs. This procedure was accomplished for both the Bayou Meto Watershed, to which Arkansas River water may be diverted (#4) (Peralta and Dutram, 1984), and the eastern part of the Grand Prairie, to which White River water may be diverted (#5) (Peralta et al, 1983c). Preliminary evaluation of the suitability of Arkansas River water for irrigation on the heavy soils of the Grand Prairie was also performed.

Once the model was validated, groundwater levels and saturated thicknesses in 1992 were predicted (#6) (Peralta et al, 1984). This information is being disseminated via Arkansas Farm Research, a bi-monthly publication of the University which has extensive distribution within the state, and via presentations sponsored by the Arkansas Farm Bureau and the Grand Prairie-White River Irrigation District.

While the technical data collection phase was proceeding, evaluation of the legal/institutional environment necessary for attaining a sustained yield and the development of an algorithm (TARGET2) to prepare sustained yield pumping strategies and desired "target" groundwater levels for the Grand Prairie were also underway. It became obvious fairly early that one of the major obstacles to achieving efficient water management is the institutional framework within which water users and managers must work. An 18 month study (#7) evaluated institutional arrangements applied in a number of states for possible use in Arkansas (Peralta, A.,1982) . The study examined physical, legal and organizational aspects of water management in some detail and laid the foundation for developing an institutionally feasible water management approach for Arkansas, a riparian/reasonable use state.

In TARGET2 (#8) the user can constrain the solution strategy and groundwater levels such that maximum allowable recharge at peripheral constant head cells are not exceeded (Peralta and Peralta, 1984a). Similarly, constraints of minimum acceptable saturated thickness, and minimum or maximum pumping can be imposed on a cell by cell basis. The hypothetical use of the procedure for developing sustained yield pumping strategies to maintain target groundwater levels in the Grand Prairie is discussed in part of the Arkansas State Water Plan (#9) (Peralta and Peralta, 1984b). This report also addresses the legal feasibility of implementing such a strategy in Arkansas, a riparian/reasonable use state. The evaluation of legislative action necessary to implement the target level approach to groundwater management is planned for the near future (#10).

TARGET2 represents a straight-forward iterative approach to developing a constrained sustained yield pumping strategy. In order to develop the most appropriate strategy for water users in the area, an optimization approach is also being utilized to design the target groundwater levels and sustained yield pumping strategy which minimize the cost of meeting water needs under a sustained yield scenario (#17). Required inputs to the optimization algorithm, SSTAR, include the cost, constraint and water availability values created by steps #11-16.

Step #11 involves developing the cell by cell set of saturated thicknesses which will provide adequate groundwater to meet needs during a time of drought. To date it has been determined that 25 feet is the minimum desirable spring-time saturated thickness for a single 500 gpm well pumping in isolation to support 50 acres of rice in the Grand Prairie, and assuming an initially horizontal water table (Peralta et al,1984). Determination of the minimum necessary spring saturated thickness for the cell with the least saturated thickness at this time has been accomplished (Dutram and Peralta, 1984). That cell has 7 irrigation wells with some drawdown interactior between wells. Determination of the full set of cell by cell drought-protection saturated thicknesses is the focus of a future project.

An occasional misapplication of groundwater models is to predict the water levels which result from a pumping scenario without evaluating whether the recharge which that scenario requires from a constant head cell is physically feasible. As previously explained, use of TARGET2 requires input of the upper limit on recharge which is permitted to occur at a constant head cell. (This is accomplished by constraining the gradient between the constant head cell and internal cells.) The same requirement exists for SSTAR. Step #12 involves the development of the upper limit on recharge for peripheral cells. For lack of better data, the upper limits which are currently imposed are the recharge rates which occur based on spring 1982 hydraulic gradients. Further desk and field work is needed to gain better cell by cell estimates of the upper limit on recharge which should be imposed in developing sustained yield pumping strategies. There is a great need to develop values of transmissivity between surface and ground water resources for peripheral cells with stream-aquifer connection.

Steps # 13 and 14 are being performed by the Corps of Engineers. These involve determining which cells can receive diverted Arkansas River water and which can receive White River water. Arkansas River water can be diverted to the western part of the Grand Prairie mainly via the Bayou Meto and existing watercourses. Estimated cost of delivering Arkansas river water to specified cells in the Bayou Meto watershed is $17/ac-ft. This figure does not include the cost of transporting water from the watercourse to a user within a cell. Cost figures on delivery of White River water are not currently available. Reconnaissance level evaluation indicates that legally and physically available Arkansas and White River water is adequate to replace current groundwater usage in the cells serviceable by those rivers, assuming average climatological and hydrologic conditions (Dixon and Peralta, 1984).

It was recognized that relying solely on groundwater or diverted surface water may be inappropriate or may be in some situations more costly than water users will be able to afford. As a result, a study of the cost of pseudosources of water was made (#15) (Harper, 1983). By this we refer to the cost or benefit, on an acre-ft or acre-in basis, of on-farm methods of reducing the need to bring groundwater or imported surface water to the farm. Examples of methods evaluated in this study include: decreasing the flood depth on rice fields, changing herbicides to those which do not require draining of the rice field, changing rice varieties, changing to alternate furrow irrigation of soybeans, increased use of tailwater recovery systems, increased use of reservoirs to catch on-farm runoff, and the use of municipal wastewater for irrigation.

Pumping simulations were performed to develop a relationshi, between initial saturated thickness and seasonal average dynamic drawdown for wells representative of the Grand Prairie (#16) (Peralta et al, 1984). This function was then imbedded in the equation used to determine total dynamic head and the resulting cost of groundwater in SSTAR.

The development of an approach for designing the target groundwater levels which will minimize the cost of meeting water needs from conjunctive water resources under a sustained yield constraint has been accomplished (#17). The SSTAR algorithm relies on the synonymity between steady state pumping strategies and sustained yield pumping strategies described by R. Peralta and A. Peralta (1984a). It has been upgraded to include the capability of having constant flux cells and stream aquifer connection in addition to constant head cells. Used as a subroutine within the program is a quadratic programming algorithm, QPTHOR (Lieffson, et al, 1981). The variables in the objective function formulated by SSTAR are the drawdown in each cell. A finite difference form of the Darcy equation (or steady-state Boussinesq equation) is used as a constraint for each cell to assure continuity. Constants include water needs, upper and lower limits on pumping and drawdown and the cost of supplemental water (water other than groundwater) on a cell by cell basis. Recharge at peripheral cells is constrained. Transmissivities are kept constant during a single optimization run, but after an optimal solution is obtained, transmissivities are recalculated based on the optimal drawdown and the procedure repeated. Experience has shown that drawdowns and transmissivities will be in harmony after about six successive optimizations.

There are system-wide economic ramifications of any sustained yield conjunctive use strategy. A procedure and program for developing and comparing the ramifications is under development (#18).

Water rules or laws can impose constraints on the solution space available to either TARGET2 or SSTAR. The economic effect which results from imposing specific sets of rules or laws is being evaluated in a project for the Winthrop Rockefeller Foundation (#19). The results will be presented in a series of workshops for water users, legislators and water managers beginning in the fall of 1984 (#20). With the input and support of water users and state and federal agencies, alternative conjunctive use strategies will be developed and evaluated (#21) and the results presented in an appropriate forum (#22).

Development of an acceptable and feasible conjunctive water use strategy is not the culmination of an effort such as this. If desired by water users and managers, implementation of a selected strategy will follow. Implementation requires, for example, knowing how well a prescribed pumping strategy is being followed. It requires knowing how much and when data should be collected. To gain an initial feel for this topic, Department of the Interior funding was used to survey existing water management districts as to their groundwater monitoring methods and procedures (#23) (Peralta et al, 1983d). An acoustic groundwater level monitoring device was interfaced to a microcomputer board to develop an automated procedure for collecting data at preprogrammed intervals without having to use a drop-down type of monitoring device. Electronics literature is continually being reviewed to identify technologies which may be inexpensively used in automated monitoring.

The location and frequency of groundwater monitoring will be a necessary part of achieving a sustained yield and maintaining target groundwater levels (#24). Kriging is being used to determine desired observation well spacing in the area's most critical cell. The standard error of the estimate of kriged gridded groundwater levels throughout the Grand Prairie range from 4 to 11 feet. The need for additional monitoring locations on an area- wide basis will probably be determined based on these standard errors.

It is extremely important to those involved in this project that user cooperation, rather than forced regulation, be the prime mover in achieving water management. To adequately convey the technical details of the ramifications of following or not following a strategy, a significant emphasis on computer graphics has been made. We were fortunate to obtain the support of a premier developer of computer graphics hardware and software, Superset, Inc. of San Diego, California. We have utilized and are continuing to use the software they provided to develop improved means of communicating technical information (#25).

To reiterate, the objective of the project is to provide a mechanism for the long-term meeting of water needs in the Grand Prairie (#27). We will not know for certain whether we have a good chance of achieving that goal unless we can first see it working in a demonstration project (#26), which will hopefully be initiated in the not too distant future.

SUMMARY AND CONCLUSIONS

Natives who commonly eat elephant meat were asked by one astonished visitor viewing the huge carcass how on earth they could eat a whole elephant. One of the diners answered, "One bite at a time, just one bite at a time." Faced with the need to develop a water management strategy to combat declining groundwater levels in the Arkansas Grand Prairie, the solution can only be achieved "one byte at a time, just one byte at a time."

In today's era of fiscal uncertainty, the likelihood of receiving sufficient single-source funding to address the needs of a sizable region is often slim. It may be necessary to seek several smaller grants and contracts from a variety of sources (both public and private) to address large-scale water management problems. Having a long-range plan with operationalized intermediate steps helps the investigator weed out untenable hypotheses and concentrate on feasible objectives. It also aids the him in evaluating which potential sources of funding are most appropriate for each project and makes it easier for the potential investor to visualize where a given project fits into the overall solution.

The project steps presented here are site-specific (to the Grand Prairie), but the basic approach is applicable for any researcher faced with the need to break a large scale project down into managable "bites." The first requirement is a statement of the long-term objective. The second is the sequential listing of the necessary steps to reach the objective. Third, is the operationalizing of each step, i.e. putting each step in terms that can be achieved. Fourth, possible sources of funding for each step should be evaluated and appropriate efforts to secure funding should be undertaken. Finally, the entire project must be periodically reviewed, updated, and revised as needed. This approach has turned a "Mission Impossible" into an achievable goal on the Arkansas Grand Prairie.

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Fig. 2. Grand Prairie Water Supply Project Flow Chart
(Part 1)

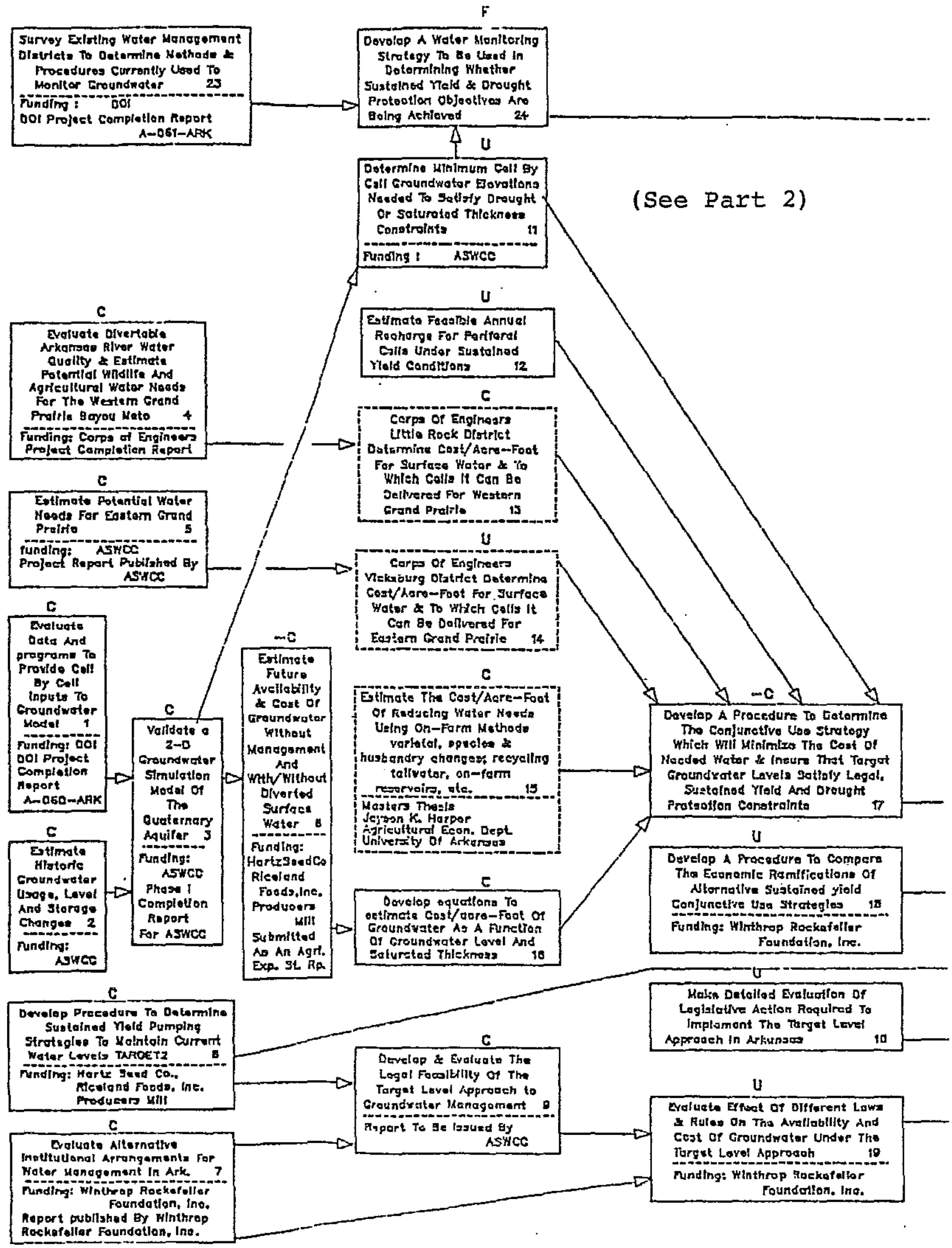

Fig. 2. Grand Prairie Water Supply Project Flow Chart
(Part 2)