DEVELOPMENT OF A COMPUTERIZED WATER BALANCE PROGRAM FOR THE EASTERN ARKANSAS REGION COMPREHENSIVE WATER SUPPLY STUDY

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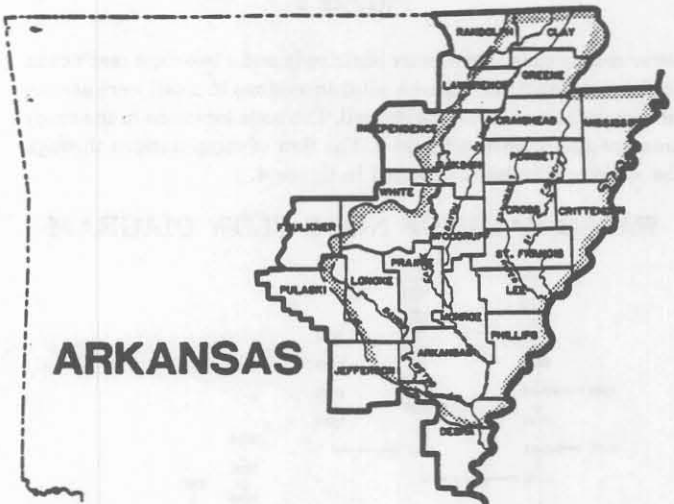
INTRODUCTION

The Eastern Arkansas Region Comprehensive Study was a Reconnaissance level study authorized by the Congress for the purpose of determining the need and feasibility for improvements in the interest of flood control, water conservation and water supply for municipal, industrial and agricultural purposes in a 24 county region of Eastern Arkansas.

A basic tool for analysis of the existing and future conditions of the area was to be the preparation of a water balance. Due to the time constraints placed on completion of the project, a computerized water balance program was developed to aid in meeting the schedule and to allow flexibility for determination of alternative future conditions. The development of this program is described herein. The final product was a FORTRAN 77 code about 500 lines in length. It was developed on a HARRIS 500 computer and utilized the HARRIS data base management system, INFO, to manipulate the input files.



INSTITUTIONAL STUDY AREA

FIGURE 1

STUDY AREA

The study area encompassed all or part of 24 counties totaling some 8,574,461 acres. This represents 25% of the land area within the state of Arkansas. The population of the area was 1,020,062 in 1980. The institutional study area is shown in

The topography of the area varies from hilly near the northwestern boundary to flat in the Grand Prairie region. Numerous surface water sources are located within or adjacent to the study area. The major ground water source is the alluvial aquifer of Quartenary age which supplies about 82% of all water used within the region, primarily for irrigation. The Tertiary aquifers are the primary source of supply for municipal and industrial use. Existing conditions in the region are similar to those in other areas of the Lower Mississippi Valley with the exception that the area utilizes more ground water for irrigation. 96% of all irrigated cropland in Arkansas is located in the study area.

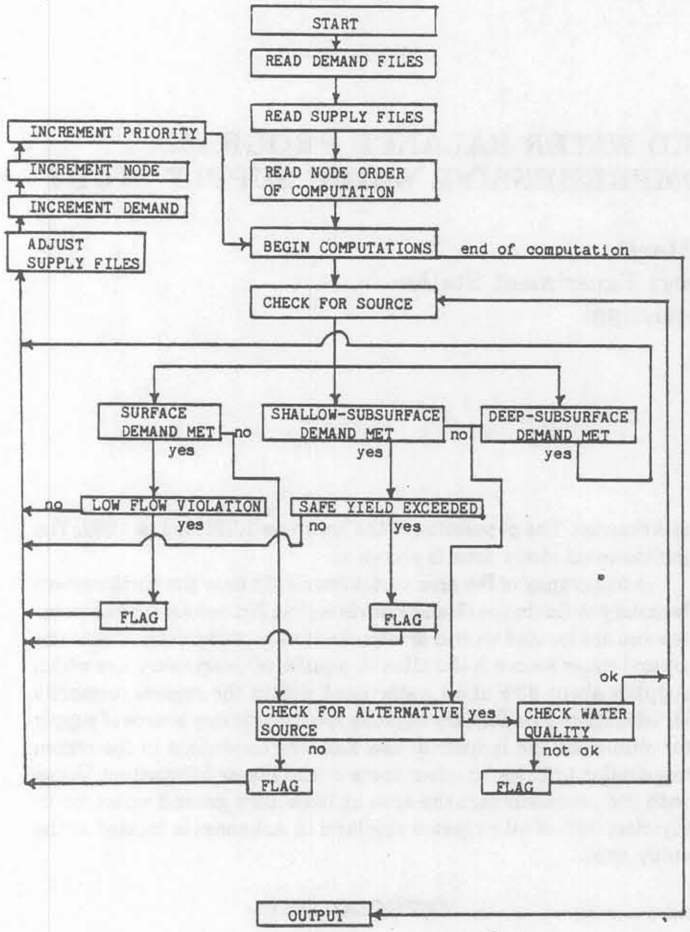
METHODOLOGY

Development

It was recognized that the water balance development was not mathematically rigorous but, particularly for an area of this size, represented a large book keeping problem. The problem was viewed as analogous to opening a checking account, making withdrawals against the account and (hopefully) replacing the withdrawals with deposits. The approach taken was to first develop a set of supply and demand files which could be independently manipulated to change the input parameters. Then, a bookkeeping program was written in FORTRAN 77 to apply the logical tests to the supply and demand files. The program logic is shown in figure 2.

The first step was to identify the input parameters. These fell into two categories, supply and demand. Supply sources could be lumped into three categories; surface water, shallow ground water, and deep ground water. Precipitation, evaporation, infiltration and return flow were implicitly represented in surface water discharge records. Shallow ground water supplies were defined as those found in the Quartenary alluvium. The depth of these deposits varied greatly but were generally between 100 and 200 feet thick. All wells less than 200 feet deep were assumed to be withdrawing from this source. Any ground water withdrawals from depths greater than 200 feet were classified as deep withdrawals and assumed to be tapping the tertiary deposits which included the Midway Group of the Paleocene series and the Wilcox, Claiborne and Jackson Groups and of the Eocene Series.

Demand was presented as seven sources which are shown in Table 1 below. Water quality demand was represented as minimum low flow criteria and were established as the 7 day duration 10 year expected return interval low flow. Navigation requirements were also considered. The demand categories were also prioritized based on human



PROGRAM LOGIC

FIGURE 2

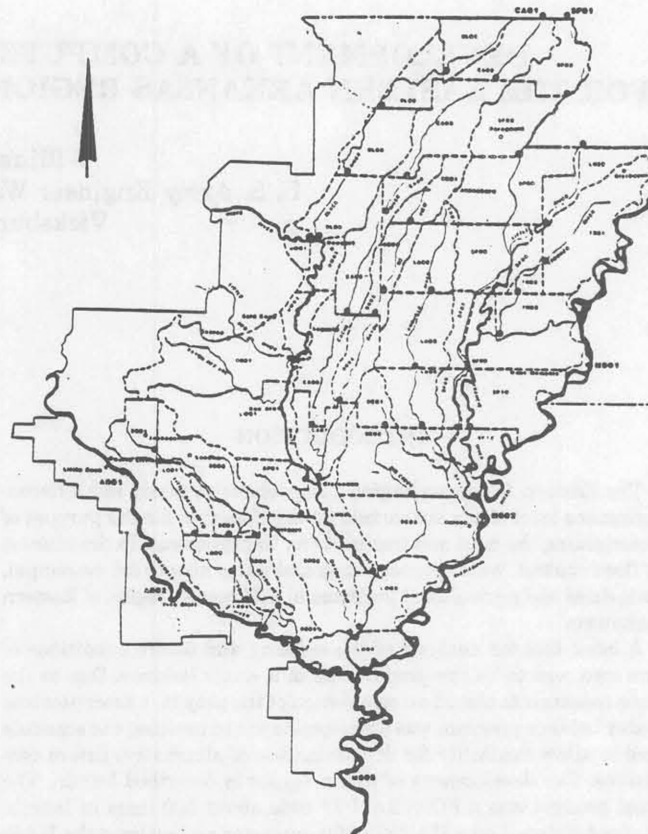
life support requirements first and then in descending importance to the regional economy. Power generation, while extremely important, could be supplemented from sources outside the study area.

Table 1.
Demand Priority and Use Codes

Priority	Demand Code	Demand Category
1	M	Municipal
2	R	Rural Domestic & Livestock
3	G	Irrigation
4	I	Industrial
5	F	Commercial Fishery
6	W	Fish & Wildlife Management
7	E	Thermoelectric Power Gen.

A decision next had to be made whether to base the water balance on physical or political boundaries. To the hydraulic engineer, stream basins seem the logical basis for subdividing the study area. However, the study was on a fast track schedule and all economic and demographic data were available by counties or groups thereof. Therefor, the study area was subdivided into cells. The study area cells are superimposed on physical features and shown in figure 3. Each cell was assigned a unique identifying code consisting of a three

EASTERN ARKANSAS STUDY AREA



STUDY AREA CELLS AND NODES

FIGURE 3

letter county code, a two letter basin code and a two digit reach code. In the computational scheme, all transactions in a cell were assumed to occur at a node within the cell. The node locations in the study area are also shown in figure 3. The flow of computations through the system of nodes is depicted in figure 4.

WATER BALANCE NODE FLOW DIAGRAM

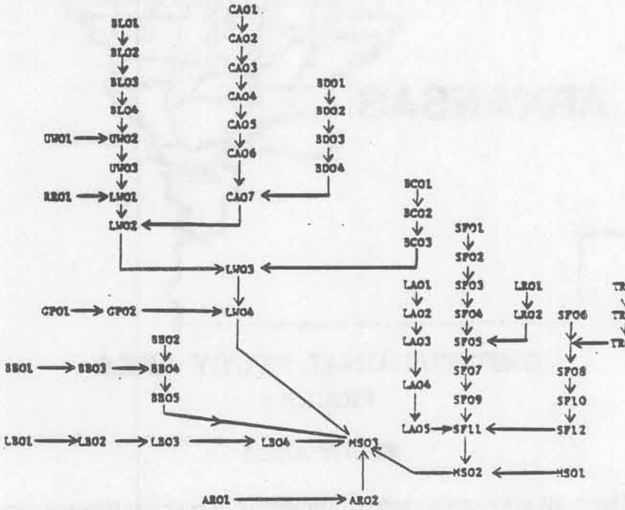


FIGURE 4

Input

The program input consisted of two sets of files, supply files and demand files. Data were input in the most convenient units. All data were converted to acre feet units internally in the program and reconverted before output. This allowed units normally associated with each source to be used such as cubic feet per second for surface flows and millions of gallons per day for municipal demand.

Supply files were developed for each cell utilizing the identity code described above. Additionally, source codes were added that identified the source(s) of water available in the cell, either surface stream, surface impoundments, shallow subsurface or deep subsurface. The stream flow was further identified as annual average, maximum and minimum flows from available discharge records. Though quantified, lakes and reservoirs were not included as available supplies. The computation of a safe yield for the many impoundments in the study area was beyond the scope of the study. Shallow subsurface (alluvial aquifer) supplies were quantified at two levels, current pumpage and safe yield. Available reserves were also computed. Deep subsurface (tertiary aquifer) supplies were quantified at the current pumpage capacities. A water quality code was also associated with each source which indicated its suitability for each category of demand.

Demand files were developed for the seven categories listed in Table 1, on an annual basis. Each demand source was associated with a cell. The demand was input on a consumption per unit basis. The consumptive units were also input. For example, municipal demand was input as gallons per capita. This was multiplied by the population (consumptive units) to arrive at total consumption for the municipality. The demand was also assigned a primary source of supply which was the same as the existing source of supply in 1980, the base year for the study. Alternative sources were designated as secondary and tertiary, if available. To illustrate, a town located on a stream currently satisfies its municipal water demand from the alluvial aquifer (wells less than 200 feet deep). If this source were depleted and the town were over a tertiary aquifer, it could still meet its demands by sinking a deeper well. If this source were depleted or unavailable, water could be obtained from the stream, though it would require treatment. Therefore, the town's primary source is shallow subsurface water, its secondary source is deep subsurface water and its tertiary source surface water.

The manipulation of the input files was accomplished with the Harris data base management system known as INFO. This system was utilized to update demands for the out years. Once input, all the data was sorted by node and priority to provide the correct order of computation. The Water Balance program then functioned as a bookkeeping tool with a number of checks and flags embedded in the code.

Assumptions

The program logic for matching demands with supplies was based on the following assumptions:

1. Demands were met from their designated primary source in the order of priority listed in Table 1.
2. If the primary source was depleted, demands were met from secondary and tertiary sources in order of priority.
3. Surface water demands were subtracted from streamflow supplies in descending order from upstream to downstream for each cell within a basin and were repeated for adjacent basins. Demands satisfied from an upstream cell reduced the water available to the next downstream cell. The hierarchy of computations is illlustrated in figure 4. The computations begin with the highest priority of demand and proceed for the entire area. They are then repeated for each category in priority sequence. Shortages and breaches of criteria are flagged. For example, when the annual flow for a cell, less upstream demands, is unable to satisfy demands in that cell that and all downstream demands are flagged "unmet". If the demand violates the 7-Q-10 lowflow criteria, the flag "low flow violation" is posted even though demands are met.
4. For some alternatives, the alluvial aquifer was allowed to be depleted. For others, when the demand exceeded the annual safe yield the demand was flagged "unmet". This assumed that the State would enact a water code that would restrict withdrawals to the safe yield by 1990. The "safe yield" being that replaced by natural recharge on an annual basis.
5. For depletion alternatives, groundwater reserves were calculated as the algebraic sum of initial reserves plus recharge less demand.
6. Ground water reserves for each cell were assumed to be limited to the area covered by that cell. This assumption is based on the unrealistic assumption that ground water was unable to move between cells. However, it was thought that this would not be an unreasonable assumption for long term or short term modeling. Long term effects would tend to reach an equilibrium condition. Short term effects would not be able to adjust to local draw downs in the aquifer.
7. The quantity of reserves and annual recharge estimates for the tertiary aquifer were not calculated for this reconnaissance level study. Therefore, the demand from this source was always considered met.

Output

The output from the program was in the form of a series of tabulations and listings. A tabulation was produced for each county showing annual demands by source and by use category with irrigation demands further subdivided by crops. A tabulation of demands in millions of gallons per day (MGD) was also produced for each cell by source and by use category with irrigated area provided by crop type. A listing was also provided for each county which identified each demand transaction grouped by cell showing the specific identifier for each demand, the use category, demand quantity, source from which it was requested, the quantity of water supplied from that source, the demand not met, and the water quality of that source. The status of each source at the completion of the run was displayed for each cell listing the initial and final status as a reduced flow for streamflow or a percent of safe yield for ground water. The summary output was a county listing which provided a comparison of total demand to unmet demand by category of use.

APPLICATION

For the Eastern Arkansas study the water balance program was used to model conditions at the end of each decade, 1980 to 2030. Demand files were based on predictions of increases in population, livestock herds, industrial activity, crop irrigation, and use for fish and wildlife. Thermo-electric power generation and commercial fishery activity was assumed constant. With usage rates held constant, the demand files were updated for each decade by use of a growth multiplier for each category and, in the case of irrigation, each crop type. This greatly facilitated the update process.

Supply files were updated based on the previous decades results for ground water. Surface water was assumed to renew at the same rate each year.

The use rates could also be easily changed to reflect conservation measures or legislative restrictions on ground water withdrawal. The water balance program was used to evaluate several scenarios for future water consumption. These are summarized in Table 2.

TABLE 2
Results of Alternative Water Use Scenarios

Use Rate	2030 Surface Water	2030 Alluvial Aquifer
1980 W/O Consv.	no depleted cells	16 cells deficient
1980 W/ Consv.	no depleted cells	13 cells deficient
Projected Increases W/O Consv.	no depleted cells	20 cells deficient
Projected Increases W/ Consv.	no depleted cells	18 cells deficient

As can be seen from Table 2, serious problems were projected for large areas of the study area. The water balance program thus identified areas where plans could be developed to alleviate the deficiencies by supplemental use of the abundant surface water or by tapping the deeper aquifer.

CONCLUSION

The water balance program described herein was developed in a relatively short time. Once the logic was developed and the computational schemes and the necessary input defined the coding was accomplished with a programming effort of about 200 hours. This included development, testing, debugging, and documentation. Several months were spent developing the supply and demand files. Without such a tool as this, the study would have been impossible to complete in the allotted time. Unfortunately, the time constraints forced many aspects of the program to be "hard wired" to suit the Eastern Arkansas study. However, it would not be difficult to develop a generalized version of this code which would greatly aid similar reconnaissance level studies in the future.

ACKNOWLEDGMENTS

Development of the model and adoption of the techniques described herein was accomplished by an interdisciplinary study team in conjunction with the ADP Center. The author, as a member of this study team, was responsible for much of the conceptual methodology and development of the Water Balance Program while working in the Planning Division of the USAE District in Memphis, Tennessee. The study was funded by the Memphis District. The Chief of Engineers has given permission to publish this paper.

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