QUANTIFYING SURFACE WATER SUPPLIES

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INTRODUCTION

This paper will present the methodology used in the "Eastern Arkansas Region Comprehensive Study" conducted by the U.S. Army Corps of Engineers, Memphis District, in which all water resources were identified and quantified for a water balance analysis. The study was undertaken to identify areas in which deficit water supplies occurred or were projected to occur, and to propose alternatives for alleviating the problems.

The first step in any study requires the careful consideration of the level of detail necessary, within time and cost constraints, to produce viable end results. As in any engineering study, the product of the study is only as accurate as the data available to perform the study. As some of the methods of discharge determination are discussed in this paper, keep in mind the sources of data available in your region.

BACKGROUND

Dependable yield

Historically, the Corps of Engineers role in surface water flows has been oriented to flood control and navigation. In flood control studies, design discharges are expressed in terms of peak discharges. Usually exceedance frequency is the basis on which the design flows are chosen. This may be anywhere from the 5 year event in agricultural areas to the probable maximum flood at large dams. In navigation, the discharge, per se, is not as critical as the available draft and the channel alignment. What then, should be, or is, the criteria to be used in evaluating the dependable yield of surface water supplies? The possibilities include low flow frequency analysis, mean annual discharges, minimum annual discharges, mean monthly discharges, and minimum monthly discharges. Again, the decision must be based on the level of detail of the study and the availability of data. The data are not just limited to surface water supplies; they also include the availability of dependable aquifer yields and demand data. In the Eastern Arkansas Reconnaissance Study, annual values as well as mean monthly values were used in a water balance program to isolate regions within the study area in which projected usage would exceed the present allocation of resources.

The Eastern Arkansas area

The 13,400 square miles in the Eastern Arkansas study encompasses a 24 county area and portions of three major tributaries to the Mississippi River. These tributaries are the St. Francis River, the White River, and the Arkansas River (Figure 1). The total drainage area of these three basins is approximately 196,685 square miles, or 17.5% of the total drainage area on the Mississippi River above Arkansas City (Figure 2).

EASTERN ARKANSAS STUDY AREA

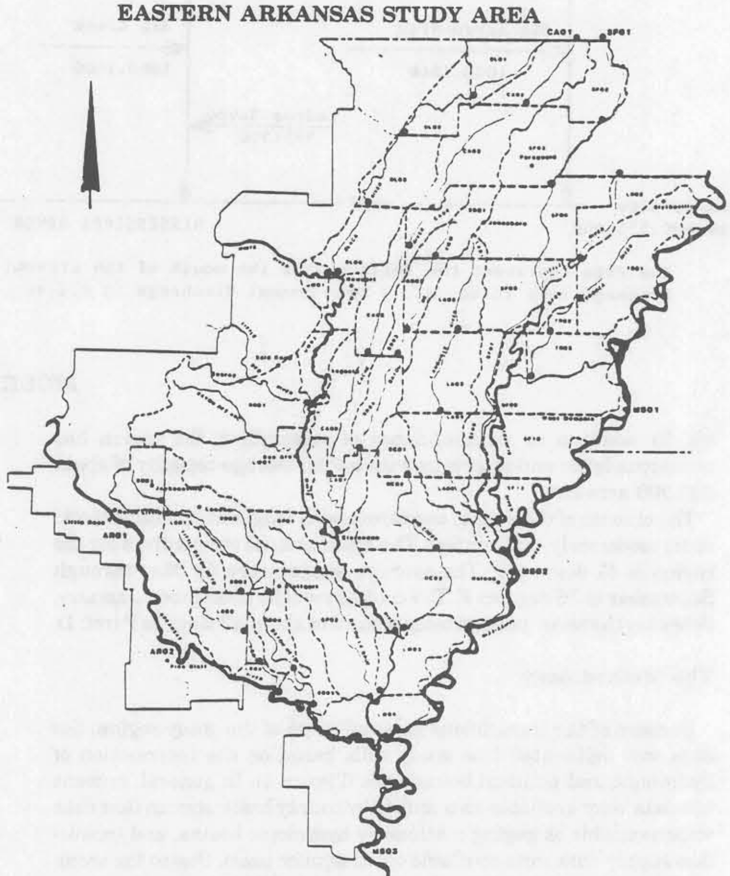

FIGURE 1

About 90% of the area is nearly flat alluvial delta land with the main physiographic feature being Crowley's Ridge which extends the length of and mainly in the middle of the St. Francis Basin. Excluding the Black River and its tributaries, the highest stream gradients in the area are about 3.0 feet per mile, which occur on the upper St. Francis River. The flattest slopes are 0.2 to 0.3 feet per mile and occur in the LaGrue Bayou Basin and on a portion of the Little River. Typical gradients fall between 0.5 and 1.0 feet per mile.

The area's average annual rainfall of 50 inches produces about 17.5 inches of runoff or 1.3 cfs per square mile. The average annual discharge generated within the study area is approximately 17,500

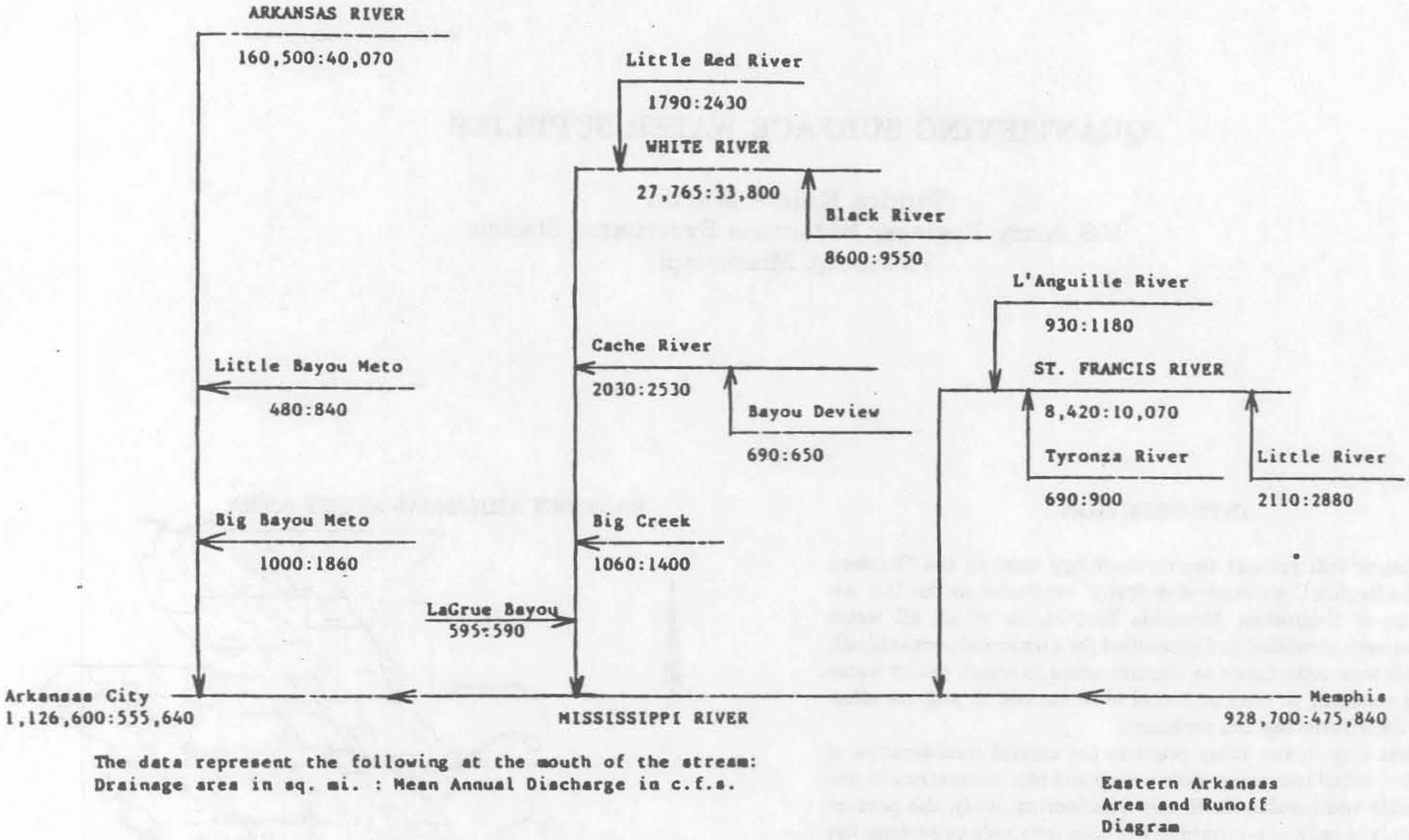

FIGURE 2

cfs. In addition to an abundance of streamflow, the region has numerous lakes and reservoirs with a total storage capacity of about 933,900 acre-feet.

The climate of the area is temperate with long, warm summers and short moderately cold winters. The mean annual temperature for the region is 61 degrees F. The average temperature for May through September is 76 degrees F. The coldest months (December, January, February) have an average temperature of about 42 degrees F (ref. 1).

The Methodology

Because of the tremendous size and scope of the study region, the area was delineated into study cells based on the intersection of hydrologic and political boundaries (Figure 1). In general, current use data were available on a county by county basis, stream flow data were available at gaging stations by hydrologic basins, and subsurface supply data were available on an aquifer basis. Due to the seemingly noncongruent data, the study team decided that the water balance could best be conducted by means of a drainage basin / county intersection. Discharges for each of fifty-nine cells in the 24 county area were determined at the location (node) where a major stream crossed the most downstream county line. Additionally, five other nodes were identified on the boundary of the study area on the Mississippi and Arkansas Rivers at specific gaging stations to represent surface water supplies in the water balance. Demand data and subsurface supply data were also determined according to the same cell subdivisions. Consequently, a node flow diagram resulted which established the sequence in which the water balance calculations would be made (Figure 3).

WATER BALANCE NODE FLOW DIAGRAM

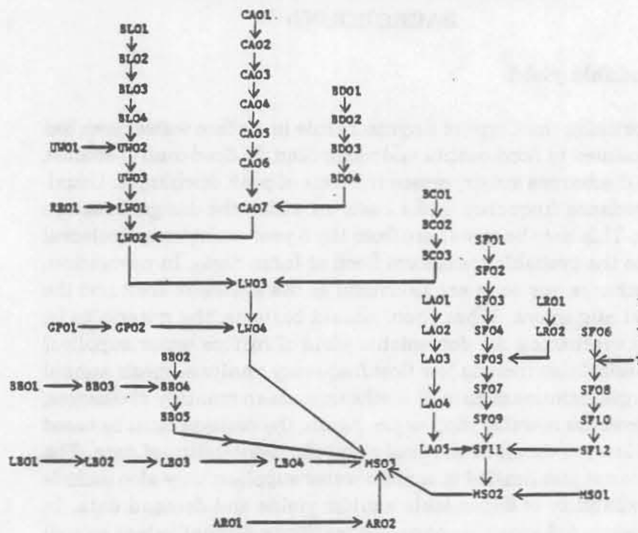

FIGURE 3

QUANTIFYING THE SUPPLY

Streamflow

The first step in quantifying the surface water supplies was to locate the streamflow gaging records in the area. The United States Geological Survey (USGS) and the United States Army Corps of

Engineers (USACE) maintain and collect data from numerous daily discharge as well as stage stations within or adjacent to the study boundaries. The USGS office at Little Rock, Arkansas provided summary data printouts from their WATSTORE data base, and also some statistical data. Table 1 presents the drainage area above the gage, the period of record, and the minimum, maximum,and average annual discharges at some of the gages based on observed flows for the given period of record.

The mean annual discharge is simply the average of all average annual discharges for the period of record. The minimum annual discharge is the minimum observed daily flow for each year, averaged over the period of record. The maximum annual discharge is the converse of the minimum. The water balance used the average annual values to identify deficit cells, and used monthly availability of surface water supplies with corresponding peak monthly irrigation demands for the design of alternatives.

As might be expected, the gaging station locations did not always coincide with the location of the nodes used in the water balance. Furthermore, in some cells data were either sparse or nonexistent. Therefore, the following discusses the means by which the data and other resources were used to translate discharges to the location of the nodes.

Table 1
Discharge Gages in Eastern Arkansas

Gage Location	Drainage Area (mi²)	Period of Record	Minimum	Maximum Annual Q (cfs)	Average
Arkansas River					
Arkansas River @ Murray Dam	158030	1928-1982	10820	88920	40074
Bayou Meto and Grand Prairie Basin					
Bayou Meto nr Lonoke	207	1955-1982	94	553	290
Lagrue Bayou nr Stuttgart	176	1936-1954	55	490	230
Bayou Meto nr Stuttgart	574	1936-1954	NA	NA	572
Crooked Creek nr	79	1941-1954	NA	NA	258
Big Creek Basin					
Big Creek nr Moro	77	1963-1970	28	113	93
Big Creek @ Poplar Grove	448	1971-1982	157	1153	591
Black River Basin					
Black River nr Corning	1750	1939-1982	660	4010	1780
Black River @ Pocahontas	4845	1937-1970	2380	10820	5520
Black River @ Black Rock	7369	1930-1982	3550	17330	8320
Strawberry River nr Poughkeepsie	473	1936-1982	NA	NA	500

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Methods of determining node discharges

A number of data sources and techniques were applied in the determination of discharges at each node. The data taken directly from the daily discharge stations were used when the nodes were located near the gage site. Since this did not occur often, the data at the gages were also used with a number of techniques which translated the data to the location of the node. Included in these techniques are the development of a drainage area versus discharge relationship, use of drainage area to discharge ratios, the application of rating curves at stage gages, and the use of available hydrologic models. In all cases, node discharges were determined based on the best source of available data.

A drainage area versus discharge relationship was developed based on uncontrolled gages in the area with similar basin characteristics (such as stream slope, drainage area, basin shape, etc.) for minimum, maximum, and mean annual discharges. (An uncontrolled basin is defined as one in which an upstream structure does not control downstream flows; a naturally drained basin). This relationship aided in the determination of discharges at nodes where data were unavailable, or where the nearest discharge station did not reflect the introduction of an ungaged tributary in the cell. The curves in Figure 4 were primarily used in portions of the Cache, Bayou DeView, St. Francis, Tyronza, and Big Creek basins. To apply this technique the drainage area above the node is determined, then the discharge is taken directly from the graphical relationship. Another similar means of obtaining data in an ungaged basin is to use the regional analysis published by the USGS in each state. This analysis presents the statistical determination of discharges as they relate to stream slopes and drainage areas and provides the data on a frequency of occurrence basis.

The drainage area ratio technique consists of extrapolating data at an upstream gage to the node location downstream by delineating the additional drainage area, adding that change in drainage area to the area represented by the upstream gage, then increasing the discharge by that percent increase in drainage area. This technique was used on the Upper White, Black, and Little Red Rivers as these streams had fairly steep stream slopes and were not comparable to the basins in which the drainage area versus discharge relationship was developed. This technique, however, must be applied such that consideration is given to channel losses downstream of the gage due to storage, and the location and quantity of inflows from a gaged tributary. Extrapolated data were also compared with possible gaging stations in which rating curves exist.

Some cell discharges were based on reliable period of record stage data and intermittent discharge data. This method was applied in the Grand Prairie-Bayou Meto area to concur with supply data determined by the Vicksburg District, Corps of Engineers in a water supply study recently completed (ref 2). Annual and monthly average stages were determined then a discharge rating curve was used to convert these stages to discharges. Detailed hydrologic models provided discharge information on the L'Anguille River and on the lower cells of the St. Francis Basin. A detailed HEC-1 model on the L'Anguille River provided discharge ratios of flows at the cells to flows at the Palestine discharge station. A period of record inflow model to the Huxtable Pumping Plant on the lower St. Francis produced annual discharge data for the two cells in the basin which are effected by the backwater pumps.

In summary, the determination of available surface water discharges may require optimization of all possible data and careful scrutiny by the engineer in the application of these techniques. The cooperative exchange of data between agencies proved to be of utmost value in the Eastern Arkansas study. Correspondence with other agencies can provide invaluable input concerning techniques, assumptions, and general stream flow characteristics of an area.

Lakes and reservoirs

The Eastern Arkansas study area has an abundance of existing lakes and reservoirs. In the 24 county area there are 1,515 lakes with a surface area greater than 5 acres. The total maximum pool storage capacity of all these lakes is 933,900 acre-ft. Private interests control about 80% of the total storage capacities of these lakes, with the remainder owned by state and federal agencies. Additionally, there are four Corps lakes which lie outside the study boundary but contribute directly to downstream discharges on major streams in the study area. The lakes and reservoirs in the study are operated for flood control, recreation, irrigation, hydropower, municipal and

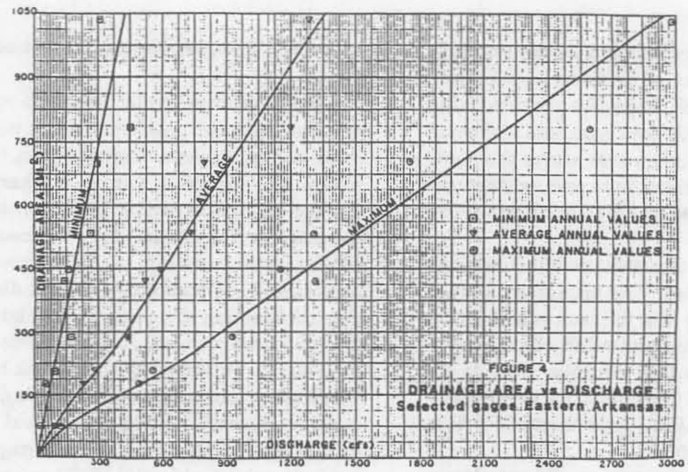

FIGURE 4

industrial uses. Of the lakes within the study boundary, the primary usage is recreation (ref. 3).

Yields from major reservoirs in the area were not determined for use in a water balance. The lakes were simply inventoried according to storage capacity, ownership, and usage. Yield data would be most pertinent in the event of more detailed studies and was recommended for the next phase of the study. The use of lakes and reservoirs for water supply storage can be a critical element for satisfying unmet demands. Storage for water supply can be met by two means; one is to reallocate pool storage in existing reservoirs and the other is to create new storage via the construction of dams.

ASSUMPTIONS AND ISSUES

The results of this study, though comprehensive in scope, required a number of assumptions which may or may not be pertinent to other areas and/or studies. These assumptions were technical and political in nature.

Technical Fallacies/Assumptions

There were several assumptions made concerning the hydrologic conditions. First, hydrologic conditions based on historical records were assumed to be accurate for both present conditions and for future conditions. This meant that runoff values which could change due to changes in land use or due to proposed channel work were not adjusted to reflect such. Flow records on major streams downstream of reservoirs reflect historical operations of reservoirs, which in some cases changed numerous times over the life of the project. Changes in operation of a reservoir, as well as, reallocation of storage pools can directly effect the expected downstream availability. However, operational changes have little effect on expected annual yields since annual volumes will likely remain constant.

When considering seasonal variations in discharge, the average annual discharge is not a realistic quantity on which to base dependable yield to meet unmet irrigation demands. In general, high irrigation demands occur during the low flow months (July to September). Therefore, monthly values would best reflect available yield, and were therefore determined in this study when identifying sources of surface water supplies.

Another minor fallacy was the location of the nodes within each cell. Certainly available discharges at the extreme downstream point are in excess of what would be reasonably available at some location upstream but still within the cell. This problem can easily be resolved by inspecting the proximity of the user to the source and prorating the discharges accordingly, or by dividing the study area into smaller cells which would alleviate the ambiguities.

Political issues

From a somewhat political viewpoint, the issue of water rights comes into focus. In the discussion of such topics as interbasin transfers, reallocation of storage pools, and priority of users, the hydraulic engineer is faced with unlimited scenarios in satisfying unmet demands. For instance, the Mississippi River appears to be an unlimited resource with an average annual flow at Arkansas City of 555,640 cfs. If in fact it is to be used as a supplemental source for irrigation demands, what then becomes the effect to availability of discharges for navigation? How are municipal users effected downstream? What are the effects of point source withdrawal on water quality? The conflicts are endless.

CONCLUSIONS

The results of the water balance analysis provided the location of cells where projected demands exceeded the present allocation of subsurface supplies. Alternatives were evaluated in which unmet demands were satisfied by using surface supplies that were available within the cell first, then by feasible supplies in adjacent basins. Since these unmet demands were for irrigation, a distribution system was designed using pumps, control structures, new reservoirs, and distribution canals to convey the surface supplies to the areas in need. The project was deemed to be cost effective and is currently in a feasibility phase of study. In this phase of study, more scrutiny will be used in quantifying the dependable yields of the resources. Also, in this phase, the area will be broken down into three- square-mile grids in which surface and subsurface yields and demands will be refined. The effects of the alternatives on conflicting use categories will be evaluated with respect to newly adopted water rights in the state of Arkansas.

ACKNOWLEDGMENTS

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