ESTIMATING AGRICULTURAL AND FISH AND WILDLIFE WATER DEMANDS: AN ESSENTIAL COMPONENT OF WATER USE MANAGEMENT

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INTRODUCTION

The availability of an abundant water supply has been a major resource of the Yazoo River Basin. However, water requirements for a number of uses has increased in recent years. Most of the State's irrigated crops, predominantly rice, soybeans, and the commercial fish farming industry, are located in the Yazoo River Basin, a 26 county area in northwest Mississippi (Figure 1). As such, State statistics on irrigated acreage and commercial fish acreage are reflective of trends in the Yazoo River Basin. According to the Census of Agriculture, irrigated acres in the State have increased from 146,000 acres in 1964 to 430,901 acres in 1982, of which 419,404 acres were in the Yazoo River Basin [U.S. Department of Commerce, 1984]. Commercial fish farm acreage grew from 18,500 acres in 1977 to over 64,000 acres in 1982 [U.S. Department of Agriculture, 1982, pp. 3-12; Mississippi Cooperative Extension Service, 1983]. This rapid growth in combination with expected future changes in farm irrigation and commercial fish farming has raised concern that future water shortages could occur in the Basin.

The U.S. Army Corps of Engineers, Vicksburg District, contracted with the Department of Agriculture Economics at Mississippi State University in 1982 to estimate the agricultural and fish and wildlife water demands for the Yazoo River Basin to the year 2030 as a part of their overall water supply study for the Yazoo River Basin. The purpose of this paper is to describe the methodology developed to provide the crop and fish farming water use estimates requested by the Corp of Engineers and to emphasize the methodology's applicability for water use management.

The paper is divided into four major components. First, the issue of why the development of water management systems will be increasingly important in the future and how research can be an integral component of the water management process are addressed. Secondly an overview of a model that was developed for examining agricultural and fish and wildlife water demands in the Yazoo Rover Basin of Mississippi is presented. Thirdly, selected results from the model depicting water requirements for 1980-2030 are shown to exemplify use of the model for purposes of projecting water demands. Finally, the paper concludes with a discussion of how the model can be used in combination with other data bases to assist decision makers in the development of water management policy.

WATER MANAGEMENT ISSUES IN MISSISSIPPI

Mississippi is just beginning to realize that future supplies of quality water may not be as readily accessible as they have historically been. After years of water management efforts directed toward disposing of excess water, a problem that still exists, certain areas of the state are beginning to realize that groundwater overdraft problems are eminent. Groundwater has been the primary source of water in

Figure 1. Yazoo River Basin Delineation

Mississippi. The U.S. Geological Survey estimated that 82 percent of the 1980 crop irrigation water came from groundwater sources [Callahan]. Certain users, aquaculture for example, rely almost totally upon groundwater sources, due to water quality requirements.

Contrary to the water resource problems faced by arid regions of the nation, topographical and climatic conditions create an excellent potential for surface water storage facilities in Mississippi. An interagency report on Mississippi's land and water resources concluded that the potential for water storage reservoirs in upstream watersheds is excellent throughout most areas of the state [U.S. Department of Agriculture, 1982]. The report did note, however, that the Delta region of the state, Major Land Resource Area, 131, (MLRA 131), where most of the irrigation use for crops and virtually all the aquaculture occurs, was an exception in that few if any storage sites are available.

Responding to the growing awareness of potential water use problems in the state, the 1985 session of the legislative passed two bills, H.B. 762 and H.B. 149, that can significantly influence future water use and the manner in which water resources are developed and managed [Mississippi Legislature]. H.B. 762 changes water rights law from a prior appropriation/riparian structure to a permit system, and H.B. 149 establishes the statutory right to set up substate districts [Mississippi Legislature]. As water management districts are developed, policymakers will be faced with decisions affecting a broad spectrum of issues ranging from the development of allocation mechanisms for determining who gets water and how much during periods of shortfall and the long range development of water supplies to meet growing needs. The following section describes a model with the capability of providing information relevant to this issue.

ANALYTICAL MODEL

Pursuant to the estimation of irrigation water requirements, several criteria were considered prior to developing a methodological procedure for performing this task. Much of the previous work that had been done in estimating water requirements for irrigated acreage had been based primarily upon physical relationships [Lower Mississippi Region Comprehensive Study, 1974 a, b, c, d; and U.S. Department of Agriculture, 1970]. A primary concern for this study was to incorporate economic analysis into the determination of irrigated acreage and subsequent water use. An aggregate linear programming was selected as the analytical tool for determining irrigation water use in the Yazoo River Basin. Linear programming as used in this study determines the resource allocation and enterprise mix which maximizes net returns to management and land ownership.

The analytical model developed for estimation of supplemental irrigation requirements for the Yazoo River Basin consisted of several components. These components are: (1) a BASIC language supplemental water needs program using the Blaney-Criddle method; (2) a Fortran matrix generator; (3) a FMPS linear programming model [Functional Mathematical Programming System]; and (4) a Fortran report writer. An overview of the model operation is presented in Figure 2.

The analysis centers around the linear programming model. The linear programming model selects profit maximizing solutions from among alternative irrigated and non-irrigated crops on alternative soils subject to certain constraints. The postulated model has two basic restrictions: (1) the acreage of land in each soil type by county, and (2) upper and lower bounds on county production of each crop.

Other model components facilitate operation of the linear programming model or interpret model results. The supplemental water needs program calculates the water requirements for irrigated crops and is used as a basic data input in the linear programming model. With many counties to model, numerous activities and few restrictions, similarities among activities, and a 10-year incremental analysis, the matrix generator greatly facilitated the formatting and inputting of data for use by the FMPS linear programming algorithm. The report writer program interprets the FMPS results and outputs them in summary form. Each of these components are more fully developed below.

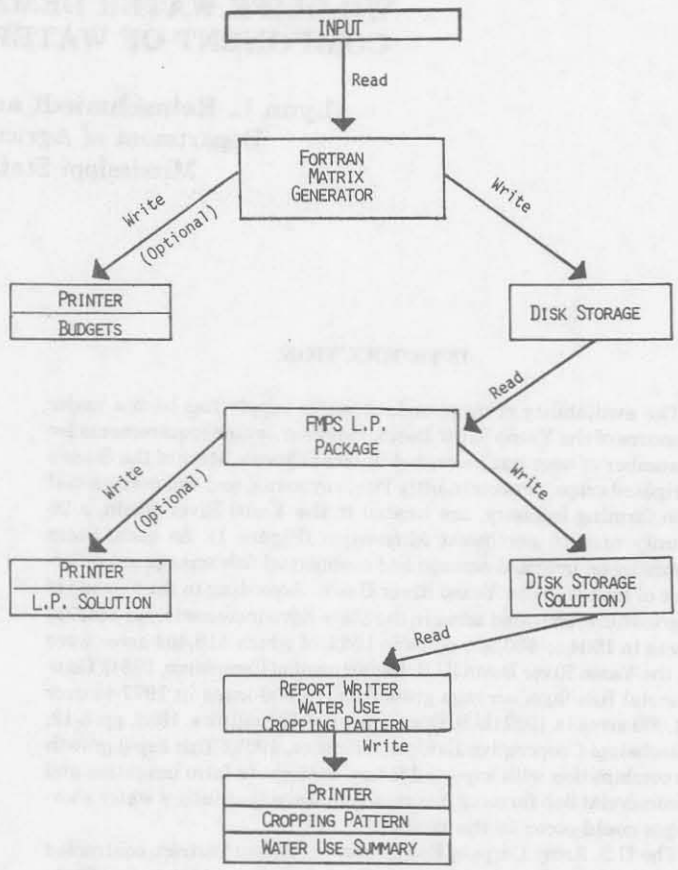

Figure 2. Diagram of the Mechanics of Model Operation

Supplemental Irrigation Water Requirements

Estimation of crop consumption use and effective precipitation provide the basis for determining supplemental irrigation requirements. The procedure for estimating supplemental irrigation requirements was based upon a modified Blaney-Criddle method of estimating consumptive crop water use [U.S. Department of Agriculture, SCS, 1970]. The Blaney-Criddle method is a temperature based procedure which correlates water consumptive use by crops with mean monthly temperatures and daylight hours. Irrigation requirements are found by subtracting effective precipitation from the calculated consumptive use.

Data needed for the Blaney-Criddle method included historical mean monthly temperature and precipitation records [U.S. Department of Commerce selected years], latitude, and growth stage relationship for crops in question. Latitude is used for determining day length and as a proxy for the amount of sunshine during the crop growing season, which is a critical factor in crop growth and water use.

Upon calculation of consumptive use, the determination of effective rainfall is required before an estimate of supplemental irrigation water can be determined. Effective rainfall is that proportion of total precipitation that remains within the root zone for use by the plant. Total rainfall, crop consumptive use, and factors reflecting the water holding capacity of the soil are data used to calculate effective rainfall. Data on irrigation soil groupings, crop rooting zones, and net depths of application were developed from data in the "Conservation Irrigation Guide for Mississippi" [U.S. Department of Agriculture, Soil Conservation Service, 1974]. Monthly growing season net irrigation requirements are calculated as the difference between effective rainfall and consumptive use.

The Matrix Generator

The tableau of the economic model seems simple enough since the only restrictions are land and crop production restrictions. However, the linear programming model requires the development of coefficients for a large number of activities. Production activities included are combinations of crop, soil type, and irrigated (sprinkler and furrow) or dryland production in each of the 26 Yazoo Basin counties. Each crop considered (rice, soybeans, cotton, wheat, corn, soybeans/wheat doublecrop, and catfish) is matched with each soil type along with dryland production, sprinkler, and furrow irrigation in each county. Thus, the number of production alternatives considered in each county is the product of the number of crops considered, the number of soil types in each county, and the number of irrigation systems (sprinkler, furrow, and non- irrigated). This unusually large number of activities for each county is often reduced significantly for the linear program, however, by the elimination of activities because some soil types are not adapted for both sprinkler and furrow irrigation or, in some cases specific crops are not recommended on some soil types.

Manual assembly of a linear programming model of the magnitude described for each of the five 10-year increments and each of the Yazoo Basin subgroups evaluated would have been impossible. Alternatively a matrix generator can be used to automatically develop the required coefficients from input data and format them for the FMPS linear programming package (Figure 3).

Data required as inputs to the matrix generator are: (1) cropping activity names; (2) irrigation water requirements for each cropping activity; (3) dryland and irrigated crop yields by soil type*; (4) dryland and irrigated costs of production [Mississippi Agricultural and Forestry Experiment Station, 1983; and Giachelli et al.]; (5) crop prices (Crops of Engineers' 1982 G-2 agricultural prices were used); (6) acreage of each soil type by county [U.S. Department of Agriculture, Soil Surveys]; (7) production level of each crop currently grown (optional); (8) total available cropland acres; and (9) estimated production projections of each crop over the 50-year time period [U.S. Water Resources Council].

In addition to input data, some data are stored internally since they are assumed to apply uniformly across all counties. These data include (1) fertilizer recommendations based on yield level [Grissom and Spurgeon; Pettiet, 1973a and 1973b] (2) fertilizer prices, (3) water cost equation coefficients, (4) interest rates, and (5) OBERS Series E' yield adjustment coefficients [U.S. Water Resources Council].

Output to the FMPS linear programming package from the matrix generator takes the form of properly formatted activity names, net revenues (objective function), irrigation water requirements and accounting row coefficients for each considered activity, and properly formatted resource constraints for acreage of each soil type by county. Further, the matrix generator outputs to the printer much of its input data and internal calculations for easy inspection and checking.

The matrix generator operates as a series of inner loops that make various calculations for each cropping activity considered combined with each soil type to produce one year's matrix; and, two outer loops which combine all counties within a region into one model

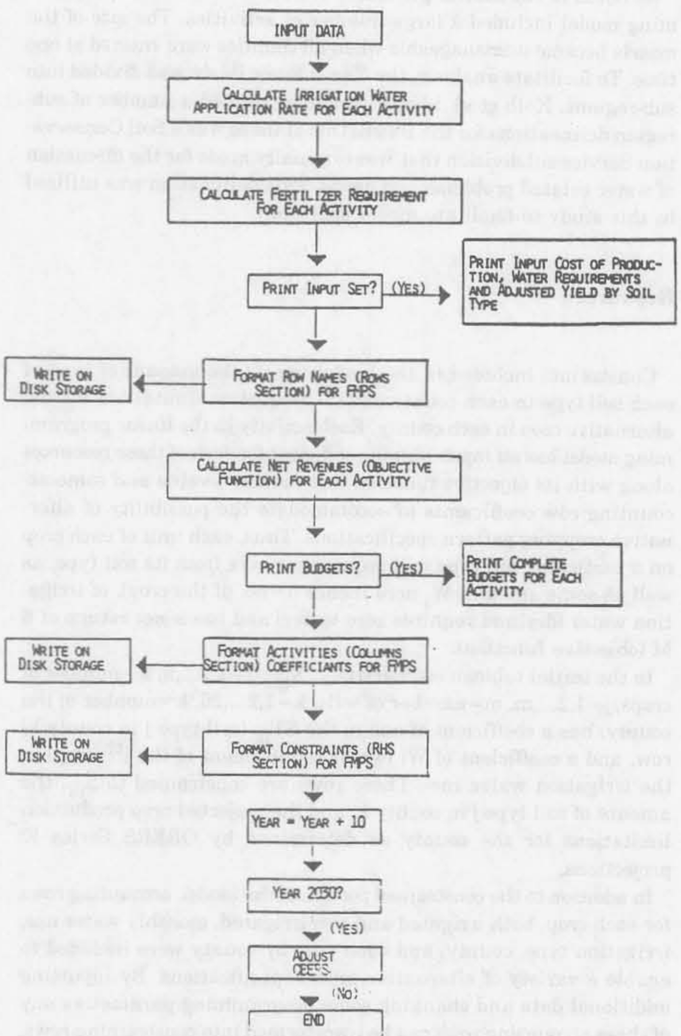

Figure 3. Diagrammatic Representation of the Matrix Generator Operation

formulation and adjusts yields over the 50-year time frame according to OBERS Series E' projections. For example, the first pass through the matrix generator creates the 1980 initial tableau, then yields are adjusted by OBERS projections and another pass through the matrix generator creates the 1980 tableau, etc.

Mathematical Linear Programming Model

The mathematical portion of the economic model, the linear program, provides a means of estimating irrigated and non-irrigated crop acreages, and, therefore, water requirements. The model objective is optimized subject to land and acreage limitations for alternative crops. Optimization is performed in 10-year intervals with temporal yield adjustments and acreage limitations causing changes in many base calculations thus requiring a new tableau each period. The mathematical model is by design created by the matrix generator. Figure 2 depicts the flow process by which the model components are linked.

Activities

As noted in the matrix generator discussion, the linear programming model included a large number of activities. The size of the matrix became unmanageable when all counties were entered at one time. To facilitate analysis, the Yazoo River Basin was divided into sub-regions. Kolb et al. identified and evaluated a number of subregion delineations for the Basin. One of these was a Soil Conservation Service subdivision that was originally made for the discussion of water related problems and needs. This delineation was utilized in this study to facilitate model operation.

Resources

Constraints included in the model are (1) the amount of land of each soil type in each county and (2) production limitations for the alternative crop in each county. Each activity in the linear programming model has an input- output coefficient for each of these resources along with its objective function (net revenue) value and some accounting row coefficients to accommodate the possibility of alternative cropping pattern specifications. Thus, each unit of each crop on a particular soil type will require one acre from its soil type, as well as some amount, W_i acre inches (i=no. of the crop), of irrigation water (dryland requires zero water) and has a net return of $ M (objective function).

In the initial tableau each activity, X_{ijk} (i=1,2...,n, n=number of crops, j=1,2...,m, m=number of soils, k=1,2...,26, k=number of the county) has a coefficient of one in the ST_{jk} (soil type j in county k) row, and a coefficient of Wi (water requirement of the i^{th} crop) in the irrigation water row. These rows are constrained to S_{jk}, the amount of soil type j in county k, and the projected crop production limitations for the county as determined by OBERS Series E' projections.

In addition to the constrained portion of the model, accounting rows for each crop, both irrigated and non-irrigated, monthly water use, irrigation type, county, and each crop by county were included to enable a variety of alternative model specifications. By inputting additional data and changing some programming parameters any of these accounting rows can be transformed into constraining rows. For example, this was done later to the crop by county accounting rows to approximate current cropping patterns and the alternative production scenarios used to evaluate alternative water uses.

The Report Writer

The report writer is the final phase of the analytical model. Upon solution of the economic problems given by the FMPS package, FMPS is signaled to write solutions on disk storage as well as printing those solutions. The report writer reads the six solutions (one base and five additional at 10-year increments) and proceeds to summarize the results of the model.

The report writer first produces a cropping pattern summary for each county. This summary consists primarily of a series of accounting rows from the linear program. First, acreage of each crop, divided into its dryland or irrigated category, is given by each 10-year model solution. Then the report writer presents the water use by month, by crop, and total water use. Finally, the report writer summarizes the cropping pattern and total water use for each designated group of counties.

RESULTS

The linear programming model described in previous sections was used to obtain estimates of cropping patterns and supplemental water requirements for agricultural production in the Yazoo River Basin. Evaluation of water use over the 1980 to 2030 time period under specified assumptions regarding rainfall, future crop production constraints, and conservation measures formed the basis of the analysis. To account for uncertainty regarding future economic and physical conditions, several scenarios were postulated.

Two basic scenarios are presented here to reflect the operation of the model. The scenarios were specified to reflect water use under normal and less than normal rainfall conditions. These two cases were identified to reflect a so-called "average" and a "maximum" quantity of supplemental water that may be needed in a given year.

Certain conditions were applicable to both scenarios and will be discussed separately. The linear programming model was constrained to meet specified production levels for the major crops over the 1980-2030 time period in the Yazoo River Basin. Base production for the 1980 time period was 1977- 1981 average production levels for each county in the Yazoo River Basin [Mississippi Crop and Livestock Reporting Service, 1981, 1982]**. For each succeeding ten-year period OBERS projections of specified percentage increases in these crops for the state of Mississippi were used to increase the 1977-1981 base production levels over the 1990-2030 time period. The 1972 Water Resources Council OBERS, Series E' projections were used rather than the 1978 projections, since the latter projected the value of total agriculture production rather than for individual crops. Since the 1972 projections were only made to 2020, the percentage change from 2010 to 2020 was applied to the 2020 to 2030 time period. Percentage changes in production for Mississippi as a whole were applied to individual county production levels through time.

The first scenario estimated supplemental water use under average rainfall conditions and the general assumptions discussed earlier. Average rainfall was determined from 20 years of historical rainfall records. A second scenario was created to reflect supplemental water requirements under conditions where rainfall is less than normal. To reflect this "dry" situation, an 80-percent chance of rainfall situation was utilized, whereby the historical average rainfall is expected to exceed estimated rainfall 8 years in 10. Other assumptions discussed earlier were held constant.

Average Rainfall Results

Supplemental irrigation water requirements as defined earlier for cotton, soybeans, wheat, corn, rice, and catfish were estimated based upon rainfall that would be expected 50 percent of the time(historical average rainfall). Based upon average rainfall and the OBERS crop production requirements for the 1990-2030 time period, supplemental water requirements were determined for each county in the Yazoo River Basin.

Results for the 26 Yazoo River Basin counties were summarized and the results presented in Table 1. The estimated crop distribution, including irrigated and non-irrigated acres by crop, total cropland use, and total irrigated acres for each 10-year period are

Table 1. Optimal cropping pattern and water use summary, 50 percent chance of water need, all counties in Yazoo River Basin.

Item	Year 1990	2000	2010	2020	2030
	1000 Acres				
Rice	248.845	280.675	287.963	297.433	310.456
Irr Soybeans	1132.754	1733.908	1656.928	1669.566	1784.747
Dry Soybeans	1079.054	1218.151	1473.011	1582.515	1533.23
Irr Cotton	152.363	224.448	368.972	425.632	573.222
Dry Cotton	682.094	639.622	498.434	474.640	336.874
Irr Wheat	.000	.000	.000	.000	.000
Dry Wheat	36.976	6.134	4.165	.000	.000
Irr Corn	.000	.000	.000	.000	.000
Dry Corn	16.641	17.600	17.701	17.560	17.813
Irr Soy/Wheat	57.160	138.056	131.140	130.709	130.594
Dry Soy/Wheat	84.240	47.960	58.259	63.716	67.300
Catfish	108.520	170.079	199.808	235.270	277.602
Total Irr Acres	1699.642	2547.167	2644.811	2758.611	3076.622
Total Crpland Use	3598.647	4476.634	4696.381	4897.041	5031.839
Total Water Use/Month:	1000 Acre Feet				
May	171.845	213.295	229.170	248.503	272.463
Jun	472.521	596.061	631.241	675.246	736.612
Jul	893.978	1222.388	1308.642	1391.525	1548.988
Aug	1162.172	1687.682	1757.792	1841.592	2034.939
Sep	230.520	368.376	426.364	480.228	560.304
Oct	47.345	74.593	87.140	102.383	120.586
Total Water Use/Crop:					
Rice	877.385	989.615	1015.311	1048.701	1094.616
Soybeans	1328.616	1936.589	1869.476	1887.539	1988.493
Cotton	186.206	277.066	455.957	528.425	706.344
Soy/Wheat	48.043	115.600	108.655	108.099	107.633
Catfish	538.076	843.310	990.716	1166.548	1376.445
Total Water Use	2978.326	4162.180	4440.115	4739.223	5273.53

identified. Figures in the table also report the estimated monthly supplemental water use in acre feet. Water use by crop and total water use for the county are also reported.

The analyses indicate that if producers organize resources in an optimal manner in 1990, 1,699,642 acres of the 3,598,647 acres of total cropland will be irrigated. Irrigated acreage is projected to reach 3,076,622 acres in 2030, which represents 61 percent of the total cropland.

A survey taken in 1982 indicated that approximately 214,000 acres of cotton, soybeans, wheat, and corn were irrigated in 1981 in the Yazoo River Basin [Laughlin and Reinschmiedt]. If 1981 rice and commercial fish production of 400,000 acres were added to this figure, approximately 614,000 acres of land was irrigated in 1981. Compared with this figure, the estimated 2030 irrigated acreage represents a 400 percent increase in irrigation over the 50 year time period. An estimated 60 percent of the total cropland utilized in 2030 is projected to be under irrigation.

Monthly water use was distributed from May to October. The months of July and August require the largest amounts of supplemental water with 893,978 and 1,162,172 acre-feet, respectively, in 1990. Total supplemental water needs for agricultural purposes increased from 2,978,326 acre feet in 1990 to 5,273,532 acre feet in 2030 for the Yazoo River Basin.

Projected water use among the specified crops is also presented in Table 1. Soybean, rice, and catfish production are the three largest water users over the time period, accounting for 85 percent of the total water use.

Dry Rainfall Condition Results

Under the assumptions associated with an 80 percent chance of rainfall, the model was forced to utilize irrigation on a larger number of acres to meet the OBERS production estimates. The 80 percent chance of rainfall summary analysis for the Yazoo River Basin is presented in Table 2. The format and content of Table 2 is the same

Table 2. Optimal cropping pattern and water use summary, 80 percent chance of water need, all counties in Yazoo River Basin.

Item	Year 1990	2000	2010	2020	2030
	1000 Acres				
Rice	248.845	280.425	287.749	297.323	309.587
Irr Soybeans	1707.776	2471.336	2553.641	2583.236	2687.366
Dry Soybeans	99.521	.000	.000	82.338	55.123
Irr Cotton	613.051	645.359	673.378	707.772	752.893
Dry Cotton	107.262	112.539	117.919	119.075	109.601
Irr Wheat	.000	.000	.000	.000	.000
Dry Wheat	48.391	25.317	26.603	10.029	2.354
Irr Corn	11.035	11.593	11.632	11.641	11.692
Dry Corn	.000	.000	.000	.000	.000
Irr Soy/Wheat	119.662	149.628	148.351	166.588	176.066
Dry Soy/Wheat	13.162	16.687	16.781	16.852	17.541
Catfish	108.520	170.079	199.808	235.270	277.602
Total Irr Acres	2808.888	3728.420	3874.560	4001.831	4215.206
Total Crpland Use	3077.224	3882.962	4035.863	4230.123	4399.825
Total Water Use/Month:	1000 Acre Feet				
Apr	.000	.000	.000	.005	.004
May	174.582	216.018	231.911	251.337	274.913
Jun	623.896	785.982	828.287	874.548	936.738
Jul	1424.859	1835.375	1922.341	1999.596	2121.070
Aug	1894.191	2535.471	2644.415	2733.825	2887.478
Sep	464.895	609.385	653.334	711.036	779.875
Oct	50.692	78.410	91.044	106.742	125.230
Total Water Use/Crop:					
Rice	877.385	988.732	1014.555	1048.312	1091.551
Soybeans	2200.674	3133.756	3231.578	3259.795	3379.504
Cotton	876.325	924.728	966.217	1015.618	1081.441
Corn	17.639	18.489	18.538	18.612	18.770
Soy/Wheat	120.029	151.522	149.585	168.083	177.444
Catfish	538.076	843.310	990.716	1166.548	1376.445
Total Water Use	4630.129	6060.537	6371.190	6676.968	7125.156

as that discussed for the normal rainfall scenario. The crop distribution under the dry-year scenario differed considerably from the normal rainfall situation. Overall, total irrigated acres in 1990 and 2030 increased to 2,808,888 and 4,215,206 acres, respectively. This represented respective increases of 65 and 37 percent over the normal year rainfall situation. For individual crops, all corn and most of the soybean and cotton acreage was irrigated over the 50-year time period.

The months in which supplemental water requirements were needed was expanded to April. Water requirements were again most demanding in July and August.

Total water use increased from an estimated 4,630,129 acre-feet in 1990 to 7,125,156 acre-feet in 2030. For 1990 and 2030, the dry year supplemental water requirements exceeded the normal year requirements by 55 and 35 percent, respectively. Soybean production in 2030 was the largest water user accounting for 47 percent of the total.

MODEL EXTENSIONS

The preceding discussion addressed the development of a linear programming model for use in projecting water demands. The model, however, was restricted to that specific use. While projecting water demands under alternative scenarios would be an issue that water managers would likely address, other issues would be of equal concern. For example, if supplies are limited and water is rationed to users, who should have access to water? Or, what would be the economic impact of restricted water availability? How would producers likely respond to changes in product price or production costs? If water use fees or taxes are levied on water use, what would be the expected impact? These are but a few of the many questions that are likely to confront water policy officials in the future.

The basic model presented in this paper has the capability of addressing many of these issues by modifying specific constraints or certain parameters within the model. For example water availability constraints could be incorporated to evaluate producer reaction to water scarcity. By doing so, policy-makers could ascertain where shifts in crop use would likely occur. Also, by restricting water supplies or allocating water to specific users in preference to others, estimates of total net returns under the alternative situations could be estimated and compared to aid in determining which of several policies is preferred. While models of the type described in this paper are not without limitations and cannot provide all the answers to water management issues, they can provide valuable information needed for the decision-making process. Data can be generated relatively easily for a number of alternatives policy scenarios and at a reasonable cost in terms of resources invested.

*Note: Base dryland yields for crops were based upon USDA, SCS "Blue Sheet" yields adjusted to reflect county average yields [Mississippi Crop and Livestock Reporting Service]. Irrigated yields were estimated with the input of USDA and Mississippi Agricultural and Forestry Experiment Station scientists. A detailed discussion of this process can be found in Laughlin and Reinschmiedt.

**Note: Production constraints were allowed to vary 10 percent above and below the specified level for the linear programming solutions.

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