PROJECTIONS OF AGRICULTURAL AND FISH AND WILDLIFE WATER DEMAND IN THE OUACHITA RIVER BASIN: A LINEAR PROGRAMMING APPROACH

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CHAPTER 1

INTRODUCTION

The availability of an abundant water supply has been a major resource of the Ouachita River Basin. In recent years, water requirements for a number of uses have increased, raising the concern that future water shortages could occur in the basin. The purpose of the study reported here was to estimate future water demand for irrigation, commercial fisheries, and fish and wildlife uses.

In recent years, the state of Arkansas has experienced an enormous increase in its irrigated agriculture. In 1975, a state irrigation inventory indicated that there were 1,422,000 irrigated acres in the state (Shulstad, 1978 p. 20). By 1980, the total irrigated acres had increased to 2,157,000 (USDA, 1983), an increase of over 50 percent in just five years. Three crops (rice, soybeans, and cotton) accounted for almost the entire irrigated acreage with over 90 percent of the total planted in rice and soybeans. Of these three crops, soybeans had the largest percentage increase, doubling in the five-year period. Rice acreage increased 22 percent while irrigated cotton increased approximately 50 percent.

The 1980 Agricultural Statistics for Arkansas (USDA, ESCS, 1981) showed that there were 542,390 acres planted to rice, cotton, and soybeans in the Ouachita Basin in 1980. The 1978 federal census indicated there were 116,131 irrigated acres in the Ouachita Basin study area in 1978. However, this figure appears low since in 1980 - only two years later - there were 208,792 acres of rice planted and all rice grown in Arkansas is irrigated.

The United States Army Corps of Engineers is conducting a water resource study for the Delta States Region. This report represents one portion of the overall study and examines the agricultural water demand for the Ouachita River Basin that lies in Arkansas. This study projects demand for the years 1990, 2000, 2010, 2020 and 2030.

OBJECTIVES

The major objective of this study is to develop 1980 and future water demands for major agricultural, fish and wildlife uses with and without water conservation measures. The major water users to be examined are crop irrigation, livestock, commercial fisheries, and fish and wildlife. The conservation measures are applicable only to the crop irrigation. Irrigation was considered for the following crops: soybeans, cotton and rice.

Specific objectives of this study include:

1. Review of existing literature pertaining to existing and/or planned water withdrawal and consumption in the Ouachita River Basin that lies in Arkansas.
2. Determination of existing (1980) water use information for the Ouachita River Basin that lies in Arkansas. Included are:
    a. An estimation of the total irrigated acreage devoted to: major crops, commercial fisheries, and fish and wildlife uses.
    b. Determination of the timing and application rate of withdrawals.
    c. Identification of existing irrigation methods.
3. Estimation of future water demand by water use category for alternative projection scenarios for 1990, 2000, 2010, 2020 and 2030 with and without conservation measures.

The specific scenarios reported on here include:

a. Scenario 1. An analysis of water demand with the assumption that agricultural yields would increase by amounts equal to OBERS[1] (United States Water Resources Council, 1975) projections for the years 1990-2030 considering average rainfall conditions (based on the 50th percentile of the cumulative distribution function for rainfall over a fifteen-year period).

b. Scenario 2. An analysis of water demand under the same conditions as Scenario 1, except that water conservation measures were applied. The effect of these conservation measures was to increase the efficiency of water use resulting in less water needed per acre. This could actually raise the total water demanded in the region due to the reduced price of irrigating each acre and a subsequent expansion of the irrigated acreage.

STUDY AREA

The study area lies within the combined Upper Ouachita and Lower Ouachita study areas identified in the Arkansas Resource Base Report (USDA, SCS, 1981, I-8, I-9). Combining the Lower and Upper basins, the Ouachita River Basin has a total land area of 13,067 square miles (approximately 8,360,000 acres). This area represents approximately 25 percent of the total land area of the State of Arkansas. Major tributaries of this basin include the Bayou Bartholomew, and the Saline, Caddo, and Little Missouri Rivers. The Ouachita River Basin is bordered on the west by the Red River Basin, on the east by the Boeuf-Tensas Basin, and on the north by the Arkansas River Basin. For purposes of this study, the Louisiana state line represents the southern boundary.

The Ouachita River Basin is comprised of mountainous to gently

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[1] OBERS is an acronym signifying the united effort of the Office of Business Economics (OBE) and the Economic Research Service (ERS).

rolling to nearly level terrain. Principal land uses include forestland (81 percent), grassland (11 percent) and cropland (5 percent). The 1980 population within the Basin is 443,390 or 19.4 percent of the total population of the State of Arkansas. Population density is approximately 34 persons per square mile. Major population centers within the Ouachita River Basin include Pine Bluff (56,576), Hot Springs (35,166) and El Dorado (26,685).

In this study, the study area was defined to be all of the Ouachita River Basin that lies in Arkansas. This encompasses all or part of 20 counties as depicted in Figure 1. The counties in the study area are as follows (the number in parentheses represents the land area that falls in the study area); Ashley (87.4 percent), Drew (99.7 percent), Lincoln (73 percent), Jefferson (64.5 percent), Bradley (100 percent), Cleveland (100 percent), Grant (99.3 percent), Saline (95.6 percent), Calhoun (100 percent), Union (100 percent), Garland (100 percent), Montgomery (100 percent), Clark (100 percent), Hot Spring (100 percent), Pike (100 percent), Hempstead (48.8 percent), Nevada (76.7 percent), Dallas (100 percent), Ouachita (100 percent), and Pulaski (nominal percent). These counties were then aggregated into eight regions in order to perform the research. Each of these regions has one or more hydrologic cataloging units in it. A cataloging unit may be a tributary or a segment of a river within an accounting unit. This classification system is used on the State of Arkansas Hydrologic Unit Map - 1974 prepared by the United States Geological Survey in cooperation


BENTON
CARROLL
BOONE
MARION
BAXTER
FULTON
RANDOLPH
CLAY
WASHINGTON
MADISON
NEWTON
SEARCY
IZARD
SHARP
GREENE
STONE
LAWRENCE
CRAIGHEAD
MISSISSIPPI
INDEPENDENCE
CRAWFORD
FRANKLIN
JOHNSON
POPE
VAN BUREN
CLEBURNE
POINSETT
JACKSON
LOGAN
CONWAY
CROSS
WHITE
CRITTENDEN
SEBASTIAN
YELL
WOODRUFF
ST. FRANCIS
FAULKNER
SCOTT
PERRY
PRAIRIE
PULASKI
LONOKE
LEE
SALINE
GARLAND
MONROE
PHILLIPS
POLK
MONTGOMERY
JEFFERSON
GRANT
HOT SPRING
ARKANSAS
HOWARD
PIKE
CLARK
SEVIER
DALLAS
CLEVELAND
LINCOLN
DESHA
NEVADA
OUACHITA
DREW
LITTLE RIVER
HEMPSTEAD
CALHOUN
MILLER
LAFAYETTE
COLUMBIA
UNION
BRADLEY
ASHLEY
CHICOT

extra

with the Water Resources Council to be used as a base map by each state for water and related land resources. An eight-digit numbering system is used that represents a hydrologic region (USDA, 1982). All of the counties being studied are in the same region (Lower Mississippi Region), and the same subregion. Two accounting regions are present, and there are nine cataloging units represented. These are shown in Table I-1. In Table I-2, the hydrologic regions are identified.

LITERATURE REVIEW

There have been several published studies that are relevant to this study on the Ouachita River Basin. Most of these encompass a larger geographic area but have the Ouachita River Basin as a component. The literature that is relevant to estimating agricultural water demand in the Ouachita River Basin can be delineated into those of national or regional scope and those that focus on the state of Arkansas or a part of the state that includes the basin being studied.

National and Regional Studies

Lower Mississippi Region Comprehensive Study, 1974

An important regional study is the Lower Mississippi Region Comprehensive Study (LMR, 1974a). The United States has been divided into 20 hydrologic regions by the Water Resources Council. Parts of two of these regions cover Arkansas. The Lower Mississippi Region (Region 08) covers about 50 percent of the state and the

Table I-1. Description of County Regions in the Ouachita River in Arkansas and the Hydrologic Regions Contained in The Basin

Region	Counties and Hydrologic Regions
1 Ashley(AS)	Ashley, Drew, Lincoln, Jefferson Counties 08040202, 08040203, 08040204, 08040205
2 Bradley(BR)	Bradley, Cleveland Counties 08040201, 08040202, 08040203, 08040204
3 Grant(GR)	Grant, Saline, Pulaski Counties 08040203
4 Calhoun(CA)	Calhoun, Union Counties 08040103, 08040201, 08040202, 08040206
5 Garland(GA)	Garland, Montgomery Counties 08040101, 08040102, 08040103, 08040203
6 Clark(CL)	Clark, Hot Spring, Pike Counties 08040101, 08040102, 08040103, 08040203
7 Hempstead(HE)	Hempstead, Nevada Counties 08040103, 08040201
8 Dallas(DA)	Dallas, Ouachita Counties 08040102, 08040103, 08040201, 08040203[1]

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[1] The eight-digit numbering system represents a hydrologic region subregion, accounting unit, and cataloging unit.

Source: Soil Conservation Service, USDA. State of Arkansas Watershed Data Listing and Hydrologic Unit Data. Little Rock, Arkansas, 1982.

Table 1-2 Coding Scheme for Hydrological Region, Ouachita River Basin

Model Code Number	Water Resource Council Hydrological Code
1	08040101 (Upper Ouachita)
2	08040102 (Caddo River)
3	08040103 (Little Missouri)
4	08040201 (Lower Ouachita)
5	08040202 (Ouachita - Moro Bay to Saline R.)
6	08040203 (Upper Saline)
7	08040204 (Lower Saline)
8	08040205 (Bayou Bartholomew)
9	08040206 (Cornie Creek)

Arkansas-White-Red Region covers the remainder of the state. The Lower Mississippi Region includes the Ouachita River Basin. It is in turn subdivided into 10 Basin and the Red River below Hot Wells, Louisiana; it is spread across both Arkansas and Louisiana.

The Comprehensive Study has a main report and 21 appendices. The appendices contain information for WRPA #5 which is of prime interest to this study.

The study provides data for 1959 and 1970 and makes projections for 1980, 2000 and 2020. Economic projections were made for two programs, designated A, National Income, and B, Regional Development. The national economic forecasts were developed for the Water Resources Council by the Bureau of Economic Analysis (BEA), U.S. Department of Commerce (formerly Office of Business Economics (OBE), and the Economic Research Service (ERS) in the U.S. Department of Agriculture. The forecasts are termed OBERS to signify a joint effort by OBE and ERS and provide national estimates of population, employment, earnings, income, and production of goods and services (LMR, 1974a, p. 1). The regional development scenario assumed that the region would grow at the same rate projected for the nation. Land acres needed for food and fiber production were determined using linear programming; OBERS projections of needed food and fiber for the Lower Mississippi Region were used as a constraint in the model and the soil resource base was provided by the Soil Conservation Service's 1967 Conservation Needs Inventory.

Estimates of water use for crops, livestock, fish and wildlife were made for the Ouachita River Basin for 1970 and projections were made for 1980, 2000 and 2020.

In 1970, total acres irrigated in the whole of the Ouachita River Basin (WRPA 5) was 212,587 acres and corresponding water use was 409,462 acre-feet. 1970 water use for livestock was 7,773 acre-feet. (LMR, 1974b, p. 63). Projected 1980 irrigated land and water use was 261,368 acres and 487,264 acre-feet for the National Income scenario and 262,646 acres and 489,712 acre-feet for the Regional Development scenario. Forty years later, in 2020, the National Income scenario projects 341,066 irrigated acres and 623,671 acre-feet and the Regional Development scenario projects 395,962 acres and 697,039 acre-feet. In 1980, water use for livestock was projected at 9,571 acre-feet for both scenarios. In 2020, water use for livestock was projected at 17,038 and 18,235 acre-feet for the National Income and Regional Development scenarios respectively (LMR, 1974b, pp. 67-69). Total water requirements for irrigation and livestock in 2020 were estimated at 640,709 and 715,333 acre-feet for the two scenarios (LMR, 1974b, p. 69).

State and Water Basin Studies

Use of Water in Arkansas, 1980

The most specific previously published data on agricultural, fisheries and wildlife water demand in that part of the Ouachita River Basin that lies in Arkansas was compiled by the Arkansas Geological Commission (Arkansas Geological Commission, 1981). The

Corps of Engineers, for the purposes of the present research study, defined that part of the Ouachita River Basin that lies in Arkansas to include all or part of 20 counties. Since the actual boundaries of the basin obviously do not correspond to county boundaries it was necessary to adjust the Arkansas Geological Commission data on irrigated acreage and acre-feet of water used in each county. Table I-3 shows Irrigated Land Acreage by Regions and Counties Prorated for the Ouachita River Basin, 1978 and 1980. In 1978 there were 114,729 irrigated acres; in 1980 there were 145,469 irrigated acres. Most of the irrigated acres were in Region 1 (Ashley, Drew, Lincoln, and Jefferson counties); of the Region 1 total 133,479 acres, 90,831 were rice acres and 42,648 were other crop acres. Table I-4 shows the number of irrigated acres in the 20 counties in the study area with no prorating. In 1980 there were a total of 207,174 irrigated acres. Table I-5, Use of Water by Regions and Counties Prorated for the Ouachita River Basin, 1980, shows the percentage of each county that lies in the Ouachita River Basin. The counties that do not lie completely in the basin are either in Region 1, Region 3 or Region 7 (there are a total of eight regions based on commonality of soils). For example, only 48.8 percent of Hempstead County (Region 7) lies in the basin and only 64.5 percent of Jefferson County (Region 1) lies in the basin. The total amount of water used for the basin for agriculture and fisheries was 419,182 acre-feet. Approximately 390,000 acre-feet per year were used in Region 1 (Ashley, Drew, Lincoln, and Jefferson counties). The only other region that used a

Table I-3. Irrigated Land Acreage by Regions and Counties, Prorated for the Ouachita River Basin, 1978 and 1980

	Percentage of County Acreage in Basin	Total Basin, 1978	Rice, 1980	Other Crops, 1980	Total Basin, 1980
Region 1-Ashley	87.41	22,226	20,147	14,687	34,834
Drew	99.68	15,766	15,586	10,870	26,456
Lincoln	73.01	29,157	20,832	8,065	28,897
Jefferson	64.47	39,660	34,266	9,026	43,292
Region 1 Totals		106,809	90,831	42,648	133,479
Region 2-Bradley	100.00	1,367	-	2,046	2,046
Cleveland	100.00	58	-	204	204
Region 2 Totals		1,425	-	2,250	2,250
Region 3-Grant	99.29	16	-	84	84
Saline	95.59	254	48	181	229
Region 3 Totals		270	48	265	313
Region 4-Calhoun	100.00	148	-	38	38
Union	100.00	78	-	121	121
Region 4 Totals		226	-	159	159
Region 5-Garland	100.00	216	-	162	162
Montgomery	100.00	305	-	460	460
Region 5 Totals		521	-	622	622
Region 6-Clark	100.00	2,946	3,456	1,213	4,669
Hot Spring	100.00	889	868	686	1,554
Pike	100.00	446	259	626	885
Region 6 Totals		4,281	4,583	2,525	7,108
Region 7-Hempstead	48.83	758	-	732	732
Nevada	76.65	49	-	209	209
Region 7 Totals		807	-	941	941
Region 8-Dallas	100.00	244	321	200	521
Ouachita	100.00	145	-	76	76
Region 8 Totals		389	321	276	597
Basin Totals		114,729	95,783	49,686	145,469

Source: USDA, ESCS. 1980 Agricultural Statistics for Arkansas, 1980. pp. 10-11, 1978. Federal Census Data. Arkansas Geological Commission. Use of Water in Arkansas, 1980. 1981. Calculated from 1980 Water Usage Data. Arkansas Geological Commission, Use of Water in Arkansas, 1980, Water Resources Summary Number 14.

Table I-4. Irrigated Land Acreage by Regions and Counties Without Prorating for the Ouachita River Basin, 1980

	Rice Irrigation	Other Crops	Total
Region 1-Ashley	23,049	16,802	39,851
Drew	15,636	10,905	26,541
Lincoln	28,533	11,046	39,579
Jefferson	53,150	14,000	67,150
Region 1 Totals	120,368	52,753	173,121
Region 2-Bradley	-	2,046	2,046
Cleveland	-	204	204
Region 2 Totals	-	2,250	2,250
Region 3-Grant	-	85	85
Saline	50	189	239
Pulaski	7,119	14,102	21,221
Region 3 Totals	7,169	14,376	21,545
Region 4-Calhoun	-	38	38
Union	-	121	121
Region 4 Totals	-	159	159
Region 5-Garland	-	162	162
Montgomery	-	460	460
Region 5 Totals	-	622	622
Region 6-Clark	3,465	1,213	4,669
Hot Spring	868	686	1,554
Pike	259	626	885
Region 6 Totals	4,583	2,525	7,108
Region 7-Hempstead	-	1,449	1,449
Nevada	-	273	273
Region 7 Totals	-	1,772	1,772
Region 8-Dallas	321	200	521
Ouachita	-	76	76
Region 8 Totals	321	276	597
Basin Total	132,441	74,733	207,174

Source: Arkansas Geological Commission, Use of Water in Arkansas, 1980, Water Resources Summary Number 14. Arkansas Geological Commission, 1981.

significant quantity of water was Region 6 (Clark, Hot Spring, and Pike counties) which used approximately 20,000 acre-feet in 1980.

Table I-5 shows that of the total 419,182 acre-feet, 324,151 were used for rice irrigation; this amounts to 77.3 percent of the total. Remaining usage was as follows: 4,981 acre-feet for livestock, 56,705 acre-feet for other crop irrigation and 33,345 acre-feet for fish and minnow farms. Eighty three point-four (83.4) percent of the acre-feet used for rice irrigation came from ground water sources, 16.6 percent from surface water sources. For other crop irrigation, 83.3 percent came from ground water sources and 16.7 percent from surface water sources. For fish and minnow farms, 53.4 percent came from ground water sources and 46.6 percent came from surface water sources.

Table I-6 shows 1980 water use in acre-feet for the 20 counties in the study area with no prorating. A total of 575,162 acre-feet were used, most of it in Region 1 (Ashley, Drew, Lincoln, and Jefferson counties) and in Region 3 (Grant, Saline, and Pulaski counties). The same data are shown in million gallons per day in Table I-7.

The Arkansas Geological Commission also has 1975 data on water use for the state. These data show that the amount of water used for rice irrigation in Arkansas increased 56 percent for the five-year period from 1975 to 1980; ground water usage increased by 53 percent and surface water usage increased by 72 percent. For other crops, water used for irrigation increased by 165 percent over the

Table I-5. Use of Water by Regions and Counties Prorated for the Ouachita River Basin, 1980
(in Acre-Feet per Year)

	Percentage of county Acreage in Basin	Livestock	Rice Irrigation			Other Crop Irrigation			Fish & Minnow Farms			TOTAL
			Ground	Surface	Total	Ground	Surface	Total	Ground	Surface	Total	
Region 1-Ashley	87.41	137	72,534	3,025	75,559	14,783	2,781	17,564	8,165	4,974	13,129	106,389
Drew	99.68	178	37,411	9,300	46,711	11,722	1,295	13,017	1,239	737	1,976	61,882
Lincoln	73.01	196	64,060	14,065	78,125	7,367	1,316	8,683	997	2,093	3,090	90,094
Jefferson	64.47	122	95,775	15,589	111,364	10,817	-	10,817	5,228	1,473	6,701	129,004
Region 1 Totals		633	269,780	41,979	311,759	44,689	5,392	50,081	15,619	9,277	24,896	387,369
Region 2-Bradley	100.0	212	-	-	-	448	1,602	2,050	78	717	725	2,987
Cleveland	100.0	258	-	-	-	-	202	202	-	179	179	639
Region 2 Totals		470	-	-	-	448	1,804	2,252	78	896	974	3,696
Region 3-Grant	99.29	156	-	-	-	-	56	56	189	323	512	724
Saline	95.59	140	64	64	128	11	54	65	107	289	396	729
Region 3 Totals		296	64	64	128	11	110	121	296	612	908	1,453
Region 4-Calhoun	100.0	67	-	-	-	-	34	34	-	22	22	123
Union	100.0	358	-	-	-	-	123	123	112	22	134	615
Region 4 Totals		425	-	-	-	-	157	157	112	44	156	738
Region 5-Garland	100.0	67	-	-	-	-	67	67	-	1,131	1,131	1,332
Montgomery	100.0	358	-	-	-	-	157	157	-	157	157	796
Region 5 Totals		616	-	-	-	-	224	224	-	1,288	1,288	2,128
Region 6-Clark	100.0	291	-	8,635	8,635	885	594	1,479	1,501	325	1,826	12,231
Hot Spring	100.0	190	-	2,173	2,173	302	179	481	-	2,677	2,677	5,521
Pike	100.0	672	650	-	650	-	672	672	-	-	-	1,994
Region 6 Totals		1,153	650	10,808	11,458	1,187	1,445	2,632	1,501	3,002	4,503	19,746
Region 7-Hempstead	48.83	629	-	-	-	405	334	739	11	306	317	1,685
Nevada	76.65	446	-	-	-	223	8	231	-	-	-	677
Region 7 Totals		1,075	-	-	-	628	342	970	11	306	317	2,362
Region 8-Dallas	100.0	78	-	806	806	246	-	246	157	56	213	1,343
Ouachita	100.0	235	-	-	-	22	-	22	45	45	90	347
Region 8 Totals		313	-	806	806	268	-	268	202	101	303	1,690
Basin Totals		4,981	270,494	53,657	324,151	47,231	9,474	56,705	17,819	15,526	33,345	419,182

Source: Arkansas Geological Commission, Use of Water in Arkansas, 1980, Water Resources Summary Number 14.

Table I-6. Use of Water by Regions and Counties in the Ouachita River Basin, Without Prorating, 1980
(in Acre-Feet per Year)

		Rice Irrigation			Other Crop Irrigation			Fish & Minnow Farms			TOTAL
	Livestock	Ground	Surface	Total	Ground	Surface	Total	Ground	Surface	Total	
Region 1-Ashley	157	82,981	3,461	86,442	16,912	3,181	20,093	9,330	5,690	15,020	121,712
Drew	179	37,531	9,330	46,861	11,760	1,299	13,059	1,243	739	1,982	62,081
Lincoln	269	87,741	19,264	107,005	10,091	1,803	11,894	1,366	2,867	4,233	123,401
Jefferson	190	148,557	24,181	172,738	16,778	-	16,778	8,109	2,285	10,394	200,100
Region 1 Totals	795	356,810	56,236	413,046	55,541	6,283	61,824	20,048	11,581	31,629	507,294
Region 2-Bradley	212	-	-	-	448	1,602	2,050	78	717	725	2,987
Cleveland	258	-	-	-	-	202	202	-	179	179	639
Region 2 Totals	470	-	-	-	448	1,804	2,252	78	896	974	3,696
Region 3-Grant	157	-	-	-	-	56	66	190	325	515	728
Saline	146	67	67	134	11	56	67	112	302	414	761
Pulaski	179	15,176	3,326	18,502	10,920	1,266	12,186	1,400	1,781	3,181	34,048
Region 3 Totals	482	15,243	3,393	18,636	10,931	1,378	12,309	1,702	2,408	4,110	35,537
Region 4-Calhoun	67	-	-	-	-	34	34	-	22	22	123
Union	358	-	-	-	-	123	123	112	22	134	615
Region 4 Totals	425	-	-	-	-	157	157	112	44	156	738
Region 5-Garland	134	-	-	-	-	67	67	-	1,131	1,131	1,332
Montgomery	482	-	-	-	-	157	157	-	157	157	796
Region 5 Totals	616	-	-	-	-	224	224	-	1,228	1,228	2,128
Region 6-Clark	291	-	8,635	8,635	885	594	1,479	1,501	325	1,826	12,231
Hot Spring	190	-	2,173	2,173	302	179	481	-	2,677	2,677	5,521
Pike	672	650	-	650	-	672	672	-	-	-	1,994
Region 6 Totals	1,153	650	10,808	11,458	1,187	1,445	2,632	1,501	3,002	4,503	19,746
Region 7-Hempstead	1,288	-	-	-	829	683	1,512	22	627	649	3,449
Nevada	582	-	-	-	291	11	302	-	-	-	884
Region 7 Totals	1,870	-	-	-	1,120	694	1,814	22	627	649	4,333
Region 8-Dallas	78	-	806	806	246	-	246	157	56	213	1,343
Ouachita	235	-	-	-	22	-	22	45	45	90	347
Region 8 Totals	313	-	806	806	268	-	268	202	101	303	1,690
Basin Totals	6,124	372,703	71,243	443,946	69,495	11,985	81,480	23,665	19,947	43,612	575,162

Source: Arkansas Geological Commission, Use of Water in Arkansas, 1980, Water Resources Summary Number 14.

Table I-7 Use of Water by Regions and Counties in the Ouachita River Basin, Without Prorating 1980
(in Million Gallons per Day)

		Rice Irrigation			Other Crop Irrigation			Fish & Minnow Farms			Wildlife Impoundment		
	Livestock	Ground	Surface	Total	Ground	Surface	Total	Ground	Surface	Total	Ground	Surface	Total
Region 1-Ashley	.14	74.09	3.09	77.18	15.10	2.84	17.94	8.33	5.08	13.41	-	-	-
Drew	.16	33.51	8.33	41.89	10.5	1.16	11.66	1.11	.66	1.77	-	8.93	8.93
Lincoln	.24	78.34	17.20	95.54	9.01	1.61	10.62	1.22	2.56	9.28	-	15.63	15.63
Jefferson	.17	132.64	21.59	154.23	14.98	-	14.98	7.24	2.04	9.28	-	15.63	15.63
Region 1 Totals	.71	318.58	50.21	368.84	49.59	5.61	55.2	7.9	10.34	28.24	-	24.56	24.56
Region 2-Bradley	.19	-	-	-	.40	1.43	1.83	.07	.64	.71	-	-	-
Cleveland	.23	-	-	-	-	.18	.18	-	.16	.16	-	-	-
Region 2 Totals	.42	-	-	-	.40	1.61	2.01	.07	.80	.87	-	-	-
Region 3-Grant	.14	-	-	-	-	.05	.05	.17	.29	.46	-	-	-
Saline	.13	.06	.06	.12	.01	.05	.06	.10	.27	.37	-	-	-
Pulaski	.16	13.55	2.97	16.53	9.75	1.13	10.88	1.25	1.59	2.84	-	-	-
Region 3 Totals	.43	13.61	3.03	16.65	9.76	1.23	10.88	1.25	1.59	2.84	-	-	-
Region 4-Calhoun	.06	-	-	-	-	.03	.03	-	.02	.02	-	-	-
Union	.32	-	-	-	-	.11	.11	.10	.02	.12	-	-	-
Region 4 Totals	.38	-	-	-	-	.14	.14	.10	.04	.14	-	-	-
Region 5-Garland	.12	-	-	-	-	.06	.06	-	1.01	1.01	-	-	-
Montgomery	.43	-	-	-	-	.14	.14	-	.14	.14	-	-	-
Region 5 Totals	.55	-	-	-	-	.20	.20	-	1.15	1.15	-	-	-
Region 6-Clark	.26	-	7.71	7.71	.79	.53	1.32	1.34	.29	1.63	-	-	-
Hot Spring	.17	-	1.94	1.94	.27	.16	.43	-	2.39	2.39	-	-	-
Pike	.60	.58	-	.58	-	.60	.60	-	-	-	-	-	-
Region 6 Totals	1.03	.58	9.65	10.23	1.06	1.29	2.35	1.34	2.68	4.02	-	-	-
Region 7-Hempstead	1.15	-	-	-	.74	.61	1.25	.02	.56	.58	-	1.61	1.61
Nevada	.52	-	-	-	.26	.01	.27	-	-	-	-	-	-
Region 7 Totals	1.67	-	-	-	1.00	.62	1.52	.02	.56	.58	-	1.61	1.61
Region 8-Dallas	.07	-	.72	.72	.22	-	.22	.14	.05	.19	-	-	-
Ouachita	.21	-	-	-	.02	-	.02	.04	.04	.08	-	-	-
Region 8 Totals	.28	-	.72	.72	.24	-	.24	.18	.09	.27	-	-	-

Source: Arkansas Geological Commission, Use of Water in Arkansas, 1980, Water Resources Summary Number 14.

1975-80 period; ground water usage increased by 182 percent and surface water usage increased by 76 percent (Arkansas Geological Commission, 1981, p.25).

Except for water used for electric energy, water used for crop irrigation dwarfs all the other categories: fish farms, public supply, industry, wildlife, livestock, and domestic use (Arkansas Geological Commission, 1981, p. 7).

Special Report: Agricultural Water Use Study for 50 Arkansas Counties - 1980 and Arkansas Agricultural Water Study - Arkansas Statewide Study Phase V

Data on irrigation in the study area are available from two related publications (USDA, SCS, 1981; USDA, 1983). The first report has data for 16 of the 20 counties in the study area: Bradley, Calhoun, Clark, Cleveland, Dallas, Garland, Grant, Hempstead, Hot Spring, Montgomery, Nevada, Ouachita, Pike, Pulaski, Saline and Union. The second study has data for the four remaining counties in the study area: Jefferson, Lincoln, Drew and Ashley. Table I-8 shows the number of groundwater wells and the number of surface pumps and relifts. The counties in Region 1 of the study area that are on the edge of the Mississippi Delta, have a lot of cropland acres, and a lot of wells and surface pumps or relifts. ninety percent of the irrigation sources were groundwater wells. In Region 6, there were a total of 50 sources, all of them surface pumps or relifts. In Bradley county there were 17 groundwater wells and no surface pumps or relifts. For all 20 counties there were an

Table I-8. Ground Water and Surface Water Irrigation Sources for the 20 Counties in the Study Area by Regions, 1980

	Ground[1] Water Wells	Surface Pumps or Relifts	Irrigated Acres	Total Irrigation Water
	number	number	acres	acre-feet
Region 1-Ashley	184	4	[2]	[2]
Drew	149	82		
Lincoln	415	12		
Jefferson	366	25		
Total	1,114	123		
Percent	90.1%	9.9%		
Region 2-Bradley	17	0	399	465.0
Cleveland	0	1	15	54.4
Total	17	1		
Percent	94.4%	5.6%		
Region 3-Grant	5	8	150	169.2
Saline	0	8	224	582.0
Total	5	16		
Percent	23.8%	76.2%		
Region 4-Calhoun	0	1	24	6.3
Union	0	0	0	no irrigation
Total	0	1		
Percent	0.0%	100.0%		
Region 5-Garland	0	9	176	130.0
Montgomery	0	10	460	317.2
Total	0	19		
Percent	0%	100.0%		
Region 6-Clark	0	33	4,587	32,737
Hot Spring	2	14	1,670	6,768.0
Pike	0	3	280	826.4
Total	2	50		
Percent	0.0%	100.0%		
Region 7-Hempstead	0	6	1,285	1,260.5
Nevada	0	3	273	307.4
Total	0	9		
Percent	0.0%	100.0%		
Region 8-Dallas	0	4	496	386.5
Ouachita	0	3	76	196.5
Total	0	7		
Percent	0.0%	100.0%		
Grand Total	1,138	226		
Percent	83.4%	16.6%		

[1] Where only part of the county was in the Ouachita River Basin, the number of irrigation sources was prorated by area.

[2] Not available

Source: USDA, SCS, Special Report-Agricultural Water Use Study for 50 Arkansas Counties-1980. 1981.

estimated 1,138 groundwater wells (83.4 percent of the total) and 226 (16.6 percent of the total) surface pumps or relifts.

Table I-9 also shows the numbers of acres irrigated by different methods for 16 counties. Acres irrigated with contour levees accounted for 46.4 percent of total irrigated acres, graded border accounted for 15.5 percent, self propelled sprinkler accounted for 13.9 percent, and other furrow accounted for 10.7 percent.

The Statewide Study - Phase V also shows irrigated acres by water application methods for the Upper and Lower Ouachita River Accounting Units (Table I-10). The results are similar to the aggregated county data: 57 percent of the acreage is irrigated with a contour levee method, 13.7 percent with a graded furrow method, and 18.9 percent with another furrow method. This table also shows that the total number of irrigated acres in the Upper and Lower Ouachita River Accounting Units combined was 55,550 acres in 1980; the total acre-feet pumped was 273,296 of which 76.3 percent was from groundwater sources and 23.7 percent from surface water sources.

The Phase V study used linear programming analysis to estimate how many acres would be irrigated in the year 2030. The analysis allows those crops that produce the greatest profit to enter into the program solution. Table I-11, 2030 Projected Acres of Irrigated Crops, Estimated Water Requirement, and Estimated Pumping Requirement shows that a total of 575,200 acres would be irrigated based on the criterion used. Of this total, 67.8 percent would be

Table I-9. Type of Irrigation System Used for 16 Counties in the Study Area by Regions, 1980

	Graded Border[1]	Sprinkle Periodic Movement	Drip	Sprinkler SP	Sprinkler Solid	Graded Furrow	Furrow Other	Contour Levee	Other
				Irrigated	Acres				
Region 1[2]-Ashley									
Drew									
Lincoln									
Jefferson									
Total									
Percent									
Region 2-Bradley		36	292				50		
Cleveland									15
Total									
Percent									
Region 3-Grant		84			303	1			14
Saline		124		50				50	
Total									
Percent									
Region 4-Calhoun			20						
Union									
Total									
Percent									
Region 5-Garland		20		142					14
Montgomery		450			10				
Total									
Percent									
Region 6-Clark				240			640	2,876	109
Hot Spring				320	24		165	976	
Pike				75				280	
Total									
Percent									
Region 7-Hempstead		658.5		271					
Nevada		32		220	23		2		390.5
Total									
Percent									
Region 8-Dallas							150	230	
Ouachita		66					10		
Total									
Percent									
Grand Total	0	1470.5	312	1,318	360	1	1,017	4,412	542.5
Percent	0.8%	15.5%	3.3%	13.9%	3.8%	0.0%	10.7%	46.4%	5.7%

[1] An additional method of irrigation is level border. However none of the 16 counties had any acreage irrigated by this method so the column was omitted.

[2] Data not available for Region 1 counties.

Source: USDA, SCS, Special Report-Agricultural Water Use Study for 50 Arkansas Counties-1980. 1981.

in soybeans, 21.7 percent in rice, and 9.9 percent in cotton. Estimated water requirement in 2030 would be 1,015,900 acre-feet. Table I-12 shows the 1980 and 2030 estimated irrigated acreages by major crop and the percentage increase. Total irrigated acres are projected to increase by 996 percent, irrigated soybean acres are projected to increase by 3,711 percent.

Table I-10. Irrigation Water Application Methods for the Upper Ouachita River and Lower Ouachita River Accounting Units, 1980

	Upper Ouachita River 080401	Lower Ouachita River 080402	Upper and Lower Ouachita River Combined	Percent of Total
	- - - - - -	acres - - - - - - -		
Sprinkler				
Permanent	32	153	185	0.33
Portable	1,118	427	1,545	2.8
Self Propelled	1,344	115	1,459	2.6
Contour Levee	12,875	18,766	31,641	57.0
Level Border	163	135	298	0.5
Graded Furrow	433	7,174	7,617	13.7
Other Furrow	6,336	4,181	10,517	18.9
Drip	47	318	365	0.7
Other	510	1,413	1,923	3.5
Total	22,868	32,682	55,550	100.00
1980 Agricultural Water Pumped				
Ground	123,097	85,361	208,458	76.3
Pumped Surface	54,786	10,052	64,838	23.7
Total	177,883	95,413	273,296	100.00

Source: USDA, SCS, ERS, Arkansas Agricultural Water Study - Akansas Statewide Study - Phase V. 1983.

Table I-11. 2030 Projected Acres of Irrigated Crops, Estimated Water Requirement, and Estimated Pumping Requirement

	Rice	Cotton	Soybeans	Other	Total	Estimated Water Requirement	Estimated Pumping Requirement[1]
			acres			acre-feet	acre-feet
Upper Ouachita River 080401	18,500	3,600	75,000	1,000	98,100	167,450	279,100
Lower Ouachita River 080402	106,100	53,400	314,900	2,700	477,100	848,450	1,414,100
Upper and Lower Ouachita River Combined	124,600	57,000	389,900	3,700	575,200	1,015,900	1,693,200
		Percent of total					
	21.7	9.9	67.8	0.6	100.0		

[1] At 60 percent efficiency.

Source: USDA, SCS, ERS, Arkansas Agricultural Water Study - Arkansas Statewide Study - Phase V. 1983.

Table I-12. 1980 Actual and 2030 Projected Acres of Irrigated Crops, Estimated Water Requirements for the Upper and Lower Ouachita River Basin Combined

	1980	2030	Percent Increase
	- - - - acres	- - - -	percent
Rice	30,617	124,600	306
Cotton	9,713	57,000	487
Soybeans	10,230	389,900	3,711
Corn, Sorghum Pasture	1,921	3,700	43
Total	52,481	575,200	996

Source: USDA, SCS, ERS, Arkansas Agricultural Water Study Arkansas Statewide Study - Phase V. 1983.

Projected Water Requirements and Surface Water Availability for Arkansas

A 1978 study by Shulstad, Ziegler and Cross (Shulstad, et al., 1978) estimated water withdrawals for livestock; soybeans, cotton and rice irrigation; and commercial fish farm, fish hatchery and wildlife impoundment water requirements. Estimates were for 1975, 1985, 2000, and 2020. Expected growth rates were used to derive these estimates. Although the estimates were not made for the Ouachita Basin they were made for the Ouachita and Mississippi-Tensas Arkansas Water Resource Planning Area (AWRPA). Compared with the 20 county Ouachita Basin study area it excludes Saline and Pulaski counties and includes Desha and Chicot counties. The latter two counties are important crop production counties and would be expected to have a lot of irrigated acres. The growth rates for rice acreage were based on average price and weather situations. Growth rates for irrigated soybean and irrigated cotton acreages were developed from projected data in the previously discussed Lower Mississippi Region Comprehensive Study (LMR, 1974b).

Water use estimates assumed continued use of flood irrigation in rice production and seven percent conveyance losses for irrigation of soybeans and cotton. The report suggests that replacement of flood contour levee irrigation might occur before 2020 - an outcome that could reduce rice irrigation water usage by 50-60 percent. The report assumed that an additional 105,815 acre-feet would be provided from surface water resources in the Ouachita and Mississippi-Tensas AWRPA.

Table I-13 shows projected irrigated acreages in the Ouachita and Mississippi-Tensas area for the three major crops and for the total. In 2020, the report projected 222,041 acres of rice, 49,200 acres of soybeans, and 35,630 acres of cotton; and a total in 2020 of 306,871 acres. Table I-14 shows irrigated crop water requirements. In 2020, rice irrigation water is estimated at 889,280 acre-feet and the total for rice, soybeans, and cotton is 306,871 acre-feet.

Arkansas Resource Base Report (1981)

This report identifies two study areas that, between them, encompass the 20 county area for this research project (the study areas were compiled from the U.S.G.S. state base map: the Upper

Table I-13 Irrigated Acreages for Rice, Soybeans, and Cotton for the Ouachita and Mississippi-Tensas Arkansas Water Resource Planning Area, 1975, 1985, 2000, 2020

	1975	1985	2000	2020
		Acres		
Soybeans	23,900	27,769	41,690	49,200
Cotton	34,248	33,829	34,930	35,630
Rice	158,457	200,217	222,041	222,041
TOTAL	216,605	261,815	298,661	306,871

Source: Shulstad, R. N., Ziegler, Joseph A. and Eddie D. Cross. Projected Water Requirements and Surface Water Availability for Arkansas.

Table I-14. Irrigated Crop Water Requirements for the Ouachita and Mississippi-Tensas Arkansas Water Resource Planning Area 1975, 1985, 2000, 2020

	1975	1985	2000	2020
		Acre-Feet		
Soybeans	12,790	14,930	22,299	26,320
Cotton	24,528	24,371	25,088	25,536
Rice	539,571	17,898	801,898	889,280
TOTAL	576,890	841,198	841,198	941,136

Source: Shulstad, R. N., Ziegler, Joseph A. and Eddie D. Cross. Projected Water Requirements and Surface Water Availability for Arkansas.

Ouachita River and the Lower Ouachita River.

The main water source found in the Upper Ouachita study area (3,462,252 acres) is the upper reaches of the Ouachita River, from its headwaters in the Ouachita Mountains downstream to a point below Camden. Major tributaries include the Caddo and Little Missouri Rivers. Major lakes include Ouachita, De Gray, Catherine and Greeson, (USDA, SCS, ERS, FS, p. I-8).

The main water source of the Lower Ouachita study area (4,900,525 acres) is the section of the Ouachita River immediately downstream of Camden, to the Louisiana state line. Major tributaries include the Saline River, Moro River, and Bayou Bartholomew, which confluences with the Ouachita River in Louisiana (USDA, SCS, ERS, FS, 1981, p. I-9).

METHODOLOGY REVIEW

Several previous studies contain pertinent information to the preparation of this research on estimating the agricultural water demand in southern Arkansas. The basis of this review will be research dealing with water demand using linear programming methodology. Particular attention will be focused on studies utilizing linear programming (LP) to estimate actual demand curves.

Many different applications of linear programming have been cited in recent studies that deal directly with water resources. Yaron and Dinar developed a programming model that first solved an irrigation water allocation problem in a linear program framework, and then used the shadow prices obtained from the LP to develop a dynamic programming (DP) framework to improve the LP solution. Using this approach, Yaron and Dinar were able to increase the overall income obtainable by the water users, but it appears that the extra detail given to this problem should have been directed at the LP portion of the problem. That is, instead of using the DP sensitivity analysis to develop a regression curve that related crop yields to different soils, LP sensitivity would have been simpler.

Candler, Fortuny-Amat, and McCarl reviewed many multilevel programming models and concluded (p. 530): "an uncharitable summary of this paper might be that the authors can recognize multilevel programming problems, but they cannot solve them!" This is not the case in the study by Yaron and Dinar, but in larger studies such as this Ouachita Basin Study, computer algorithms are necessary for solving the linear programming problems. Candler, et al., also concluded that, "in certain cases, solutions may be available relatively easily using linear programming" (p. 530). Andrews and Weyrick state that, "next to cost-benefit analysis, linear programming is the easiest model to understand and modern computer routines such as MPS 360 will produce an abundance of analytical information at very low cost" (p. 272).

Andrews and Weyrick utilized a linear programming model with nine different objective functions (each considered separately) for evaluating water resources and cost-benefit allocation of surface water uses in a small southern New Hampshire River Basin. Their basin-wide firm concept combined all firms into one decision-making unit. Thus, their study was conducted on a macro basis; whereas, the study mentioned earlier by Yaron and Dinar was conducted on a micro basis, allowing Yaron and Dinar to justify the application of dynamic programming. The Ouachita River Basin study was also a basin-wide study; that is, the entire basin acts as if it were a single firm.

Sowell, Sneed, and Chen conducted a study of agricultural water demands in the Tar and Neuse River Basin in North Carolina. The major emphasis of their study was the development of computer models to study the interaction between water for irrigation of crops and value of production of these crops. As in this study, Sowell, Sneed and Chen entered water available from rainfall as a function of time throughout the growing season into their model. Input to Sowell, Sneed, and Chen's model included soil type by acreage, crops by acreage and soil type, crop planting, maturity and harvest dates, crop response to irrigation, and rainfall data.

Results of the Tar and Neuse River Basin study indicated a potential increase in net returns of approximately 25 percent when crops were irrigated at medium and high levels. Also, water requirements were approximately 666,667 feet using 1971 rainfall data. They also state that in three counties studied separately, over a ten year period (1961-70), profitability of irrigation varied significantly from year to year. In some years, the profitability varied inversely with total rainfall during the growing season;

however, they state that in other cases this relationship does not hold, indicating the importance of water needs of the crop at particular stages of growth. Sowell, et al., concluded their linear programming optimization model provides a tool for determining the best allocation of water resources to the various crops grown in a county or region and also for determining economically feasible irrigation water requirements.

In a similar study, Gisser applied a parametric linear programming model consisting of six crops, three soil classes, eight salinity levels, two irrigation intensities, two sources of water (local and imported), and two irrigation activities, to estimate the demand function for imported water in the Pecos River Basin for 1980. The demand function derived by Gisser would enable the government to estimate the total subsidy that it would need to provide to prevent the abandonment of certain agricultural acres, where deterioration of local water supplies could be replaced by a costly outside supply of water. One major assumption of Gisser's study was that the farms in 1966 were optimizing and that the modified price of imported water through parameterization would not cause different farms to respond differently to the altered conditions.

The results of Gisser's profit maximization model showed that at prices higher than $38.55 per acre-foot farmers would not buy imported water. This result would convey to the government that if the water table in the Pecos River Basin was lowered to a dangerous level or if for other reasons the government wanted to protect the basin, it could start subsidizing the imported water in the price range of $ 38.55 and higher.

Morton, Christensen and Heady utilized the Iowa State University interregional programming model to simulate increases in the price of surface water for irrigated agriculture, and to evalute the economic impact of these increases on U.S. agricultural water use and production patterns. Their cost minimization model was parameterized using four alternative price levels of surface water. The model employed 1975 surface water prices as the base level to project 1985 commodity demand and resource levels. Three relevant conclusions were drawn by Morton, et al.: (1) national surface water demand is relatively price inelastic; (2) as surface water prices rise, irrigated land become less valuable relative to dryland; and (3) U.S. agriculture appears able to withstand large increases in the real price of surface water without exerting much upward pressure on farm level prices of the commodities studied (barley, corn, corn silage, cotton, legume hays, nonlegume hays, oats, sorghum silage, soybeans, wheat, beef cows, beef feeders, dairy, and hogs). The basis for conclusion number three above was the fact that irrigated agriculture contributed less than five percent of production of the crops in the base solution (1975), therefore, commodity shadow prices are largely unaffected by rising surface water prices.

A study by Craddock presented the fundamentals of developing a demand curve. Craddock states that the procedure is to first separate the cost of irrigation water from other variable and fixed costs for each irrigated crop activity in the linear programming matrix. Next, successively solving the models for alternative water prices will give sufficient data for developing a demand curve.

Whether or not a parameterization of water price is undertaken or whether deliberate incremental changes are made in the water price and the resulting solution obtained, the demand curve will be a step function rather than a smooth continuous curve. This occurs because of the linearities of the objective function and constraints in linear programming models which give rise to "corner" solutions. As a result, the price or objective function value will usually have to change by a discrete amount before a different corner point is found as the solution and a change takes place in one or more activities in the basis. He also states that the aggregate curve can be found by weighing the quantities of water required for the model solutions by the number of farms in each representative farm class.

The derived demand for irrigation water has been addressed by several researchers. The demand for resources is generally a derived demand--derived, that is, from the demand for the goods and services which the resources help produce. In the case of derived demand for irrigation water, water is demanded because it will produce increased yields, up to a certain point, for certain crops. Crops are demanded by the population; thus, water is demanded by the farmer to produce more of the crops. Another example might be a derived demand for diesel fuel to run the irrigation pumps.

The equilibrium point for irrigation water demand is where the marginal value product (MVP) of the irrigation water equals the marginal factor cost (MFC) of the water. In the Ouachita Basin Study, MVP is the value of crops produced with the last acre-inch of water. If MVP is greater than MFC, the farmer will demand more irrigation water for his crops. But, if MVP is less than MFC, the farmer will decrease his demand for irrigation water.

Shumway used a linear programming model to derive a demand equation for irrigation water in a developing subregion in California--the West Side of the San Joaquin Valley. In Shumway's study, parametric programming was applied to the model solution to determine the demand function for irrigation water in this subregion. Using eight parametric program observations, the following least squares regression equation for the quantity of water demanded was obtained by Shumway (p. 197):

$$\text{Log}_{10} Q = 3.77 - .052P$$

where Q is the quantity of water demanded in the subregion (in 1,000 acre-feet) at price P. After plotting the price of water versus the total quantity demanded, Shumway concluded that the demand for water was elastic at prices above $8.50 and inelastic below (the price elasticity of demand is defined as the percentage change in quantity demanded resulting from a one percent change in price, that is, $e = -(d(Q)/d(P)) * (P/Q)$, where P is price and Q is quantity). Shumway also concluded that annual revenues to suppliers of water in this subregion may be increased by lowering the unit price of water.

This was due to the fact that the demand for irrigation water was elastic with respect to prices at higher levels.

In contrast to Shumway's generally elastic demand function for water on the West Side of the San Joaquin Valley, a study by Moore and Hedges found an inelastic demand for water on the East Side farms in Tulare county. Moore and Hedges stated that at a price of $23.30 per acre-foot demand was still estimated to be inelastic, although at prices above $23.30 per acre-foot, water demand would become increasingly elastic.

Moore and Hedges concluded from their study that the demand for irrigation water in a specific, highly commercialized area appears to be relatively inelastic in the lower range of water prices, but becomes increasingly elastic as prices rise. Also, they concluded that demand for irrigation water in the lower price range also tends to be less elastic for lower quality soils because of the lack of economically adaptable alternative crops--growers tend to take low-quality soils out of production at much lower prices than the better soils.

Moore and Hedges also used parametric programming to derive their demand curve for water, but their price ranges for elastic and inelastic demand for water were different than those found by Shumway. There are two main reasons for the differences in the demand curves developed by Shumway and Moore and Hedges. First, Shumway's demand function was for a developing area, and Moore and Hedge's demand function was for an area already fully developed for agricultural production and existing water distribution systems. Second, the most significant reason for the different elasticities estimated by the two studies was the method of fitting the regression equation to the parametric programming results. The relationship between water price and quantity demanded derived from Shumway's study was well represented by a continuous exponential function. Moore and Hedges concluded that the demand curve for water in Tulare County consisted of two discontinuous segments. While the price elasticity of demand is low over the two segments, the elasticity between them is infinite and the elasticity between the midpoints on both segments is near unity. Therefore, if only one regression line had been used, the differences between the estimates of elasticity from these two studies would not be as great as it appears at first glance.

The theory that the demand for irrigation water is elastic is strengthened by Howitt, Watson, and Adams. Howitt, et al., agree with the findings of Shumway but state further that the elasticity of demand of water for irrigation had in fact been under-estimated when linear programming was used exclusively. Howitt, et al., used a quadratic programming approach as a method of correcting this bias.

The Howitt, et al., position was criticized by Martin, Selley, and Cory for being logically incorrect. Martin, et al., argue that the quadratic programming formulation should normally develop a demand curve for water that is less elastic than a demand curve developed from a linear programming formulation, rather than more elastic as claimed by Howitt, et al. Since product prices are allowed to rise as less water is used in production and output is decreased, the product will be better able to pay for higher-cost water than projected in the LP formulation.

As shown in the above review, the derived demand for irrigation water has been the center of debate between several schools of thought. The geographical region in which a study is conducted seems to affect the results of the various studies reviewed. Areas with ample rainfall and preexisting irrigation methods would be less affected by increases in the cost of water than those areas that receive little rainfall and especially those areas that are just developing into agricultural producers. Shumway's study in which the demand elasticities range from inelastic at low costs to very elastic at high costs seems to represent the behavior of the Ouachita River Basin.

CHAPTER II

ANALYTICAL PROCEDURES AND DATA DEVELOPMENT

A number of techniques, of varying degrees of sophistication, can be used to project the agricultural water demand of a region. These techniques can range from fairly simplistic trend analyses, to gross water requirements on a per unit basis (i.e., acres of cropland or numbers of livestock), to simulation models of various forms. While more sophisticated models may be more accurate, data availability and the cost of research can produce problems with these models. The relative potential of the simulation models for more accuracy may never be achieved if the necessary data is unreliable or non-existent.

The dynamics which effect the development of regional agricultural water demands are often quite complex. The demand will be produced by a large number of decentralized decision-making units which may have differing goals and may face substantially different decision environments. The goals may include profit maximization, risk reduction, firm survival, and cash flow management. The decision environments may be altered by different levels of available resources, yield responses, product prices, input prices, risk aversion, debt loads, and management capabilities.

The projection of water demand for a region will require some quantification of the decision environment for each decision-making unit, a representation of the goals of the units and an aggregation of the behavior of the various units into a regional behavior. The procedure selected for this study to accomplish these requirements is focused on the use of a linear programming model.

LINEAR PROGRAMMING MODEL

Any model is an approximation of a real world system. The more relevant factors that the model uses in the approximation, the better the approximation of the actual system will be. Models do not magically generate new information. However, they can organize existing information into patterns which are more readily used. To understand a model, it is necessary to understand the approximation that is being made, the relevant factors included and excluded, the accuracy of the basic data which the model uses and the way the model organizes that data into new patterns of information.

The credibility of a model can be examined by two criteria-verification and validation (Johnson). Verification is the check on internal consistency which examines the logic of the model, its correspondence to theory, and its use of basic data. Validation is the check of the model's correspondence to reality--an empirical examination on how well it may simulate an observable performance of the real system, given the objectives of the study. This chapter will discuss the objectives of the model component of the study, examine the analytical procedures and data development, and briefly address the verification of the model. The validation of the model will be presented in Chapter IV, immediately preceding the discussion of the model results.

The objectives of the linear programming model are to project the regional water demand for irrigated crop production under a variety of production conditions. The conditions will be handled through the use of model scenarios. The scenarios will examine the impact on water use that adoption of water conservation practices and alternative irrigation costs will make.

The linear programming model will examine a set of possible production alternatives and identify the cropping pattern which will generate the greatest profit for the region. The production alternatives are defined as cropping activities using different irrigation systems (dryland, center pivot, furrow or flood) on specified soil classes. The selection process is constrained by the number of acres of each soil class that are available in each county and hydrologic region. It is also constrained by a minimum percentage of the 1980 acreage of each crop. This minimum acreage must be replicated in the model solution regardless of the profitability of the production activities involved. In addition, total production of each crop must be within ± 10% of the OBERS crop projections for the state of Arkansas.

The model assumes that the goal of all decision-making units in the region is to maximize profits. It also assumes that by maximizing the profit for the entire region it is adequately approximating what happens when each individual decision-making unit maximizes its own profit. In other words, it assumes that the region is owned by a single firm which manages the entire region's resources in the most efficient manner possible, given the constraints on soil availability, minimum acreage and production bounds.

The data necessary for the model to run include: descriptions of the soil resources including the number of available acres of each class; product prices; crop yield responses; enterprise budgets showing the per acre costs of production; irrigation costs; land conversion costs and supplemental irrigation needs. The development of each of these data items will follow in the concluding portion of this chapter.

The model organizes these data in an iterative fashion that examines the use of all soil resources in all possible production activities and selects the activity which contributes the most to regional profit. The opportunity cost of each production activity, expressed in terms of the sacrifice made by foregoing the use of the resources in alternative activities guides the process. A cropping pattern is determined which satisfies all of the model constraints and from this cropping pattern, the irrigation water requirements are identified.

The model verification can be addressed in two parts. First, the objective function of the linear programming model may not be an accurate representation of the goals of the producers in the Ouachita Basin. Individual profit maximization may not be precisely reflected by regional profit maximization. Furthermore, the single goal of profit maximization may ignore additional objectives, particularly risk management. Irrigation in the south has been recognized as a risk-reducing input (Boggess, et al.), and the neglect of risk aversion may underestimate the use of irrigation. The criticism of the objective function of linear programming models is often times expressed in terms of normative versus positive models. It can be argued that the results of linear programming models do not reflect what producers actually do, but what they should do to maximize profits. In this sense, the model results may be more normative than positive.

The second part of the issue deals with the aggregation biases inherent in the model. The model assumes that every acre of each soil class in each county/hydrologic region will be managed the same and that those resources will respond in a similar fashion. Furthermore, the model does not use the fact that better managers do get above average yields. Certain activities, such as the projected rates of adoption of irrigation scheduling for double crop soybeans and conservation practices, may not fall into the discrete groups identified by the model. The adoption process may be much more continuous. The soil classes used by the model are aggregations of different soil units--this aggregation results in an averaging process which may be unrepresentative of the resource availabilities of particular decision environments within the basin. In addition, irrigation costs can vary by more than simply the soil characteristics and irrigation systems. Depth of well, distance from surface source, capacity of pump are all factors which might cause these costs to vary across farms, but a standard cost is employed with only slight variations by soil classes. A final note about the verification of the model should be made. The drought scenarios assume that all producers recognize that a drought is coming before the season begins and all necessary adjustments to irrigation systems can then be made to insure efficient production. This is a simplistic view of the world and does not really reflect either the weather risks or asset fixities which can plague agriculture. Additional limitations will be discussed in the section on model validation.

SOIL RESOURCE DATA

The basic soil resources data used to construct the eleven soil classes for the model are found in the 1977 Arkansas Resource Information Data System (RIDS) system developed by the Soil Conservation Service. RIDS is documented in the *Arkansas Resource Base Report*. The RIDS system identifies 64 soil groups. Each group is an aggregation of related units. These units are designated as soil numbers and are soil map units which are roughly comparable to soil series. The eleven soil classes developed for this study are aggregations of the RIDS soil numbers, independent of the RIDS soil groups.

The process involved the identification of the characteristics of soils which are suitable for the production of the crops using the various irrigation systems. The combinations of crops and irrigation systems considered are: (1) rice; (2) soybeans-center pivot; (3) soybeans-furrow; (4) soybeans-flood; (5) cotton-center pivot; (6) cotton-furrow and (7) cotton-flood. The combinations including center pivot systems were further divided into one group of soils with gently undulating or slopes of 3 percent or less and one group with undulating or slopes of 3 to 8 percent.

The eleven soil classes were determined by grouping the soils which had similar characteristics. In some cases, there were soils which had characteristics suitable for production of more than one crop-irrigation system combination. These soils formed a distinct group. This expanded the number of classes from the original seven associated with each crop-irrigation system combination to a grand total of eleven.

The soil class which contained the soils suitable for only rice production had an insignificant acreage so the class which consisted of the soils suitable for all crop-irrigation system combinations was sub-divided. All soils in this latter class which were categorized in RIDS soil groups 1 and 39 were grouped into the new soil class. The soil classes are identified by the crop-irrigation system combinations in Table II-1.

The available acreage for each soil class was determined from the RIDS system data as well. The 1977 RIDS survey includes information on the soils and land use at the center point of every tenth square kilometer within each county. From this survey data, estima-

Table II-1 Soil Classes and Their Suitability for Various Crop-Irrigation Production Systems.

Soil Classes	Rice	Soybeans Flood	Soybeans Furrow	Soybeans Sprinkler 0-3%	Soybeans Sprinkler 3-8%	Cotton Flood	Cotton Furrow	Cotton Sprinkler 0-3%	Cotton Sprinkler 3-8%
1	-	-	-	-	X	-	-	-	-
2	-	-	-	-	X	-	-	-	X
3	-	-	-	X	-	-	-	-	-
4	-	-	-	X	-	-	-	X	-
5	-	-	X	X	-	-	-	-	-
6	-	-	X	X	-	-	X	X	-
7	-	X	X	X	-	-	-	-	-
8	-	X	X	X	-	X	X	X	-
9	X	X	X	X	-	X	X	X	-
10	X	X	X	X	-	-	-	-	-
11	X	X	X	X	-	X	X	X	-

*The model uses the assumption that dryland production of each crop is possible in all soil classes which are suitable for irrigated production.

Table: II-2 Land Areas of Counties and Soil Classes in the Ouachita Basin

County	Total Acres	Basin Acres	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Class 10	Class 11
Ashley	593,920	519,168	-	72,631	24,193	71,749	-	3,582	42,156	30,527	56,485	109,544	12,460
Bradley	416,832	416,832	11,659	94,620	69,958	24,776	4,372	4,372	37,894	11,659	2,914	27,691	1,457
Calhoun	402,304	402,304	-	137,605	5,732	76,447	34,401	-	16,245	-	-	33,446	-
Clark	561,792	561,792	4,297	157,903	10,742	40,818	5,370	11,816	29,002	12,890	6,445	18,260	1,074
Cleveland	384,640	384,640	10,731	87,313	64,542	22,847	4,000	4,000	34,964	10,770	2,689	25,540	1,342
Dallas	430,080	430,080	11,687	92,327	-	30,306	38,567	-	10,518	-	-	35,060	-
Drew	532,288	530,560	-	74,467	24,804	73,562	-	3,672	43,221	31,298	57,912	112,312	12,870
Garland	420,800	420,800	-	66,896	4,316	6,474	-	-	-	15,106	-	-	-
Grant	403,840	400,960	-	71,967	1,285	62,971	-	-	-	-	-	50,120	-
Hempstead	464,640	226,863	2,534	120,402	7,604	31,604	-	-	1,267	-	1,267	11,406	13,941
Hot Spring	397,568	397,568	3,021	111,716	7,593	29,022	3,816	8,348	20,673	9,104	4,532	12,920	755
Jefferson	588,656	360,166	-	50,387	16,784	49,774	-	2,485	29,245	21,177	39,186	75,995	8,643
Lincoln	360,000	262,832	-	36,770	12,248	36,323	-	1,813	21,341	15,454	28,596	55,458	6,308
Montgomery	495,936	495,936	-	78,853	5,108	7,637	-	-	-	17,804	-	-	-
Nevada	394,112	302,072	3,352	160,400	10,119	42,199	-	-	1,691	-	1,691	15,194	18,426
Ouachita	470,976	470,976	12,716	101,259	-	33,439	42,234	-	11,303	-	-	38,384	-
Pike	383,872	383,872	2,917	107,868	7,331	28,022	3,685	8,061	19,961	8,791	4,376	12,475	729
Saline	463,168	442,720	-	79,247	1,417	69,507	-	-	-	-	-	55,340	-
Union	672,256	672,256	-	229,916	9,613	127,728	57,478	-	27,159	-	-	55,864	-
Total	8,007,698	8,082,397	62,914	1,932,547	283,390	865,365	193,923	48,149	346,640	184,580	206,093	745,009	78,005

tes were derived on the proportion of each county region which is contained in each soil class and the proportion of each soil class which appears in each land use. The estimates derived for the land areas of the soil classes are presented in Table II-2. The land use estimates are discussed in the section dealing with land conversion costs.

PRODUCT PRICES

The market prices for the four crops considered by the model were provided by the Corps of Engineers and reflect the "current normalized prices" for the State of Arkansas. The values used appear in Table II-3.

Table II-3. Product Prices For Cotton, Soybeans, Rice and Wheat

Crop	Market Price
Cotton	$.74/lb.
Soybean	$6.87/bu.
Rice	$11.15/cwt.
Wheat	$3.88/bu.

CROP YIELDS

The yields for the crop activities will vary by the soil classes and the use of irrigation. Yield estimates used by the model were based upon the information contained in the RIDS system. The RIDS system includes yield estimates for normal dryland production, potential dryland production and irrigated production. These estimates are provided for 64 soil groups that are aggregations of soil numbers which in the RIDS taxonomy are roughly comparable to soil series. The eleven soil classes used in this model are also aggregations of the RIDS soil numbers, but they are independent of the RIDS soil groups. The RIDS production data including the yield estimates were developed in 1977-1980. RIDS yield estimates attempt to reflect average conditions and management for each soil. They may not reflect potentials for expert management as would be observed on experiment station farms.

The yield estimates for the model are weighted averages of the RIDS yield estimates. Since the RIDS system did not provide estimates for the soil numbers, the yield for the group to which the soil number was assigned was used as an approximation. These approximations of the yields for the soil numbers were then weighted by the proportion of the total acreage in each soil class to construct the yield coefficient for the model. Yield coefficients were thus determined for each county/hydrologic region. Yield increases through time were based upon OBERS Series E national projections of per acre annual yield changes. These projections for the relevant crops are displayed in Table II-4.

Table II-4. OBERS Series E National Projections Of Per Acre Annual Yield Changes*

Commodity		1970-2020
Wheat	(Bu)	0.33
Rice	(Lbs)	59.43
Cotton	(Lbs)	6.67
Soybeans	(Bu)	0.18

*Laughlin and Reinschmidt. "Agricultural and Fish and Wildlife Water Demand Study, Yazoo River Basin - Volume I. "Mississippi State University. p. 80.

Cropping activities, including the soybean/wheat double crop, were handled in a slightly different manner. The yield coefficients for the wheat component of the double crop activity were unchanged. However, due to a later planting date soybean yields were adjusted. Based upon discussions with members of the Department of Agronomy, University of Arkansas the following assumptions regarding appropriate adjustments were made: (1) dryland double crop soybeans should average about 80% of the single crop soybeans under management practices and levels commonly employed in Arkansas; and (2) irrigated double crop soybeans can currently be grown in experimental fields with identical yields to single crop beans but necessary practices to achieve such results have not been commonly adopted--so the double crop yield coefficient was adjusted through time to reflect adoption in the following way: 1980-80%; 1990-85%; 2000-90%; 2010-95%; 2020-100% and 2030-100%. The percentages are percentages of the single crop soybean yield.

PRODUCTION BOUNDS

The model also employs a series of production bounds for each crop which constrain the solution. These bounds are based upon the OBERS crop projections for the state of Arkansas. The model is constrained to place in solution an amount between 90% and 110% of the production projection in each year. The state projections were allocated to the basin using the proportion of the state production contributed by the counties in Ouachita River Basin. The OBERS based production projections appear in Table II-5. The use of the production bounds are discussed in Chapter III.

Table II-5
Crop Production Projections for Ouachita
Basin: Based on OBERS, Series E
State Production Projections

Crop	1980	1990	2000	2010	2020	2030
			(1,000's of Units)			
Wheat (bu)	3,474	4,235	5,162	5,471	5,799	6,146
Rice (bu)	11,718	12,944	14,298	15,154	16,062	17,024
Soybean (bu)	7,370	7,812	8,279	8,703	9,147	9,615
Cotton (lbs)	60,270	61,788	63,345	62,103	60,886	59,692

ENTERPRISE BUDGETS

The costs of production used in the model are based upon the Budgets and Production Cost Estimates published by the Arkansas Agricultural Experiment Station and the Cooperative Extension Service. The information contained in these budgets was supplemented with additional information on the costs of irrigation and land conversion. The costs used by the model are grouped into five separate categories. The categories are: variable production and harvest costs; fixed production and harvest costs; land conversion costs; variable irrigation costs and fixed irrigation costs. The values for the first two categories were derived directly from the Production Cost Estimates published jointly by the Arkansas Agricultural Experiment Station and the Arkansas Cooperative Extension Service. Estimates for the land conversion and irrigation costs will be discussed in the following sections.

The fixed and variable production costs do reflect costs for harvest activities (including ginning for cotton) but exclude any land conversion or irrigation costs. The estimates for soybeans, wheat and cotton are based on "typical farm" scenarios using six row equipment. The cost coefficients used by the model appear in Table II-6.

Table II-6. Production Cost Coefficients

Cropping Activity	Fixed Costs Soil Classes 1-8,10	 Soil Classes 9,11	Variable Costs Soil Classes 1-8,10	 Soil Classes 9,11
	dollars per acre		dollars per unit	
Dryland Cotton	115.71	110.55	.51/lb	.51/lb
Irrigated Cotton	115.71	110.55	.50/lb	.50/lb
Dry Soybeans	52.35	52.35	3.94/bu	3.94/bu
Furrow Irrigated Soybeans	52.35	52.35	2.78/bu	2.78/bu
Flood Irrigated Soybeans	52.35	52.35	2.78/bu	2.78/bu
Sprinkler Irrigated Soybeans	52.35	52.35	2.78/bu	2.78/bu
Wheat	36.32	36.32	1.809/bu	1.836/bu
Rice	107.08	107.08	2.65/bu	2.65/bu

IRRIGATION COST

The costs associated with the operation of the center pivot, furrow and flood irrigation systems can vary substantially by a number of factors. Source of water, age of equipment, size of pump, input prices and water usage can influence these costs. To account for any variation in these factors, a series of ten cost scenarios was used in the model.

The first three scenarios were all based upon published estimates of fixed and variable costs for delta production systems. These publications are respectively "Soybean Irrigation" (Arkansas Soybean Asociation), "An Economic Analysis of Soybean Yield Response to Irrigation of Mississippi River Delta Soils" (Delta Branch Experiment Station at Stoneville, Mississippi) and "Agricultural and Fish and Wildlife Water Demand Study, Yazoo River Basin" (Mississippi State University). The additional seven scenarios are adjustments of one of the first three, usually adding or subtracting a standard 10%, 20% or 30% from the variable irrigation costs. These scenarios appear in Table II-7. Cost scenario number 2 was selected for display in the text because it was felt that it best represented "average" condition in the basin. Sensitivity to irrigation costs can be inferred by examining all ten scenarios. This may be critical since no single cost scenario will likely represent the entire range of situations through the period of study.

Table II-7. Irrigation Cost Scenarios

	Fixed Irrigation Costs			Variable Irrigation Costs		
	Sprinkler	Furrow	Flood	Sprinkler	Furrow	Flood
	per acre			per acre-inch		
1.	48.34	18.95	16.71	4.10	1.65	2.51
2.	65.85	25.00	17.82	2.47	2.82	3.60
3.	37.71	20.94	16.45	2.65	1.95	1.49
4.	48.34	18.95	16.71	4.10	1.65	1.64
5.	65.85	25.00	17.82	2.47	2.82	1.64
6.	37.71	20.94	16.45	2.40	1.75	1.30
7.	65.85	25.00	17.82	2.70	3.10	4.00
8.	48.34	18.95	16.71	4.50	1.80	2.75
9.	65.85	25.00	17.82	2.25	2.50	3.15
10.	37.71	20.94	16.45	3.15	2.55	2.15

WOODLAND CONVERSION COSTS

Much of the land in the Ouachita River Basin is currently in forest land. Suitability of the land resources for conversion to cropland was examined and the costs of such conversions were included into the production costs of each possible production activity.

In 1979 the Southern Forest Experiment Station estimated the woodland acreage in each county in the basin. These results are presented in Table II-8.

Table II-8. Estimated Woodland Acres ln Each County*

County	Total Area	Woodland Area	% Woodland
Ashley	597,800	369,200	62%
Bradley	417,300	366,000	88%
Calhoun	404,500	336,300	83%
Clark	561,900	400,200	71%
Cleveland	384,600	319,000	83%
Dallas	430,100	360,400	84%
Drew	535,000	364,000	68%
Garland	470,400	313,200	67%
Grant	403,800	333,200	83%
Hempstead	474,900	268,800	57%
Hot Spring	398,700	259,600	65%
Jefferson	580,500	214,200	37%
Lincoln	364,800	133,400	37%
Montgomery	512,600	0,400	80%
Nevada	394,200	306,800	78%
Ouachita	473,000	384,400	81%
Pike	393,600	296,400	75%
Pulaski	515,200	221,400	43%
Saline	466,600	355,100	76%
Union	674,000	594,000	88%

*These estimates were obtained from a new forest survey of Arkansas completed in 1979 by the Southern Forest Experiment Station. Acreage estimates were determined from aerial photos with an adjustment for ground truth at selected locations. Sampling error for the estimates is .3%.

As can be seen, the majority of the acreage in most counties remains in woodland. While this information is useful, it must be supplemented with data from the RIDS system to be of use in the model. The model analysis will require that the woodland acreage be identified by soil class. The RIDS system provides a correlation between the soil classes and land use. It contains information for each survey observation (every tenth square kilometer cell) on the type of land use during 1977. From this information, estimates can be made as to the proportion of each soil class in each county region and drainage basin that are devoted to cropland, grassland, woodland and other uses.

Conversions from woodland to cropland are more expensive than similar conversions of grasslands to cropland. Two sources of conversion cost data were used to derive the cost figures employed in the model. A study in 1978 based on interviews of farmers and custom land clearers in eastern Arkansas (Shulstad, May and Herrington) served as the first source. These costs were updated to 1982 through the use of the Index of Prices Paid By Farmers from the 1983 Agricultural Statistics. The second source of conversion cost information data was obtained from the researchers' survey of ASCS County Directors in selected counties in the basin. The data from the two sources were compared and the estimates to be used in the model were selected. The cost estimates derived by this comparison and employed in the model appear in Table II-9.

Table II-9. Per Acre Conversion Costs

	Woodland to Cropland	Grassland to Cropland
	Dollars Per Acre	
Clearing	245.00	-
Drainage	55.20	55.20
Rough Levelling	20.70	20.70
Chunking	29.90	29.90
Total	350.80	105.80

These costs were analyzed using the following assumptions: (1) the market value of timber at time of clearing was zero due to clearing procedures used; 2) no lands with slopes greater than 3 percent would be cleared; and 3) conversion costs would be annualized over a 40 year period with 50 percent of the cost being financed at a 14 percent interest rate.

These annualized conversion costs were then included in each possible crop activity and would be considered by the model in determining the most profitable cropping pattern. In cases where a given soil class in a particular county and hydrologic region had more than one land use, a weighted average based on acreage was used to determine the appropriate conversion costs.

WEATHER DATA

Two sets of scenarios for the model were identified. These were normal rainfall conditions and a ten-year drought. The monthly rainfall estimates for these scenarios were derived from historical data series from selected weather experiment stations in each county region. The data series contained 16 years of observations. Weather conditions can vary throughout a county region, but the records from a single location were used to approximate the entire region. The stations selected for each county region appear in Table II-10. The data series began in 1968 and ended in 1983.

Table II-10. Weather Experiment Stations By County Region

County Region	Station	Number Of Year In Data Series	Latitude	
			Degrees	Minutes
1	Monticello 3 SW	16	33	36
2	Warren	16	33	36
3	Sheridan Tower	16	34	17
4	Morobay Lock #8	16	33	19
5	Mount Ida	16	34	32
6	Arkadelphia	16	33	9
7	Hope 3 NE	16	33	43
8	Camden 1	16	33	36

Cumulative probability distributions were constructed from each historical data series. Normal rainfall conditions for each month were defined by the median of the series showing that 50% of the time this level or more rain should be observed in the region. The ten-year drought conditions defined a rainfall level that should be exceeded 90% of the time.

The table also includes the latitude of each weather experiment station. The latitude is used in the Blaney Criddle method to estimate supplemental irrigation needs for the crops examined in the model.

ESTIMATION OF SUPPLEMENTAL CROP IRRIGATION NEEDS

There are many factors which influence the consumptive use of water by plants. Knowledge of consumptive use is necessary to predict supplemental irrigation needs. Such factors as precipitation, temperature, length of growing season, latitude and hours of sunlight, humidity, wind movement, convection, stage of plant growth, availability of irrigation water, the quality of water and soil fertility are important. Unfortunately, accurate data on these factors may not be available. Furthermore, the effects of these factors on the amount of water consumed by plants may not be constant but may differ with locality and fluctuate through time. It is possible, though, to use data on some of the factors to approximate consumptive use and supplemental water needs for our purposes.

There are several alternative methods available for calculating consumptive use. Bajwa, Crosswhite and Gadsby list four basic approaches. They are: 1) the Heat-Unit approach; 2) the Evapotranspiration approach; 3) Palmer's Drought Index; and 4) the Blaney-Criddle method. The Heat-Unit approach assumes a linear relationship between water consumed and heat energy available. Sources of heat energy considered are solar radiation, air temperature and soil temperatures. The Evapotranspiration approach really consists of a number of evolutionary adaptations. Basically, these evolutions all try to estimate evapotranspiration with empirical formulae based on temperature. One example is the estimate developed by Williams, Ritter and Eastburn. Their formula is:

$$PET = (0.014T - 0.37)R_S$$

and

$$AET = KC * PET$$

where

PET = potential evapotranspiration in mm/day
T = average daily temperature (Tmax-Tmin)/2 in degrees F
R_S = solar radiation expressed as mm/day water equivalent,

Langleys * 0.0171 = mm
AET = actual evapotranspiration
KC = crop coefficient, reflecting crop growth stages.

The approach using the Palmer's Drought Index produces an estimate of potential evapotranspiration based upon the drought or anomaly index. This index indicates the severity of a drought from deviations from normal precipitation, long-term soil moisture recharge and long-term soil moisture loss for the considered period.

The most commonly used approach is the Blaney-Criddle method. This approach assumes that consumptive use varies directly with temperature, available daylight hours, soil moisture and crop growth stage. The necessary formulae are:

$$U = \sum kf$$

and

$$k = k_t * k_c$$

$$k_t = 0.0173(t) - 0.314$$

$$f = tP/100$$

where

U = evapotranspiration in inches for the season

k = monthly consumptive use

k_t = a climatic coefficient related to mean monthly temperature

k_c = coefficient for crop growth stage

t = mean monthly air temperature

P = mean monthly percent of annual daytime hours

Bajwa, Crosswhite and Gadsby conclude that of these four approaches, the Blaney-Criddle formula provided the most reliable estimates of evapotranspiration during the crop season. This study will employ the Blaney-Criddle method to estimate both consumptive use and supplemental crop water needs. The procedure is described more fully in Chapter III.

ESTIMATION OF LIVESTOCK WATER USE

Water use for livestock production was estimated exogenous to the linear programming model developed for crop water use. Estimates of livestock water use were based upon standard per animal requirements. These standard quantities were then multiplied by the number of animals projected for each time interval. The resulting product is the estimate of total water use for livestock production. The per animal per day water consumption requirements used in the study appear in Table II-11. These per animal water consumption coefficients were developed by the United States Geological Survey (as quoted by Laughlin and Reinschmidt).

Table II-11. Per Animal Water Consumption Coefficients

	Gal/Day/Animal	Acre- Feet/Yr/Animal
Cattle	10.00	.0112014
Hogs	3.00	.0033604
Broilers	.04	.0000448
Chickens (excluding broilers)	.04	.0000448

Adjustments to the 1980 Arkansas Agricultural Statistics inventory numbers were made using the OBERS projections for the state. These projections are exhibited in Table II-12.

Table II-12. OBERS Series E Projection on Annual Changes in Livestock Numbers

	Annual Changes (%)
Cattle	+0.9
Hogs	-1.7
Broilers	+1.6
Chickens (excluding broilers)	+1.6

ESTIMATION OF FISH AND WILDLIFE WATER USE

The estimation of the fish and wildlife water use was similar to the estimation of water use for livestock production. The total number of acres devoted to commercial fish production and wildlife and fishery habitat were estimated. Per acre water use coefficients were calculated from the U.S.G.S. study and the product of water use per acre and the number of acres provided an estimate of total water use for these activities. Due to the lack of information to guide any reasonable forecasts on projected acreage in fish and wildlife use, an assumption was made that neither expansion nor contraction would likely occur. These calculations were also made exogenously to the linear programming model.

ALTERNATIVE SCENARIOS

The analytical model was examined under a number of different scenarios. The scenarios reported on here include a set of two scenarios for each ten-year interval designed to study differences in irrigation patterns and water usage due to the adoption of water conservation practices. These scenarios included: normal rainfall without water conservation practices and normal rainfall with water conservation practices. The model was solved for the years 1980, 1990, 2000, 2010, 2020 and 2030.

Normal rainfall conditions were defined as monthly precipitation levels where it would be expected that in 50% of the years more rain would be observed. This corresponds to the 50th percentile of the cumulative probability distribution.

Water conservation practices were assumed to impact on the efficiency with which water is delivered for use by the crops. These practices may result from improvements in either off-farm or on-farm water management. Off-farm improvements could arise from better management of delivery systems utilizing surface water. Such practices as weed control along conveyance channels, lining of canals and laterals to reduce seepage and improved scheduling systems may be implemented. On-farm conservation practices can be directed at delivery systems, field application systems and water management techniques. These will focus on the rate, amount and timing of water application. On-farm water conservation may include land levelling, automated irrigation systems, soil moisture sensors, flow measurement devices, tailwater recovery systems and adaptation of the appropriate irrigation system to particular soil conditions (Laughlin and Reinschmidt).

The adoption of these water conservation practices will impact directly on the profitability of irrigation and hence the agricultural water demand in the basin. Total water usage may be decreased on a per acre basis, but if the profitability of irrigation is greatly increased there may be an expansion in the number of irrigated acres resulting in an actual increase in water demand. The examination of these scenarios will provide insights into these potential impacts.

The irrigation efficiency measures used for cotton and soybeans appear in Table II-13. These measures were used to adjust the supplemental water needs from the Blaney-Criddle method to produce estimates of the total water applied. The adjustment process is described in the following equations:

$$TWA = SWN \div EM$$

where

TWA = Total Water Applied

SWN = Supplemental Water Need

EM = Efficiency Measure

Table II-13. Irrigation Efficiency Measures for Soybeans and Cotton

	Without Conservation	With Conservation
Sprinkler	.8	.9
Furrow	.6	.7
Flood	.4	.5

Conservation practices in rice irrigation were assumed to result in water usage equal to 70 percent of the water being applied without conservation.

The second set of scenarios involves the use of 10 different series of estimates for the irrigation costs. These scenarios were examined only for the years 1990 and 2030. Two issues can be addressed with these scenarios. First, given the problems associated with accurately estimating irrigation costs into the future, the different scenarios can indicate how responsive the agricultural industry in the basin will be to water cost changes. This can be displayed by deriving a demand curve for irrigation water. When a single irrigation cost scenario is analyzed, only one point on the demand curve is identified and the response to cost changes is ignored. The demand curve will display the relationship between the cost of irrigation and the number of acre-feet of water that can be optimally used. The demand curve for irrigation water is in actuality dependent upon the market for the crops which are produced by the water. Such a demand is referred to as a derived demand and can be measured with the marginal value product of the water. The marginal value product is simply the value of the crop produced by the last increment of water applied. To derive the best estimates of the marginal value products, the basin crop production bounds were dropped from the model. This allows the model to determine production levels on profitability rather than the OBERS production projections.

The price elasticity of the derived demand will provide a quantifiable measure of the responsiveness of water usage to cost changes. It will show the percentage change in the quantity of water demanded associated with a one percent change in the cost of irrigation.

The second issue that can be addressed by the irrigation cost scenarios is focused on the impact that conservation practices can have on the derived demand for water. Chapman argues that conservation may affect demand curves in several different ways. Three of the common effects that he discusses are: (1) a parallel shift in demand maintaining elasticities; (2) a movement along a demand curve maintaining elasticities and not resulting in any shift of the curve itself; and (3) a change in elasticities, maintaining the approximate position of the curve but significantly increasing the responsiveness of producers to both low and high prices. An examination of the demand curves with and without conservation will identify which of these three models most closely approximates the situation in the Ouachita Basin. Each model may have particular implications for water management in the basin.

CHAPTER III

ANALYTICAL MODEL

The analytical model used to estimate the agricultural water demand for the basin was developed in several components. These components are: (1) a Fortran Supplemental Water Needs program using the Blaney-Criddle method; (2) a Fortran matrix generator; (3) a mathematical linear programming model using MPSIII; and (4) a Fortran report writer. Each of these components will be more fully described in the next section.

The linear programming model is the heart of the analysis. It is a procedure which sorts the various combinations of soils, irrigation systems, and crops to determine the production system which will result in the greatest profit to the region. The model operates with three basic constraints: a) the number of acres available for each soil in each county and hydrologic region; b) selected minimum acreage levels of each crop in each county region; and c) upper and lower bounds on the basin production of each crop.

The other components all facilitate the operation of the linear programming model or the interpretation of its results. The Supplemental Water Needs program calculates the amount of supplemental water that is necessary to obtain potential crop yields given the weather pattern, the planting date and the soil characteristics. It provides basic data which is later combined with other data on yields, costs, product prices, available acres and minimum crop production levels in the matrix generator. The matrix generator prepares the data and puts it into a format that can be read by the MPSIII algorithm. The MPSIII algorithm solves the linear program. The report writer interprets the MPSIII results and presents the information in tabular form.

The final stage of the analysis is the estimation of the derived demand for irrigation water in the years 1990 and 2030. This process takes the model solutions from the ten irrigation cost scenarios and econometrically fits a curvilinear demand equation to the solution data. The solution data indicate the optimal regional water use at each irrigation cost. From the demand equation, price elasticities can be calculated which will reflect how responsive the demand for water will be to price changes.

SUPPLEMENTAL IRRIGATION NEEDS

Since accurate estimates of the amount of irrigation water required by different crops in different production environs were not available, these water requirements were derived using the Blaney-Criddle method (SCS, Technical Release No. 21; Bajwa, Crosswhite and Gadsby). The Blaney-Criddle method will provide the necessary data for the analytical model to discriminate between cropping activities on the basis of relative differences in required supplemental irrigation. These differences will result from variations in soil characteristics, rainfall patterns, monthly temperatures and length of daylight.

The Blaney-Criddle method estimates consumptive use, effective precipitation and supplemental water need from basic climatological and soil information. Consumptive-use is directly correlated with crop growth. Crop growth, in turn is affected by solar radiation which can be approximated with temperature and sunshine. Sunshine can be measured by length of day based upon the latitude of the site in question. Given the latitude, the monthly temperature and the planting date, the Blaney-Criddle provides crop growth curves which will indicate the amount of consumptive use a plant will have.

The consumptive-use formulae to implement the Blaney-Criddle method appear below:

$$U = kF$$

$$u = kf$$

$$k = k_t * k_c$$

$$k_t = .0173t - .314$$

$$f = \frac{t * p}{100}$$

where

U = consumptive-use of the crop in inches for the growing season

k = empirical consumptive-use crop coefficient for the growing season

F = sum of the monthly consumptive-use factors for the growing season

u = monthly consumptive-use of the crop in inches

k_t = climatic coefficient which is related to the mean air temperature (t)

k_c = coefficient reflecting growth stage of crop (SCS Technical Release No. 21)

f = monthly consumptive-use factor

t = mean monthly air temperature in degrees Fahrenheit

p = monthly percentage of daylight hours in the year (Table 1 ofSCS Technical Release No. 21)

Effective rainfall is defined as the proportion of total precipitation that remains within the root zone for use by the plant and does not include any amounts which percolate below the root zone or which are lost to surface runoff. Root zones, field capacities and net depths of applications, for the crops and soils were defined using data from the "Irrigation Guide" (Arkansas Soil Conservation Service). Effective rainfall can be affected by such factors as field capacity, frequency and intensity of rains, consumptive use, net depth of application, and carryover moisture. Carryover moisture is moisture stored within the root zone when the crop is dormant or before it has been planted. The formulae for the calculation of effective rainfall are presented below:

$$r_e = (0.70917\ r_t^{0.82416} - 0.11556)\ (10)^{0.02426u}\ (f)$$

$$f = (0.531747 + 0.294164D - 0.057697D^2 + 0.003804D^3)$$

where

r_e = effective precipitation

f = monthly consumptive-use factor

D = net depth of application

u = average monthly consumptive-use

r_t = average monthly rainfall

The effective rainfall cannot exceed either the monthly rainfall or the monthly consumptive-use. If it does, it should be reassigned to a value equal to u or r_t, whichever is lower.

The effective rainfall can be further adjusted to reflect the impact of carryover moisture. For the crops under consideration by the model, with the exception of the double cropped soybeans, the following assumptions were used to guide this adjustment: (1) carryover soil moisture is sufficient to bring the soil profile up to field capacity and (2) one half of this carryover soil moisture will be used consumptively before irrigation is commenced and the remainder will be used at the end of the growing season (SCS, Technical Bulletin No. 21, p. 36).

The net irrigation requirements for each month of the growing season are calculated by simply subtracting the effective precipitation from the consumptive use. The Fortran program developed to handle these calculations was also used to calculate the supplemental irrigation needs for soybeans and cotton. The irrigation needs for rice were based upon the assumptions that irrigation needs for the heavy clay soils (class 10) would be 42.3 acre-inches while on the lighter soils (classes 9 and 11) the requirements would be 36 acre-inches.

THE MATRIX GENERATOR

The matrix generator was developed to format the linear program into the form specified by the computer algorithm utilized to solve this problem.

In general, a model for an optimization study can be assembled manually and then coded into a suitable problem function, or it can be generated using computer aids of various levels of sophistication. In the case of the small scale equation-oriented models, the linear equations and inequalities can be written by hand and the coefficients coded into an array suitable for processing by an LP algorithm. Alternatively, a matrix generator can be used to automatically assemble the coefficients for certain classes of constraints, and generate all appropriate array entries. All commercial LP algorithms require that input data be in a standard MPS (mathematical programming system) form in which each array entry is identified by its row, column, and numerical value, with each such triplet constituting a data record. Manual generation of such data files can be very tedious and the potential for errors is high; hence, some form of matrix generator is commonly used.

The matrix generator used in this study was a FORTRAN program which was written to facilitate all data entry into the LP algorithm and to convert the mathematical model of the LP into the format required by the algorithm. The FORTRAN matrix generator supplied all the forecasting models necessary for every run of the MPSIII algorithm (all scenario and yearly changes were made internally).

The matrix generator was a time-consuming part of this project due to the large size of the model and because of the many "comment statements" included in the FORTRAN program to internally document it. The program was written in the same order that the LP algorithm requires the data to be entered: therefore, the program can be easily changed for other projects once the requirements of the LP are known.

The operation of this matrix generator is most easily followed by referring to the representational diagram of the generator given in Figure III-1. The matrix generator first reads all of the required data from disk storage and then makes all appropriate changes to reflect the year and scenarios considered. Next, the matrix formats the row names and writes the results on a disk (each row name represents a constraint in the LP).

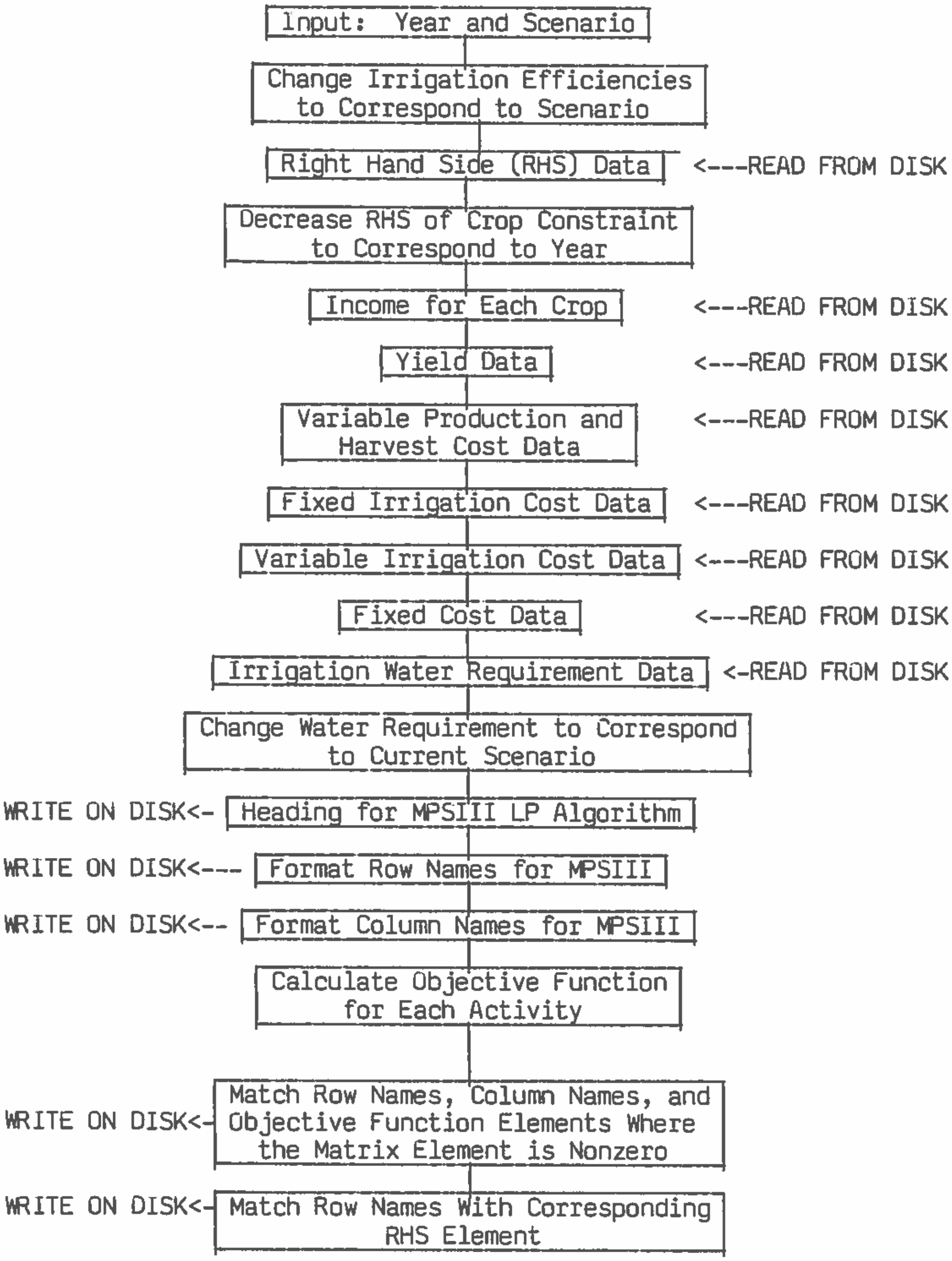

Figure III-1. Representational Diagram of the Matrix Generator

The matrix generator next proceeds by formatting and writing each activity name along with its objective function element. The naming convention for the column names is similar to that of the row names except that the column names include the irrigation element (F-Furrow; S-Sprinkler; D-Dry; X-Flood irrigation). The naming convention for the columns is presented in Figure III-2. An example would be BD108AS which represents the combination of soybeans (B), in dry irrigation (D), in soil class (10), in hydrological region (8), located within Ashley county region (AS). See tables I-1 and I-2 for a listing reference of the coding of the county and hydrological region names. The last function of the matrix generator is to write each row element along with its respective RHS limit on disk storage. The output from one of the matrix generator runs consists of approximately 6000 lines; therefore, no listing of this output is given.

Figure III-2. Naming Convention for Columns Developed by the Matrix Generator

(1)	(2)	(3)	(4)	(5)	(6)	(7)
B	D	0	8	5	A	S

Column 1 Identifies The Crop

B = soybeans**
C = cotton
R = Rice

Column 2 Identifies the Irrigation Method*

D = dryland
F = furrow
S = sprinkler (center pivot)
X = flood
W = wheat**

Column 3 and 4 Identify Soil Class 00 through 11

Column 5 Identifies Hydrological Region 1 through 9

Column 5 and 7 Identify County Region

AS = Ashley, Drew, Jefferson and Lincoln
BR = Bradley and Cleveland
GR = Grant, Saline and Pulaski
CA = Calhoun and Union
GA = Garland and Montgomery
CL = Clark, Hot Spring and Pike
HE = Hempstead and Nevada
DA = Dallas and Ouachita

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* All irrigated soybeans are doubled cropped with wheat.
** BW indicated dryland double crop soybean and wheat.

LINEAR PROGRAMMING MODEL

This linear programming model provides a means for estimating irrigated and nonirrigated crop acreages, and thus agricultural water requirements for each scenario examined. Profit represented by the objective function is maximized subject to land availability and irrigation and crop limitations. Optimization is performed in 10-year intervals with temporal adjustments in yield estimates crop acreage limitations, and with crop production bounds being met. This requires a new LP for each period. The new LP is easily formatted by the matrix generator.

The symbols used in the model are the following:

π = net revenue (value of the objective function to be maximized);
P = price in dollars per unit (bushels, pounds);
X = acreage X, the solution variable, is supplied by the MPSIII algorithm (X indicates the acreage of a certain crop activity);
Y = expected yield (bushels, pounds), per acre;
VC = variable production and harvest cost in dollars per unit (bushels, pounds);
FC = fixed production and harvest cost in dollars per acre;
FIC = fixed irrigation cost in dollars per acre;
VIC = variable irrigation cost in dollars per acre-inch;
LC = land conversion costs in dollars per acre;
W = supplemental irrigation water necessary for agriculture to produce stated yield (Y): this seasonal water need is expressed in acre-inches.

The subscripts used in the model are the following:

i = crop: (1) soybeans, (2) cotton, (3) rice;[1]
j = irrigation method: (1) dry (no irrigation), (2) furrow, (3) sprinkler, and (4) flood;
k = soil type: (1-11) soil classes;

---

[1] Double crop soybeans and wheat are identified as: BW-dryland; BR-dryland wheat followed by furrow irrigated soybeans; BX-dryland wheat followed by flood irrigated soybeans; BS-dryland wheat followed by center pivot irrigated soybeans.

l = hydrological region (watershed): (1-9) hydrological regions;
m = county region: (1-8) county regions.

The model is setup as follows: maximize the objective function

$$\Pi = \sum_{ijklm} [((P)_i-(VC)_i) * (Y)_{ijklm} - (FC)_{iklm} - (FIC)_{kj} - (LC)_{klm}$$
$$-(VIC)_j * (W)_{ijm}] \, (X)_{ijklm}$$

subject to:

<u>Soil Acreage Constraints</u>:

$$\sum_{ij}(X)_{ijklm} \leq (Acreage)_{klm}$$

(k=1,...,11; l=1,...,9; m=1,...,8)

(if soil type (k) is found in hydrological region (l) and county region (m)).

Example:

$$\sum_{ij}(X)_{ij126} \leq 10,433$$

<u>Crop Constraints</u>:

$$\sum_{jkl}(X)_{ijklm} \geq K_t * (\text{Agri. Stat. Acreage})_{im}$$

(i=1,2,3; m=1,...,8;

K_t = a time dependent constant equal to .8 exponential t).

Example:

$$\sum_{jkl} (X)_{1jkl2} \geq 1{,}680$$

Irrigation Constraint (for 1980 and 1990 only):

$$\sum_{iklm} (X)_{i3klm} \geq .04 \sum_{ijklm} (X)_{ijklm}$$

(i=1,2,3; l=1,...,9;
j=2,3,4; m=1,...,8;
k=1,...,11)

Crop Production Bounds

$$\sum_{jklm} (X)_{ijklm} \geq .9 \text{ (Basin Production Projection)}$$

$$\sum_{jklm} (X)_{ijklm} \leq 1.1 \text{ (Basin Production Projection)}$$

(j=1,2,3,4; k=1,...,11; l=1,...9; m-1,...,8)

Example:

$$\sum_{jklm} (X)_{1jklm} \leq .9 \text{ (7,370,523)}$$

Objective Function

The objective function (Π) is an equation of net revenue; net revenue is calculated as the difference between total revenue and total costs. Total revenue is simply calculated as the expected yield (Y) for each activity, including all appropriate adjustments (over the 10-year intervals) multiplied by the product price (P) for that crop. Total costs include both fixed and variable costs. The fixed production and harvest costs (FC) principally include repairs, taxes, and depreciation on tractors and field machinery, and overhead labor. Variable costs (VC) include variable production costs for fertilizer, harvesting activities, labor, pesticides, and other inputs. Fixed irrigation costs reflect the costs of owning and maintaining irrigation machinery while the variable irrigation costs consist of the costs of labor and machinery operation per acre-foot of water applied. The land conversion costs include the costs of clearing, draining and levelling land not currently being used for cropland.

Decision Variables

As shown by the mathematical representation, the linear program includes production activities which are combinations of crop, soil type and irrigation methods in each of the nine hydrological regions among the eight Ouachita Basin county regions. Each crop considered is matched with each soil type along with dryland production, sprinkler, furrow and flood irrigation in each of the nine hydrological regions within each of the eight county regions (where that combination actually exists). Thus, the decision variable X_{ijklm} indicates the number of acres of land assigned to crop (i), irrigation method (j), soil class (k), in hydrological region (l), and in county region (m), when the LP is solved.

Constraints

The four categories of constraints - soil, crop acreage, irrigation and crop production - make up a total of approximately 450 constraints which enable the model to represent the Ouachita River Basin realistically. The soil constraints were necessary because of limits on actual available acreages of the various soil types. Total acres of each soil type appearing in the solution must be no greater than the total acres of that soil type in the study area. The soil constraint example given above constrains the acres of soil type (1) in hydrological region (2) within county region (6). This constraint limits the area considered by the model to 10,433 acres--the actual acres available for production. The crop constraints (flexibility constraints) force the LP to resemble past production; these constraints will be less and less restricting through time due to the time dependent variable K_t. The crop constraint example given above constrains the LP to use a minimum of 1,680 acres for growing crop (1) in county region (2). The irrigation constraint, which will be used for the runs in years 1980 and 1990 only, reflects the current proportion of sprinkler irrigated acres to the total irrigated acres. This helps the model distribute acreage to the irrigation methods in a more representative fashion. The crop production bounds force the model to behave consistent with the OBERS projections discussed earlier. Validation of the model is discussed in Chapter IV.

THE REPORT WRITER

The report writer program was developed to calculate the amount of agricultural water demanded under the four scenarios during the five periods studied. The report writer converts the standardized output from the MPSIII system into a more useful form. The report writer constructs a series of tables displaying optimal acreage by crop, county region, hydrological region, and irrigation method. It also determines the total water demanded for the same categories.

The report writer has three functions. First, the FORTRAN report writer reads all of the MPSIII solutions for the combinations of scenarios and years studied. The data is read from disk storage. Next, using the data from the consumptive use program, the report writer calculates the amount of irrigation water necessary to support the optimal cropping pattern derived by the MPSIII computer code. Recall that the consumptive use program uses the Blaney-Criddle method to determine the amount of supplemental irrigation water necessary for each crop to achieve its potential yield. Thirdly, the program proceeds to summarize the results of the model in a tabular form. The results summarized by the report writer include the optimal cropping pattern and the water use summary under the four scenarios and the five time periods for which estimates were made. The tables developed were summarized by county regions and also by hydrological (watershed) regions. The report writer also calculates the annual water requirements for livestock in the Ouachita River Basin by county regions. The livestock water requirements were calculated for cattle and calves, hogs and pigs, broilers, and chickens.

In order to facilitate the use of the report writer, the program was functionally divided into six FORTRAN programs. Like the matrix generator program, the report writer programs include many comment statements to make the FORTRAN program internally documented. See Figure III-3 for a representational diagram of the operational sequence of the report writer. The main program reads all of the data output from the MPSIII system, the output from the consumptive use program, and the 1980 Arkansas Agricultural Statistics data. The program then determines the acres of each crop planted in every county region and in every hydrological region. Next, the program calculates the supplemental irrigation water necessary to produce the stated yield (Y) for each crop. Then, the program produces a table that compares the 1980 model results to the 1980 Agricultural Statistics data. See Tables IV-1 and IV-2a for the model validation table. All summations of the MPSIII results are written on disk storage until the next sections of the report writer are run.

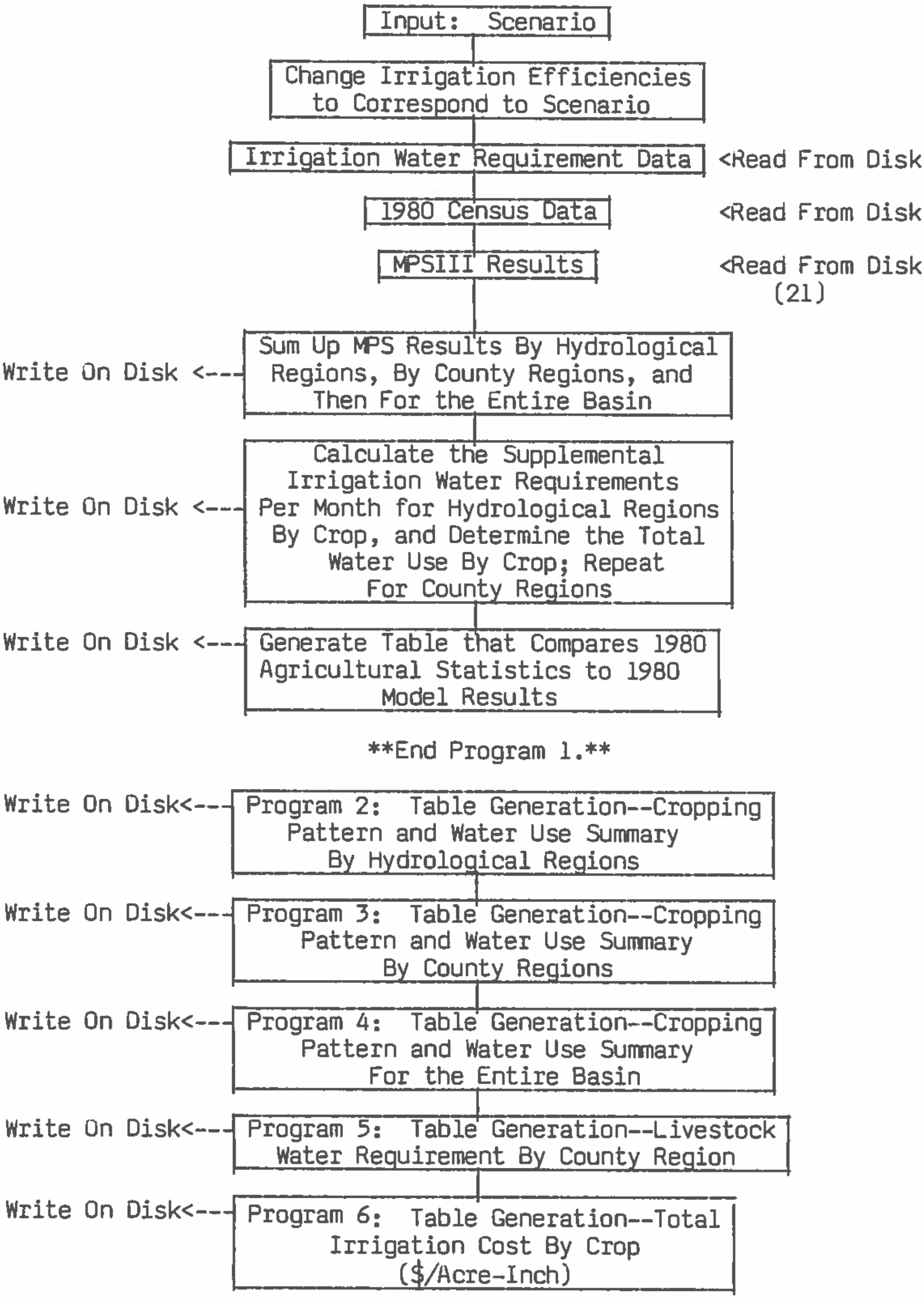

Figure III-3. Representational Diagram Of The Report Writer

Programs 2-5 read the summations calculated by the main program of the report writer, and then the programs tabulate the results into a useful form. Program 6 determines the total cost of irrigation water by crop and then prints the necessary tables. The data calculated by program 6 was used in the regression analysis to derive a water demand curve for irrigation water.

CHAPTER IV

MODEL VALIDATION AND RESULTS

As mentioned in Chapter II, there are two major ingredients necessary to establish the credibility of a model--verification and validation. Verification was discussed earlier. The validation of the analytical model will involve an empirical test to see how well the model results compare to observations of the actual production system in the Ouachita River Basin. Two sets of observations are available which will focus on the primary variables of interest--the acres of each crop produced and the number of acre-feet of water applied in irrigation. The observation on the distribution of acres in the cropping pattern is from the *1981 Agricultural Statistics for Arkansas*. The Arkansas Geological Commission report (*Use of Water in Arkansas, 1980*) provides the necessary data on the irrigation water use.

The comparison of the model results to the cropping pattern found in the Agricultural Statistics is presented in Table IV-1. This comparison uses the model results produced for 1980 with the second scenario for the irrigation costs. For the entire basin, it can be seen that for soybeans, cotton, and rice the model acreages are 80 percent of the acreages in the Agricultural Statistics. The rice acreage corresponds the closest with the model results at 91 percent. The wheat acreage is the farthest from the base acreage, recording a percentage of 124. Total cropland acreage, devoted to these four crops is slightly over 91 percent of the acreage reported in the statistics.

The comparison of the water use estimated by the model and estimated by the Arkansas Geological Commission (A.G.C.) appears in Table IV-2. For all cropland in the total basin, the model estimate is 121 percent of the A.G.C. estimate. For rice, the principal water user, the model comes much closer, showing 106 percent of the A.G.C. estimate. The model overestimates the amount of water used by other crops by 211 percent. The same comparison is made for the model version without the crop production bounds. This comparison appears in Table VI-1 in Chapter VI where the derived demand for irrigation water is considered.

These results provide an indication of how valid the model is. The model does a better job of estimating the distribution of acres in the cropping pattern than it does with actual water use. For the most relevant components of water usage (rice), the model is within 5-7 percent of the water use in the observed system. It should be noted that in the comparison of the cropping pattern there has been no distinction between irrigated and dryland acreage. The accuracy of the model in estimating water use may suggest that the errors in the estimates of crop acreages are less with dryland production than with irrigated production. The A.G.S. and model estimates may also vary due to the differences in the per acre water use figures employed by the studies.

TABLE IV-1: COMPARISON OF MODEL CROPPING PATTERN TO 1981 AGRICULTURAL STATISTICS--1980 WITH IRRIGATION COST SCENARIO # 2 AND NORMAL RAINFALL WITH NO CONSERVATION

	CENSUS		MODEL		
	ACRES	PERCENT	ACRES	PERCENT	(MODEL/AGSTAT)X100
BASIN					
SOYBEANS	331200.	49.1%	287852.	46.8%	86.9%
COTTON	140552.	20.8%	112441.	18.3%	80.0%
RICE	115194.	17.1%	105493.	17.2%	91.6%
WHEAT	87908.	13.0%	109206.	17.8%	124.2%
	674854.		614992.		
COUNTY REGION 1					
SOYBEANS	245400.	43.7%	219212.	52.6%	89.3%
COTTON	138242.	24.6%	110593.	26.5%	80.0%
RICE	108794.	19.4%	87035.	20.9%	80.0%
WHEAT	69388.	12.3%	106252.	25.5%	153.1%
	561824.		416840.		
COUNTY REGION 2					
SOYBEANS	3100.	69.3%	2480.	89.3%	80.0%
COTTON	370.	8.3%	296.	10.7%	80.0%
RICE	0.	0.0%	0.	0.0%	0.0%
WHEAT	1000.	22.4%	0.	0.0%	0.0%
	4470.		2776.		
COUNTY REGION 3					
SOYBEANS	1300.	60.2%	1040.	100.0%	80.0%
COTTON	0.	0.0%	0.	0.0%	0.0%
RICE	0.	0.0%	0.	0.0%	0.0%
WHEAT	860.	39.8%	0.	0.0%	0.0%
	2160.		1040.		
COUNTY REGION 4					
SOYBEANS	1500.	59.1%	1200.	86.2%	80.0%
COTTON	240.	9.4%	192.	13.8%	80.0%
RICE	0.	0.0%	0.	0.0%	0.0%
WHEAT	800.	31.5%	0.	0.0%	0.0%
	2540.		1392.		
COUNTY REGION 5					
SOYBEANS	0.	0.0%	0.	0.0%	0.0%
COTTON	0.	0.0%	0.	0.0%	0.0%
RICE	0.	0.0%	0.	0.0%	0.0%
WHEAT	0.	0.0%	0.	0.0%	0.0%
	0.		0.		
COUNTY REGION 6					
SOYBEANS	40200.	76.2%	32160.	88.5%	80.0%
COTTON	330.	0.6%	264.	0.7%	80.0%
RICE	4900.	9.3%	3920.	10.8%	80.0%
WHEAT	7300.	13.8%	0.	0.0%	0.0%
	52730.		36344.		
COUNTY REGION 7					
SOYBEANS	35500.	83.0%	28400.	68.0%	80.0%
COTTON	0.	0.0%	0.	0.0%	0.0%
RICE	0.	0.0%	12338.	32.0%	0.0%
WHEAT	7260.	17.0%	2954.	7.1%	40.7%
	42760.		41728.		
COUNTY REGION 8					
SOYBEANS	4200.	50.2%	3360.	59.4%	80.0%
COTTON	1370.	16.4%	1096.	19.4%	80.0%
RICE	1500.	17.9%	1200.	21.2%	80.0%
WHEAT	1300.	15.5%	0.	0.0%	0.0%
	8370.		5656.		

PERCENTS INDICATED ARE THE PERCENT OF THE TOTAL ACRES OF SOYBEANS, COTTON, RICE, AND WHEAT.

Table IV-2. Comparison of Model Results and Arkansas Geological Commission Survey Results--1980, Normal Rainfall and No Conservation With OBERS Projected Projection Constrants

	Model Cost Scenario 2	Arkansas Geological Commision	(Model/A.G.C.) *100
		1000 acre-feet	
Rice	342.6	324.2	105.6%
Other Crops	119.8	56.7	211.3%
Total Crop Irrigation	462.4	380.9	121.4%

Source: Arkansas Geological Commission. Use of Water in Arkansas, 1980. Water Resources Summary No. 14.

In Table IV-3, the irrigated acreages estimated from records of the Agricultural Stabilization and Conservation Service, the Arkansas Statistical Crop Reporting Service and the Cooperative Extension Service are shown. These data were provided by the U.S.G.S. and will henceforth be referred to as the U.S.G.S. esti-amates. These estimates are compared in Table IV-4 with the implicit acreages derived from the A.G.C. water use estimates. The model results, showing the irrigated acreages are illustrated and compared to these estimates in Table IV-5. It can be seen that the acreage estimates from the two secondary sources are fairly consistent. However, with the exception of the rice acreage, the model results tend to overestimate cotton and soybean acreage.

Table IV-3 Irrigated Land Acreages, Prorated * for Basin:
Estimated for 1980 by Variety of Sources **

	Rice	Cotton	Soybeans	All Crops
Ashley	20,147	9,178	5,245	34,833
Drew	15,585	5,283	4,984	26,456
Lincoln	20,831	4,162	2,701	28,167
Jefferson	34,266	5,802	3,223	43,292
Bradly	- -	- -	40	2,046
Cleveland	- -	- -	- -	204
Grant	- -	- -	- -	85
Saline	48	- -	- -	238
Calhoun	- -	- -	- -	38
Union	- -	- -	- -	121
Garland	- -	- -	- -	162
Montgomery	- -	- -	- -	460
Hot Spring	868	- -	165	1,554
Pike	259	- -	500	885
Hempstead	- -	- -	244	732
Nevada	- -	- -	168	209
Dallas	321	- -	200	521
Ouachita	- -	- -	10	76
Basin Totals	92,325	14,425	17,480	140,079

* Proportions used to prorate county acreage are listed in Table 1-4.

** Estimates provided by A.H. Ludwig (U.S.G.S.): Rice estimates derived from ASCS records; cotton and soybean acreage are based on Arkansas Crop Reporting Service information; and other crop acreages are based on Cooperative Extension Service estimates.

The differences between the model results and the system observations can be attributed to many of the same issues that arose in the discussion of the model verification. Aggregation biases in the soil classes, yields, costs of production and product prices are possible explanations. Differences in production goals, particularly risk management could contribute to the region not managing its resources in a manner similar to what the model predicts. All rice was assumed to be grown in one-year rice/one-year soybean rotation. Deviations from that rotation would provide for actual cropping patterns different from the model results. Finally, the per acre water requirements estimated with the Blaney-Criddle method may not be as precise as desired.

Table IV-4 Comparison of Estimated Irrigated Acreages from Two Secondary Sources, 1980

	U.S.G.S	Implicit Acreages from A.G.C.
Rice	92,325	95,783
Other crops	47,754	49,686
Cotton	24,425	--
Soybeans	17,480	—
Total Basin	140,079	145,469

Table IV-5 Comparison of Model Results to Estimates of Irrigated Acreages in the Basin 1980

	Model	U.S.G.S.	A.G.C.	(Model/USGC) *100	(Model/AGC) *100
Rice	105.5	92.3	95.8	114.3	110.1
Other Crops	113.5	47.8	49.7	237.4	228.4
Cotton	- -	24.4	- -	0.0	- -
Soybean	113.5	17.5	- -	649.6	- -
Total Basin	219.8	140.1	145.5	156.9	151.1

MODEL SCENARIOS

The model was used to make projections on agricultural water for the years 1980, 1990, 2000, 2010, 2020 and 2030. For each year, two separate runs were made--each examining a different production scenario. The two scenarios were: (a) normal rainfall with no adoption of water conservation practices; and (b) normal rainfall with complete adoption of water conservation practices.

In addition to these scenarios, for the years 1980, 1990, and 2030 various irrigation cost scenarios were also examined; these were presented in Table II-7. Three scenarios were used for 1980 for model valioation purposes (Tables VI-6 through VI-6) and ten scenarios were employed for 1990 and 2030 in conjunction with the estimation of the derived demand curves. These data will be discussed in Chapter VI.

MODEL RESULTS

The scenario with normal rainfall and no adoption of conservation practices is presented in Table IV-6. This run was made without the OBERS production projection constraints. This table exhibits both the cropping pattern and the water use for the entire basin. Water use by crop by month is also displayed. It should be noted that without the OBERS projected production bounds, the rice acreage of cost scenario is 99.89% of the U.S.G.S. estimates and 96.3% of the A.G.C. estimates. The total irrigated acreages are closer as well, with the same model results recording 137% of the U.S.G.S. estimates and 132% of the A.G.C. estimates.

In Tables IV-7 and IV-8, the cropping pattern and water use data are presented for the years 1990, 2000, 2010, 2020 and 2030. Each table exhibits the model results for each of the four basic scenarios. All of the information presented was determined through the

TABLE IV-6: OPTIMAL CROPPING PATTERN AND WATER USE SUMMARY,
50 PERCENT CHANCE OF WATER NEED,
FOR THE OUACHITA RIVER BASIN

ITEM	YEAR		
	1980 COST SCENARIO 1	1980 COST SCENARIO 2	1980 COST SCENARIO 3
	1000 ACRES		
DRY SOYBEANS	60.6	165.1	86.5
DRY COTTON	14.2	112.4	14.2
WHEAT(DOUBLE CROP)	112.2	86.3	86.3
RICE	92.2	92.2	92.2
IRR SOY(DOUBLE CROP)	112.2	7.7	86.3
IRR SOY(RICE ROTATION)	92.2	92.2	92.2
IRR COTTON	98.2	0.0	98.2
TOTAL IRR ACRES	394.8	192.0	368.8
TOTAL CROPLAND USE	469.6	469.6	469.6
TOTAL WATER USE/MONTH:	1000 ACRE FEET		
MAY	42.9	43.8	44.1
JUN	104.5	107.0	107.4
JUL	138.0	127.5	143.5
AUG	231.6	125.0	263.2
SEP	11.9	0.6	12.8
OCT	0.0	0.0	0.0
TOTAL WATER USE/CROP			
SOYBEANS	167.0	102.1	167.4
COTTON	67.0	0.0	100.5
RICE	294.8	301.6	303.0
TOTAL WATER USE	528.8	403.7	570.9

The three cost scenarios are presented in Table II-7.

TABLE IV-7: OPTIMAL CROPPING PATTERN AND WATER USE SUMMARY, 50 PERCENT CHANCE OF WATER NEED, FOR THE OUACHITA RIVER BASIN

ITEM	YEAR 1990	 2000	 2010	 2020	 2030
			1000 ACRES		
DRY SOYBEANS	213.1	225.8	208.9	211.3	83.0
DRY COTTON	92.3	103.0	92.0	84.9	77.1
WHEAT(DOUBLE CROP)	121.6	136.5	134.1	132.4	132.7
RICE	103.1	101.8	119.4	115.6	112.8
IRR SOY(DOUBLE CROP)	8.6	0.0	0.0	0.0	121.3
IRR SOY(RICE ROTATION)	103.1	101.8	119.4	115.6	112.8
IRR COTTON	0.0	0.0	0.0	0.0	0.0
TOTAL IRR ACRES	214.7	203.6	238.8	231.3	347.0
TOTAL CROPLAND USE	520.1	532.4	539.7	527.5	507.0
TOTAL WATER USE/MONTH:			1000 ACRE FEET		
MAY	47.1	45.2	55.2	53.6	52.8
JUN	114.8	112.7	134.5	130.7	128.7
JUL	143.6	141.8	166.1	160.9	157.1
AUG	142.8	138.2	160.1	154.6	208.2
SEP	0.7	0.0	0.0	0.0	12.8
OCT	0.0	0.0	0.0	0.0	0.0
TOTAL WATER USE/CROP					
SOYBEANS	125.2	121.1	136.5	131.2	196.6
COTTON	0.0	0.0	0.0	0.0	0.0
RICE	323.8	317.7	379.4	368.5	362.9
TOTAL WATER USE	449.0	438.8	515.9	499.7	559.5

TABLE IV-8 OPTIMAL CROPPING PATTERN AND WATER USE SUMMARY,
50 PERCENT CHANCE OF WATER NEED,
WITH SPECIFIED CONSERVATION MEASURES,
FOR THE OUACHITA RIVER BASIN

	YEAR				
ITEM	1990	2000	2010	2020	2030
	1000 ACRES				
DRY SOYBEANS	191.7	206.1	83.1	82.8	82.6
DRY COTTON	92.3	103.0	92.0	84.9	77.1
WHEAT(DOUBLE CROP)	121.6	136.5	136.9	134.4	132.7
RICE	125.9	124.4	119.4	115.6	112.8
IRR SOY(DOUBLE CROP)	10.5	0.0	116.9	119.2	121.6
IRR SOY(RICE ROTATION)	125.9	124.4	119.4	115.6	112.8
IRR COTTON	0.0	0.0	0.0	0.0	0.0
TOTAL IRR ACRES	262.3	248.9	355.8	350.5	347.2
TOTAL CROPLAND USE	546.4	558.0	530.8	518.2	506.9
TOTAL WATER USE/MONTH:	1000 ACRE FEET				
MAY	40.9	40.1	39.1	37.9	36.9
JUN	99.8	97.8	95.3	92.3	90.1
JUL	126.6	124.5	119.4	115.6	112.8
AUG	134.1	128.2	170.0	166.9	164.8
SEP	0.7	0.0	10.6	10.8	11.0
OCT	0.0	0.0	0.0	0.0	0.0
TOTAL WATER USE/CROP					
SOYBEANS	120.6	114.8	165.5	163.1	161.6
COTTON	0.0	0.0	0.0	0.0	0.0
RICE	281.5	275.7	268.7	260.3	254.0
TOTAL WATER USE	402.1	390.5	434.2	423.4	415.6

use of irrigation cost scenario 2. The OBERS production projection constraints were used in these runs. In the scenario with normal rainfall and no conservation, it can be seen in Table IV-7 that the total irrigated acres decrease in 2000, increase in 2010, decrease slightly in 2020 and finally increase to the peak in 2030. The pattern observed in years 2000, 2010 and 2020 is explained by the movement of the rice acreage. It decreases in 2000, increases in 2010 and then decreases in both 2020 and 2030. The increase in total irrigated acres in 2030 arises from emergence of the irrigated double crop soybeans as a profitable activity.

The acreage predicted by the model is closely related to the OBERS production projection bounds. These bounds assign a minimum and a maximum amount of production for each of the four crops. As can be seen in Table IV-9, these bounds do indeed constrain the model solutions. When the lower bound is constraining, as in the case of rice in 1990, the bound forces the model to produce the minimum production level regardless of whether or not that crop is the most profitable for that region. When the upper bound is constraining, as in the case of wheat in 1990, the model restricts the production to the specified maximum level despite the fact that regional profit could be increased by expanding production of this crop. Only in the case of cotton in 1990, do the bounds not influence the production predicted by the model. Soybeans and wheat are always constrained by the upper bound but rice production in 1990 and 2000 by the lower bound and by the upper bound in 2010, 2020 and 2030. This explains the observed pattern in the rice acreage and the sudden increase in 2010. The rate of increase in the yields is greater than the rate of increase in the OBERS projected production for the basin. Therefore, without a shift in the relative profitability between crops, it is expected that the acreage in each year would contract. Obviously, in 2010 a shift in the profitability did occur between dryland single crop soybeans and cotton and the rice/soybean rotation. The rice/soybean rotation increased by 35,200 acres in 2010, with 48% of the increase coming from dryland soybeans, 31% from dryland cotton and 21% from idle land. Of course, these are net transfers and do not imply that 21% the land not previously planted to rice were idle before 2010. It is more probable that lands in soybeans or cotton were converted to rice and idle land converted to soybeans.

Table IV-9: An Indication of the Constraints
Imposed by Production Projection Bounds:
Normal Rainfall and No Conservation

	1990	2000	2010	2020	2030
Cotton Upper Bound	NO	YES	YES	YES	YES
Cotton Lower Bound	NO	NO	NO	NO	NO
Rice Upper Bound	NO	NO	YES	YES	YES
Rice Lower Bound	YES	YES	NO	NO	NO
Soybeans Upper Bound	YES	YES	YES	YES	YES
Soybean Lower Bound	NO	NO	NO	NO	NO
Wheat Upper Bound	YES	YES	YES	YES	YES
Wheat Lower Bound	NO	NO	NO	NO	NO

The irrigated double crop soybeans become relatively more profitable than the dryland single crop soybeans in 2030. Due to the discontiguous nature of linear programming, this results in a large shift of some 121,000 acres to the irrigation of double crop soybeans. This explains the increase in the total number of irrigated acres in 2030.

Similar patterns and explanations exist for the other scenario as well.

Table IV-8 shows the results for the scenario dealing with conservation. Rice acreage declines in each year. The shift to irrigated double crop soybeans occurs in 2010.

The impact of the conservation practices can be examined by comparing Table IV-7 with Table IV-8. Two major effects of conservation can occur: a savings in the per acre use of water resulting in a decrease in regional water use or an expansion in irrigated acreage due to lower per acre cost resulting in an increase irrigational water use. The tables show that the total irrigated acres have increased in every year except 2030, reflecting the lower costs of irrigation with the adoption of conservation. Nevertheless, total water use is less in each year with the conservation--demonstrating that the savings per acre have dwarfed the expansion effect the average savings in water use due to the adoption of the conservation practices are 15.7%.

CHAPTER V

LIVESTOCK, FISH AND WILDLIFE WATER USE

LIVESTOCK WATER REQUIREMENTS

Estimates for livestock water use are based on an approach using water requirements per animal. The per animal estimates for each category of livestock were presented in Table II-11. In comparison to the crop water requirements, livestock production in the basin will not account for a significant portion of the agricultural water demand. Of the livestock activities considered, broiler and cattle production will generate the greatest demand. Broiler water use increases faster than that of cattle due to a larger annual increase in broiler numbers. Water requirements through time for hogs and pigs will decrease reflecting the decline in inventories projected with the OBERS data. All of the other livestock uses will increase in the future. The total livestock water usage is presented in Table V-1.

Table V-1. Total Livestock and Poultry Water Use

Year	Acre- Feet
1980	8,609
1990	9,723
2000	11,007
2010	12,487
2020	14,192
2030	16,157

FISHERIES WATER DEMAND

Data are available from two sources to estimate the water demand for commercial fisheries. Shulstad estimated demand for 1975, 1985, 2000, and 2020 for the Ouachita and Mississippi-Tensas AWRPA. In 1975 withdrawal for this use was estimated at 71,742 acre-feet per year. For the future years it was estimated at 74,322 acre-feet per year. These estimates were based on the opinion of the Special Projects Coordinator and Supervisor of Hatcheries for the Arkansas Game and Fish Commission who expected little change in fish farming acreage in the near future.

The second source of data on fisheries demand is the Arkansas Geological Commission publication entitled Use of Water in Arkansas, 1980. For the state of Arkansas, water use at fish and minnow farms in 1980 was estimated to be 464,800 acre-feet per year or 1 percent of the total water withdrawal in the State. Sixty-eight percent of the water was withdrawn from wells. The report points out that most of the fish and minnow farms are located outside of the Ouachita Basin in the Grand Prairie region where the fish are raised in large levee ponds. Table I-3 shows water use by fish and minnow farms for the study area; in 1980 the usage for the area was 33,345 acre-feet per year; this was prorated for the study area.

WILDLIFE WATER DEMAND

There are several wildlife areas in the Ouachita Basin that are water using. Shulstad obtained data from the Arkansas Game and Fish Commission and from the Vicksburg District of the U.S. Army Corps of Engineers. For the whole of Arkansas, 76,765 acre-feet per year were withdrawn in 1975 from both ground water wells and streams to fill impoundments for migrating ducks and geese. By 1985, it was estimated that an additional state impoundment of 1,100 acres at White Oak in Ouachita County would be constructed. Also the Felsenthal National Wildlife Refuge was estimated at approximately 65,000 acres (27,764 acres in Union county, 17,829 acres in Bradley county, and 19,387 acres in Ashley county). It was estimated by the Corps of Engineers that 140,000 acre-feet per year would be required for the Felsenthal complex. For the Ouachita and Mississippi-Tensas AWRPA, Shulstad estimated withdrawals for wildlife impoundments as follows: 1975, 3,999 acre-feet; for 1985, 2000, and 2020, the estimate was constant at 145,999 acre-feet per year. The Felsenthal complex was not in existence in 1975.

The Arkansas Geological Commission data for 1980 also show water withdrawals for wildlife impoundments in several other counties of the study region: Drew, Lincoln, Jefferson, and Hempstead counties. However, except for Drew county, these wildlife impoundments lie outside of the Ouachita Basin.

This study assumes that there will be no contraction or expansion in either the commercial fisheries or the wildlife use of water. This assumption is necessary since there is little basis to forecast a change. In the years for which the Arkansas Agricultural Statistics provided data on acreage of commercial fisheries, there was very little change. The total water use estimated for livestock purpose ranges between 8,600 acre-feet to 16,100 acre-feet. For fish and wildlife the estimate is 173,300 acre-feet per year. The majority of this usage is attributed to the Felsenthal National Wildlife Refuge.

CHAPTER VI

ESTIMATION OF THE DERIVED DEMAND FOR IRRIGATION WATER

DEMAND AND PRICE ELASTICITY ESTIMATION

The procedure to identify the derived demand involves three stages: (1) the solution of the profit maximizing linear programming model; (2) sensitivity analysis on how the optimal solution will change when irrigation costs are altered; and (3) an econometric derivation of a regression equation showing the relationship between the per acre-inch irrigation costs and the amount of water demanded. The price elasticities can then be derived to demonstrate how responsive the demand will be to changes in the cost of irrigation. The price elasticity coefficent is defined as

$$\left| \frac{\partial Q}{\partial P} . \frac{P}{Q} \right|$$

and can be interpreted as the percentage change in the quantity of water demanded associated with a one percent change in the cost of the water. A coefficient equal to 3.5 would indicate that a one percent change in the cost of the water would produce a three and one half percent change in the optimal quantity of water used.

The sensitivity analysis involved the use of ten different irrigation cost scenarios. These scenarios have been discussed in a previous section and the scenarios are described in Table II-6. It should be noted that these runs were made without the OBERS projected production bounds which were found to be too constraining.

The model solution from these scenarios provided the data necessary to estimate the regression equation. Four alternative functional forms of the demand equation were estimated. The resulting equations were then compared to see which form produced the best statistical fit. The four functional forms estimated were:

1) $Q = a + bP$
2) $LnQ = a + bLnP$
3) $LnQ = a + bP$
4) $Q = a + bLnP$

where Q = the total number of acre-feet in the optimal model solution

P = the cost per acre-inch of the irrigation water

Different equations were fitted for rice, soybeans, cotton and total irrigated cropland. Equations were only fitted for the years 1990 and 2030.[1] For both time periods, the series of equations were estimated for both the conservation and no conservation scenarios. The cost per acre-inch of the irrigation water is a weighted average over all cropping activities falling into the broad groups used as independent variables.

The price elasticities for the different functional forms can be calculated using the definition of

$$\varepsilon = \frac{\partial Q}{\partial P} \cdot \frac{P}{Q}$$

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[1] OBERS is an acronym signifying the united effort of the Office of Business Economics (OBE) and the Economic Research Service (ERS).

The derivatives of the elasticity for each functional is as follows:

(1) $Q = a + bP$

$$\varepsilon = \frac{\partial Q/Q}{\partial P/P} = \frac{\partial Q}{\partial P}.\frac{P}{Q} = b.\ \frac{P}{Q} = \frac{bP}{a+bP}$$

(2) $LnQ = a + bLnP$

$$\varepsilon = \frac{\partial Q/Q}{\partial P/P} = \frac{\partial(LnQ)}{\partial(LnP)} = b$$

(3) $LnQ = a + bP$

$$\varepsilon = \frac{\partial Q/Q}{\partial P/P} = \frac{\partial(LnQ)}{\partial P}.P = bP$$

(4) $Q = a + bLnP$

$$\varepsilon = \frac{\partial Q/Q}{\partial P/P} = \frac{\partial Q}{\partial(LnP)} * \frac{\partial(LnP)}{\partial P} * \frac{P}{Q} = \frac{b}{Q} = \frac{b}{a+bLnP}$$

These formulae were used to calculate the price elasticities for the derived demand of water at various costs of irrigation. The coefficients derived are presented in the next section.

In Table VI-1, the comparison between the cost scenario 2 model results and the A.G.C. estimates on water use are presented. These results were produced without the OBERS projected production constraints. It can be seen that the total water use estimated by the model is within 6 percent of the A.G.C. estimate.

Table VI-1. Comparison of Model Results and Arkansas Geological Commission Survey Results--1980

	Model Cost Scenario 2	Arkansas Geological Commission	(Model/A.G.C.)*100
		1000 acre-feet	
Rice	301.6	324.2	93.0%
Other Crops	102.1	56.7	180.1%
Total Crop Irrigation	403.7	380.9	105.6%

Source: Arkansas Geological Commission. Use of Water in Arkansas, 1980. Water Resources Summary No. 14.

Additional model runs were made for the years 1990 and 2030 using all ten irrigation cost scenarios. With the results from these scenarios, entire demand curves can be estimated rather than only a single point on the curve. The demand curves can then be interpreted to discover how responsive the use of irrigation water will be to changes in the costs of irrigation. This responsiveness is measured in the price elasticity coefficients.

The results for both years and all ten irrigation cost scenarios appear in Tables lV-2 through IV-9. Water usage does adjust a great deal to the different irrigation costs. The adjustments are both in the expansion or contraction of the total number of irrigated acres and in the distribution of crops. Under some scenarios all three crops can be irrigated.

As stated above, the four different functional forms for the demand equations were fitted and the best estimates were selected on the basis of statistical fit and consistency with economic theory.

TABLE VI-2. OPTIMAL CROPPING PATTERN AND WATER USE SUMMARY, 50 PERCENT CHANCE OF WATER NEED, FOR THE OUACHITA RIVER BASIN, 1990

ITEM	YEAR				
	1990 COST SCENARIO 1	1990 COST SCENARIO 2	1990 COST SCENARIO 3	1990 COST SCENARIO 4	1990 COST SCENARIO 5
	1000 ACRES				
DRY SOYBEANS	66.4	256.3	69.9	69.9	86.2
DRY COTTON	1.5	89.9	1.5	1.5	89.9
WHEAT(DOUBLE CROP)	218.7	198.9	198.9	198.9	198.9
RICE	73.7	73.7	90.0	90.0	73.7
IRR SOY(DOUBLE CROP)	195.1	6.1	176.3	176.3	176.3
IRR SOY(RICE ROTATION	73.7	73.7	90.0	90.0	73.7
IRR COTTON	88.5	0.0	88.5	88.5	0.0
TOTAL IRR ACRES	432.0	153.6	444.7	444.7	323.7
TOTAL CROPLAND USE	499.8	499.8	516.1	516.1	499.8
TOTAL WATER USE/MONTH:	1000 ACRE FEET				
MAY	32.4	32.4	40.8	40.7	32.5
JUN	79.0	79.0	99.5	99.3	79.3
JUL	111.2	101.6	139.8	134.9	101.6
AUG	242.4	103.5	318.6	255.2	223.3
SEP	24.5	0.5	26.8	18.6	27.2
OCT	0.0	0.0	0.0	0.0	0.0
TOTAL WATER USE/CROP					
SOYBEANS	206.4	94.3	254.2	208.4	240.4
COTTON	60.3	0.0	90.5	60.3	0.0
RICE	222.7	222.7	280.9	280.0	223.7
TOTAL WATER USE	489.4	316.9	625.6	548.7	464.0

TABLE VI -3: OPTIMAL CROPPING PATTERN AND WATER USE SUMMARY,
50 PERCENT CHANCE OF WATER NEED.
FOR THE OUACHITA RIVER BASIN, 1990

ITEM	YEAR				
	1990 COST SCENARIO 6	1990 COST SCENARIO 7	1990 COST SCENARIO 8	1990 COST SCENARIO 9	1990 COST SCENARIO 10
	1000 ACRES				
DRY SOYBEANS	68.2	256.3	86.2	256.3	89.1
DRY COTTON	1.5	89.9	1.5	89.9	89.9
WHEAT(DOUBLE CROP)	198.9	193.9	198.5	198.5	74.7
RICE	91.7	73.7	73.7	73.7	73.7
IRR SOY(DOUBLE CROP)	176.3	6.2	176.2	6.2	49.2
IRR SOY(RICE ROTATION	91.7	73.7	73.7	73.7	73.7
IRR COTTON	88.5	0.0	88.5	0.0	0.0
TOTAL IRR ACRES	448.2	153.6	412.2	153.6	196.6
TOTAL CROPLAND USE	517.8	499.8	499.8	499.8	375.6
TOTAL WATER USE/MONTH:	1000 ACRE FEET				
MAY	41.6	32.4	32.4	32.4	37.1
JUN	101.5	79.0	79.0	79.0	90.5
JUL	142.3	101.6	111.2	101.6	102.3
AUG	321.2	103.5	234.5	103.5	117.8
SEP	26.8	0.5	18.6	0.5	5.0
OCT	0.0	0.0	0.0	0.0	0.0
TOTAL WATER USE/CROP					
SOYBEANS	256.8	94.3	192.5	94.3	97.3
COTTON	90.5	0.0	60.3	0.0	0.0
RICE	286.1	222.7	222.7	222.7	255.3
TOTAL WATER USE	633.4	316.9	475.7	316.9	352.6

TABLE VI-4 : OPTIMAL CROPPING PATTERN AND WATER USE SUMMARY.
50 PERCENT CHANCE OF WATER NEED,
WITH SPECIFIED CONSERVATION MEASURES,
FOR THE OUACHITA RIVER BASIN, 1990

ITEM	YEAR				
	1990 COST SCENARIO 1	1990 COST SCENARIO 2	1990 COST SCENARIO 3	1990 COST SCENARIO 4	1990 COST SCENARIO 5
	1000 ACRES				
DRY SOYBEANS	66.4	256.3	62.9	62.9	69.9
DRY COTTON	1.5	89.9	1.5	1.5	1.5
WHEAT(DOUBLE CROP)	205.9	198.9	198.9	198.9	198.9
RICE	86.5	73.7	105.3	97.0	90.0
IRR SOY(DOUBLE CROP)	183.2	6.1	176.3	176.3	176.3
IRR SOY(RICE ROTATION	86.5	73.7	105.3	97.0	90.0
IRR COTTON	88.5	0.0	88.5	88.5	88.5
TOTAL IRR ACRES	444.7	153.5	475.4	458.8	444.7
TOTAL CROPLAND USE	512.6	493.8	539.8	523.1	516.1
TOTAL WATER USE/MONTH:	1000 ACRE FEET				
MAY	27.2	22.7	33.3	30.7	28.6
JUN	66.4	55.3	81.2	75.0	69.7
JUL	94.9	73.4	117.9	105.7	101.8
AUG	206.9	79.8	269.0	215.6	251.3
SEP	17.7	0.4	21.5	15.9	21.6
OCT	0.0	0.0	0.0	0.0	0.0
TOTAL WATER USE/CROP					
SOYBEANS	174.2	75.6	221.6	179.8	204.1
COTTON	51.7	0.0	72.4	51.7	72.4
RICE	187.3	155.9	228.9	211.4	196.7
TOTAL WATER USE	413.2	231.5	522.9	442.9	473.1

TABLE VI-5.: OPTIMAL CROPPING PATTERN AND WATER USE SUMMARY.
50 PERCENT CHANCE OF WATER NEED.
WITH SPECIFIED CONSERVATION MEASURES.
FOR THE OUACHITA RIVER BASIN, 1990

ITEM	YEAR 1990 COST SCENARIO 6	 1990 COST SCENARIO 7	 1990 COST SCENARIO 8	 1990 COST SCENARIO 9	 1990 COST SCENARIO 10
			1000 ACRES		
DRY SOYBEANS	62.9	255.3	66.4	255.3	69.9
DRY COTTON	1.5	89.3	1.5	89.9	89.9
WHEAT(DOUBLE CROP)	201.2	198.9	205.9	198.9	198.9
RICE	247.6	73.7	86.5	73.7	90.0
IRR SOY(DOUBLE CROP)	178.6	6.1	183.3	6.1	176.3
IRR SOY(RICE ROTATION	247.6	73.7	86.5	73.7	90.0
IRR COTTON	88.5	0.0	88.5	0.0	0.0
TOTAL IRR ACRES	762.3	153.5	444.7	153.6	356.2
TOTAL CROPLAND USE	826.7	499.8	512.6	499.8	516.1
TOTAL WATER USE/MONTH:			1000 ACRE FEET		
MAY	77.6	22.7	27.2	22.7	28.6
JUN	189.4	55.3	66.4	55.3	69.7
JUL	250.5	73.4	94.9	73.4	90.3
AUG	427.0	79.7	206.9	79.7	191.3
SEP	21.3	0.4	17.7	0.4	21.8
OCT	0.0	0.0	0.0	0.0	0.0
TOTAL WATER USE/CROP					
SOYBEANS	369.4	75.6	174.2	75.6	205.2
COTTON	72.4	0.0	51.7	0.0	0.0
RICE	534.1	155.9	187.3	155.9	196.7
TOTAL WATER USE	975.9	231.5	413.2	231.5	401.8

TABLE VI-6: OPTIMAL CROPPING PATTERN AND WATER USE SUMMARY.
50 PERCENT CHANCE OF WATER NEED.
FOR THE OUACHITA RIVER BASIN, 2030

ITEM	YEAR				
	2030 COST SCENARIO 1	2030 COST SCENARIO 2	2030 COST SCENARIO 3	2030 COST SCENARIO 4	2030 COST SCENARIO 5
	1000 ACRES				
DRY-SOYBEANS	588.6	1608.7	901.6	588.6	1057.4
DRY COTTON	571.1	752.8	621.7	571.1	621.7
WHEAT(DOUBLE CROP)	1450.0	1816.7	1188.5	1412.4	1364.8
RICE	397.5	123.3	503.0	416.3	414.8
IRR SOY(DOUBLE CROP)	861.4	208.0	286.9	823.8	307.4
IRR SOY(RICE ROTATION	397.5	123.3	503.0	416.3	414.8
IRR COTTON	0.0	0.0	0.0	0.0	0.0
TOTAL IRR ACRES	1656.3	454.6	1292.8	1656.3	1137.0
TOTAL CROPLAND USE	2816.1	2816.1	2816.1	2816.1	2816.1
TOTAL WATER USE/MONTH:	1000 ACRE FEET				
MAY	175.4	53.8	229.5	185.1	184.3
JUN	427.3	131.1	559.7	451.4	449.5
JUL	554.5	169.5	701.2	581.7	579.1
AUG	1017.2	267.8	918.2	1023.8	821.6
SEP	188.7	23.7	56.5	182.6	33.3
OCT	0.0	0.0	0.0	0.0	0.0
TOTAL WATER USE/CROP					
SOYBEANS	1156.9	276.0	888.6	1151.5	800.2
COTTON	0.0	0.0	0.0	0.0	0.0
RICE	1206.5	369.9	1572.2	1272.3	1267.6
TOTAL WATER USE	2363.4	645.9	2464.9	2424.3	2067.9

TABLE VI-7: OPTIMAL CROPPING PATTERN AND WATER USE SUMMARY,
50 PERCENT CHANCE OF WATER NEED,
FOR THE OUACHITA RIVER BASIN, 2030

ITEM	YEAR 2030 COST SCENARIO 6	2030 COST SCENARIO 7	2030 COST SCENARIO 8	2030 COST SCENARIO 9	2030 COST SCENARIO 10
	1000 ACRES				
DRY SOYBEANS	817.6	1843.3	785.7	1422.5	1057.4
DRY COTTON	599.3	752.3	621.7	752.3	654.6
WHEAT(DOUBLE CROP)	1210.3	1843.3	1405.2	1633.5	1331.9
RICE	503.0	30.2	394.6	214.9	414.8
IRR SOY(DOUBLE CROP)	393.3	0.0	619.6	211.0	274.5
IRR SOY:RICE ROTATION	503.0	30.2	394.6	214.9	414.8
IRR COTTON	0.0	0.0	0.0	0.0	0.0
TOTAL IRR ACRES	1399.2	60.4	1408.7	540.8	1104.1
TOTAL CROPLAND USE	2816.1	2656.5	2816.1	2816.1	2816.1
TOTAL WATER USE/MONTH:	1000 ACRE FEET				
MAY	229.5	13.2	173.9	95.0	184.3
JUN	559.7	32.1	424.2	231.7	449.5
JUL	701.2	41.5	549.8	296.9	579.1
AUG	1003.0	41.5	882.1	394.8	759.0
SEP	104.9	0.0	100.1	24.4	23.7
OCT	0.0	0.0	0.0	0.0	0.0
TOTAL WATER USE/CROP					
SOYBEANS	1019.6	37.8	933.8	389.5	727.9
COTTON	0.0	0.0	0.0	0.0	0.0
RICE	1578.3	90.6	1196.3	653.3	1267.6
TOTAL WATER USE	2597.9	128.4	2130.1	1042.8	1995.5

TABLE VI-8: OPTIMAL CROPPING PATTERN AND WATER USE SUMMARY.
50 PERCENT CHANCE OF WATER NEED.
WITH SPECIFIED CONSERVATION MEASURES
FOR THE OUACHITA RIVER BASIN, 2030

ITEM	YEAR 2030 COST SCENARIO 1	 2030 COST SCENARIO 2	 2030 COST SCENARIO 3	 2030 COST SCENARIO 4	 2030 COST SCENARIO 5
			1000 ACRES		
DRY SOYBEANS	556.6	1057.4	682.3	566.6	918.8
DRY COTTON	540.3	752.8	599.3	540.3	621.7
WHEAT(DOUBLE CROP)	1446.3	1233.7	1210.9	1270.0	1188.5
RICE	414.8	414.8	503.0	503.0	503.0
IRR SOY(DOUBLE CROP)	879.7	176.3	528.5	703.4	269.7
IRR SOY(RICE ROTATION	414.8	414.8	503.0	503.0	503.0
IRR COTTON	0.0	0.0	0.0	0.0	0.0
TOTAL IRR ACRES	1709.3	1005.9	1534.5	1709.3	1275.6
TOTAL CROPLAND USE	2816.2	2816.1	2816.2	2816.2	2816.1
TOTAL WATER USE/MONTH:			1000 ACRE FEET		
MAY	129.0	129.0	160.6	160.6	160.5
JUN	314.7	314.7	391.8	391.8	391.8
JUL	419.4	418.3	505.0	506.2	505.0
AUG	849.4	537.0	850.7	861.3	705.4
SEP	171.1	16.3	129.9	154.5	43.0
OCT	0.0	0.0	0.0	0.0	0.0
TOTAL WATER USE/CROP					
SOYBEANS	996.2	528.3	932.9	969.6	700.9
COTTON	0.0	0.0	0.0	0.0	0.0
RICE	887.3	887.2	1104.8	1104.8	1104.8
TOTAL WATER USE	1883.5	1415.5	2037.7	2074.4	1805.7

TABLE VI-9: OPTIMAL CROPPING PATTERN AND WATER USE SUMMARY,
50 PERCENT CHANCE OF WATER NEED,
WITH SPECIFIED CONSERVATION MEASURES,
FOR THE OUACHITA RIVER BASIN, 2030

ITEM	YEAR				
	2030 COST SCENARIO 6	2030 COST SCENARIO 7	2030 COST SCENARIO 8	2030 COST SCENARIO 9	2030 COST SCENARIO 10
	1000 ACRES				
DRY SOYBEANS	566.6	1086.2	588.6	1057.4	1057.4
DRY COTTON	540.3	752.8	571.1	752.8	621.7
WHEAT(DOUBLE CROP)	1270.0	1299.2	1415.5	1233.7	1188.5
RICE	503.0	382.1	414.8	414.8	503.0
IRR SOY(DOUBLE CROP)	703.4	211.0	826.8	176.3	151.1
IRR SOY(RICE ROTATION	503.0	382.1	414.8	414.8	503.0
IRR COTTON	0.0	0.0	0.0	0.0	0.0
TOTAL IRR ACRES	1709.3	975.1	1656.4	1005.9	1157.0
TOTAL CROPLAND USE	2816.2	2816.1	2816.1	2816.1	2816.1
TOTAL WATER USE/MONTH:	1000 ACRE FEET				
MAY	160.6	117.7	129.0	129.0	160.6
JUN	391.8	287.0	314.7	314.7	391.8
JUL	506.4	385.1	418.6	418.3	505.0
AUG	942.1	514.9	824.1	537.3	630.5
SEP	189.0	20.9	157.1	16.3	7.2
OCT	0.0	0.0	0.0	0.0	0.0
TOTAL WATER USE/CROP					
SOYBEANS	1084.8	516.2	956.2	528.2	590.1
COTTON	0.0	0.0	0.0	0.0	0.0
RICE	1104.8	809.4	887.3	887.3	1104.8
TOTAL WATER USE	2189.6	1325.6	1843.5	1415.5	1694.9

Previous work in the area has shown that the derived demand of water should be more elastic at high prices than at low ones. The equations selected as most appropriate from the set of all estimated equations are found in Table VI-10. The price elasticity coefficients derived from these equations can be found in Table IV-11.

The elasticity coefficients are interpreted as the percentage change in water use resulting from a one percent change in the cost of irrigation. A coefficient of -0.25 would indicate that water usage would not be responsive to cost changes and a -0.25% decrease in usage would result from a 1.0% increase in the cost of irrigation.

As expected the demand equation display increases in elasticities as the cost of irrigation increases. However, it was not expected that in the equation for 2030, the introduction of conservation practices would actually decrease the elasticities. In the 1990 results, conservation lead to more price responsiveness as suggested by Chapman. It appears that both an increase in elasticities and a shift in the demand curves can be observed with these data. The case of total cropland for 1990 follows Chapman's case of no shift in demand but an increase in elasticities at high and low prices. The results for 2030 do not follow any one of the three possible effects of conservation proposed by Chapman. A possible explanation is that in 2030 the rice acreage has contracted to that acreage where it has a significant superiority and the remaining acreage suitable for irrigation is largely dominated by soybeans.

Table VI-10. Selected Demand Equations for 1990 and 2030

Q	Intercept	Price	R^2
1990 Conservation Rice A.I.	5,700,088	-2,815,810 LnP (2.800)	.417
Soybean A.I.	10,381,987	-5,311,507 LnP (7.143)	.865
Total Cropland A.I.	19,679,152	-11,025,567 LnP (5.648)	.799
1990 No Conservation Rice A.I.	3,758,308	-822,901 LnP (3.778)	.640
Soybean A.I.	8,062,461	-4,112,830 LnP (9.651)	.923
Total Cropland A.I.	12,463,910	-5,924,853 LnP (4.770)	.740
2030 Conservation Rice A.I.	16,639,959	-4,425,314 LnP (6.714)	.850
Soybean A.I.	28,058,784	-13,240,818 LnP (9.369)	.916
Total Cropland A.I.	38,589,792	-14,809,666 LnP (7.732)	.881
2030 No Conservation Rice A.I.	29,553,136	-16,766,777 LnP (6.469)	.839
Soybean A.I.	32,030,496	-1,698,656 LnP (6.411)	.837
Total Cropland A.I.	63,991,840	-37,971,600 LnP	.788

A.I. = acre-inches; Ln = natural logs; P = irrigation cost per acre-inch. Computed T-values appear in parentheses.

Table VI-11. Price Elasticity Coefficients for Derived Demand for Irrigation Water - Ouachita River Basin*

		Rice			Soybeans			Total Cropland	
	P	No Conservation	Conservation	P	No Conservation	Conservation	P	No Conservation	Conservation
1990	$1.75	-0.25	-0.68	$3.50	-1.41	-1.42	$2.50	-0.84	-1.15
	2.75	-0.28	-0.99	4.50	-2.19	-2.22	3.50	-1.18	-1.18
	3.75	-0.31	-1.42	5.50	-3.91	-4.00	4.50	-1.66	-3.56
	4.50	-0.33	-1.92	6.25	-7.82	-8.19	5.00	-2.02	-5.70
2020	$2.00	-0.94	-0.32	$3.50	-1.58	-1.15	$2.50	-1.30	-0.59
	3.00	-1.51	-0.38	4.50	-2.62	-1.62	3.50	-2.31	-0.74
	4.00	-2.66	-0.42	5.50	-5.53	-2.41	4.50	-5.52	-0.91
	4.50	-3.87	-0.44	6.00	-10.65	-3.05	5.00	-13.19	-1.00

*Demand equations appear in Table VI-10.

Likewise, on this acreage, irrigated soybeans has superiority over dryland production and is less sensitive to price changes even though it is still showing an elastic demand. The conservation practices further the superiority enjoyed by rice and soybeans on these acreages and have contributed to the insensitivity to price changes.

CHAPTER VII

SUMMARY AND CONCLUSIONS

The total water use for the basin projected for the four basic scenarios using the second irrigation cost scenario appear in Tables VII-1 and VII-2. The water use associated with the irrigated cropland accounts for between 60 percent and 80 percent of the total basin agricultural water use. In almost all cases, the model results indicate that water use will start to decline, then increase as the profitability of rice grows, then decline again until irrigated double crop soybeans become significantly profitable. The total water use in 2030 ranges from 110 percent to 125 percent of the 1980 levels. In most cases, the adoption of the conservation practices will lead to less water being used in the region.

The model verification and validation have been discussed, identifying areas where credibility in the results may be established. Problems with the model have also been discussed and resolution of these difficulties may further enhance the projections made in this study. Demand equations were estimated and price elasticity coefficients were derived. Water use for soybean production is very responsive to changes in the cost of irrigation. Water use for all irrigated cropland is also very responsive to price changes, except in the case of complete adoption of the conservation practices in the year 2030. In most cases, a 1 percent change in the cost of irrigation will produce a greater than 2 percent change in the amount of water used in irrigation.

Table VII-1. Total Agricultural and Fish and Wildlife Water Use--
Entire Basin, Normal Rainfall and No Conservation*

	1980	1990	2000	2010	2020	2030
	1000's acre-feet					
Irrigated Cropland	462.4	449.0	438.8	515.9	499.7	559.5
Livestock	8.6	9.7	11.0	12.5	14.2	16.2
Commercial Fisheries**	33.3	33.3	33.3	33.3	33.3	33.3
Wildlife Habitat***	140.0	140.0	140.0	140.0	140.0	140.0
Total	644.3	632.0	623.1	701.7	687.2	749.0

*Irrigation Cost Scenario 2.
**Source: Arkansas Geological Commission.
***Source: Corps of Engineers (as quoted by Shulstad, et al.).

Table VII-2. Total Agricultural and Fish and Wildlife Water Use--
Entire Basin, Normal Rainfall and Conservation*

	1980	1990	2000	2010	2020	2030
	1000's acre-feet					
Irrigated Cropland	306.0	402.1	390.5	434.2	423.4	415.6
Livestock	8.6	9.7	11.0	12.5	14.2	16.2
Commercial Fisheries**	33.3	33.3	33.3	33.3	33.3	33.3
Wildlife Habitat***	140.0	140.0	140.0	140.0	140.0	140.0
Total	487.9	585.1	574.8	620.0	610.9	605.1

*Irrigation Cost Scenario 2.
**Source: Arkansas Geological Commission.
***Source: Corps of Engineers (as quoted by Shulstad, et al.).

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