ON-FARM RESERVOIR CONSTRUCTION IN THE GRAND PRAIRIE REGION OF ARKANSAS: AN ENGINEERING ECONOMIC ANALYSIS

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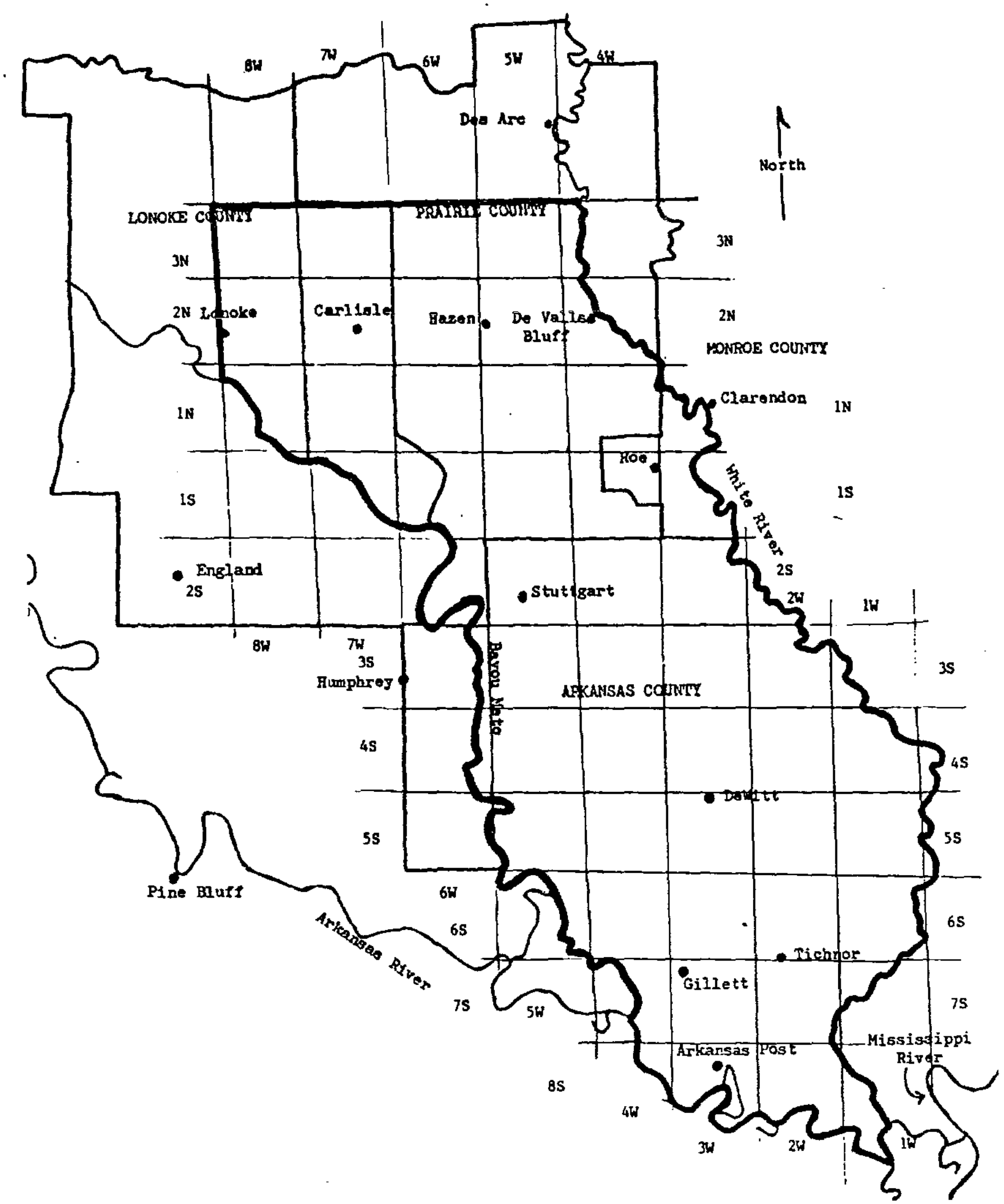
On-Farm Reservoir Construction in the Grand Prairie Region of Arkansas: An Engineering Economic Analysis

The Grand Prairie region has traditionally been one of the major rice-producing areas in Arkansas (Figure 1). A combination of favorable soil conditions for holding flood water and a once abundant source of groundwater for irrigation led to the development of the Grand Prairie as a leading rice area. Declining groundwater levels coupled with institutional and economic barriers to alternative surface-water supplies, however, threaten the continuation of rice production in many parts of the region (Hartz and Moorhead). One alternative to groundwater for irrigation is the use of on-farm reservoirs.

On-farm reservoirs have been an important source of irrigation water in the Grand Prairie region. Based on a survey conducted by the authors in the Spring of 1983, 26.7 percent of Grand Prairie irrigators used reservoirs, from which they obtained an average of 43.0 percent of their irrigation water. On-farm reservoirs are often used as secondary sources of irrigation water. Only 11 percent of the farmers who use on-farm reservoirs reported using over 90 percent reservoir water for irrigation; the remaining users reported getting 50 percent or less of their irrigation water from reservoirs.

Reservoir water has two advantages over groundwater: 1) it has better chemical quality and 2) it is warmer than groundwater. Groundwater in the Grand Prairie is generally high in calcium and magnesium carbonates and bicarbonates. Some soils irrigated with groundwater have had alkaline

Figure 1. The Grand Prairie Region, Arkansas



problems. The precipitation of these carbonates leads to zinc deficiency in the soil which in turn causes chlorosis (yellowing) in seedling rice. Some rice varieties such as Mars and Nato are tolerant to alkalinity and the use of these varieties can reduce the incidence of chlorosis. Most long grain rice varieties, however, have poor tolerance for alkaline soils. Water temperature can also influence the quality of the rice. Use of low-temperature irrigation water can lead to pockets of immature rice in the field at harvest. Use of reservoirs decreases the risk of immature rice because surface water is warmer than groundwater (Huey).

Good reservoir sites are those that require small amounts of fill for embankments and take advantage of the storage potential of stream valleys. Few good sites for reservoirs remain in the agricultural areas of the Grand Prairie due to the lack of physiographic relief in the region. For this reason, totally enclosed reservoirs are required.

Objectives

The principle objective of this study is to analyze the feasibility of constructing on-farm reservoirs for rice irrigation. The Grand Prairie region of Arkansas is used as a case study. The analysis considers nine reservoir sizes: 30-, 60- and 90-acre totally enclosed reservoirs with respective depths of 4, 5 and 6 feet. These sizes account for over 70 percent of existing Grand Prairie reservoirs (Arkansas Soil and Water Conservation Commission). The specific objectives of this study are to:

1) outline the engineering criteria for reservoir construction in the Grand Prairie region.

2) estimate construction and operating costs of the nine reservoir systems.

3) compare the relative cost of using on-farm reservoir systems versus the cost of using groundwater wells as irrigation sources.

ENGINEERING CRITERIA

Note: This section is provided to define terms and illustrate design features for those unfamiliar with the construction of on-farm irrigation reservoirs. It is not intended to serve as a guide to constructing on-farm irrigation reservoirs. Persons who need a complete explanation of the engineering design principles for constructing on-farm reservoirs should consult the Soil Conservation Service's Engineering Field Manual.

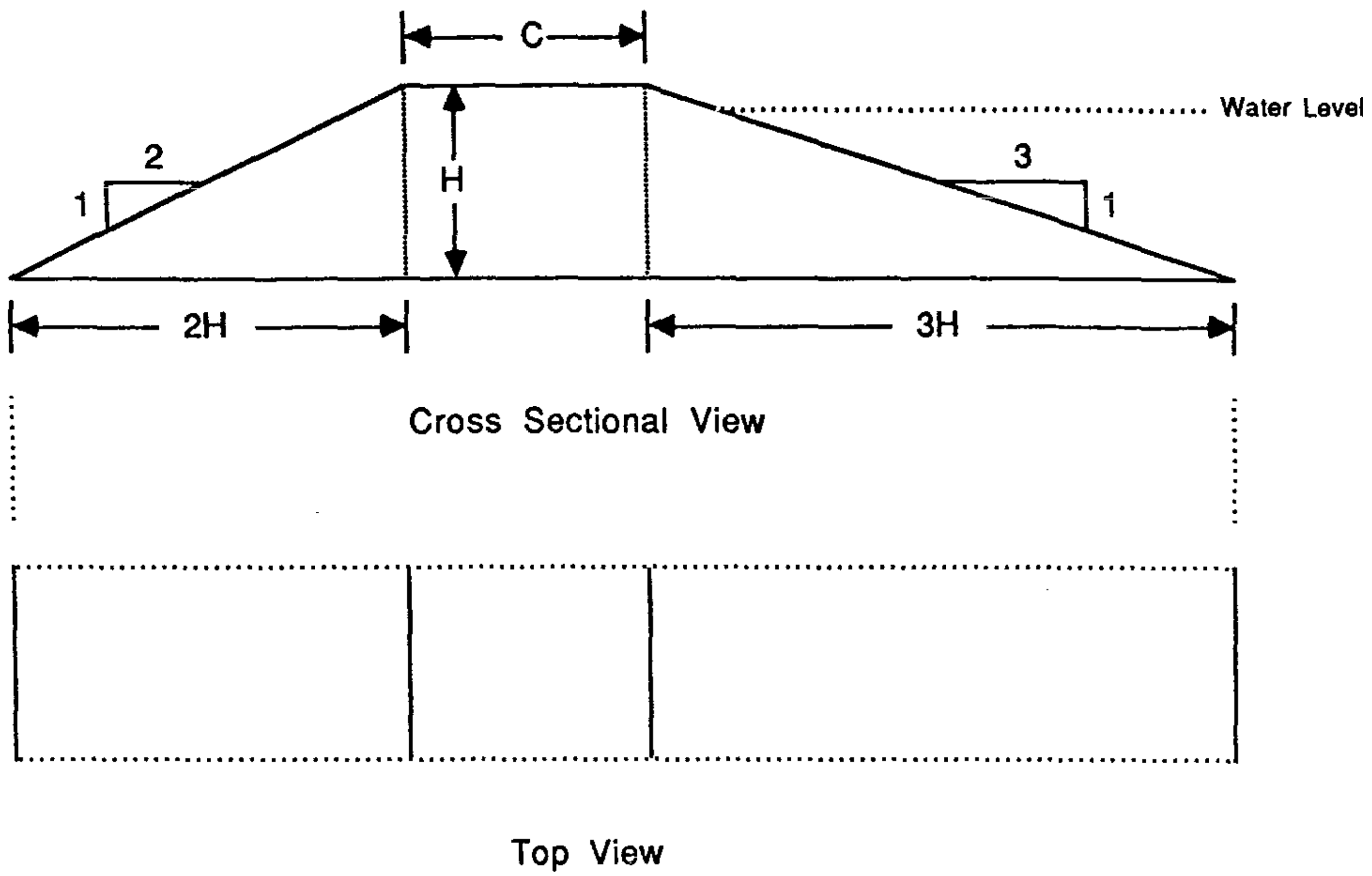
Design of Earthfill Embankments

Regardless of size, earthen embankments have trapezoidal cross sections (Figure 2) and are constructed of fill materials found at the site. To avoid embankment failure or deterioration, however, certain engineering design criteria need to be followed. Among the more important criteria for reservoir construction are those pertaining to embankment top widths, embankment side slopes, freeboard height, and fill settlement.

Proper top width is essential to the stability of the reservoir embankment. Top width depends upon the height of the embankment; as the height of the embankment increases, top width also needs to be increased. For embankments under 10 feet high, the Soil Conservation Service suggests a top width of 8 feet (USDA, SCS 1975).

Maximum slopes for the sides of the reservoir embankment depend primarily upon the stability of the material comprising the fill. Steeper side slopes are possible with more stable fill materials. Side slopes of 3:1

Figure 2. Embankment Cross Section



inside and 2:1 outside are recommended for the soil types found in the Grand Prairie region (USDA, SCS 1975).

Freeboard is the added height of an embankment needed to prevent waves or runoff from overtopping the embankment (USDA, SCS 1975). Since a fully enclosed reservoir would be adjacent to and not in natural drainage channels, freeboard must be adequate to prevent overtopping caused by rainfall and wave action. Freeboard requirements vary in accordance with reservoir size (length of fetch). The Soil Conservation Service suggests a freeboard of 1-½ feet for pond lengths between 600 and 1320 feet (30-acre reservoir) and 2 feet for ponds up to 2640 feet in length (60- and 90-acre reservoirs) (USDA, SCS 1975).

The initial height of the embankment must be great enough to offset the loss of height caused by consolidation of the fill and foundation materials. Consolidation results from the weight of the embankment and the increased moisture caused by the storage of water (USDA, SCS 1975). A minimum increase in embankment height of 15 percent is needed as an allowance for settlement. To compensate for consolidation and achieve the recommended side slopes, side slopes are commonly overbuilt to 2.4:1 outside and 3.2:1 inside (Hayes).

Preparation of the Reservoir Site

Prior to excavation, clearing and foundation preparation are undertaken to insure the quality and safety of the reservoir and the embankment. Clearing involves the removal of trees, brush, woody growth, and other debris from the foundation and reservoir areas (USDA, SCS 1971). This operation facilitates excavation and prevents unsuitable materials from becoming incorporated into the reservoir embankment.

Foundation preparation is extremely important to the integrity of the embankment. The first operation in foundation preparation is the excavation and removal of materials that are unsuitable for structural foundations. Excavation involves removing surface soils that contain vegetation and root growth and the removal of soils that do not have the proper support characteristics (USDA, SCS 1975). A second operation in foundation preparation is scarifying. Scarifying the foundation surface is done to improve the bond between the embankment and the foundation materials (USDA, SCS, 1971).

Construction of the Reservoir Embankment

After clearing and foundation preparation is completed, construction of the reservoir embankment may begin. Excavation is most often done with a dragline equipped with a two cubic yard scoop. Smoothing and shaping of the embankment is completed with bulldozers. Reservoir embankments in the Grand Prairie are generally constructed of materials found in the reservoir area. Fill materials need to be free of sod, roots, and any stones greater than 6 inches in diameter, and any material that could prevent firm compaction (USDA, SCS 1971). Fill is most pliable when it is moist; however, if the soil is too wet it will not spread or compact properly.

Protection of the Reservoir Embankment

Stability and safety of the embankment is an extremely important consideration. As soon after construction as practicable, the exposed surfaces of the embankment need to be seeded with a good sod-forming grass. In the Grand Prairie, bermudagrass is most often used. The grass helps prevent erosion and improves the appearance of the reservoir. Where grazing animals are present (though not generally the case in the Grand Prairie) fencing is required to protect the grass from being trampled.

Flooded rice fields and reservoirs provide excellent muskrat habitat (Huey). Reservoir embankments are weakened by the burrowing of muskrats and action must be taken to minimize muskrat numbers. A female muskrat can produce three to five litters per year with a gestation period of only 30 days. The average litter size is five (Huey). The combination of an abundant food supply and suitable habitat can lead to the rapid proliferation of muskrats throughout an area unless control methods are utilized. Control is best accomplished during the winter months by trapping or by the use of poisoned baits. Depriving the muskrat of an overwintering habitat is also an effective means of control. This is accomplished by keeping water levels in ditches and reservoirs as low as possible during the winter months and reducing or eliminating adjacent vegetation. Many times, however, this results in the relocation of muskrat populations and not in a reduction of numbers.

Reservoirs experience fluctuations in water levels during the year and as a result the embankment may require more protection than freeboard alone can provide. The inside slopes of the reservoir can be further protected from wave action by the placement of riprap (any material used for the purpose of reducing wave erosion). Ideally, riprap should extend from the top of the embankment down to a point at least 3 feet below the lowest anticipated water level (USDA, SCS 1971). In the Grand Prairie, rice producers generally do not protect the entire reservoir with riprap, but only those areas where wave damage has occurred historically.

ANALYSIS OF RESERVOIR COSTS

Reservoir cost (initial and annual) involves several factors: construction costs, embankment stabilization costs, pumping plant costs, and seasonal operating costs. The economics of irrigation reservoirs in the Grand Prairie were first analyzed in a 1958 study using actual data from 106 reservoirs (Gerlow and Mullins; Gerlow). Using information derived from these initial studies and the survey of irrigation practices conducted by the authors in 1983, the establishment, maintenance, and operating costs of on-farm reservoirs were determined.

Construction Cost

To estimate the construction cost for the reservoir embankment, it is necessary to determine the volume of fill required. Using the assumption that the reservoir is square, the volume of fill required is:

$$V_F = 4[(S-2(3H+C+2H))(5/2\ H^2 + CH) + 40/3\ H^3 + 8CH + C^2H]/27 \qquad (1)$$

where:

V_F = volume of fill required for the embankments of the reservoir (cubic yards),
S = length of the reservoir side (feet),
= $A^{1/2} * 208.7$
A = reservoir size (acres),
H = the height of the embankment (feet), and
C = crown width (8 feet).

The cost of embankment construction was determined by multiplying V_F times a custom rate of $0.80 per cubic yard of fill (Coose). Embankment construction cost ranged from $15,760 for the 30 acre, 4 foot deep reservoir up to $51,440 for the 90 acre, 6 foot deep reservoir.

Cost of Embankment Stabilization

To avoid erosion of the embankment, a good cover of sod-forming grass should be established soon after construction. Common bermudagrass is usually well-suited for this purpose. The simplest, most inexpensive method for seeding and fertilizing the embankment is to use a hand-held, crank-operated broadcaster. Dehulled bermudagrass seed costs $2.15 per pound (Johnson Seed Co.) and is broadcast at 4 pounds per acre on the embankment (University of Arkansas, Cooperative Extension Service). A 33-20-20 fertilizer mixture valued at $13.20 per acre is applied prior to seeding. Labor is valued at $4.00 per hour and is capable of seeding or fertilizing an 8 foot strip of embankment at a speed of one mile per hour.

The surface area of the embankment which requires stabilization is determined using the following equation:

$$SA = [4(5)^{1/2}H(B+2H) + 4C(B-C) + 4(10)^{1/2}F(B-2C-3F)]/43560 \qquad (2)$$

where:

SA = surface area of the embankment (acres),
$B = S - 4H$,
$S = A^{1/2} * 208.7$,
H = height of the embankment,
A = reservoir area (acres),
C = crown width (8 feet), and
F = freeboard (feet).

The cost of planting bermudagrass for stabilization is quite modest, ranging between $77.39 and $173.34 per reservoir.

Cost of Pumping Plant

Since most new reservoirs in the Grand Prairie require total enclosure, water from nearby drainage canals or streams will need to be lifted over the embankment with pumps. The cost of the reservoir pumping plant is determined by whether it is necessary to pump water both in and out of the reservoir, the size of pump needed for maximum use of the reservoir, and the kind of power plant that is to be used (Gerlow and Mullins). Because canals and drainages are often intermittent, high-capacity pumping plants are necessary. For this report, one high-capacity, low-head, 50-horsepower, diesel-powered pump of 8,000 gpm is assumed for moving water both in and out of the reservoir. Pump installations of this type cost $23,500 ($13,500 for pump, motor, and gearbox and $10,000 for pipe, valves, dresser cups, and installation). A life of 15 years is assumed on pump and motor and 50 years on the pipe. Four pumping systems would be installed to deliver reservoir water during the 50-year service life of the reservoir. As in the case of the well system, only five years of the 15-year service life are valued for the fourth pump and motor when computing the present value of the reservoir system over the 50 years.

Total initial costs associated with reservoir construction are summarized in column 4 of Table 1. Total initial costs are the sum of construction, stabilization, and pumping plant expenditures.

Annual Operating Expenses

Annual operating expenses include costs for embankment repairs, miscellaneous upkeep, pump operation (fuel, repairs, and lubrication), interest on investment, insurance, and taxes. Based on cost relationships

Table 1. Costs of Reservoir Construction and Utilization

Reservoir Size (acres)	Depth (ft.)	Effective Volume (ac.-ft.)	Reservoir Initial Costs ($)	Reservoir Annual Operating Expenses ($)	Reservoir Present Value of Cost ($)
30	4	108	39337	3727	93587
30	5	134	44304	4258	105341
30	6	159	49831	4831	118192
60	4	222	48542	5006	120140
60	5	275	56991	5852	138403
60	6	327	65401	6772	158572
90	4	338	55490	5949	138141
90	5	419	64701	7057	161515
90	6	499	75113	8257	187265

reported by Gerlow and Mullins, embankment repairs and miscellaneous upkeep are grouped together and valued at 1.7 percent, 1.5 percent and 1.4 percent of embankment construction cost for the 30-, 60- and 90-acre reservoirs. Pump operation expense is based on an 8000 gpm, 50- horsepower, diesel-powered pump with a 15-foot head and diesel fuel at $1.00 per gallon. Annual repairs and lube are valued at 2.5 percent and 0.5 percent of the initial pump installation cost (Smith, et al.). Approximate annual operating expenses for the nine reservoir sizes are listed in column 5 of Table 1. The total present value of cost for the fifty year life of the reservoir discounted at 7 5/8 percent (Federal Register) is listed in column 6 of Table 1.

Value of Foregone Production

The economic benefits of having a reservoir must outweigh the profits that would have been made from the agricultural production at the reservoir site. The value of foregone production rather than the market price of an acre of land is the crucial consideration since a reservoir could be returned to its former agricultural use at any time. The farmer, by constructing and using a reservoir, forgoes the yearly return (Ricardian rent) from the land. Determining innate productivity is very difficult since different soil types have different productivities.

Based on discussion with extension and USDA personnel (Garner; Grant), the total specified costs associated with rice production were estimated to be $400 per acre, and the total specified costs of soybean production were estimated to be $130 per acre. If rice were selling for $4.50 per bushel with a yield of 100 bushels per acre and soybeans for $6.25 per bushel with a yield of 25 bushels per acre, the returns above specified costs will equal $50 per acre for rice and $26.25 for soybeans. If this land were in a one-year rice and two-year soybean rotation, the present value of these returns above specified cost discounted at 7 5/8 percent over 50 years will equal $444 per acre (Table 2). This is the value of foregone production from each acre of land used for the reservoir. By varying the market price of rice and soybeans, all other present values in Table 2 were generated. The value of foregone production increases with an increase in crop prices or an increase in yields, other things being equal. The present values listed in Table 3 assume a soil with a 125 bushel per acre rice yield and a 30 bushel per acre soybean yield. Table 4 assumes a soil with a 150 bushel per acre rice yield and a 35 bushel per acre soybean yield. If the per acre value of foregone production multiplied by reservoir size is less than the difference between the present cost of irrigation wells and an on-farm reservoir, then the cost of irrigation water from the reservoir is lower than the cost of an equal amount of irrigation water from groundwater. Throughout the analysis the opportunity cost of the surface or groundwater was assumed to be zero.

RESERVOIR PUMPING REQUIREMENTS

To estimate the amount of pumping needed to fill a reservoir, it is necessary to: 1) determine how much water the reservoir can store and 2) estimate losses caused by seepage and evaporation. Adding these losses to the capacity of the reservoir determines the annual pumping requirement.

Table 2. Present Value of Foregone Production for a One-Year Rice, Two-Year Soybean Rotation on Land Producing 100 bu./acre Rice Yields and 25 bu./acre Soybean Yields.

Soybean Price	Rice Price ($/bu.)										
($/bu.)	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25
4.00	-819	-704	-590	-475	-361	-246	-131	-17	98	213	327
4.25	-768	-653	-539	-424	-309	-195	-80	35	149	264	379
4.50	-717	-602	-487	-373	-258	-143	-29	86	200	315	430
4.75	-665	-551	-436	-321	-207	-92	22	137	252	366	481
5.00	-614	-500	-385	-270	-156	-41	74	188	303	418	532
5.25	-563	-448	-334	-219	-104	10	125	240	354	469	583
5.50	-512	-397	-282	-168	-53	61	176	291	405	520	635
5.75	-461	-346	-231	-117	-2	113	227	342	457	571	686
6.00	-409	-295	-180	-65	49	164	279	393	508	623	737
6.25	-358	-243	-129	-14	101	215	330	444	559	674	788
6.50	-307	-192	-78	37	152	266	381	496	610	725	840

Table 3. Present Value of Foregone Production for a One-Year Rice, Two-Year Soybean Rotation on Land Producing 125 bu./acre Rice Yields and 35 bu./acre Soybean Yields.

Soybean Price ($/bu.)	Rice Price ($/bu.)										
	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25
4.00	-176	-33	111	254	397	541	684	827	970	1114	1257
4.25	-104	39	182	326	469	612	756	899	1042	1185	1329
4.50	-33	111	254	397	541	684	827	971	1114	1257	1400
4.75	39	182	326	469	612	756	899	1042	1186	1329	1472
5.00	111	254	397	541	684	827	971	1114	1257	1401	1544
5.25	183	326	469	613	756	899	1042	1186	1329	1472	1616
5.50	254	398	541	684	828	971	1114	1257	1401	1544	1687
5.75	326	469	613	756	899	1043	1186	1329	1472	1616	1759
6.00	398	541	684	828	971	1114	1258	1401	1544	1687	1831
6.25	469	613	756	899	1043	1186	1329	1473	1616	1759	1903
6.50	541	684	828	971	1114	1258	1401	1544	1688	1831	1974

Table 4. Present Value of Foregone Production for a One-Year Rice, Two-Year Soybean Rotation on Land Producing 150 bu./acre Rice Yields and 45 bu./acre Soybean Yields.

Soybean Price	Rice Price ($/bu.)										
($/bu.)	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25
4.00	467	639	811	983	1155	1327	1499	1671	1843	2015	2187
4.25	559	731	903	1075	1247	1419	1591	1763	1935	2107	2279
4.50	652	824	995	1167	1339	1511	1683	1855	2027	2199	2371
4.75	744	916	1088	1260	1432	1604	1776	1948	2119	2291	2463
5.00	836	1008	1180	1352	1524	1696	1868	2040	2212	2384	2556
5.25	928	1100	1272	1444	1616	1788	1960	2132	2304	2476	2648
5.50	1020	1192	1364	1536	1708	1880	2052	2224	2396	2568	2740
5.75	1113	1285	1457	1628	1800	1972	2144	2316	2488	2660	2832
6.00	1205	1377	1549	1721	1893	2065	2237	2409	2581	2752	2924
6.25	1297	1469	1641	1813	1985	2157	2329	2501	2673	2845	3017
6.50	1389	1561	1733	1905	2077	2249	2421	2593	2765	2937	3109

Reservoir Storage

Reservoir storage is not equal to surface acres multiplied by depth; such calculation neglects to subtract the lost volume attributable to the sloping sides of the reservoir embankment. The water storage capacity of a square reservoir on level land is:

$$V_{AF} = [G^2D + 6GD^2 + 2D^2]/ 43560 \qquad (3)$$

where:

- V_{AF} = reservoir storage volume (acre-feet),
- G = $(A^{1/2} * 208.7) - 2[2H + C + 3(F+D)]$,
- A = reservoir size (acres),
- H = embankment height (feet),
- F = freeboard (feet), and
- D = water depth (feet).

The amount of effective storage for each of the nine reservoirs is given in column 3 of Table 1.

Seepage Losses and Darcy's Law

Seepage losses occur both through the embankment and beneath the embankment into the underlying soil. Using Darcy's law, the magnitude of these losses can be determined.

In 1856, Darcy showed that the flow rate through porous media is proportional to the head loss and inversely proportional to the length of the flow path (Todd). Stated mathematically,

$$Q = [(K*24)/12 * A_{CS}(D/L)*365]/43560 \qquad (4)$$

where:

- Q = seepage (acre-feet per year),
- K = hydraulic conductivity (permeability expressed in inches per hour),
- A_{CS} = cross-sectional area of porous media (square feet), and
- D/L = hydraulic gradient in the direction of decreasing hydraulic head (height of water in the reservoir over length of flow).

Hydraulic conductivity (K) is a constant that serves as a measure of permeability of porous medium (Todd). The hydraulic gradient refers to the head loss that occurs over a path of distance L. This relationship is used to determine seepage losses in the reservoir system.

Seepage Beneath the Embankment

To determine the amount of seepage occurring in the soil beneath the reservoir embankment this study assumes that the reservoir embankment is impervious. To solve for the flow rate, Q, the following are assumed or estimated: 1) K, the hydraulic conductivity (permeability) of the porous medium, 2) d, the depth of the porous medium, 3) D, the depth of water in the reservoir, 4) L, the length of flow, and 5) the width of the cross section.

If the reservoir rests on a single soil type, values for K can be estimated from permeability data contained in soil surveys. Values for K (Table 5) are obtained by weighted averages for soil profiles of 72 inches and assumed to apply for a depth of 10 feet (d = 10). Values of K for similar soil types may differ from county to county because of differences in genesis, deposition, and composition. The depths of water in a reservoir, D, are the assumed values of 4, 5, and 6 feet used in the construction section multiplied by 0.5 as an adjustment for the average depth of water in the reservoir throughout the year. The values of L, the width of the embankment, are determined from:

$$L = C + (3*H) + (2*H) \qquad (5)$$

Table 5. Weighted Average Permeabilities for Soils found in the Grand Prairie Region (Values for K in inches/hour).

Soil Type	County Arkansas	Lonoke	Prairie
Acadia	.515	--	--
Amagon	.197	--	--
Amagon, heavy substratum	.146	--	--
Calhoun	.300	.197	.197
Calloway	.272	.552	.552
Caspiana	--	1.300	--
Commerce	--	--	.462
Crowley	.335	.169	.169
Dubbs	--	--	2.575
Falaya	1.315	--	--
Grenada	.237	--	--
Herbert	3.471	1.007	--
Jackport	--	--	.067
Kobel	--	--	.073
Loring	.900	.900	.900
McKamie	.168	.588	.588
Miller	.174	--	--
Muskogee	--	.281	.281
Norwood silt loam	1.315	--	--
Norwood silty clay loam	.881	--	--
Oaklimeter	--	1.300	1.300
Perry	.166	.030	.030
Portland	.051	.138	--
Rilla	1.052	1.300	--
Sharkey	.030	--	--
Stuttgart	.239	.133	.133
Tichnor	.360	.617	.617

where:

C = crown width (8 feet),
H = embankment height (feet),
$3*H$ = length on 3:1 side (feet), and
$2*H$ = length on 2:1 side (feet).

The value for the width of the cross-sectional flow area used in Darcy's law is the length of a side of a square reservoir of 30, 60 or 90 acres. This length is the product of 208.7 feet and the square root of the surface acreage. Since a square, totally enclosed reservoir is assumed, seepage beneath the embankment will occur on all four sides, necessitating multiplication of seepage loss by four. For this situation, the equation for Darcy's law becomes:

$$Q_1 = 4[((K*24)/12)(d(A)^{\frac{1}{2}}*208.7)(D/L)*365]/43560 \quad (6)$$

where:

Q_1 = seepage beneath the embankment (acre-feet per year),
$(K*24)/12$ = permeability (feet per day),
= (in./hr.)(hr./day)(feet/in.) = (feet/day),
d = 10 feet,
A = reservoir area (acres),
h = average depth of water in the reservoir (feet), and
L = bottom width of the embankment (feet).

Seepage Through Embankments

Any earthen embankment, regardless of the degree of compaction, has some amount of seepage. The degree of compaction influences the hydraulic conductivity of the soil; the greater the compaction, the lower the hydraulic conductivity. Under Grand Prairie conditions, little or no compaction occurs, other than that which results from the use of the construction machinery and from the weight of the overlying fill.

Locating the seepage line (or phreatic line) is essential in order to estimate the quantity of water lost through the embankments of a reservoir. Stated simply, the seepage line is the line of saturation in the embankment (Figure 3). Above the seepage line there is no hydrostatic pressure, while below it there is positive hydrostatic pressure (Schwab et al.). A simple method for determining the location of the seepage line through the most impervious portion of the embankment is given by the following equation (Creager, Justin, and Hinds):

$$e = D/3 \tag{7}$$

where:

e = the distance from the "impervious" base of the embankment to the intersection of the seepage line and the downstream face of the embankment (feet) and
D = the depth of water in the reservoir (feet).

By assuming that the mean discharge area equals (D+e)/2, the form of Darcy's law for determining the amount of discharge through a unit width of the embankment is (Creager, Justin and Hinds):

$$Q_2 = 4[(K'/2 * (D^2 - e^2)/L')(A^{1/2} * 208.7) * 365]/43,560 \tag{8}$$

where:

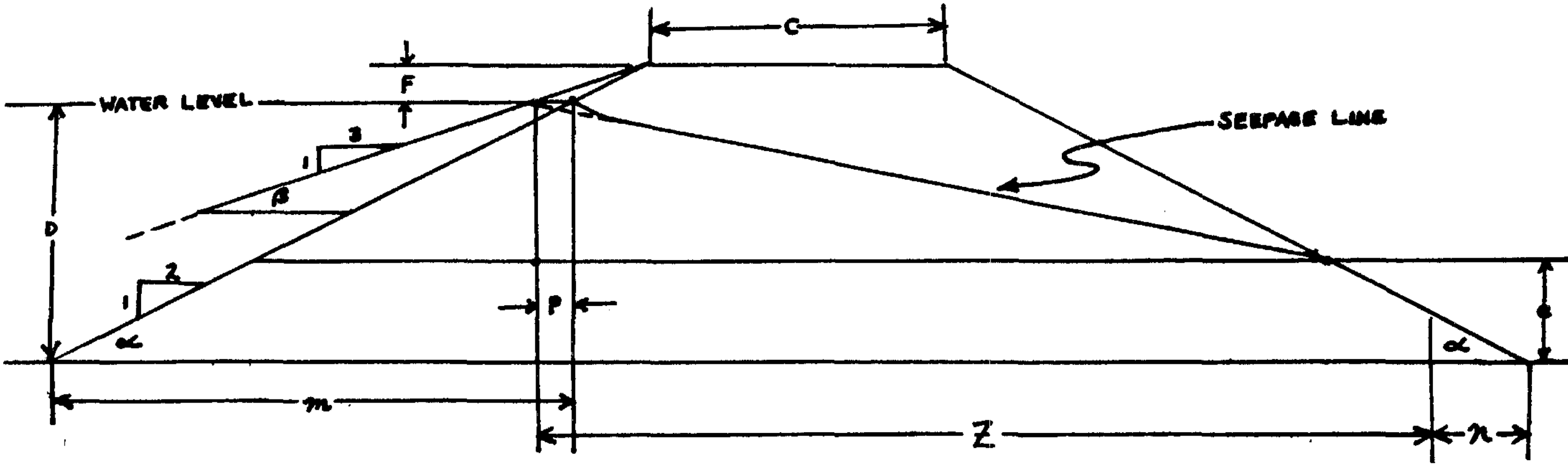
Q_2 = seepage through the embankment (acre-feet per year),
K' = hydraulic conductivity of the material comprising the least permeable section of the embankment (feet per day),
= (K*24)/12, and
L' = mean length of the seepage line (feet).

By substituting D/3 for e in the last equation, an equation for determining flow in cubic feet per minute is obtained (Creager, Justin and Hinds):

$$Q_2 = 4[(4D^2K'/9L')(A_{1/2} * 208.7) * 365]/43,560 \tag{9}$$

With the value of L' determined from (Creager, Justin and Hinds):

Figure 3. Seepage Through Embankments



$$L' = Z - m - n + P \qquad (10)$$

where:

- L' = mean length of the seepage line (feet),
- Z = $2(D+F) \cot \alpha$ (in feet),
- m = $D \cot \alpha$ (in feet),
- n = $(e/2) \cot \alpha$ (in feet),
- P = $F \cot \beta - F \cot \alpha$ (in feet),
- D = depth of water (feet),
- F = freeboard (feet),
- C = crown width (8 feet), and
- e = $D/3$ (in feet).

The amount of yearly seepage ($Q_1 + Q_2$) for the nine reservoir sizes by soil type is given in column 2, Appendix Tables 1-9. Seepage losses for the major soils in the study area (Stuttgart silt loam, Grenada silt loam, Perry silty clay, Tichnor silt loam, Calhoun silt loam, Calloway silt loam, and Loring silt loam) range from less than 1 percent (Perry) to 39 percent (Loring) of stored water depending upon reservoir size.

Estimation of Reservoir Evaporation

The U.S. Department of Commerce Weather Bureau has developed coefficients for converting pan evaporation rates to reservoir evaporation rates. These coefficients are used because pan evaporation rates exceed reservoir evaporation rates due to many factors, including water temperature and surface area. In 1932, the "0.7 pan coefficient" was recommended by the American Society of Civil Engineers for this purpose. A Weather Bureau Class A land pan is a pan 4 feet in diameter and 10 in. deep, usually filled with 7 to 8 in. of water (U.S. Department of Commerce, 1950). To estimate reservoir evaporation from Class A pan evaporation data one multiplies by 0.7. Further work by Kohler, Nordenson, and Fox led to a revised idea of the reasonable range of the coefficient (.60 to .82). Kohler, Nordenson, and Baker later developed evaporation maps and average annual coefficient maps for the United States. The Class A pan evaporation coefficient isoline, passing near the Grand Prairie region, has a value of .75 (Kohler, Nordenson, and Baker). They determined this by dividing the average annual reservoir evaporation for the period 1946 to 1955 (42 inches) by the average annual Class A pan evaporation for the same period (56 inches). For this study, the annual evaporation from reservoirs in the Grand Prairie region is estimated to be 45 inches using pan evaporation rates (U.S. Department of Commerce) modified by the pan coefficient (.75 as determined by Kohler, Nordenson, and Baker).

Direct precipitation into the reservoir is also accounted for in estimating the pumping requirements for the reservoirs. Since direct precipitation adds an average of 51.6 inches of water to the reservoir system during the year and evaporation removes 45 inches, this represents a net gain of 6.6 inches.

IRRIGATION WITH RESERVOIR WATER VERSUS GROUNDWATER

In this section, the present cost (discounted at 7 5/8 percent for 50 years) of establishing and operating an on-farm reservoir is compared to the cost of establishing and operating groundwater wells of equivalent capacity. The costs of drilling and operating new wells are calculated by assuming the pump is operated initially for 1300 hours per year yielding 500 gpm from a 10-inch casing and an 8-inch discharge. The well is assumed to be 150 feet deep with an initial total dynamic head of 131.6 feet (120 feet dynamic head plus 2.31 feet per psi x 5 psi operating pressure). Groundwater is assumed to decline at a constant one-half foot per year, causing decreased well yield and increased operating time. By year 15, well yield declines to 472 gpm and operating time increases to 1377 hours to deliver the same quantity of water as originally pumped during year one at 500 gpm for 1300 hours. Based on these pumping rates, one well would be required to match the capacity of the 108 acre-foot (30 acre, 4 foot deep) reservoir and 5 wells to match the 499 acre-foot (90 acre, 6 foot deep) reservoir (Column 3 of Table 6).

The power unit used for the well systems is a 45-horsepower continuous-brake diesel motor. The well and casing have a service life of 25 years, and the diesel motor, pump, and gear drives have a life of 15 years. Based on lengths of service, two wells and four pumping plants would need to be installed to deliver groundwater during the equivalent 50-year service life of the reservoir. The well, casing, screen, and discharge pipe are valued at $7,000, and the motor, pump, and gear drive are valued at $12,500. Well system initial costs are summarized in column 4 of Table 6. All components of the well system are depreciated over their useful life on a straight line basis with zero percent salvage value.

The coefficients used for annual operating expenses (pumping plant repairs, lubrication, taxes, and interest on investment) are the same for the groundwater wells as for the reservoir. The annual operating expenses of the equivalent well systems are given in column 5 of Table 6. The present values of operating well systems of capacity equivalent to the nine reservoirs are listed in Table 6, column 6.

The amount of seepage in acre-feet per year, the present value of cost of the well alternative, the present value of cost of the reservoir alternative, and the maximum allowable foregone value of production are presented in Appendix Tables 1-9. To make the reservoir alternative more attractive than the groundwater alternative the value of foregone production

Table 6. Costs of Well System Installation and Utilization

Equivalent Reservoir Size (acres)	Equiv. Depth (ft.)	Number of Wells* --	Well System Initial Costs ($)	Well System Annual Operating Expense ($)	Well System Present Value of Cost ($)
30	4	0.90	19500	4003	7770
30	5	1.12	39000	5943	129170
30	6	1.33	39000	6572	137210
60	4	1.85	39000	8156	157457
60	5	2.30	58500	10776	217549
60	6	2.73	58500	12083	234255
90	4	2.82	58500	12360	237796
90	5	3.50	78000	15683	306874
90	6	4.17	97500	18982	375645

* Number of well on which variable costs are calculated. Initial and fixed costs are determined for the number of well rounded up to the next whole number.

must be less than this amount. Appendix Tables 10-18 show the value of foregone production from land in a one-year rice and two-year soybean rotation discounted at 7 5/8 percent under a range of rice and soybean prices and three yield levels for the nine reservoir sizes. The solid line marks the feasibility boundary at which foregone production changes from less than the difference (left of the line) between well and reservoir cost to greater than the difference (right of the line) for the 4-foot reservoirs. Thus construction of four-foor reservoirs is economically feasible shen expected prices are in the range of prices to the left of the solid line.

Similarly, the dashed line represents the feasible boundary for the 5-foot reservoirs, and the dash/star line represents the feasible boundary 6-feet reservoirs. If no lines appear in the tables, then all reservoir sizes are feasible for the given range of prices. It should be recognized that since investment cost (construction cost plus pumping plant cost) per acre-foot of storage declines with reservoir capacity, the large reservoirs would be more economical over a wider range of prices and yields than the small reservoirs. If loan rates reflect producer price expectations over time, then additional inferences about the cost of irrigation water from reservoirs versus the cost of irrigation water from groundwater well systems can be made. Loan rates have hovered in the $8.00 per hundred weight ($3.60/bushel) and $5.00 per bushel range for rice and soybeans during the period 1981 to 1986 (USDA, ERS 1987, 1988). Using these values, the cost of providing irrigation water from on-farm reservoirs and groundwater well systems was calculated. The percentage difference in cost between the reservoirs and the well systems are presented in Table 7. The results indicate: 1) the 30 acre, 4 foot deep reservoir is not economically feasible

Table 7. Percentage Difference Between the Cost of Irrigation Water From On-Farm Reservoirs and Groundwater Well Systems. (Rice Price: $3.60/bushel, Soybean Price: $5.00/bushel)

		Yield Situation		
Reservoir Acres	Size Depth	100 bu. Rice 25 bu. Soybeans	125 bu. Rice 35 bu. Soybeans	150 bu. Rice 45 bu. Soybeans
30	4	+12.2	+43.9	+75.6
30	5	-23.2	- 4.1	+15.0
30	6	-18.4	- 0.4	+17.6
60	4	-31.9	- 0.5	+30.8
60	5	-42.3	-19.6	+ 3.1
60	6	-37.8	-16.7	+ 4.4
90	4	-50.1	-19.0	+12.1
90	5	-53.7	-29.6	- 5.4
90	6	-55.3	-35.6	-15.9

under any of the three yield situations, 2) the remaining eight reservoir sizes are all economically feasible for the 100 bushel rice/25 bushel soybean and 125 bushel rice/35 bushel soybean yield situations, and 3) it is not economically feasible to build on-farm reservoirs on highly productive land except for the two largest reservoir sizes (90 acre, 5 foot deep and 90 acre, 6 foot deep). Overall, on-farm reservoirs can provide irrigation water for between 75.6 percent more and 55.3 percent less than well systems. If the 30 acre, 4 foot deep reservoir is removed from consideration, reservoirs can provide irrigation water for between 18.4 and 55.3 percent less for the 100 bushel rice/25 bushel soybean yield situation and between 0.4 percent and 35.6 percent less for the 125 bushel rice/35 bushel soybean yield situation.

It is possible that the real price of energy for pumping will rise faster than real commodity prices. This would cause the cost of the well alternative to rise more quickly than the cost of the reservoir alternative, thus increasing the value of allowable foregone production.

SUMMARY

The major objective of this study was to identify the principal engineering and economic aspects of reservoir construction in the Grand Prairie region. The proper engineering design and construction of the reservoir embankment was discussed. This included consideration of freeboard, fill settlement, site preparation, fill quality, and embankment protection. Construction, stabilization, and annual operating expenses were presented for nine reservoir sizes. Initial costs ranged from just under $40,000 for the 30-acre, 4-feet reservoir up to slightly over $79,000 for the 90-acre, 6-feet reservoir. Annual operating expenses (levee repairs, miscellaneous upkeep, pump operation, interest on investment, insurance and taxes) ranged from approximately $3800 to $8600 per reservoir.

Estimated seepage losses from the reservoirs for the major soils in the study area varied from 1 percent of storage for Perry silty clay up to 41 percent of storage for Loring silt loam. Evaporation loss was estimated at 45 inches per year using a .75 pan coefficient.

The value of lost agricultural production from a reservoir site was included when comparing the cost of reservoir systems to wells of equivalent water-supply capability. The cost of pumping water from groundwater wells of 132 feet of total dynamic head was used for comparison against the reservoir alternatives. For the prices assumed in the analysis, reservoir systems can provide irrigation water for between 75.6 percent more and 55.3 percent less cost than can groundwater wells (depending upon reservoir size and soil productivity).

REFERENCES

Arkansas Soil and Water Conservation Commission. Arkansas State Water Plan, Appendix "A". Little Rock, AR: Dept. of Soil and Water Resources, 1976.

Coose, C. Personal Communication to R. Peralta, August 1986.

Creager, W. P., J. D. Justin and J. Hinds. Engineering Plans for Dams. vol. III. New York: John Wiley and Sons, 1945.

Federal Register, 23 October 1981, p. 52066.

Garner, C. R. Personal Communication. Cooperative Extension Service, University of Arkansas, Fayetteville, AR, August 1986.

Gerlow, A. R., "Reservoir Systems in the Grand Prairie". Arkansas Farm Research. 7-4(1958):2.

Gerlow, A. and T. Mullins. Reservoirs for Irrigation in the Grand Prairie Area: An Economic Appraisal. Agricultural Experiment Station Bulletin 606, Fayetteville, AR: December 1958.

Grant, W. R. Personal Communication. USDA, ERS, College Station, TX August 1986.

Harper, J. K. "An Economic Analysis of On-Farm Water Management Strategies, to Reduce Groundwater Demand in the Grand Prairie Region, Arkansas". Unpublished masters thesis. Fayetteville, AR: University of Arkansas, 1983.

Hartz, J. Jr. and W. M. Moorhead. "Presentation for the Arkansas Water Code Study Commission Hearing". Little Rock, AR: November 5, 1981.

Hayes, R. Personal Communication. USDA, SCS, DeWitt, AR, March 1983.

Huey, B. A. Rice Production in Arkansas. Circular 476. Fayetteville, AR: Agricultural Extension Service, 1971.

Johnson Seed Company. Personal Communication, Springdale, AR, May 1983.

Kohler, M. A., T. J. Nordenson, and D. R. Baker. Evaporation Maps of the United States. Weather Bureau Technical Paper No. 38. Washington, DC: GPO, 1959.

Kohler, M. A., T. J. Nordenson, and W. E. Fox. Evaporation from Pans and Lakes. U.S. Department of Commerce, Weather Bureau Technical Paper No. 38, Washington, DC: GPO, 1955.

Schwab, G. O., R. K. Fervert, T. W. Edminster, and K. K. Barnes. Soil and Water Conservation Engineering. 2nd Edition. New York: John Wiley and Sons, 1966.

Smith, D. A., C. Farler, R.W. Hale, C.A. Stuart, C.R. Garner, D. Dorland, and R.E. Coats. Arkansas Rice Budgets, 1983: A Guide to Estimating Rice Production Costs. Cooperative Extension Service Miscellaneous Publication 206. Fayetteville, AR: 1983.

Soybean Industry Advisory Committee. Soybean Irrigation. West Memphis, AR: Arkansas Soybean Association, June 1979.

Todd, D. K. Groundwater Hydrology. 2nd Edition. New York: John Wiley and Sons, 1980.

University of Arkansas, Cooperative Extension Service. Arkansas Field and Forage Crops. Leaflet 249. Little Rock, AR: May 1981.

U.S. Department of Agriculture, Economic Research Service. Oil Crops Situation and Outlook Yearbook. OCS-18. Washington, DC: GPO July 1988.

U.S. Department of Agriculture, Economic Research Service. Rice Situation and Outlook Report. RS-50. Washington, DC: GPO, September 1987.

U.S. Department of Agriculture, Soil Conservation Service. Engineering Field Manual. Washington, DC: GPO, 1975.

U.S. Department of Agriculture, Soil Conservation Service. Ponds for Water Supply and Recreation. Agricultural Handbook No. 387. Washington, DC: GPO, 1971.

U.S. Department of Agriculture, Soil Conservation Service. Soil Survey of Arkansas County, Arkansas. Washington, DC: GPO, 1972.

U.S. Department of Agriculture, Soil Conservation Service. Soil Survey of Lonoke and Prairie Counties, Arkansas. Washington, DC: GPO, 1981.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Climatological Data: Arkansas. Environmental Data Service, Asheville, NC. Various years.

U.S. Department of Commerce, Weather Bureau. Mean Monthly and Annual Evaporation from Free Water Surfaces for the United States, Alaska, Hawaii, and the West Indies. Technical Paper No. 13. Washington, DC: July 1950.

Appendix Table 1. Reservoir Seepage Loss, Well System Present Value of Cost, Reservoir Present Value of Cost, and Allowable Foregone Value of Production for the Soil Types Found in the Grand Prairie Region of Arkansas.

Reservoir Size: 30 Acres, 4 Feet Deep, 108 Acre Feet

Soil Type	Seepage[1]	Well Cost[2]	Reservoir Cost[3]	Allowable Foregone Value of Production
Arkansas County				
Acadia	22.4	77770	94239	-16469
Amagon	9.4	77770	93855	-16085
Amagon H-S	7.2	77770	93791	-16021
Calhoun	13.8	77770	93983	-16213
Calloway	12.6	77770	93945	-16175
Crowley	14.6	77770	94009	-16239
Falaya	66.0	77770	95517	-17747
Grenada	11.1	77770	93906	-16136
Herbert	152.6	77770	98048	-20278
Loring	41.6	77770	94801	-17031
McKamie	7.4	77770	93791	-16021
Miller	7.7	77770	93804	-16034
Norwood SL	66.0	77770	95517	-17747
Norwood SCL	38.2	77770	94699	-16929
Perry	7.3	77770	93791	-16021
Portland	2.4	77770	93651	-15881
Rilla	48.2	77770	94993	-17223
Sharkey	1.5	77770	93625	-15855
Stuttgart	11.2	77770	93906	-16136
Tichnor	16.4	77770	94060	-16290

(continued)

Appendix Table 1 (continued). Reservoir Seepage Loss, Well System Present Value of Cost, Reservoir Present Value of Cost, and Allowable Foregone Value of Production for the Soil Types Found in the Grand Prairie Region of Arkansas. (cont.)

Reservoir Size: 30 Acres, 4 Feet Deep, 108 Acre Feet

Soil Type	Seepage[1]	Well Cost[2]	Reservoir Cost[3]	Allowable Foregone Value of Production
Lonoke and Prairie Counties				
Calhoun	9.4	77770	93855	-16085
Calloway	24.7	77770	94303	-16533
Caspiana	65.3	77770	95491	-17721
Commerce	22.7	77770	94251	-16481
Crowley	7.5	77770	93804	-16034
Dubbs	120.4	77770	97115	-19345
Herbert	46.3	77770	94942	-17172
Jackport	3.1	77770	93676	-15906
Kobel	12.3	77770	93945	-16175
Loring	41.6	77770	94801	-17031
McKamie	25.5	77770	94328	-16558
Muskogee	12.8	77770	93957	-16187
Oaklimeter	65.3	77770	95491	-17721
Perry	1.5	77770	93625	-15855
Portland	6.1	77770	93766	-15996
Rilla	65.3	77770	95491	-17721
Stuttgart	5.9	77770	93753	-15983
Tichnor	27.5	77770	94392	-16622

[1]Seepage loss from the reservoir in acre-feet per year.

[2]Present value of cost (in dollars) for a well system with capacity equivalent to reservoir storage (discounted at 7 5/8%).

[3]Present value of cost (in dollars) for the reservoir (expected life of 50 years). Replacement components discounted at 7 5/8%.

Note: Reservoir storage is not equal to surface acres multiplied by depth; use of such a calculation neglects to subtract the lost volume attributable to the sloping sides of the reservoir embankment.

Appendix Table 2. Reservoir Seepage Loss, Well System Present Value of Cost, Reservoir Present Value of Cost, and Allowable Foregone Value of Production for the Soil Types Found in the Grand Prairie Region of Arkansas

Reservoir Size: 30 Acres, 5 Feet Deep, 134 Acre Feet

Soil Type	Seepage[1]	Well Cost[2]	Reservoir Cost[3]	Allowable Foregone Value of Production
Arkansas County				
Acadia	24.6	129170	106057	23113
Amagon	10.6	129170	105648	23522
Amagon H-S	8.2	129170	105584	23586
Calhoun	15.5	129170	105788	23382
Calloway	14.1	129170	105750	23420
Crowley	16.1	129170	105814	23356
Falaya	75.4	129170	107552	21618
Grenada	12.5	129170	105712	23458
Herbert	168.2	129170	110262	18908
Loring	46.6	129170	106709	22461
McKamie	8.2	129170	105584	23586
Miller	8.5	129170	105584	23586
Norwood SL	75.4	129170	107552	21618
Norwood SCL	41.9	129170	106568	22602
Perry	8.1	129170	105571	23599
Portland	2.7	129170	105418	23752
Rilla	53.8	129170	106913	22257
Sharkey	1.7	129170	105392	23778
Stuttgart	12.6	129170	105712	23458
Tichnor	18.3	129170	105878	23292
Lonoke and Prairie Counties				
Calhoun	10.6	129170	105648	23522
Calloway	27.4	129170	106146	23024
Caspiana	74.7	129170	107527	21643
Commerce	25.9	129170	106095	23075
Crowley	8.3	129170	105584	23586
Dubbs	135.0	129170	109291	19879
Herbert	51.7	129170	106849	22321
Jackport	3.4	129170	105443	23727
Kobel	16.7	129170	105827	23343
Loring	46.6	129170	106709	22461
McKamie	28.1	129170	106159	23011
Muskogee	14.3	129170	105763	23407
Oaklimeter	74.7	129170	107527	21643
Perry	1.7	129170	105392	23778
Portland	6.8	129170	105533	23637
Rilla	74.7	129170	107527	21643
Stuttgart	6.5	129170	105533	23637
Tichnor	30.5	129170	106236	22934

Note: Footnotes located at the end of Appendix Table 1.

Appendix Table 3. Reservoir Seepage Loss, Well System Present Value of Cost, Reservoir Present Value of Cost, and Allowable Foregone Value of Production for the Soil Types Found in the Grand Prairie Region of Arkansas.

Reservoir Size: 30 Acres, 6 Feet Deep, 159 Acre Feet

Soil Type	Seepage[1]	Well Cost[2]	Reservoir Cost[3]	Allowable Foregone Value of Production
Arkansas County				
Acadia	26.4	137210	118972	18238
Amagon	11.7	137210	118537	18673
Amagon H-S	9.1	137210	118461	18749
Calhoun	16.9	137210	118691	18519
Calloway	15.5	137210	118652	18558
Crowley	17.3	137210	118703	18507
Falaya	84.1	137210	120659	16551
Grenada	13.7	137210	118601	18609
Herbert	180.8	137210	123497	13713
Loring	50.9	137210	119688	17522
McKamie	8.8	137210	118448	18762
Miller	9.1	137210	118461	18749
Norwood SL	84.1	137210	120659	16551
Norwood SCL	44.9	137210	119509	17701
Perry	8.7	137210	118448	18762
Portland	2.9	137210	118282	18928
Rilla	58.5	137210	119905	17305
Sharkey	1.9	137210	118243	18967
Stuttgart	13.8	137210	118601	18609
Tichnor	19.9	137210	118780	18430
Lonoke and Prairie Counties				
Calhoun	11.7	137210	118537	18673
Calloway	29.6	137210	119061	18149
Caspiana	83.3	137210	120633	16577
Commerce	28.7	137210	119036	18174
Crowley	8.9	137210	118461	18749
Dubbs	147.8	137210	122525	14685
Herbert	56.3	137210	119841	17369
Jackport	3.7	137210	118307	18903
Kobel	21.3	137210	118818	18392
Loring	50.9	137210	119688	17522
McKamie	30.1	137210	119074	18136
Muskogee	15.5	137210	118652	18558
Oaklimeter	83.3	137210	120633	16577
Perry	1.9	137210	118243	18967
Portland	7.3	137210	118409	18801
Rilla	83.3	137210	120633	16577
Stuttgart	7.1	137210	118397	18813
Tichnor	32.9	137210	119164	18046

Note: Footnotes located at the end of Appendix Table 1.

Appendix Table 4. Reservoir Seepage Loss, Well System Present Value of Cost, Reservoir Present Value of Cost, and Allowable Foregone Value of Production for the Soil Types Found in the Grand Prairie Region of Arkansas.

Reservoir Size: 60 Acres, 4 Feet Deep, 222 Acre Feet

Soil Type	Seepage[1]	Well Cost[2]	Reservoir Cost[3]	Allowable Foregone Value of Production
Arkansas County				
Acadia	29.6	157457	121009	36448
Amagon	12.4	157457	120498	36959
Amagon H-S	9.5	157457	120421	37036
Calhoun	18.3	157457	120677	36780
Calloway	16.7	157457	120626	36831
Crowley	19.3	157457	120702	36755
Falaya	87.1	157457	122684	34773
Grenada	14.7	157457	120575	36882
Herbert	201.6	157457	126045	31412
Loring	55.0	157457	121750	35707
McKamie	9.8	157457	120421	37036
Miller	10.2	157457	120434	37023
Norwood SL	87.1	157457	122684	34773
Norwood SCL	50.5	157457	121623	35834
Perry	9.7	157457	120421	37036
Portland	3.1	157457	120229	37228
Rilla	63.7	157457	122006	35451
Sharkey	1.9	157457	120191	37266
Stuttgart	14.8	157457	120575	36882
Tichnor	21.7	157457	120779	36678
Lonoke and Prairie Counties				
Calhoun	12.4	157457	120498	36959
Calloway	32.6	157457	121099	36358
Caspiana	86.2	157457	122658	34799
Commerce	30.0	157457	121022	36435
Crowley	9.9	157457	120434	37023
Dubbs	158.9	157457	124793	32664
Herbert	61.1	157457	121929	35528
Jackport	4.1	157457	120255	37202
Kobel	16.2	157457	120613	36844
Loring	55.0	157457	121750	35707
McKamie	33.8	157457	121124	36333
Muskogee	16.9	157457	120638	36819
Oaklimeter	86.2	157457	122658	34799
Perry	1.9	157457	120191	37266
Portland	8.1	157457	120370	37087
Rilla	86.2	157457	122658	34799
Stuttgart	7.8	157457	120370	37087
Tichnor	36.4	157457	121201	36256

Note: Footnotes located at the end of Appendix Table 1.

Appendix Table 5. Reservoir Seepage Loss, Well System Present Value of Cost, Reservoir Present Value of Cost, and Allowable Foregone Value of Production for the Soil Types Found in the Grand Prairie Region of Arkansas.

Reservoir Size: 60 Acres, 5 Feet Deep, 275 Acre Feet

Soil Type	Seepage[1]	Well Cost[2]	Reservoir Cost[3]	Allowable Foregone Value of Production
Arkansas County				
Acadia	32.8	217549	139361	78188
Amagon	14.1	217549	138812	78737
Amagon H-S	10.9	217549	138722	78827
Calhoun	20.6	217549	139003	78546
Calloway	18.8	217549	138952	78597
Crowley	21.5	217549	139029	78520
Falaya	100.3	217549	141342	76207
Grenada	16.6	217549	138888	78661
Herbert	224.0	217549	144972	72577
Loring	62.0	217549	140218	77331
McKamie	10.9	217549	138722	78827
Miller	11.3	217549	138735	78814
Norwood SL	100.3	217549	141342	76207
Norwood SCL	55.9	217549	140039	77510
Perry	10.8	217549	138722	78827
Portland	3.6	217549	138505	79044
Rilla	71.6	217549	140499	77050
Sharkey	2.2	217549	138466	79083
Stuttgart	16.8	217549	138901	78648
Tichnor	24.4	217549	139118	78431
Lonoke and Prairie Counties				
Calhoun	14.1	217549	138812	78737
Calloway	36.5	217549	139476	78073
Caspiana	99.4	217549	141317	76232
Commerce	34.4	217549	139412	78137
Crowley	11.0	217549	138722	78827
Dubbs	179.7	217549	143669	73880
Herbert	68.8	217549	140422	77127
Jackport	4.6	217549	138543	79006
Kobel	22.1	217549	139054	78495
Loring	62.0	217549	140218	77331
McKamie	37.4	217549	139502	78047
Muskogee	19.0	217549	138965	78584
Oaklimeter	99.4	217549	141317	76232
Perry	2.2	217549	138466	79083
Portland	9.0	217549	138671	78878
Rilla	99.4	217549	141317	76232
Stuttgart	8.7	217549	138658	78891
Tichnor	40.6	217549	139591	77958

Note: Footnotes located at the end of Appendix Table 1.

Appendix Table 6. Reservoir Seepage Loss, Well System Present Value of Cost, Reservoir Present Value of Cost, and Allowable Foregone Value of Production for the Soil Types Found in the Grand Prairie Region of Arkansas.

Reservoir Size: 60 Acres, 6 Feet Deep, 327 Acre Feet

Soil Type	Seepage[1]	Well Cost[2]	Reservoir Cost[3]	Allowable Foregone Value of Production
Arkansas County				
Acadia	35.4	234255	159607	74648
Amagon	15.6	234255	159019	75236
Amagon H-S	12.2	234255	158930	75325
Calhoun	22.6	234255	159224	75031
Calloway	20.7	234255	159173	75082
Crowley	23.2	234255	159249	75006
Falaya	112.5	234255	161857	72398
Grenada	18.3	234255	159096	75159
Herbert	242.3	234255	165666	68589
Loring	68.1	234255	160566	73689
McKamie	11.9	234255	158917	75338
Miller	12.3	234255	158930	75325
Norwood SL	112.5	234255	161857	72398
Norwood SCL	60.2	234255	160336	73919
Perry	11.7	234255	158904	75351
Portland	3.9	234255	158674	75581
Rilla	78.4	234255	160860	73395
Sharkey	2.5	234255	158636	75619
Stuttgart	18.5	234255	159109	75146
Tichnor	26.7	234255	159352	74903
Lonoke and Prairie Counties				
Calhoun	15.6	234255	159019	75236
Calloway	39.7	234255	159735	74520
Caspiana	111.5	234255	161831	72424
Commerce	38.5	234255	159697	74558
Crowley	11.9	234255	158917	75338
Dubbs	197.8	234255	164362	69893
Herbert	75.4	234255	160770	73485
Jackport	5.0	234255	158713	75542
Kobel	28.4	234255	159403	74852
Loring	68.1	234255	160566	73689
McKamie	40.3	234255	159748	74507
Muskogee	20.8	234255	159173	75082
Oaklimeter	111.5	234255	161831	72424
Perry	2.5	234255	158636	75619
Portland	9.8	234255	158853	75402
Rilla	111.5	234255	161831	72424
Stuttgart	9.5	234255	158840	75415
Tichnor	44.1	234255	159863	74392

Note: Footnotes located at the end of Appendix Table 1.

Appendix Table 7. Reservoir Seepage Loss, Well System Present Value of Cost, Reservoir Present Value of Cost, and Allowable Foregone Value of Production for the Soil Types Found in the Grand Prairie Region of Arkansas.

Reservoir Size: 90 Acres, 4 Feet Deep, 338 Acre Feet

Soil Type	Seepage[1]	Well Cost[2]	Reservoir Cost[3]	Allowable Foregone Value of Production
Arkansas County				
Acadia	36.3	237796	139215	98581
Amagon	15.2	237796	138589	99207
Amagon H-S	11.6	237796	138486	99310
Calhoun	22.4	237796	138806	98990
Calloway	20.4	237796	138742	99054
Crowley	23.7	237796	138844	98952
Falaya	106.6	237796	141273	96523
Grenada	18.0	237796	138678	99118
Herbert	247.0	237796	145389	92407
Loring	67.4	237796	140123	97673
McKamie	12.0	237796	138499	99297
Miller	12.4	237796	138512	99284
Norwood SL	106.6	237796	141273	96523
Norwood SCL	61.8	237796	139956	97840
Perry	11.9	237796	138499	99297
Portland	3.9	237796	138256	99540
Rilla	78.0	237796	140429	97367
Sharkey	2.4	237796	138218	99578
Stuttgart	18.1	237796	138678	99118
Tichnor	26.6	237796	138921	98875
Lonoke and Prairie Counties				
Calhoun	15.2	237796	138589	99207
Calloway	40.0	237796	139317	98479
Caspiana	105.6	237796	141235	96561
Commerce	36.8	237796	139228	98568
Crowley	12.1	237796	138499	99297
Dubbs	194.7	237796	143855	93941
Herbert	74.9	237796	140340	97456
Jackport	5.0	237796	138295	99501
Kobel	19.9	237796	138729	99067
Loring	67.4	237796	140123	97673
McKamie	41.4	237796	139356	98440
Muskogee	20.7	237796	138755	99041
Oaklimeter	105.6	237796	141235	96561
Perry	2.4	237796	138218	99578
Portland	9.9	237796	138435	99361
Rilla	105.6	237796	141235	96561
Stuttgart	9.6	237796	138423	99373
Tichnor	44.5	237796	139445	98351

Note: Footnotes located at the end of Appendix Table 1.

Appendix Table 8. Reservoir Seepage Loss, Well System Present Value of Cost, Reservoir Present Value of Cost, and Allowable Foregone Value of Production for the Soil Types Found in the Grand Prairie Region of Arkansas.

Reservoir Size: 90 Acres, 5 Feet Deep, 419 Acre Feet

Soil Type	Seepage[1]	Well Cost[2]	Reservoir Cost[3]	Allowable Foregone Value of Production
Arkansas County				
Acadia	40.2	306874	162704	144170
Amagon	17.3	306874	162026	144848
Amagon H-S	13.4	306874	161911	144963
Calhoun	25.2	306874	162256	144618
Calloway	23.1	306874	162192	144682
Crowley	26.3	306874	162295	144579
Falaya	122.9	306874	165119	141755
Grenada	20.4	306874	162116	144758
Herbert	274.4	306874	169568	137306
Loring	76.0	306874	163752	143122
McKamie	13.4	306874	161911	144963
Miller	13.9	306874	161924	144950
Norwood SL	122.9	306874	165119	141755
Norwood SCL	68.4	306874	163522	143352
Perry	13.3	306874	161911	144963
Portland	4.4	306874	161655	145219
Rilla	87.7	306874	164097	142777
Sharkey	2.8	306874	161604	145270
Stuttgart	20.5	306874	162116	144758
Tichnor	29.9	306874	162397	144477
Lonoke and Prairie Counties				
Calhoun	17.3	306874	162026	144848
Calloway	44.7	306874	162831	144043
Caspiana	121.7	306874	165094	141780
Commerce	42.2	306874	162755	144119
Crowley	13.5	306874	161911	144963
Dubbs	220.1	306874	167970	138904
Herbert	84.3	306874	163995	142879
Jackport	5.6	306874	161681	145193
Kobel	27.0	306874	162307	144567
Loring	76.0	306874	163752	143122
McKamie	45.8	306874	162857	144017
Muskogee	23.3	306874	162205	144669
Oaklimeter	121.7	306874	165094	141780
Perry	2.8	306874	161604	145270
Portland	11.1	306874	161847	145027
Rilla	121.7	306874	165094	141780
Stuttgart	10.7	306874	161834	145040
Tichnor	49.7	306874	162972	143902

Note: Footnotes located at the end of Appendix Table 1.

Appendix Table 9. Reservoir Seepage Loss, Well System Present Value of Cost, Reservoir Present Value of Cost, and Allowable Foregone Value of Production for the Soil Types Found in the Grand Prairie Region of Arkansas.

Reservoir Size: 90 Acres, 6 Feet Deep, 499 Acre Feet

Soil Type	Seepage[1]	Well Cost[2]	Reservoir Cost[3]	Allowable Foregone Value of Production
Arkansas County				
Acadia	43.3	375645	188531	187114
Amagon	19.2	375645	187828	187817
Amagon H-S	14.9	375645	187700	187945
Calhoun	27.7	375645	188083	187562
Calloway	25.4	375645	188007	187638
Crowley	28.4	375645	188096	187549
Falaya	137.8	375645	191304	184341
Grenada	22.5	375645	187930	187715
Herbert	296.7	375645	195957	179688
Loring	83.5	375645	189719	185926
McKamie	14.5	375645	187687	187958
Miller	15.0	375645	187700	187945
Norwood SL	137.8	375645	191304	184341
Norwood SCL	73.7	375645	189425	186220
Perry	14.4	375645	187687	187958
Portland	4.8	375645	187406	188239
Rilla	96.1	375645	190077	185568
Sharkey	3.1	375645	187355	188290
Stuttgart	22.7	375645	187930	187715
Tichnor	32.7	375645	188224	187421
Lonoke and Prairie Counties				
Calhoun	19.2	375645	187828	187817
Calloway	48.6	375645	188697	186948
Caspiana	136.5	375645	191266	184379
Commerce	47.1	375645	188646	186999
Crowley	14.6	375645	187700	187945
Dubbs	242.3	375645	194372	181273
Herbert	92.3	375645	189975	185670
Jackport	6.2	375645	187444	188201
Kobel	34.8	375645	188288	187357
Loring	83.5	375645	189719	185926
McKamie	49.4	375645	188710	186935
Muskogee	25.5	375645	188019	187626
Oaklimeter	136.5	375645	191266	184379
Perry	3.1	375645	187355	188290
Portland	12.1	375645	187623	188022
Rilla	136.5	375645	191266	184379
Stuttgart	11.6	375645	187610	188035
Tichnor	54.0	375645	188850	186795

Note: Footnotes located at the end of Appendix Table 1.

Appendix Table 10. Present Value of Foregone Production*: 30 Acre Reservoir Site on Land Producing 100 bu./acre Rice Yields and 25 bu./acre Soybean Yields

Soybean Price ($/bu.)	Rice Price 2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25
4.00	-24573	-21134	-17695	-14255	-10816	-7377	-3937	-498	2941	6381	9820
4.25	-23036	-19597	-16158	-12718	-9279	-5840	-2401	1039	4478	7917	11357
4.50	-21500	-18060	-14621	-11182	-7742	-4303	-864	2576	6015	9454	12894
4.75	-19963	-16523	-13084	-9645	-6206	-2766	673	4112	7552	10991	14430
5.00	-18426	-14987	-11547	-8108	-4669	-1229	2210	5649	9088	12528	15967
5.25	-16889	-13450	-10011	-6571	-3132	307	3747	7186	10625	14065	17504
5.50	-15352	-11913	-8474	-5034	-1595	1844	5283	8723	12162	15601	19041
5.75	-13816	-10376	-6937	-3498	-58	3381	6820	10260	13699	17138	20578
6.00	-12279	-8839	-5400	-1961	1478	4918	8357	11796	15236	18675	22114
6.25	-10742	-7303	-3863	-424	3015	6455	9894	13333	16773	20212	23651
6.50	-9205	-5766	-2327	1113	4552	7991	11431	14870	18309	21749	25188

*Discounted at 7 5/8% for fifty years.

Appendix Table 11. Present Value of Foregone Production*: 30 Acre Reservoir Site on Land Producing 125 bu./acre Rice Yields and 35 bu./acre Soybean Yields

Soybean Price ($/bu.)	Rice Price										
	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25
4.00	-5280	-980	3319	7618	11917	16216	20515	24814	29114	33413	37712
4.25	-3128	1171	5470	9769	14069	18368	22667	26966	31265	35564	39863
4.50	-977	3323	7622	11921	16220	20519	24818	29117	33417	37716	42015
4.75	1175	5474	9773	14072	18372	22671	26970	31269	35568	39867	44166
5.00	3327	7626	11925	16224	20523	24822	29121	33420	37720	42019	46318
5.25	5478	9777	14076	18375	22675	26974	31273	35572	39871	44170	48469
5.50	7630	11929	16228	20527	24826	29125	33424	37724	42023	46322	50621
5.75	9781	14080	18379	22679	26978	31277	35576	39875	44174	48473	52772
6.00	11933	16232	20531	24830	29129	33428	37727	42027	46326	50625	54924
6.25	14084	18383	22682	26982	31281	35580	39879	44178	48477	52776	57076
6.50	16236	20535	24834	29133	33432	37731	42030	46330	50629	54928	59227

* Discounted at 7 5/8% for fifty years.

Appendix Table 12. Present Value of Foregone Production*: 30 Acre Reservoir Site on Land Producing 150 bu./acre Rice Yields and 45 bu./acre Soybean Yields

Soybean Price ($/bu.)	Rice Price 2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25
4.00	14014	19173	24332	29491	34650	39809	44968	50127	55286	60445	65604
4.25	16780	21939	27098	32257	37416	42575	47734	52893	58052	63211	68370
4.50	19547	24706	29864	35023	40182	45341	50500	55659	60818	65977	71136
4.75	22313	27472	32631	37790	42949	48108	53267	58426	63585	68744	73902
5.00	25079	30238	35397	40556	45715	50874	56033	61192	66351	71510	76669
5.25	27845	33004	38163	43322	48481	53640	58799	63958	69117	74276	79435
5.50	30612	35770	40929	46088	51247	56406	61565	66724	71883	77042	82201
5.75	33378	38537	43696	48855	54014	59173	64332	69491	74650	79808	84967
6.00	36144	41303	46462	51621	56780	61939	67098	72257	77416	82575	87734
6.25	38910	44069	49228	54387	59546	64705	69864	75023	80182	85341	90500
6.50	41676	46835	51994	57153	62312	67471	72630	77789	82948	88107	93266

* Discounted at 7 5/8% for fifty years.

Appendix Table 13. Present Value of Foregone Production*: 60 Acre Reservoir Site on Land Producing 100 bu./acre Rice Yields and 25 bu./acre Soybean Yields

Soybean Price ($/bu.)	Rice Price										
	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25
4.00	-49146	-42268	-35389	-28511	-21632	-14753	-7875	-996	5883	12761	19640
4.25	-46073	-39194	-32316	-25437	-18558	-11680	-4801	2078	8956	15835	22713
4.50	-42999	-36121	-29242	-22363	-15485	-8606	-1727	5151	12030	18908	25787
4.75	-39926	-33047	-26168	-19290	-12411	-5532	1346	8225	15103	21982	28861
5.00	-36852	-29973	-23095	-16216	-9338	-2459	4420	11298	18177	25056	31934
5.25	-33778	-26900	-20021	-13143	-6264	615	7493	14372	21251	28129	35008
5.50	-30705	-23826	-16948	-10069	-3190	3688	10567	17446	24324	31203	38081
5.75	-27631	-20753	-13874	-6995	-117	6762	13641	20519	27398	34276	41155
6.00	-24558	-17679	-10800	-3922	2957	9836	16714	23593	30471	37350	44229
6.25	-21484	-14605	-7727	-848	6031	12909	19788	26666	33545	40424	47302
6.50	-18410	-11532	-4653	2225	9104	15983	22861	29740	36619	43497	50376

* Discounted at 7 5/8% for fifty years.

Appendix Table 14. Present Value of Foregone Production*: 60 Acre Reservoir Site on Land Producing 125 bu./acre Rice Yields and 35 bu./acre Soybean Yields

Soybean Price ($/bu.)	Rice Price 2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25
4.00	-10559	-1961	6637	15236	23834	32432	41031	49629	58227	66825	75424
4.25	-6256	2342	10940	19539	28137	36735	45334	53932	62530	71128	79727
4.50	-1953	6645	15244	23842	32440	41038	49637	58235	66833	75431	84030
4.75	2350	10948	19547	28145	36743	45341	53940	62538	71136	79735	88333
5.00	6653	15251	23850	32448	41046	49644	58243	66841	75439	84038	92636
5.25	10956	19554	28153	36751	45349	53948	62546	71144	79742	88341	96939
5.50	15259	23857	32456	41054	49652	58251	66849	75447	84045	92644	101242
5.75	19562	28160	36759	45357	53955	62554	71152	79750	88348	96947	105545
6.00	23865	32463	41062	49660	58258	66857	75455	84053	92651	101250	109848
6.25	28168	36767	45365	53963	62561	71160	79758	88356	96955	105553	114151
6.50	32471	41070	49668	58266	66864	75463	84061	92659	101258	109856	118454

* Discounted at 7 5/8% for fifty years.

Appendix Table 15. Present Value of Foregone Production*: 60 Acre Reservoir Site on Land Producing 150 bu./acre Rice Yields and 45 bu./acre Soybean Yields

Soybean Price ($/bu.)	Rice Price 2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25
4.00	28028	38346	48664	58982	69300	79618	89936	100254	110572	120890	131207
4.25	33561	43879	54196	64514	74832	85150	95468	105786	116104	126422	136740
4.50	39093	49411	59729	70047	80365	90683	101001	111319	121637	131955	142272
4.75	44626	54944	65261	75579	85897	96215	106533	116851	127169	137487	147805
5.00	50158	60476	70794	81112	91430	101748	112066	122384	132702	143020	153337
5.25	55691	66008	76326	86644	96962	107280	117598	127916	138234	148552	158870
5.50	61223	71541	81859	92177	102495	112813	123131	133449	143767	154084	164402
5.75	66756	77073	87391	97709	108027	118345	128663	138981	149299	159617	169935
6.00	72288	82606	92924	103242	113560	123878	134196	144514	154832	165149	175467
6.25	77820	88138	98456	108774	119092	129410	139728	150046	160364	170682	181000
6.50	83353	93671	103989	114307	124625	134943	145261	155579	165896	176214	186532

* Discounted at 7 5/8% for fifty years.

Appendix Table 16. Present Value of Foregone Production*: 90 Acre Reservoir Site on Land Producing 100 bu./acre Rice Yields and 25 bu./acre Soybean Yields

Soybean Price	Rice Price										
($/bu.)	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25
4.00	-73720	-63402	-53084	-42766	-32448	-22130	-11812	-1494	8824	19142	29460
4.25	-69109	-58791	-48473	-38155	-27837	-17520	-7202	3116	13434	23752	34070
4.50	-64499	-54181	-43863	-33545	-23227	-12909	-2591	7727	18045	28363	38681
4.75	-59888	-49570	-39253	-28935	-18617	-8299	2019	12337	22655	32973	43291
5.00	-55278	-44960	-34642	-24324	-14006	-3688	6630	16948	27265	37583	47901
5.25	-50668	-40350	-30032	-19714	-9396	922	11240	21558	31876	42194	52512
5.50	-46057	-35739	-25421	-15103	-4785	5532	15850	26168	36486	46804	57122
5.75	-41447	-31129	-20811	-10493	-175	10143	20461	30779	41097	51415	61733
6.00	-36836	-26518	-16201	-5883	4435	14753	25071	35389	45707	56025	66343
6.25	-32226	-21908	-11590	-1272	9046	19364	29682	40000	50318	60635	70953
6.50	-27616	-17298	-6980	3338	13656	23974	34292	44610	54928	65246	75564

* Discounted at 7 5/8% for fifty years.

Appendix Table 17. Present Value of Foregone Production*: 90 Acre Reservoir Site on Land Producing 125 bu./acre Rice Yields and 35 bu./acre Soybean Yields

Soybean Price ($/bu.)	Rice Price 2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25
4.00	-15839	-2941	9956	22854	35751	48648	61546	74443	87341	100238	113135
4.25	-9384	3513	16411	29308	42206	55103	68000	80898	93795	106693	119590
4.50	-2930	9968	22865	35763	48660	61558	74455	87352	100250	113147	126045
4.75	3525	16422	29320	42217	55115	68012	80910	93807	106704	119602	132499
5.00	9980	22877	35774	48672	61569	74467	87364	100262	113159	126056	138954
5.25	16434	29332	42229	55126	68024	80921	93819	106716	119613	132511	145408
5.50	22889	35786	48684	61581	74478	87376	100273	113171	126068	138965	151863
5.75	29343	42241	55138	68036	80933	93830	106728	119625	132523	145420	158318
6.00	35798	48695	61593	74490	87388	100285	113182	126080	138977	151875	164772
6.25	42252	55150	68047	80945	93842	106739	119637	132534	145432	158329	171227
6.50	48707	61604	74502	87399	100297	113194	126092	138989	151886	164784	177681

*Discounted at 7 5/8% for fifty years.

Appendix Table 18. Present Value of Foregone Production*: 90 Acre Reservoir Site on Land Producing 150 bu./acre Rice Yields and 45 bu./acre Soybean Yields

Soybean Price ($/bu.)	Rice Price 2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25
4.00	42042	57519	72996	88473	103950	119427	134904	150381	165858	181334	196811
4.25	50341	65818	81295	96772	112249	127725	143202	158679	174156	189633	205110
4.50	58640	74117	89593	105070	120547	136024	151501	166978	182455	197932	213409
4.75	66938	82415	97892	113369	128846	144323	159800	175277	190754	206231	221707
5.00	75237	90714	106191	121668	137145	152622	168099	183575	199052	214529	230006
5.25	83536	99013	114490	129967	145443	160920	176397	191874	207351	222828	238305
5.50	91835	107311	122788	138265	153742	169219	184696	200173	215650	231127	246604
5.75	100133	115610	131087	146564	162041	177518	192995	208472	223949	239425	254902
6.00	108432	123909	139386	154863	170340	185816	201293	216770	232247	247724	263201
6.25	116731	132208	147685	163161	178638	194115	209592	225069	240546	256023	271500
6.50	125029	140506	155983	171460	186937	202414	217891	233368	248845	264322	279799

* Discounted at 7 5/8% for fifty years.