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FINAL REPORT

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Introduction

Rapid ground water depletion has become a significant problem for parts of the Southern Mississippi River Valley. In 1997, the Arkansas Soil and Water Conservation Commission (ASWCC) declared six counties in the Grand Prairie of Arkansas critical ground water areas. A proposed solution to the ground water depletion problem in this region is to divert surplus flows from the White River by a canal system to the farmer stakeholders. To make the system work, on-farm reservoirs will be needed to store and manage the diverted surface water for crop irrigation use during the growing season.

The objective of this study was to estimate the optimal use of water sources utilizing on-farm reservoirs and tail water recovery under different ground water resource situations for a 30-year period, with and without access to supplemental diverted surface water.

This study follows previous work by the authors that investigated the economics of on-farm reservoir investment. The Modified Arkansas Off-stream Reservoir Analysis (MARORA) model was developed to determine the optimal reservoir size subject to ownership and operating costs associated with alternative cropping systems, soil, water, and other environmental conditions for an individual farm (Wailes, et al. 2000). This model framework was validated through interaction with farmer panels to develop representative farms for the study region. The research of this study is based on an application of the MARORA model. The Grand Prairie Area Demonstration Project was proposed in the Energy and Water Development Appropriations Act of 1992, which directed the Secretary of the Army to develop a demonstration project in the eastern Arkansas region for agricultural water supply, groundwater management and conservation. In July 1998, the U.S. Army Corps of Engineers, Memphis District, issued the project report. Based on an assessment of the problems and opportunities for coordination of stakeholders in the Grand Prairie Area, the proposed project plan is a combination of measures: conservation of groundwater, on-farm storage, imported surface water and various environmental features. The primary component is to provide a supplemental source of surface water, diversion from the White River, for irrigation to allow the Alluvial Aquifer in the area to stabilize. At the current rate of ground water use from the Alluvial Aquifer, irrigated agriculture in most of eastern Arkansas is not sustainable (Scott, et al. 1998). Research based on the MARORA model has shown over a 30-year time horizon, that there is no strong private incentive to invest in on-farm reservoirs unless the saturated groundwater depth is already as critically low as 25 feet. At a saturated depth of 50 feet, public investment cost-sharing is necessary to stimulate on-farm reservoir construction. The Corps of Engineers project plan would require a significant increase in on-farm reservoirs in the region (8,800 acre feet) to store the diverted irrigation water from the White River. This study examines, from an individual farm perspective, the net economic benefits of access to the diverted White River with existing on-farm reservoir capacity compared to optimal reservoir capacity.

Problems and Research Objectives

The project evaluated representative farm irrigation systems with common crop rotations in the Grand Prairie Areas using the MARORA model to measure benefits of irrigation from diverted White River surface water. Irrigation benefits of the individual farms were estimated under variable weather with and without access to diverted surface water over a 30-year period with projected changes in ground water supplies. Benefits to irrigators were analyzed given the current irrigation infrastructure on the farm and then with an optimal on-farm reservoir and tail-water recovery system. On-farm reservoirs were evaluated in the irrigation system as a water conservation practice to collect rainfall runoff, recycle tail water and complement the available ground water supply as well as serving as storage for diverted surface water over the projected 30-year period.

Specific research objectives were:

1) To estimate the optimal use of available water sources for irrigation utilizing on-farm reservoirs under different ground water resource situations for a 30-year period.

2) To identify the optimal use of on-farm reservoirs with and without access to supplemental diverted surface water over a 30-year period.

3) To estimate the economic benefits of diverted surface water for different farm situations and water supply conditions over a 30-year period.

In order to simulate the irrigation system with access to the diverted ground water, revisions to the MARORA model were made[1]. The proposed White River diversion project has been developed with collaboration between the White River Irrigation District and the U.S. Army Corps of Engineers. Elements of the project design were explicitly incorporated into the MARORA model (White River Irrigation District, 2000). The following items are particularly critical changes imposed upon the model specification:

1) Diverted water will cost $27.71 per acre foot,

2) the farmer will be assessed $1-3 per irrigated acre, the amount depending on the extent of pre- existing irrigation water conservation practices,

3) the farmer will be guaranteed 1.5 acre feet per irrigated acre annually

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[1]A detailed description of the MARORA model is presented in the Appendix.

4) the delivery rate of diverted water will be 2.5 gallons per irrigated acre per minute, and

5) the farmer will receive a 65% cost share to subsidize reservoir investment.

The model specification also depends on parameters that are unique to the farm including soil type, total and irrigated acreage, crop rotation, ground water conditions, and existing irrigation structures such as irrigation wells, on-farm reservoirs, and tail water recovery systems. Only irrigated area of each farm case study was included in the model application.

Case Studies

For this study, five case studies were used to assess the water diversion effects. Details of each representative case study follow:

Case 1. This farm is owned and operated on 1,350 total acres in two parcels with 1,012 acres irrigated in one contiguous unit of which 400 acres were laser-leveled. The cropping pattern is 420 acres of rice and 635 acres of soybeans. Soybeans are double-cropped with 270 acres of oats and 50 acres of wheat (basically a 1/3 rice - 2/3 soybean rotation). Rice yield is 155-165 bushels/acre (dry weight) and soybean yield is 40 bushels/acre.

Ground water is supplied from four deep wells including three 8-inch wells @ 1,000-1,200 GPM and one 6-inch well @ 700 GPM from a depth to water of 220 feet. The power sources are electricity and natural gas. The farm currently has four reservoirs including: 105 acre feet (15 acres by seven feet), 162 acre feet (27 acres by six feet), 280 acre feet (40 acres by seven feet), and 516 acre feet (80 acres by 6.5 feet deep). About 500 acres are irrigated from reservoirs. Reservoirs are 90% filled by March with 50% from on-farm runoff and 50% from other runoff. Tail-water is collected during the summer as available. The reservoir fill pump is electric with a capacity of 1,000-1,300 gallon per minute (GPM). Discharge is from an electric pump of 1,000-1,200 GPM capacity. The farm has underground pipe distribution and both flood (contour levy) and row irrigation.

Case 2. This farm includes 2,000 total acres, 640 owned and 1,360 leased, with 1,327 irrigated and 300 dryland cultivated. Non-contiguous parcels include 160, 230, 320, 630 and 660 acres. The basic crop rotation is 1/3 rice and 2/3 soybeans plus 1/3 wheat double-cropped. Rice yield is 7,000 pounds/acre and soybean yield is 50 plus bushel/acre. There are a total of 10 wells including one diesel unit to pump 1,500 GPM from a 290 feet well, a second diesel unit to pump 800 GPM from a 90 foot well, and an electric unit to pump 500 GPM from a 105 foot well. The farm has underground pipe and uses both sprinkler and flood irrigation. Irrigation efficiency is 80% for both rice and soybeans and the water use was 29-30 inches/acre for rice and 18 inches/acre for soybeans.

The farm has one 233 acre-feet reservoir roughly, eight feet deep and 30 acres in surface area. The reservoir is filled with 60 acre-feet from wells (in July) and 173 acre-feet during December-March each year from on-farm runoff. The reservoir is filled with a 3,500 GPM diesel pump and empties with an 1,800 GPM diesel pump. Levee maintenance is reported to be $3,000 per year or $100 per surface acre. A total of 280 acres are irrigated from the reservoir.

Case 3. The third farm totals 1,695 acres with 1,195 owned (960 cultivated) and 500 leased (460 cultivated) in two contiguous units. A total of 1,053 acres are irrigated. The average cropping pattern is 550 acres in rice, 850 acres in soybeans, and 400 in other crop. Average reported yields per acre are 170 hundred weight for rice, 45 bushels for soybeans, and 65 bushels for other crops. The normal rotation is 40% rice and 60% other. The farm has five shallow and two deep wells. Two deep wells include a diesel unit of 1800 GPM and one of 1,400 GPM with a pump setting of 350 feet. There is a diesel-powered shallow well of 900 GPM with a well depth of 140 feet. There are two reservoirs totaling 805 acre-feet capacity with 115 acres surface area and an average depth of seven feet. The reservoirs irrigate 900 acres and are filled about half from bayous and half from on-farm runoff from December to March.

There are two diesel pumps with a capacity of 20,000 GPM used to fill and empty the reservoirs. There is also a tailwater recovery pit of 12 acre-feet equipped with a 3,500 GPM diesel pump. The efficiency of tailwater recovery is 90%. Tailwater includes both on-farm runoff and other farm runoff.

Case 4. The fourth farm totals 1,800 acres with 180 owned and 1,620 leased. There are six non-contiguous tracts including three of 320 acres, one of 180 acres, one of 240 acres, and one of 420 acres. Irrigated acreage is 1,456 including one third in rice and two thirds in soybeans.

There are six wells of 800 GPM with electric power units at 140 feet depth to water. The farm has underground pipe and flood irrigation. There is a 60-acre reservoir eight feet deep collecting on-farm run-off. The reservoir irrigates 240 acres and is filled 80% by January and 100% by April. The fill pump is a 3,000 GPM diesel unit and the discharge is through a 12 inch free flow pipe.

Case 5. The fifth farm totaled 1,263 acres in one contiguous unit except for a railway line that divided the farm into a 553 acre tract and a 709 acre tract. There are seven wells ranging from 120 to 140 feet deep with a capacity of 500 to 1,400 GPM. The three 1,000 GPM wells serve the 553 acre tract and the 709 acre tract is served by the other four wells. The farm has a relatively high average soybean yield of 50 bushels per acre but a low rice yield of 140 bushels per acre. Much of the ground water and also the surface water runoff has high salinity that may limit the rice yield.

Research Method

The five representative case study rice farms in the Grand Prairie area of eastern Arkansas were compared to assess the economic impact of declining ground water. Projections were developed over a 30-year time frame on crop irrigation and farm income with and without participation in the White River surface water diversion program. The existing reservoir and well yield capacity of each case farm was incorporated in the model to evaluate the returns from using White River water. White River water was assumed to be delivered to each farm for $27.71 per acre foot, at the recommended maximum delivery rate of 2.5 GPM and total quantity of 1.5 acre feet per year per irrigated acre. Four of the representative farms selected for analysis had already constructed on-farm reservoirs to conserve ground water and utilize the current available on-farm surface water (See case studies).

Analysis for the five representative case study farms include different scenarios regarding changing the on-farm reservoir capacity(within a 10-acre-foot tolerance level), drilling additional wells if feasible, and constraining the volume of on-farm collection of surface water to fill reservoirs. The current rice and soybean acreage of each case study farm is assumed to continue until irrigation becomes restricted. Only the current irrigated area of each farm was evaluated. Specific baseline estimates and farm case study scenarios included:

(1) A baseline projection for the five case study farms without access to White River water with the alternatives of either 30 or 45 feet initial saturated thickness of the aquifer, one foot per year decline and three different on-farm water supply scenarios. These included: (a)

continued access to current surface water sources with no increase in the number of wells used, (b) access only to on-farm generated surface water with no increase in the number of wells used, and (c) access only to on-farm generated surface water with a permitted increase in the number of wells used.

(2) Access to the White River Project was analyzed for the five case study farms at the two alternative initial water table thicknesses of 30 or 45 feet, with one foot per year decline. For the White River Project access scenarios, it was assumed that the only additional surface water was restricted to on-farm sources, i.e. no run-off from the neighbors or access to a bayou. Two different reservoir capacity scenarios were evaluated for the White River Project. These included (a) with the current on-farm reservoir capacity and (b) with an optimal reservoir capacity.

When a farm experiences restricted water, additional wells may be drilled if feasible or rice acreage may be shifted to additional soybean acreage. As noted above, the projections for each case study farm are based on an average initial ground water saturated depth of either 30 or 45 feet for the alluvial aquifer and an annual decline rate of one foot. The selected parameter for water table decline corresponds to the definition by the Arkansas Soil and Water Conservation Commission (ASWCC) of a critical ground water area having a water level decline of more than 0.3 meters per year within a five-year period. The estimated 1996 water budget for the Grand Prairie region (ASWCC, 1977) showed an average saturated thickness of about 15 meters, i.e. about 45 feet. An alternative initial 30-foot saturated level for year 1 is also evaluated to determine the impact on farms in the Grand Prairie with below average saturated thickness and to represent the average Grand Prairie ground water supply situation in 2010. Saturated thicknesses above 45 feet were not evaluated as there would be a low incentive to construct reservoirs and use White River water without special compensation.

The primary performance variable used to measure the impact of access to the White River diversion project is the 30-year sum of present worth of net farm income. The difference in present worth of projected annual net farm income with and without access to the White River Project is a measure of profitability or residual returns. For this study, present worth is estimated at an annual discount rate of eight percent. Since the model includes all costs except management and land, the net returns are essentially a return to these two factors. Since land is the more fixed resource of these two we will ascribe the net returns strictly to land and thereby interpret how participation in the project is likely to affect the current land value for each case study farm.

Analysis

Impacts on Farming Operations

Current farming operations on the five case study farms generally involve an irrigated crop rotation of one-third rice and two-thirds soybeans that is typical of most of the Arkansas delta (Tables 1 and 2). The current cultivated area per farm excluding land in reservoirs ranged from 1,053 acres for the case 3 farm to 1,456 acres for the case 4 study farm. Existing on-farm reservoir capacity at the time of this study ranged from none on case 5 farm to a range of 240 acre feet on case 2 farm to 1,100 acre feet for the case 1 farm.

Without the White River Project and with reliance on only the on-farm water resources, at the end of the 30 year period all five case study farms at both 30 and 45-feet initial saturated depths were projected to shift out of rice to soybeans only (Tables 1 and 2). However, the on-farm water resources and current reservoir capacity were sufficient under both initial saturated thickness levels to enable partial soybean irrigation to continue over the projected 30-year period except for the case 5 farm which did not have a reservoir. Projected annual total farm water use after 30 years was 573 acre-feet for farm 1; 387 acre-feet for farm 2; 640 acre-feet for farm 3; 643 acre-feet for farm 4, and 0 acre-feet for farm 5. By year 30, virtually no ground water was being extracted for irrigation including farms with 45 feet initial saturated thickness. Wells were abandoned at a saturated thickness of 20-25 feet as the wells typically begin to surge during the irrigation season at these saturated thickness levels, as predicted by MARORA computer model. It would be possible for farmers to extend irrigation longer by replacing pumps with smaller capacity units; however, the cost of well replacement is generally not feasible for most farms at the 20 to 25 feet saturated thickness level due to the short projected life left with continued annual depletion.

With the White River Project, there are major differences between farms with different initial saturated thickness levels in the projected beneficial use of White River water. With 30 feet initial saturated thickness, the analysis shows that all five case study farms benefit from constructing an optimal size reservoir to utilize the White River water. This result accounted for the fact that irrigated land area of each farm was reduced -- by 146 acres on farm 1; 255 acres on farm 2; 142 acres on farm 3; 211 acres on farm 4; and 91 acres on farm 5 as a result of constructing an optimal size reservoir to supplement the existing reservoir (if any). Projected annual total farm water use in year 30 with the White River Project for the 30 feet initial saturated depth ranged from 1,436 acre-feet for case farm 5 up to 2,655 acre-feet for case farm 4, as indicated in Table 1. New well development is not feasible for farms with only 30 feet initial saturated thickness and an annual decline of one foot as ground water pumping would be discontinued within only a few years.

With 45 feet initial saturated thickness, all ground water use would be discontinued before the end of 30 years (Table 2). However, as the ground water supply does last longer with 45 feet as compared with the 30 feet initial saturated thickness level, there will be a higher use of ground water and less benefit from surface water. Construction of larger optimal size reservoirs with the White River Project compared with the original reservoirs was projected to be more profitable for only case farms 1 and 4 (Table 2). These two new reservoirs with the White River Project for case farms 1 and 4 are smaller than the optimal reservoir sizes estimated in Table 1 for the initial 30 feet saturated thickness. The program estimated that with 45 feet initial saturated thickness it was not profitable to increase the on-farm reservoir capacity of the other three farms to more effectively utilize White River water. Projected annual total farm water use in year 30, with the 45 foot initial saturated acre feet thickness level, was 1,480 acre feet for case farm 1; 387 acre feet for case farm 2; 640 acre feet for case farm 3; 1,614 acre feet for farm 4, and 0 acre feet for farm 5. Rice production was continued in year 30 only on farms 1 and 4 that had increased reservoir capacity to utilize White River water (Table 2).

The analysis of farm adjustments to the declining aquifer with the MARORA model included an evaluation of new well development on farms with 45 feet saturated thickness to determine if increased well capacity was a more economical solution than using White River water. New well development to cope with a farm shortage of irrigation water does help sustain irrigation and improve net returns for case farms 1 and 4 with 45 feet saturated thickness and an annual decline rate of one foot per year. However, the option of drilling additional wells is only a temporary solution to help maintain farm income for a few more years and it does not affect the final outcome after 30 years of regional water table decline.

Impacts on Farm Income

Annual income projections with and without the White River project for the case study farms are shown in Tables 3 and 4. These tables compare net incomes in the first five year and last five years of the 30 year net income stream to demonstrate the impacts on sustainability of net incomes. Farms with an initial saturated thickness of 30 feet incurred a rapid loss of annual income in the baseline projection without the White River project (Table 3). Annual net incomes dropped by over half over the projected 30-year period for case farms 1, 2 and 3 and by over 70 percent for case farm 4, with existing on-farm reservoirs and current available surface water. Annual income dropped by over 75% for the case 5 farm which did not have a reservoir and was not currently using any surface water collection to supplement the declining ground water.

Further analysis, based on an assumption that the farm cannot obtain surface water from neighbor run-off and bayous, but only from on-farm run-off, shows a major decrease not only for case farm 5 but for the other case farms as well, both in the initial years and throughout the 30-year period (Table 3). Case study farm 5 was not affected by this restriction as it did not collect any surface water.

Projections of annual farm income with access to the White River project varied with the size of reservoir used. With the current reservoir capacity, the annual income was slightly less for cases 1 to 4 during the first few years due to higher expense of using White River water. Annual income with White River water and the existing reservoir capacity fell off sharply over the 30-year period because the current reservoir capacity of the case study farms was too small to utilize the White River water effectively as the ground water supply declined.

Analysis of access to the White River water with an estimated optimal size reservoir for each farm shows that annual income was less with the optimal size reservoir compared to the current size reservoir during the first five years, but substantially higher during the last five years of the 30-year projection period (Table 3). All five case study farms were estimated to maximize the present worth of annual net income with the use of White River water and with an optimal reservoir size than the current size when the saturated thickness was 30 feet in year 1 (Table 5).

At a 45 feet initial saturated thickness, the use of White River water was projected to be much less profitable than at a 30 feet initial saturated thickness (Tables 5 and 6). It was estimated that none of the five case study farms would benefit economically by constructing a larger reservoir to fully utilize the White River water unless the White River water cost was substantially reduced below $27.71 per acre foot. The five case study farms with 45 feet initial saturated thickness would realize the highest present worth of annual income by continuing to use their own water including drilling more wells if needed (Table 6).

The difference in present worth values for the five case study farms, comparing no access to White River water to with access and an optimal size reservoir, ranged from $423,000 to $1,186,000 with 30-feet initial saturated thickness (Table 5). With a 45-feet initial saturated thickness, none of the case farms were estimated to benefit from the project unless new well drilling was prohibited. The case 1 and case 4 farms had only a slight fall in the present worth of projected annual net income by using White River water and an optimal size reservoir compared with using additional wells and on-farm surface water (Table 6). Without adding more wells, the case 1 and 4 farms would realize the best return from using White River water and an optimal size reservoir.

Graphical comparisons of the with and without White River project cumulative 30-year net income projections are shown in Figures 1 to 5 for the 30-feet initial saturated thickness situation and in Figures 6 to 10 for the 45-feet initial saturated thickness situation. Income is measured in terms of the cumulative present worth of projected annual income indicating the present value of the farm property based on projected annual net farm income from year 1 through year 30.

For case farms 1 to 4 with 30 feet initial saturated thickness (Figures 1 to 5), the maximum 30-year present worth value would be attained with the use of White River water and use of an optimal size reservoir to utilize this water. However, this option is does not become optimal until year 16 for case study farm 1, year 5 for case study farm 2, year 15 for case study farm 3, year 12 for case study farms 4 and 5. The next best option is the current situation based on access to off-farm run-off. However, since these off-farm surface waters are not guaranteed into the future, the respective farms will likely have to depend only on their wells and on-farm surface water. The potential loss of off-farm surface water would result in a substantially lower present worth projection of less than $400,000 for case 1 (Figure 1) compared with over $1,400,000 with White River and optimal reservoir option. The case 2 to 4 farms would also have the least present worth value by continuing to rely only on wells and available on-farm surface water for irrigation.

The case 5 farm (Figure 5) did not currently rely on any surface water but would attain the highest net worth value after about 12 years with the use of White River water and an optimal reservoir size. Present worth is limited to about $1,250,000 with the current situation and would increase to about $1,750,000 with the White River Project. Additional wells are not economic as a method of maintaining irrigation with 30-feet initial saturated thickness and an annual decline of one foot per year.

As shown in Figures 6 to 10, none of the case farms with 45 feet initial saturated thickness would maximize profits from accessing White River water with an optimal reservoir over the projected 30-year period unless additional well drilling was not allowed.

The case 2 farm with 45 feet initial saturated thickness would earn about the same present worth of annual income with either option including the current situation (current wells and current surface water use), the current situation with only on-farm surface water, and with the White River Project. Other case farms attained the highest present worth of income with either the current situation or with additional wells under the 45 feet saturated thickness assumption and would not profit over the 30-year projected period from the White River Project. Case 3 and case 5 farms currently had a large number of wells including seven for case 3 and 10 for case 5. Case 3 had an existing 800 acre foot reservoir and case 5 had no reservoir. It may be noted from Figures 8 and 10 for these two farms that there was very low annual income after around 20 years due to the failure of wells whereas the annual income would be sustained after 20 years with the White River Project. Projections beyond 30 years would have shown more profit from using White River water as estimated earlier for the 30-foot initial saturated thickness situation.

Figures 6 and 8 show that drilling additional wells was profitable for cases 1 and 4 with 45 feet initial saturated thickness. However, even with the additional wells annual income dropped very low within about 20 years because of the water table depletion (See Table 4).

Summary and Conclusion

The MARORA model was modified to evaluate the utilization and benefits of access to surface water from the White River Diversion Project for representative case study rice and soybean farms in the Mississippi Delta Region of Arkansas. Five case study farms in this region were selected for analysis. They were evaluated at a 45 feet initial saturated thickness (the 1997 average for the Grand Prairie region) and for a 30-feet initial saturated thickness. While a sizable area of the region is already at this vulnerable level, the entire region will on average be at the 30-feet saturated thickness by 2010.

Four of the case study farms had existing on-farm reservoirs and all had varying numbers of irrigation wells. The existing reservoir and well yield capacity and cultivated area of each case farm were incorporated into the model simulation to evaluate the returns from using White River water at the estimated farm delivery cost of $27.71 per acre foot and at the recommended maximum delivery rate of 2.5 GPM or 1.5 acre feet per year per cultivated acre. The analysis included results with 1) use of all current surface water available for each farm, which is not guaranteed into the future, 2) with only on-farm surface water use, and 3) with the option of drilling additional irrigation wells for farms with a beginning saturated thickness of 45 feet. Results were compared in terms of the discounted present worth of projected annual farm income over a 30-year period using an annual discount rate of 8%.

Results with 30 feet initial saturated thickness were that all five case study farms would realize substantial profit from constructing an optimal size on-farm reservoir and using the White River water. Adding additional wells to maintain ground water irrigation was not feasible with 30 feet initial saturated thickness. Compared with the option of continuing with ground water irrigation and the available on-farm surface water, the use of an optimal reservoir and White River water increased the present worth of annual income from a low of $423,000 for the case 5 farm to a high of $1,186,000 for the case 1 farm.

Results of accessing the White River water were very marginal with a 45-feet initial saturated thickness, depending on the existing reservoir capacity, the current importance of using off-farm surface water sources and the number of wells in use. None of the case farms were projected to profit from use of an optimal size reservoir and from purchasing White River water in a 30-year period unless no further well drilling was permitted. The case 2 farm would earn about the same present worth of income with White River water as with wells over the 30-year period. The case 3 and case 5 farms would earn much less projected present worth of income over the 30-year period by purchasing White River water compared with continuing to rely on ground water. However, after 15 years of further water table depletion, all five farms would reach the depletion stage of 30 feet saturated thickness and would profit for the next 30 years by constructing an optimal size reservoir to utilize purchased White River water.

The marginal results obtained for farms with 45 feet initial saturated thickness indicate that accessing the White River Project may not be profitable currently for farms with little or no current on-farm reservoir capacity, a large number of wells, and other off-farm sources of water to supplement the ground water supply. For most farmers, these existing off-farm surface water sources used now from local streams or bayous which are not guaranteed for the future. However, they do provide a cheaper alternative to purchasing White River water. Continued use of wells is also a cheaper option than White River water until the water table becomes depleted to range of 20 to 25 feet. At this thickness level, it becomes uneconomic to replace the pumps and drill additional wells with expected further decline of the water table.

The general conclusion of this study is that farmers in the Grand Prairie region of Arkansas will profit from the White River Project. The results are consistent with the intuitive logic that those farms most vulnerable will benefit from immediate access. The net benefit of the project to farms at an initial saturated thickness of 30-feet can be measured in terms of present value of irrigated land. Compared to no access and reliance upon current wells and on-farm run-off, access to the project with an optimal size well increases land value by $1,172 per acre for case farm 1; by $690 per acre for case farm 2; by $806 per acre for case farm 3; by $762 per acre for case farm 4 and by $338 per acre for case farm 5. The average increase in land value across all five farms is $754 per acre. The significance of this finding is that the agricultural economy, land value and associated value-added activities would be sharply curtailed without the development of alternative surface water for the critical ground water region in the Grand Prairie of Arkansas. Based on the results of this study, for the 350 thousand irrigated acres in the Grand Prairie, total loss of land value would be $264 million and loss of value-added economic activities would be approximately double that amount.

Those farms with better current ground water conditions, with 45 feet of saturated thickness and a decline rate of one foot per year or less would not profit from the White River Project immediately with the expected diverted water cost of $27.71 per acre foot unless they were restricted from further well drilling. Our analysis of economic benefits from the White River project is based on the present worth of projected net annual income for 30 years criterion with an assumed discount rate of eight percent.

Another project benefit not assessed in this study is the promised 65% subsidy for land leveling and underground pipe if farmers elect to participate in the project. This could be a more powerful incentive than the land tax benefit; however, there is a limit on funding for this financial assistance. Many of the case study farms included in our panel for this study already had underground pipe and some land leveling, thus it was not certain what the cost share benefit would be for these case farms. Further study of this benefit for farmers may be useful to determine the effect on farm participation in the White River Project.

The White River Project was estimated to be generally unprofitable currently for farmers with 45 feet saturated thickness. However, without participation in the project, the projected annual income would drop off sharply within 30 years and rice production would be terminated. Analysis using the present worth criterion, of course, puts a higher value on short term projected income. A discount rate less than eight percent would help to justify the White River Project by giving more weight to future income when ground water pumping declines. However, most farmers have a strong time preference for income that supports the use of a higher discount rate on future earnings.

Since the average water table depth is still near 45 feet in the Grand Prairie region as reported by the ASWCC (1997), there may be a problem with farmer participation in the White River Project with the proposed water cost of $27.71 per acre foot. We suggest that additional study of this project may be needed to improve the prospective farm participation.

Selected References

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Young, Kenneth B., Eric J. Wailes, and Jim Smartt. 1998. "Analyzing Conjunctive Use of On-Farm Reservoirs and Irrigation Wells in the Arkansas Delta." In Scott, H. Don, ed. *Vulnerability and Use of Ground and Surface Waters in the Southern Mississippi Valley Region*, Scott, H. Don. Pub. No. 269. Arkansas Water Resources Center.

Table 1. Projected changes in farming operations in 30 years with alternative water supply conditions (30 feet initial saturated thickness and one foot decline per year)

Water Supply Situation	Case Study Farm[1]				
	1	2	3	4	5
1. Without White River Project:					
total farm size (cultivated acres)	1,012	1,327	1,053	1,456	1,263
current reservoir (acre feet)	1,100	240	810	480	0
current soybean acres per farm	607	796	632	971	846
current rice acres per farm	405	531	421	485	417
year 30 rice acres per farm	0	0	0	0	0
year 30 soybean acres per farm	1,012	1,327	1,053	1,456	1,263
year 30 water use per cultivated acre (inches)	6.8	3.5	7.3	5.3	0
year 30 total water use (acre feet)	573	387	640	643	0
2. With White River Project:					
total farm size (cultivated acres)	866	1,072	911	1,235	1,172
optimal reservoir (acre feet)	2,800	3,200	2,600	3,300	1,100
year 30 rice acres per farm	346	429	364	411	0
year 30 soybean acres per farm	520	643	546	823	1,172
year 30 water use per cultivated acre (inches)	26.6	26.7	26.7	25.8	14.7
year 30 total water use (acre feet)	1,920	2,385	2,027	2,655	1,436

[1]See farm case studies for individual farm data.

Table 2. Projected changes in farming operations in 30 years with alternative water supply conditions (45 feet initial saturated thickness and one foot decline per year)

Water Supply Situation	Case Study Farm[1]				
	1	2	3	4	5
1. Without White River Project:					
total farm size (cultivated acres)	1,012	1,327	1,053	1,456	1,263
current reservoir (acre feet)	1,100	240	810	480	0
current soybean acres per farm	607	796	632	971	846
current rice acres per farm	405	531	421	485	417
year 30 rice acres per farm	0	0	0	0	0
year 30 soybean acres per farm	1,012	1,327	1,053	1,456	1,263
year 30 water use per cultivated acre (inches)	6.8	3.5	7.3	5.4	0
year 30 total water use (acre feet)	573	387	640	655	0
2. With White River Project:					
total farm size (cultivated acres)	960	1,327	1,053	1,354	1,263
optimal reservoir (acre feet)	1,700	0[2]	0[2]	1,800	0[2]
year 30 rice acres per farm	384	0	0	451	0
year 30 soybean acres per farm	576	1,327	1,053	903	1,263
year 30 water use per cultivated acre (inches)	18.5	3.5	7.3	14.3	0
year 30 total water use (acre feet)	1,480	387	640	1,614	0

[1]See farm case studies for individual farm data.
[2]Optimal reservoir size is zero in these cases but farm will continue operating with the original reservoir

Table 3. Projected annual income of case study farms with alternative water supply conditions (30 feet initial saturated thickness)

Water Supply Situation	Case Study Farm[1]				
	1	2	3	4	5
	($1,000 income)				
1. Without White River Project:					
current reservoir					
-current surface water					
years 1-5 average	223	246	263	266	286
years 26-30 average	95	119	114	74	64
-on-farm surface water/current wells[2]					
years 1-5 average	86	245	219	145	286
years 26-30 average	43	103	72	55	64
2. With White River Project:					
current reservoir					
years 1-5 average	202	242	240	198	na[3]
years 26-30 average	74	116	97	68	na[3]
optimal reservoir					
years 1-5 average	142	207	182	177	212
years 26-30 average	159	225	197	194	140

[1]See farm case studies for individual farm data
[2]Additional well drilling was not economic for 30 feet saturated thickness
[3]not applicable as there is no existing reservoir

Table 4. Projected annual income of case study farms with alternative water supply conditions (45 feet initial saturated thickness)

Water Supply Situation	Case Study Farm[1]				
	1	2	3	4	5
	($1,000 income)				
1. Without White River Project:					
current reservoir					
-current surface water					
years 1-5 average	247	309	294	208	286
years 26-30 average	95	120	121	82	65
-on-farm surface water/current wells					
years 1-5 average	237	307	287	145	286
years 26-30 average	43	104	73	57	65
-on-farm surface water/additional wells[4]					
years 1-5 average	235	-	-	297	-
years 26-30 average	83	-	-	44	-
2. With White River Project:					
current reservoir					
years 1-5 average	229	np[3]	271	np[3]	na[2]
years 26-30 average	69	np[3]	100	np[3]	na[2]
optimal reservoir					
years 1-5 average	185	np[3]	np[3]	230	np[3]
years 26-30 average	171	np[3]	np[3]	219	np[3]

[1]see farm case studies for individual farm data
[2]not applicable as there is no existing reservoir
[3]np= not profitable with White River water
[4]added 4 new wells for case 1 and for case 4. Not profitable for other cases

Table 5. Projected present value of annual net income of case study farms with alternative water supply conditions (30 feet initial saturated thickness)

Water Supply Situation	Case Study Farm[1]				
	1	2	3	4	5
	($1,000 income)				
1. Without White River Project:					
current reservoir					
-current surface water	1,461	1,402	1,786	1,405	1,290
-on-farm surface water	364	1,289	1,083	752	1,290
2. With White River Project					
current reservoir	1,184	1,363	1,498	1,085	na[3]
optimal reservoir	1,550	2,204	1,932	1,862	1,713
3. Net Benefit of White River Project[2]:					
current reservoir	820	74	415	333	na[3]
optimal reservoir	1,186	915	849	1,110	423

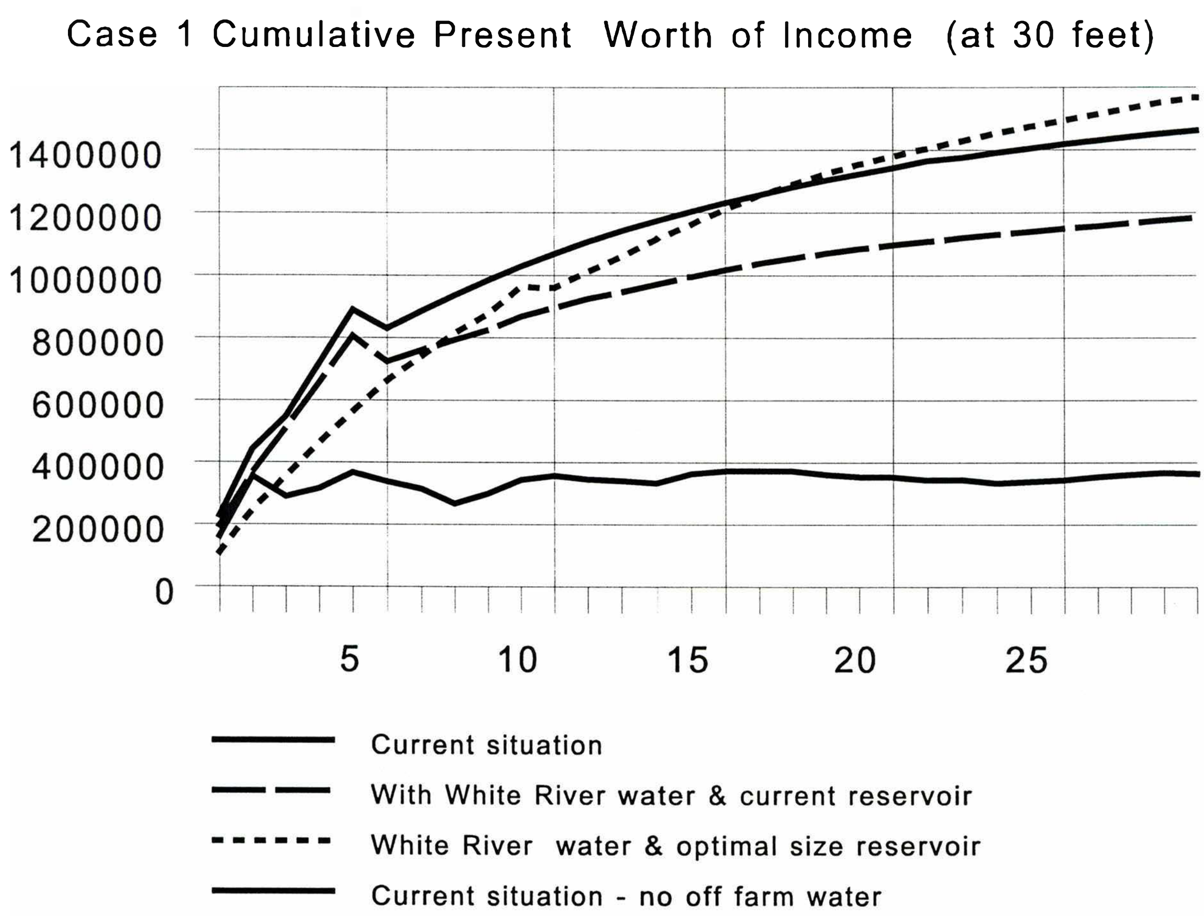
[1]See farm case studies for individual farm data
[2]This analysis considers only farm surface water that originates on the farm and not from adjacent lands or streams
[3]not applicable as there is no existing reservoir

Table 6. Projected present value of annual net income of case study farms with alternative water supply conditions (45 feet initial saturated thickness)

Water Supply Situation	Case Study Farm[1]				
	1	2	3	4	5
	($1,000 income)				
1. Without White River Project:					
current reservoir					
-current surface water	2,239	3,079	2,921	1,554	2,819
-on-farm surface water/current wells	1,303	3,058	2,718	1,246	2,819
-on-farm surface water/additional wells	2,255	-	-	2,836	-
2. With White River Project:					
current reservoir	1,828	np[3]	2,675	1,407	np[3]
optimal reservoir	2,040	np[3]	np[3]	2,573	np[3]
3. Net Benefit of White River Project:[2]					
current reservoir	np[3]	np[3]	np[3]	np[3]	np[3]
optimal reservoir	np[3]	np[3]	np[3]	np[3]	np[3]

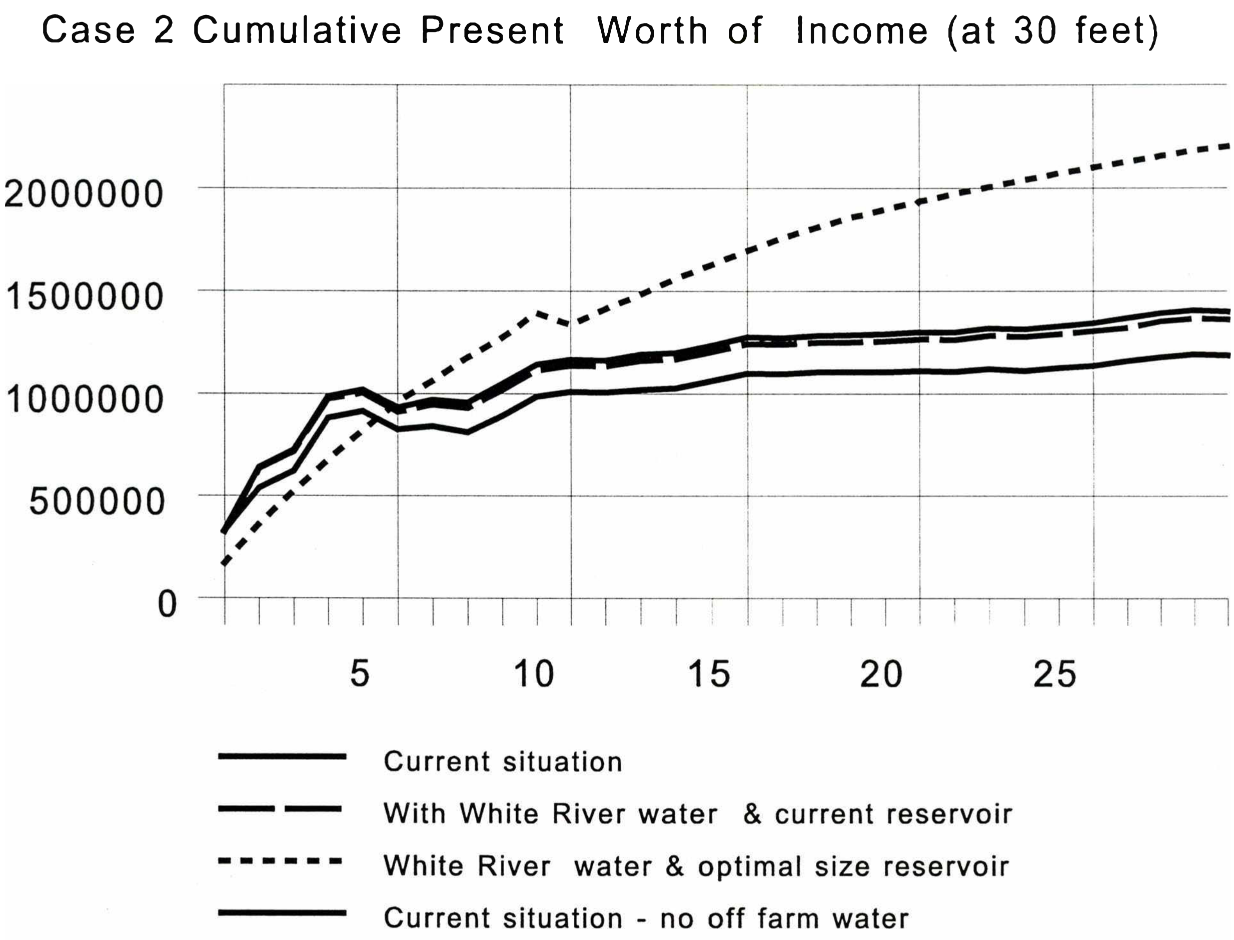
[1]see farm case studies for individual farm data
[2]analysis only includes farm surface water on farm property plus the ground water
np[3]= not profitable with White River water in the 30-year present value calculation.

Figure 1.



Case 1 Cumulative Present Worth of Income (at 30 feet)
1400000
1200000
1000000
800000
600000
400000
200000
0
5
10
15
20
25
Current situation
With White River water & current reservoir
White River water & optimal size reservoir
Current situation - no off farm water

Figure 2.



Case 2 Cumulative Present Worth of Income (at 30 feet)
2000000
1500000
1000000
500000
0
5
10
15
20
25
Current situation
With White River water & current reservoir
White River water & optimal size reservoir
Current situation - no off farm water

Figure 3.

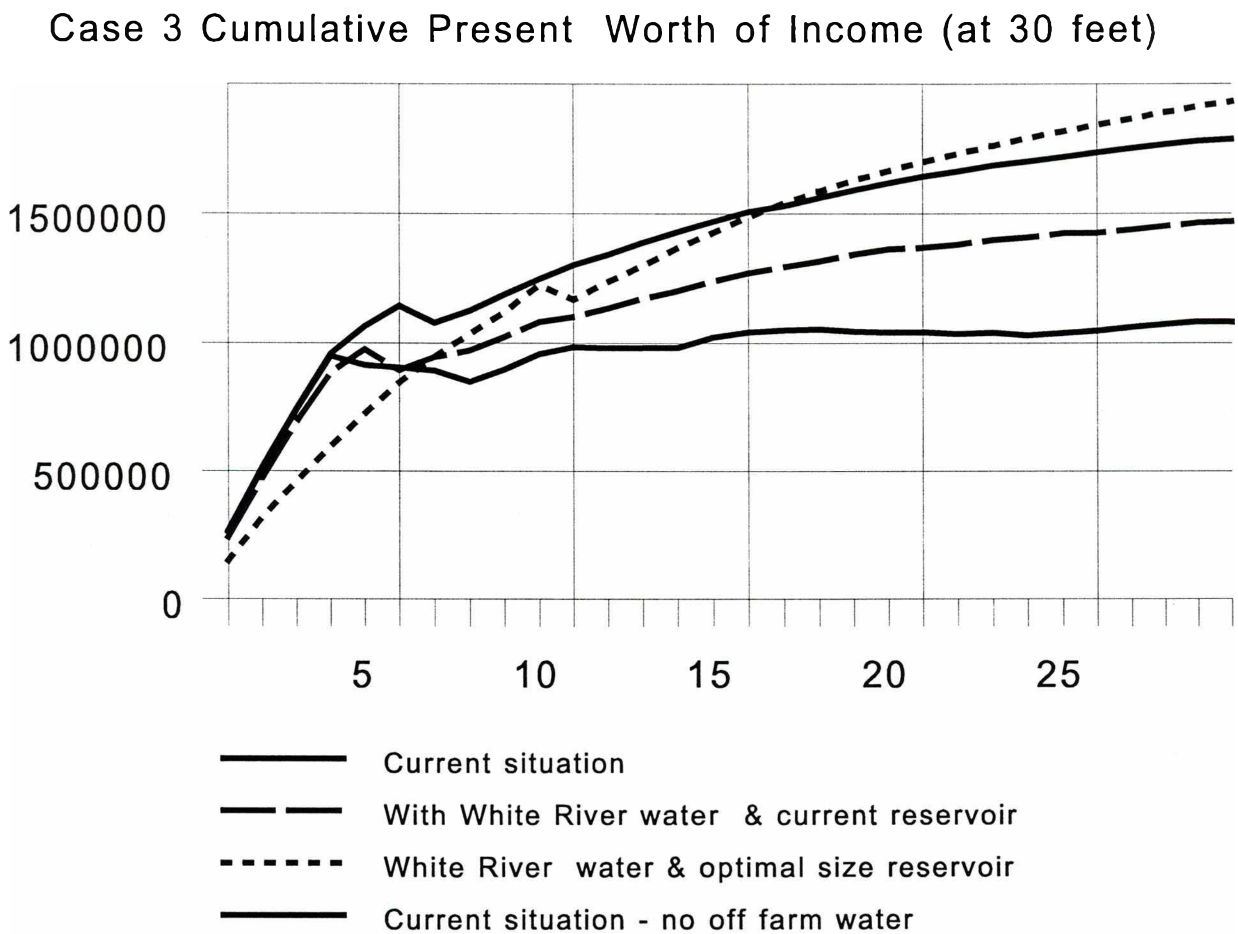

Case 3 Cumulative Present Worth of Income (at 30 feet)
1500000
1000000
500000
0
5
10
15
20
25
Current situation
With White River water & current reservoir
White River water & optimal size reservoir
Current situation - no off farm water

Figure 4.

Case 4 Cumulative Present Worth of Income (at 30 feet)

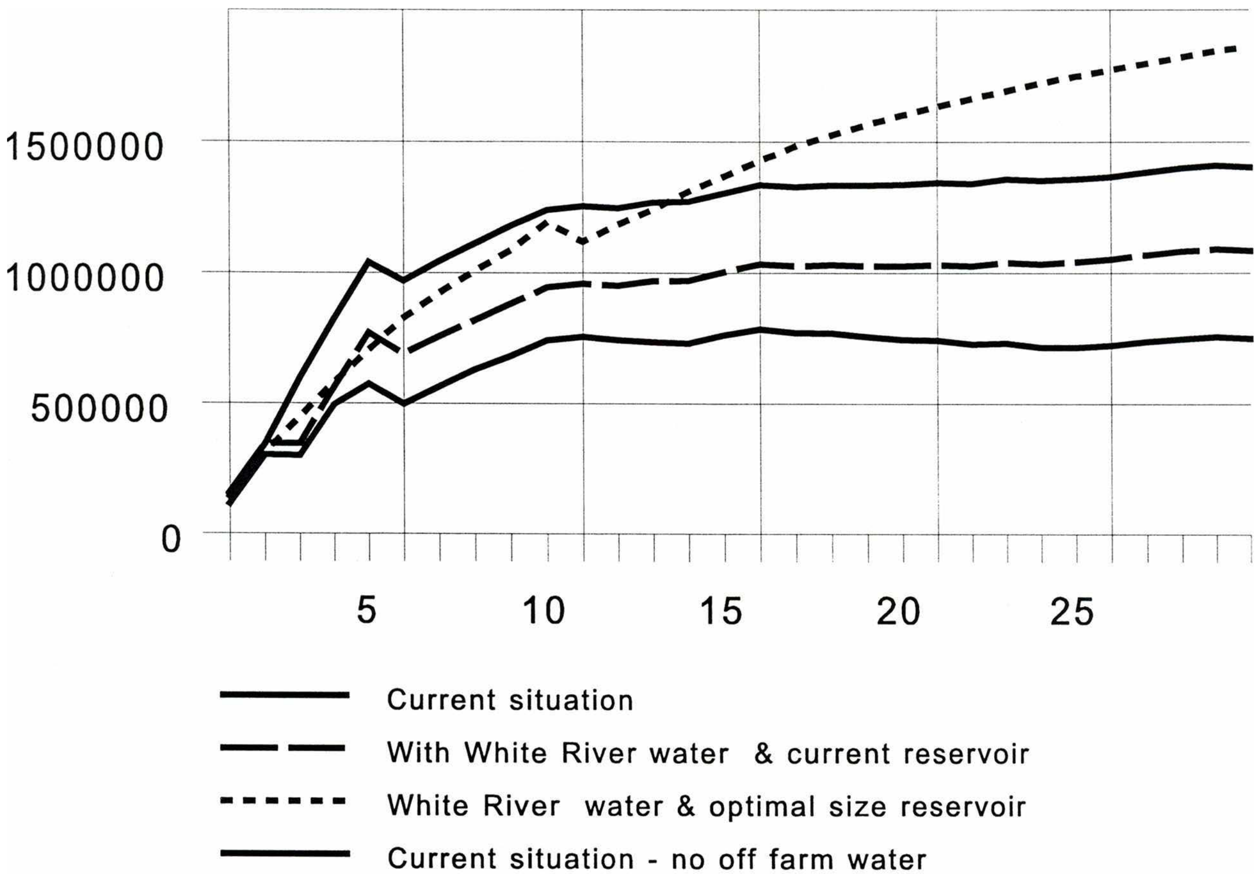
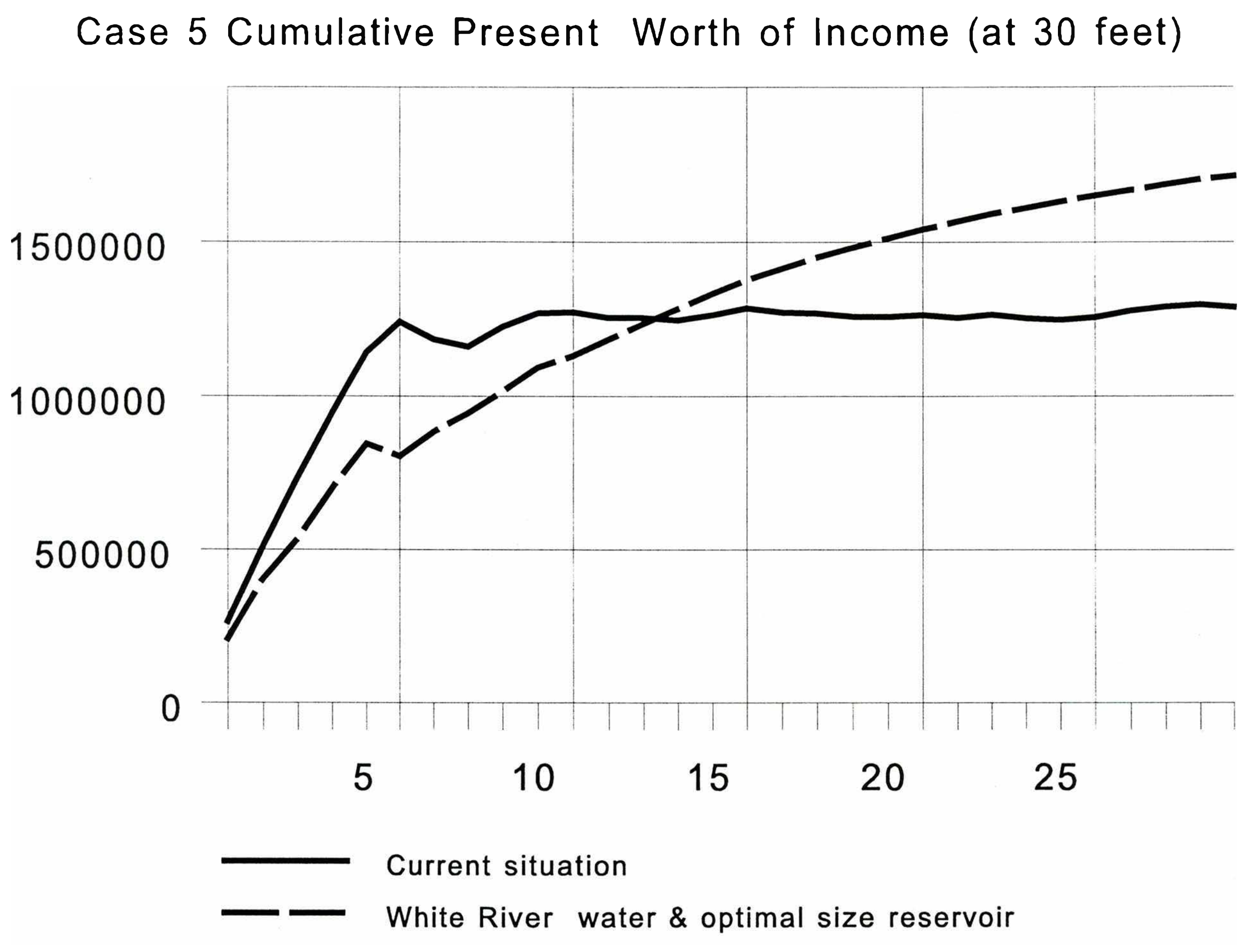


Figure 5.



Case 5 Cumulative Present Worth of Income (at 30 feet)
1500000
1000000
500000
0
5
10
15
20
25
Current situation
White River water & optimal size reservoir

Figure 6.

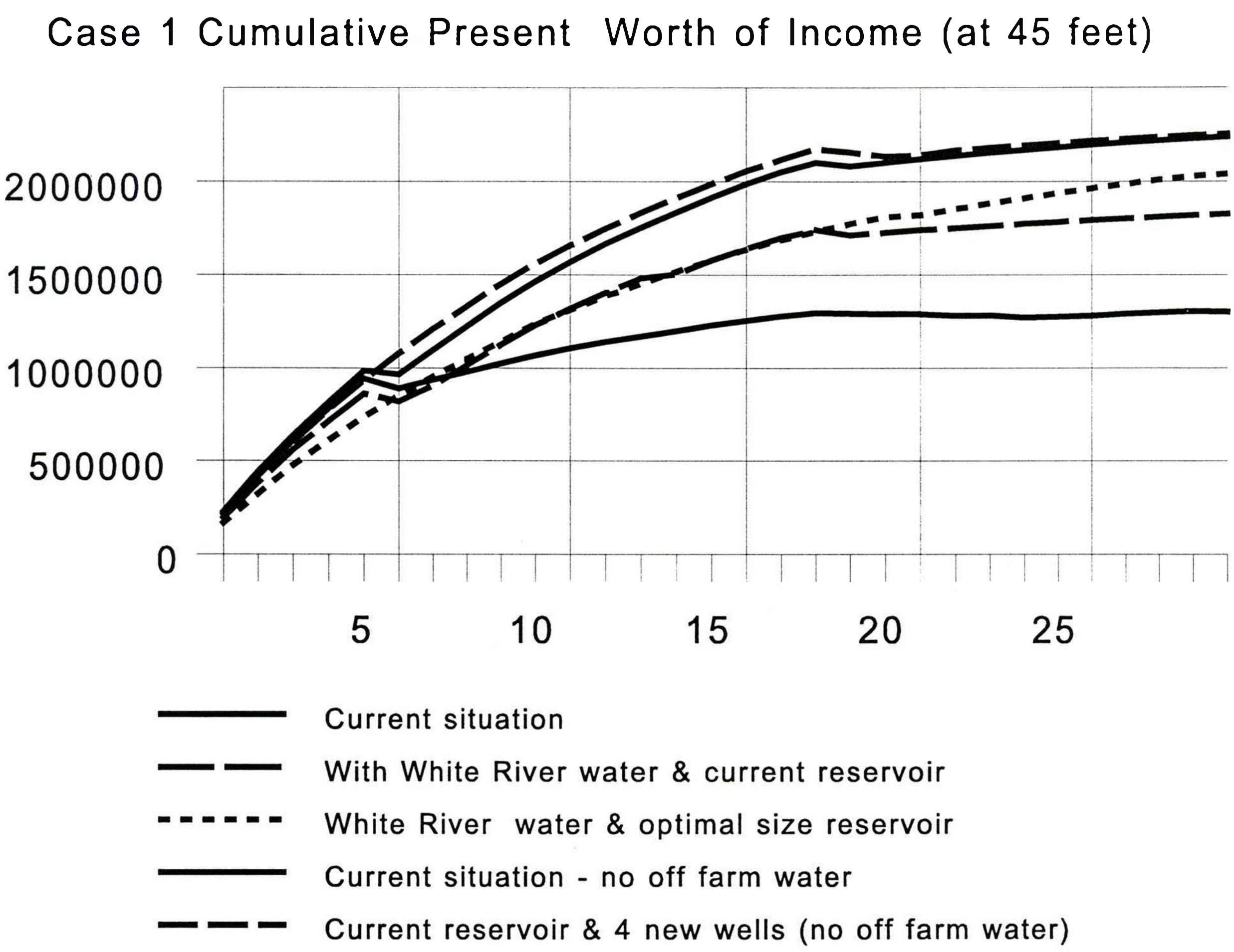
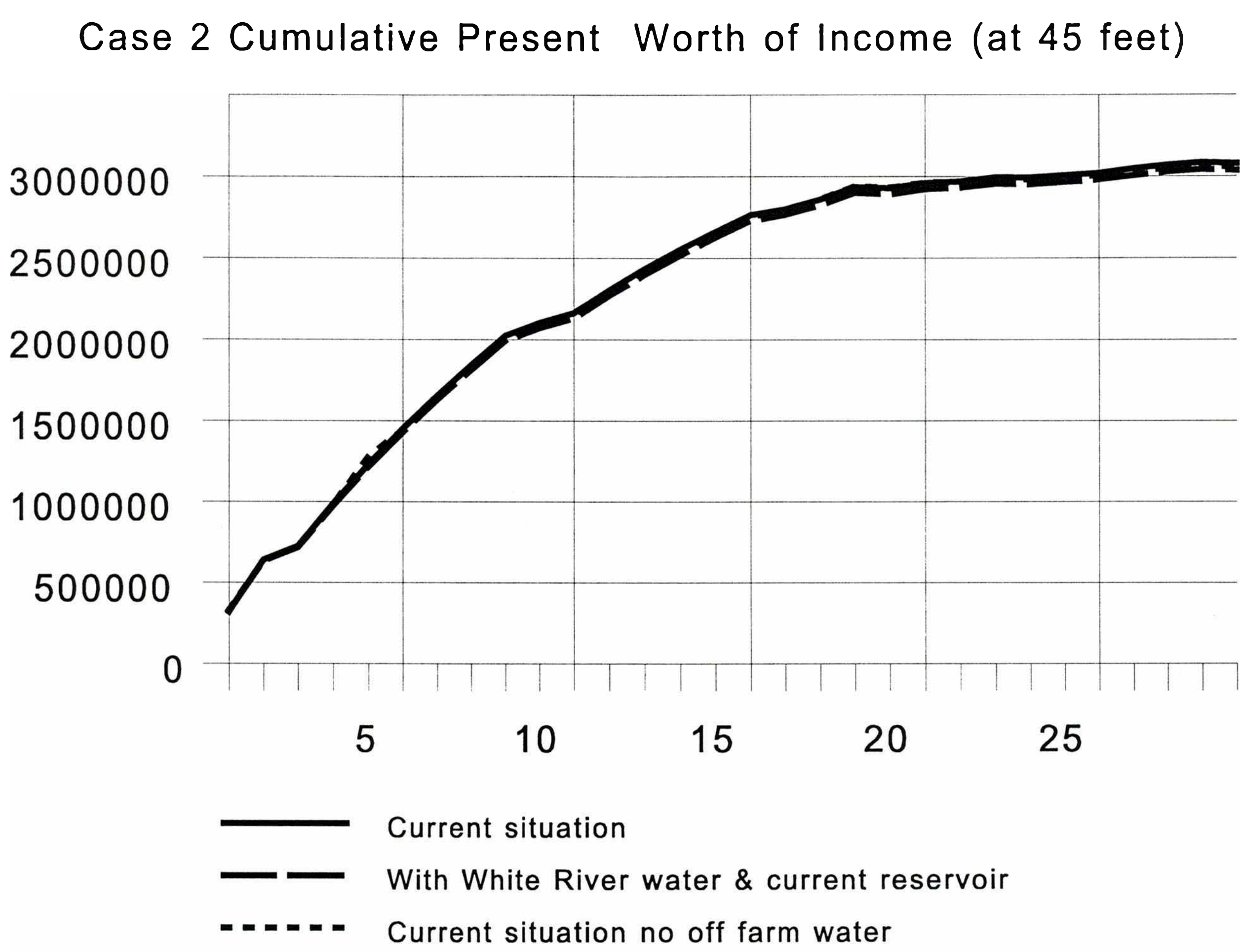

Case 1 Cumulative Present Worth of Income (at 45 feet)
2000000
1500000
1000000
500000
0
5
10
15
20
25
Current situation
With White River water & current reservoir
White River water & optimal size reservoir
Current situation - no off farm water
Current reservoir & 4 new wells (no off farm water)

Figure 7.



Case 2 Cumulative Present Worth of Income (at 45 feet)
3000000
2500000
2000000
1500000
1000000
500000
0
5
10
15
20
25
Current situation
With White River water & current reservoir
Current situation no off farm water

Figure 8.

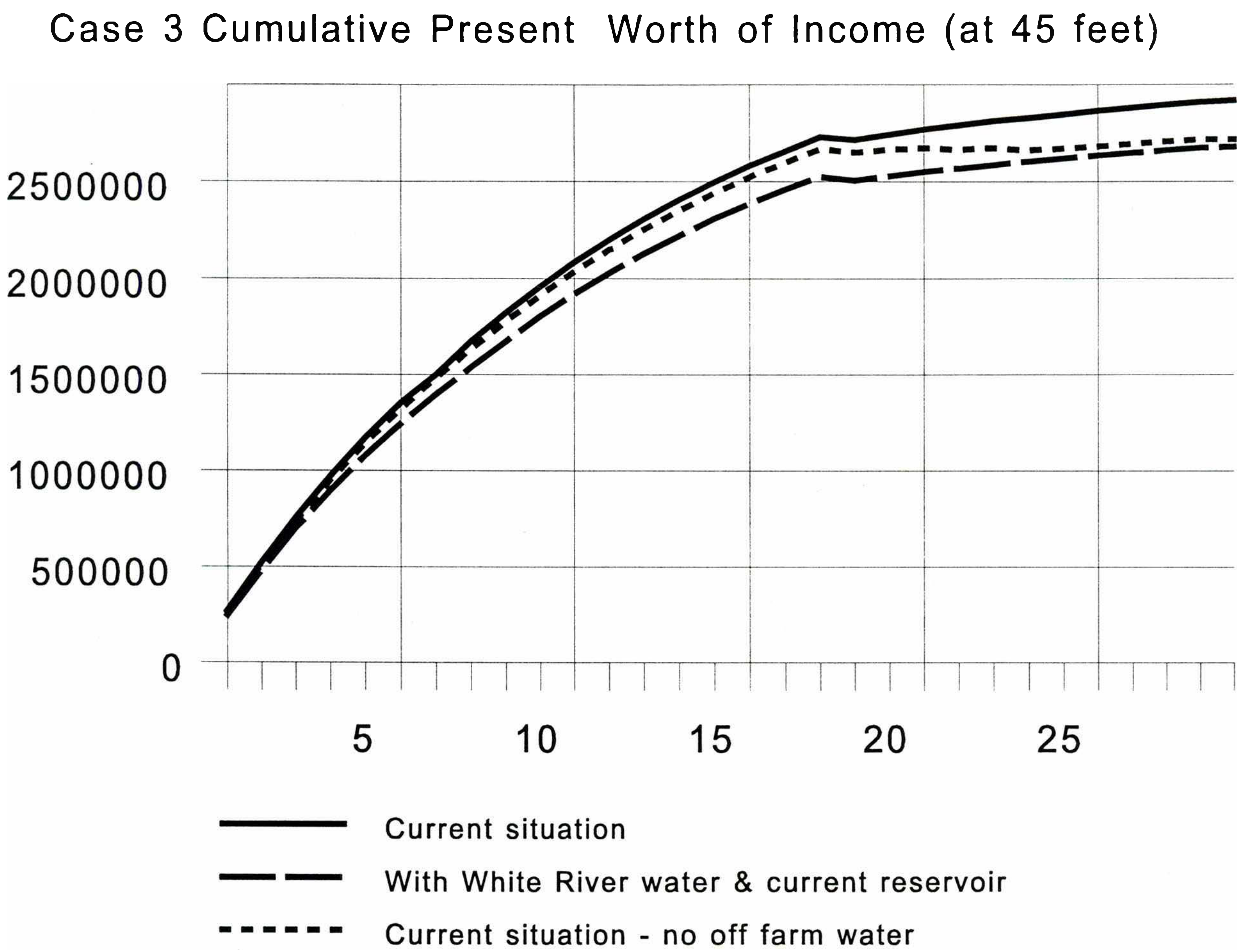
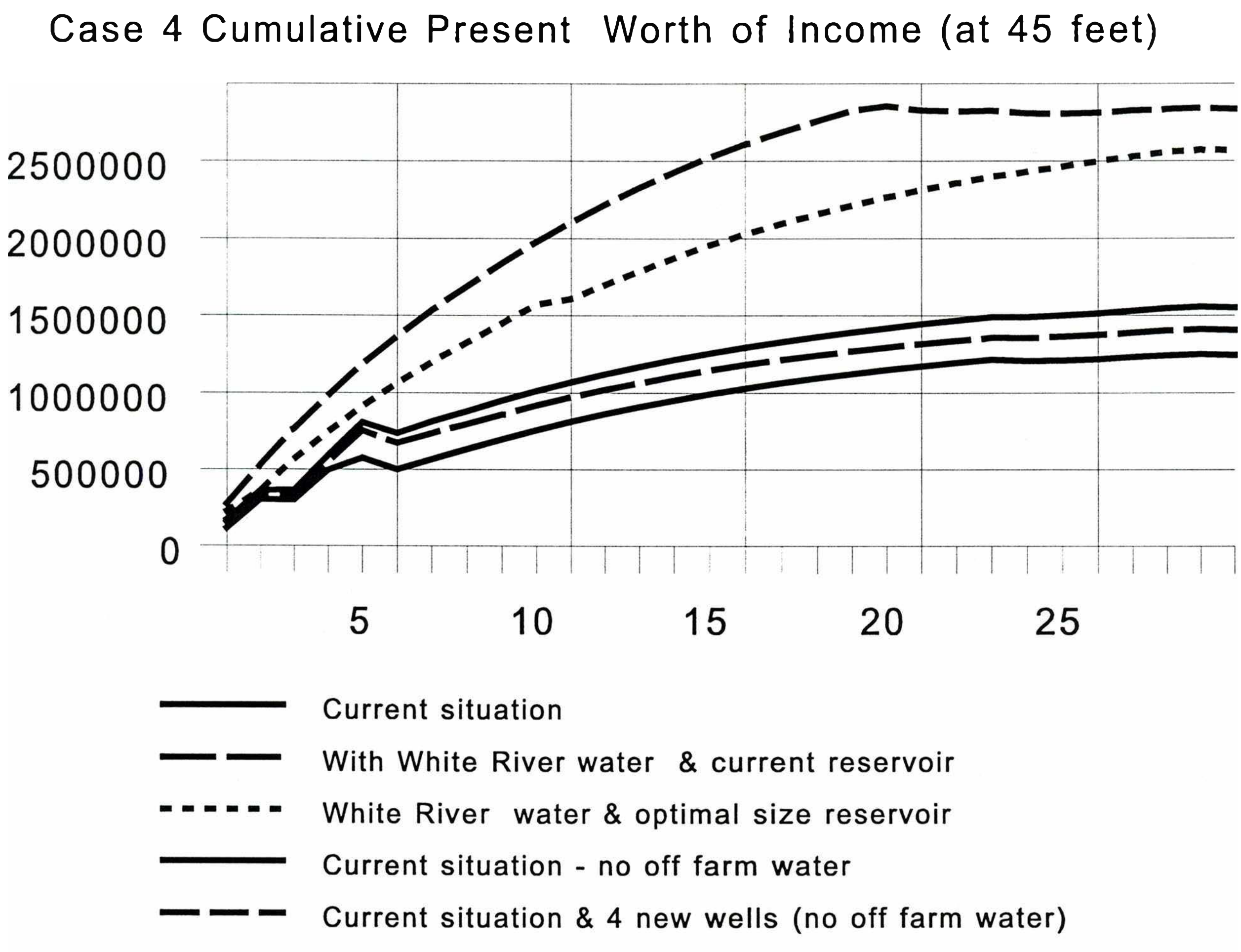
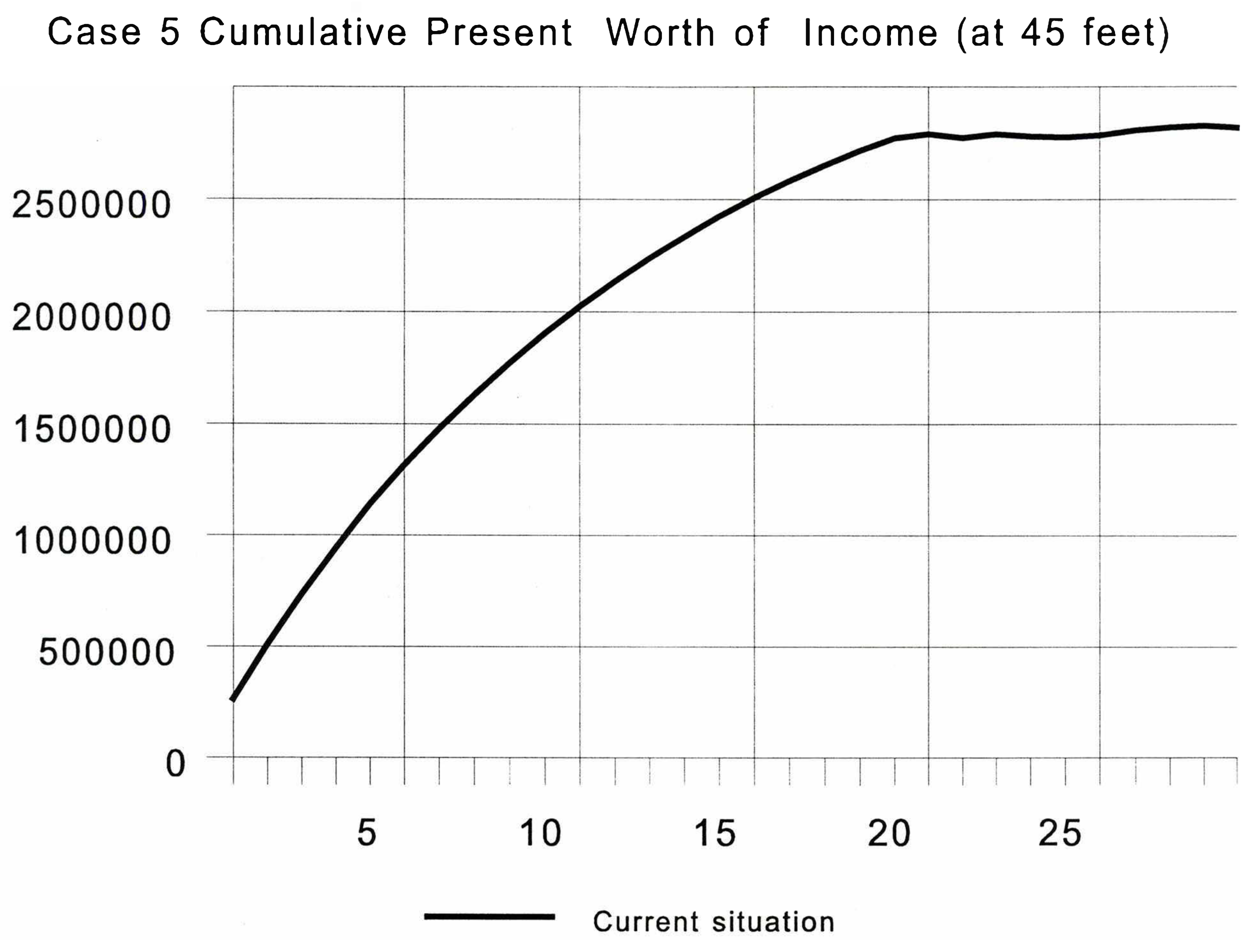

Case 3 Cumulative Present Worth of Income (at 45 feet)
2500000
2000000
1500000
1000000
500000
0
5
10
15
20
25
Current situation
With White River water & current reservoir
Current situation - no off farm water

Figure 9.



Case 4 Cumulative Present Worth of Income (at 45 feet)
2500000
2000000
1500000
1000000
500000
0
5
10
15
20
25
Current situation
With White River water & current reservoir
White River water & optimal size reservoir
Current situation - no off farm water
Current situation & 4 new wells (no off farm water)

Figure 10.



Case 5 Cumulative Present Worth of Income (at 45 feet)
2500000
2000000
1500000
1000000
500000
0
5
10
15
20
25
Current situation

APPENDIX

MARORA MODEL DESCRIPTION

The MARORA model uses weather, farm, and field data, along with economic data related to soybean and rice production in order to simulate the income and expenses associated with off stream reservoirs of various capacities. When executed in optimization mode, the program will operate in a manner which will identify the reservoir size which will result in the maximum present worth of simulated net income for the number of years specified. When executed in non-optimization mode, the model will identify yearly costs and returns for a reservoir of a specified capacity. The MARORA model incorporates algorithms to simulate reservoir and soil water balances, water dispersion and recapture, rice and soybean production costs , crop yields and profits, and other processes related to reservoir performance. It is written in the FORTRAN programming language and is intended for use on PCs (personal computers) with at least a 386 processor. Input data for the program are read from two separate files. The first contains weather data for 30 years for a particular geographic area. (Weather files for the major agricultural areas of eastern Arkansas are available) The second file contains a large number of agricultural and economic variables which allow the simulation to be fine tuned for a particular area and adjusted to investigate the impact of numerous factors on optimal reservoir size and performance.

The basic structure of the model remains unchanged from the original ARORA model as presented by Edwards and Ferguson (1990). Some minor changes to the order in which events unfold were required in order to support the program enhancements. These enhancements include the simultaneous simulation of water use by both soybeans and rice, the dynamic reallocation of rice acreage to soybeans when insufficient water for rice production is detected, the recovery of excess runoff and tail water, the ability to specify multiple wells, lift pumps and irrigation pumps, the ability to calculate the cost and returns for flooding the harvested rice fields for duck hunting and the constraints associated with access to the White River diversion project.

The following numbered text describes the basic processes and organization of the modified ARORA water resource model.

1. Weather and other input data are read into memory and appropriate unit conversions are performed.

2. If ground water is available, then the associated costs of the well and pump(s) are computed.

3. If a reservoir is indicated then the ownership costs for the reservoir and pump(s) are calculated. Dimensions are calculated based on capacity. Depreciation, interest, maintenance, and tax costs are calculated.

4. Rice and soybean field sizes are determined based on input data minus the area occupied by the reservoir if a reservoir is indicated.

5. Depreciation and interest cost associated with the irrigation system are calculated. If no reservoir is indicated and no ground water is available, then these costs are set to zero.

6. Ownership and operating costs which are not associated with irrigation or dependent on crop yield are computed.

7. Reservoir fill begins on the date specified and continues until the reservoir capacity has been met. Costs are computed.

8. Recharge of the aquifer surrounding the well is allowed providing that ground water is available and the well is not currently being used for irrigation, and ground water has been used during the current year. If recharge is allowed then the new potentiometric surface elevation is computed.

9. Rainfall for the day is checked and any runoff from the soybean fields and from any rice fields (if they are not presently flooded), is specified as recoverable runoff. Runoff from a flooded rice field is calculated if the rainfall amount when added to the flood level brings the flood level above six inches. Any amount over the six inch level is assumed to be drained off to protect the levees and is marked as recoverable runoff.

10. If the day of the year is the specified initial rice flush date then the rice soil moisture deficit is set to trigger a two inch flush of the rice field. One inch of the flush is specified as recoverable as tail water.

11. If the day of the year is the specified rice flood date then the rice soil moisture deficit is set to trigger a four inch flood of the rice fields (four inches at the deep end within each levee).

12. If the day of the year is the specified rice "drain for harvest" date then the rice fields are drained and the drainage marked as recoverable tail water.

13. If the day of the year is the "flood for ducks" date (optional) then the soil moisture deficit is set to trigger a 2 inch flood for duck habitat.

14. Check for any available runoff or tail water and return this water to the reservoir. Any amount exceeding the reservoir capacity is lost. The recovery cost is computed.

15. Determine whether to irrigate. Irrigation is allowed if (a) no rain occurred on the current day, (b) surface or ground water is available, (c) the soil moisture deficit is greater than the triggering value, (d) the date is within the growing season of the crop to be irrigated.

Irrigation is provided from the reservoir if available. Otherwise it is provided from ground water if available. Irrigation is supplied based on irrigation pump(s) capacity and system efficiency and constrained by the amount needed to negate the soil moisture deficit.

16. If any irrigation was supplied by ground water then a new potentiometric surface depth is calculated. If the saturated depth surrounding the well is drawn down to zero then ground water irrigation is decreased and restricted until one day of recharge takes place.

17. Irrigation costs are calculated.

18. Evapotranspiration is computed for rice and soybeans, and reservoir evaporation is calculated.

19. Soil moisture deficit values for both rice and soybeans are calculated based on rainfall, irrigation, and evapotranspiration.

20. Reservoir water level is calculated based on changes due to seepage, percolation, evaporation, irrigation, rainfall, and tail water/runoff recovery. (Steps 7 thru 17 are repeated for each day of the year)

21. Crop yield and value for soybeans are computed based on plant transpiration over the growing season and the current price of soybeans. Rice yield is assumed to be the maximum specified provided the water requirements are met, but is reduced by 10 percent each day the rice flood level drops to zero inches. If the rice yield drops to zero for a year it is assumed that the ground water and reservoir water combination is no longer sufficient to support rice so the rice field acreage is converted to soybeans for the remaining years of the simulation. Rice crop value is calculated based on yield and the current rice price. Net income is computed. (This step is repeated for each year of the simulation)

22. Yearly net incomes are converted to present worth.

23. When operating in optimizing mode, the program seeks the reservoir size that maximizes the total of net yearly incomes converted to present worth. The program does this by running through the 30- year simulation for a series of reservoir sizes. The user specifies the maximum reservoir size to be examined and an increment size (normally 5 or 10 acre ft.). The program calculates the present worth of income for the series beginning with no reservoir and continuing for reservoir sizes up to the maximum. It then writes detailed data to file for the reservoir size that resulted in the greatest present worth value.

MARORA PROGRAM INPUT PARAMETERS

The modified ARORA program requires two data files for execution. The first file contains 30 years ' daily weather data to include precipitation, temperature minimum, temperature maximum, solar radiation and wind run. A modified version of the WGEN weather generator program was used to produce weather data for the major agricultural areas of eastern Arkansas. The second data file contains the general simulation parameters, crop and field data, operating and ownership data, ground water data, irrigation system data, reservoir data, well, lift, and irrigation pump data, economic, and optimization data. In order to facilitate modifications to this data, a template file (arsd2.tmp) has been created which contains an explanation or description of each parameter followed by an asterisk and an example value. This values in this file can be modified using any editor found on your computer system. The user then executes a data transformation program (datatran) which takes this data and creates the data file (arsd2.dat) which is used by the modified ARORA program. A printout of this template file follows:

```
Num years to simulate                                          * 30
option (0 = non-optimizing  1 = optimizing)                    * 1
insufficient water option (1=more wells 0=stop rice)           * 0
tailwater recovery option (1=all year 0=growing season)        * 0
total farm acres (decimal)                                     * 160.0
SCS curve num for average moisture (integer)                   * 75
ave elevation of fields in feet (integer)                      * 220
mean of solar radiation sine wave (decimal)                    * 570.46
amplitude of solar radiation sine wave (decimal)               * 234.50
phase shift of solar radiation sine wave (decimal)             * 1.22
soil evaporation parm  (alphasoil) (mm)                        * 4.04
soil evaporation parm  (usoil) (mm)                            * 9
depth of soybean root zone    (inches)                         * 18.00
available water in root zone  (in/in)                          * 0.22
albedo (soil)                                                  * 0.17
day of year for planting soybeans (julian date)                * 140
days past plant day until maturity for soybeans                * 145
maximum expected soybean crop yield  (bu/ac)                   * 52.6
maximum expected rice crop yield     (bu/ac)                   * 135.0
rice plant day                                                 * 140
days until rice maturity                                       * 120
percent of acreage planted in rice                             * .333
tailwater recovery rate                                 * .80
day of year to flood rice stuble for ducks (999 = never)       * 999
duck lease rate (dollars per acre)                             * 30.00
interest rate                                                  * 0.08
discount rate                                                  * 0.08
insurance rate                                                 * 0.025
tax rate as fraction of initial cost                           * 0.01
```

soybean price ($/bu)	* 6.75
rice price ($/bu)	* 5.00
soybean seed cost ($/ac)	* 10.80
soybean fertilizer cost ($/ac)	* 14.00
soybean lime & application cost ($/ac)	* 7.91
soybean herbicide cost ($/ac)	* 15.03
soybean fungicide cost ($/ac)	* 1.53
soybean insecticide cost ($/ac)	* 0.00
soybean defoliant cost ($/ac)	* 0.00
soybean aerial application cost ($/ac)	* 0.00
soybean machinery fuel, oil, and lubricants cost ($/ac)	* 10.69
soybean annual machine repair cost ($/ac)	* 20.82
soybean labor cost ($/ac)	* 8.65
soybean custom spread cost ($/ac)	* 3.00
soybean custom haul cost ($/bu)	* 0.15
soybean custom drying costs ($/bu)	* 0.00
soybean misc cost ($/ac)	* 0.00
soybean crop insurance costs ($/ac)	* 0.00
soybean other costs ($/ac)	* 0.00
rice seed costs ($/ac)	* 14.81
rice fertilizer costs ($/ac)	* 42.90
rice lime cost ($/ac)	* 0.00
rice herbicide costs ($/ac)	* 39.39
rice fungicide costs ($/ac)	* 16.67
rice insecticide costs ($/ac)	* 4.72
rice defoliant costs ($/ac)	* 0.00
rice aerial application cost ($/ac)	* 30.73
rice machinery fuel, oil, & lubricants cost ($/ac)	* 11.10
rice annual machine repair costs ($/ac)	* 24.59
rice labor costs ($/ac)	* 12.00
rice custom spread costs ($/ac)	* 3.50
rice custom haul costs ($/bu)	* 0.11
rice custom dry or ginning costs ($/bu)	* 0.24
rice misc costs ($/ac)	* 4.70
rice crop insurance costs ($/ac)	* 0.00
rice other costs ($/ac)	* 0.00
tractor depreciation ($/ac)	* 8.49
tractor interest ($/ac)	* 7.01
equipment depreciation ($/ac)	* 7.30
equipment interest ($/ac)	* 4.00
special equipment depreciation ($/ac)	* 10.98
special equipment interest ($/ac)	* 4.02
misc equipment depreciation ($/ac)	* 0.00
misc equipment interest ($/ac)	* 0.00

taxes and insurance ($/ac)	* 3.42
interest ($/ac)	* 0.37
overhead labor ($/ac)	* 0.00
other overhead ($/ac)	* 0.00
land and property tax ($/ac)	* 0.00
management cost ($/ac)	* 0.00
initial groundwater depth (ft)	* 120
ground water decline rate (ft/yr)	* 1.0
storage coefficient (decimal)	* 0.30
saturated hydraulic conductivity of aquifer (ft/day)	* 270.00
initial saturated thickness of aquifer (ft)	* 50.0
number of wells in operation (decimal)	* 1.0
well diameter (ft)	* 1.33
well cost ($)	* 4320.00
expected life of well (yrs)	* 30
annual well repair cost as % initial cost (dec)	* 0.01
well flow (gal/min)	* 1100.00
well pumping plant efficiency (decimal)	* 0.18
cost of pump and gearhead ($/well)	* 6060.00
expected life of pump and gearhead (yr)	* 15.00
pump & gearhead repair as % of initial cost (decimal)	* 0.025
discharge diameter of well pump (ft)	* 0.75
cost of power unit ($)	* 5600.00
expected life of power unit (yr)	* 15.00
annual repair cost of power unit as % of initial cost ($)	* 0.025
energy cost ($/KW-hr)	* 0.075
lubrication cost as % of initial cost ($)	* 0.03
soybean application efficiency (decimal)	* 0.65
rice application efficiency (decimal)	* 0.80
cost of irrigation system ($)	* 11715.00
expected life of irrigation system (yr)	* 15.00
annual irrig system repair cost as % of initial cost (dec)	* 0.005
irrigation labor (hr/acre-inch)	* 0.18
irrigation labor cost ($/hr)	* 4.15
irrigation system operating pressure (psi)	* 15.00
soil moisture deficit to begin soybean irrigation (mm)	* 50.80
drop in flood level to begin rice irrigation (mm)	* 50.80
reservoir freeboard (ft)	* 1.50
top width of reservoir levees (ft)	* 12.00
outside slope (hor to vert) of reservoir levee	* 3.00
inside slope of reservoir levee	* 3.00
excavation cost ($/cu-yd)	* 0.75
levee seeding cost ($)	* 1000.00
expected life of the reservoir (yr)	* 30.00

annual res maintenance cst as % of construction cst (dec)	* 0.02
saturated hydraulic conductivity of levee bottom (ft/day)	* 0.009
average ablbedo of water (decimal)	* .36
day of year to begin reservoir fill	* 110
number of relift pumps	* 1.0
operating head for relift pump(s) (ft)	* 20.00
capacity of relift pumps (gal/min)	* 2200.00
efficiency of relift pumps (decimal)	* 0.18
cost of relift pump(s) ($/pump)	* 8000.00
expected life of relift pumps (yr)	* 15.00
cost of relift pump repairs as % of initial cost	* 0.025
relift pump lubrication cost as % of fuel costs	* 0.03
number of irrigation pumps	* 1.0
operating head for irrigation (ft)	* 10.00
capacity of irrigation pump(s) (gal/min)	* 2200.00
irrigation pump efficiency (decimal)	* 0.18
cost of irrigation pump(s) ($/pump)	* 10500.00
expected life of irrigation pump(s) (yr)	* 15.00
irrigation pump(s) repair cost as % of initial cost	* 0.025
irrig pump lubrication cost as % of fuel cost	* 0.03
maximum value of reservoir capacity (ac-ft)(decimal)	* 260.0
reservoir size increment (for optimization) (ac-ft)	* 10.0

MARORA MODEL OUTPUT

*** SUMMARY OF METEOROLOGICAL DATA ***

YR	TOTAL RAIN (IN)	POT ET (IN)	ACT ET (IN)	PLANT TRANS (IN)	YIELD (SOYB) (BU/AC)	POT R EVAP (IN)	ACT R EVAP (IN)
--	----	----	----	----	-----	----	----
1	49.8	51.7	39.1	17.0	40.0	41.2	24.5
2	48.7	47.4	37.7	15.5	40.0	39.6	29.0
3	44.9	48.9	37.5	15.7	40.0	40.8	28.8
4	42.3	49.6	38.7	16.3	40.0	41.4	23.0
5	50.5	49.7	37.6	16.4	40.0	41.5	27.1
6	42.3	50.5	38.9	16.8	40.0	42.1	23.7
7	34.0	50.7	38.5	16.3	40.0	42.3	19.7
8	33.8	49.3	34.2	15.9	40.0	41.0	23.3
9	60.1	48.1	38.5	16.0	40.0	40.2	30.2
10	57.4	49.9	39.4	16.6	40.0	41.7	34.8
11	43.3	50.9	36.9	16.6	40.0	42.4	29.7
12	41.6	50.0	37.8	16.2	40.0	41.6	25.0
13	51.6	50.0	37.8	6.2	40.0	41.6	26.6
14	38.8	50.9	38.2	17.0	40.0	42.2	27.6
15	52.0	49.1	38.7	16.3	40.0	40.9	34.4
16	47.9	48.7	36.4	16.1	40.0	40.5	28.1
17	42.4	49.8	37.0	16.8	40.0	41.6	27.2
18	45.0	49.0	38.3	16.6	39.9	40.9	21.4
19	33.8	50.3	29.3	9.3	22.8	41.9	19.5
20	33.1	49.0	27.9	10.8	26.5	41.0	23.6
21	33.7	48.9	28.5	11.6	27.0	40.9	19.6
22	40.4	49.2	30.2	7.4	18.7	41.0	23.4
23	42.1	47.4	31.3	10.8	27.7	39.5	23.3
24	45.8	49.9	27.2	5.9	14.4	41.7	27.1
25	45.8	49.5	33.1	12.2	30.9	41.2	32.5
26	45.1	49.1	34.1	12.7	32.1	40.9	27.5
27	50.5	48.2	36.2	14.8	37.8	40.2	25.2
28	62.8	48.8	37.9	14.1	35.2	40.8	35.6
29	52.0	48.0	34.8	13.4	33.7	40.1	33.1
30	37.6	49.6	28.9	8.9	21.7	41.5	29.9
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AVG	45.0	49.4	35.4	14.2	34.9	41.1	26.8

*** SUMMARY OF RICE IRRIGATION DELIVERY OPERATING COSTS ***

YR	NET IRRIG (IN)	GROSS IRRIG (IN)	SUP GND (IN)	SUP SURF (IN)	TOTAL COST* ($)	GND COST* ($)	SURF COST* ($)	RICE IRRIG (IN)
--	----	----	----	----	------	------	------	----
1	19.1	23.9	23.0	.9	14715.	12630.	453.	19.1
2	16.1	20.1	10.8	9.3	9120.	6510.	978.	16.1
3	23.6	29.5	14.2	15.3	11218.	8230.	1356.	23.6
4	18.5	23.1	21.0	2.1	13921.	11756.	533.	18.5
5	21.9	27.4	22.8	4.6	15080.	12761.	687.	21.9
6	25.0	31.2	28.7	2.5	17942.	15753.	557.	25.0
7	26.6	33.3	33.0	.2	20289.	18243.	413.	26.6
8	25.2	31.6	29.6	1.9	18727.	16576.	519.	25.2
9	16.1	20.1	13.7	6.4	10698.	8269.	798.	16.1
10	17.7	22.1	6.3	15.9	7374.	4350.	1391.	17.7
11	25.2	31.5	18.4	13.0	13679.	10832.	1214.	25.2
12	28.2	35.3	26.6	8.7	17745.	15170.	943.	28.2
13	17.6	22.0	17.6	4.4	12818.	10515.	672.	17.6
14	24.7	30.9	24.0	7.0	16285.	13817.	836.	24.7
15	15.8	19.8	3.6	16.2	6050.	3006.	1412.	15.8
16	21.5	26.8	23.1	3.7	15927.	13664.	631.	21.5
17	25.9	32.3	18.3	14.1	13854.	10943.	1279.	25.9
18	22.3	27.9	18.2	9.7	13584.	10948.	1005.	22.3
19	12.6	15.7	12.2	3.5	9965.	7712.	622.	12.6
20	.0	.0	.0	.0	3120.	0.	400.	.0
21	.0	.0	.0	.0	3120.	0.	400.	.0
22	.0	.0	.0	.0	3120.	0.	400.	.0
23	.0	.0	.0	.0	3120.	0.	400.	.0
24	.0	.0	.0	.0	3120.	0.	400.	.0
25	.0	.0	.0	.0	3120.	0.	400.	.0
26	.0	.0	.0	.0	3120.	0.	400.	.0
27	.0	.0	.0	.0	3120.	0.	400.	.0
28	.0	.0	.0	.0	3120.	0.	400.	.0
29	.0	.0	.0	.0	3120.	0.	400.	.0
30	.0	.0	.0	.0	3120.	0.	400.	.0
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AVG	13.5	16.8	12.2	4.6	9777.	7056.	690.	13.5

***** SUMMARY OF SOYBEAN IRRIGATION DELIVERY OPERATING COSTS *****

YR	NET IRRIG (IN)	GROSS IRRIG (IN)	SUP GND (IN)	SUP SURF (IN)	TOTAL COST* ($)	GND COST* ($)	SURF COST* ($)	BEAN IRRIG (IN)
--	----	----	----	----	------	------	------	----
1	10.0	13.4	12.3	1.1	12417.	10830.	499.	10.0
2	11.3	15.1	13.7	1.3	13605.	11994.	523.	11.3
3	9.8	13.0	12.3	.7	12636.	11085.	463.	9.8
4	12.3	16.4	15.4	1.0	14893.	13308.	497.	12.3
5	8.2	10.9	9.9	1.0	10857.	9277.	492.	8.2
6	14.8	19.7	18.6	1.1	17523.	15934.	501.	14.8
7	14.5	19.3	18.2	1.1	17289.	15698.	503.	14.5
8	16.2	21.6	20.5	1.1	19056.	17464.	504.	16.2
9	8.5	11.4	10.1	1.2	11153.	9549.	516.	8.5
10	10.6	14.2	10.1	4.1	11428.	9557.	783.	10.6
11	11.6	15.4	14.5	.9	14672.	13099.	485.	11.6
12	13.8	18.4	17.5	.9	17103.	15527.	488.	13.8
13	12.0	16.0	15.1	1.0	15219.	13639.	492.	12.0
14	11.9	15.8	15.0	.8	15224.	13662.	474.	11.9
15	9.3	12.4	8.5	3.9	10325.	8476.	761.	9.3
16	10.3	13.8	10.6	3.2	12001.	10213.	700.	10.3
17	14.5	19.3	18.4	.8	18184.	16617.	479.	14.5
18	12.8	17.1	16.8	.3	16830.	15314.	429.	12.8
19	6.5	8.6	8.3	.3	9957.	8439.	430.	6.5
20	5.2	7.0	6.2	.8	8304.	7833.	471.	5.2
21	3.4	4.5	3.4	1.1	6050.	5549.	501.	3.4
22	2.6	3.5	1.6	1.9	4601.	4021.	581.	2.6
23	1.0	1.4	.7	.7	3752.	3290.	463.	1.0
24	.9	1.2	.4	.8	3542.	3071.	471.	.9
25	6.9	9.2	.1	9.1	4094.	2842.	1253.	6.9
26	5.0	6.7	.1	6.6	3825.	2807.	1018.	5.0
27	1.0	1.4	.0	1.3	3285.	2762.	523.	1.0
28	4.4	5.9	.0	5.9	3690.	2739.	951.	4.4
29	4.8	6.4	.0	6.4	3730.	2731.	1000.	4.8
30	5.1	6.8	.0	6.8	3759.	2720.	1039.	5.1
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AVG	8.6	11.5	9.3	2.2	10634.	9335.	610.	8.6

* COSTS ARE FOR FUEL, LUBRICANTS, AND LABOR
DOES NOT INCLUDE RESERVOIR OR IRRIGATION SYSTEM COSTS

*** SUMMARY OF RESERVOIR FILL, LOSSES, AND OPERATING COST DATA ***

YEAR	SEEPAGE LOSSES (AC-FT)	EVAPORATION LOSSES (AC-FT)	RAINFALL ADDITIONS (AC-FT)	VOLUME OF FILL (AC-FT)	COST OF FILL* ($)	RECOVERED WATER AC-FT
----	-------	-------	-------	-------	-------	-------
1	195.7	180.8	439.1	344.5	612.	344.5
2	240.7	217.6	430.8	503.8	802.	503.8
3	211.6	216.7	377.4	231.8	477.	231.8
4	175.7	170.4	354.2	185.3	421.	185.3
5	218.9	200.6	418.4	195.2	433.	195.2
6	197.4	175.3	347.9	171.7	405.	171.7
7	160.4	145.9	277.8	139.6	367.	139.6
8	207.2	172.5	289.8	263.8	515.	263.8
9	249.5	223.9	572.3	658.0	986.	658.0
10	255.3	264.3	496.7	519.2	820.	519.2
11	234.2	222.8	402.6	555.8	864.	555.8
12	209.1	186.9	336.3	122.2	346.	122.2
13	208.0	197.0	457.0	464.8	755.	464.8
14	222.1	206.0	362.0	516.9	818.	516.9
15	250.2	260.2	457.5	415.3	696.	415.3
16	236.6	209.0	426.9	536.3	841.	536.3
17	226.2	204.2	378.2	409.6	689.	409.6
18	189.3	159.4	391.0	300.4	559.	300.4
19	172.9	144.2	291.7	171.4	405.	171.4
20	197.1	175.1	278.0	112.1	334.	112.1
21	174.5	145.3	274.6	38.7	246.	38.7
22	198.4	173.1	344.0	174.3	408.	174.3
23	194.2	172.6	343.4	54.5	265.	54.5
24	212.4	201.1	393.8	232.7	478.	232.7
25	237.5	244.7	410.0	365.7	637.	365.7
26	198.8	205.5	396.8	301.2	560.	301.2
27	214.1	186.5	417.8	114.7	337.	114.7
28	266.9	265.0	543.2	342.0	608.	342.0
29	244.7	247.5	474.3	490.1	785.	490.1
30	228.7	225.8	356.5	472.2	764.	472.2
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AVG	214.3	200.0	391.3	313.5	374.	313.5

* FUEL, LUBRICANTS, AND REPAIRS USED TO FILL RESERVOIR
DOES NOT INCLUDE RESERVOIR MAINTENANCE COSTS

*** SUMMARY OF COST DATA ***

YEAR	OWNERSHIP COSTS ($)	OPERATING COSTS ($)	RETURNS ($)	NET INCOME ($)	PRESENT WORTH ($)	SB INCOME ($)	RICE INCOME ($)
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1	64823.	201163.	487910.	221924.	205485.	163986.	323924.
2	64823.	196777.	487910.	226310.	194024.	163986.	323924.
3	64823.	197614.	487910.	225473.	178988.	163986.	323924.
4	64823.	202714.	487910.	220373.	161980.	163986.	323924.
5	64823.	199734.	487910.	223353.	152010.	163986.	323924.
6	64823.	209615.	487910.	213472.	134524.	163986.	323924.
7	64823.	211771.	487910.	211316.	123301.	163986.	323924.
8	64823.	212140.	487910.	210947.	113968.	163986.	323924.
9	64823.	196060.	487910.	227027.	113570.	163986.	323924.
10	64823.	192716.	487910.	230371.	106706.	163986.	323924.
11	64823.	202692.	487910.	220395.	94524.	163986.	323924.
12	64823.	208910.	487910.	214177.	85053.	163986.	323924.
13	64823.	202253.	487910.	220834.	81200.	163986.	323924.
14	64823.	205928.	487910.	217159.	73934.	163986.	323924.
15	64823.	190063.	487910.	233024.	73459.	163986.	323924.
16	64823.	202229.	487910.	220858.	64466.	163986.	323924.
17	64823.	206346.	487910.	216741.	58578.	163986.	323924.
18	64823.	204513.	487524.	218189.	54601.	163601.	323924.
19	64823.	163521.	93409.	-134935.	-31266.	93409.	0.
20	64823.	127212.	181095.	-10940.	-2347.	181095.	0.
21	64823.	124861.	184719.	-4966.	-986.	184719.	0.
22	64823.	122200.	127465.	-59558.	-10955.	127465.	0.
23	64823.	122594.	189162.	1745.	297.	189162.	0.
24	64823.	120492.	98091.	-87224.	-13755.	98091.	0.
25	64823.	123841.	211021.	22357.	3265.	211021.	0.
26	64823.	123665.	218999.	30510.	4125.	218999.	0.
27	64823.	123775.	258040.	69443.	8693.	258040.	0.
28	64823.	124067.	240265.	51375.	5955.	240265.	0.
29	64823.	124067.	230474.	41585.	4463.	230474.	0.
30	64823.	122172.	148199.	-38797.	-3856.	148199.	0.
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AVG	64823.	172190.	365431.	128418.	67800.	171077.	194354.

*** SUMMARY OF RESERVOIR CHARACTERISTICS ***

DESIGN CHARACTERISTICS:

CAPACITY	=	1100.00 ACRE-FEET
EXCAVATED DEPTH	=	1.26 FEET
STORAGE HEIGHT ABOVE GROUND LEVEL	=	10.71 FEET
FREEBOARD	=	1.50 FEET
TOTAL DEPTH	=	13.47 FEET
LEVEE SLOPE OUTSIDE	=	3.00:1
LEVEE SLOPE INSIDE	=	3.00:1
BOTTOM BASE OF RESERVOIR	=	1964.30 FEET
TOTAL BASE OF RESERVOIR	=	2053.37 FEET
AREA OCCUPIED	=	96.79 ACRES
AREA OF FOREGONE PRODUCTION	=	97.74 ACRES
REMAINING IRRIGATED AREA	=	1012.26 ACRES
TOTAL SOYBEAN ACRES	=	607.36 ACRES
SOYBEAN ACRES AFTER YEAR 19	=	1012.26 ACRES
TOTAL RICE ACRES	=	404.90 ACRES
RICE ACRES AFTER YEAR 19	=	.00 ACRES

ASSOCIATED COSTS:

EXCAVATION COST AT .00/CU YD	= $	.00
SEEDING COST AT 0./AC	= $	.00
COST OF LIFT PUMP(S)	= $	8000.00
COST OF SURFACE IRRIGATION PUMP(S)	= $	16000.00

TOTAL CONSTRUCTION COST	= $	24000.00

AVERAGE ANNUAL OPERATING COSTS

RESOURCE OR INPUT	SB COST	COST/ACRE	RICE COST	COST/ACRE
SEED	9523.	12.60	4795.	18.70
FERTILIZER	9070.	12.00	8847.	34.50
LIME + APPLICATION	4535.	6.00	0.	.00
HERBICIDE	22675.	30.00	10129.	39.50
FUNGICIDE	1020.	1.35	2116.	8.25
INSECTICIDE	0.	.00	0.	.00
DEFOLIANT	0.	.00	0.	.00
AERIAL APPLICATION	0.	.00	6385.	24.90
MACHINERY:				
FUEL,OIL,LUBRICANTS	7936.	10.50	2436.	9.50
REPAIRS	15736.	20.82	6306.	24.59
LABOR	8692.	11.50	2564.	10.00
CUSTOM SPREAD	2645.	3.50	898.	3.50
CUSTOM HAUL	3961.	5.24	7515.	18.56
CUSTOM DRY OR GINNING	0.	.00	18788.	46.40
MISCELLANEOUS	0.	.00	1205.	4.70
CROP INSURANCE PREMIUM	0.	.00	0.	.00
OTHER	0.	.00	0.	.00
IRRIGATION FROM WELL:				
FUEL,OIL,LUBRICANTS	7093.	9.38	6183.	24.11
REPAIRS	2031.	67.70	689.	22.97
IRRIGATION LABOR	211.	.28	184.	.72
IRRIGATION FROM RESERVOIR:				
FUEL,OIL,LUBRICANTS	159.	.21	220.	.86
REPAIRS	299.	.40	101.	.40
IRRIGATION LABOR	51.	.07	70.	.27
SUBTOTAL OP COST	95637.	191.54	79432.	292.42

*** the remaining categories show combined costs ***

RESERVOIR MAINTENANCE	0.	.00
RESERVOIR FILL		
FUEL,OIL,LUBRICANTS	374.	.37
REPAIRS	200.	.20
INTEREST ON OP CAPITAL	6623.	6.54
IRRIGATION SYS REPAIRS	60.	.06
TOTAL SPECIFIED OP COST	**182327.**	

AVERAGE ANNUAL OWNERSHIP COSTS

RESOURCE OR INPUT	COST	COST/ACRE
TRACTORS:		
DEPRECIATION	8594.	8.49
INTEREST	7096.	7.01
EQUIPMENT:		
DEPRECIATION	7390.	7.30
INTEREST	4049.	4.00
SPECIAL EQUIPMENT:		
DEPRECIATION	11115.	10.98
INTEREST	4069.	4.02
MISCELLANEOUS:		
DEPRECIATION	0.	.00
INTEREST	0.	.00
IRRIGATION:		
DEPRECIATION	6667.	6.59
INTEREST	8000.	7.90
RESERVOIR:		
DEPRECIATION	799.	.79
INTEREST	959.	.95
TAXES AND INSURANCE	5544.	5.48
INTEREST	444.	.44
OVERHEAD LABOR	0.	.00
LAND AND PROPERTY TAX	0.	.00
OTHER OVERHEAD	0.	.00
MANAGEMENT	0.	.00
TOTAL SPECIFIED OWN COSTS	64726.	56.93

AVERAGE ANNUAL RETURNS	365431.	361.00
TOTAL OP AND OWN COSTS	247052.	244.06
DIFFERENCE	118379.	116.95