WRC Report No. 198

ANALYSIS OF POTENTIAL FOR SUPPLEMENTAL IRRIGATION IN SOUTHERN ILLINOIS

by

John T. Scott,Jr. Professor
James A.K. Taylor, Graduate Research Assistant
and
John B. Braden, Associate Professor
Department of Agricultural Economics
University of Illinois

The research on which this report is based was financed in part by the U.S. Department of the Interior, as authorized by the Water Resources Research Act of 1984 (P.L. 98-242).

Grant Project Completion Report No. INT 14-08-0001-G904-05

December, 1985

Water Resources Center
2535 Hydrosystems Laboratory
Urbana, Illinois 61801

December 1985

Acknowledgements

This study reflects partial work on the doctoral dissertation research project of Mr. James A.K. Taylor. Two senior civil engineering students also worked on the project on an hourly basis. The support of the U.S. Geological Survey through the Illinois Water Resources Center, and particularly of WRC Director Glenn Stout, is gratefully acknowledged.

This study has benefitted from suggestions, data, and other help provided by Gary Johnson, David White, Pei-Ing Wu, Ravi Venkat, Parveen Setia, Changwoo Pyo, Joeng Lim, Walt Lembke, Kent Mitchell, Royce Hinton, Ron Brown, Emerson Smalley, and Doyce Sheraden. Sylvia Fry and Debbie Etzwiler typed the report. We appreciate the help given by these individuals.

ABSTRACT

The aim of this study is to determine the potential for supplemental crop irrigation of the tight subsoil area of Southern Illinois with surface water impounded in small catchment reservoirs.

The geographic area of the tight soils (mainly the southern 1/3 of Illinois includes almost 25 percent of the state. Random statistical sampling was used to select topographic quadrangles in this area for investigation of reservoir sites. Costs and water volume were then computed for sites with potential for reservoir siting. The results of the survey of potential reservoirs and cost analysis indicate abouat 1.2 million acres of land in the claypan area of Southern Illinois can be irrigated under current cost conditions depending on the price of corn and soybeans.

From inspection of the best potential reservoir sites, watersheds, and irrigation areas, a specific site was selected for detailed analysis. Site analysis showed the most profitable management practice to be a corn-soybean rotation with reduced tillage, up-and-down slopes plowing, and irrigation. Further analysis was performed concerning the effect of sedimentationon reservoir capacity and, optimal land use. The results indicate that, over a thirty-year period, sedimentation will not have any appreciaable effect on reservoir capacity and on land use practice.

Finally, the supplemental irrigation system was analysed to determine its overal economikc feasibility. A supply curve for irrigation from reservoirs was developed.

Key Words: Irrigation Potential, Supplemental Irrigation, Waste Water Irrigation, Agricultural Runoff, Rainfall Runoff Relationships, Reservoir Capacity, Reservoir Siting, Water Conservation, Conservation Storage, Recycling, Management System or Practice.

Executive Summary

This report presents the results of an investigation into the potential for supplemental crop irrigation of the tight subsoil area of Southern Illinois with surface water impounded in small catchment reservoirs. The aim of the study was to determine the geographic and economic feasibility of irrigation from surface impoundments in this region.

The geographic area of the tight soils (mainly the southern 1/3 of Illinois) was determined. This soil area includes almost 25 percent of the state. A random statistical sampling procedure was used to select topographic quadrangles within the study area for investigation of reservoir sites. Reservoir costs and water volume were then computed for the sites within quadrangles with good potential for reservoir siting. The results of the geographic sample survey of potential catchment reservoirs and the subsequent cost analysis indicate that there is a potential for irrigating about 1.2 million acres of land in the claypan area of Southern Illinois with surface catchment runoff water under current cost conditions depending on the price of corn.

From on-site inspection of the potentially best reservoir sites, watersheds, and area for irrigation, a specific site was selected for detailed analysis. The specific site analysis showed irrigation of corn to be profitable, with the most profitable management practice being a corn-soybean rotation with reduced tillage, plowing up and down slopes, and irrigation. Further analysis was performed concerning the potential effect of sedimentation on reservoir capacity and, hence,

on optimal land management practices. The results indicate that, over a thirty year planning horizon, sedimentation did not have any appreciable effect on reservoir capacity and consequently, on the choice of an optimal set of management practices.

Finally, the supplemental irrigation system was subjected to financial analysis to determine its overall economic feasibility. All sizes of reservoirs were found to be clearly profitable.

Table of Contents

List of Tables

List of Figures and Maps

1. Aggregate Assessment of Irrigation from Surface Water Impoundments in Illinois

1.1 Introduction and Background

The research reported here was designed to evaluate the economic feasibility of supplemental irrigation of corn and soybeans in Illinois south of the Wisconsin glaciation by impoundment and use of water runoff. If economically feasible, this would improve management of water resources. Since the exploitable quantity of ground water in this area is very limited for most uses, including human consumption as well as irrigation, the physical and overall economic feasibility of establishing catchment reservoirs for irrigation is of interest. Moreover, production cost risk is a function of yield variability of the two dominant crops, corn and soybeans. The variability in yields occurs mainly from the variability in rainfall and this variability in rainfall and the resultant crop yield response can be reduced substantially by supplemental irrigation.

In any kind of catchment reservoir system for runoff water, an important aspect of water control is the control of nonpoint source pollution. The report estimates sediment runoff and costs of obtaining sediment reductions. The effect of sediment deposition on reservoir life is also considered.

Irrigation in agriculture has a long and successful history in many arid and semiarid environments. However, only recently has interest in irrigation for grain crops occurred in the humid and sub-humid environments. The most intensive interest and successful application of supplemental irrigation in the humid to sub-humid environments has centered in the western regions of the "Corn Belt" states (Sisson and Wiersma). Almost without exception of water for irrigation in these areas has come from underground sources.

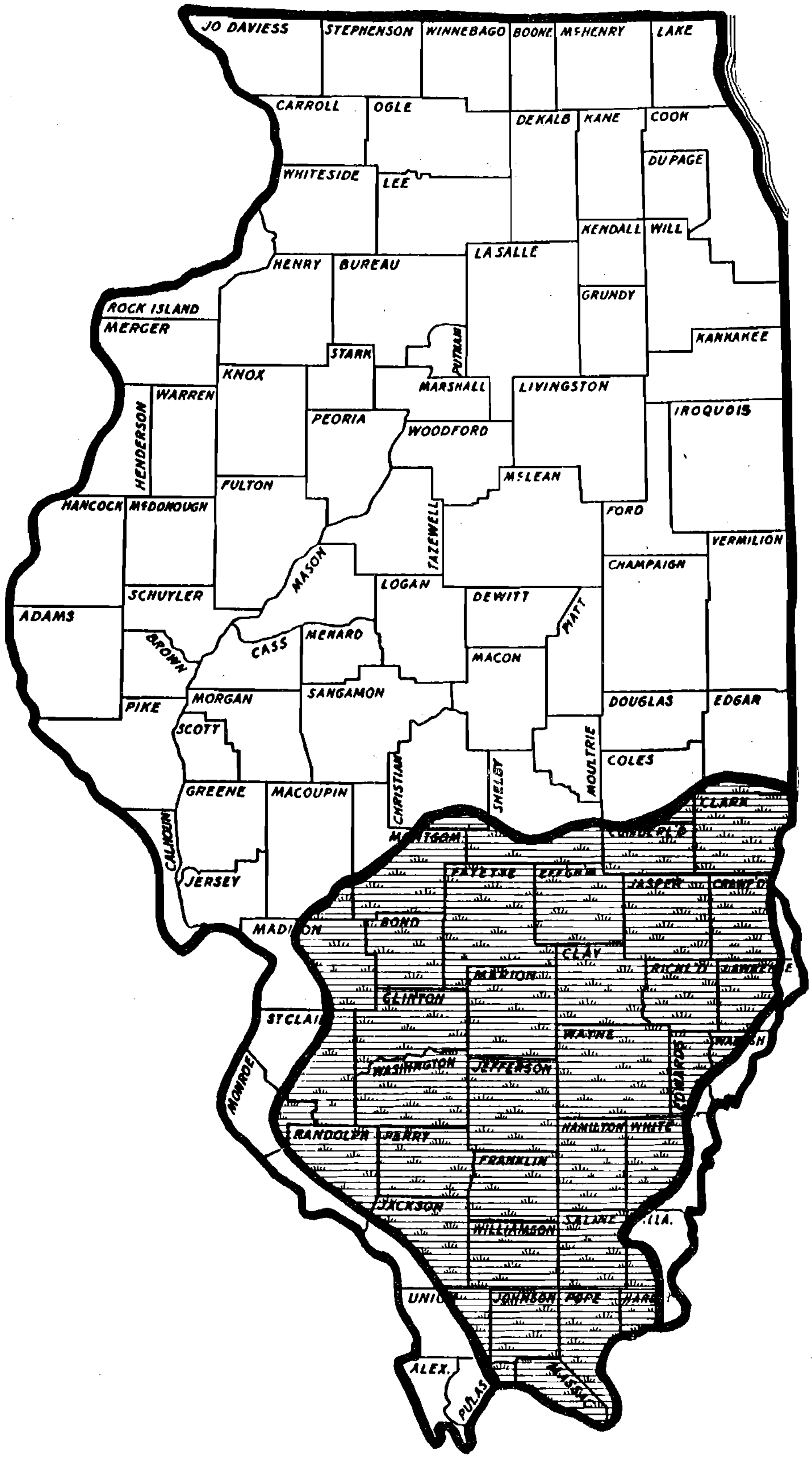
Because grain farmers operate in a competitive market and are not able to influence the prices of their output to any significant degree, they have tried to reduce costs per unit of production by increasing output. Additionally, cost savings resulting from increased size of farm or reduced costs per unit are not expected to any significant extent in the foreseeable future. Further increases in yield in humid areas are now likely only through development of new technologies and varieties and through improved water control and water use. A recent study by Lazarus and Scott shows that the variance of yield on individual farms over the years is substantially larger than expected based on previously known information on the variation from year to year of county yields. For example, in Effingham County, Illinois which is in the study area, a sample of 10 high management farms studied over a period of 21 years shows an average standard error of 23 bushels per acre for corn yield even after removing the time trend for yield increases. This means that if the variation is normally distributed, then 2/3 of the time the range in yield expected is 46 bushels per acre. Assuming that on these high management farms most of the known technologies are being applied, then this large variation will be due largely to low soil water holding capacity and variation in rainfall. Looking only at the county average yields over the same period, we would mistakenly assume the standard error to be only 12 bushels per acre or about half the actual variation faced by individual farmers. The difference is a consequence of aggregating across farms that may experience partially offsetting yield results in a given year.

In nonirrigated areas, soil moisture in the form of natural occurring rainfall has been regarded as a ubiquitous and free input. However, scientific research has documented the importance of rainfall, particularly during the flowering period, on corn and soybean yields (Runge and Odell). Given the optimum economic level of chemical inputs, seeding rate, and time of planting, the soil moisture level during the flowering stage is the most limiting factor on yields. If yields per acre are to be significantly increased, soil moisture availability will have to be increased during the actual flowering stages.

While it is true that every section of Illinois normally receives more water as rain or snow each year than is lost by evapotranspiration, there is never a year when soil moisture is not deficient for optimum crop growth sometime during the growing season, particularly in the area south of the Wisconsin glaciation. (Shown on Map 1.1) In an "average" year evaporation plus transpiration exceeds precipitation from May to September. Crops will grow well during this period only if stored soil moisture is sufficient to make up the deficit, evapotranspiration is reduced appreciably below potential, or water is added by irrigation (Hinesly, Pendleton, and Peters).

The low moisture holding capacity of soils, high evapotranspiration, and low probability of getting rain in Southern Illinois during the critical flowering stage of corn and soybeans have all contributed to producer risk and limited their maximum potential economic use of fertilizers (especially nitrogen). This in turn limits

Map 1.1 Map of Clay Pan Area



the total supply (of corn and soybeans) available from this area. Response to additional water has been estimated by Runge and Odell (1960). The probability of getting an inch of rain per week is lowest in all sections of Illinois during the time of corn and soybean flowering--the last half of July. Supplemental irrigation during this relatively short period of flowering could significantly increase yields.

As was mentioned previously, supplemental irrigation water in the Western states of the "Corn Belt" is supplied from ground water. This source of water is not infinite and increases in irrigation costs will occur as the depth of the water table is lowered and/or energy costs increase (Great Plains Agricultural Council). In fact, energy costs have risen so that already some of the areas using underground aquifers have gone out of production. In a rainfall and runoff catchment irrigation system, as examined by this study, the supply of water will be replenished during the year. The fact that the water is renewable will increase the stability of yield and reduce long-term producers' risk.

There is a great loss of nutrients and chemicals on soils in the claypan area because a small share of precipitation filters into the soil. Most drainage is surface runoff with little or no tile drainage. Improved water runoff control by collection in a system of small catchments will lower downstream pollution due to runoff of sediment, nutrients and chemicals. Of course, sediment deposition in the reservoirs will affect their useful lives.

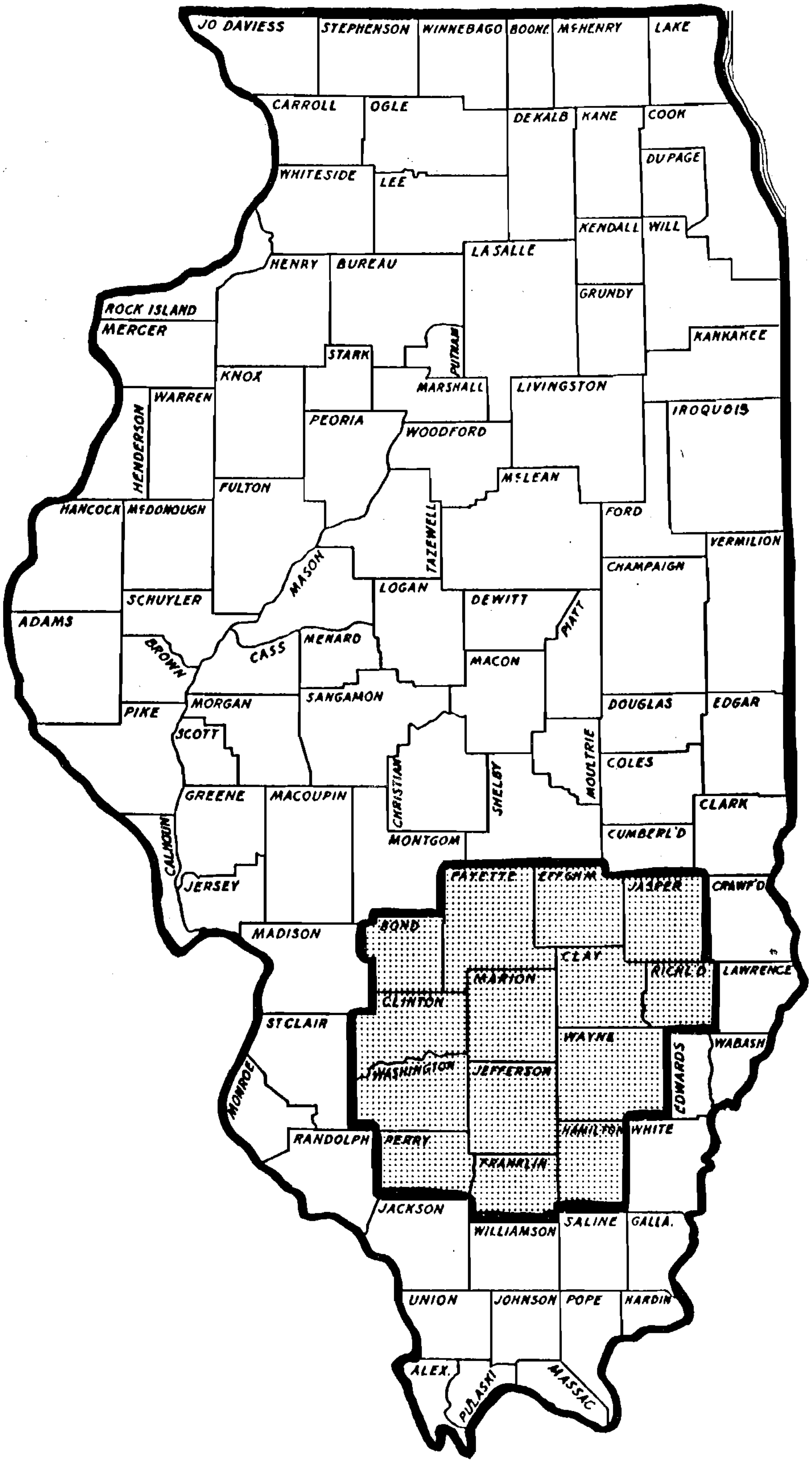
Thus, the reasons for selection of the area in Illinois south of the Wisconsin terminal morain for this study are as follows: The coefficient of yield variation in this area is substantially greater than elsewhere in Illinois indicating greater potential gains to effective water management; the basic water holding capacity or amount of water available for plant growth in the older claypan soils of Illinois is low, making the amount and distribution of water added during the growing season much more critical; distribution of aquifers in southern Illinois is limited and the water available from such aquifers is even more limited (Great Plains Agricultural Council); the soils of southern Illinois are not very permeable to water and therefore provide a good medium for holding water in catchment reservoirs; the topography in much of southern Illinois is conducive to surface impoundment; and the climatic temperatures are such that greater evapotranspiration occurs making added water during the growing season more critical for obtaining maximum yield potential.

A sample survey of the area shown in the map of southern Illinois (Map 1.2) has been taken and estimates of potential reservoir catchment locations have been made. Random representative sample segments which are geographic segments of the region were taken and examined with aerial photographs, topographic maps and soil type maps coupled with a subsampling of on-site assessment of water catchment potential.

1.2 Objectives of the Project

The research was designed to evaluate the economic feasibility of supplemental irrigation of corn and soybeans in Illinois south of the Wisconsin terminal morain by better management of water runoff.

Map 1.2 Map of Counties Selected



The specific objectives of the study are:

(1) To estimate a set of physical and economic data for on-farm rainfall catchment reservoirs and supplemental irrigation costs based on a statistical probability sample of locations in the area of claypan and associated soils in southern Illinois. (See Map 1.1)

(2) Use irrigation yield data available from the Brownstown Experiment Station and corollary data from similar soil types from other stations to project yields which could be expected with adequate water availability.

(3) To estimate the potential reduction in sediment, chemical, and nutrient runoff into streams from an effective system of small catchment reservoirs for water reuse and to evaluate the costs of alternative approaches to agricultural pollution reduction.

1.3 Project Phases

The first phase of the project was to draw a statistical probability geographic sample of potential catchments. The specific counties in southern Illinois (See Map 1.2) where the tight subsoil is located which were included in the area of the catchment site survey are: Bond, Clay, Clinton, Effingham, Fayette, Hamilton, Jasper, Jefferson, Marion, Perry, Richland, Washington, Wayne and Franklin Counties (Map 1.2). While there are additional counties in southern Illinois which also have some claypan soils, most of these counties are on the fringe of the main claypan area and are also contiguous with either the Illinois, Ohio or the Wabash Rivers, the fringe counties contain substantial amounts of overflow sand and rocky deposits which are not directly associated with the claypan area. Since only a few of the sites could be examined, a random sampling of the geographic area involved in these counties was necessary.

The land area of each county was determined. The plat maps of each county were examined carefully and the total number of sections of land in each county were calculated then examined. A section of land is an area measured by one mile on each side or one square mile. Table 1.1 indicates the number of sections of land in each county. The range of land sections was from 349 sections in Richland County, the smallest county in the area, up to Wayne County which contained 703 sections. Then a 1/100 sample was taken in each county in a stratified random sampling procedure. Each county is a stratum and 1/100 of the sections in each county were drawn on a random basis. This resulted in a total of 67 randomly selected sections out of a total of 6,724 sections in the study area.

Topographic maps for each section sampled were obtained from the Illinois Geological Survey. Each section was carefully examined to determine whether or not there was any potential from the standpoint of the geological maps for the siting of a catchment reservoir (See Table 1.2). Certain sections were discarded from further analysis because they either fell too close to a village or city, were divided by existing highways or railroads, or had other physical features that precluded the use of the watershed or the area for a catchment basin. Then each of the remaining sections was carefully analyzed from the topographic maps and further sections were discarded because of the lack of any potential site for a reservoir appropriate for irrigation.

Other criterion which were believed to be important in making final selections of segments to analyze further with regard to costs of the catchments were the length, depth and cross-section of the dam, the acre feet of water contained in the catchment reservoir and the acres of land which would be removed from production. The drainage area of the watershed where the water would run off into the dam or into the catchment area was also considered to be important and this was measured.

A reservoir cross section at the dam site was made for each reservoir site and the number of acre feet were calculated for each potential reservoir. Engineering notes on dam size and cross section, reservoir size, depths and capacity are available on all sites from the authors.

Table 1.1 also shows the number of sites selected after the first screening of the sampled segments: Bond County had two, Clay County - three, Clinton County - one, Effingham County two out of five, Fayette County two out of seven, Hamilton County had none that we considered worth further analysis, Jasper County - three, Jefferson - four, Marion - three, Perry County - one, Richland County - one, Washington - two, Wayne - four and Franklin - three. The total was 30 sites. At these sites topographic maps were used to calculate the reservoir size, the cross section of the dam and the watershed area for water being collected in the dam.

Then after studying the physical measurements, thirteen sites were selected out of the 30 initial sites to calculate cost of impoundment (See Table 1.3). The criteria used in making selections for cost calculations were based on the area of the impoundment, the acre feet

Table 1.1. Stratified Random Sampling
Counties are Strata, and Sampling Fraction within strata is 1 in 100
with a section (square mile) the sampling unit

County	Number of Sections	Sections Sampled	Sections Topographically Selected	Section Selected for Cost Estimates
Bond	376	4	2	0
Clay	471	5	3	1
Clinton	505	5	1	
Effingham	486	5	2	
Fayette	696	7	2	1
Hamilton	414	4	0	
Jasper	485	5	3	
Jefferson	475	5	4	3
Marion	467	5	3	
Perry	358	4	1	1
Richland	349	3	1	
Washington	538	5	2	2
Wayne	703	7	4	3
Franklin	401	4	3	1
	6,724	68	30	13

Number of Sections in all Counties in the Claypan Area 6,724
Number of Sections Sampled 67

Our Sampling Fraction is $\frac{67}{6724} = \frac{1}{100}$

Table 1.2. Engineering Work Based on Topographic Maps Completed on the Following Sampling Units

County	Legal Description of Sampling Unit	Reservoir in (Acres)	Acre Feet of Water Impounded	Acre Feet of Water per Acre of Reservoir	Length of Dam in Feet	Depth in Feet
Bond	S33T4NR4W	124	1320	10.7	625	35
	S7T6NR3W	103	804	7.8	875	25
Clay	S29T3NR5E	86.8	482	5.6	500	15
	S5T4-5NR8E	58.9	487.5	8.3	488	21
	S1&12T5NR5E	463.5	5503	11.9	732	20
Effingham	S1T6NR6E	661.4	10778	16.3	1302	45
	S28T7NR7E	207.6	2642	12.7	651	30
Fayette	S4T6NR3E	160.4	2170	13.5	651	30
	S13T7NR2E	188.7	2240	11.9	651	25
Jasper	S12T7NR8E	443.5	6439	14.5	651	35
	S20T6-7NR10E	250	5256	21	814	45
	S4T6-7NR10-11E14W	95.2	461		625	15
Clinton	S28T2NR4W	91.8	689	7.5		5
Jefferson	S3T4SR1E	94.5	864	9.1	625	25
	S20T4SR4E	43.1	267	6.2	500	15
	S21T2SR2E	19.5	48	2.5	500	5
	S30T2SR4E	44.5	390	8.8	750	20
Marion	S10T3NR3E	72.1	432	6	500	20
	S33T3NR4E	61.6	518	8.4	562	25
	S35T4NR2E	118.3	1241	10.5	625	30
Perry	S29T4SR4W	221.2	1379	6.2	625	15
Richland	S20T3-4R14W	39.2	350	8.9	375	30
Washington	S23T3SR4W	112	1022	9.1	750	25
	S15T3SR3W	72.8	616	8.5	688	30
Wayne	S6T2-3SR8E	8.1	51	6.3	500	15
	S17T1SR6E	33.8	250	7.4	500	15
	S16T1SR7E	33.8	185.8	5.5	500	12.5
	S5T1NR6E	28.4	223	7.9	375	15
Franklin	S7T5SR2E	21.6	114.7	5.3	375	15
	S7T5SR2E	13.5	77.5	5.7	473.5	15
	S7T5SR2E	232.3	1644.5	7.1	625	25
	S19T5SR4E	40.5	232.5	5.7	625	15
	S18T7SR4E	191.8	2877	15		15

of water expected to be stored in the impoundment, the acres of land consumed by the impoundment area, the length and cross-section of the dam, and the depth of the water. Preliminary cost estimates indicated that the capital cost of the reservoir, which would include the dam, a flood spillway and a drop box ranged from a low of $22 per acre foot of water stored to a high of $1294 per acre foot of water stored. The median is about $250 per acre foot of water stored. At 9.5% interest amortized over 30 years, the median cost would be $25 per year per acre foot of water stored. (Long term government bonds are now yielding 9.5% return.)

When private individuals look at alternative investments, normally several things are considered: the annual rate of return, the depreciation rate, the variation in return overtime or from year to year, the permanency of the asset and the potential resale or recovery of the asset value. For a depreciating asset which has little risk associated with the investment, the market shows that few investors are willing at least from a planning standpoint to accept less than the amortization rate covers both in the market. The eventual outcome, of course, may be different. The amortization rate covers both the interest rate and the depreciation so that the initial cost of the asset is fully recovered and the investor gets a competitive rate earned on his investment. With a permanent asset such as land which has no depreciation and may appreciate in value with increase in sectoral demand or increase in general inflation, the annual rate of return should be at least equal to the real rate of interest. The real rate of interst is the rate which individuals are willing to accept on a permanent asset in a stable economic environment where there is no

Table 1.3. Estimated Costs of Potential Reservoir Sites

Sampling	Legal Description of Unit	Drainage Area in Acres	Acre Feet of Water	Cost Per Acre	Total Cost	Cost Per Acre Foot Count of Water
Clay	S1&12T5NR5E	1248.5	5503	$242	302,137	55
Fayette	S13T7NR2E	348.8	2240	143	49,874.4	22
Jasper	S12T7NR8E	5056.2	6439	396	2,002,255.2	310
Jefferson	S3T4SR1E	890.5	864	206	183,443	212
	S20T4SR4E	541.6	267	167	90,447.2	338
	S21T2SR2E	385.6	48	148	57,068.8	1189
Perry	S29T4SR4N	4672.6	1379	382	1,784,933	1294
Washington	S23T3SR4W	936.4	1022	210	196,644	192
	S15T3SR3W	752.8	616	191	143,784.8	233
Wayne	S17T1SR6E	192.8	250	119	22,943.2	572
	S16T1SR7E	573.3	185	171	98,034.3	856
	S5T1NR6E	918.1	223	208	190,964.8	226
Franklin	S7T5SR2E	1432.1	1644	260	372,346	250

inflation and no deflation. This has been shown to range from 3% to 4% in most economies. We assume 9.5% and 4% for the two rates of return for purposes of project analysis.

The catchments which have less than 320 acre feet of water storage are also omitted from further analysis since it is assumed that twice as many acre feet of water are necessary on the average per acre foot of irrigation, so that in a drought year or following abnormally low recharge of the reservoir, there will be a reserve available. The minimum size of pivot irrigation system which gives preferred economic results is approximately 160 acres. This would mean that 320 acre feet of water storage would be needed in order to maintain a satisfactory reserve. In all the water reservoirs which are estimated by our sampling procedures, we have 19,707 acre feet of water available. This means that from these reservoirs approximately 9,854 acres could be irrigated even in years of drought on a supplemental basis each year with a reserve of one year with little or no recharge.

The multiplier factor on our sampling procedure is 100. This means that 985,000 acres of land could potentially be irrigated in the Southern Illinois claypan area from surface catchment water if our random sample is representative of the area.

The project leaders personally inspected the sites which seemed feasible for catchment after the cost analysis of all the sites was completed. A site in Washington County was selected for sedimentation analysis (see Chapter 2).

1.4 Projection of Potential Irrigation in Southern Illinois

Based on the earlier yield and cost work by Lazarus and Scott (1982), it was assumed that 8 inches of water would be optimal on the average to adequately irrigate corn or soybeans in the claypan area of Southern Illinois on a supplemental basis. Additional corn yields based on experiments at the Brownstown station of the Illinois Agricultural Experiment Station should average 40 bushels per acre. The variable costs of water application are estimated at $3 per acre inch, and the fixed costs of irrigation application for 8 acre inches with a center pivot and pumping equipment is estimated at $40 per acre based on experience in Mason County, Illinois. Thus, irrigation costs in addition to the cost of storage for 8 inches of water applied are $64 per acre.

For purposes of this study it was assumed that the land used for reservoirs was not under production. It is assumed that surface evaporation would easily be taken care of by the reserve.

Costs estimated for water assuming an additional year in reserve have a wide range. The range in annual cost for the water source per irrigated acre ranged from a low of $2.88 to a high of $172.53. (Table 1.4). The feasible cost range is from $2.88 to $45.06 per acre irrigated. When using our sampling multiplier of 100, 1,280,600 acres can be irrigated within this cost range. Aggregate economic supply response data obtained from Table 1.4 are used to graph a supply response curve given in Figure 1.3. Two reservoir locations originally sited are ruled out because the number of acres of potential irrigation would be less than 160.

Table 1.4. Fixed Cost of Water Stored
From Lowest to Highest Reservoir Cost Analyzed

County	Legal Description	Total Acre Feet Available	Total Fixed Cost Per Acre Foot[1]	Potential Acres Irrigated	Annual Fixed Cost Per Inch Used[2]	Annual Cost Per Acre Irrigated[3]	Potential Acres Irrigated In the Claypan Area	Cumulative
Fayette	S13T7NR1E	2240	$22	1680	$ .36	$ 2.88	168,000	168,000
Clay	S1&12T5NR5E	5503	55	4137	0.92	7.36	413,700	581,700
Washington	S23T3SR4W	1022	192	766	3.20	25.60	76,600	658,300
Jefferson	S3T4SR1E	864	212	648	3.53	28.26	64,800	723,100
Washington	S15T3SR3W	616	233	431	3.88	31.07	43,100	766,200
Franklin	S7T5SR2E	1644	250	1150	4.17	33.36	11,500	777,770
Jasper	S12T7NR8E	6439	310	4829	5.17	41.33	482,900	1,260,600
Jefferson	S20T4SR4E	267	338	200	5.63	45.06	20,000	1,280,600
Wayne	S17T1SR6E	250	572	187	9.53	76.24	18,700	
Wayne	S5T1NR6E	223	226	167	14.26	114.08	16,700	
Wayne	S16T1SR7E	187	856	141	14.27	114.16	14,100	
Perry	S29T4SR4N	1379	1294	1034	21.56	172.53	103,400	

[1] In years when more than 8" of water are needed or when there has not been a full recharge of the reservoir from the previous year, part of the reservoir reserve would be used. The reserve is an amount equal to the expected average use.

[2] {Total fixed cost/acre foot} * 10% ÷ 12 * 2 = annual cost per inch used (assuming 8" used). Ten percent is the amortization rate, twelve is the number of inches in one foot, and two is the reservoir reserve factor.

[3] Assumes an average use of 8" of water.

If we add the per acre cost for water source to the other variable and fixed costs, we get a feasible range of $67 to $109 per acre. If we get 40 bushels of additional corn from irrigation and 25% of the additional returns must go to cover other marginal costs of producing the higher yield such as seed and fertilizer, then corn at $2.23 per bushel would break even at the low cost end and $3.64 per bushel corn would break even at the upper end of the feasible cost range.

The cost of the last four reservoirs given in Table 1.4 is far above any feasible economic range. They are not included in any further analysis. For example, the $114.13 per acre water source for the Wayne County site, would require $6 per bushel corn and the $172.53 per acre water source for the Perry County site would require $7.86 per bushel corn, which is totally out of the realm of possibility with the foreseeable supply and demand relationships. (See Table 1.4)

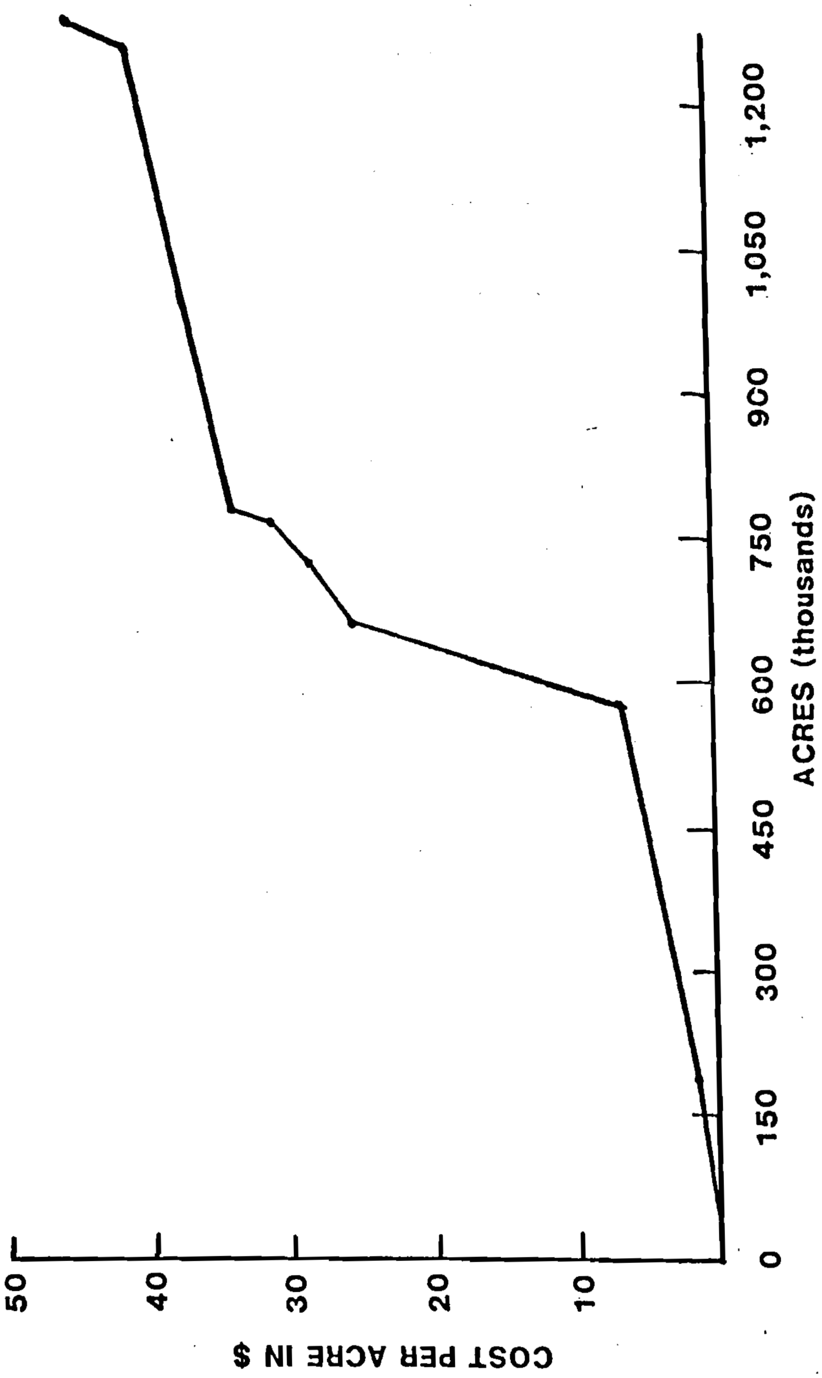


Figure 1.3. Aggregate Supply Curve for Potential Irrigated Acreage

2. Analysis of Land Management for Supplemental Irrigation in Southern Illinois

Sedimentation of water impoundments, and consequent reduction of capacity, has been a widespread, chronic problem in cropland areas of Illinois. In this section we analyze the extent to which land management changes that can reduce sedimentation are economically worthwhile in order to preserve water-holding capacity of the impoundment for irrigation. Table 2.1 presents a schematic description of the analytical procedures employed in this section.

2.1 Microcomputer Budget Management Systems (MBMS)

The MBMS computer software package (McGrann, Olson, Powell and Nelson) was used to generate budgets for different combinations of crop rotations and tillage practices under irrigation and dryland (no irrigation) conditions. MBMS provides systematic information storage for crop and livestock enterprise budgeting. It performs the necessary calculations for determining budget costs and returns, including costs of machinery, equipment, and irrigation systems. MBMS also provides total farm reports for fuel, labor, and machinery use.

For this study, MBMS was used to generate budgets for 24 crop management systems, made up of 4 crop rotations (continuous corn - CC, corn-soybeans - CS, continuous soybeans - S, and double-cropped soybeans - DS), 3 tillage practices (conventional tillage - CTL, reduced tillage - RTL, and no till - NT), and 2 irrigation practices (irrigation - IRR, and no irrigation - NIRR). The crop rotations and tillage practices were chosen for the study because they are the ones

Table 2.1. A Schematic of Model Components

	MBMS
Data:	Crop yields, quantities and prices of inputs like fertilizers, pesticides, herbicides, seed, machinery and equipment, drying costs, labor, and management costs, and irrigations costs for different combinations of crop rotations, tillage practices and irrigation practices.
Compute:	Budgets for different management systems.
Output:	Total operating cost for each management system.
	↓
	SOILEC
Data:	Crop budgets (total operating costs) from MBMS, soil types and depths, crop yields, slope, and rainfall for each Land Management Unit (LMU); baseline management practices.
Compute:	Erosion rates and long-term net returns for each management system available in each LMU.
Optimize:	Select management practices that achieve erosion rates at least cost relative to the baseline.
Output:	Non-dominated management practices for each LMU.
	↓
	SEDEC
Data:	SOILEC output, physical and management inter-relationships between LMUs, deposition points.
Compute:	Total sediment deposition for all feasible combinations of least cost erosion management options at all LMUs, allowing for interrelationships.
Output:	Option lists of possible sets of management practices for each transect together with total sediment and total net returns/total cost for each set of management practices in each option list for each transect.
	↓
	Binary Integer Programming Model
Data:	Total sediment and total net returns for each set of management systems in the option list for each transect, reservoir capacity.
Compute:	Total net returns for entire drainage area.
Optimize:	Select management practices on each transect that maximize total net returns for drainage area without violating reservoir capacity constraint.
Output:	Optimal management systems and associated total net return.

most prevalent in Illinois. Corn and soybeans are the major irrigated crops in the state. Over half of the irrigated acreage in 1977 was in field and seed corn, while 19 percent was in soybeans, and there is every reason to believe that these figures have been rising in recent years. The soybean acreage included 1,067 acres of double-cropped soybeans, which can benefit greatly from irrigation during dry periods in July and August [Lah, Drablos, and Thorne]. The three tillage practices - conventional, reduced, and no tillages - are the most widely practiced systems in Illinois.

Data used in MBMS in generating budgets for the different crop rotations and tillages included crop yields, quantities and prices of inputs like fertilizers, pesticides, herbicides and seed, machinery and equipment, drying costs and management costs. Data on input use and cost came from a variety of sources - Brownstown Experimental Station, U.S. Soil Conservation Service, Agricultural Prices Handbooks, etc. The key data are listed in Table 2.2. Irrigation costs for the center-pivot systems were estimated using information from January, 1982 issue of Illinois Irrigation Newsletter.

The base budgeting year was 1982, so the prices of inputs and outputs, yields, etc. were from that year. The total operating cost generated by MBMS for each of the 24 crop management systems was used in SOILEC (see the next section).

2.2 SOILEC Model

The SOILEC (Soil Conservation Economic) model [Eleveld, Johnson and Dumsday] was used to analyze the long-term economic and physical impacts of adopting alternative management systems for corn and

Table 2.2. Selected Data Used for MBMS Budgets

Input	Irrigated Corn	Irrigated Soybean	Irrigated Double Crop Soybean	Non-irrigated Corn	Non-irrigated Soybean	Non-irrigated Double Crop Soybean
Nitrogen	180 lb/a	---	---	120 lb/a	---	---
Phosphate	140 lb/a	140 lb/a	180 lb/a	90 lb/a	90 lb/a	90 lb/a
Potash	140 lb/a	140 lb/a	180 lb/a	90 lb/a	90 lb/a	
Bladex 4L	1 qt/a	---	---	1 qt/a	---	---
Aatrex 4K	2.5 qt/a	---	---	1 pt/a	---	---
Lasso	2.5 qt/a	---	3 qt/a	2.5 qt/a	---	3 qt/a
Diazinon	1 lb/a	---	---	1 lb/a	---	---
Sencor 4	---	0.75 pt/a	---	---	0.75 pt/a	---
Treflan	---	0.75 pt/a	---	---	0.75 pt/a	---
Dual	---	0.75 pt/a	---	---	0.75 pt/a	---
Poast	---	1 qt/a	---	---	1 qt/a	---
Benlate 50	---	0.5 lb/a	---	---	0.5 lb/a	---
Paraquat	---	---	1 qt/a	---	---	1 qt/a
Hoelon	---	---	1.5 qt/a	---	---	1.5 qt/a
Surflan	---	---	1 qt/a	---	---	1 qt/a
Yield bu/a	149.8	43.4	28.7	87.8	36.7	20.6

Quantity of Input Use

Source: Sipp, et.al., p. 28-29.

soybeans. SOILEC is a long-run computer simulation model designed, among other things, to analyze the physical and economic trade-offs involved in management decisions to accomplish soil erosion control for row crops. For a given soil type, this model quantifies the on-site physical and financial consequences of soil erosion for alternative management systems versus a base system. The model simulates the soil losses and economic outcomes of each of the crop management systems over a one-year (short-term) or a 50-year (long-run) planning horizon.

The simulation model calculates annual net income per acre for each management system. These annual net incomes are then discounted by a specified discounting rate and summed to their present value at the beginning of the planning horizon. An estimate is also made of the remaining or salvage value of the land, which is also discounted to the present and included in the present value sum for each management system.

The four basic relationships underlying the SOILEC model are - the Universal Soil Loss Equation (USLE) taken from Wischmeier and Smith (1965), discounted net returns, the relationship between yield and soil depth, and the relationship between costs and soil loss. The Universal Soil Loss Equation is used in the calculation of annual soil loss while the other three relationships are used in the projection of annual crop yields and the calculation of discounted net returns.

The USLE is formulated as follows:

$$A = R \cdot LS \cdot K \cdot C \cdot P \qquad (2.2.1)$$

where:

A = the annual soil loss in tons per acre;

R = the rainfall and runoff factor;

LS = a calculated factor involving the slope of the field and the length of that slope;

K = the soil erodibility factor;

C = a cover and management factor determined by crop rotation and tillage system; and

P = the support practice (vertical tillage, contour plowing, strip cropping, etc.) factor.

The basic economic relationship in SOILEC involves discounted net returns. This relationship for the two-crop rotation case is:

$$PVNR = \frac{1}{2} \sum_{t=1}^{T} \frac{P_1 \times Y_{t1} + P_2 \times Y_{t2} - C_{t1} - C_{t2}}{(1 + i)^t} \qquad (2.2.2)$$

where:

PVNR = the discounted net returns for a management system.

P_{ti} = the prices for the i^{th} crop;

Y_{ti} = the yield per acre for the i^{th} crop at time t for the management system;

C_{ti} = the cost for the i^{th} crop in year t for the management system;

i = the real rate of interest;

t = time from year zero; and

T = number of years in the planning horizon.

By summing net returns per acre for the two crops, and dividing by 2, a rotation is represented as the simple average of net returns per acre. This average is discounted to present value terms. The sum of the PVNR's for all years gives the present value of net returns over a planning horizon for a given management system.

The third relationship underlying SOILEC relates crop yields and soil loss from erosion. This relationship for a given management system can be generalized as

$$Y_t = f\left(\sum_{i=0}^{t} d_i\right) \qquad (2.2.3)$$

where:

Y_t = the yield for a crop in a given year T;

f = is the yield function; and

d_i = the depth of top soil lost in year i.

As soil erodes over time, the total soil loss grows larger and yields decline. This reflects the assumption that soil erosion impacts long-term productivity causing it to decline. [See Bost (1980) for empirical results verifying this assumption].

The final relationship that forms the basis of SOILEC reflects efforts by farmers to maintain yields, in the face of lost productivity due to soil erosion, by increasing the use of inputs such as fertilizer. This results in increased costs for a particular crop in Equation (2), that is,

$$C_t = g\left(\sum_{i=0}^{t} d_i\right) \qquad (2.2.4)$$

where:

C_t = the cost in year t for a given crop and management system; and

d_t = as defined in Equation (2.2.3)

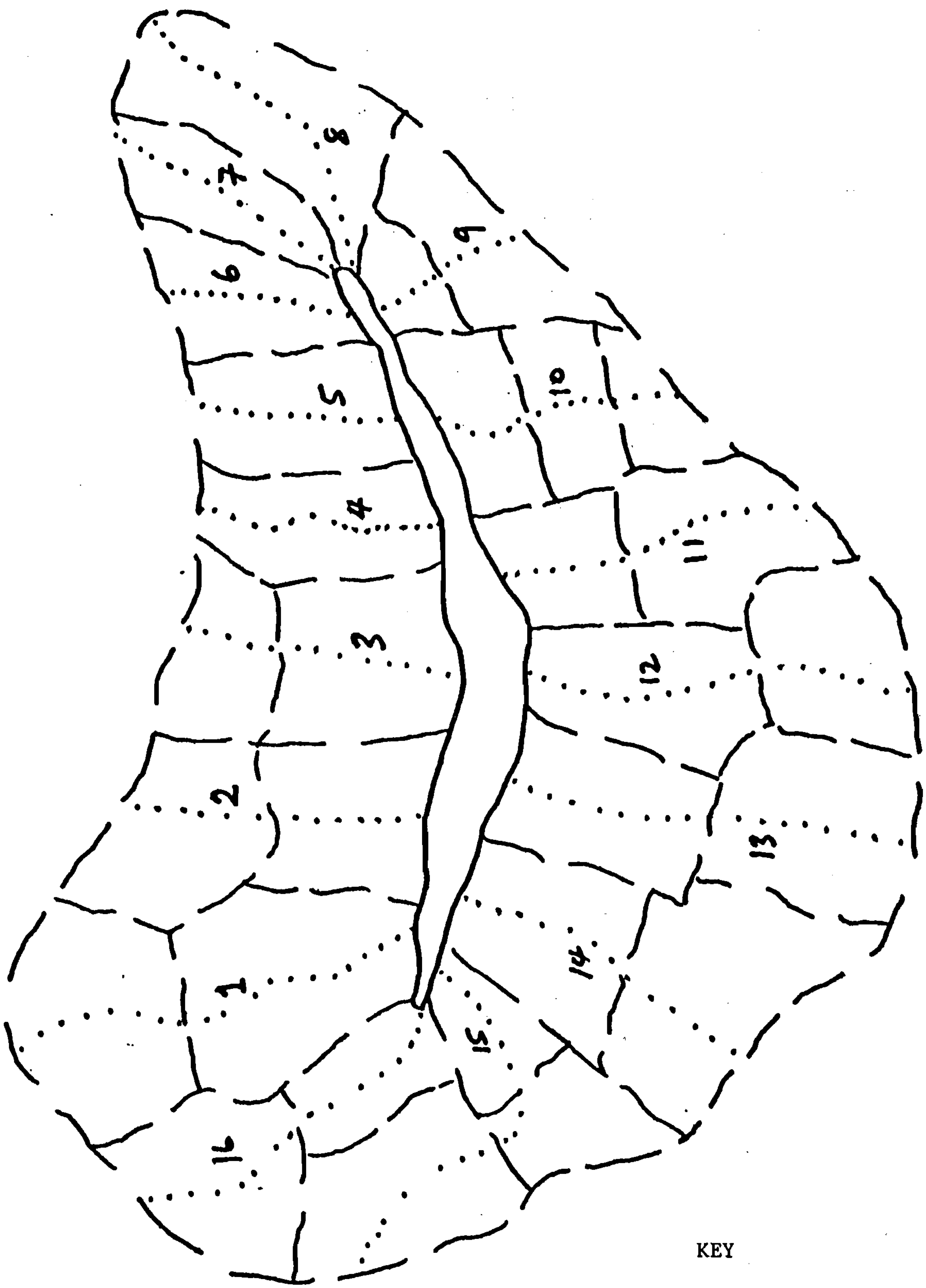
Depending on local soil conditions, C_t may increase, decrease, or stay constant as d_t increases.

but one of the management systems being considered are compared to a base management system and the dominated and non-dominated systems indicated. The determination of dominance is done by a cutting plane algorithm within the model using averages of annual net revenues and annual soil losses for the specified planning horizon for each management system. A management system is dominated when the same or a lower annual soil loss can be obtained with the same or a greater annual net revenue. For example, if 2 management systems have annual soil losses and net revenues per acre of 0.9 tons and $44.90, and 0.9 tons and $42.90, respectively, and if the annual soil losses are lower and the net revenues greater than those for the base system, the former system will be chosen as the dominant one. Since both management practices produce the same amount of annual soil loss, the one with a higher net revenue will dominate the other. The algorithm includes a distance function that makes it possible to specify a value for difference in annual soil loss and net returns between two management systems. If the actual difference is less than the specified difference, the two management systems are treated as if they are equal and not dominated.

2.3 Study Site Results from SOILEC

For this study, a site in S23T.3S.-R.4W near Oakdale, in Washington County, was selected for further analysis. The area is depicted in Figure 2.1. The site contains a drainage area of 936.4 acres. This was partitioned into 29 fields of varying sizes. The land base was subdivided such that each field was associated with one surface drainage path, called a transect. For this site, 16 transects

Figure 2.1. Outlines of Study



KEY

Field Boundaries

Transects

Reservoir

were defined and the number of fields within transects varied from one to three. Corn and soybeans are the dominant crops in the area.

The topographic information for this study site was developed from U.S. Geological Survey 7.5 minute contour maps. Farm boundaries and transects were identified from these maps, plat maps and aerial photographs obtained from the Agricultural Stabilization and Conservation Service in Washington County. Soil types, soil depths and productivity characteristics were obtained from the U.S. Soil Conservation Service (SCS).

For each of the 29 fields within the 16 transects of the Oakdale site, 72 different management systems were analyzed using the SOILEC model. Since there was only one soil type - Cisne, for all the fields and the average slope - 1-2%, and average length of slope - 300 ft., were the same for all the fields, only two computer runs were made with the SOILEC model. The first run was done for the 36 non-irrigated management systems, made up of four crop rotations (continuous corn - CC, corn-soybeans - CS, continuous soybeans - S, and double-cropped soybeans - DS); three tillages (conventional tillage - CTL, reduced tillage - RTL, and no-till - NT), three mechanical control practices vertical (up and down-slope) cultivation - VT, contour cultivation - CN, and contour strip cropping - ST), and one irrigation practice (no-irrigation - NIRR).

The second run was made with the 36 irrigated practices, comprising the same management systems listed above but with irrigation (IRR).

The data used in SOILEC for the case study came from a number of sources. Yield data came from the Brownstown Experimental Station, while data on erosion factors came from U.S. Soil Conservation Service.

Cost data were extracted from the MBMS budgets. Two discount rates - 4.00% and 8.00% were specified.

Two separate frontier analyses, one with only the non-irrigated management systems, and the other with irrigated practices only, were performed within the SOILEC model to determine the dominant practices on each field. Five non-irrigated practices and four irrigated practices respectively, were found to be dominant [see Tables 2.3 and 2.4].

The cumulative net present values of returns per acre for each of the 36 non-irrigated and the 36 irrigated management systems considered in the study, are presented in Tables 2.5 and 2.6. The tables show quite clearly that irrigated corn under the two corn rotations - CC and CS, and all three tillages - CTL, RTL, and NT, and all three mechanical control practices, VT, CN and ST is more profitable than non-irrigated corn under the same tillages and mechanical control practices. For soybeans, however, the opposite is true, that is, non-irrigated soybeans are more profitable than irrigated soybeans under the same tillages and mechanical control practices.

2.4 SEDEC Model

The SEDEC (Sediment Economics) simulation/optimization model [Braden, Johnson, and Martin] conjoins a farm profit function, an erosion function, and a spatial sediment movement function. The financial and erosion relationships are simulated using SOILEC, and the Universal Soil Loss Equation (USLE) is the basic erosion relationship.

In SEDEC, a procedure developed by C.D. Clarke (1983) of the U.S. Soil Conservation Service (SCS) is used to simulate the sediment

Table 2.3. Frontier Analysis for Non-Irrigated Systems

REDUCTION IN EROSION COMPARED WITH BASE ROTATION-TILLAGE SYSTEMS: CC CTL
AND BASE MECHANICAL CONTROL PRACTICE(S): CN
DISCOUNT RATE (%): 4.00

NO.	ROTATION-TILLAGE SYSTEM		MECHANICAL CONTROL PRACTICES	USLE FACTORS LS	C	P	REMAINING ANNUAL SOIL LOSS	NET REV. CHNG PER UNIT AREA	ANN. CST PER UNIT REDUCTN
							(TON/AC)	($/ACRE)	($/TON)
1	CC	CTL	CN	.179	.250	.60	2.1	19.39	0.00 B
2	S	NT	VT	.179	.170	1.00	2.4	78.68	N.A.
3	S	RTL	VT	.179	.220	1.00	3.1	77.40	N.A. D
4	S	NT	CN	.179	.170	.60	1.4	68.77	-102.45
5	S	RTL	CN	.179	.220	.60	1.8	67.52	-268.22 D
6	S	NT	ST	.179	.170	.60	1.4	66.77	-99.47 D
7	S	RTL	ST	.179	.220	.60	1.8	65.52	-260.28 D
8	S	CTL	VT	.179	.370	1.00	5.2	61.05	N.A. D
9	CS	RTL	VT	.179	.110	1.00	1.5	54.84	-98.04 D
10	S	CTL	CN	.179	.370	.60	3.1	51.24	N.A. D
11	S	CTL	ST	.179	.370	.60	3.1	49.24	N.A. D
12	CS	NT	VT	.179	.110	1.00	1.5	47.67	-85.22 D
13	CS	CTL	VT	.179	.310	1.00	4.3	47.36	N.A. D
14	CS	RTL	CN	.179	.110	.60	.9	44.90	-38.22
15	CS	RTL	ST	.179	.110	.60	.9	42.90	-36.52 D
16	CS	NT	CN	.179	.110	.60	.9	37.72	-32.11 D
17	CS	CTL	CN	.179	.310	.60	2.6	37.52	N.A. D
18	CS	NT	ST	.179	.110	.60	.9	35.72	-30.41 D
19	CS	CTL	ST	.179	.310	.60	2.6	35.52	N.A. D
20	CC	NT	VT	.179	.040	1.00	.6	16.63	-10.81
21	CC	RTL	VT	.179	.050	1.00	.7	13.92	-9.95 D
22	CC	CTL	VT	.179	.250	1.00	3.5	9.88	N.A. D
23	CC	NT	CN	.179	.040	.60	.3	6.65	-3.77
24	CC	NT	ST	.179	.040	.60	.3	4.65	-2.64 D
25	CC	RTL	CN	.179	.050	.60	.4	3.94	-2.35 D
26	CC	RTL	ST	.179	.050	.60	.4	1.94	-1.16 D
27	CC	CTL	ST	.179	.250	.60	2.1	-2.00	N.A. D
28	DS	RTL	VT	.179	.150	1.00	2.1	-5.00	N.A. D
29	DS	RTL	CN	.179	.150	.60	1.3	-14.94	17.81 D
30	DS	NT	VT	.179	.080	1.00	1.1	-15.45	15.78 D
31	DS	RTL	ST	.179	.150	.60	1.3	-16.94	20.19 D
32	DS	CTL	VT	.179	.140	1.00	2.0	-19.39	138.67 D
33	DS	CTL	CN	.179	.140	.60	1.2	-19.39	21.01 D
34	DS	CTL	ST	.179	.140	.60	1.2	-19.39	21.01 D
35	DS	NT	CN	.179	.080	.60	.7	-19.39	13.60 D
36	DS	NT	ST	.179	.080	.60	.7	-19.39	13.60 D

VT = UP-AND-DOWN-SLOPE (VERTICAL) CULTIVATION
CN = CONTOUR CULTIVATION
ST = CONTOUR STRIP CROPPING
TR = TERRACING
NA = NOT APPLICABLE

B = BASE MANAGEMENT SYSTEM
D = DOMINATED MANAGEMENT SYSTEM

NOTE - Nondominated management systems do not have any letters assigned to them.

Table 2.4. Frontier Analysis for Irrigated Systems

REDUCTION IN EROSION COMPARED WITH BASE ROTATION-TILLAGE SYSTEMS: CC CTL
AND BASE MECHANICAL CONTROL PRACTICE(S): CN
DISCOUNT RATE (%): 4.00

NO.	ROTATION-TILLAGE SYSTEM		MECHANICAL CONTROL PRACTICES	USLE FACTORS LS	C	P	REMAINING ANNUAL SOIL LOSS (TON/AC)	NET REV. CHNG PER UNIT AREA ($/ACRE)	ANN. CST PER UNIT REDUCTN ($/TON)
1	CC	CTL	CN	.179	.250	.60	2.1	66.09	0.00 B
2	CS	RTL	VT	.179	.080	1.00	1.1	33.89	-34.62
3	S	RTL	VT	.179	.170	1.00	2.4	25.85	N.A. D
4	CS	CTL	VT	.179	.310	1.00	4.3	24.25	N.A. D
5	CS	RTL	CN	.179	.080	.60	.7	23.94	-16.78
6	S	NT	VT	.179	.170	1.00	2.4	23.06	N.A. D
7	CS	NT	VT	.179	.030	1.00	.4	22.95	-13.68
8	CS	RTL	ST	.179	.080	.60	.7	21.94	-15.38 D
9	S	RTL	CN	.179	.170	.60	1.4	15.95	-23.76 D
10	CC	RTL	VT	.179	.030	1.00	.4	15.30	-9.12 D
11	CS	CTL	CN	.179	.310	.60	2.6	14.44	N.A. D
12	S	RTL	ST	.179	.170	.60	1.4	13.95	-20.78 D
13	S	NT	CN	.179	.170	.60	1.4	13.15	-19.59 D
14	CS	NT	CN	.179	.030	.60	.3	12.97	-7.03
15	CS	CTL	ST	,179	.310	.60	2.6	12.44	N.A. D
16	CC	NT	VT	.179	.030	1.00	.4	11.97	-7.13 D
17	S	NT	ST	.179	.170	.60	1.4	11.15	-16.62 D
18	CS	NT	ST	.179	.030	.60	.3	10.97	-5.94 D
19	CC	CTL	VT	.179	.250	1.00	3.5	9.84	N.A. D
20	S	CTL	VT	.179	.370	1.00	5.2	7.05	N.A. D
21	CC	RTL	CN	.179	.030	.60	.3	5.32	-2.88 D
22	CC	RTL	ST	.179	.030	.60	.3	3.32	-1.80 D
23	CC	NT	CN	.179	.030	.60	.3	1.98	-1.07 D
24	CC	NT	ST	.179	.030	.60	.3	-.02	.01 D
25	CC	CTL	ST	.179	.250	.60	2.1	-2.00	N.A. D
26	S	CTL	CN	.179	.370	.60	3.1	-2.74	N.A. D
27	S	CTL	ST	.179	.370	.60	3.1	-4.74	N.A. D
28	DS	RTL	VT	.179	.150	1.00	2.1	-54.18	N.A. D
29	DS	CTL	VT	.179	.140	1.00	2.0	-63.66	455.21 D
30	DS	RTL	CN	.179	.150	.60	1.3	-64.11	76.40 D
31	DS	RTL	ST	.179	.150	.60	1.3	-66.07	78.74 D
32	DS	CTL	CN	.179	.140	.60	1.2	-66.09	71.61 D
33	DS	CTL	ST	.179	.140	.60	1.2	-66.09	71.61 D
34	DS	NT	VT	.179	.080	1.00	1.1	-66.09	67.52 D
35	DS	NT	CN	.179	.080	.60	.7	-66.09	46.33 D
36	DS	NT	ST	.179	.080	.60	.7	-66.09	46.33 D

VT = UP-AND-DOWN-SLOPE (VERTICAL) CULTIVATION
CN = CONTOUR CULTIVATION
ST = CONTOUR STARIP CROPPING
TR = TERRACING
NA = NOT APPLICABLE

B = BASE MANAGEMENT SYSTEM
D = DOMINATED MANAGEMENT SYSTEM

NOTE - Nondominated management systems do not have any letters assigned to them.

Table 2.5. 30-Year Cumulative Net Present Values for Non-Irrigated Management Systems

Management System	4.00%	8.00%
	- - - - - - - ($/ac)	- - - - - -
1. CC-CTL-VT-NIRR	731.93	367.20
2. CC-CTL-CN-NIRR	484.82	243.15
3. CC-CTL-ST-NIRR	434.82	218.15
4. CC-RTL-VT-NIRR	832.79	416.65
5. CC-RTL-CN-NIRR	583.38	291.84
6. CC-RTL-ST-NIRR	533.38	266.84
7. CC-NT-VT-NIRR	900.60	450.50
8. CC-NT-CN-NIRR	651.06	325.64
9. CC-NT-ST-NIRR	601.06	300.64
10. CS-CTL-VT-NIRR	1,668.94	836.12
11. CS-CTL-CN-NIRR	1,422.79	712.39
12. CS-CTL-ST-NIRR	1,372.79	687.39
13. CS-RTL-VT-NIRR	1,855.87	928.53
14. CS-RTL-CN-NIRR	1,607.26	803.99
15. CS-RTL-ST-NIRR	1,557.26	778.99
16. CS-NT-VT-NIRR	1,676.58	838.87
17. CS-NT-CN-NIRR	1,727.92	714.31
18. CS-NT-ST-NIRR	1,377.92	689.31
19. S-CTL-VT-NIRR	2,010.95	1,007.51
20. S-CTL-CN-NIRR	1,765.70	884.07
21. S-CTL-ST-NIRR	1,715.70	859.07
22. S-RTL-VT-NIRR	2,419.81	1,211.16
23. S-RTL-CN-NIRR	2,172.74	1,087.12
24. S-RTL-ST-NIRR	2,122.74	1,062.12
25. S-NT-VT-NIRR	2,451.88	1,226.85
26. S-NT-CN-NIRR	2,204.02	1,102.56
27. S-NT-ST-NIRR	2,154.02	---
28. DS-CTL-VT-NIRR	---	---
29. DS-CTL-CN-NIRR	---	---
30. DS-CTL-ST-NIRR	---	---
31. DS-RTL-VT-NIRR	359.77	180.50
32. DS-RTL-CN-NIRR	111.20	55.97
33. DS-RTL-ST-NIRR	61.20	30.97
34. DS-NT-VT-NIRR	98.58	49.61
35. DS-NT-CN-NIRR	---	---
36. DS-NT-ST-NIRR	---	---

Table 2.6. 30-Year Cumulative Net Present Values for Irrigated Management Systems

Management System		4.00%	8.00%
		($/ac)	
1.	CC-CTL-VT-IRR	1,898.42	950.89
2.	CC-CTL-CN-IRR	1,652.33	827.17
3.	CC-CTL-ST-IRR	1,602.33	802.17
4.	CC-RTL-VT-IRR	2,034.81	1,017.61
5.	CC-RTL-CN-IRR	1,785.29	892.77
6.	CC-RTL-ST-IRR	1,735.29	867.77
7.	CC-NT-VT-IRR	1,951.46	975.93
8.	CC-NT-CN-IRR	1,701.92	851.08
9.	CC-NT-ST-IRR	1,651.92	826.08
10.	CS-CTL-VT-IRR	2,258.56	1,131.31
11.	CS-CTL-CN-IRR	2,013.30	1,007.87
12.	CS-CTL-ST-IRR	1,963.30	982.87
13.	CS-RTL-VT-IRR	2,499.47	1,250.27
14.	CS-RTL-CN-IRR	2,250.72	1,125.68
15.	CS-RTL-ST-IRR	2,200.72	1,100.68
16.	CS-NT-VT-IRR	2,226.13	1,113.26
17.	CS-NT-CN-IRR	1,976.58	988.41
18.	CS-NT-ST-IRR	1,926.58	963.41
19.	S-CTL-VT-IRR	1,828.58	916.53
20.	S-CTL-CN-IRR	1,583.81	793.25
21.	S-CTL-ST-IRR	1,533.81	768.25
22.	S-RTL-VT-IRR	1,533.81	768.25
23.	S-RTL-CN-IRR	2,051.01	1,026.15
24.	S-RTL-ST-IRR	2,001.01	1,001.15
25.	S-NT-VT-IRR	2,228.82	1,115.40
26.	S-NT-CN-IRR	1,981.16	991.18
27.	S-NT-ST-IRR	1,931.16	966.18
28.	DS-CTL-VT-IRR	60.85	31.07
29.	DS-CTL-CN-IRR	---	---
30.	DS-CTL-ST-IRR	---	---
31.	DS-RTL-VT-IRR	297.95	149.68
32.	DS-RTL-CN-IRR	49.60	25.22
33.	DS-RTL-ST-IRR	0.52	0.43
34.	DS-NT-VT-IRR	---	---
35.	DS-NT-CN-IRR	---	---
36.	DS-NT-ST-IRR	---	---

delivery process. Runoff and sediment are assumed to move downslope along "transects", across land management units (farm fields), toward a stream channel or impoundment. A transect depicts a characteristic overland drainage path for water that has not formed into concentrated flow channels.Soil that becomes eroded on one land management unit (LMU) may settle out downhill if decreasing steepness or dense vegetative stands cause water to lose momentum.

The SEDEC approach determines land management practices that will minimize the cost required to meet a specified level of sediment deposited from cropland into a watershed. Within the model, a profit maximization criterion is applied to identify sets of non-dominated management practices, first on each land management unit and then on each transect. On each land management unit, only those management practices that cannot be improved upon through higher profits or lower erosion rates are considered. At the transect level, only those management combinations that cannot be improved upon through higher profits or lower sediment loads within each subdivision are considered. The management practices that are dominant on each transect are viewed as mutually exclusive nodes in a network flow problem. The combination of practices on different transects that yields the highest profits is determined, as is the combination that causes the lowest sediment loads. Then a branch and bound search algorithm is used to find the most profitable combination that meets the sediment load constraint. The optimal combination is identified when it is determined that no other set of management practices can possibly attain higher profits while satisfying the constraint.

The SEDEC approach was adapted to the aims of this study by modifying the criteria for selecting the non-dominated sets of management systems at both the land management unit (LMU) and transect levels. For each LMU, profit maximization is now applied to identify only those management practices that cannot be improved upon through higher net revenues, lower erosion rates, or lower water use. At the transect level, only sets or combinations of management practices that cannot be improved upon through higher total net revenues and lower sediment loads or higher total net revenues and lower water use are included in the option list for each transect. The last criterion makes it possible for both irrigated and non-irrigated option lists to be included in the set of dominant practices. Also, for each option list on a transect, all the LMUs must share an irrigation facility or be non-irrigated. Since we are interested in determining the effect of total sediment loads from all transects on reservoir capacity and consequently, the effect on the choice of the optimal set of management systems, the watershed-wide sediment load constraint in the original SEDEC model was replaced by a reservoir capacity constraint. The revised model is described below.

2.5 A Binary Integer Programming Model

The problem that remains is to find a procedure for choosing from amongst the enumerated sets of dominant management practices for each of the different transects, one and only one set for each transect that would maximize total net returns without violating the reservoir capacity constraint.

Sediment deposited from transects into a reservoir reduces the reservoir water storing (holding) capacity and requires costly removal. If the accumulated sediment is not removed from the reservoir, the amount of water that would be made available from the reservoir for irrigation practices would get smaller and smaller with each passing year. This annual reduction in the total irrigation water will, in turn, affect the choice of management systems that maximizes total net returns for the entire drainage area.

Let k = 1, 2, 3, ..., K represent transects in a watershed. Each transect is hydrologically independent in surface drainage of storm water into a reservoir. Let i = 1, 2, 3, ..., I^k represent farm fields or LMUs within transect k. Net returns per acre in field (i,k) is denoted by $W_i^k(x)$, where $x \in X$, the set of management systems that are applicable in the study area the study area. Let $\underline{x}_o$ denote the vector of baseline management systems in the watershed. The change in net returns per acre from adoption of another management system x' on field i on transect k is

$$R_i^k(x') = W_i^k(x') - W_i^k(x_o) \qquad (2.5.1)$$

Expression (2.5.1) may take on any sign because the elements of $\underline{x}_o$ need not be profit maximizing. Assuming net returns are proportional to area for a specific soil and slope class, the overall change in profits of moving from $\underline{x}o$ to $\underline{x}'$ is simply the sum of the r_i^ks, each multiplied by the respective area a_i^l:

$$TR(\underline{x}') = \sum_{k=1}^{K} \sum_{i=1}^{I^k} R_i^k(x') \cdot a_i^k \qquad (2.5.2)$$

Let RC be the reservoir capacity as measured by the maximum amount of water it can store and let $S^k(x)$ be a sediment delivery function for transect k and $Q^k(\underline{x}_k)$ be the amount of supplemental irrigation water required by vector $\underline{x}^k$ of management practices on transect k. Finally, Finally, let $j = 1, \ldots J^k$ denote lists of nondominated management options for the fields on transect k. These lists are identified by the SEDEC model.

The management systems that maximize overall net returns without violating the reservoir capacity constraint constitute the solution to the following mathematical programming problem:

$$\text{Maximize } TR = \sum_{k=1}^{K} \sum_{j=1}^{J^k} a_k \cdot R_{kj} \cdot X_{kj} \qquad (2.5.3)$$

Subject to:

$$\sum_{k=1}^{K} \sum_{j=1}^{J^k} [a_k \cdot Q_{kj} + m \cdot S_{kj}] X_{kj} \leq RC \qquad (2.5.4)$$

$$\sum_{j=1}^{J^k} X_{kj} = 1, \text{ for all } k = 1, 2, \ldots, K; \qquad (2.5.5)$$

$$\sum_{j=1}^{J^k} X_{1j} = \sum_{j=1}^{J^k} X_{2j}, \text{ for all irrigated } j; \qquad (2.5.6)$$

$$\sum_{j=1}^{J^k} X_{3j} = \sum_{j=1}^{J^k} X_{4j} = \sum_{j=1}^{J^k} X_{5j} = \sum_{j=1}^{J^k} X_{6j} = \sum_{j=1}^{J^k} X_{7j}, \text{ for all irrigated } j; \qquad (2.5.7)$$

$$\sum_{j=1}^{J^k} X_{8j} = \sum_{j=1}^{J^k} X_{9j} = \sum_{j=1}^{J^k} X_{10j}, \text{ for all irrigated } j; \qquad (2.5.8)$$

$$\sum_{j=1}^{J^k} X_{11j} = \sum_{j=1}^{J^k} X_{12j} = \sum_{j=1}^{J^k} X_{13j}, \text{ for all irrigated } j; \qquad (2.5.9)$$

$$\sum_{j=1}^{J^k} X_{14j} = \sum_{j=1}^{J^k} X_{15j} = \sum_{j=1}^{J^k} X_{16j}, \text{ for all irrigated } j; \qquad (2.5.10)$$

$$X_{kj} = 0,\ 1. \qquad (2.5.11)$$

The objective is to maximize net returns from management of land in the study area. Constraint (2.5.4) requires that management systems use no more irrigation water than the reservoir capacity (RC) less the acre-inches equivalent of total sediment loads ($m \cdot S_{kj} \cdot X_{kj}$). The constant m converts tons of sediment into acre-inches of reservoir capacity. S_{kj} is the sediment load associated with the management option list j on transect k.

Constraint equation (2.5.5) allows only one set of management system to be chosen for each transect, given the fact that all X_{kj} must be either zero or one, as specified in (2.5.11). Equations (2.5.6) - (2.5.10) establish the land areas covered by each center pivot irrigation system. All fields associated with the transects in each of the following sets must be treated alike in terms of irrigation: [1 and 2]; [3, 4, 5, 6, and 7]; [8, 9, and 10]; [11, 12, and 13]; and [14, 15, and 16]. Reference can be made to Figure 2.1 to establish the locations of these transects.

The choice variables in the above problem take on the discrete values, 0 or 1. Therefore, necessary conditions for a maximum cannot be derived using conventional differentiation techniques. In order to be optimal, however, the solution must approximate as closely as possible the conventional first order conditions for profit maximization. Within transects, management systems must be selected, such that the revenue from an additional unit of supplemental irrigation water is approximately the same for all fields in that transect. A similar condition should characterize optimal management system vectors in different transects. If net revenues from additional irrigation water is higher in some transects than in others, a profit maximization solution would emphasize management systems in the former areas.

The zero-one integer optimization model, described above is static and does allow management to change over the planning horizon, nor does sediment accumulation in the reservoir alter its capacity. SOILEC takes into account the "time" element, by using averages over the entire planning horizon of annual net revenue changes and annual soil losses from each management system, but this is the only way in which time enters explicitly.

The main purpose of this section is to determine the annual effect of sediment deposition on reservoir capacity and, thus, on the choice of irrigated and non-irrigated management practices over the entire planning horizon. Time, therefore, plays a very important role in this study and must be accounted for explicitly. To achieve this, it is assumed that at the end of every 5 years, the management choices would be re-evaluated to determine how much of the reservoir capacity has been lost to sedimentation and how that in turn would affect the choice of irrigated and non-irrigated management practices in subsequent years.

In this study, we make an implicit assumption that the portion of the reservoir capacity that remains after irrigation usage and sediment deposition will be refilled with runoff and rainfall water sometime between the end of the farming season and the beginning of the following growing season. We do not consider year to year variation in precipitation. Also, we assume that irrigation does not affect sheet and rill erosion rates due to rainfall.

2.6 Dominant Management Options

The data on the 2 base management systems, 5 dominant non-irrigated practices, and 4 dominant irrigated practices were merged to provide 11 management systems. The base system for the non-irrigated options (CC-CTL-CN-NIRR) was selected as the base system for further analysis of the composite set of dominant options. For each of the 11 systems, data on net revenue change per unit area ($/ac), remaining annual soil loss (tons/ac) and C and P factors provided by frontier analysis within SOILEC, together with data on the number of transects in the study area, number of farm fields, acres in each field within a transect, slope of each field within a transect, etc., were used in the modified SEDEC framework (discussed in section 2.4) to select non-dominated sets of management practices for fields within each transect. For each transect then, an option list, made up of sets of possible management systems to be used on the fields within that transect is provided. Associated with each set of management systems in an option list are the total sediment loads (tons/yr) and total net returns from the adoption of that set of practices in that particular transect.

Table 2.7. Variation of Results with Reservoir Capacity

Reservoir Capacity (ac-in)	Objective Function Value in $	Optimal Management Systems	Transect (No.) Associated with Optimal Practice
12,264	66,445.75	CS-RTL-VT-IRR	All 16 transects
7,900	66,165.61	CS-RTL-VT-IRR	1,2,8,9,10,11,12,13,14,15,16
		S-NT-VT-NIRR	3,4,5,6,7
6,000	65,879.89	CS-RTL-VT-IRR	1,2,8,9,10,11,12,13
		S-NT-VT-NIRR	3,4,5,6,7,14,15,16
5,000	65,851.47	CS-RTL-VT-IRR	1,2,11,12,13
		S-NT-VT-NIRR	3,4,5,6,7,8,9,10
4,000	65,565.75	CS-RTL-VT-IRR	1,2,11,12,13
		S-NT-VT-NIRR	3,4,5,6,7,8,9,10,14,15,16
1,000	64,855.90	S-NT-VT-NIRR	All 16 transects

CS = Corn-Soybeans
S = Continuous Soybeans
RTL = Reduced Till
NT = No Till
VT = Up-and-Down-Slope (vertical) Cultivation
IRR = Irrigation
NIRR = No Irrigation

2.7 Model Parameters

The data on net returns and sediment loads from each set of management systems from the option list for each of the 16 transects were used in specifying the binary integer programming optimization model presentation in Section 2.5. Constraint (2.5.5) forced the model to choose one and only one set of management systems from the option list for each transect. Additional constraint equations (2.5.6 - 2.5.10) were included to make sure that each of the 5 center-pivot systems that would serve the entire study area served only specific transects without overlapping - that is, no transect can be served by more than one center-pivot system. As a result of these constraints, if any one of the center-pivot systems is shut off because of water shortage, or any other reason, all transects served by it do not receive irrigation water. This constraint is required in order to be consistent with the dominance procedures used at the transect level.

The APEX integer programming computer package was used to determine the optimal solution for the model. Q was taken as 8.0 acre-inches (Lazarus and Scott; Sipp, Lembke, Boast, Thorne and Walker) and m as 0.0007 acre-inches/ton.

2.8 Results

The results (summarized in Table 2.8) indicate that when the reservoir capacity constraint is not binding, only one irrigated management system, CS-RTL-VT-IRR, is chosen for all 29 fields. At the other extreme, when the reservoir capacity constraint is very limiting, that is, when the reservoir is quite small, only one non-irrigated

Table 2.8. Results of 5-Year Iterations.

Reservoir Capacity in Acre-Inches	Optimal Management Systems	Transect (No.) Associated with Optimal System	Conversion of 5-Year Sediment Load in Tons	Sediment Load into Ac-In
7,900.00	1. CS-RTL-VT-IRR	1,2,8,9,10,11,12,13,14,15,16	6,428.57	4.5
	2. S-NT-VT-NIRR	3,4,5,6,7		
7,895.50				
7,891.00				
7,886.50				
7,882.00				
7,877.50				
6,000.009	1. CS-RTL-VT-IRR	1,2,8,9,10,11,12,13	8,029.00	5.6
	2. S-NT-VT-NIRR	3,4,5,6,7,14,15,16		
5,994.40				
5,988.80				
5,983.20				
5,977.60				
5,972.00				
5,000.00	1. CS-RTL-VT-IRR	1,2,11,12,13,14,15,16	8,218.50	5.8
4,994.20				
4,988.40				
4,982.60				
4,976.80				
4,971.00				

practice, S-NT-VT-NIRR, is chosen for all 16 transects. In the in-between case where the reservoir capacity is not very limiting, a mix of irrigated and non-irrigated management practices is chosen in the optimal solution. In no case did sedimentation during the 30 year study period prompt a change in land management practices.

Optimal solutions were obtained with arbitrarily chosen levels of reservoir capacity - 12,264, 7,900, 7,000, 6,000, 5,000, 4,000, 3,000, 2,000, and 1,000 acre-inches. At each of these specified levels of reservoir capacity, the total sediment load associated with the optimal management practices was calculated. Total sediment load for five years under the optimal management set was then computed and converted into acre-inches of reservoir capacity. This figure was subtracted from the specified reservoir capacity and an optimal solution was found using the remaining reservoir capacity. Six iterations of this procedure were performed on each of the specified reservoir capacities, each time using the remaining reservoir capacity in constraint equation (2.5.4). At a reservoir capacity of 7,900 acre-inches, for example, 6 iterations were performed using 7,900, 7,895.5, 7,891, 7,886.5, 7,882, and 7,877.5 acre-inches, respectively. Sedimentation during the five year intervals accounted for the reductions in reservoir capacity.

The optimal set of management practices included CS-RTL-VT-IRR on transects 1, 2 and 8 through 16, and S-NT-VT-NIRR on transects 3 through 7 (Table 2.8). The optimal practices did not change over the 6 planning intervals, indicating sedimentation was not sufficient to bring about progressive management adaptations. The total annual sediment load associated with the above solution was 1,285.71 tons or 0.90 acre-inches and the 5-year total was 6,428.57 tons or 4.5 acre-inches. The solution would not change until the reservoir capacity falls to 6,519.36 acre-inches. Any small reduction in this amount would result in a new optimal solution. A 0.01 reduction in reservoir capacity from 6,5519.36 to 6,519.35 acre-inches resulted in a new optimal solution. The total net return changed from $66,165.61 to $66,160.03 with CS-RTL-VT-IRR on transects 1 through 13 and S-NT-VT-NIRR on transects 14, 15, and 16.

The results of some iterations performed with other specified levels of reservoir capacity are presented in Tables 2.7 and 2.8. The optimal solutions showed a mix of 2 practices, CS-RTL-VT-IRR and S-NT-VT-NIRR, on different transects with reservoir capacities ranging between 7,915.03 and 1,398.54 acre-inches. With a reservoir capacity of anything above 7,915.03 acre-inches, only CS-RTL-VT-IRR comes into the solution. Similarly, with a reservoir capacity of anything below 1,398.54 acre-inches, only S-NT-VT-NIRR appears in the optimal solution.

3. Investment Analysis

To determine the profitability of irrigating corn and soybeans on claypan soils in Southern Illinois, an investment analysis was carried out with different sizes of reservoir capacity. Five reservoir capacities - 12,264.00, 7,900.00, 6,000.00, 5,000.00, and 4,000.00 acre-inches were investigated.

The discounted cash flow method was used for the investment analysis. The present value of annual net income flows (annual cash flow less annual operating costs) from the set of optimal management systems chosen under each of the specified reservoir capacities was computed over the 30-year planning horizon at a discount rate of 4.00 percent. The resulting cumulative net present values for the different reservoir capacities were then compared to their respective total reservoir construction and irrigation system costs. (Summarized in Table 3.1) The results are presented in Table 3.2.

To compute the total cost of the irrigation system, the reservoir construction cost per acre was projected from a cost curve employed by the U.S. Soil Conservation Service. (See Figure 3.1) The total drainage area of the study site (936.4 acres) is the independent variable in the cost relationship. To get the total cost of constructing a reservoir with a capacity of 12,264.00 acre-inches, the projected cost per acre of drainage area of about $210.00 was multiplied by 112 acres - the drainage area used up for the construction of the reservoir. The total construction cost came to (112) x ($210.00) = $23,520.00. Other irrigation costs included the cost of the 112 acres used for reservoir construction - $134,400.00, with a per acre land cost of $1,200.00 (1982, Census of Agriculture); the cost of 5

Table 3.1. Reservoir Construction and Irrigation Costs for Reservoir Capacity of 12,264 Acre-Inches.

Initial Investment	Cost
5 Center-pivot systems	$200,000.00
Pump and gear head	35,000.00
130-hp diesel motor	50,000.00
Reservoir (25 ft deep)	23,520.00
5280 ft of 6" aluminum pipe	13,054.00
Cost of 112 acres of reservoir site	134,400.00
TOTAL	$455,974.00

Source: Erickson, et.al.

Table 3.2. Results of Investment Analysis

Reservoir Capacity in ac-ins	30 yr Cumulative NPV from Optimal Management Systems @ 4.0% Discount Rate	Total Cost of Reservoir Construction & Irrigation Systems	Net Return to Investment	Net Return as Percent of Total Irrigation Cost
		($ x 1000)		%
12,264.00	2,060.80	456.00	1,604.80	351.9
7,900.00	2,053.90	407.60	1,646.30	403.9
6,000.00	2,046.90	364.00	1,682.90	462.3
5,000.00	2,026.10	362.10	1,684.00	465.1
4,000.00	2,039.10	320.10	1,719.00	537.0

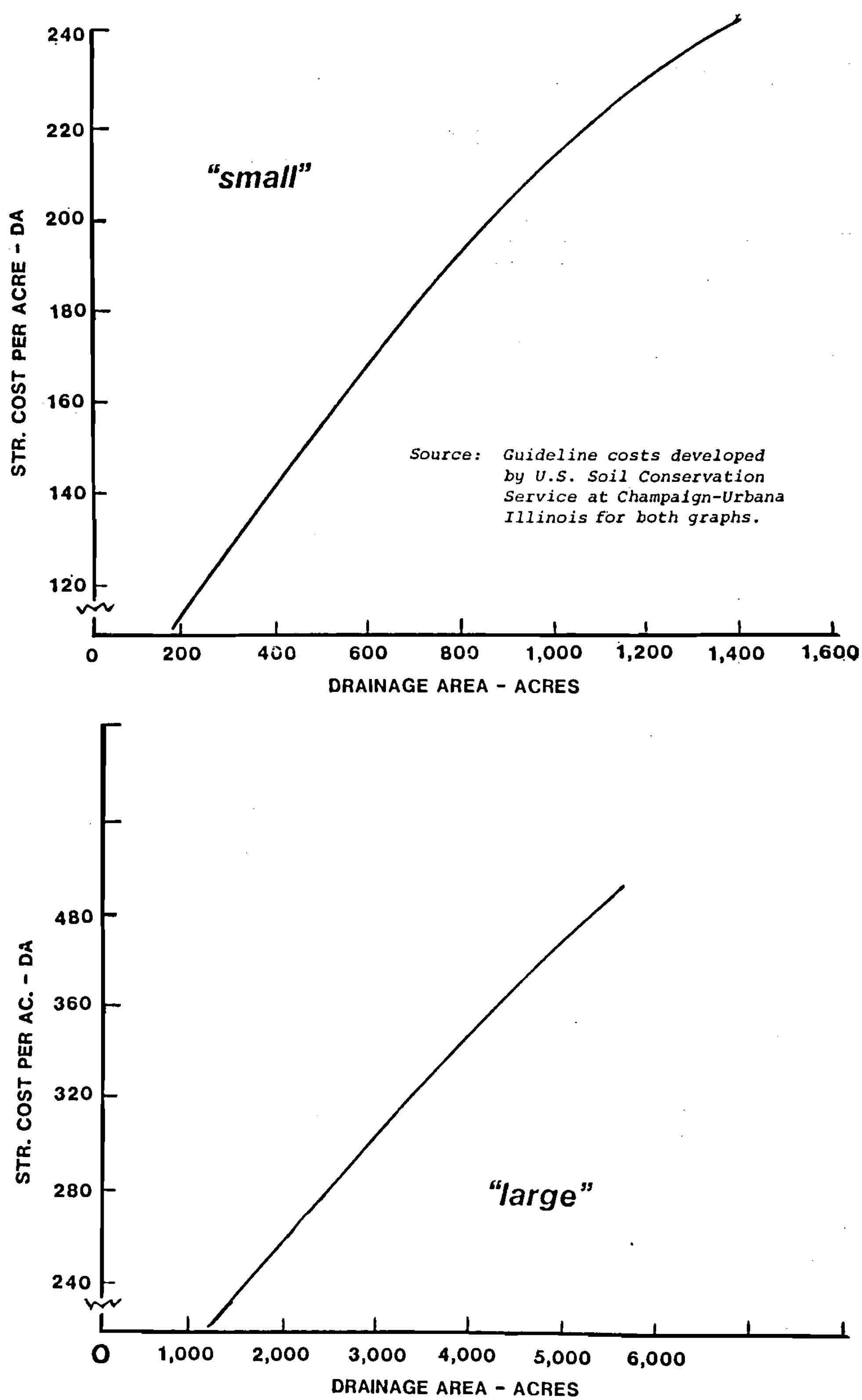


Figure 3.1. Reservoir Structure Cost per Acre By Size of Drainage Area

center-pivot irrigation systems - $200,000.00 at $40,000.00 each (See Table 3.1 for details.) For the other reservoir capacities, reservoir construction costs were estimated as linear proportions of the $23,520.00 estimate for the reservoir size of 12,264.00 acre-inches.

The results of the investment analysis (Table 3.2) indicate that at each of the five specified levels of reservoir capacity, the 30-year cumulative net present values of total returns at a real discount rate of 4.00 percent was far greater than the cost of reservoir construction and irrigation systems. The net returns to investment increased with smaller reservoir capacities. At a reservoir capacity of 12,264.00 acre-inches, the net return to investment was $1,604,800.00 or 351.9 percent, while the net return for a reservoir size of 4,000.00 acre-inches was $1,719,000.00 or 537.0 percent. The discount rate of 4.00 percent used in the analysis is a reasonable long-term average for real rates of return on financial investments. At discount rates higher than 4.00 percent, the cumulative net present value of total returns would be far lower than those in Table 3.2 for each level of reservoir capacity.

References

Bost, K.W., Microeconomic Analysis of the Relationship Between Soil Erosion and Returns from Crop Production on Sixteen Illinois Soils. Unpublished M.S. Thesis, University of Illinois, 1981.

Braden, J. B., 1982, "Some Emerging Rights in Agricultural Land', AJAE, 64(1):19-27.

Braden, J.B., G.V. Johnson, and D.G. Martin, "Efficient Control of Agricultural Sediment Deposition in Water Courses." Options for Reaching Water Quality Goals, Tech. Pub. No. 84-2, American Water Resources Association, Bethesda, MD, 1985.

Braden, J. B. and D. L. Uchtmann, 1983. "Soil Conservation Programs Amidst Faltering Environmental Commitments and the 'New Federalism'". Boston College Environmental Affairs Law Review, 10(3):639-96.

Changnon, Stanley A., Jr., "A Climatological - Technological Method for Climating Irrigation Water Requirements for Maximum Crop Yields", Journal of Soil and Water Conservation, 24(1):12-15, January-February, 1969.

Clarke, C.D. "Procedure for Ranking Sediment Source Areas." U.S. Department of Agriculture, Midwest Tech. Center, Lincoln, NE, 1983. (Draft)

Eleveld, B., G.V. Johnson, and R.G. Dumsday. "SOILEC: Simulating the Economics of Soil Conservation." Journal of Soil and Water Conservation 38(1982) 5:387-9.

El-Saadi, M. A. A. and E. R. Swanson, "Effect of Supplemental Irrigation on Income and Net Worth: A Simulation Analysis", Illinois Agricultural Economics, January, 1972.

Erickson, D.E., P. Ellinger, and D. Brucker. "Irrigation: Some Economic Considerations - Update, 1981-82." Illinois Irrigation Newsletter, 4(No. 1, 1982).

Hinesly, T. D., "Supplemental Irrigation of Corn in Illinois", Agronomy Facts, C-35, University of Illinois, 1965.

Hinesly, T. D., "Increasing the Amount of Water for Producing Corn", Agronomy Facts, C-36, University of Illinois, 1965.

"Irrigated Corn Yields in the North Central Region of the United States", North Central Regional Research Publication No. 204, Special Report 65, November, 1972.

"Irrigation as a Factor in the Growth, Operation and Survival of Great Plains Farms", Great Plains Agricultural Council Publication No. 30, November, 1967.

Johnson, G. V. and J. B. Braden. 1983. "An Economic Model for Targeting Erosion Controls to Improve Water Quality". Proposal funded by the Illinois Water Resources Center.

Kliebenstein, James B. and John T. Scott, Jr., "Farm Production Decision- Making Using Quadratic Programming - An Empirical Application", Department of Agricultural Economics, University of Illinois, Urbana, AERR-138, April, 1975.

Lah, R.A., J.W. Drablos, and M.D. Thorne. "Irrigation on the Increase in Illinois." Illinois Research 20(1978) 4:6-7.

Lazarus, W.F., and J.T. Scott, Jr. "A Present Value Analysis of Returns to Irrigation in South Central Illinois." North Central Journal of Agricultural Economics 3(1981) 1:63-9.

McGann, J.M., K.D. Olson, T.A. Powell, and T.R. Nelson. Microcomputer Budget Management System User Manual. Department of Agricultural Economics, Texas A & M University, November, 1984.

Pendleton, J. W., "Corn and Climate", Agronomy Facts, C-18, University of Illinois, 1957.

Peters, D. B., "Water Use by Corn", Agronomy Facts, C-17, University of Illinois, 1957.

Runge, E. C. A. and R. T. Odell, "Effects of Summer Precipation and Temperature on Corn Yields", Agronomy Facts, C-19, University of Illinois, 1957.

Runge, E. C. A., and R. D. Odell, "The Relationship Between Precipitation, Temperature, and the Yield of Soybean on the Agronomy South Farm, Urbana, Illinois, Agronomy Journal, Vol. 52:245-247, 1960.

Scott, John T., Jr., and C. B. Baker, "A Practical Way to Select an Optimal Farm Plan Under Risk", American Journal of Agricultural Economics, Vol. 54, No. 4, pp. 657-660, November, 1972.

Sipp, S.K., W.D. Lembke, C.D. Boast, M.D. Thorne, and P.N. Walker. 1984. "Water Management on Claypan Soils in the Midwest." Report 186. Urbana, Illinois: Water Resources Center, University of Illinois.

Sisson, Donald R. and Dan Wiersma, "Corn Irrigation in the Humid Area", Paper presented at Sprinkler Irrigation Convention Technical Meeting, February 20-21, 1967, Denver, Colorado.

Smith, L. E., D. W. Thman, and D. Wiersma, "An Economic Analysis of Water, Nitrogen, and Seeding Rate Relationships in Irrigated Corn Production", Research Bulletin No. 755, Purdue University, November, 1962.

Swanson, E. R. and B. A. Jones, Jr., "Estimated Annual Investment Returns from Irrigation of Corn", Journal of Soil and Water Conservation, Vol. 21:64-66, 1966.

U.S. Department of Commerce. 1982. Census of Agriculture, Geographic Area Series. Illinois: State and County Data. Volume 1, Part 13.

Wischmeier, W.H. and D.D. Smith. 1978. "Predicting Rainfall Erosion Losses: A Guide to Conservation Planning." U.S. Department of Agriculture, Washington, D.C., Agriculture Handbook No. 537, 58 pp.