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AN ECONOMIC AND INSTITUTIONAL ANALYSIS OF LAND TREATMENT AS A WASTEWATER MANAGEMENT ALTERNATIVE FOR SOUTHEASTERN MICHIGAN

By

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ABSTRACT

Communities are evaluating land treatment as a wastewater management alternative to meet water quality requirements. A public entity implementing a land treatment system requires access or rights to land. The willingness of a landowner to provide access depends on how it effects his goals. This study was undertaken to analyze acquisition and management options for land treatment systems and to evaluate the economic and institutional impacts of land treatment.

The analysis was in three sections; (1) a description of the land treatment concept and its applications, (2) an institutional analysis identifying options for acquiring property rights and managing farm operations and evaluating the impacts of these options on farmer and wastewater authority goals, and (3) an empirical analysis of the impacts of land treatment on crops and farm and regional production and revenue, and the sensitivity of these impacts to alternative assumptions of yield response, price, crop rotation, and irrigation cost.

Land treatment is a wastewater management alternative that should be evaluated in terms of specific community conditions. A land treatment system can be designed to

maximize wastewater renovation, to maximize crop production, or to combine both objectives. When both objectives are pursued, regional crop production can increase and wastewater renovation can occur without major community disruptions. A system designed primarily for renovation can increase regional forage productions and reduce grain production and disrupt existing channels for production input distribution and crop marketing.

The acquisition options used reflect varying capacities of communities to impose the costs of wastewater treatment on landowners, and impact differently on the goals of farmers and wastewater authorities. Acquisition options include fee simple, real property interests other than fee, and contractual agreements. Fee simple acquisition is the most costly option to an authority and can be disruptive to individual farmers and the agricultural economy. Easements are an acquisition option for other than fee interest, with the conditions of access specified in an agreement between the farmer and authority. Through contractual agreements or through the formation of wastewater cooperatives, access to land can be obtained without acquiring property rights.

Breakeven and sensitivity analysis were used to estimate the impacts of alternative data sets on individual crops, the farm firm, and the region. Crop yield increases required to offset irrigation costs were estimated with a number of price and cost assumptions for corn, soybeans, dry beans, wheat, and alfalfa. The total revenues of a 320 acre and 580 acre farm were estimated with irrigation, alternative crop rotations, yields, and prices. Total revenues increased for all rotations but especially with rotations with large acreages of corn and dry beans. The total irrigation costs for the individual farms were offset by increased revenues only with the most optimistic yield increase and price assumptions. The impact of a land treatment project on regional production requirements for Southeastern Michigan was relatively slight, and the greatest impact occurred in corn production. As with the farm firms, net revenues increased only when a high proportion of the annual irrigation costs was paid by the wastewater authority.

Land treatment has implications for farmers, wastewater authorities, and the region. It provides an opportunity to increase farm revenues, especially if most of the irrigation costs are paid by the wastewater authority. Fee simple acquisition has the greatest disruptive impact on farmers, the exact extent influenced by the management option selected by the authority. Fee simple acquisition gives the authority the greatest control, but at a high land cost. It enables an authority to unilaterally pursue its own goals. Less than fee rights reduces control from a wastewater management viewpoint, but reduces costs to the authority and is less disruptive to the agricultural economy.

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TABLE OF CONTENTS

Chapter | Page

Chapter		Page

LIST OF TABLES

Table		Page

Table		Page

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The Problem

The hierarchy of problems addressed in this study begins with water pollution resulting from inadequate wastewater treatment. Legal requirements to clean up the water encourage the consideration of land treatment as a wastewater management alternative. Wastewater treatment utilizing land treatment requires rights to land held by the existing landowners. A body responsible for wastewater treatment requires rights insuring access to the land. The present landowner may or may not wish to provide the required access. This study addresses the problem of acquiring land rights and managing treatment systems.

Water pollution has been, and continues to be, a significant environmental and economic problem for communities of all sizes in the United States. A major source of water pollution is effluent from domestic and industrial wastes which is directly or indirectly discharged into streams, rivers, and groundwater supplies. Approximately 7 1/2 billion gallons of wastewater requiring treatment and disposal was produced daily in 1972. The waste load from municipal systems is expected to nearly quadruple over the next 50 years [Council on Environmental Quality, 1970]. Phosphorous levels increased in 84 percent of major U.S. rivers over the five year period 1968-1973, and nitrogen levels increased in 74 percent of the rivers over the same period. EPA phosphorous guidelines were exceeded in 54 percent of the river reaches [USEPA, 1973]. Metropolitan growth and the proliferation of localized treatment centers contributes to inadequate and inefficient wastewater treatment. Extensions of sewer services far beyond corporate boundaries to serve developing areas causes overloads on both sewers and treatment plants. Discharge of raw sewage directly into waterways often results from the common practice of combining storm and sanitary sewers. Small "package" treatment plants used for residential and business developments are often operated and maintained in a careless manner. In unsewered areas individual septic tanks have been installed, often of inadequate size and in poorly drained soils, and overflow into local drainage courses. When the quality of the receiving water fails to meet legal standards, the responsible governmental agency usually takes steps to install a local treatment plant. As more areas develop, the cycle is repeated and a proliferation of small treatment plant construction or enlargement results.

Zero discharge of pollutants to navigable waters by 1985 has been set as a national wastewater management goal.

Federal and state laws to reduce water pollution have been passed. The Amendments to the Federal Water Pollution Control Act of 1972, Public Law 92-500, require all publicly owned treatment plants to process their wastewater to the level of secondary treatment by July 1, 1977. Michigan has issued stipulations to municipal corporations of over 1500 population to restrict the pollution content of wastes discharged into Lake Michigan or its tributaries. These orders required facilities to remove a minimum of 80% of the phosphorous contained in the untreated sewage and wastes by December 1972 [Corps of Engineers, 1971].

Communities faced with meeting the legal requirements for wastewater treatment will closely evaluate alternative treatment methods to determine the most cost-effective method to provide secondary and tertiary treatment. The basic alternatives for advanced wastewater treatment are land treatment, advanced biological treatment, and physical-chemical treatment. The land treatment alternative is receiving increased attention due to a number of factors, including public concern for adequate sewage treatment, increased wastewater volume, Federal recommendations for the elimination of ocean dumping of municipal sludges, and recent Federal legislation restricting the discharge of pollutants into navigable waters and promoting recycling of such pollutants. Specific provisions on land treatment become a part of Federal legislation for the first time in the Water Pollution Act Amendments of 1972. These are the first Federal laws that specifically encourage land treatment and reclamation and authorize Federal construction grants to State and local agencies to assist in the establishment of such systems. Subsection 201(d) of the 1972 Amendments furnishes encouragement for waste treatment management which results in the construction of revenue producing facilities providing for: (1) the recycling of potential sewage pollutants through agricultural and forestry production; (2) the reclamation of wastewater; and (3) the ultimate disposal of sludges in a manner not harmful to the environment. In addition, encouragement is to be given to waste treatment management that combines "open space" and recreational considerations, and that results in integrating facilities for sewage treatment and recycling with facilities to treat, dispose of, or utilize other industrial and municipal wastes.

The basic idea in land treatment is the application of wastewater following primary and secondary treatment to land. The soil and agricultural crops or forest products then absorb and filter nitrates, phosphates, and other elements from wastewater. Remaining "purified" water drains through the soil to recharge the groundwater or to return via underdrains to the water course. Data on the "living filter" concept has been collected at Pennsylvania State University since 1963 [Parizek, 1967, Sopper, 1973].

Muskegon County, Michigan has received national attention for its wastewater irrigation project, where a land treatment system will eventually treat the industrial and municipal wastewater from approximately 160,000 people [Sheaffer, 1970, Bauer, 1973]. Approximately 50 other municipalities in Michigan are investigating land treatment as an alternative or supplemental means to biological or physical-chemical treatment of wastewater [Pierce, 1973]. Michigan State University is involved in a campus wastewater management plan [Stevens, 1972, Bahr, 1974]. The land treatment concept is also being studied by the U.S. Army Corps of Engineers. In 1971 it undertook five pilot wastewater management studies for the metropolitan areas of Boston, Detroit, Cleveland, Chicago, and San Francisco. These studies evolved into an urban studies program covering many of the major metropolitan areas of the United States. Both the pilot studies and the urban studies program evaluate land treatment as an alternative for wastewater treatment [Corps of Engineers, 1972b, 1972c].

Land treatment affects farmers and the agricultural community through its requirements for land, a basic factor of agricultural production. The amount of land required varies with the treatment system objectives and with the volume of wastewater. For example, estimates of the land needed to treat the total wastewater volume from Southeastern Michigan range from 760,000 acres to 1,955,000 acres [Corps of Engineers, 1974]. Smaller regions or communities require less land. Communities evaluating land treatment are faced with the problem of acquiring land rights. Both communities and farmers are confronted with determining the impacts on their respective goals of the options for transferring land rights and managing land treatment systems.

Objectives and Scope of the Study

Objectives

This study evaluates some economic and institutional aspects of land treatment as a wastewater management alternative for Southeastern Michigan. It focuses on the options available to acquire land rights and to manage treatment sites, and the impacts of these options on the goals of farmers and wastewater authorities. The impact of land treatment on the agricultural economy at the farm and regional level is also evaluated.

Specifically, the study objectives are:

1. To describe the land treatment concept, its applications, and its potential for use in Southeastern Michigan.

2. To identify and evaluate alternatives for acquiring land use rights and for managing the farming operations of land treatment systems.

   a. Specify the options for acquisition of land rights and farm management and relate these to the goals of farmers and wastewater authorities.

b. Use budgeting and sensitivity analysis to identify alternatives for the distribution of costs and benefits of a land treatment system between a wastewater authority and farmers.

3. To identify and estimate some of the parameters involved in the investigation of a land treatment system and the uncertainties surrounding them.

4. To specify implications of land treatment at the farm, firm and regional level.

a. Identify and evaluate opportunities for increasing farm revenues through land treatment operations under alternative cost sharing arrangements.

b. Identify some of the macro implications of large scale land treatment operations in Southeastern Michigan.

The achievement of these objectives will provide information useful to communities, wastewater authorities, and to farmers evaluating land treatment proposals. Results will focus on land treatment from the perspective of the individual farmer and the agricultural community. Data on the management options will aid in specifying a bargaining area for farmers and wastewater management authorities as they negotiate the division of costs and benefits associated with a land treatment project.

Scope

This study considers institutional alternatives for land acquisition as well as managerial possibilities. Parties affected include the farmer, the wastewater authority and the community. This study focuses on the effects on farmers.

A partial equilibrium approach was used to evaluate the primary economic effects of land treatment on the farm, firm and region. Sensitivity analysis was applied in a static framework to estimate revenue changes under alternative assumptions.

Specific Land Treatment Proposals from the Southeastern Michigan Wastewater Management Study provide the basis for empirical work [Corps of Engineers, 1974]. This study covers a nine county area of Southeastern Michigan, an area identified as the largest single source of municipal and industrial wastewater flowing into Lake Erie [U.S. Department of Interior, 1968]. This same area corresponds to the boundaries of the Southeastern Michigan Water Resources Study. Projections of agricultural production for 1980 from the Water Resources Study are assumed to depict the situation without land treatment [Rhoade, 1969].

This study uses descriptive information to provide an understanding of the water pollution problem and approaches to wastewater treatment. Land treatment is described using examples of past and present applications.

Institutional alternatives for the acquisition of land for treatment purposes are discussed in terms of their strengths and weaknesses, along with options for managing the farming operations. The possible impacts of the acquisition and managerial alternatives on an assumed set of farmer's goals are estimated on a subjective basis.

Empirical analysis at the farm, firm and regional level is used to estimate changes in total and net revenues under alternative assumptions related to land treatment. Sensitivity analysis is applied to yield, price, rotation, and cost sharing assumptions because of the uncertainties surrounding their values. Results from the most probable combinations of variables are presented as guides for bargaining between land owners and wastewater authority.

Organization

The study is organized to identify the problem, provide background information, present a conceptual framework and data for problem analysis, and estimate the impact of land treatment. Chapter I identifies the problem of water pollution and the objectives and scope of the study. Chapter II discusses wastewater treatment policies and alternatives, but focuses on the land treatment concept and some of its applications. A conceptual framework for inquiry into options for the acquisition of property rights and the management of farming operations is presented in Chapter III. Data is presented in Chapter IV and used in

Chapter V to estimate the impacts of land treatment at the farm and regional level. The study closes with a summary and implications discussion, Chapter VI.

CHAPTER II

THE LAND TREATMENT CONCEPT

Background on Wastewater Treatment

The Reason for Public Investment

In most urban areas the collection and treatment of human wastes is done on a collective rather than an individual basis. This is based on concern for public health and recognition of economies of scale in wastewater treatment. The provision of wastewater treatment by municipalities rather than individuals also recognizes the difficulties in making each user pay according to the value of wastewater treatment services received. Market failures related to common property, resources, the public goods nature of certain resource flows, external diseconomies, and imposed public ownership are rationale for public policies such as those related to wastewater treatment [Haveman, 1973]. The failure most applicable to the analysis of wastewater treatment policies are the public goods nature of the waste assimilation capacity of watercourses and market failures related to external diseconomies in production or consumption.

The waste assimilation capacity of streams has characteristics of a common property resource. The rights to this assimilation capacity are held in common by everyone, which makes its use costless, in the absence of rules, to discharge into the stream. As a result, streams are exploitated and polluted. As a result of the overuse of the waste assimilation capacity, governments have adopted a rules and enforcement policy strategy. The common property rights of the waste disposal services have been made the object of status rights, where the use of the resource is dependent upon meeting certain eligibility conditions [Dales, 1972].

Historically, water pollution control in the U.S. has been based upon Federal subsidies for the construction of wastewater treatment plants and the enforcement of violations against individual waste dischargers. Federal grants of more than three billion dollars have been awarded for the construction of municipal wastewater treatment plants since passage of the 1956 Water Pollution Control Act. Additional billions of dollars are scheduled to be spent in the next several years. These grants have been for secondary treatment facilities for municipal wastewater treatment [Council on Environmental Quality, 1973].

Industrial wastewaters are continually discharged into watercourses because construction grants are not provided for its treatment. Incentives for industries to clean up their discharges are tax law provisions for accelerated depreciation on wastewater treatment investments. Accompanying this subsidy policy is a regulatory-enforcement policy. The Federal government has assigned states the responsibility of establishing water quality standards and of developing a program to meet the standards. Most states have met the responsibility by determining the maximum quantity of discharges consistent with national standards, issuing licenses to dischargers consistent with this maximum, and initiating judicial proceedings when dischargers exceed permitted amounts.

Treatment System Growth and Costs

Sanitary sewer service has grown with the United States population. The first sanitary sewer was constructed in Chicago in 1855. Approximately 163 million Americans were served by sanitary sewerage facilities in 1973, up from 118 million in 1962 [USEPA, 1973]. Treatment of collected wastes has increased. Some type of treatment was given 98 percent of the collected wastes in 1973 compared to 85 percent in 1962. In 1973, tertiary treatment was given to wastes from less than two percent of the population served by sewer systems. Approximately 64 percent of the population was on systems with secondary treatment plants and 28 percent were on systems providing only primary treatment [USEPA, 1973].

Large capital investments are represented in past and projected collection and treatment facilities. Between

1855 and 1971, the U.S. invested an estimated $58 billion (1972 dollars) in its public sewer facilities [USEPA, 1973]. More than 30 percent invested since 1961, 60 percent since World War II, and 80 percent since 1929. The estimated cost ($60.1 billion) of constructing new municipal and treatment facilities eligible for Federal Funding under the 1972 Amendments, is greater than the total system investment to date. The 1972 Amendments require industry to use "best practicable" water pollution control technology by mid-1977 and "best available" technology by mid-1983. It has been estimated that industry will have to invest an additional $11.9 billion by 1977 to meet pollution abatement standards set for that year, assuming current water use technology remains unchanged. Estimated construction expenditures for Michigan for new public treatment facilities are $3.3 billion, or a 1972 per capita cost of $366 [USEPA, 1973].

Wastewater Treatment Problems for Rural Communities

Many rural communities face special problems as they deal with more stringent water quality standards. The local tax base is often inadequate to finance even a secondary treatment system let alone a tertiary system. Data indicate that per capita expenditures for sanitation services in non-metropolitan areas was less than in metropolitan areas in 1967, both absolutely and relatively. Approximately $7 per capita was spent in non-metropolitan areas compared to nearly $16 in metropolitan communities.

As a percent of total per capita expenditures, 3% of the typical non-metropolitan area budget total went to sanitation, compared to 3.41% of the metropolitan area budget [U.S. Congress, 1971].

A grants provision of $300 million for water and waste disposal systems for rural communities was authorized in Title 1 of the Rural Development Act of 1972, PL 92-419. However, funds for fiscal 1973 were impounded and none were budgeted for 1974. Consequently, grants for rural sewer and solid waste treatment programs have been discontinued except for those initiated by the Environmental Protection Agency.

Wastewater Treatment Methods

Treatment begins with the collection and transmission of wastewater from individual sources to a treatment plant. The degree of treatment given is primarily determined by resource availability and legal requirements. The general levels of treatment, moving from the least to the most complex, are primary, secondary, and tertiary treatment.

Primary treatment is a mechanical process relying on natural sedimentation and some chemical precipitation to remove suspended solid materials. Primary treatment normally removes about 90% of the settleable solids and about 50% of the suspended solids. The BOD (biological oxygen demand) removal rate of primary treatment is approximately 35%-50%, and the removal of phosphorous, nitrogen, or other suspended pollutants is negligible [Stevens, 1972].

Secondary treatment reduces the BOD of wastewater. One of three methods normally employed are activated sludge, trickling filters, or lagoons. In each case the purification process is biological, as the actual agents of treatments are microorganisms which oxidize the remaining suspended and colloidal solids in the wastewater. These processes are essentially accelarations of the natural decomposition processes that occur in streams and rivers. Under optimum conditions, secondary treatment can remove up to 90% of the BOD and approximately 85% of the suspended solids. Secondary treatment is also effective in removing nitrogen. However, it is nearly useless in removing phosphorus and other chemicals not readily consumed by biological processes [Stevens, 1972].

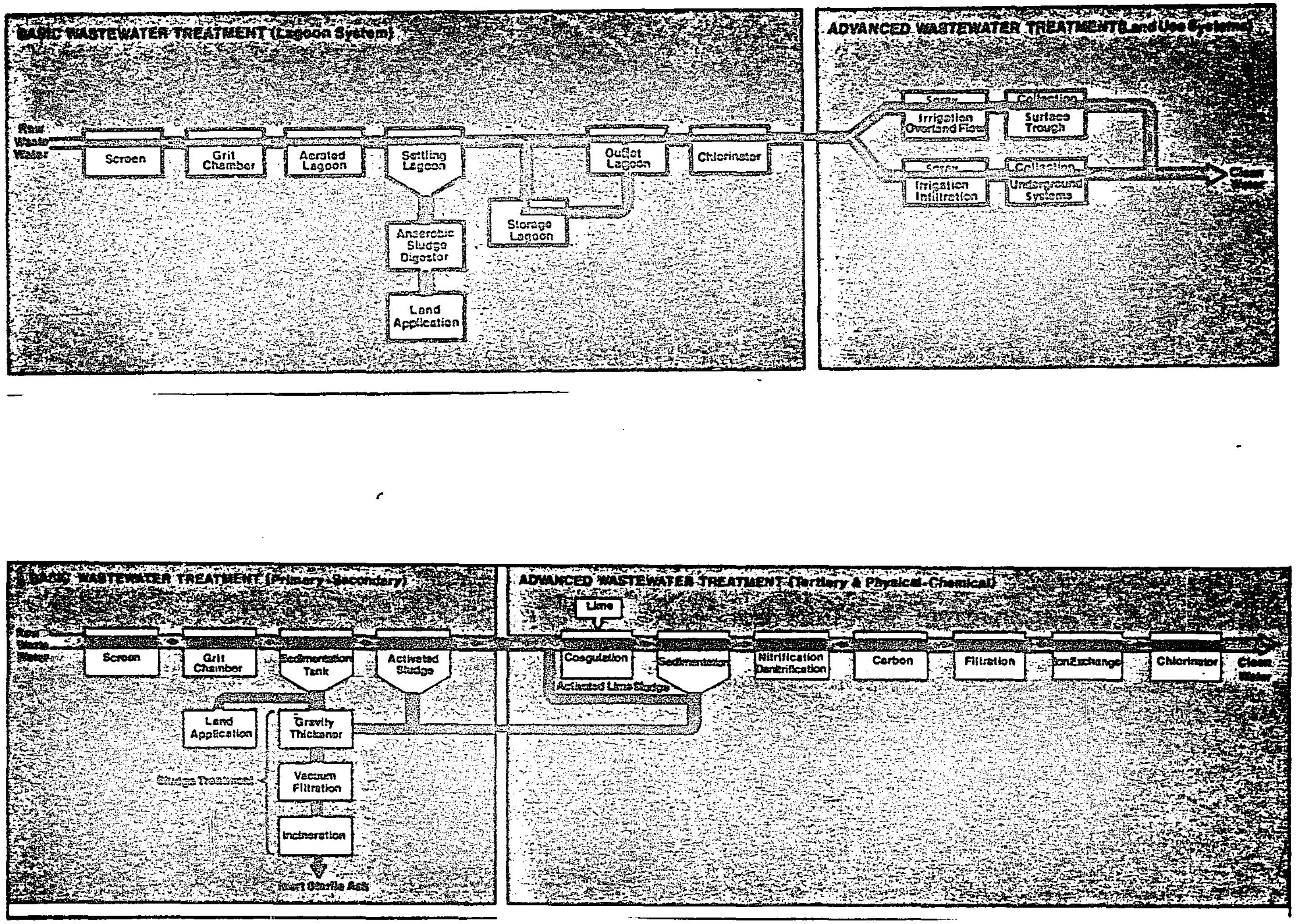
Advanced, or tertiary treatment, is the highest level of treatment. This step removes pollutants remaining after primary and secondary treatment. Generally tertiary treatment relies principally upon chemical processes, such as nitrogen stripping towers and calcium processes for phosphorous removal. It has been estimated that providing tertiary treatment facilities to meet the proposed national water quality standards will double the capital cost of the existing secondary facilities [Stevens, 1972].

Land treatment is a means of providing advanced wastewater treatment. It employs mechanical, biological, and chemical processes in the purification of wastewater. Land treatment is compatible with the materials balance approach to environmental pollution control. The materials balance view underlines the fact that the throughput of new materials necessary to maintain a given level of production and consumption decreases as the technical conversion and materials utilization increases. Through the practice of a high level recovery and recycle of waste materials and fostering of low residual production processes, very little residual materials would be returned to any of the environmental media [Kneese, 1972]. The reuse and recycling of municipal and industrial wastewater through land treatment is a prime example of this approach. Rather than discharging plant nutrients in effluent and sludge and into water-courses or air, they can be returned to the agricultural production system.

The flow through primary, secondary, and advanced wastewater treatment is shown in Figure 1. Two systems are shown, one leading to land treatment and the other to physical-chemical treatment.

Land Treatment - An Historical Perspective

Land application of sewage effluents began long before the complex technology of today's treatment system was developed. The simplest and most logical disposal method for man was to put his sewage in the ground by burying it in trenches or pits. Such disposal of simple wastes was



Source: [Corps of Engineers, 1972c]

Figure 1. Flow Diagram of Alternative Wastewater Treatment Methods

adequate in early pastoral and nomadic societies, where man could function as an integral part of an efficient ecosystem. However, when populations began to concentrate in cities and towns and to produce more complex wastes, waste problems began. The historical emphasis of land treatment of wastewater has been that of disposal in contrast to emphasis today of treatment and reuse. In the past, performance has been judged on the basis of a convenient and economical approach to wastewater disposal as opposed to effect on animal life, plant life, soil, and groundwater. Interest in the overall effects of land treatment on the environment will place more emphasis on the treatment and reuse concepts of future land treatment approaches.

Land treatment is referred to in the Old Testament and was practiced in Athens in the B.C. period. It has been reported that an irrigation project was designed to treat the waste from Bunslau, Prussia, in 1559 and operated for over 300 years. The practice of sewage farming spread to England in the 1700s and to the United States in the 1870s [Pounds, 1973a]. Long time users of land disposal include some large municipalities such as Berlin, Germany; Paris, France; Melbourne, Australia; and Moscow, Russia. A U.S. survey conducted in 1895 identified sites in 20 states scattered from Massachusetts to California, but primarily in the western states. A 1935 survey found 113 localities in 15 western states irrigating crops with wastewater

[Hutchins, 1939]. A later survey noted 316 localities in 13 states practicing crop irrigation with municipal effluents in 1972 [Thomas, 1973]. Examples of older operations around the world are shown in Table 1, many of which, including those at Mexico City and Melbourne, are still in operation.

The first U.S. projects started in the late 19th century were developed only for irrigation practices. Groundwater recharge projects were not started until the early twentieth century in the semiarid region of California and Utah [Pounds, 1973b]. During the first half of the 20th century, land treatment sites continued primarily in the west, as increased land costs and treatment capacity problems led to the abandonment of many eastern U.S. sites.

A 1964 survey identified 2,192 land disposal systems in the U.S., including 1,278 industrial systems and 914 municipal systems [Pounds, 1973a]. The 1972 EPA Municipal Wastewater Facilities Inventory identified 571 land application systems [Pounds, 1973b]. A partial survey by the American Public Works Association in 1972 contacted 196 sites, only a portion of the total land disposal systems presently in operation [Sullivan, 1973].

The majority of earlier facilities applied untreated domestic wastewater with varying degrees of control and success. A key factor in the success of a system was competent management. Land treatment was used less frequently as knowledge of wastewater treatment processes improved.

Table 1. Examples of Land Treatment Operations

Date	Location	Description	Wetted Area, Acres	Flow, mgd	Average Loading in./wk
	Non-United States				
1559	Bunzlau, Germany	Sewage farm	--	--	--
1861	Croydon-Beddington, England	Sewage farm	420	4.5	2.8
1864	South Norwood, England	Sewage farm	152	0.7	1.2
1869	Berlin, Germany	Sewage farm	27,250[a]	150[a]	1.4
1875	Leamington Springs, England	Sewage farm	400	0.8	0.5
1880	Birmingham, England	Sewage farm	1,200	22	4.7
1893	Melbourne, Australia	Irrigation	10,376[b]	50[b]	1.2
	Melbourne, Australia	Overland flow	3,472[b]	70[b]	5.2
1902	Mexico City, Mexico	Irrigation	112,000[b]	570[b]	1.3
1923	Paris, France	Irrigation	12,600	120	2.5
1928	Cape Town, South Africa	Irrigation	--	--	--
	United States				
1872	Augusta, Maine[c]	Irrigation	3	0.007	0.6
1880	Pullman, Illinois[c]	Irrigation	40	1.85	12.0
1881	Cheyenne, Wyoming	Irrigation	1,330[d]	7.0[d]	1.3
1887	Pasadena, California	Irrigation	300	--	--
1895	San Antonio, Texas	Irrigation	4,000[a]	20[a]	1.3
1896	Salt Lake City, Utah	Irrigation	180	4	5.7
1912	Bakersfield, California	Irrigation	2,400[d]	11.3[d]	1.2
1928	Vineland, New Jersey	Irrigation	14	0.8	14.7

Source: [Pounds, 1973a]

[a] Data for 1926.
[b] Data for 1971.
[c] Abandoned around 1900.
[d] Data for 1972.

Biological and chemical treatment methods were constructed which could confine the entire treatment process to a much smaller area than land treatment.

Since 1940, there has been an absolute increase in the total number of land treatment systems (Table 2). However, such systems represent a very small proportion of the approximately 15,000 communities with some type of waste treatment facilities.

Table 2. Municipalities Using Land Application and the Population Served

Year	Number of Systems	Population Served (millions)
1940	304	0.9
1945	422	1.3
1957	461	2.0
1962	401	2.7
1968	512	4.2
1972	571	6.6

Source: [Thomas, 1973]

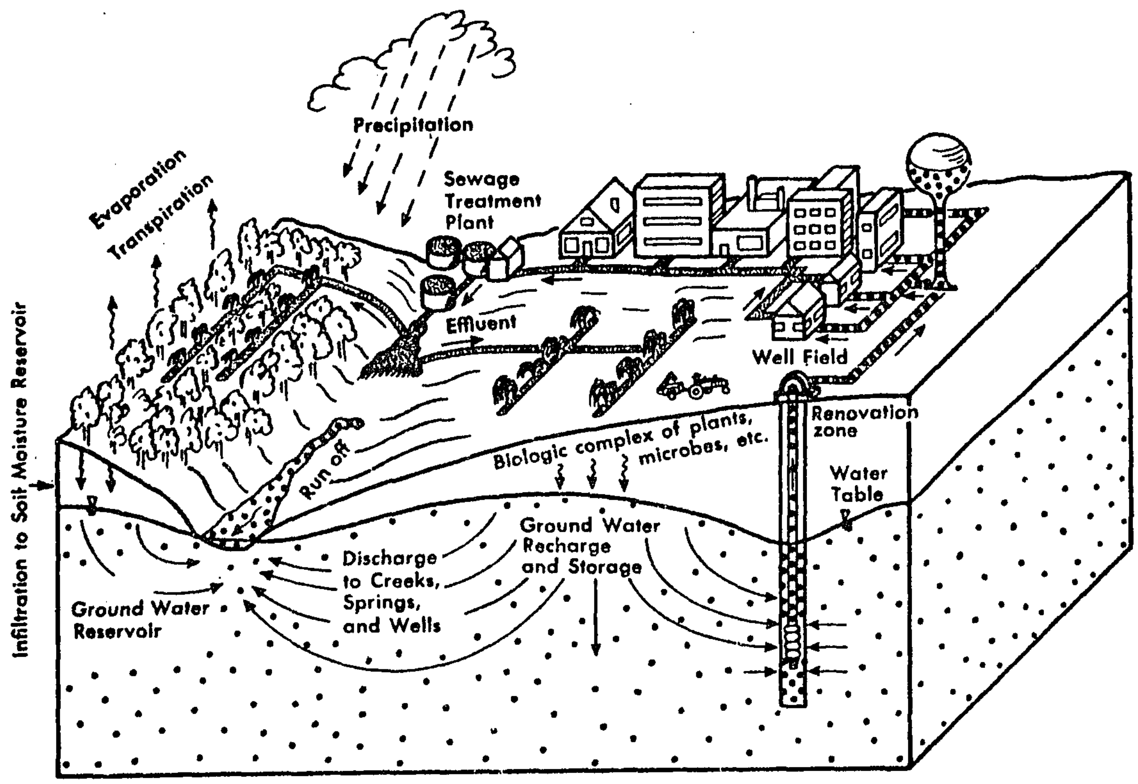
Description of Land Treatment

Goals of Land Treatment

Sewage farming was the early terminology used to describe what is currently referred to as land disposal or land treatment. Sewage farming originally involved transporting sewage to rural areas for land disposal. Later practices included reusing the water for irrigation and fertilization [Pounds, 1973a]. Generally stated, land application, is the discharge of wastewater and sludges onto the soil for treatment or reuse.

Properly designed land treatment systems can provide treatment or renovation equivalent to existing tertiary treatment methods. Land application can provide a more economical method of treatment of domestic and industrial wastewater. Irrigation with wastewater can result in increased crop production and an increase in the supply of irrigation water available for agriculture, can renovate the wastewater by lowering nutrient content, by reducing biochemical oxygen demand (BOD), by removing some of the dissolved solids from industrial wastewater, and by removing bacteria from the wastewater. In addition, such irrigation or surface spreading onto a soil system normally will result in recharge to groundwater of a portion of the effluent, with minimum threat to the continued quality of that valuable resource. The early recognition and elimination of undesirable results can be assured by the installation of appropriate monitoring devices.

The renovation of wastewater by land application can be expressed as the percent reduction in the average concentration of each constituent in the effluent. Figure 2 depicts this renovation process. Treated effluent applied to the land is filtered through the soil, water is consumed by plants and returned into the air through evaporation and transpiration, nutrients are absorbed by plant uptake, and the excess water is filtered to the groundwater reservoir or is discharged to a nearby stream via a drainage system.

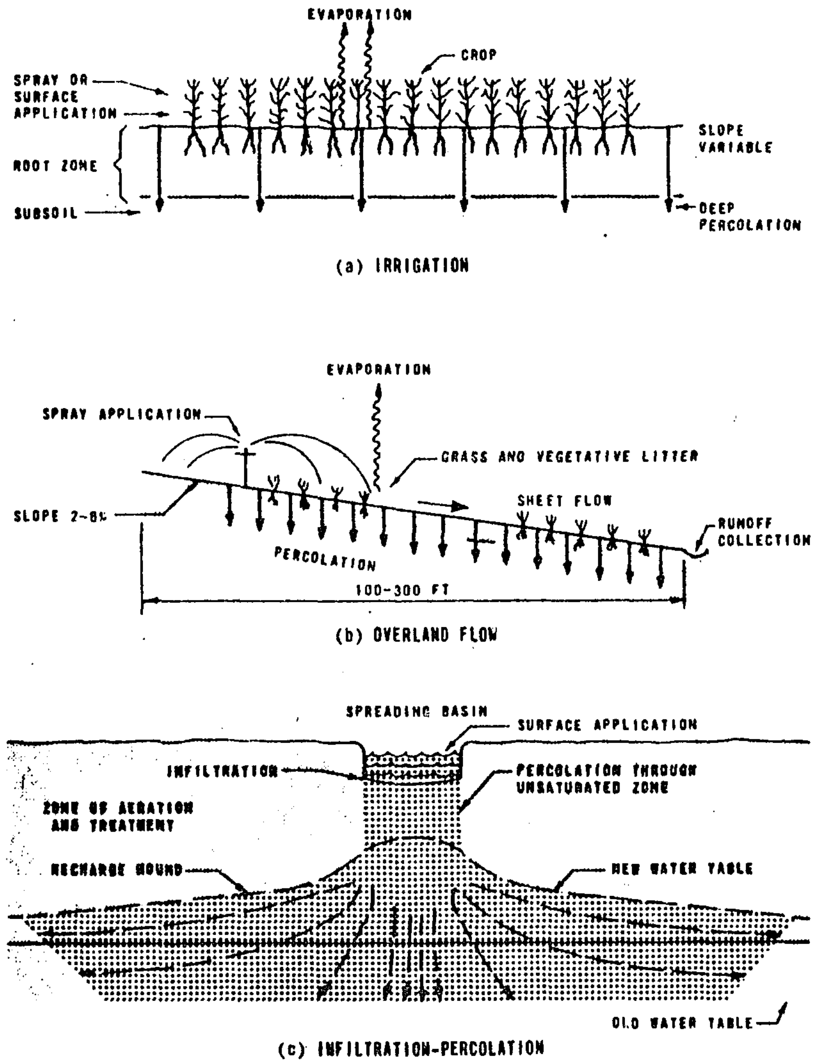


Source: [Parizek, 1967]

Figure 2. The Waste Water Renovation and Conservation Cycle

Land Treatment Alternatives

Land treatment approaches can be classified into three categories; irrigation, overland flow or spray-runoff, and infiltration-percolation (Figure 3). Each has unique characteristics which influence the situations in which they may be used.



Source: [Pounds, 1973a]

Figure 3. Land Application Approaches

Irrigation

Irrigation is the controlled discharge of effluent, by spraying or surface spreading, onto land to support plant growth. The wastewater is "lost" to plant uptake, to air by evapotranspiration, and to groundwater by percolation. Application rates are measured either in inches per day or week, or in gallons per acre per day. The method of application depends upon the soil, the type of crop, the climate, and the topography. Sloping land is acceptable for irrigation provided that application rates are modified to prevent excessive erosion and runoff.

Renovation of the wastewater occurs generally after passage through the first 2 to 4 feet of soil. Monitoring to determine the extent of renovation is generally not practiced; when it is practiced, however, removals are found to be on the order of 99 percent for BOD and suspended solids. Depending upon the soil type and the crop harvested, removals of nitrogen and phosphorous from the wastewater may also be quite high.

The use of irrigation as a treatment and disposal technique has been developed for municipal wastewater and a variety of industrial wastewaters, including those from the food processing industry, the pulp and paper industry, tanneries, animal feedlots, dairies, and some chemical plants. Crops grown have included grasses, forage crops, grains and vegetables [Pounds, 1973b].

Overland Flow

Overland flow is the controlled discharge, by spraying or other means, of effluent onto the land with a large portion of the wastewater appearing as runoff. The rate of application is measured in inches per week, and the wastewater travels in a sheet flow down the grade or slope.

Soils suited to overland flow are clays and clay loams with limited drainage. The land for an overland flow treatment site should have a moderate slope--between 2 and 6 percent. The surface should be evenly graded with essentially no mounds or depressions. The smooth grading and ground slope make possible sheet flow of water over the ground without ponding or stagnation. Grass is usually planted to provide a habitat for the biota and to prevent erosion. As the effluent flows down the slope, a portion infiltrates into the soil, a small amount evaporates, and the remainder flows to collection channels. As the effluent flows through the grass, the suspended solids are filtered out and the organic matter is oxidized by the bacteria living in the vegetative litter.

The overland flow treatment process has been developed in this country for treatment of high strength wastewater, such as that from canneries, with the resultant reductions in BOD from around 800 mg/L down to as low as 2 mg/L. Reductions of suspended solids and nitrogen are also high although phosphorous reduction is reported to be on the order of 40 to 60 percent. In Australia, overland flow or grass filtration has been used for municipal waste treatment for many years, with BOD and suspended solids removals of about 95 percent. Research is presently being conducted on the use of the overland flow treatment system for treatment of raw sewage. Use of overland flow in the United States has been very limited [Pounds, 1973b].

Infiltration-Percolation

This method of treatment is similar to intermittent sand filtration in that application rates are measured in feet per week or gallons per day square foot. The major portion of the wastewater enters the groundwater although there is some loss to evaporation. The spreading basins are generally dosed on intermittent basis to maintain high infiltration rates. Soils are usually coarse textured sands, loamy sands, or sandy loams.

This process has been developed for groundwater recharge of municipal effluents, municipal wastewater disposal, and industrial wastewater treatment and disposal. The distinction between treatment and disposal for this process is quite fine. Unquestionably, industrial wastewater applied to the land for the purpose of disposal is also undergoing treatment by infiltration and percolation, whether or not monitoring for detection of renovation is being practiced [Pounds, 1973b].

Other Treatment Approaches

There are several other approaches to the treatment of wastewater on land, including subsurface leach fields, injection wells, and evaporation ponds. Such techniques are generally limited in their range of application. Leach fields are prevalent in rural areas and are likely to remain so. The largest known municipal installation employing leach trenches is at North Lake Tahoe, California, and is only a temporary design.

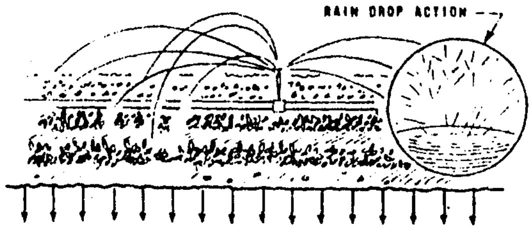
Deep well injection of reclaimed wastewater is being practiced in Orange County, California, and has been proposed for Long Island, New York. Evaporation ponds have limited applicability because of the large land requirements and climatic constraints. Although such ponds are designed for disposal, they will act as stabilization ponds and limited treatment by microorganisms will take place. Where crop irrigation or groundwater recharge are not permissible because of high salinity of the wastewater, consideration of evaporation ponds may be in order.

Application Methods

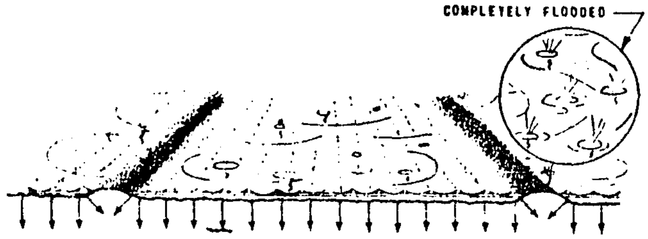
There are a number of different ways to apply wastewater to the land. Each site will have its own physical characteristics that will influence the choice of the method of application. The three that are most commonly used for irrigation are spraying, ridge and furrow, and flooding. Each of these methods is illustrated on Figure 4.

Spray Irrigation

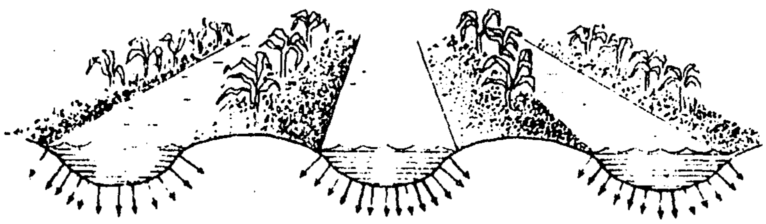
With spray irrigation, effluent is applied above the ground surface in a way similar to rainfall. The spray is developed by the flow of effluent under pressure through nozzles or sprinkler heads. The pressure is supplied by a pump or a source high enough above the sprinkler heads. By adjusting the pressure and nozzle aperture size, the rate of discharge can be varied to any desired rate.



(a) SPRINKLER



(b) FLOODING



(c) RIDGE AND FURROW

Source: [Pounds, 1973a]

Figure 4. Basic Methods of Application

The elements of a spray system are the pump or source of pressure, a supply main, laterals, risers, and nozzles or sprinkler heads. Since the system operates under pressure, there is a wide variety of ground configurations suitable for this type of disposal. The spray system can be portable or permanent, moving or stationary.

The cost of a spray system is relatively high because of pump and piping costs and pump operating costs. The effluent used in a spray disposal system cannot have solids that are large enough to plug the nozzles. Sprinkling is the most efficient method of irrigation with respect to uniform distribution.

Ridge and Furrow

The ridge and furrow method is accomplished by gravity flow only. The effluent flows in the furrows and seeps into the ground. Ground that is suitable for this type of operation must be relatively flat. The ground is grooved into alternating ridges and furrows, the width and depth varying with the amount of effluent to the disposed and the type of soil. The rate of infiltration into the ground will control the amount of effluent used. If crops are to be irrigated with effluent, the width of the ridge where the crop is planted will vary with the type of crop. The furrows must be allowed to dry out after application of sewage effluent so that the soil pores do not become clogged.

Flooding

The third type of application is flooding. This type can be accomplished in different ways: border strip, contour check, or spreading basin. Flooding, as the term implies, is the inundation of the land with a certain depth of effluent. The depth is determined by the choice of vegetation and the type of soil. The land has to be level or nearly level so that a uniform depth can be maintained. The land does need "drying out" so that soil clogging does not occur. The type of crop grown has to be able to withstand the periodic flooding.

The border strip method consists of sloped (0.2 to 0.3 percent) strips of land 600 to 1,000 feet long divided by borders or dikes every 20 to 60 feet. The major differences between this method and the spreading basins is that this method uses smaller segments of a field and the ground is sloped.

Contour check is the creation of dikes or levees along the contour of a hill or slope. The dikes contain the effluent so it does not run down the slope. The dikes are generally placed at contour intervals of 0.2 to 0.3 feet.

Spreading basins are shallow ponds which are periodically flooded with effluent. The basins hold the effluent until it is percolated into the ground, is used by crops, or is evaporated into the air. Spreading basins are generally used for rapid infiltration.

Important Physical Parameters

Land can be used as a medium for treatment of a variety of wastes including those which will be transformed to harmless forms by soil processes or utilized and removed by agriculture or forest crops. Using the soil and its associated biosystems as an extensive recycling system enables one to utilize the important physical, chemical and biological buffering capacity of the soil to relieve the various types of water pollution crises resulting from the waste discharges to surface streams.

Physical parameters in evaluating a land treatment system include soil loading factors, the volume and rate of application, the potential for system abandonment, and the yield response of various crops [Pounds, 1973b].

Soil Loading Factors

There are several constraints which relate to the capacity of soils for waste assimilation. At least five loading factors should be considered in the design and successful operation of a land treatment system: (1) hydraulic loading, (2) organic loading, (3)nutrient loading, (4) salt loading, and (5) toxic elements. For any particular soil-waste treatment system, any one of the five listed criteria may be the limiting design component depending upon the waste characteristics, soil assimilation capacity and land management programs followed. Overloading some segment of the assimilation process is the cause for failure in any malfunctioning land disposal system.

Hydraulic loading is of concern since the soil must remain unsaturated for sufficient periods of time to allow exchange of gases with the aerial atmosphere through open pathways or pores in the soil matrix to the depth of plant roots and microbial activity. When the soil pores remain filled with water for extended periods, the rate of diffusion of oxygen to and carbon dioxide away from roots and microbial sites may be reduced to levels inhibiting normal plant growth and microbial activity. When this occurs, plant roots cannot absorb the water, and nutrients required to support normal growth of above-ground portions of plants and microorganisms cannot sustain maximum activity to fully utilize organic contaminants in the applied wastewater. Water movement in unsaturated soils insures more complete filtering and absorbing of wastewater pollutants since the water moves under tension, which insures more direct contact between wastewater contaminants and surface areas of soil organic and mineral particles.

Although organic loading is not likely to be the constraining parameter in applying secondary treated municipal wastewaters to soil, it may be the constraining parameter for wastewaters from such sources as food processing plants, organic-chemical plants and any source of organic sludge. Permissible organic loading to soils must be based on an understanding of the processes governing the fate of carbon in soils. To maintain maximum rates of organic degradation in soils, and to prevent nuisance odors, aerobic conditions must be maintained through upper portions of the soil profile.

Nutrient loading in waste applications to soils is of some concern because of possible transformations of the nitrogen in the waste to the nitrate form in the soil. The nitrate formed may be subject to leaching and accumulation in water supplies with subsequent hazards for drinking water or may find its way into surface waters with accompanying problems of eutrophication. The removal of nitrogen from the wastewater applied to a well-drained soil is accomplished by the growing crop. During peak growing periods, a crop like corn may require 4 to 5 pounds of nitrogen per acre per day while many winter cover crops will absorb as much as 2 pounds of nitrogen per acre per day during peak growing periods in spring. A well-managed crop of coastal bermuda grass over seeded with winter rye may utilize as much as 600-700 pounds of nitrogen per acre per year [Pounds, 1973b].

To prevent excessive nitrate pollution where nitrogen is applied at rates exceeding crop utilization, the soil would have to act as a denitrifying system. This would require selection of soil, site, and hydraulic load to obtain alternating aerobic and anaerobic cycles or to produce aerobic conditions in the upper root zone and anaerobic conditions in the lower root zone by controlling drainage through subsurface drains or field ditches.

Salt loadings in land application systems may be a problem at a few specific sites where industrial wastes with high salt or sodium concentrations are being applied to the soil. The soil organic and inorganic components have a defined capacity for the absorption of cations in wastewater, nominally defined as the cation exchange capacity (CEC) but only very limited capacity to absorb anions. When a soil with significant amounts of clay in the profile is treated with a wastewater of sufficient sodium concentration such that the percent sodium satisfying the CEC of the soil reaches 12 to 15 percent, some dispersion of the soil structure may occur, reducing the ability of the soil to conduct water. Some of these adverse effects may be overcome by application of soil amendments such as gypsum if the sodium levels are not excessive. Information on the concentrations of various salts in the wastewater, soil mineralogical components, and soil chemical characteristics are all necessary to predict the interactions of salts in land disposal systems.

The presence of toxic heavy metals in effluent and sludge is a problem which has been cited as a long-term hazard to land treatment [Chaney, 1973]. In excess of normal concentrations, toxic elements with potential hazards to plants or the food chain are Boron (B), Cadmium (Cd), Cobalt (Co), Chromium (Cr), Copper (Cu), Mercury (Hg), Nickel (Ni), Lead (Pb), and Zinc (Zn). Sewage sludge contains Zn, Cu, Ni and Cd in excess of soil levels.

Two bases have been recommended for the addition of toxic metals to agriculture as sludge or effluent. These are (1) Benefit : risk ratio, and (2) limitation of metal additions to permit continued general farming [Chaney, 1973].

Benefits attributable to sludge and effluent include water, organic matter, N, PO_4, Zn, and Cu. Risks include the toxic metals which should be minimized wherever possible. Table 3 shows the reasonably attainable (in 1973) minimum toxic metal content. Higher than minimum Cd, Co, Cr, Ni, Pb, Hg, and B contents are a result of industrial pollution. Zn and Cu in digested sludge probably will never drop below 500 and 200 ppm, respectively. The metal content shown in Table 3 is asserted to represent an attainable, reasonable, toxic metal content for digested sludge, and hence a good benefit: risk ratio for land application. Sludges with higher toxic metal contents should not be applied to agricultural land. These criteria (except the Cd:Zn ratio) apply primarily for lands growing crops for sale, and can be modified for sites not used for saleable crops.

Table 3. Metal Content of a Sludge Appropriate for Land Application

Element	Content
Zn	2000 ppm
Cu	800 ppm
Ni	100 ppm
Cd	0.5% of Zn
B	100 ppm
Pb	1000 ppm
Hg	15 ppm

Source: [Chaney, 1973]

If the composition of a sludge meets the above recommendation, the next consideration is to limit toxic metal additions to levels which permit continued general farming on the amended soil even after the added organic matter is gone and an equilibrium of metals and PO_4 has been reached. Because lowering the soil pH below 6.5 leads to extensive increase in toxic metal availability to plants, some assumption has to be made about the pH of the amended soils. Thus, it was presumed that the toxic-metal-amended (sludge or effluent) soil used for food crops will be maintained at pH 6.5 or above.

Application Rates

The rates of effluent application at existing sites varies considerably, reflecting the requirement to tailor the application rate to site specific characteristics. These include the treament approach used, climatic factors, soil characteristics, and system objectives. A rate commonly cited is 2 inches per week for 35 weeks or 70 inches per year. This, however, is based upon the Penn State experience and reflects a system with crop production and renovation as joint objectives. An upper limit of 4 inches per week and 8 feet per year has been suggested as an upper limit for an irrigation classification to apply [Pounds, 1973b].

Systems Abandonment

Many systems reported in operation in earlier surveys were not found in subsequent surveys, indicating some abandonment of land treatment systems. Information is very sketchy on why this abandonment took place. A survey of 24 abandoned sites in California and Texas found that effluent irrigation was generally abandoned when the city expanded its sewage treatment facilities and either changed plant locations or had inadequate land available to expand the irrigation system [Pounds, 1973b].

Crop Yield Response

Crop yields have increased with wastewater application, but the relationship between wastewater application and yield response is not clearly specified. Yield increases are attributed to both increased water availability and nutrients in the effluent. Conversely, yields can be adversely effected due to too much water, or to plant toxicity due to extensive accumulations of heavy metals.

Some of the most extensive yield response data available is that from the Penn State Project. Crop data for 1963-1970 generally show yield increases associated with wastewater irrigation of corn, corn silage, wheat, and alfalfa. During this eight-year period the crop areas irrigated with two inches of effluent weekly received a total of 392 inches of wastewater equivalent to applying 10,000 pounds of 13-6-15 commercial fertilizer. The control area was fertilized with commercial fertilizer ranging from 200 pounds of 0-20-20 per acre for oats to 1000 pounds of 10-10-10 on corn. Effluent irrigation at two inches per week resulted in annual yield increases ranging from -8 to 346 percent for corn grain, 5 to 130 percent for corn silage, 85 to 191 percent for red clover, and 79 to 139 percent for alfalfa. Yield differences between the effluent-irrigated and control plots were greatly influenced by growing season precipitation. During the years 1963-1966, when growing season precipitation was five to eight inches below normal, yields on the irrigated areas were significantly greater than on the control areas, but usually differences between the one-inch- and two-inch-per-week applications were not significant. In 1967 and 1969, when growing season precipitation was slightly above normal, yield differences were not significant. In 1970, when growing season precipitation was again below normal (1.55 inches), yield differences between the control and irrigated areas were again significant but the two levels of irrigation were not [Sopper, 1973].

Land Treatment Applications

Communities of varying size have or are investigating the land treatment concept for the renovation of municipal wastewater. While the concept if far from new, recent attention can be attributed to at least three factors: the long term research project at Pennsylvania State University [Parizek, 1967], the national attention and interest generated by the application of the concept on a large scale at the Muskegon County, Michigan project [Shaeffer, 1970, Bauer, 1973] and the requirement of PL 92-500 that cities consider the land treatment alternative as one possible means of meeting water quality requirements. The Army Corps of Engineers involvement in wastewater pilot studies for Boston, Detroit, Chicago, Cleveland, and San Francisco in 1971 subsequently evolved into their urban studies program, one aspect of which is urban wastewater management [Corps of Engineers, 1972b]. Approximately 50 other municipalities in Michigan are investigating land treatment [Pierce, 1973]. The campus wastewater plan at Michigan State University is another example of the use of the land treatment concept [Bahr, 1974].

Data on existing systems is relatively scarce and of considerable variation in type and quality. Experimental data from the project at Pennsylvania State University covers the period from 1963 to the present and provides useful data on crop and forest response as well as water renovation. A recent field survey of operational systems was conducted for EPA in 1972 [Sullivan, 1973].

Muskegon County, Michigan, Wastewater Management System

The largest land treatment system recently constructed in the United States is the Muskegon County Wastewater Management System. Grants from the Environmental Protection Agency and the Michigan Department of Natural Resources helped finance a large scale land treatment system. The system is designed to treat 43.4 MGD by 1992, is estimated to cost $42 million, excluding land costs, and will cover 10,800 acres of land with lagoons and irrigation sites [Chaiken, 1973].

The Muskegon County plan is a complete advanced wastewater treatment system which replaces the county's existing treatment facilities rather than supplementing them. The county plan is designed to handle all the sewered wastewater from the county except for that treated on site by two industrial firms. The project is designed to totally abate the discharge of inadequately treated sewered wastewater into the Muskegon and White Rivers. These two rivers contribute 6.9% of the daily inorganic nitrogen and 10.8% of the daily phosphorous from the western shore of the lower Michigan Peninsula into Lake Michigan [Chaiken, 1973].

The treatment system has six components: a collection and transport network, biological treatment cells, storage basins, irrigation land and facilities for crop production, a filter (land), and a drainage network. Raw sewage is collected from households and industries in Muskegon and transported by sewers, interceptors, and force main to the treatment site eleven miles east of Muskegon. There the raw sewage enters aerated treatment lagoons, where microorganisms decompose sewage organic matter. Leaving the aerated lagoons, the effluent is diverted into a storage lagoon, where suspended particles settle out. The effluent is then diverted into an outlet lagoon where some additional settling takes place. Effluent leaving this lagoon is chlorinated in an open channel to kill remaining pathogenic microorganisms. The pipe network transports the effluent to spray irrigation rigs at the treatment sites. It is applied to the soil. Evaporation and plant use consume part of the effluent. That which moves through the soil is collected in a drainage system and returned to surface waters. At this stage treatment comparable to tertiary treatment has been received.

The first step in the system is the collection of wastewater from the various domestic and industrial sources. For the larger subsystem, a thirteen mile long interceptor network of sewers, force mains, and pumping stations collects wastewater from eleven access points in the existing sewer system. This wastewater is transported eleven miles to the treatment site through a 66-inch concrete pipe. This portion of the plan represents approximately one-third of the total system's capital cost.

The second stage is the one which most clearly approximates the treatment provided in conventional secondary plants. The wastewater is pumped through three artificial lakes or lagoons called treatment cells. Each treatment cell has eight acres of surface area and a depth of fifteen feet. The aerobic microbiotic treatment in these cells is facilitated by six mixing units and twelve mechanical surface aerators which pump the water up from the bottom and spray it out over the surface of the cell. This combination of mechanical and biologic treatment maintains all solids in suspension and reduces BOD by 70-90%.

After a three-day period in the biological treatment cells, the water is pumped to storage basins. Here, the suspended solids are allowed to settle, biologic treatment continues at a slower rate than in the treatment cells, and water is stored for irrigation. Because of the cold, humid climate in Muskegon County, a large amount of storage capacity was provided in the plan. There are two storage basins each with an 850-acre surface area and a depth of nine feet. Together, the two basins provide storage for 5,100 million gallons, or the average flow of 120 days. Seepage is controlled by an impervious clay layer sixty feet beneath the soil surface. This restricts the water to horizontal movement. A system of wells and a drainage ditch collects all the water which might escape from the storage basins. This collected water is pumped back into the storage basins.

The storage basins are also useful as secondary receiving areas to cushion the system against the shock of accidental toxic industrial spills. If toxic material threatens the biologic activity in the treatment cells, it can be diverted to the storage basins. The large volume of stored water will dilute and assimilate such toxic materials.

As the water is transferred from the storage basin to the irrigation fields, it is disinfected with chlorine in amounts sufficient to reduce the total coliforms to less than 1,000 per 100 ml, Michigan's standard for body contact recreational water.

Irrigation of six thousand acres of cultivated land is the plans' fourth stage. The water is transported to two irrigation pumping stations in open channels. This contact with the air accomplishes the dechlorination necessary so that the irrigation water will not be toxic to the microbiotic activity in the soil.

From the irrigation pumping stations, the water is transported through twenty-seven miles of underground asbestos-cement pipes to irrigation spray rigs. These are rotating rigs covering approximately 160 acres from a central point. They have a radius of 750 to 1,300 feet and are self-propelled. They complete a rotation in a period that can vary from one to seven days. The plan calls for a maximum total water application of both wastewater and rainfall of four inches per week. This is intended to apply 2.5 million gallons per acre within a seven month irrigation period. The initial rate of application will be 2.1 inches per week and build up to a proposed average of three inches per week.

The total cost of the project including land and relocation expenses is estimated at $42 million. The U.S. Environmental Protection Agency and the State of Michigan are providing grant assistance to Muskegon County (Federal share-55 percent; state share-25 percent). EPA assistance for research studies has been approved for $1,083,750 and may be increased to $2,325,450 [Chaiken, 1973].

The local share will be paid from a $16 million bond issue. The County will recover part of the capital costs through agreements with the participating cities, townships, and industries. A portion of the capital costs and all of the operating costs will be recovered by a user charge based on flow. The total annual operating cost is estimated at $980,000 in the first year of operation, and at $1,345,000 by 1992. The system is expected to have relatively low operating cost, approximately $90 per million gallons treated, or approximately half the operating cost of conventional advanced treatment. The county estimates a $38 annual charge for a family of four. A portion of the operating costs will be defrayed from revenues from the sale of agricultural products.

The county provided relocation benefits to 154 homeowners, 30 tenants, 2 farm owners, 4 businesses, and 2 nonprofit organizations to obtain land for the project. The cost was $1.6 million, most of which was reimbursed by EPA.

The Teledyne Triple R Corporation, a private firm, has been responsible for the system operation, including the farms. Effective January 1975 the Muskegon County Department of Public Works will take over the system operation.

Pennsylvania State University

In 1962, Pennsylvania State University had to correct pollution of a local stream caused by its sewage treatment plant. A cyanide wastes discharge from laboratories had caused a fish kill, and the State Health Department raised questions about phosphorous and nitrogen removals and general improvements in effluent quality. The University set up a committee of its various science departments to advise on the best means of meeting State requirements and solving the pollution problem. This group of scientists proposed a research project to determine the effectiveness and economy of utilizing treatment plant effluent for irrigation on University-owned lands in the area. From these proposals and studies has come the so-called "Pennsylvania State Wastewater Renovation and Conservation Research Project" [Parizek, 1967].

The decision to initiate the recommended demonstration project was based on availability of University lands in a farming area, adequate soils for irrigation consisting of sandy-loam and clayey-loam, depth of groundwater ranging from 100 feet to some 350 feet, the availability of University personnel to control and evaluate data, opportunity to utilize crops of hay and corn for animal feeding at the University, and means for evaluating forest tree growth, with and without irrigation.

A supplementary study on the irrigation of strip mine coal culm with effluent and sludge was also undertaken. The ability to convert barren strip mine areas to productive land for crops and trees has been demonstrated.

Based upon the cumulative effects of the research experience, the University decided to expand the land treatment system to handle effluent from the town of State College as well as from the University. This project will involve approximately 800 acres of land, in contrast to the 80 acres in the demonstration project.

The system is designed for sanitary sewage effluent that received secondary pretreatment. Heavy metals are low because the community sewage flow is basically residential with no industrial and only a limited commercial area. University Laboratories do contribute chemicals to the flow.

The areas used for spray irrigation are surrounded by buffer zones of varying sizes. No attempt has been made to adhere to any minimum buffer area, apparently because aerosol pollution possibilities are minimal or absent. In the Game-land area, a store and some residences are less than one-quarter mile from the spray areas. A new residential development known as "Toftree" is situated along the University property line and in general proximity to the spray irrigation areas.

Much of the spray irrigation demonstration has been based on an application rate of two inches per week, with actual application for a continuous period of 12 hours and a resting period of six and one-half days. This rate was considered to include an adequate measure of protection against accidental runoff. Water was applied at rates varying from one to five inches per week. Until state criteria were set up in 1972, a rate of four inches per week was planned for a portion of the expanded application area. The new full-scale project will be based on two inches per week, apparently, but some changes may be provided. The per hour rate has been varied from one-sixth inch to one-fourth inch--the former rate being utilized for an eight-hour dosage period. The 12-hour application period has been favored because of simplicity of operation. The same rates have been applied to open crop fields and forest areas.

No holding facilities are provided at the irrigation site or the sewage treatment plant because application for 12 months per year is anticipated. In the Gameland Area, for crop lands and forest lands, irrigation is carried out throughout the winter. In the Agronomy-Forestry area irrigation is from mid-April to mid-November [Sullivan, 1973].

National Community Survey

In 1972, the Environmental Protection Agency contracted with the American Public Works Association to conduct a field survey of sites across the United States where municipal or industrial wastewaters were being applied to the land. The approximately 100 facilities surveyed were relatively large, long-established operations. Land treatment applications for municipal wastewater were primarily in the western portions of the country, while land treatment facilities for industrial wastewater were generally located in the mid-continent and northeastern sections [Sullivan, 1973].

The survey results provide a detailed description of the systems involved. Its recommendations call for the establishment of criteria for land application of wastewater, and the recognition that land treatment must not be considered as a panacea or a universal method of treatment. It concluded that there are successful land treatment operations reflecting considerable variety in the annual application rates, amount of sewage pretreatment, and reason for land treatment. It also concluded that land treatment facilities are generally not "stressing" the system, nor do they necessarily create a nuisance or downgrade the adjacent environment. In fact, there was a general improvement of the affected environment. Important for purposes of this study was the conclusion that sale of effluent for beneficial use has been generally unsuccessful. Also, local public opposition to receive "somebody else's wastes" could be a major limiting factor in the development of large land application systems.

Michigan State University Campus Water Plan

The Institute of Water Research at Michigan State University is involved in a complex experimental project known as the "Campus Water Plan." Its purpose is to combine knowledge from several disciplines into a comprehensive study of the overall strategy of water quality management. The system is designed to conduct experiments on the treatment of wastewater of natural ecosystems, and in particular, remove nitrogen and phosphorous from the water and use it in harvestable food and fiber products.

The facility will initially divert 2,000,000 gallons per day from the local municipal wastewater treatment plant to the experiment's conventional activated sludge plant for initial treatment. The treated effluent will be pumped approximately four miles to the Field Laboratory site. The

Field Laboratory consists of an aquatic system and a terrestrial system. The aquatic complex is composed of a lake system of four artificial lakes with a total surface area of 40 acres joined in series to permit the continuous flow of the diverted wastewater, and a marsh system of 3 one-acre marshes for internal nutrient recycling. The terrestrial area is on 350 acres next to the lake system. It contains hardwood forest areas, a pine plantation, cultivated fields, and fields where vegetation and fields regressed to old-field plant associations. Within the area is a 145 acre spray irrigation site where experimentation on a variety of food and fiber crops is under way [Bahr, 1974].

Wastewater from the city of East Lansing is pumped into the first pond of the four-lake system in the aquatic complex. It then flows through each of the four lakes and becomes increasingly purified as a result of biologic processes associated with the ecology of each lake.

The research in the lakes will involve management of the aquatic plant and animal material to maximize the consumption of the nutrients contained in the wastewater.

Water discharged from the fourth lake will be used in the terrestrial treatment complex. The effluent is to be applied on a wide range of vegetation under a variety of controlled conditions.

The managment program of the lake system is designed to determine at what rate nitrogen and phosphorous are absorbed by the aquatic plant life. Several aspects of aquatic plant management including cultivation, harvesting, and control of unwanted growth are associated with this program. Special emphasis will be made to study the acceptability of harvested aquatic plant material as animal food.

The managment program for the terrestrial complex will focus on the removal of phosphorous, nitrogen, heavy metals and pesticides by cultivated plants as well as those found in the various stages of natural succession.

Michigan Community Experience

There are currently 50 Michigan communities with designed land treatment systems, but only two have been in operation longer than one year. At the end of 1972, 15 municipal spray irrigation projects were completed and in operation, and it is expected that nearly all 50 systems will eventually be in operation [Pierce, 1973].

Problems encountered at some of the operational systems included inadequate capacity of the storage lagoons and the inability of soils to accept design loads and the associated runoff. In addition, an inadequate understanding in the complex natural interactions between wastewater and soil particles involved in land treatment often leads to poor system design.

Southeastern Michigan Wastewater Management Study

One of the pilot wastewater management studies initiated by the Corps of Engineers in 1971 was for the Detroit metropolitan area [Corps of Engineers, 1971]. This study evolved into the Southeastern Michigan Wastewater Management Survey Scope Study. Its objective was to identify the present and future water pollution problems of Southeastern Michigan and to design and evaluate the feasibility and consequences of alternative wastewater management programs in solving these problems. It developed long-range wastewater management plans that would complement the water quality plans of the State of Michigan and thus assist in meeting the planning requirements of the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500). To reach this aim the needs and objectives related to water pollution problems in Southeastern Michigan were defined, alternative plans were formulated, treatment systems were designed, and the impacts of these alternative plans were assessed and evaluated based on technical, economical, institutional, aesthetic, ecological, and social considerations [Corps of Engineers, 1971].

The basic information and proposals developed in the Southeastern Michigan Wastewater Management Study serve as a starting point for much of the analysis in this study. Proposals for land treatment sites in Lenawee and St. Clair are selected and are evaluated from a firm and regional level.

CHAPTER III

CONCEPTUAL FRAMEWORK

The Relationship of Institutions to Land Treatment

Land treatment of wastewater requires the usual economic inputs of land, labor, and capital. It differs from other treatment methods in its more extensive requirements for land. The acquisition of rights to the required land base is important to wastewater authorities and may be obtained in a number of ways. The alternatives available are normally defined by the institutions affecting ownership and use of land.

The analysis of environmental quality problems such as wastewater treatment often occurs in an ecosystem framework which emphasizes the natural and physical elements of the ecosystem. This approach implies that man's total environment is intelligible through the rational processes of the physical definition of an optimum environment purely on the basis of natural laws fails to give adequate recognition to the fact that what is optimal depends upon people's perspectives and values [Ditwiler, 1973]. These values are reflected through the institutions that determine the distribution and use of political and economic power and thereby influence and control individual behavior and group action. Institutions have been defined as "collective action in control, liberation, and expansion of individual action" [Commons, 1959], and as "sets of ordered relationships among people which define their rights, exposure to the rights of others, privileges, and responsibilities" [Schmid, 1972]. Institutions represent established arrangements in society and established ways of doing things. They involve the working rules of society; in many instances they provide systems of control that indicate what is considered acceptable individual and group behavior. Institutions reflect a distribution of political power. Each institution implies a distribution of authority to impose costs, indicated by the amount of discretion it allows individuals or groups, and a capacity for one segment of society to impose its will on another. When a particular institution takes away all rights to select a course of action, the total cost of a particular action or policy is transferred from one group to another. The exercise of the capacity to impose cost, that is, to take away discretionary rights, is determined by the relative political power of the individuals or groups involved [Samuels, 1972].

The concept of property rights is a very important legal-economic insitution that governs the contracts and conditions for the acquisition and use of the total "bundle of rights" ascribed to land ownership. The "bundle of rights" to property represents the total of several distinct interests or rights. The largest bundle is ownership in fee simple, which includes the right to possess, use, buy, sell, or enter into contractual arrangements. This "bundle of rights" is exclusive rather than absolute as government places limitations on it through the use of taxation, eminent domain, and police power [Barlowe, 1972].

The ability to impose the cost of a public policy such as wastewater treatment on private individuals is reflected in the way land rights are obtained. If wastewater treatment areas are created through zoning by the exercise of the police power, discretionary power is removed from the landowners and they bear the full cost of public policy actions. On the other hand, if fee simple interest is obtained without the use of eminent domain authority, the landowner is presumably paid the full market value of the land and thereby is not required to bear the cost of public action. If rights are acquired through the use of eminent domain, some public costs are transferred to the landowner. Acquisition of land rights in any form other than a voluntary fee simple transaction reflects some imposition of public will on private actions.

Land is used for several functions in a treatment operation, each with varying implications for the portion of the "bundle of rights" acquired. Management and environmental considerations suggest that a wastewater authority acquire the total "bundle of rights" to land used for such integral operations as treatment lagoons, pre-treatment facilities, and pumping and distribution facilities. Access to land for the actual application of wastewater can be acquired without acquiring the complete "bundle of rights."

Acquisition and Management Options

An important distinction is made between options to obtain access to land for treatment purposes and the options available for the management of the farming operation at the treatment sites. The acquisition options are used to acquire control over a resource while the management options are means to obtain services or behavioral actions. The acquisition options include fee simple property rights, less than fee simple property rights, and contractual agreements, no real property interest. Acquisition options for wastewater treatment purposes are similar to those used for other public purposes such as the preservation of open space and agricultural land on the fringe of metropolitan areas. A number of management options can be exercised in conjunction with these acquisition options, particularly for the fee simple and contractual acquisition options. Each of the acquisition options has characteristics which influence the distribution of costs and benefits of land treatment to the landowners, the wastewater authority, and to other members of society.

Fee Simple Acquisition

A public agency obtains absolute land ownership through fee simple acquisition. Rights of fee simple absolute ownership include the total bundle of rights to a piece of land not reserved to the state and not interfering with the rights of other landowners. The power of eminent domain may be used to obtain fee simple title if an owner does not want to sell and if legal authority is available. This power insures that the Federal Government or the State or local government can acquire a particular tract of land needed for a public purpose. The use of eminent domain allows authorized public authority to take private property without regard to its present use or the wishes of the present private owner, upon payment of just compensation. Proceedings in eminent domain are usually well defined by statute.

The largest monetary cost of fee simple acquisition to a wastewater authority is the purchase price of the land, such as the interest and principal on bonds raised to finance land purchase and administrative costs. It may be necessary to create a mechanism to reimburse communities for property tax revenues foregone if land is purchased by a tax-exempt body. Some of these costs may be recouped from a farming operation or profits from appreciation in land value upon subsequent resale.

The characteristics of fee simple acquisition option specify the distribution of its effects among a wastewater authority, the landowners, and society at large. Some of its advantages to an authority is that it permits the use of the land in any manner compatible with its objectives without obtaining agreement from a second party. This is particularly important since it subjects the engineering and environmental considerations of the treatment system to unilateral rather than bilateral decision making. Fee simple acquisition insures a long-term planning horizon for the treatment site. Disadvantages to the authority include the high costs of fee simple interests and the public opposition that may be encountered with large scale government involvement in the real estate market. With fee simple acquisition, landowners exchange their rights for a consideration. Under certain circumstances it may be to their advantage to sell their lands, but if they are forced to sell, they must relocate or leave farming entirely, or work for the authority as an employee. Social benefits are realized from fee simple aquisition as it insures continued operation of the waste treatment site. Fee simple acquisition facilitates the selection of lands to also serve broader level public planning objectives. Sites can be specifically selected for soil type, location, and secondary uses such as the preservation of open space, protection of recharge areas, and the channelization of urban expansion. The acquisition of large tracts of farmland may impose a social cost if communities are disrupted and social and economic bonds are broken.

Management Options

When fee simple title is acquired, the wastewater authority can manage the farming operations in several ways. These include purchase and manage, purchase and leaseback, and purchase and resale on condition.

Purchase and Manage

This is a management option when fee simple title is acquired. A wastewater authority may choose to manage the farming operations as a subsystem of the overall wastewater treatment operation. These additional managerial responsibilities may tax the managerial resources of the wastewater authority and this could lead to some type of subcontracting arrangement for custom farm operations. However, custom farming may be impractical for a large metropolitan system due to the size of the farming operation. The wastewater authority would have to negotiate numerous contracts with custom operators, provided there were enough operators in the area. An alternative arrangement is to negotiate a management contract with a firm to handle the farming operations. Such an arrangement was used at the Muskegon, Michigan, land treatment site, where a contract existed between Teledyne Corporation and Muskegon County for the operation and monitoring of the treatment system, including the farming operation.

Purchase and Leaseback

Under this management option the operating authority acquires fee simple title to land and leases it to another party for farming operations. The leasee may be the previous landowner or a third party, such as a management firm. This option may require that the government unit provide some managerial services. Furthermore, maintenance costs (which in this case are usually borne by the government unit) may be high. However, these costs may be passed on to the leasee. Purchase and leaseback has the advantage of quite definitely establishing subsequent uses for the land. Moreover, purchase and leaseback can be done within the well-established legal framework of the landlord-tenant law. Enforcement of use limitations is not difficult, especially if the terms of the lease spell out the rights and duties of each party and the remedies available for breach of contract. Purchase and lease or sell back has been used in the United States and Western Europe as a means of obtaining land for open space. In these instances, the open space was designated for recreation or wildlife preserves, or was earmarked for future orderly urban development [Schneider, 1973].

Uses of the purchase and leaseback option on a large scale in the United States are unknown. However, such an arrangement might be attractive to a farmer approaching retirement age, who wants to relinquish some ownership responsibilities but is not ready to completely withdraw from farming. The amount of land acquired by purchase and leaseback depends on the farm operator's participation and the public's acceptance of the program. Public acceptance will probably influence the amount of land acquired. The participation of a public agency in land speculation and the novelty of this approach might cause some public resistance. To implement purchase and lease or sell back, legislation may be necessary in order to authorize the creation of a public agency. The effectiveness of such a public agency would be enhanced if it was given the authority to issue tax-free bonds for financing the initial purchase of the land.

The term and form of any negotiated lease influence the usefulness of the purchase and leaseback option. The term may vary from less than a year, one to ten years or for longer periods of up to 99 years. Long term leases normally run for periods of fifteen years or more. Such long planning horizons are important for land treatment sites. Main forms of leases include cash-rent and share rent. Cash rent leases call for a specific cash payment every month or every year. Typically a cash rent protects the landowner but leaves the tenant subject to the risk and uncertainties of the farming activities. Share rents specify a division of the crop yields and the production costs between the landlord and tenant. A major effect is to shift some risks and responsibilities of management from the tenant to the landlord [Barlowe, 1972].

Purchase and Resale on Condition

This option entails the public purchase of land and its subsequent resale for private use, under conditions designed to achieve legitimate public ends. It has been used most frequently in urban renewal projects, and is a means of insuring that land acquired by a public body shall be properly transferred so that development and use will conform to the development plan. The intent is to ensure that subsequent use of land is compatible and in conformity with public land use objectives.

The public body can enforce the conditions of sale by a suit for damages or injunctive relief. This approach also returns land to the tax rolls and public land maintenance costs are eliminated once the resale takes place.

This option enables a wastewater authority to obtain the rights to land without making a long-term capital investment. It reduces administrative problems as it gets the public out of the real estate business fairly quickly. Conditions important to the operation such as amounts of wastewater to be accepted and necessary environmental protection, can be prescribed in the resale conditions. Operation from the time of purchase to the time of resale can be accomplished under lease options or other agreements.

A variation of purchase and resale under condition is the purchase and resale when the land is no longer needed for wastewater application. Any gains realized from lease arrangements or subsequent sale of the land could help finance the wastewater authority, or compensate the community for any tax loss resulting from the reduction in taxable property.

Real Property Interest Other Than Fee

An alternative to fee simple acquisition is acquisition of only that portion of the total "bundle of rights" necessary to meet specific objectives. Easements are a prime example of real interest--other than fee. An easement is a transfer of only a part of the total "bundle of rights" vested in fee simple ownership, from an individual to a government body. Easements have a common property character as they represent governmental action to secure property rights for non-owners.

There are two general classes of easements, positive and negative [Whyte, 1968]. A positive easement is a right held by the purchaser or recipient of that easement to use the property according to some set agreement. Examples of positive easements include fishing rights, and a utility company's right to install lines on, in, or above one's property. Rights for wastewater distribution lines are another example. A negative easement is a transfer of rights that prevent the landowner from exercising a specific right. Negative easements have most commonly been designated for scenic, conservation, and wetland purposes. An example of a negative easement is a farmer transferring his rights to drain lands used as geese landing areas. He transfers his rights to drain his land in exchange for considerations of some type.

Many States have used easements either at the State or local level, to preserve scenic beauty, conserve natural resources, maintain the natural state, or provide the public with access to private land for such activities as fishing, hunting, and hiking. The early experience with easements was primarily attempts by individuals or groups to obtain scenic easements. The National Park Service initiated the widespread application of easements in the 1930s to preserve the landscape along the Blue Ridge and Natchez Trail Parkways. After World War II, easements were again used to acquire land from parks. The first State Legislative Act, the Open Space Easement act, made history in California in 1959. Similar open space acts were rapidly adopted by most large urban States; however, their potentialities are only now being realized [Schneider, 1973].

The easement concept is well established in agriculture as a method to maintain agricultural land in the path of urban development [U.S. Congress, 1974]. The California Land Conservation Act is a prime example [Collin, 1971]. Easements are permitted in Michigan; authority for its use is established by Public Act 116, passed in 1974 [State of Michigan, 1974].

Easements can be donated, purchased, or acquired through condemnation by public agencies. However, authority for the acquisition of easements is not as widespread as the authority to purchase the fee simple title. In several instances, legislation has been passed which enables the acquisition of lesser interests in land than fee simple, but excludes the use of the power of eminent domain.

As in the case of fee simple acquisition, the easement concept has characteristics which influences the distribution of its impacts among farmers, the wastewater authority, and society in general. A characteristic of easements favorable to farmers is that it allows them to maintain ownership and they relinquish certain rights in exchange for negotiated compensation. A disadvantage is that they may have difficulties in enforcing their individual rights.

The major characteristics of easements are framed within the context of advantages and disadvantages to the wastewater authority. Some advantages of easements to an authority are:

1. Costs and financing requirements are generally less than with fee simple acquisition, both for acquisition and maintenance.

2. The rights required can be tailored to a specific objective. For example, easements, to certain parcels of land may be to irrigate, while easements to other parcels may obtain the right for wastewater transmission pipes to pass.

3. Less community opposition would be encountered as land remains in private ownership and on the tax rolls.

Also, there is a time dimension to an easement which can lessen landowners concerns over irrevocable transfer of land rights.

Disadvantages to an authority include:

1. It is difficult to establish easement values for negotiation purposes. An indicator used is the price difference of a particular plot of land before and after easement restrictions are attached.

2. Administrative problems arise in enforcing authority rights.

3. When easements are established to protect special conditions, the permanence of the easement can be affected if these conditions change.

4. In rapidly developing areas, the easement cost can approximate the cost of fee simple ownership. Administrative authorities in such areas may be reluctant to acquire easements that may cost as much as 60-80 percent of fee simple ownership.

5. There may be a problem of enforcement against subsequent fee purchases or if the easement is not properly recorded.

No Real Property Interest - Contractual Agreement

The third category of acquisition options are those which insure access to land without any transfers of real property rights. In this case, negotiation between the parties involved determines the terms of the agreement, which are normally specified in some type of contractual agreement. Contracts between a farmer and a wastewater authority, wastewater cooperatives, and transfer of development rights are examples of this acquisition option.

Contracts

Contracts between two or more parties generally specify an agreement of actions to be taken or refrained from in exchange from a specified consideration. An example is a contract between a farmer and county, city, or wastewater authority specifying the terms of an agreement to operate a land treatment system.

The terms of a contract vary from location to location reflecting specific management situations. The contract terms can include agreements on the construction of irrigation delivery and drainage systems, the distribution of crops from the farming operation, cost sharing arrangement, duration of the contract, review procedures, and termination clauses [Lewis, 1974]. A contract can also specify the annual amount of effluent that the farmer will receive from the authority. The farmer could then allocate the wastewater to crops compatible with his management objectives. A wastewater authority may contract to sell effluent to farmers, although a survey of operating land disposal systems found such that the sales have generally been unsuccessful. Few examples were found where a public agency was able to obtain more than token payment for the treated effluent. Examples of sale of wastewater were most common for gold courses. Lake Havasu City, Arizona, for example, sold effluent to golf courses for $20/per acre-foot, compared with $40 to $75/per acre-foot for domestic water [Sullivan, 1973].

The land treatment system at Lubbock, Texas is an example of a contractual agreement between a municipality and farmers. Approximately 2,900 acres are involved in a system operating since 1937. Approximately 4-6 acre feet of effluent are applied annually for use in forage and livestock farming.

A prime contractor (farmer) is the middle man between the municipality and other farmers using the effluent. Some land is owned by the city, some owned by the prime contractor, and some leased from adjoining farms. A twenty year cash lease was negotiated for city owned land. The prime contractor is required to take all the effluent from the holding tanks at all times. Land preparation, construction of ditches, installation of pipe lines, and related costs are paid by the irrigators, rather than the city. A cooperative and understanding attitude between the municipal government and the operator of the project were identified as essential to the success of the system. Just as a city wants to insure a place to dispose of its wastes, the farmer must be protected with a long-term contract in order to make the investments necessary to handle the effluent [Gray, 1968].

Wastewater Cooperatives

Group action through a cooperative effort is a familiar concept in American agriculture. Although farmers form cooperatives to purchase production supplies and sell their crops, these cooperative ventures are not generally extended to land use. It has been suggested that increasing partnerships and greater cooperative action will be necessary for farmers to function in an environment of contractual systems of control [Breimyer, 1973].

A use of cooperatives for land treatment is an alternative to the two party contractual arrangements often existing between an individual farmer and wastewater authority. Such a cooperative approach is used in Braunschweig, Germany. The Sewage Utilization Association of Braunschweig was organized in 1954 to expand the activities of a sewage farm operating in the area since the 1890s. The association combined the city, 550 farmers, 10,400 acres of land, and approximately 8 mgd. of raw sewage into a land treatment irrigation system. The total Braunschweig area is divided into four districts of comparable size. Policy decisions are made by a committee of five farmers and four city representatives. The cost of the system is divided; farmers pay 25 percent and the city 75 percent. The water cost to the farmers is about $30/acre-foot. There is an average annual rainfall deficit of 2" for the area's principle crops of potatoes, sugar beets and small grains, so farmers are interested in obtaining additional water [Tietjen, 1973].

A cooperative venture in wastewater management would probably be more cognizant than an outside agency of the well-being of the rural community, as it would build upon the existing economic and social organization. Such a cooperative might also serve as a basis for planning and implementing other community goals. Irrigation districts in the Western United States are a form of cooperative venture with a successful tradition.

A disadvantage in cooperative land use decisions could be the perceived or real loss of freedom of individual decision making. Farmers tend to place a high degree of emphasis on "freedom." However, the history of the cooperative movement indicates mutual gains from cooperation on input purchases and commodity sales exceeds any perceived loss of freedom.

Transfer of Development Rights

Transfer of development rights (TDR's) is a land use management tool receiving increased attention and acceptability. They can be used by a governmental body for greater police control of development. Using TDR's, conservation zones are established where development is restricted, and the development potential is "severed" from the land. Transfer zones are also created where a certain density will be allowed if development rights are purchased.

The idea of TDR's is that through the purchase of development rights by landowners in the transfer zones, conservation zone landowners will be compensated for the governmental restriction placed upon their land without the expenditure of public funds [Schnidman, 1974].

The application of the TDR concept to land treatment projects needs further exploration. It offers an opportunity for communities to coordinate a number of public policy objectives such as wastewater treatment, the redevelopment of downtown areas, and the maintenance of agricultural lands in the rural-urban fringe areas.

The Impact of Acquisition and Management Options on Farmer's Goals

Goals Framework

A community or wastewater authority acquires land rights from existing landowners. The options for acquiring these rights and for managing a land treatment system have varying impacts on the goals of the affected farmers. Farmer acceptance and cooperation will be a key factor in the degree of success achieved by a land treatment system. Acceptance and a positive response are related to the compatibility of acquisition and management options with a farmer's goals.

The options for acquisition and management are assumed to effect farm operators' goals of income generation, wealth accumulation, firm growth, relative freedom of decision making, and a sense of community participation.

The goal of income generation assumes an operator has sufficient resources (land, labor, and capital) to provide additional capital to expand the firm. Thus, both the short-term (1-3 years) and long-term (4 years or more) planning goals must be considered. Long-term goals are based on expectations of sufficient continuity of farming operations to insure adequate returns from long-term investment. Furthermore, income can be realized if there is a market for goods produced. Production without adequate markets has caused surpluses, depressed farm incomes, and increased government costs for price supports. Some theoretical considerations for income maximization are presented in Appendix A.

Wealth accumulation and firm growth reflect the diversion of current income from consumption to investment and the impact of capital appreciation. Future consumption of some type is generally expected, such as providing for retirement or making it possible for a son to farm. Many farmers reinvest large shares of income in land and equipment, rather than raise their level of consumptive spending. Farmers need long-range planning horizons to continue such investment patterns.

Freedom of decision making is highly valued in the agricultural community. However, "freedom" has several interpretations. Most individuals are willing to give up some "freedom" in order to attain a higher objective People work, thereby giving up some freedom, in order to earn money to satisfy their needs and desires. Freedom has been defined as the ability to act or not to act. A common restriction of freedom is the loading of the consequences of doing an act or not doing an act in such a manner that it will cause a person to choose a course of action he would not otherwise choose. However, farmers make a tradeoff between freedom on one hand and security on another hand by their acceptance of government programs. Some freedom is surrendered in return for some income security [Hathaway, 1953]. This suggests that emphasis on potential income increases from land treatment systems can work to offset any farmer concern over loss of freedom.

The goal of community participation assumes the farmer needs and seeks a sense of identity with the community. Community patterns of settlement, community cohesion, and the owner's cultural ties to the land should be considered in selecting wastewater treatment sites. Centers for supplying farming and living needs and markets for the sale of farm products are essential to the landowner, as are the means of meeting cultural, educational, religious, recreational, and health care needs.

Some Hypothesized Impacts of Options on Farmer's Goals

The options available for obtaining access to and management of land for wastewater application each have relative strengths and weaknesses. The selection of a particular option reflects tradeoffs indicative of the relative economic and political power of the farmer and the wastewater authority. Such tradeoffs are an expression of payment for the rights to property. The amount of payment and the portion of rights relinquished vary with the option selected. The following discussion of the acquisition and management options, and the hypothesized effect of each on the farmer's goals is summarized in Table 4. This ranking is based on the author's subjective judgment and summarizes some of the considerations involved.

Fee Simple Acquisition

The impact of fee simple acquisition on farmer's goals varies with the management option selected, purchase and manage, purchase and leaseback, or purchase and resale.

Purchase and Manage

This option transfers the risk-bearing function of management from the former owner to the wastewater authority or to its representative. Former land owners, if retained, are employees rather than self-employed. The transfer of fee simple rights has adverse effect on the farmer's goals of wealth accumulation, firm growth, and freedom of decision-making when the transfer price doesn't cover all his costs. The effect on income will vary with the realtionship between wages received and farm income foregone. The sense of community can be diminished or destroyed because of the displacement of farmers, and to the degree that the attitude of hired farm managers

Table 4. An Assessment of Some Relative Impacts of Land Acquisition and Management Options on Farmer Goals

Acquisition and Management option	Farmer Goals				
	Income generation	Wealth accumulation	Firm growth	Freedom of decision-making	Sense of community participation
	Impact Indicator[1]				
FEE SIMPLE ACQUISITION					
Purchase and manage	2	3	3	3	3
Purchase and leaseback to present landowner	2	3	2	2	1
Purchase and leaseback to third party	2	3	3	3	2
LESS THAN FEE SIMPLE ACQUISITION					
Easements	2	1	1	1	0
CONTRACTUAL AGREEMENTS-NO REAL PROPERTY INTEREST					
Wastewater cooperative	2	2	2	2	2
Contracts for wastewater delivery to landowner	1/3	1	1	1	0

[1] 0 = little or no impact, either positive or negative
1 - slight impact, either positive or negative
2 - moderate impact, either positive or negative
3 = considerable impact, either positive or negative

downgrades the need for a sense of community. Also, if scale economies lead to purchase of farm supplies and sale of products outside the local community, existing supply firms may be forced out of business. The effect on community participation depends on how many farmers would be displaced. However, it is possible with this option for farmers to remain on the land through a subcontracting agreement.

Purchase and Leaseback

If land is purchased and in turn leased back to the original owner, the adverse effect will be somewhat less than under purchase and manage. The income generation goal is affected since the leasee would receive returns only for his labor, and perhaps for some capital assets such as equipment; previously, his income consisted of returns to land, labor, and capital.

There would be adverse effects on wealth accumulation because any appreciation in land values would accrue to the wastewater authority, rather than the leasee. The prospects of firm growth would be dimished but not completely eliminated. Freedom of decision-making would be restricted as the leasee would be bound by the conditions of the lease. However, these restrictions might be no more constraining than some imposed on landowners as conditions for obtaining bank loans.

The sense of belonging to a community may be slightly affected in that there may be a real or perceived loss of status associated with the shift from an owner to a tenant status. This would depend in part on the portion of the community so affected.

If the land is purchased and leased to a third party, such as a management firm, the risk-bearing function is transferred from the former owner to the third party. The displaced farmer loses previous oppotunities for income and wealth generation, as well as firm growth.

Real Property Interests Other Than Fee

Easement Purchase

The use of this option has a different effect on the farmer's goals than does fee simple acquisition. The full impact depends on the conditions of the easement. If these conditions require that certain crops be grown, the income generation goal from crop sales may be moderately affected, depending on the crops selected. To be equitable in this case, the value of the easement should at least equal the annual value of estimated loss in revenues.

Easements are perceived to have a slight affect on wealth accumulation, firm growth, and freedom of decision-making. Conditions of the easement may cause some minor problems at the time of subsequent title transfer, but any increase in wealth would accrue in full to the landowner just as if there were no easement. Firm growth would be hindered by the easement to the extent that it imposed rigid conditions on income-generating and expansion opportunities. There would be slight loss in freedom in that some discretionary options would be eliminated. Presumably the value received in exchange for the easement would adequately compensate for such losses. Conditions might require that the cooperating farmer accept a certain amount of water each year, with penalties for not accepting it when offered. Another possible condition might require certain crops be grown to absorb a minimum amount of nutrients from the water applied, i.e., to provide a minimum acceptable treatment.

Contractual Agreements - No Real Property Interests

Contracts with Farmers

This option presents considerable flexibility for both the farmer and the wastewater authority. It assumes that some type of agreement is entered into whereby the farmer will either buy the treated wastewater or receive it free, but with no interest in real estate being acquired.

Purchase of wastewater would be feasible from an economic viewpoint up to a point where the value of increased yields would equal the cost of the last unit of wastewater applied. The value of additional water would vary considerably with the annual moisture conditions and with soil types in a humid area such as Michigan. However, estimated target yields with wastewater application support expectations of sustained economic benefits to wastewater irrigation [Ellis, 1973]. Under such conditions, there would be a slight to moderate effect on income goals. Assuming that cooperating landowners would receive wastewater (containing plant nutrients), irrigation equipment, and tile drainage, at no cost, they could realize a considerable financial benefit. Portions of increased income would normally be reinvested and contribute toward firm growth. Wealth accumulation would be enhanced through increased investment in capital assets. Freedom of decision-making would be affected slightly by the requirement to take prescribed amounts of wastewater on schedule. However, if the only condition is that the farmer accept water of known quantity and quality at specified times, he would still be free to select the agricultural crops and rotation pattern compatible with the irrigation schedule.

Wastewater Cooperative

The goals most affected by this option would be freedom of decision-making and a sense of community participation. The collective decision-making process, especially as applied to land management decisions, would conflict with the freedom typically exercised by individual landowners. On the other hand, this same collective decision-making process could increase civic interest as individuals would be working closely together on a common problem. This association might stimulate community participation in accomplishing other goals

The cooperative could have a beneficial effect on income generation, wealth accumulation, and firm growth provided the constraints imposed by the cooperative balance these goals with the goal of wastewater renovation.

CHAPTER IV

BACKGROUND AND METHODOLOGY FOR THE EVALUATION OF LAND TREATMENT IN SOUTHEASTERN MICHIGAN

Regional Delineation

The general study area is the Southeastern Michigan region. It consists of a mixture of highly urbanized, suburban, and outlying agricultural areas. The area includes all of St. Clair, Macomb, Monroe, Wayne, Washtenaw, Oakland, Lenawee, Livingston, and Sanilac Counties. This area coincides with River Basin Group 4.1 as defined in the Great Lakes Basin Framework Study and with the boundary of the Southeast Michigan Rivers Basin Study [Great Lakes Basin Commission, 1972].

Analysis in this study focuses on land treatment recommendations developed in the Southeastern Michigan Wastewater Management Study. The bounds of this study are the same as those specified above except that all of Sanilac County and the outer portions of Oakland, Lenawee, Livingston, and Monroe Counties are omitted because these areas are outside the hydrologic basin boundary or are expected to retain their rural character through 1990. Areas bordering Ohio were omitted from the study area because of both their economic and demographic orientation to Toledo, Ohio.

Southeastern Michigan Wastewater Management Study

This study, completed by the Detroit District U. S. Army Corps of Engineers in 1974, developed long-range wastewater management plans for Southeastern Michigan. Its objective was to identify the present and future water pollution problems of the Southeastern Michigan study area and to design and evaluate the feasibility and consequences of alternatives for solving the problems. In the process of developing the plans, the needs and objectives related to water pollution problems in Southeastern Michigan were defined, treatment systems and related components were designed, alternative plans were formulated, and their impacts were assessed and evaluated [Corps of Engineers, 1974]. Four plans were selected as final alternatives for choice, including three representative plans and one Interim Water Quality Plan. These plans include biological, physical-chemical and land treatment components. The plans incorporating land treatment contribute information used in this study.

Soils Information

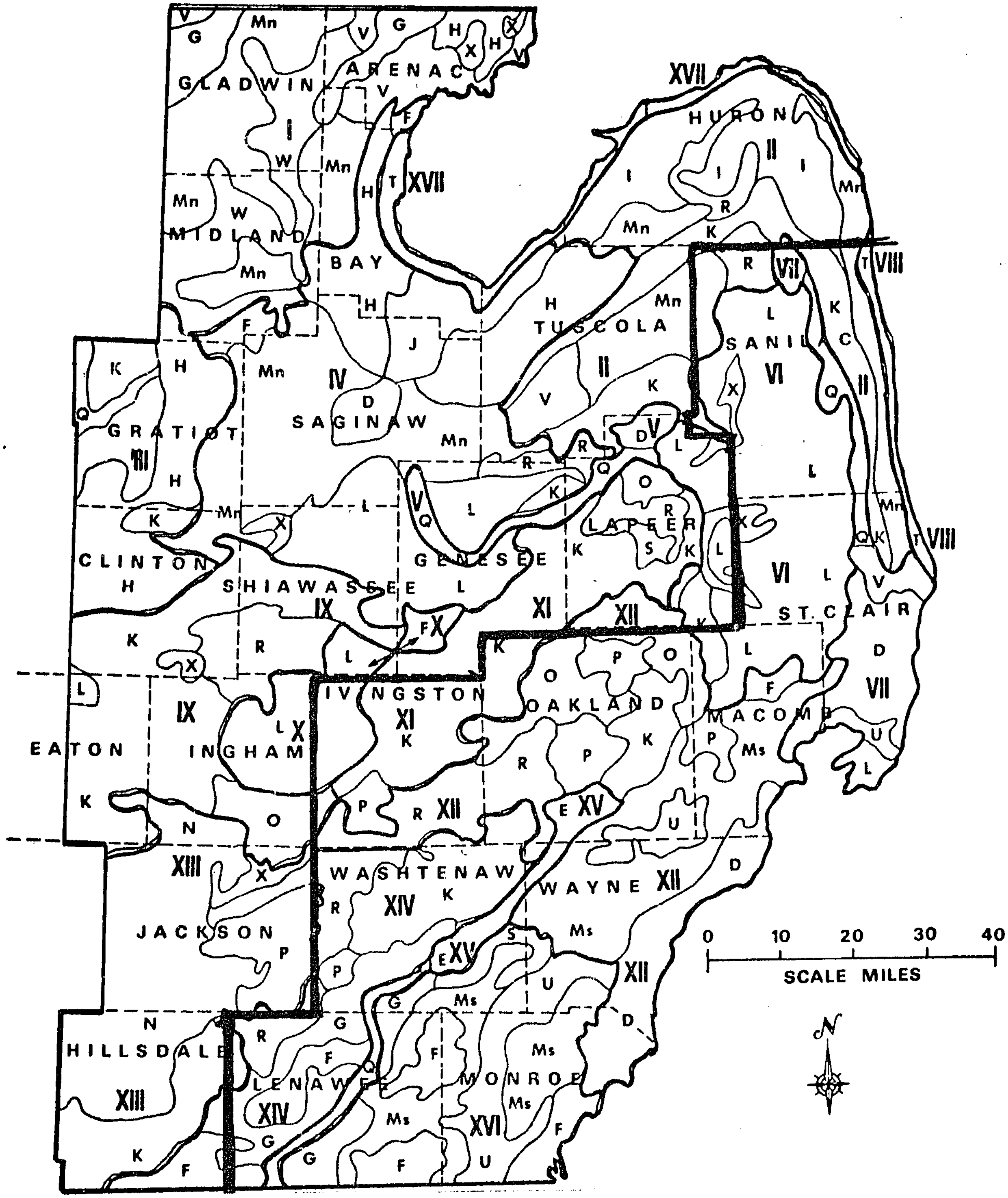
Information on the applicability of land treatment in Southeastern Michigan was developed and evaluated by the Crops and Soils Department, Michigan State University, and by Dow Engineering, Midland, Michigan. The potential of extensive areas for land treatment of the 1990 projected wastewater plan of 2.7 billion gallons per day (36.3 million acre-inches per year) was investigated [Dow Engineering, 1973]. It was estimated that agricultural land was available for land treatment of about 66.5 million acre-inches per year in a twenty-five county area of Southeast Michigan bordered by Gladwin and Arenac on the north and Midland, Gratiot, Clinton, part of Eaton, Jackson, and Hillsdale Counties on the west [Ellis, 1973].

While most soils within Southeastern Michigan are capable of wastewater renovation, the phosphorous sorption rate and hydraulic characteristics of the soils limit the rate of wastewater application and renovation. Furthermore, the agricultural crop grown on the soils influences the quantity and time of wastewater applications. Only a portion of the total acreage within a soil association area is cropland suited to wastewater treatment. Urban, forest, and other agricultural land use not compatible with a complementary crop production and wastewater treatment system are found in each soil association area.

Soils and land use information was collected on a county basis. Soil associations were then used as building blocks for the development of wastewater treatment zones by Dow Engineering. Application rate (acre-inches per year) based on soil and crop considerations for each soil association within each county was the basis of zone selection [Dow Engineering, 1973]. These zones cross county boundaries at random and result in the configuration shown in Figure 5 . The seventeen zones were grouped according to the soils' capabilities to receive wastewater and to facilitate cost identification for specific areas within Southeastern Michigan. Much of Zones 2, 3, 4, 6, 10, 13, 15, and 16 can receive an average rate of more than eight inches of wastewater per year. Zones 1, 7, 9, 11, 12, 14, and 16 generally can receive less than eight inches per year. Certain large areas within Zones 7 and 12 and the Zones 5, 8, 15, and 18, are unsuitable for any wastewater application because of heavy soils, slopes greater than 6 percent, or presence of large urban areas. The Wastewater Management Study area includes Zones 2, 6, 7, 8, 11, 12, 14, 15, and 16.

Plan Development

Soils information was used to design a land treatment system to handle all the total 1990 wastewater from Southeastern Michigan. Two plans were formulated, one relying entirely on public ownership of necessary land, and another based on a mix of public and private ownership. Large land areas are required for the treatment plant, stormwater storage, waste treatment facilities, and sludge disposal under either plan. Requirements under complete public ownership are 759,900 acres compared to 1,955,200 acres under mixed ownership [Corps of Engineers, 1974]. More land is required under mixed ownership because of reduced application rates on land in private ownership. The area in these



Source: [Dow Engineering, 1973]

Figure 5. Wastewater Treatment Zones and Soil Associations for Southeastern Michigan

proposals represent about 30 to 79 percent of the agricultural land in the region outlined in Figure 5.

Because of excessive social and economic disruptions, prohibitive costs and high energy requirements, wastewater management based entirely on land treatment was judged not feasible for Southeastern Michigan [Corps of Engineers, 1974]. As a result, a plan incorporating advanced waste treatment, independent physical-chemical treatment, and land treatment was proposed. This proposal includes land treatment sites in Lenawee and St. Clair Counties.

Two representative plans were developed, one emphasizing public land ownership (Plan A), and the other based upon private land ownership (Plan B). Representative Plan A proposes irrigation in central Lenawee and southern St. Clair Counties for treatment of both stormwater and municipal-industrial wastewater. In each system wastewater would be treated in aerated lagoons, disinfected, and then irrigated on publicly owned lands. Sludge would be applied on adjacent disposal sites, also publicly owned.

With representative Plan B, treatment sites remain in private ownership. The majority of the region's wastewater would receive conventional treatment rather than lagoon treatment. Disinfected effluent would then be irrigated on privately owned land. Sludge from the treatment lagoons would, as in Plan A, be applied to adjacent disposal sites. Data for the two representative plans is presented in Table 5. Land requirements are compatible with available

Table 5. Design Capacity and Land Use and Ownership Under Alternative Treatment Plans

Area	Capacity				Land Area & Ownership		
	Municipal & Industrial Wastewater		Stormwater		Plan A	Plan B	
	Plan A	Plan B	Plan A	Plan B	Public	Public	Private
	(MGD)				(Acres)		
St. Clair Co.	12	12	125	125	23,779	5,179	57,200
Lenawee Co.	12	12	10.5	10.5	4,940	1,040	15,320
					28,719	6,219	72,520
Stormwater Collection					23,500	23,500	
					52,219	29,719	72,520
						102,239	

Source: [Corps of Engineers, 1974, p. 104 & 112]

supply as 220,000 acres in Lenawee County and 94,000 acres in St. Clair County have been identified as suitable for effluent irrigation [Ellis, 1973]. Design specification and cost estimates for Plan B are in Table 6.

Representative Plan A uses 52,000 acres of publicly owned land. Representative Plan B uses 102,000 acres, of which 72,520 acres remains in private ownership. This is equivalent to approximately 28 four-square-mile module units, a design unit used for land treatment systems, two hundred twenty 320-acre farms, or one hundred twenty-five 580-acre farms. Plan A uses 4.8 percent of the land in Lenawee County; Plan B 1.5 percent. Comparable statistics for St. Clair County are 35.7 percent and 13.6 percent.

Table 6. Summary of Data for Proposed St. Clair and Lenawee County Irrigation Areas, Plan B

Characteristic	St. Clair Area	Lenawee Area
Design Flow		
Maximum Annual - Million Gallons	32,120	6,720
- Acre Inches	1,185,000	247,300
Average Annual - Million Gallons	16,800	5,440
- Acre Inches	618,700	200,300
Annual Application Rate for Selected Soil-Acre-In./Acre-Yr.	20.7	19.2
Land Required - Acres	57,200	12,880
Capital Cost	$172,580,000	$41,115,000
Amortized Capital Cost	10,192,000	2,428,000
Annual O and M Cost	6,177,000	1,547,000
Total Annual Cost	16,369.000	3,975,000

Source: [Corps of Engineers, 1974]

Estimated land requirements in St. Clair County, under Plan B, are 62,379 acres. Soil association L, the dominant association in the county, has acreage enough to meet this requirement. Similar requirements for Lenawee County are 16,360 acres for effluent treatment and 23,500 acres for stormwater collection. There is sufficient acreage of soil association M in Lenawee County for treatment purposes [Ellis, 1973]. The dominant soil management units of soil association L are 1.5, 2.5, and 4/2. It is comprised of nearly level, somewhat poorly drained and poorly drained loam and clay loam soils. The recommended water application rate is 20.6 inches per year. The dominant soil management units of soil association M are 3/2, 4/2, 1.5 and 2.5 which are comprised of nearly level, somewhat poorly drained and poorly drained sandy loam or loamy sand over loam to clay loam, clay loam, and loam soils. The sandy loam or loam sand over clay loam comprise 50 to 80 percent of the association. The recommended average application rate is 25 inches per year.

Methodology for Firm and Regional Analysis

The effects of land treatment on agricultural production are estimated within a framework of limited data on crop production and costs. Existing land treatment operations provide only fragmentary yield and cost data. Crop budgets and sensitivity analysis are used to evaluate alternative assumptions made for yields, prices, crop rotations, and cost sharing arrangements. Data is aggregated to the farm firm and regional level and evaluated using sensitivity analysis.

Two farm firm models are used, a 320-acre and a 580-acre cash grain farm. These models are based on data from the Telfarm Management Program [Kyle, 1972]. They are assumed to represent well managed farms that could incorporate land treatment into their existing farming operation. Individual crop budgets are developed to show their contributions to the gross margin of the firms with and without effluent irrigation, and are presented in Appendix B. They are illustrative of how land treatment can be evaluated using single valued expectations of yield, price, and costs.

Sensitivity analysis is used to evaluate many of the uncertainties surrounding land treatment. Several assumptions are evaluated using alternative variable sets for analysis purposes. Four data sets based upon research at Michigan State University and work by consultants to the Detroit District Corps of Engineers are used in this study. The sets reflect alternative crop yields, product prices, production costs, and crop rotations.

Crop Yields

Yields used reflect a current yield level and projects for 1985 with and without effluent irrigation (Table 7).

Table 7. Alternative Crop Yields

Crop	Unit	Yield Set[1]					
		Y_1	Y_2	Y_3	Y_4	Y_5	Y_6
		units per acre					
Corn	bu.	79	100	110	150	188	75
Soybeans	bu.	22	23	32	35	44	17
Drybeans	cwt.	9	9	16	20	25	10
Wheat	bu.	38	46	50	60	75	30
Alfalfa Hay	ton	-	-	3.0	5.0	6.2	2.5

[1]The yield sets are based on the following:

Y_1 - 1971 Yields, Michigan Cash Grain Farms [Kyle, 1972]
Y_2 - 1985 Projected yields without irrigation (based on regression on 1959-72 county data)
Y_3 - 1985 Projected yields without irrigation [Ellis, 1973]
Y_4 - 1985 Projected yields with irrigation [Ellis, 1973] 1973]
Y_5 - 1.25 Y_4
Y_6 - .5 Y_4

Additional yield estimates with irrigation reflect a possibility of a larger increase than estimated by soil scientists as well as a possibility of an adverse yield effect. The experience at Pennsylvania State University supports expectations of positive yield responses to effluent irrigation. Corn yields increased 55 percent and alfalfa yields increased 118 percent [Sopper, 1973]. Applying this response to the present data suggests a corn yield of 170 bushels and an alfalfa yield of 6.5 tons.

Product Prices

Farm product prices have increased sharply in recent years. Long term prices developed by the Water Resources Council are generally below current spot prices and are assumed to reflect a conservative price set. Two other price sets are used reflecting higher prices (Table 8). The consideration of higher prices is supported by the September, 1974 Michigan farm prices; corn - $3.22 per bushel,

Table 8. Alternative Product Price Sets

Crop	Unit	Price Set		
		P_1[1]	P_2	P_3
		$/unit		
Corn	bu.	1.64	2.50	3.50
Soybeans	bu.	4.12	5.00	8.00
Drybeans	cwt.	16.84	20.00	30.00
Wheat	bu.	2.36	3.00	5.00
Alfalfa Hay	ton	33.00	40.00	50.00

[1]Source: [Water Resources Council, 1974]

soybeans - $7.06 per bushel, dry beans - $18.50 per hundredweight, wheat - $3.83 per bushel, and alfalfa - $37. per ton [Michigan State University, 1974].

The total revenue sets in Table 9 combine data from the alternative yield and price sets and are used in the empirical analysis of Chapter 5.

Production Inputs and Costs

The addition of effluent irrigation activity to a farm firm will change production costs. It is assumed that existing farm machinery will be adequate except for irrigation equipment. Additional costs will be incurred for additional seed, and harvesting and hauling. Fertilizer costs may decrease, depending upon the nutrient content of the effluent and its substitution for commercial fertilizer. The individual drop budgets in Appendix B illustrate how changes in production costs influence gross margins.

Nutrient Substitution

Effluent contains nitrogen and phosphorous that are near perfect technical substitutes for nutrients in commercial fertilizers. This substitution is likely to reduce requirements for commercial fertilizers when effluent is applied. For example, it is estimated that by 1992 effluent at the Muskegon project will supply approximately 150 pounds of nitrogen and 50 pounds of phosphorous per acre [Stevens, 1972]. It is estimated that the level of phosphorous in most effluents will exceed removal by crops except at low

Table 9. Total Revenue Per Acre for Selected Yield and Price Sets.

Crop	Yield and Price Set				
	Y_2P_1	Y_3P_1	Y_4P_1	Y_5P_1	Y_6P_1
	----------	----------	dollars	----------	----------
Corn	164.00	180.40	246.00	308.32	123.00
Soybeans	94.76	131.84	144.20	181.28	70.04
Drybeans	151.56	269.44	336.80	421.00	168.40
Wheat	108.56	118.00	141.60	177.00	70.80
Alfalfa	99.00	99.00	165.00	204.60	82.50
	Y_2P_2	Y_3P_2	Y_4P_2	Y_5P_2	Y_6P_2
Corn	250.00	275.00	375.00	470.00	187.50
Soybeans	115.00	160.00	175.00	220.00	85.00
Drybeans	180.00	320.00	400.00	500.00	200.00
Wheat	138.00	150.00	180.00	225.00	90.00
Alfalfa	120.00	120.00	200.00	248.00	100.00
	Y_2P_3	Y_3P_3	Y_4P_3	Y_5P_3	Y_6P_3
Corn	350.00	385.00	525.00	658.00	262.50
Soybeans	184.00	256.00	280.00	352.00	136.00
Drybeans	270.00	480.00	600.00	750.00	300.00
Wheat	230.00	250.00	300.00	375.00	150.00
Alfalfa	150.00	150.00	250.00	310.00	125.00

Source: [Water Resources Council, 1974].

Y_1 - 1971 Yields, Michigan Cash Grain Farms [Kyle, 1972]

Y_2 - 1985 Projected yields without irrigation (based on regression on 1959-72 county data)

Y_3 - 1985 Projected yields without irrigation [Ellis, 1973]

Y_4 - 1985 Projected yields with irrigation [Ellis, 1973]

Y_5 - 1.25 Y_4

Y_6 - .5 Y_4

application rates [Ellis, 1973].

Additional data on the nutrient content of effluent and estimates of its substitution for commercial fertilizers are included in Appendix B.

Irrigation Systems Design and Cost

The land treatment system considered in this study incorporates sprinkler irrigation into the production system. It consists of a large interdependent network of distribution lines and sprinkler systems that covers a number of farms. Each farm has an independent distribution system that takes effluent from a common delivery system. Wastewater is delivered to individual farms in pressure pipes, where each has the appropriate valves and a complete irrigation system independent of neighboring farms.

Two irrigation methods are possible, a fixed-set sprinkler system and a center pivot sprinkler system. The major advantages of a fixed-set system include 1) adaptability to crops, soil type, terrain, and shape and size of field, and 2) low labor requirements, and 3) low application rate. Its major disadvantage is its relatively high capital cost, which can be 5-7 times the capital cost for a center pivot system [Dow Engineering, 1973].

The center pivot sprinkler system generally has a lower capital cost, but higher labor and maintenance cost than fixed set systems. One of its major disadvantages is the high application rate at the far end of the pivot system. Because each succeeding sprinkler head must move farther and faster than the one before it, more water must be applied per foot of system length toward the far end. A design difficulty is encountered in fitting center pivot systems to irregularly shaped and relatively small fields. Both the disadvantages of high rates at the end of the pipe and the tailoring to smaller fields can be ameliorated somewhat by designing 600-foot systems rather than 1300-foot systems [Dow Engineering, 1973].

Irrigation costs in this study are based on center pivot sprinkler irrigation systems. Cost data developed for the Southeast Michigan Wastewater Management Study are extrapolated to the farm firm level. The irrigation system differs from the usual farm irrigation system as treated effluent is pumped from the lagoons to irrigation areas rather than pumped from individual wells or streams. Each farmer would have an independent valve and center pivot system for irrigation. These systems are expensive because of the pumping stations and long transmission lines. Estimates of annual ownership and operating costs of a center pivot component of a four-square-mile module are presented in Table 10. Costs of a combined and individual system are compared in Table 11. Annual ownership costs include 1) depreciation, and 2) interest on the investment, and taxes and insurance. Operating costs include energy, maintenance and supplies, and labor. The annual costs of the central distribution center pivot system are estimated

Table 10. Irrigation Cost Estimates for 160 Acre Center Pivot System Tied Into a 4 Square Mile Module[1]

Investment and Depreciation	Investment	Years of Life	Annual Costs	
Pumping Station	10,562.50	15	704.17	
Irrigation Rights	20,000.00	15	1,333.33	
Pressure Pipes & Valves	70,347.50	15	4,689.83	
	100,910		6,727.33	
Depreciation			6,727.33	
Interest (8% on 1/2 I)			4,036.40	
Insurance (1.5% of I)			1,513.65	
Total			12,277.38	
Annual Ownership Cost/Acre			76.73	
Annual Operating Costs				
Energy (5600 hrs @ 0.0125KWH)			3,800	3,800
Maintenance & Supplies			620	620
Labor			4,025	1,365[2]
Total			8,445	5,785
Annual Operation & Maintenance Cost/Acre			52.78	36.15
Summary				
Annual Ownership			76.73	76.73
Annual Operating			52.78	36.15
Total			129.51	112.88

[1] Based upon cost data [Dow Engineering, 1973].

[2] 546 @ $2.50/hr. Total labor costs split on basis of capital cost ratio.

Table 11. Cost Comparisons for Alternative Irrigation Systems[1]

Cost Item	160 Acre Center Pivot System							
	Central Distribution System				Individual Water Supplies			
	Useful Life	Investment	Cost Factor	Annual Cost	Useful Life	Investment	Cost Factor	Annual Cost
<u>Ownership Costs</u>								
Irrigation Pumping Station	15	10,500	.1067[3]	1120				
Irrigation Rig (1450')	15	20,000	.1067	2134		20,000	.1067	2134
Pressure Pipe	15	69,000	.1067	7362		6,000	.1067	640
Valves & Misc. Fittings	15	1,600	.1067	170		1,000	.1067	107
Water Supply Charge[2]								800
Total Investment		101,100		10786		27,000		3681
Taxes & Insurance (Total Investment x .015)				1516				1516
Total Capital Cost				12302				5197
Total Capital Cost/acre				77				32
<u>Operation & Maintenance Costs</u>								
Pumping Station				100				
Irrigation Rig				400				
Pressure Pipes				70				
Valves & Misc.				50				
Energy				3800				2000
Maintenance & Supplies								1800
Labor				4025				125[4]
Total O & M				8445				3925
Total O & M/acre				53				25

[1]Costs based on data in Dow Engineering, [1973] and Hoglund, [1972].
[2]Based on $5/acre
[3]Takes into account annual depreciation and interest
[4]50 hours @ $2.50

at $77 per acre for ownership and $36 and $53 per acre for operation and maintenance depending upon assumptions related to labor costs.

Irrigation cost estimates from other studies differ from project irrigation costs as they are generally for individual farm systems. Capital costs in particular are lower, but operation costs are similar. One estimates the required investment for a 140-acre center pivot system at $25,300, with an annual ownership costs per acre of $21.90. Operating costs include 1) labor, 2) electricity or fuel to operate the pump, 3) maintenance and repairs, 4) loss due to land taken out of production by the irrigation system, 5) added plant population, and 6) added fertilizer. Annual operating costs range from $22.36 per acre for a 7 inch application to $33.58 for a 13 inch application [Hoglund, 1972].

Crop Rotations

Individual crops are combined into a farm plan reflective of rotation practices expected under effluent irrigation. Idle cropland or land in government are assumed to be used more intensely with irrigation. Alternative rotations evaluated with effluent irrigation are 1) corn - 35%, wheat - 10%, and alfalfa - 20%, and 2) corn - 40%, beans - 40%, and wheat - 20% [Ellis, 1973]. These rotations are used in Chapter 5 in the estimation of firm and regional production.

CHAPTER V

SOME IMPACTS OF LAND TREATMENT AT THE FIRM AND REGIONAL LEVEL

Introduction

This study evaluates land treatment as a wastewater management alternative, but does not compare it with other wastewater treatment methods. It also estimates the total and net magnitude of monetary benefits from irrigation and shows how alternative cost sharing arrangements influence the distribution of these net benefits. The influence of the acquisition and management options on the distribution of benefits are identified in some instances. However, the emphasis in this chapter is to show how alternative assumptions influence estimates of the total and net benefits from effluent irrigation. The analysis is most applicable to the contractual agreement acquisition option.

Sensitivity analysis is applied to crop yields, rotations, prices, and irrigation costs. Information on individual crops is aggregated to the firm and regional level.

The changes in the costs and returns associated with effluent irrigation are emphasized. Several estimates of cost changes are compared with estimates of total revenue changes. Cost change estimates primarily reflect fertilizer cost savings because of nutrient substitution and the total annual costs of irrigation systems, broken down into ownership costs and operating costs. Total revenue sets are estimated using alternative price and yield combination. Finally, changes in net revenue are estimated.

Crop Analysis

Corn for grain, soybeans, dry beans, wheat, and alfalfa are crops normally grown in the Southeastern Michigan area and are compatible with wastewater irrigation [Ellis, 1973]. Breakeven analysis is used with alternative cost and revenue sets to identify the yield increase necessary to offset irrigation costs. This helps to identify the minimum conditions a farmer might require before agreeing to use wastewater on his crops. For example, if corn sells for $2.50 per bushel and the annual irrigation costs are $50 per acre, a yield increase of greater than 20 bushels per acre is required for profits to increase.

Three types of information are provided for the five crops being evaluated. Tables 12, 13 and 14 contain data on corn. Appendix C has the same information for soybeans, dry beans, wheat, and alfalfa. Total revenues with alternative corn yields and prices and the changes in total revenues due to yield changes with irrigation are in Table 12. The breakeven yields for corn with alternative price and irrigation cost assumptions are in Table 13. Finally, Table 14 shows the changes in net revenues associated with alternative

Table 12. Total Revenue Per Acre and Changes in Total Revenue Associated with Alternative Yield and Price Combinations, Corn

Yield	Total Revenue at Price/Bushel					
	1.50	1.64	2.00	2.50	3.00	3.50
bushels	dollars					
75	112.50	123.00	150.00	187.50	225.00	262.50
100	150.00	164.00	200.00	250.00	300.00	350.00
110	165.00	180.40	220.00	275.00 [1]	330.00	385.00
125	187.50	205.00	250.00	312.50	375.00	437.50
150	225.00	246.00	300.00	375.00 [2]	450.00	525.00
175	262.50	287.00	350.00	437.50	525.00	612.50
188	282.00	308.32	376.00	470.00	564.00	658.00
200	300.00	328.00	400.00	500.00	600.00	700.00

Yield Increase	Increase in Total Revenue at Price/Bushel					
	1.50	1.64	2.00	2.50	3.00	3.50
bushels	dollars					
10	15.00	16.40	20.00	25.00	30.00	35.00
25	37.50	41.00	50.00	62.50	75.00	87.50
40	60.00	65.60	80.00	100.00 [2]	120.00	140.00
50	75.00	82.00	100.00	125.00	150.00	175.00
75	112.50	123.00	150.00	187.50	225.00	262.50
78	117.00	127.92	156.00	195.00	234.00	273.00
100	150.00	164.00	200.00	250.00	300.00	350.00

[1]Best estimate without irrigation.
[2]Best estimate with irrigation.

Table 13. Incremental Corn Yield Increases Required to Breakeven on Irrigation Costs with Alternative Prices and Costs

Irrigation Costs [1]	Breakeven Yield at Price/Bushel dollars					
	1.50	1.64	2.00	2.50	3.00	3.50
dollars	bushels/acre					
10.00	6.7	6.1	5.0	4.0	3.3	2.9
25.00	16.7	15.2	12.5	10.0	8.3	7.1
35.00	23.3	21.3	17.5	14.0	11.7	10.0
40.00	26.7	24.4	20.0	16.0	13.3	11.4
45.00	30.0	27.4	22.5	18.0	15.0	12.9
50.00	33.3	30.5	25.0	20.0	16.7	14.3
55.00	36.7	33.5	27.5	22.0	18.3	15.7
60.00	40.0	36.6	30.0	24.0	20.0	17.1
65.00	43.3	39.6	32.5	26.0	21.7	18.6
70.00	46.7	42.7	35.0	28.0	23.3	20.0
75.00	50.0	45.7	37.5	30.0	25.0	21.4
80.00	53.3	48.8	40.0	32.0	26.7	22.9
85.00	56.7	51.8	42.5	34.0	28.3	24.3
90.00	60.0	54.9	45.0	36.0	30.0	25.7
95.00	63.3	57.9	47.5	38.0	31.7	27.1
100.00	66.7	61.0	50.0	40.0	33.3	28.6
110.00	73.3	67.1	55.0	44.0	36.7	31.4
125.00	83.3	76.2	62.5	50.0	41.7	35.7

1 Irrigation costs vary with the system used, and may represent annual capital costs, annual operating and maintenance costs, or annual total costs. For example, capital costs range from $32 - $77 and operating costs from $25 - $53 in the systems specified in Table 11.

Table 14. Net Revenue Per Acre for Alternative Sets of Irrigation Costs, Yield Changes, and Prices, Corn

Irrigation Cost	Yield Change	Net Revenues				
		Dollars/Bushel				
		1.50	1.64	2.50	3.00	3.50
dollars	bushels	dollars				
25	10	-10.00	-8.60	0.00	5.00	10.00
	25	12.50	16.00	37.50	50.00	62.50
	40	35.00	40.60	75.00	95.00	115.00
	50	50.00	57.00	100.00	125.00	150.00
	75	87.50	98.00	162.50	200.00	237.50
	78	92.00	102.92	170.00	209.00	248.00
	100	125.00	139.00	225.00	275.00	325.00
50	10	-35.00	-33.60	-25.00	-20.00	-15.00
	25	-12.50	-9.00	12.50	25.00	37.50
	40	10.00	15.60	50.00	70.00	90.00
	50	25.00	32.00	75.00	100.00	125.00
	75	62.50	73.00	137.50	175.00	212.50
	78	67.00	77.92	145.00	184.00	223.00
	100	100.00	114.00	200.00	250.00	300.00
75	10	-60.00	-58.60	-50.00	-45.00	-40.00
	25	-37.50	-34.00	-12.50	0.00	12.50
	40	-15.00	-9.40	25.00	45.00	65.00
	50	0.00	7.00	50.00	75.00	100.00
	75	37.50	48.00	112.50	150.00	187.50
	78	42.00	52.92	120.00	159.00	198.00
	100	75.00	89.00	175.00	225.00	275.00
100	10	-85.00	-83.60	-75.00	-70.00	-65.00
	25	-62.50	-59.00	-37.50	-25.00	-12.50
	40	-40.00	-34.40	0.00	20.00	40.00
	50	-25.00	-18.00	25.00	50.00	75.00
	75	12.50	23.00	87.50	125.00	162.50
	78	17.00	27.92	95.00	134.00	173.00
	100	50.00	64.00	150.00	200.00	250.00

yield, price, and irrigation cost sets. Data in Tables 12-14 are used in several ways to show the effects of alternative assumptions for corn. Corn yielding 110 bushels per acre and selling at \$2.50 per bushel generates total revenue per acre of \$275. If effluent irrigation increases the yield by 40 bushels, with prices constant, total revenues increase \$100 per acre (Table 12). Additional irrigation costs are related to yield increases using break-even analysis. For example, if the corn price is \$2.50 per bushel and irrigation costs are \$50, a yield increase of 20 bushels per acre is required to breakeven on irrigation costs (Table 13). Alternative irrigation costs, net of estimated fertilizer cost savings, are combined with yield changes and prices to estimate net revenue changes from irrigation (Table 14). If net irrigation costs are \$50 per acre, yields increase 40 bushels per acre and the price is \$2.50 per acre, net revenue increases by \$50.00. However, if the price is \$3.00 per bushel, net revenues increase by \$70.

Changes in net revenues for the other crops based on alternative yields, price and irrigation costs are estimated using the tables in Appendix C. Thus, if the net irrigation expense is \$50 per acre, and yields increase from level Y_3 to Y_4 with irrigation and the price set P_2 is assumed, there is a net revenue change per acre of +\$50 for corn, -\$35 for soybeans, +\$30 for dry beans, -\$20 for wheat, and +\$30 for alfalfa.

Farm Firm Analysis

Production and Revenue Changes

Several situations are hypothesized and evaluated for two representative farms, one 320 acres and the other 580 acres. The major effects of wastewater irrigation on the firm's total revenue are assumed to be reflected in the interaction of the alternative levels of crop yields and prices presented in Chapter 4 and the rotations specified in Table 15. Changes in total revenues are estimated under a number of assumptions and presented in Table 16 for the 320 acre farm and in Table 17 for the 580 acre farm. For example, there is an estimated total revenue increase of \$14,080 with irrigation for the 320 acre farm assuming 267 acres in crops, rotation R_1, yield set Y_4, and price set P_1. If the optimistic yield response set Y_5 occurs, total revenue increases approximately \$29,000. A wide range of total revenues and changes in total revenues result from alternative yield and price assumptions. The changes in total revenue reflect the gross benefits to effluent irrigation, and represent revenues available to offset irrigation expenses and to provide incentives for farmer participation. Bargaining between the farmer and the wastewater authority over the distribution of these revenues is anticipated.

The effect of irrigation on total revenue of a farm is expressed as:

Table 15. Alternative Crop Rotations, 320 and 580 Acre Farms

Crop Rotation	Crop Rotation[1]								
	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9
	---Acres---								
<u>320 Acre Farm</u>									
Corn	184	93	93	106	106	105	105	120	120
Soybeans	50	93	0	106	0	105	0	120	0
Dry beans	14	0	93	0	106	0	105	0	120
Wheat	19	27	27	55	55	30	30	60	60
Alfalfa	0	54	54	0	0	60	60	0	0
Total Tillable	267	267	267	267	267	300	300	300	300
Total Acres	320								
<u>580 Acre Farm</u>									
Corn	360	190	190	190	215	215	215		
Soybeans	45	190	0	95	215	0	110		
Dry beans	53	0	190	95	0	215	105		
Wheat	48	50	50	50	110	110	110		
Alfalfa	34	110	110	110	0	0	0		
Total Tillabel	540	540	540	540	540	540	540		
Total Acres	580								

[1] R_1 reflects that 1971 telfarm cropping pattern [Kyle, 1972]. The remaining combinations reflect 1) 35% corn, 35% beans, 10% wheat, 20% alfalfa or 2) 40% corn, 40% beans, and 20% wheat.

Table 16. Total Revenue and Changes in Total Revenue with Irrigation, Alternative Crop Rotations, Yields, and Prices, 320 Acre Farm[1]

Crop Rotation		Acres	Revenue with Alternative Yield and Price Sets								
			Y3P1	Y4P1	Y5P1	Y3P2	Y4P2	Y5P2	Y3P3	Y4P3	Y5P3
			dollars								
R1	Corn	184	33,194.	45,264.	56,731.	50,600.	69,000.	86,480.	70,840.	96,600.	121,072.
	Soybeans	50	6,592.	7,210.	9,064.	8,000.	8,750.	11,000.	12,800.	14,000.	17,600.
	Dry Beans	14	3,772.	4,715.	5,894.	4,480.	5,600.	7,000.	6,720.	8,400.	10,500.
	Wheat	19	2,242.	2,690.	3,363.	2,850.	3,420.	4,275.	4,750.	5,700.	7,125.
	Total	267	45,800.	59,880.	75,052.	65,930.	86,770.	108,755.	95,110.	124,700.	156,297.
	Change			14,080.	29,252.		20,840.	42,825.		29,590.	61,187.
R2	Corn	93	16,777.	22,878.	28,674.	25,575.	34,875.	43,710.	35,805.	48,825.	61,194.
	Soybeans	93	12,261.	13,411.	16,859.	14,880.	16,275.	20,460.	23,808.	26,040.	32,736.
	Wheat	27	3,186.	3,823.	4,779.	4,050.	4,860.	6,075.	6,750.	8,100.	10,125.
	Alfalfa	54	5,346.	8,910.	11,048.	6,480.	10,800.	13,392.	8,100.	13,500.	16,740.
	Total	267	37,570.	49,022.	61,360.	50,985.	66,810.	83,637.	74,463.	96,465.	120,795.
	Change			11,451.	23,790.		15,825.	32,652.		22,002.	46,312.
R3	Corn	93	16,777.	22,878.	28,674.	25,575.	34,875.	43,710.	35,805.	48,825.	61,194.
	Dry Beans	93	25,058.	31,322.	39,153.	29,760.	37,200.	46,500.	44,640.	55,800.	69,750.
	Wheat	27	3,186.	3,823.	4,779.	4,050.	4,860.	6,075.	6,750.	8,100.	10,125.
	Alfalfa	54	5,346.	8,910.	11,048.	6,480.	10,800.	13,392.	8,100.	13,500.	16,740.
	Total	267	50,367.	66,934.	83,654.	65,865.	87,735.	109,677.	95,295.	126,225.	157,809.
	Change			16,566.	33,287.		21,870.	43,812.		30,930.	62,514.
R4	Corn	106	19,122.	26,076.	32,682.	29,150.	39,750.	49,820.	40,810.	55,650.	69,748.
	Soybeans	106	13,975.	15,285.	19,216.	16,960.	18,550.	23,320.	27,136.	29,680.	37,312.
	Wheat	55	6,490.	7,788.	9,735.	8,250.	9,900.	12,375.	13,750.	16,500.	20,625.
	Total	267	39,587.	49,149.	61,633.	54,360.	68,200.	85,515.	81,696.	101,830.	127,685.
	Change			9,562.	22,045.		13,840.	31,155.		20,134.	45,989.
R5	Corn	106	19,122.	26,076.	32,682.	29,150.	39,750.	49,820.	40,810.	55,650.	69,748.
	Dry Beans	106	28,561.	35,701.	44,626.	33,920.	42,400.	53,000.	50,880.	63,600.	79,500.
	Wheat	55	6,490.	7,788.	9,735.	8,250.	9,900.	12,375.	13,750.	16,500.	20,625.
	Total	267	54,173.	69,565.	87,043.	71,320.	92,050.	115,195.	105,440.	135,750.	169,873.
	Change			15,392.	32,870.		20,730.	43,875.		30,310.	64,433.
R6	Corn	105	18,942.	25,830.	32,374.	28,875.	39,375.	49,350.	40,425.	55,125.	69,090.
	Soybeans	105	13,843.	15,141.	19,034.	16,800.	18,375.	23,100.	26,880.	29,400.	36,960.
	Wheat	30	3,540.	4,248.	5,310.	4,500.	5,400.	6,750.	7,500.	9,000.	11,250.
	Alfalfa	60	5,940.	9,900.	12,276.	7,200.	12,000.	14,880.	9,000.	15,000.	18,600.
	Total	300	42,265.	55,119.	68,994.	57,375.	75,150.	94,080.	83,805.	108,525.	135,900.
	Change			12,854.	26,729.		17,775.	36,705.		24,720.	52,095.
R7	Corn	105	18,942.	25,830.	32,374.	28,875.	39,375.	49,350.	40,425.	55,125.	69,090.
	Dry Beans	105	28,291.	35,364.	44,205.	33,600.	42,000.	52,500.	50,400.	63,000.	78,750.
	Wheat	30	3,540.	4,248.	5,310.	4,500.	5,400.	6,750.	7,500.	9,000.	11,250.
	Alfalfa	60	5,940.	9,900.	12,276.	7,200.	12,000.	14,880.	9,000.	15,000.	18,600.
	Total	300	56,713.	75,342.	94,165.	74,175.	98,775.	123,480.	107,325.	142,125.	177,690.
	Change			18,629.	37,451.		24,600.	49,305.		34,800.	70,365.
R8	Corn	120	21,648.	29,520.	36,998.	33,000.	45,000.	56,400.	46,200.	63,000.	78,960.
	Soybeans	120	15,821.	17,304.	21,754.	19,200.	21,000.	26,400.	30,720.	33,600.	42,240.
	Wheat	60	7,080.	8,496.	10,620.	9,000.	10,800.	13,500.	15,000.	18,000.	22,500.
	Total	300	44,549.	55,320.	69,372.	61,200.	76,800.	96,300.	91,920.	114,600.	143,700.
	Change			10,771.	24,823.		15,600.	35,100.		22,680.	51,780.
R9	Corn	120	21,648.	29,520.	36,998.	33,000.	45,000.	56,400.	46,200.	63,000.	78,960.
	Dry Beans	120	32,333.	40,416.	50,520.	38,400.	48,000.	60,000.	57,600.	72,000.	90,000.
	Wheat	60	7,080.	8,496.	10,620.	9,000.	10,800.	13,500.	15,000.	18,000.	22,500.
	Total	300	61,061.	78,432.	98,138.	80,400.	103,800.	129,900.	118,800.	153,000.	191,460.
	Change			17,371.	37,078.		23,400.	49,500.		34,200.	72,660.

[1]Yield and price sets are specified in Tables 7 and 8, rotations in Table 15.

Table 17. Total Revenue and Change in Total Revenue with Irrigation, Alternative Crop Rotations, Yields, and Prices, 580 Acre Farm [1]

Crop Rotation		Acres	Y3P1	Y4P1	Y5P1	Y3P2	Y4P2	Y5P2	Y3P3	Y4P3	Y5P3
			Revenue with Alternative Yield and Price Sets								
			dollars								
R1	Corn	360	64,944.	88,560.	110,995.	99,000.	135,000.	169,200.	138,600.	189,000.	236,880.
	Soybeans	45	5,933.	6,489.	8,158.	7,200.	7,875.	9,900.	11,520.	12,600.	15,840.
	Dry Beans	53	14,280.	17,850.	22,313.	16,960.	21,200.	26,500.	25,440.	31,800.	39,750.
	Wheat	48	5,664.	6,797.	8,496.	7,200.	8,640.	10,800.	12,000.	14,400.	18,000.
	Alfalfa	34	3,366.	5,610.	6,956.	4,080.	6,800.	8,432.	5,100.	8,500.	10,540.
	Total	540	94,187.	125,306.	156,918.	134,440.	179,515.	224,832.	192,660.	256,300.	321,010.
	Change			31,119.	62,731.		45,075.	90,392.		63,640.	128,350.
R2	Corn	190	34,276.	46,740.	58,581.	52,250.	71,250.	89,300.	73,150.	99,750.	125,020.
	Soybeans	190	25,050.	27,398.	34,443.	30,400.	33,250.	41,800.	48,640.	53,200.	66,880.
	Wheat	50	5,900.	7,080.	8,850.	7,500.	9,000.	11,250.	12,500.	15,000.	18,750.
	Alfalfa	110	10,890.	18,150.	22,506.	13,200.	22,000.	27,280.	16,500.	27,500.	34,100.
	Total	540	76,116.	99,368.	124,380.	103,350.	135,500.	169,630.	150,790.	195,450.	244,750.
	Change			23,252.	48,264.		32,150.	66,280.		44,660.	93,960.
R3	Corn	190	34,276.	46,740.	58,581.	52,250.	71,250.	89,300.	73,150.	99,750.	125,020.
	Dry Beans	190	51,194.	63,992.	79,990.	60,800.	76,000.	95,000.	91,200.	114,000.	142,500.
	Wheat	50	5,900.	7,080.	8,850.	7,500.	9,000.	11,250.	12,500.	15,000.	18,750.
	Alfalfa	110	10,890.	18,150.	22,506.	13,200.	22,000.	27,280.	16,500.	27,500.	34,100.
	Total	540	102,260.	135,962.	169,927.	133,750.	178,250.	222,830.	193,350.	256,250.	320,370.
	Change			33,702.	67,667.		44,500.	89,080.		62,900.	127,020.
R4	Corn	190	34,276.	46,740.	58,581.	52,250.	71,250.	89,300.	73,150.	99,750.	125,020.
	Soybeans	95	12,525.	13,699.	17,222.	15,200.	16,625.	20,900.	24,320.	26,600.	33,440.
	Dry Beans	95	25,597.	31,996.	39,995.	30,400.	38,000.	47,500.	45,600.	57,000.	71,250.
	Wheat	50	5,900.	7,080.	8,850.	7,500.	9,000.	11,250.	12,500.	15,000.	18,750.
	Alfalfa	110	10,890.	18,150.	22,506.	13,200.	22,000.	27,280.	16,500.	27,500.	34,100.
	Total	540	89,188.	117,665.	147,153.	118,550.	156,875.	196,230.	172,070.	225,850.	282,560.
	Change			28,477.	57,966.		38,325.	77,680.		53,780.	110,490.
R5	Corn	215	38,786.	52,890.	66,289.	59,125.	80,625.	101,050.	82,775.	112,875.	141,470.
	Soybeans	215	28,346.	31,003.	38,975.	34,400.	37,625.	47,300.	55,040.	60,200.	75,680.
	Wheat	110	12,980.	15,576.	19,470.	16,500.	19,800.	24,750.	27,500.	33,000.	41,250.
	Total	540	80,112.	99,469.	124,734.	110,025.	138,050.	173,100.	165,315.	206,075.	258,400.
	Change			19,357.	44,622.		28,025.	63,075.		40,760.	93,085.
R6	Corn	215	38,786.	52,890.	66,289.	59,125.	80,625.	101,050.	82,775.	112,875.	141,470.
	Dry Beans	215	57,930.	72,412.	90,515.	68,800.	86,000.	107,500.	103,200.	129,000.	161,250.
	Wheat	110	12,980.	15,576.	19,470.	16,500.	19,800.	24,750.	27,500.	33,000.	41,250.
	Total	540	109,696.	140,878.	176,274.	144,425.	186,425.	233,300.	213,475.	274,875.	343,970.
	Change			31,182.	66,578.		42,000.	88,875.		61,400.	130,495.
R7	Corn	215	38,786.	52,890.	66,289.	59,125.	80,625.	101,050.	82,775.	112,875.	141,470.
	Soybeans	110	14,502.	15,862.	19,941.	17,600.	19,250.	24,200.	28,160.	30,800.	38,720.
	Dry Beans	105	28,291.	35,364.	44,205.	33,600.	42,000.	52,500.	50,400.	63,000.	78,750.
	Wheat	110	12,980.	15,576.	19,470.	16,500.	19,800.	24,750.	27,500.	33,000.	41,250.
	Total	540	94,560.	119,692.	149,905.	126,825.	161,675.	202,500.	188,835.	239,675.	300,190.
	Change			25,132.	55,345.		34,850.	75,675.		50,840.	111,355.

[1] Yield and Price sets are specified in Tables 7 and 8, rotations in Table 15.

$$\begin{aligned} TR &= f\ (R,\ Y,\ P,\ I) \quad (1)\\ \text{where} \quad TR &= \text{Total revenue}\\ R &= \text{Crop rotation}\\ Y &= \text{Yield}\\ P &= \text{Product price}\\ I &= \text{Intensity of land use} \end{aligned}$$

The interaction of these variables for a 320- and 580-acre farm are shown in Table 16 and 17. Each horizontal set of data reflects changes in revenues where Y and P vary and R and I are held constant. The effects of R and I can be estimated through comparisons between the horizontal data sets.

An estimate of revenue change and its component parts is made by comparing $R_1\ Y_3\ P_1$, the baseline situation without irrigation, with $R_7\ Y_4\ P_1$, a situation with irrigation depicting changes in R, Y, and I. For the 320-acre farm, the total revenue for $R_1\ Y_3\ P_1$ is \$45,800. If a yield increase was experienced on R_1 due to irrigation, total revenue will increase to \$59,880. However, an additional increase of \$7,054 is possible by changing the cropping pattern to one with more dry beans and less corn, as reflected in R_3.

The effect of I and Y can be estimated when irrigation is added to the 320-acre farm. By bringing idle and diverted acres into production, 300 instead of 267 acres are cropped. The irrigation yield effect on this increased acreage translates to total revenue of \$75,342 ($R_7\ Y_4\ P_1$). Thus the component effects of moving from the situation without irrigation with total revenues of \$45,800 to a situation with revenues of $75,342 are:

	Total Revenue	Change
Without irrigation (R_1 Y_3 P_1)	$45,800	
R effect (R_3 Y_3 P_1)	50,367	+$4,567
I effect (R_7 Y_3 P_1)	56,713	+ 6,346
Y effect (R_7 Y_4 P_1)	75,342	+18,629
With irrigation (R_7 Y_4 P_1)	75,342	+29,542

Total revenue increases by $29,542, of which 15 percent is attributed to R, 21 percent to I, and 64 percent to Y.

A similar analysis of the data for the 580-acre farm shows a total revenue increase of 44 percent, or $41,775. Of the increase, 19 percent is attributable to R and 81 percent to Y. There is no I effect assumed for the 580-acre farm as it was cropped more intensely before irrigation.

	Total Revenue	Change
Without irrigation (R_1 Y_3 P_1)	$94,187	
R effect (R_3 Y_3 P_1)	102,260	+$8,073
Y effect (R_3 Y_4 P_1)	135,962	+33,702
With irrigation (R_3 Y_4 P_1)	135,962	41,775

The component parts of the total revenue change attributed to irrigation influence the determination of net benefits. Revenue changes due to more intense land use (I) will be accompanied by production cost increases exclusive of irrigation costs. However, to simplify the comparison of changes in revenues associated with alternative assumption sets and cost sharing arrangements, Y and P are assumed to change, but R and I are held constant.

Distribution of Costs and Benefits

A two party situation is assumed involving a governmental body responsible for land treatment of wastewater, a wastewater authority, and a farmer who owns land suitable for land treatment. The wastewater authority has a number of options for acquisition of land and management of treatment sites. It can purchase fee simple interest and manage the farming operations. It can acquire less than fee interest, under which land titles are retained by the current owners. A third acquisition option is a contractual agreement involving no property interests.

The various acquisition and management options have varying influence on the distribution of costs and benefits from irrigation and in some instances establish the ranges for bargaining between the two parties. When the wastewater authority acquires fee simple interest in the farm land, the former owner relinquishes all property rights and managerial decisions in exchange for the purchase price. In this case additional revenues from irrigation do not enter directly into the bargaining process. However, the total revenue from the farming operations serve as the upper limit on benefits a cooperating farmer would realize from an agreement. Changes in total revenues, specified through alternative assumptions, define the total pool of benefits for distribution between the two parties.

The allocation of revenues from land treatment is essentially a unilateral decision when the authority has acquired fee simple title. The authority may manage the farming operation itself or it may lease the land back to the present landowner or to a third party. However it is managed, it would be more reflective of employer-employee relationships than that of a bargain between two resource owning entities.

Bargaining over the terms of the agreement can occur with a less-than-fee arrangement, such as an easement purchase. The wastewater authority can acquire access to land for wastewater management purposes through the use of a positive easement. One method of determining the value of an easement is to use the difference in the market value of the land before and after the easement restrictions are attached. If income streams reflective of alternative assumption sets are capitalized into land values, estimates of easement values can be based on the differences in land values with and without irrigation. If the total returns to wastewater irrigation are negative, the traditional easement valuation procedure is appropriate. The farmer would be compensated for the reduced income stream associated with the irrigation process. However, when there are positive benefits associated with irrigation, the income-capitalized value of the land will increase. This suggests that the use of easement purchase would be a viable alternative when effluent irrigation results in a reduced income stream. However, when there is a positive benefit, the traditional process for easement valuation encounters difficulty. This does not, however, eliminate the easement as a means for acquiring rights to land.

The alternative levels of total revenue presented previously in Table 16 and 17 represent the pool of benefits from irrigation under a variety of prices, yields, and crop rotations. Bargaining occurs between the farmer and the authority over the distribution of revenue increases from irrigation and the associated costs. Net benefits for the farmers are estimated under a number of cost sharing assumptions. The alternatives differ according to the portion of the annual irrigation costs paid by the farmer: total costs, capital costs, operating costs, or some fraction of total costs (20 percent and 50 percent). If the authority pays all irrigation costs, the increase in total revenue with irrigation and the increase in net revenue to the farmer are identical. Net benefits with alternative revenue and cost sharing arrangements for the 320 and 580-acre farm are estimated (Tables 18 and 19). The greater the yield change, the higher the product price, and the greater the share of irrigation costs paid by the wastewater authority, the larger will be the net benefits to the farmers. Some inferences are drawn from the data, using the 320-acre farm as an example. If the change in revenues are as reflected in R_1 Y_4 P_1 (\$14,080), the firm can pay annual irrigation operating costs or 25 percent of the total costs and still realize an increase in net

Table 18. Changes in Total Revenue and Net Revenue for a 320 Acre Farm in a Regional Wastewater Irrigation Project with Alternative Assumptions on Rotation, Yield, Price, and Irrigation Cost Sharing

	Rotation, Yield and Price Data Set Combination[1]					
	R1Y4P1	R1Y5P1	R1Y4P2	R1Y5P2	R1Y4P3	R1Y5P3
	dollars					
Annual Change in Total Revenue	14,080.	29,252.	20,840.	42,825.	29,590.	61,187.
Net Revenues after Deduction of:						
Total Irrigation Cost (33,000)	-18,920.	-3,748.	-12,160.	9,825.	-3,410.	28,187.
Capital Cost (22,500)	-8,420.	6,752.	-1,660.	20,325.	7,090.	38,687.
50% of Total Cost (16,500)	-2,420.	12,752.	4,340.	26,325.	13,090.	44,687.
Operating Cost (10,500)	3,580.	18,752.	10,340.	32,325.	19,090.	50,687.
25% of Total Cost (8,250)	5,830.	21,002.	12,590.	34,575.	21,340.	52,937.

	Rotation, Yield and Price Data Set Combination[1]					
	R2Y4P1	R2Y5P1	R2Y4P2	R2Y5P2	R2Y4P3	R2Y5P3
	dollars					
Annual Change in Total Revenue	11,451.	23,790.	15,825.	32,652.	22,002.	46,332.
Net Revenues after Deduction of:						
Total Irrigation Cost (33,000)	-21,549.	-9,210.	-17,175.	-348.	-10,998.	13,332.
Capital Cost (22,500)	-11,049.	1,290.	-6,675.	10,152.	-498.	23,832.
50% of Total Cost (16,500)	-5,049.	7,290.	-675.	16,152.	5,502.	29,832.
Operating Cost (10,500)	951.	13,290.	5,325.	22,152.	11,502.	35,832.
25% of Total Cost (8,250)	3,201.	15,540.	7,575.	24,402.	13,752.	38,082.

	Rotation, Yield and Price Data Set Combination[1]					
	R3Y4P1	R3Y5P1	R3Y4P2	R3Y5P2	R3Y4P3	R3Y5P3
	dollars					
Annual Change in Total Revenue	16,566.	33,287.	21,870.	43,812.	30,930.	62,514.
Net Revenues after Deduction of:						
Total Irrigation Cost (33,000)	-16,434.	287.	-11,130.	10,812.	-2,070.	29,514.
Capital Cost (22,500)	-5,934.	10,787.	-630.	21,312.	8,430.	40,014.
50% of Total Cost (16,500)	66.	16,787.	5,370.	27,312.	14,430.	46,014.
Operating Cost (10,500)	6,066.	22,787.	11,370.	33,312.	20,430.	52,014.
25% of Total Cost (8,250)	8,316.	25,037.	13,620.	35,562.	22,680.	54,264.

	Rotation, Yield and Price Data Set Combination[1]					
	R4Y4P1	R4Y5P1	R4Y4P2	R4Y5P2	R4Y4P3	R4Y5P3
	dollars					
Annual Change in Total Revenue	9,562.	22,045.	13,840.	31,155.	20,134.	45,989.
Net Revenues after Deduction of:						
Total Irrigation Cost (33,000)	-23,438.	-10,955.	-19,160.	-1,845.	-12,866.	12,989.
Capital Cost (22,500)	-12,938.	-455.	-8,660.	8,655.	-2,366.	23,489.
50% of Total Cost (16,500)	-6,938.	5,545.	-2,660.	14,655.	3,634.	29,489.
Operating Cost (10,500)	-938.	11,545.	3,340.	20,655.	9,634.	35,489.
25% of Total Cost (8,250)	1,312.	13,795.	5,590.	22,905.	11,884.	37,739.

	Rotation, Yield and Price Data Set Combination[1]					
	R5Y4P1	R5Y5P1	R5Y4P2	R5Y5P2	R5Y4P3	R5Y5P3
	dollars					
Annual Change in Total Revenue	15,392.	32,870.	20,730.	43,875.	30,310.	64,433.
Net Revenues after Deduction of:						
Total Irrigation Cost (33,000)	-17,608.	-130.	-12,270.	10,875.	-2,690.	31,433.
Capital Cost (22,500)	-7,108.	10,370.	-1,770.	21,375.	7,810.	41,933.
50% of Total Cost (16,500)	-1,108.	16,370.	4,230.	27,375.	13,810.	47,933.
Operating Cost (10,500)	4,892.	22,370.	10,230.	33,375.	19,810.	53,933.
25% of Total Cost (8,250)	7,142.	24,620.	12,480.	35,625.	22,060.	56,183.

	Rotation, Yield and Price Data Set Combination[1]					
	R6Y4P1	R6Y5P1	R6Y4P2	R6Y5P2	R6Y4P3	R6Y5P3
	dollars					
Annual Change in Total Revenue	12,854.	26,729.	17,775.	36,705.	24,720.	52,095.
Net Revenues after Deduction of:						
Total Irrigation Cost (33,000)	-20,146.	-6,271.	-15,225.	3,705.	-8,280.	19,095.
Capital Cost (22,500)	-9,646.	4,229.	-4,725.	14,205.	2,220.	29,595.
50% of Total Cost (16,500)	-3,646.	10,229.	1,275.	20,205.	8,220.	35,595.
Operating Cost (10,500)	2,354.	16,229.	7,275.	26,205.	14,220.	41,595.
25% of Total Cost (8,250)	4,604.	18,479.	9,525.	28,455.	16,470.	43,845.

Table 18. Changes in Total Revenue and Net Revenue for a 320 Acre Farm in a Regional Wastewater Irrigation Project with Alternative Assumptions on Rotation, Yield, Price, and Irrigation Cost Sharing (Continued)

	Rotation, Yield and Price Data Set Combination[1]					
	R7Y4P1	R7Y5P1	R7Y4P2	R7Y5P2	R7Y4P3	R7Y5P3
	dollars					
Annual Change in Total Revenue	18,629.	37,451.	24,600.	49,305.	34,800.	70,365.
Net Revenues after Deduction of:						
Total Irrigation Cost (33,000)	-14,371.	4,451.	-8,400.	16,305.	1,800.	37,365.
Capital Cost (22,500)	-3,871.	14,951.	2,100.	26,805.	12,300.	47,865.
50% of Total Cost (16,500)	2,129.	20,951.	8,100.	32,805.	18,300.	53,865.
Operating Cost (10,500)	8,129.	26,951.	14,100.	38,805.	24,300.	59,865.
25% of Total Cost (8,250)	10,379.	29,201.	16,350.	41,055.	26,550.	62,115.

	Rotation, Yield and Price Data Set Combination[1]					
	R8Y4P1	R8Y5P1	R8Y4P2	R8Y5P2	R8Y4P3	R8Y5P3
	dollars					
Annual Change in Total Revenue	10,771.	24,823.	15,600.	35,100.	22,680.	51,780.
Net Revenues after Deduction of:						
Total Irrigation Cost (33,000)	-22,229.	-8,177.	-17,400.	2,100.	-10,320.	18,780.
Capital Cost (22,500)	-11,729.	2,323.	-6,900.	12,600.	180.	29,280.
50% of Total Cost (16,500)	-5,729.	8,323.	-900.	18,600.	6,180.	35,280.
Operating Cost (10,500)	271.	14,323.	5,100.	24,600.	12,180.	41,280.
25% of Total Cost (8,250)	2,521.	16,573.	7,350.	26,850.	14,430.	43,530.

	Rotation, Yield and Price Data Set Combination[1]					
	R9Y4P1	R9Y5P1	R9Y4P2	R9Y5P2	R9Y4P3	R9Y5P3
	dollars					
Annual Change in Total Revenue	17,371.	37,078.	23,400.	49,500.	34,200.	72,660.
Net Revenues after Deduction of:						
Total Irrigation Cost (33,000)	-15,629.	4,078.	-9,600.	16,500.	1,200.	39,660.
Capital Cost (22,500)	-5,129.	14,578.	900.	27,000.	11,700.	50,160.
50% of Total Cost (16,500)	871.	20,578.	6,900.	33,000.	17,700.	56,160.
Operating Cost (10,500)	6,871.	26,578.	12,900.	39,000.	23,700.	62,160.
25% of Total Cost (8,250)	9,121.	28,828.	15,150.	41,250.	25,950.	64,410.

1 Data sets combine rotation information from Table 15, yield information from Table 7, and price information from Table 3.

Table 19. Changes in Total Revenue and Net Revenue for a 580 Acre Farm in a Regional Wastewater Irrigation Project with Alternative Assumptions on Rotation, Yield, Price, and Irrigation Cost Sharing

	Rotation, Yield and Price Data Set Combination[1]					
	R1Y4P1	R1Y5P1	R1Y4P2	R1Y5P2	R1Y4P3	R1Y5P3
	dollars					
Annual Change in Total Revenue	31,119.	62,731.	45,075.	90,392.	63,640.	128,350.
Net Revenues after Deduction of:						
Total Irrigation Cost (59,400)	-28,281.	3,331.	-14,325.	30,992.	4,240.	68,950.
Capital Cost (40,500)	-9,381.	22,231.	4,575.	49,892.	23,140.	87,850.
50% of Total Cost (29,700)	1,419.	33,031.	15,375.	60,692.	33,940.	98,650.
Operating Cost (18,900)	12,219.	43,831.	26,175.	71,492.	44,740.	109,450.
25% of Total Cost (14,850)	16,269.	47,881.	30,225.	75,542.	48,790.	113,500.
	Rotation, Yield and Price Data Set Combination[1]					
	R2Y4P1	R2Y5P1	R2Y4P2	R2Y5P2	R2Y4P2	R2Y5P3
	dollars					
Annual Change in Total Revenue	23,252.	48,264.	32,150.	66,280.	44,660.	93,960.
Net Revenues after Deduction of:						
Total Irrigation Cost (59,400)	-36,148.	-11,136.	-27,250.	6,880.	-14,740.	34,560.
Capital Cost (40,500)	-17,248.	7,764.	-8,350.	25,780.	4,160.	53,460.
50% of Total Cost (29,700)	-6,448.	18,564.	2,450.	36,580.	14,960.	64,260.
Operating Cost (18,900)	4,352.	29,364.	13,250.	47,380.	25,760.	75,060.
25% of Total Cost (14,850)	8,402.	33,414.	17,300.	51,430.	29,810.	79,110.
	Rotation, Yield and Price Data Set Combination[1]					
	R3Y4P1	R3Y5P1	R3Y4P2	R3Y5P2	R3Y4P3	R3Y5P3
	dollars					
Annual Change in Total Revenue	33,702.	67,667.	44,500.	89,080.	62,900.	127,020.
Net Revenues after Deduction of:						
Total Irrigation Cost (59,400)	-25,698.	8,267.	-14,900.	29,680.	3,500.	67,620.
Capital Cost (40,500)	-6,798.	27,167.	4,000.	48,580.	22,400.	86,520.
50% of Total Cost (29,700)	4,002.	37,967.	14,800.	59,380.	33,200.	97,320.
Operating Cost (18,900)	14,802.	48,767.	25,600.	70,180.	44,000.	108,120.
25% of Total Cost (14,850)	18,852.	52,817.	29,650.	74,230.	48,050.	112,170.
	Rotation, Yield and Price Data Set Combination[1]					
	R4Y4P1	R4Y5P1	R4Y4P2	R4Y5P2	R4Y5P3	R4Y4P3
	dollars					
Annual Change in Total Revenue	28,477.	57,966.	38,325.	77,680.	53,780.	110,490.
Net Revenues after Deduction of:						
Total Irrigation Cost (59,400)	-30,923.	-1,434.	-21,075.	18,280.	-5,620.	51,090.
Capital Cost (40,500)	-12,023.	17,466.	-2,175.	37,180.	13,280.	69,990.
50% of Total Cost (29,700)	-1,223.	28,266.	8,625.	47,980.	24,080.	80,790.
Operating Cost (18,900)	9,577.	39,066.	19,425.	58,780.	34,880.	91,590.
25% of Total Cost (14,850)	13,627.	43,116.	23,475.	62,830.	38,930.	95,640.

Table 19. Changes in Total Revenue and Net Revenue for a 580 Acre Farm in a Regional Wastewater Irrigation Project with Alternative Assumptions on Rotation, Yield, Price and Irrigation Cost Sharing (Continued)

	Rotation, Yield and Price Data Set Combination[1]					
	R5Y4P1	R5Y5P1	R5Y4P2	R5Y5P2	R5Y4P3	R5Y5P3
	dollars					
Annual Change in Total Revenue	19,357.	44,622.	28,025.	63,075.	40,760.	93,085.
Net Revenues after Deduction of:						
Total Irrigation Cost (59,400)	-40,043.	-14,778.	-31,375.	3,675.	-18,640.	33,685.
Capital Cost (40,500)	-21,143.	4,122.	-12,475.	22,575.	260.	52,585.
50% of Total Cost (29,700)	-10,343.	14,922.	-1,675.	33,375.	11,060.	63,385.
Operating Cost (18,900)	457.	25,722.	9,125.	44,175.	21,860.	74,185.
25% of Total Cost (14,850)	4,507.	29,772.	13,175.	48,225.	25,910.	78,235.
	Rotation, Yield and Price Data Set Combination[1]					
	R6Y4P1	R6Y5P1	R6Y4P2	R6Y5P2	R6Y4P3	R6Y5P3
	dollars					
Annual Change in Total Revenue	31,182.	66,578.	42,000.	88,875.	61,400.	130,495.
Net Revenues after Deduction of:						
Total Irrigation Cost (59,400)	-28,218.	7,178.	-17,400.	29,475.	2,000.	71,095.
Capital Cost (40,500)	-9,318.	26,078.	1,500.	48,375.	20,900.	89,995.
50% of Total Cost (29,700)	1,482.	36,878.	12,300.	59,175.	31,700.	100,795.
Operating Cost (18,900)	12,282.	47,678.	23,100.	69,975.	42,500.	111,595.
25% of Total Cost (14,850)	16,332.	51,728.	27,150.	74,025.	46,550.	115,645.
	Rotation, Yield and Price Data Set Combination[1]					
	R7Y4P1	R7Y5P1	R7Y4P2	R7Y5P2	R7Y4P3	R7Y5P3
	dollars					
Annual Change in Total Revenue	25,132.	55,345.	34,850.	75,675.	50,840.	111,355.
Net Revenues after Deduction of:						
Total Irrigation Cost (59,400)	-34,268.	-4,055.	-24,550.	16,275.	-8,560.	51,955.
Capital Cost (40,500)	-15,368.	14,845.	-5,650.	35,175.	10,340.	70,855.
50% of Total Cost (29,700)	-4,568.	25,645.	5,150.	45,975.	21,140.	81,655.
Operating Cost (18,900)	6,232.	36,445.	15,950.	56,775.	31,940.	92,455.
25% of Total Cost (14,850)	10,282.	40,495.	20,000.	60,825.	35,990.	96,505.

1 Data sets combine rotation information from Table 15, yield information from Table 7, and price information from Table 8.

revenue. Any agreement requiring the firm to pay more than $14,080 of the irrigation costs would decrease its net revenues. Alternatively, if increases reflected in yield set Y_5 are realized, the same cropping pattern and price combination provide a net revenue increase under all the specified cost sharing arrangements except for paying the full cost of the system. Similar conditions exist for the 580-acre farm. The greatest increases in total revenue for the 320 acre farm is $72,660, or $242 per acre of cropland. This reflects the combination of the most optimistic yield and price assumptions and a corn-dry beans-wheat rotation (R_9 Y_5 P_3). The largest increase in total revenue for the 580 acre farm is $130,495, or $241 per acre of cropland (R_6 Y_5 P_3). Under the optimistic assumptions, there is a net benefit of approximately $132 per acre of cropland for both farms after paying the total annual irrigation costs.

Regional Analysis

The regional impact of a large land treatment project is estimated using the concept of a wastewater cooperative. A collective organization is formed to consolidate and coordinate negotiations with the wastewater authority. Rather than the individual farmer and the wastewater authority entering into individual contractual agreements, bargaining over sharing of irrigation costs is assumed. In the Braunschweig, Germany cooperative, for example, twenty-five percent of the costs are paid by the farmers and seventy-five percent by the city [Tietjen, 1973].

The collective approach is applied to the proposed land treatment component of the Southeast Michigan Wastewater Management Study. A total of about 102,000 acres is involved, 72,500 of which remain in private ownership. The impacts of alternative cost sharing arrangements are estimated by aggregating the costs and returns of the total system. The expected benefits are allocated according to several criteria. The cooperative and the authority can each pay one-half of the total costs. Alternatively, the cooperative can pay the annual operating costs but not the capital costs. The cooperative may be willing to enter into a long term financing agreement for capital costs. Another possible agreement could provide the cooperative a specified percentage increase in net revenues above the level they would have been without irrigation.

Construction and operation and maintenance costs for a system to irrigate the projected acreage of approximately 72,000 acres were estimated based on costs for modules covering 4 square miles. Approximately 28 modules are required, each consisting of 16 center pivot system covering 160 acres. The costs of the entire system are estimated by aggregating the data for single center pivot presented previously in Table 10. The annual total costs are $9.3 million, of which $5.5 million is capital cost and $3.8 million are operation and maintenance costs.

Table 20. Estimates of Regional Production from a Land Treatment Proposal under Alternative Rotation and Yield Assumptions, Southeast Michigan

Crop	Acres	Unit	Production				Index of Production			
			Yield Set[1]				Yield Set[1]			
			Y_3	Y_4	Y_5	Y_6	Y_3	Y_4	Y_5	Y_6
			- - - - - 1,000 units - - - - - -							
Corn	25,400.	bu	2,794.0	3,810.0	4,775.2	1,905.0	100.00	136.36	170.91	68.18
Soybeans	25,400.	bu	812.8	889.0	1,117.6	431.8	100.00	109.37	137.49	53.12
Wheat	7,200.	bu	360.0	432.0	540.0	216.0	100.00	120.00	149.99	60.00
Alfalfa	14,500.	ton	43.5	72.5	89.9	36.3	100.00	166.67	206.65	83.45
Total	72,500.									
Corn	29,000.	bu	3,190.0	4,350.0	5,452.0	2,175.0	100.00	136.36	170.91	68.18
Soybeans	29,000.	bu	928.0	1,015.0	1,276.0	493.0	100.00	109.37	137.49	53.12
Wheat	14,500.	bu	725.0	870.0	1,087.5	435.0	100.00	120.00	149.99	60.00
Total	72,500.									
Corn	29,000.	bu	3,190.0	4,350.0	5,452.0	2,175.0	100.00	136.36	170.91	68.18
Soybeans	14,500.	bu	464.0	507.5	638.0	246.5	100.00	109.37	137.49	53.12
Drybeans	14,500.	cwt	232.0	290.0	362.5	145.0	100.00	125.00	156.25	62.50
Wheat	14,500.	bu	725.0	870.0	1,087.5	435.0	100.00	120.00	149.99	60.00
Total	72,500.									

1 Yield sets are specified in table 7.

Crop production changes for the total irrigation system are estimated using alternative yield sets and three rotations. The yield sets and rotations are the same as those used in the firm analysis. Alternative levels of total production from the entire irrigation project are presented in Table 20. The absolute and relative production changes vary with the crop and assumption sets used. Corn production varies from a decrease of 32 percent to an increase of 71 percent. The greatest relative increase is in alfalfa, 106 percent.

Regional production requirements for major commodities from Southeastern Michigan have been estimated in conjunction with the Great Lakes Basin Framework Study and the Southeastern Michigan Water Resources Study. These are normative estimates of regional shares of national requirements for food and fiber, and serve as benchmarks for comparison with production with irrigation (Table 21).

Table 21. Regional Production Requirements for Southeastern Michigan Wastewater Management Study Area, 1980 and 2000.

Crop	Unit	Production 1980	Production 2000
		----1000 units------	
Corn	bu.	24,537	26,608
Soybeans	bu.	11,833	12,648
Dry Beans	cwt.	910	1,202
Wheat	bu.	10,286	11,702
Alfalfa Hay	ton	495	427

Source: [Great Lakes Commission, 1972]

Table 22. Total Revenue and Change in Total Revenue with Irrigation, Alternative Crop Rotations, Yields, and Prices, Regional Land Treatment Project[1]

Crop Rotation		Acres	Revenue with Alternative Yield and Price Sets								
			Y3P1	Y4P1	Y5P1	Y3P2	Y4P2	Y5P2	Y3P3	Y4P3	Y5P3
			dollars								
R1	Corn	25,400.	4,582.2	6,248.4	7,831.3	6,985.0	9,525.0	11,938.0	9,779.0	13,335.0	16,713.2
	Soybeans	25,400.	3,348.7	3,662.7	4,604.5	4,064.0	4,445.0	5,588.0	6,502.4	7,112.0	8,940.8
	Wheat	7,200.	849.6	1,019.5	1,274.4	1,080.0	1,296.0	1,620.0	1,800.0	2,160.0	2,700.0
	Alfalfa	14,500.	1,435.5	2,392.5	2,966.7	1,740.0	2,900.0	3,596.0	2,175.0	3,625.0	4,495.0
	Total	72,500.	10,216.0	13,323.1	16,676.9	13,869.0	18,166.0	22,742.0	20,256.4	26,232.0	32,849.0
	Change			3,107.1	6,460.9		4,297.0	8,873.0		5,975.6	12,592.6
R2	Corn	29,000.	5,231.6	7,134.0	8,941.3	7,975.0	10,875.0	13,630.0	11,165.0	15,225.0	19,082.0
	Soybeans	29,000.	3,823.4	4,181.8	5,257.1	4,640.0	5,075.0	6,380.0	7,424.0	8,120.0	10,208.0
	Wheat	14,500.	1,711.0	2,053.2	2,566.5	2,175.0	2,610.0	3,262.5	3,625.0	4,350.0	5,437.5
	Total	72,500.	10,766.0	13,369.0	16,764.9	14,790.0	18,560.0	23,272.5	22,214.0	27,695.0	34,727.5
	Change			2,603.0	5,998.9		3,770.0	8,482.5		5,481.0	12,513.5
R3	Corn	29,000.	5,231.6	7,134.0	8,941.3	7,975.0	10,875.0	13,630.0	11,165.0	15,225.0	19,082.0
	Soybeans	14,500.	1,911.7	2,090.9	2,628.6	2,320.0	2,537.5	3,190.0	3,712.0	4,060.0	5,104.0
	Dry Beans	14,500.	3,906.9	4,883.6	6,104.5	4,640.0	5,800.0	7,250.0	6,960.0	8,700.0	10,875.0
	Wheat	14,500.	1,711.0	2,053.2	2,566.5	2,175.0	2,610.0	3,262.5	3,625.0	4,350.0	5,437.5
	Total	72,500.	12,761.2	16,161.7	20,240.8	17,110.0	21,822.5	27,332.5	25,462.0	32,335.0	40,498.5
	Change			3,400.5	7,479.7		4,712.5	10,222.5		6,873.0	15,036.5

[1] Yield and price sets are specified in Tables 7 and 8.

The contributions of irrigation to the regional production requirements is relatively small. If the most optimistic yield, Y_5, is realized on a rotation with 40 percent corn, the additional production of 2.3 million bushels represents 9 percent of the 1980 requirements. The contribution to regional corn production from the project area will increase from 13 percent without irrigation to 22 percent with irrigation.

Estimates of total revenues from alternative sets of yields, prices, and rotations are presented in Table 22. Total revenue estimates vary between \$10.2 and \$25.4 million without irrigation, and between \$13.3 and \$40.5 million with irrigation, depending upon the data sets used.

The specification of cost sharing arrangements are important to the formation of a wastewater cooperative. The data in Table 23 shows the net benefits remaining after adjustments for irrigation cost sharing. If a conservative yield and price set is assumed for all rotations, (Y_4 P_1), the cooperative realizes net benefits only when the wastewater authority pays 75 percent of the total annual costs. If greater yield increases result (Y_5 P_1), the cooperative realizes positive benefits with all cost sharing arrangements except when it pays the total cost of the irrigation system.

Table 23. Changes in Total Revenue and Net Revenue for a Regional Wastewater Irrigation Project with Alternative Assumptions on Rotation, Yield, Price, and Irrigation Cost Sharing

	Alternative Rotation, Yield, and Price Sets[1]					
	R1Y4P1	R1Y5P1	R1Y4P2	R1Y5P2	R1Y4P3	R1Y5P3
	1,000 dollars					
Annual Change in Total Revenue	3,107.1	6,460.9	4,297.0	8,873.0	5,975.6	12,592.6
Net Revenues after Deduction of:						
Total Irrigation Cost (9,304)	-6,196.9	-2,843.1	-5,007.0	-431.0	-3,328.4	3,288.6
Capital Cost (5,511)	-2,403.9	949.9	-1,214.0	3,362.0	464.6	7,081.6
50% of Total Cost (4,652)	-1,544.9	1,808.9	-355.0	4,221.0	1,323.6	7,940.6
Operating Cost (3,783)	-675.9	2,677.9	514.0	5,090.0	2,192.6	8,809.6
25% of Total Cost (2,326)	781.1	4,134.9	1,971.0	6,547.0	3,649.6	10,266.6
	Alternative Rotation, Yield, and Price Sets[1]					
	R2Y4P1	R2Y5P1	R2Y4P2	R2Y5P2	R2Y4P3	R2Y5P3
	1,000 dollars					
Annual Change in Total Revenue	2,603.0	5,998.6	3,770.0	8,482.5	5,481.0	12,513.5
Net Revenues after Deduction of						
Total Irrigation Cost (9,304)	-6,701.0	-3,305.4	-5,534.0	-821.5	-3,823.0	3,209.5
Capital Cost (5,511)	-2,908.0	487.6	-1,741.0	2,971.5	-30.0	7,002.5
50% of Total Cost (4,652)	-2,049.0	1,346.6	-882.0	3,830.5	829.0	7,861.5
Operating Cost (3,783)	-1,180.0	2,215.6	-13.0	4,699.5	1,698.0	8,730.5
25% of Total Cost (2,326)	277.0	3,672.6	1,444.0	6,156.5	3,155.0	10,187.5

Table 23. Changes in Total Revenue and Net Revenue for a Regional Wastewater Irrigation Project with Alternative Assumptions on Rotation, Yield, Price, and Irrigation Cost Sharing (Continued)

	Alternative Rotation, Yield, and Price Sets[1]					
	R3Y4P1	R3Y5P1	R3Y4P2	R3Y5P2	R3Y4P3	R3Y5P3
	1,000 dollars					
Annual Change in Total Revenue	3,400.5	7,479.7	4,712.5	10,222.5	6,873.0	15,036.5
Net Revenues after Deduction of:						
Total Irrigation Cost (9,304)	-5,903.5	-1,824.3	-4,591.5	918.5	-2,431.0	5,732.5
Capital Cost (5,511)	-2,110.5	1,968.7	-798.5	4,711.5	1,362.0	9,525.5
50% of Total Cost (4,652)	-1,251.5	2,827.7	60.5	5,570.5	2,221.0	10,384.5
Operating Cost (3,783)	-382.5	3,696.7	929.5	6,439.5	3,090.0	11,253.5
25% of Total Cost (2,326)	1,074.5	5,153.7	2,386.5	7,896.5	4,547.0	12,710.5

1 Data sets combine rotation information from Table 20, yield information from Table 7, and price information from Table 8.

Table 24. Incremental Yields to Breakeven on Irrigation Costs Under Alternative Prices, Representative Field Crops

Crop	Price	Irrigation Cost $/Acre 25	50	75	100
		------------Breakeven Units/Acre[1]------------			
Corn	P_1 (1.64)	15.2	30.5	45.7	61.0
	P_2 (2.50)	10.0	20.0	30.0	40.0
	P_3 (3.50)	7.1	14.3	21.4	28.6
Soybeans	P_1 (4.12)	6.1	12.1	18.2	24.3
	P_2 (5.00)	5.0	10.0	15.0	20.0
	P_3 (8.00)	3.1	6.3	9.4	12.5
Dry Beans	P_1 (16.84)	1.5	3.0	4.5	6.0
	P_2 (20.00)	1.3	2.5	3.8	5.0
	P_3 (30.00)	0.8	1.7	2.5	3.3
Wheat	P_1 (2.36)	10.6	21.2	31.8	42.4
	P_2 (3.00)	8.3	16.7	25.0	33.3
	P_3 (5.00)	5.0	10.0	15.0	20.0
Alfalfa	P_1 (33.00)	0.8	1.7	2.5	3.3
	P_2 (40.00)	0.6	1.3	1.9	2.5
	P_3 (50.00)	0.5	1.0	1.5	2.0

[1]Units are bushels for corn, soybeans, and wheat, cwt. for drybeans, and tons for alfalfa.

Highlights of Crop, Firm and Regional Analysis

Crop Analysis

The minimum change in yield response to offset irrigation costs is used to estimate the profitability of individual crops with effluent irrigation. These minimum yield changes are compared to yield responses projected with irrigation. A complete array of incremental breakeven yields is presented in Table 24 for alternative irrigation costs. More specific focus is provided in Table 25 where incremental breakeven yields based on specific point estimates of prices and irrigation costs are compared with the yield sets used in this study.

Table 25. Incremental Breakeven Yields Compared to Projected Yield Increases with Irrigation

Crop	Unit	Incremental Breakeven Yield[1]	Yield Increase with Irrigation[2]	
			Y_4	Y_5
		----------Units/Acre----------		
Corn	bu.	20.0	+40	+78
Soybeans	bu.	10.0	+3	+12
Dry Beans	cwt.	2.5	+4	+9
Wheat	bu.	16.7	+10	+25
Alfalfa	ton	1.3	+2.0	+3.2

[1]Based upon price set P_2, Table 8, and irrigation costs of $50.00 per acre.

[2]Yield estimates are in Table 7.

Net revenues increase and irrigation costs are offset under more situations with corn, dry beans and alfalfa than with woybeans or wheat. The breakeven level is exceeded for corn, dry beans and alfalfa under both yield assumptions. However, breakeven yields for soybeans and wheat are exceeded only under the most optimistic yield set, Y_5. With the highest irrigation costs, $100 per acre, the breakeven yield level for corn will be met or exceeded. However, yield increases below the breakeven level will be realized for soybeans and wheat.

Breakeven prices on those required to pay alternative irrigation costs from increased production are presented in Table 26. When irrigation costs are $50 per acre, the breakeven prices for all crops, except soybeans in one case, are within the range of prices specified earlier in Table 8. However, if irrigation costs are $100 per acre, the breakeven prices for soybeans and wheat are greater than projected. The breakeven prices for corn, dry beans, and alfalfa, even at this high irrigation cost level, are realistic price ranges.

Firm Analysis

Highlights on crop rotations and cost sharing arrangements are presented only for the 320 acre farm. Similar highlights can be drawn from the data on the 580 acre farm.

Crop Rotations

The data for the 320 acre farm in Table 16 is analyzed to determine the effect of alternative rotations on the total revenue from crop sales and to test the price and

Table 26. Breakeven Prices to Cover Irrigation Costs for Representative Field Crops and Yields

Crop	Yield Increase Per Acre[1]	Irrigation Cost $/Acre			
		25	50	75	100
		--Breakeven Price Per Unit[1]------			
Corn	Y_4 (40)	0.62	1.25	1.88	2.50
	Y_5 (78)	0.32	0.64	0.96	1.28
Soybeans	Y_4 (3)	8.33	16.66	25.00	33.33
	Y_5 (12)	2.08	4.16	6.25	8.33
Dry Beans	Y_4 (4)	6.25	12.50	18.75	25.00
	Y_5 (9)	2.77	5.55	8.33	11.11
Wheat	Y_4 (10)	2.50	5.00	7.50	10.00
	Y_5 (25)	1.00	2.00	3.00	4.00
Alfalfa	Y_4 (2.0)	12.50	25.00	37.50	50.00
	Y_5 (3.2)	7.81	15.62	23.43	31.25

[1]Units are bushels for corn, soybeans and wheat, cwt. for dry beans, and tons for alfalfa.

yield sensitivity of these rotations. Indices of total revenues for all rotation, yield, and price combinations are computed using R_1 as a base. Indices in Table 27 are for price set P_2 and are representative of the indices for price sets P_1 and P_3. Positive increases in revenues are realized for rotations R_3, R_5, R_7, and R_9 with all yield and price sets, with a minor exception in R_3 Y_3 P_2. Total revenues decreased in all other cases. R_3 and R_7 are the same rotation applied to different acreage bases, 35 percent corn, 35 percent dry beans, 10 percent wheat, and 20 percent alfalfa. Rotations R_5 and R_9 are also the same rotations on

Table 27. Indices of Total Revenues for the 320 Acre Farm Model Under Alternative Rotations, Yields, and Prices[1]

Rotation	Yield and Price Sets		
	Y_3P_2	Y_4P_2	Y_5P2
	------Indices of Total Revenues-------		
R_1	100.00	100.00	100.00
R_2	75.84	77.00	76.88
R_3	99.90	101.11	100.83
R_4	80.93	78.60	78.62
R_5	108.18	106.08	105.90
R_6	87.02	86.70	86.50
R_7	112.50	113.84	113.52
R_8	92.82	88.50	88.53
R_9	121.94	119.63	119.42

[1]Rotations are identified in Table 15, yields in Table 7, and prices in Table 8. Revenue data comes from Table 16.

different bases; 40 percent corn, 40 percent dry beans, and 20 percent wheat.

Total revenue decreased for all rotations with soybeans, except for the base, R_1, for all price and yield combinations. This is true with or without effluent irrigation. The most profitable rotation without irrigation, R_9, is also the most profitable with irrigation. The base rotation of 69 percent corn, 19 percent soybeans, 5 percent dry beans, and 7 percent wheat is relatively profitable with irrigation.

Cost Sharing

The conditions specifying profitable farming operations with land treatment are important to both the farmer and the wastewater authority, and influence the choice of the acquisition and management options. If the farmer and authority enter into a contractual arrangement, guidelines on the terms of the agreement are helpful. If the authority uses the fee simple acquisition option, it still must choose a management option for the farming operation. The indicator used to specify profitable conditions is total revenue and net revenues remaining under alternative arrangements for paying irrigation costs.

The data in Table 18 related to the 320 acre farm are analyzed to identify the sensitivity of net revenues to alternative cost sharing arrangements, rotations, yields, and prices. The summary of this analysis is in Table 28, where the total revenue increases from irrigation are arrayed against irrigation costs to identify where costs exceed returns. The irrigation costs are arrayed from highest (total annual cost) to the lowest (25 percent of total annual cost). In between these extremes are annual capital costs, 50 percent of total annual cost, and annual operating costs. The largest cost exceeded by revenues from alternative data combinations is identified. Thus with yield set Y_4 and price level P_2, total irrigation costs are not offset by increased revenues. However, positive net revenues are realized with rotations R_7 and R_9 after capital costs are paid. Revenues from rotations R_3, R_5, and R_6 will offset 50 percent of total costs. The remaining rotations will cover lesser portions of the irrigation

Table 28. Irrigation Costs Offset by Revenue Increases, 320 Acre Farm

Rotation	Yield and Price Sets[1]					
	Y_4P_1	Y_5P_1	Y_4P_2	Y_5P_2	Y_4P_3	Y_5P_3
	Irrigation Costs Offset[2]					
R_1	4	2	4	1	4	1
R_2	4	2	4	4	3	1
R_3	3	1	3	1	2	1
R_4	5	3	4	4	3	1
R_5	4	2	3	1	2	1
R_6	4	2	3	1	2	1
R_7	3	1	2	1	1	1
R_8	4	2	4	1	2	1
R_9	3	1	2	1	1	1

[1]Yields and prices are detailed in Tables 7 and 8, and rotations in Table 15. Irrigation cost information is based on Table 18.

[2]Numbers indicate net revenues remaining after the following annual irrigation costs are paid.

1. Total costs
2. Capital costs
3. 50 percent of total costs
4. Operating costs
5. 25 percent of total costs

costs and still provide net revenues. Larger net revenues will remain after offsetting the irrigation costs if higher yields or prices are realized. For example, with price level P_2, positive net benefits remain with all rotations except R_2 and R_4 after paying the total irrigation costs.

Regional Analysis

Information highlights from the regional analysis relate projected regional production to projected requirements. Conclusions relative to crop rotations and cost sharing are generally similar to those for the 320 acre farm.

The aggregate contribution of production from the land treatment project to regional requirements is summarized in Table 29. Production estimates under three rotation assumptions are presented as a percentage of individual crop requirements. Dry beans from the project contribute the largest share of regional requirements, 25-40 percent. The contribution of soybeans is the least, 4-9 percent.

Table 29. Aggregated Production from a Land Treatment Project as a Share of Regional Production Requirements Under Alternative Yield and Rotation Assumptions, Southeastern Michigan

Crop	Regional[1] Requirements (1000 units)	Yield Per Acre[2]	Rotation[3]		
			R_1	R_2	R_3
			---% of Requirements---		
		110	11.4	13.0	13.0
Corn	24,537 bu.	150	15.5	17.7	17.7
		188	19.5	22.2	22.2
		32	6.9	7.8	3.9
Soybeans	11.833 bu.	35	7.5	8.6	4.3
		44	9.4	10.8	5.4
		16	--	--	25.5
Dry Beans	910 cwt.	20	--	--	31.9
		25	--	--	39.8
		50	3.5	7.0	7.0
Wheat	10,286 bu.	60	4.2	8.5	8.5
		65	5.2	10.6	10.6
		3.0	8.9	--	--
Alfalfa Hay	495 tons	5.0	14.6	--	--
		6.2	18.2	--	--

[1]From Table 21 [2]From Table 7

[3]R_1 - 35% corn, 35% soybeans, 10% wheat, 20% alfalfa
R_2 - 40% corn, 40% soybeans, 20% wheat
R_3 - 40% corn, 20% soybeans, 20% wheat

CHAPTER VI

SUMMARY AND IMPLICATIONS

Summary

Objectives

The purpose of this study was to evaluate the economic and institutional aspects of land treatment as a wastewater management alternative for Southeastern Michigan, and to measure their impacts on the agricultural economy and on wastewater authorities. Specifically the objectives of the study were:

1. To describe the land treatment concept, its applications, and its potential for use in Southeastern Michigan.

2. To identify and evaluate alternatives for acquiring land use rights and for managing the farming operations of land treatment systems.

   a. Specify the options for acquisition of land rights and farm management and relate these to the goals of farmers and wastewater authorities.

   b. Use budgeting and sensitivity analysis to identify alternatives for the distribution of costs and benefits of a land treatment system between a wastewater authority and farmers.

3. To identify and estimate some of the parameters involved in the investigation of a land treatment system and the uncertainties surrounding them.

4. To specify implications of land treatment at the farm, firm and regional level.

   a. Identify and evaluate opportunities for increasing farm revenues through land treatment operations under alternative cost sharing arrangements.

   b. Identify some of the macro implications of large scale land treatment operations in Southeastern Michigan.

Procedure

Descriptive information on the land treatment concept and its applications was presented. An institutional analysis identified options for the acquisition of property rights and the management of farming operations at the treatment sites and evaluated the impacts of these options on the goals of farmers and wastewater authorities. Empirical analysis was used to investigate the impacts of land treatment on specific crops, farm revenues, and regional production and revenues. Sensitivity analysis was used to show the impact of how alternative assumptions of yield response, price, crop rotations, and irrigation costs can effect the estimates of total and net revenues of crop production from effluent irrigation.

Conclusions

The findings of the study are presented as results of descriptive analysis, institutional analysis, and empirical analysis.

Descriptive Analysis

Land treatment of municipal and industrial wastewater, though not a new concept, has received increased attention in recent years as an alternative wastewater management technique in the United States. It has been used under a number of climatic conditions and for a variety of community sizes, with varying degrees of success. It is not a universal solution to all wastewater management problems, but it is an alternative communities, particularly rural communities, should investigate.

Land treatment is the application of sewage effluents and/or sludges to the land for purposes of purification and nutrient removal. A land treatment system can be designed and managed to maximize wastewater renovation, to maximize crop production from the treatment area, or to combine objectives of both wastewater renovation and crop production. Alternative approaches to land treatment include rapid infiltration, slow infiltration (irrigation) and overland flow. The application methods generally used for slow infiltration are sprinkler irrigation, flooding, or ridge and furrow.

Some important physical parameters that influence land treatment are soil loading factors, the volume and rate of application, the potential for systems abandonment, and crop yield response.

Institutional Analysis

The public policy goal of wastewater treatment can be met using land treatment systems. Property rights or other access to land must be obtained from the present landowner by a wastewater authority. The methods used to obtain property rights or access reflect varying capacities of the communities or wastewater authorities to impose the monetary and non-monetary costs of wastewater treatment on the landowners.

The options available to acquire the property rights or access impact differently on the goals of the farmers and the goals of the wastewater authorities. Goals postulated for the farmers were income generation, wealth accumulation, firm growth, freedom of decision making, the sense of community. The goals for the wastewater authority were to provide the required level of wastewater treatment in an economic manner.

The options for acquisition of rights to land include fee simple acquisition, real property interests other than fee, and no real property interests--contractual agreements.

Fee Simple Acquisition

Through fee acquisition, a wastewater authority obtains the total "bundle of rights" ascribed to property, with the exception of those rights reserved by the State. An authority can obtain fee simple title through a normal market exchange between buyer and seller. If legal authority exists, an authority may exercise the right of eminent domain and obtain the rights from a reluctant seller in exchange for just compensation.

Fee simple acquisition is the most costly option available to an authority, and is disruptive to individual farmers and to an entire region if large amounts of land are involved. It was found to be most appropriate for acquiring land for integral operations such as pumping stations and storage lagoons, and where engineering and environmental considerations warrant complete control of the land.

Three options for the management of the farming operation with fee simple acquisition are purchase and manage, purchase and leaseback, and purchase and resale on condition. With purchase and manage, the managerial and operational decisions remain with the wastewater authority. With purchase and leaseback, some managerial and all operational responsibilities are transferred to the lessee. The purchase and resale on condition option enables the authority to initially acquire the required land, but then resell with conditions attached compatible with land treatment requirements.

Real Property Interest Other Than Fee

Easements are an example of ownership of only a part of the total "bundle of rights" vested in land, or real property interest other than fee. Easements have been used for a number of public purposes and are well established as a method to maintain agricultural land in the path of urban development. They may be acquired in a number of ways, through donation, purchases, or condemnation.

Through the use of easements, a wastewater authority can acquire limited rights to land, such as passage for irrigation pipes or other equipment. Easements are also a method to compensate farmers for participation in a land treatment, particularly if crop revenues decreased due to land treatment. The easement conditions can impose some constraints on a farmer's managerial decisions, but primary farm management responsibility remains with the landowners.

No Real Property--Contractual Agreement

A wastewater authority can obtain access to land without the acquisition of any property rights through contracts or wastewater cooperatives. Contracts between two or more parties specify an agreement of actions to be taken or refrained from in exchange for a consideration. Contracts between farmers and wastewater authorities have been used to specify agreements to apply effluent on private farms. Contracts to sell effluent to farmers have generally been unsuccessful.

A cooperative attitude between the contract parties and a long term contract are essential. Terms of the agreements must be clear, and review and termination clauses should be included.

A wastewater cooperative is a collective management venture that has been used in land treatment applications. It is an alternative to two party contractual agreements between an individual farmer and a wastewater authority. Though the cooperative concept is familiar in American agriculture for obtaining inputs and marketing crops, it generally has not been applied to land use activities.

Empirical Analysis

Alternative data sets were specified for crop yields, product prices, crop rotations, and irrigation costs. Breakeven and sensitivity analysis were used to estimate the impacts of these data sets on individual crops, on the farm firm, and on the region.

Crop Analysis

The profitability of individual crops with effluent irrigation was estimated. Crop yield increases required to offset irrigation system expenses were estimated using a number of price and cost assumptions. The crops evaluated were corn for grain, soybeans, dry beans, wheat and alfalfa. Yields projected with irrigation were valued and compared with alternative irrigation costs. For the assumption sets specified, net revenues increase and irrigation costs were offset more frequently with corn, dry beans, and alfalfa than with soybeans or wheat. Corn provided the largest increase in net revenue per acre in more situations than any other crop. Soybeans will contribute to net farm revenues using only the most optimistic yield assumptions. In most cases, the increase in soybean yields will not offset irrigation costs.

Firm Analysis

Data were analyzed for two representative farms, 320 acres and 580 acres. Generally the conclusions were the same for both. Therefore results are presented only for the 320-acre farm.

The total revenues of the farm firm with effluent irrigation were reflective of changes in the cropping pattern, intensity of land use, yields, and prices. Net revenues from irrigation were influenced by fertilizer cost savings due to nutrients in the effluent and by the sharing agreements for the construction and operation costs of the irrigation system. Total revenues from crop sales were estimated for representative farms to estimate the impact of irrigation with alternative data sets. Net farm revenues were then estimated under alternative agreements between the farmer and the wastewater authority for irrigation cost sharing.

Nine rotations were evaluated for the 320 acre representative farm using three price and two yield sets. Total revenues increased in all situations with effluent irrigation. However, for any assumed yield and price set, the largest increases in total revenues were for the rotations with high proportions of corn and dry beans. Total revenues increased considerably less for those rotations containing soybeans, indicative of the small yield response of soybeans to irrigation.

The total annual capital and operating costs for the irrigation system on the 320 acre farm were offset by increased revenues using only the most optimistic assumptions of yield increases and prices. However, with conservative yield and price sets Y_4 P_2 the most profitable rotations provided net revenue increases after the annual capital costs were paid. All rotations using these data had net revenues remaining after offsetting at least twenty-five percent of the annual total costs.

Regional Analysis

Total production and revenue changes were estimated for the land treatment component of the Southeastern Michigan Wastewater Management Study. The production from 72,500 acres of land was estimated using the same data sets as for the firm analysis. The impact on regional production requirements was relatively small, with the greatest impact occurring in corn production.

The effect of alternative cost sharing agreements is similar to that experienced at the firm level. If a conservative yield and price set are assumed, there are net revenues only if 75 percent of the total annual costs are paid by the wastewater authority. When higher yields or prices are achieved, net revenues are realized under all cost sharing arrangements except for paying the total cost of the irrigation system.

Implications

The economic and institutional impacts of a land treatment system have implications for farmers, wastewater authorities, and the region.

Farmers

1. Land treatment offers an opportunity to increase farm revenues under a number of circumstances. The increase is greatest when all or a major portion of the irrigation system costs are paid by the wastewater authority. The economic analysis of land treatment must consider the interaction of many factors. These include yield response, product prices, production costs, and cost sharing agreements for the construction and operation and maintenance of irrigation systems.

2. The impact of land treatment on farmer's goals is the greatest when fee simple title is acquired by the

wastewater authority. Easement acquisition and contractual arrangements have less impact as the farmer continues his operations influenced only by the terms of the easement or contract.

3. When fee simple title is sold, the impact on the farmer is influenced by the management option selected by the authority. If a purchase and leaseback arrangement enables the farmer to remain on the land under a tenancy arrangement, the impact would be far less severe than if the farming operations were turned over to the third parties and existing farmers were relocated. When a treatment site is obtained in fee, the former owner could be retained as a tenant or wastewater authority employee. The lease arrangement would afford a former owner the greatest stake in the operation. A share of the crops would belong to him, enabling him to share the risks of failure as well as the rewards of success. A variation is that of owner-sharecropper. This more nearly approximates a situation where the farmer is an employee of the authority, the main difference is that the share cropper may provide his own farm machinery and receive a share of the crop, rather than a flat salary. Under the employee or "hired-hand" arrangement, the farmer would bear no risk of failure relative to the land-treatment operation, nor would he share in any of the crop revenues or benefits. However, he would be guaranteed a steady income, and if he supplied the farm machinery, an additional rental fee.

4. Contractual arrangements between the farmer and the wastewater authority should be reviewed on a regular basis. While an initial agreement would indicate agreement over the distribution of benefits and costs, changes in the underlying factors would require a regular review of contractual terms.

Wastewater Authority

1. Fee simple acquisition affords the wastewater authority the greatest control over a land treatment system. But, this control comes at a large land acquisition cost to the wastewater authority. This may be a reasonable cost for treating small wastewater volumes, as in a small municipality. But treatment of a large volume of wastewater requires large land areas. It has been estimated that 759,900 acres of land would have to be acquired in fee simple to treat projected wastewater volume from Southeastern Michigan if land treatment was used for the total wastewater volume under total public ownership. Assuming an average farm size of 320 acres, a minimum of 2,375 farms would be purchased, implying an adjustment problem for a large number of farm families. A representative plan incorporating land treatment with other wastewater treatment methods was estimated to require 52,219 acres of publically owned land. Only 30,000 acres of publically owned land was required for this plan when land for the actual wastewater treatment remained in private ownership.

2. Fee simple acquisition enables a wastewater authority to unilaterally pursue its primary objective of wastewater treatment and renovation. When other than fee simple means are used, the distinct goals of the wastewater authority and the farmers may conflict. Thus more land is required for a treatment system designed to both treat wastewater and to maintain normal agricultural production patterns. Approximately 2,000,000 acres are estimated to be needed for a total land treatment system for Southeastern Michigan meeting both production and renovation objectives. About 102,000 acres are needed for the proposed plan combining land treatment with physical chemical treatment.

3. Using fee simple, all rights to the land would be acquired by the wastewater authority. The authority may need to acquire only croplands in some areas, allowing owners who prefer to retain homesites, buildings, and immediately adjacent lands. A key result of fee simple purchase, when title passed to a governmental entity, would be the removal of the lands from the real property tax rolls. At the same time, fee simple title would give the wastewater authority the greatest flexibility in using the lands for a variety of public purposes over an extended period of time.

4. Real property interest other than fee may be obtained through the use of easements. Title to the

treatment site would be retained by the current owner. The wastewater authority would acquire only those property rights necessary to carry out the particular management practices and controls required by the land treatment system. Easements would not take land from the local property tax base. Easements provide a real property interest that remains with the land if the landowner transfers the fee title to other parties. While acquiring a less-than-fee interest means reduced control from a wastewater management viewpoint, the long-run cost of acquiring and maintaining those interests may equal or exceed the cost of acquiring fee title. However, the social and political impacts of less-than-fee acquisition could be of overriding concern, particularly for the maintenance of a viable and productive rural community.

5. The potential problems anticipated in publically acquiring large blocks of land for wastewater treatment suggest that public ownership of actual treatment sites is more viable for smaller communities than for a large metropolitan area such as Detroit. Even when land remains in private ownership, the acreage required for large wastewater volumes suggests that land treatment is most applicable for smaller communities or for treatments of only part of the total wastewater volume from a large metropolitan area.

6. A land treatment system can be designed for the primary objective of wastewater treatment and renovation or

for the objective of maximizing crop production. Trade-offs between the objectives of the system, land requirements, and the number of years the treatment site will be used should be evaluated. A system designed to maximize wastewater renovation requires less land for a given volume of wastewater. This reduces land costs to the authority, but is more disruptive to agriculture on the acreage involved. Alternatively, the maximization of the crop production objective requires more land for treatment, but is more compatible with the existing agricultural structure of a region. The number of years a system functions effectively is influenced by the balance between nutrient application rates and their removal through plant uptake and soil absorption. Heavy applications without corresponding plant uptake will shorten the period of effective land treatment.

Region

1. A properly designed and operated land treatment system can both increase the regional supply of crops and renovate wastewater without major disruptions to the agricultural community. Ownership can remain with the farmers and the usual crops produced more intensively with the addition of irrigation.

2. A treatment system designed for wastewater renovation rather than crop production may change the regional supply of various crops as more extensive enterprices such as grasses and hays replace the more intensive

enterprises such as grains and oil crops.

3. An extremely large land treatment system, such as that required to treat all the wastewater from Southeastern Michigan, can disrupt existing distribution channels for production inputs of machinery, petroleum products, seed and fertilizers, as well as the marketing channels for crops and livestock. The number of local suppliers could be reduced if large scale operations emphasized volume purchases at the lowest price. Substitution of nutrients in wastewater for commercial fertilizers may reduce fertilizer sales. The market effect of land treatment will depend on the aggregate production effect from all treatment sites in the market area. Increased crop yields attributed to water and nutrients from wastewater will not automatically translate into monetary benefits. A market must exist for the product produced, and this market will reflect the effect of supply and demand both in and outside the region. Production increases of any particular crop may put downward pressure on prices within a region and to a lesser extent nationally. Agricultural prices are generally inelastic in demand, with the implication that price changes for the products produced with effluent irrigation will be greater opposite in direction to changes in total production.

4. A land treatment operation will be less disruptive to a firm or region if its design is compatible

with the existing type of farming. Farm organization usually evolves gradually on the basis of custom and trial and error operating within a framework of market forces. Existing cropping and livestock patterns reflect a relative comparative advantage. A treatement system designed primarily for renovation can shift this advantage requiring adjustments in the economic structure of the region.

Limitations

Recognition of the following limitations of this study is required for proper interpretation of results.

1. The empirical analysis was completed in a static, partial equilibrium framework. The time consideration involved in the adjustment of the firm or region to land treatment was ignored. The economic impacts estimated were primary impacts. Evaluation of secondary impacts was limited to the recognition of their existence.

2. The empirical analysis was limited by a lack of data and by uncertainties surrounding crop yield response prices, and costs. Because of the uncertainties surrounding the use of single valued expectations, ranging and sensitivity analysis was used extensively to identify interrelationships and to answer "what if" types of questions.

3. The emphasis of the study was on land treatment systems, and did not evaluate other wastewater treatment alternatives or identify a least cost method to treat wastewater. Impacts were evaluated primarily from the

perspective of farmers, the agricultural community, and the authority responsible for wastewater treatment.

4. The framework of farmer's goals used to evaluate the impact of acquisition and management options was based on judgment and inference rather than data.

5. The discussion of the distribution of total revenues in the empirical analysis section is more applicable to a contractual agreement between a wastewater authority and a farmer or group of farmers than to the other acquisition and management options presented.

6. Data generated in the empirical analysis primarily identified changes in total and net revenues with land treatment, and how cost sharing agreements influenced the net revenues received by farmers. The study did not develop data for a marginal analysis of factor-product, factor-factor, and product-product relationships.

Suggestions for Future Research

Additional research is needed to more fully identify the economic and institutional impacts of land treatment on Michigan farmers and communities. Researchable questions resulting from this study are:

1. What acquisition and management options have been used by Michigan communities? Knowledge of the successes and problems and the reasons options were selected would be useful to communities planning land treatment systems.

APPENDICES

APPENDIX A

PRODUCTION ECONOMIC RELATIONSHIPS APPLICABLE TO LAND TREATMENT

2. How does land treatment compare with alternative treatment methods on a cost basis? A constant cost framework is needed to compare alternatives and to identify the sensitivity of the least-cost solution to changes in such variables as community size, wastewater volume,

3. What substitutions of nutrients in effluent for commercial fertilizer nutrients are possible on a firm and regional basis? Factors bearing consideration include effluent quantity and nutrient content, relative prices, and nutrient availability throughout the growing season.

4. What is the production response of various crops to effluent irrigation for varying application rates and fixed levels of nutrients in the wastewater? Most data on yield response with effluent irrigation lacks nutrient content information and reflects a limited number of water application rates.

5. What are the primary and secondary economic impacts of a large scale land treatment system on a regional economy?

6. How could farmer's participation in a land treatment system be evaluated, under a number of situations? It would be useful to specify a method for measuring their acceptance or rejection of land treatment.

APPENDIX A

PRODUCTION ECONOMIC RELATIONSHIPS APPLICABLE TO LAND TREATMENT

A total systems analysis of a land treatment alternative should consider the multiple objectives of maximizing profit from the cropping activities, minimizing the cost of wastewater treatment, and meeting environmental quality objectives. The profit maximizing objective is the most important from the viewpoint of the farm firm. Economic theory assumes that the farm operator will organize his resources to maximize his profits. Crop and livestock enterprises are selected in type and combination to meet the economic conditions for efficient organization. Wastewater effluent adds two additional factors of production, water and nutrients. The use of these factors is determined by associated changes in technical coefficients and price relationships.

There are three basic production economics relationships useful in an economic analysis of wastewater irrigation. They are factor-product relationships, factor-factor relationships, and product-product relationships.

The factor-product relationship is used to identify wastewater application rights for a particular crop. The rule for profit maximization is to add more of the variable resource (effluent) as long as the value of added product is greater than the cost of the added amount of resource used in producing it. Thus, with perfect knowledge and no limitation on the use of capital, profit will be maximized when the factor is added to the point where the marginal value product and the cost of the last unit of resource are just equal, i.e., $MVP_y = MFC_x$. Thus the most profitable level of resource use (effluent) depends upon the relationship of the product and the resource prices as well as on the physical relationship in production. For a given production relationship and resource price, less resource will be used if the price of the product falls and more will be used if the product price increases. Similarly for a given production relationship and product prices, production and resource use will increase when the resource price falls. The profit maximization condition consistent with using the largest volume of effluent compatible with production relationships would be that which has the lowest effluent price, and the largest volume would be used when the effluent is free.

The second basic relationship is the factor-factor relationship. This specifies the optimum combination of resources to produce a given product when the price of factors and product are known. Since effluent contains plant nutrients, a substitution relationship exists between nutrients from effluent (X_1) and from commercial fertilizer, (X_2). Since they are near perfect substitutes, the use of either is very responsive to price. A small change in the relative prices of X_1 and X_2 makes it profitable to substitute relatively large amounts of the less expensive factor for the more expensive. If they were perfect substitutes, only the least expensive factor would be used and none of the more expensive. In the case of near perfect substitutes, the equi-marginal condition states that profits will be maximized at that level of output where the marginal value products of X_1, effluent nutrients and X_2, commercial nutrients, are equal to the marginal factor cost of X_1, and the marginal factor cost of X_2. Thus the profit maximizing combination of inputs is where $MVPx_1/Px_1 = MVPx_2/Px_2 = 1$, i.e., when the marginal value productivity of each resource is equal to the cost of acquiring another unit of that resource for each resource being used. If Px declines, there is an incentive to use more X_1 since $MVPx/Px>1$.

The substitution relationship between wastewater nutrients and commercial fertilizers is illustrated in Figure A-1, where X_1 and X_2 are near substitutes.

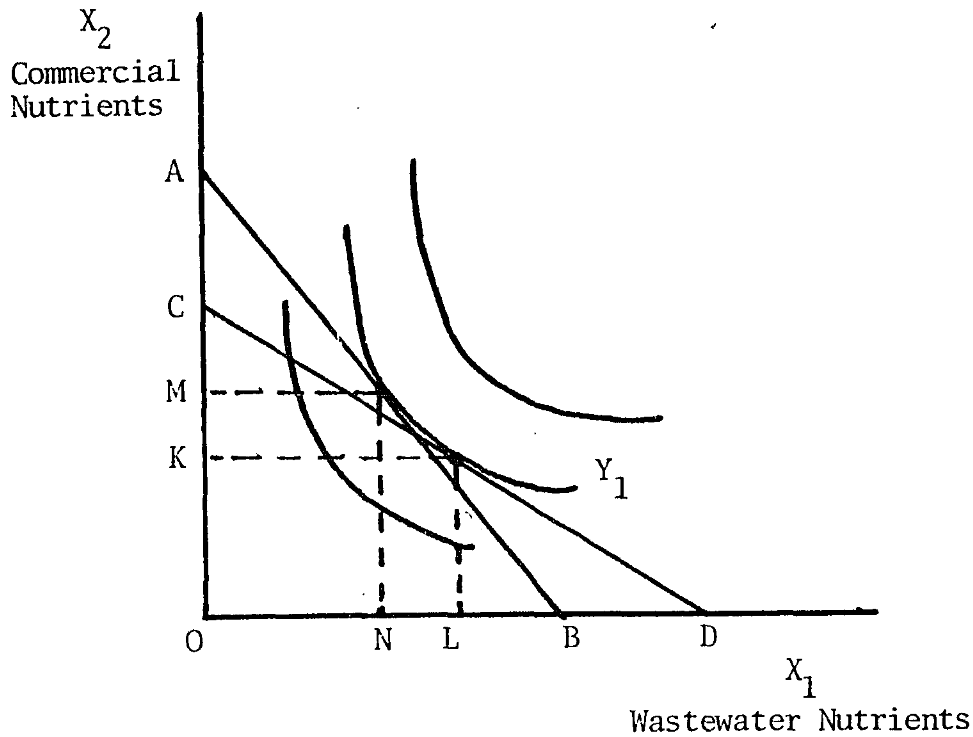


Figure A-1. Nutrient Substitution $Y=f(X_1,X_2/X_3,. . .,X_n)$.

Lines AB and CD are iso-cost lines for commercial nutrients and wastewater nutrients at different relative price levels. With initial price relationships represented by AB, the optimum factor combination for output level Y_1 is OM of X_2 and ON of X_1. With a relative decrease in the price of X_1, more of X_1 is used, OL, and less of X_2 OK.

In addition to nutrients, effluent contributes water to crop production. If water and nutrients are perfect complements, the proportion of combination dominates and relative prices are unimportant in determining the optimal level of output. The complementary relationships of nutrients and water is illustrated in Figure A-2. Initial production is at level Y_1, with OA of X_2 and OB of X_1 used. Additional water will not increase production without additional nutrients. If OB represents nutrient supplied by the

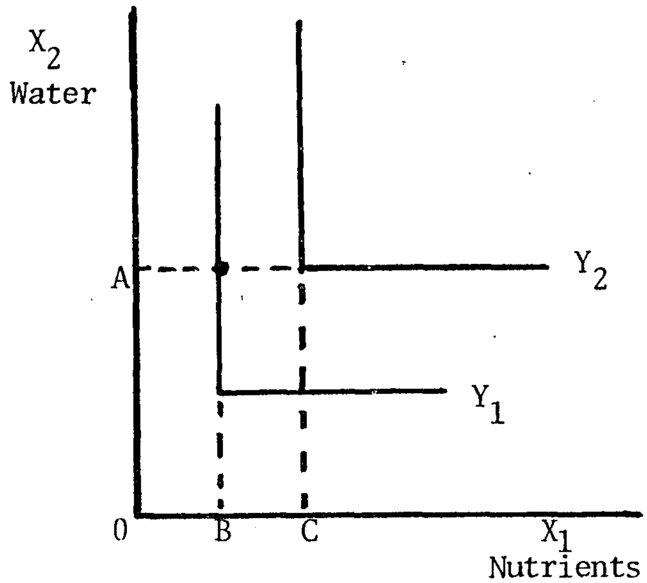


Figure A-2. Complementarity between water and nutrients $Y = f(X_1, X_2/X_3, \ldots, X_n)$.

wastewater, total production can be increased to Y_2 with the same amount of wastewater through the addition of BC nutrients supplied by commercial fertilizers.

The third production relationship, the product-product relationship, identifies the most profitable combination of products to produce, e.g., how much corn, hay, or wheat? The problem is to determine the best combination of products for a given outlay of resources or the best use of resources for a given combination of products. It is necessary to distinguish between two types of enterprise combination, horizontal and vertical combinations. Horizontal combination refers to situations where the products are marketed directly rather than used in the productions of another product within the firm. Under vertical combination, primary products enter the production function as resources in the production of a second product. Thus if effluent is used to produce corn silage or hay which in turn is fed to livestock, a vertical enterprise combination exists.

The objective in a horizontal combination of enterprises is to identify the conditions which will yield the largest amount of revenue. Thus wastewater would be allocated to crops with the largest combined effect of yield response and price effect. To solve this problem it is necessary to know the appropriate prices and the production relationships. Expanding upon the factor-product relationship defined earlier, the conditions for profit maximization in the use of effluent in the production of several products is to produce that combination where $MVPx(Y_1)/Px = MVPx(Y_2)/Px = 1$, or where the resource (effluent) yields the same marginal value product in the production of one product as in the other.

The application of the three production relationship aids in the analysis of the potential to increase farm income through effluent irrigation. The variable inputs of primary interest are the water and the nutrients in the effluent. The willingness on the part of a farmer to pay for these inputs will depend on the prices charged relative to their contributions to farm income.

APPENDIX B

GROSS MARGIN ESTIMATES

APPENDIX B

GROSS MARGIN ESTIMATES

Gross margin planning is used to identify the contribution of wastewater irrigation to farm income. The gross margin is the value of output for an enterprise less its direct production costs. It represents the contribution of an enterprise to fixed costs, labor, and management. The difference between the total of the gross margins for all enterprises and the fixed costs is net farm income.

Enterprise budgets are presented in Tables B-1 through B-5 for corn, soybeans, dry beans, wheat and alfalfa hay and represent how specific data estimates can be used to evaluate crop enterprises with and without effluent irrigation. Differences in the gross margins of the various alternatives with and without irrigation represent income gains attributable to effluent irrigation under the assumed conditions. These gains, when aggregated to the firm level, help define the bargaining area cost sharing discussions between a farmer and a wastewater authority.

A major difference in the budgets with and without irrigation is the substitution of nutrients in effluents for commercial fertilizers. An important factor influencing nutrient substitution is the wastewater application rate and

Table B-1. Corn--Estimated Returns, Variable Costs and Gross Margin Per Acre, With and Without Effluent Irrigation

Item	Unit	Price or Cost/Unit	Yield Without Irrigation		Yield With Irrigation	
			Quantity	Value or Cost	Quantity	Value or Cost
I. Income[1]						
Yield per acre[2]	bu.	1.64	110	180.40	150	246.00
II. Variable Cash Costs[3]						
Seed	bu.	25.00	.25	6.25	.28	7.00
Fertilizer ($N+P_2O_5+K_2O$)[4]	lb.	.24-.19-.067	120-30-30	36.51	125-0-0	30.00
Herbicide, Atrazine (80w)	lb.	2.30	2	4.60	2	4.60
Power and Machinery Cost						
Preharvest	acre	5.92	1	5.92	1	5.92
Harvest	acre	11.00	1	11.00	1	11.00
Hauling	bu.	.10	110	11.00	150	15.00
Irrigation O&M costs[5]	acre			--		36.00
III. Summary						
Total Variable Costs	$			75.28		109.52
Gross Margin	$			105.12		136.48
Unit Variable Cost	bu.			.68		.73

[1]Prices from [Water Resources Council, 1974].

[2]Yields from [Ellis, 1973].

[3]Adapted from[Trinble, 1971].

[4]Based upon data in Table B-8.

[5]Irrigation costs based upon the design reflectdd in Table 11.

Table B-2. Soybeans--Estimated Returns, Variable Costs and Gross Margin Per Acre, With and Without Effluent Irrigation

Item	Unit	Price or Cost/Unit	Yield Without Irrigation		Yield With Irrigation	
			Quantity	Value or Cost	Quantity	Value or Cost
I. Income[1]						
Yield per acre[2]	bu.	4.12	32	131.84	35	144.20
II. Variable Cash Costs[3]						
Seed	bu.	8.50	.83	7.05	.83	7.05
Fertilizer $(N+P_2O_5+K_2O)$[4]	lb.	.24-.19-.067	10-25-25	8.83	0	0
Herbicide, (Amiben)	lb.	4.83	1	4.83	1	4.83
Power & Machinery Cost						
Preharvest	acre	6.24	1	6.24	1	6.24
Harvest	acre	9.25	1	9.25	1	9.25
Hauling	bu.	.10	32	3.20	35	3.50
Irrigation O&M costs[5]	acre					36.00
III. Summary						
Total Variable costs	$			39.40		66.87
Gross Margin	$			92.44		77.33
Unit Variable Cost	bu.			1.23		1.91

[1]Prices from [Water Resources Council, 1974].

[2]Yields from [Ellis, 1973].

[3]Adapted from [Trimble, 1971].

[4]Based upon data in Table B-8.

[5]Irrigation costs based upon the design reflected in Table 11.

Table B-3. Dry Beans--Estimated Returns, Variable Costs and Gross Margin Per Acre, With and Without Effluent Irrigation

Item	Unit	Price or Cost/Unit	Yield Without Irrigation		Yield With Irrigation	
			Quantity	Value or Cost	Quantity	Value or Cost
I. Income[1]						
Yield per acre[2]	cwt.	16.84	16	269.44	20	336.80
II. Variable Cash Costs[3]						
Seed	bu.	45.00	.67	30.15	.67	30.15
Fertilizer ($N+P_2O_5+K_2O$)[4]	lb.	.24-.19-.067	40-25-25	16.03	0	0
Herbicide (Eptom)	lb.	2.41	2	4.82	2	4.82
Power & Machinery Cost						
Preharvest	acre	11.66	1	11.66	1	11.66
Harvest	acre	9.00	1	9.00	1	9.00
Hauling	cwt.	.18	16	2.88	20	3.60
Irrigation)&M costs[5]	acre					36.00
III. Summary						
Total Variable Costs	$			74.54		95.23
Gross Margin	$			228.58		241.57
Unit Variable Cost	cwt.			4.66		4.76

[1] Prices from [Water Resources Council, 1974].

[2] Yields from [Ellis, 1973].

[3] Adapted from [Trimble, 1971].

[4] Based upon data in Table B-8.

[5] Irrigation costs based upon the design reflected in Table 11.

Table B-4. Wheat--Estimated Returns, Variable Costs and Gross Margin Per Acre, With and Without Effluent Irrigation

Item	Unit	Price or Cost/Unit	Yield Without Irrigation		Yield With Irrigation	
			Quantity	Value or Cost	Quantity	Value or Cost
I. Income[1]						
Yield per acre[2]	bu.	2.36	50	118.00	60	141.60
II. Variable Cash Costs[3]						
Seed	bu.	4.50	1.75	7.87	1.75	7.87
Fertilizer (N+P_2O_5+K_2O)[4]	lb.	.24-.19-.067	60-50-50	27.25	20-0-0	4.80
Herbicide						
Power & Machinery Cost						
Preharvest	acre	4.33	1	4.33	1	4.33
Harvest	acre	9.00	1	9.00	1	9.00
Hauling	bu.	.10	50	5.00	60	6.00
Irrigation)&M costs[5]	acre					36.00
III. Summary						
Total Variable Costs	$			53.45		68.00
Gross Margin	$			64.55		73.60
Unit Variable Cost	bu.			1.07		1.13

[1]Prices from [Water Resources Council, 1974].

[2]Yields from [Ellis, 1973].

[3]Adapted from [Trimble, 1971].

[4]Based upon data in Table B-8.

[5]Irrigaiton costs based upon the design reflected in Table 11.

Table B-5. Alfalfa--Estimated Returns, Variable Costs and Gross Margin Per Acre, With and Without Effluent Irrigation

Item	Unit	Price or Cost/Unit	Yield Without Irrigation		Yield With Irrigation	
			Quantity	Value or Cost	Quantity	Value or Cost
I. Income[1]						
Yield per acre[2]	ton	33.00	3	99.00	5	165.00
II. Variable Cash Costs[3]						
Seed	lb.	1.85	2	3.70	2	3.70
Fertilizer ($N\_P_2O_5+K_2$))[4]	lb.	.24-.19-.067	0-50-50	12.85	0-0-25	1.68
Herbicide						
Power & Machinery Cost						
Preharvest	acre	.36	1	.36	1	.36
Harvest	acre	6.15	1	6.15	1	6.15
Hauling	ton	8.25	3	24.75	5	41.25
Irrigation)&M costs[5]	acre					36.00
III. Summary						
Total Variable Costs	$			47.81		89.14
Gross Margin	$			51.19		75.86
Unit Variable Cost	ton			15.94		17.82

[1]Prices from [Water Resources Council, 1974].

[2]Yields from [Ellis, 1973].

[3]Adapted from [Trimble, 1971].

[4]Based upon data in Table B-8.

[5]Irrigation costs based upon the design reflected in Table 11.

nutrient removal by crops, and plant residues. Estimates of the nutrient content of alternative application rates are presented in Table B-6. Examples of additional nutrient requirements for alternative soils, annual application rates and crops are identified in Table B7.

Table B-6. Estimated Nutrient Content of Alternative Amounts of Effluent

Nutrient	Acre-Inches of Effluent						
	1	15	20	25	30	35	40
	lb/acre						
N	2.22	33	44	55	66	77	88
P	1.59	24	32	40	48	56	64
K	1.93	29	39	48	58	68	77

Source: [Ellis, 1973]

Table B-7. Requirements for Nutrients Applied as Fertilizer, in Addition to Effluent for Alternative Soils, Application Rates, and Crops

Soil Management Group	Corn Following Row Crop or Small Grain	Corn Following Alfalfa	Wheat Following Corn or Soybeans	Soybeans Dry Beans	Alfalfa-Brome annual after Establishment
	lbs of N - P_2O_5 - K_2O				
2.5 (25")	125-0-0	50-0-0	20-0-0	0-0-0	0-0-145
3 (40")	85-0-55	0-0-55	0-0-0	0-0-0	0-0-96

Source: [Ellis, 1973]

Estimates of commercial fertilizer requirements for the alternative yield sets identified for this study, with and without irrigation, are presented in Table B-8.

APPENDIX C

BREAKEVEN AND SENSITIVITY DATA FOR SELECTED CROPS

Table C-1. Total Revenue Per Acre and Changes in Total Revenue Associated with Alternative Yield and Price Combinations, Soybeans

Yield	Total Revenue at Price/Bushel 3.00	3.50	4.00	4.12	4.50	5.00	6.00	7.00	8.00
bushels	dollars								
17	51.00	59.50	68.00	70.04	76.50	85.00	102.00	119.00	136.00
20	60.00	70.00	80.00	82.40	90.00	100.00	120.00	140.00	160.00
25	75.00	87.50	100.00	103.00	112.50	125.00	150.00	175.00	200.00
30	90.00	105.00	120.00	123.60	135.00	150.00	180.00	210.00	240.00
32	96.00	112.00	128.00	131.84	144.00	160.00 [1]	192.00	224.00	256.00
35	105.00	122.50	140.00	144.20	157.50	175.00 [2]	210.00	245.00	280.00
40	120.00	140.00	160.00	164.80	180.00	200.00	240.00	280.00	320.00
45	135.00	157.50	180.00	185.40	202.50	225.00	270.00	315.00	360.00
50	150.00	175.00	200.00	206.00	225.00	250.00	300.00	350.00	400.00

Yield Increase	Total Revenue at Price/Bushel 3.00	3.50	4.00	4.12	4.50	5.00	6.00	7.00	8.00
bushels	dollars								
3	9.00	10.50	12.00	12.36	13.50	15.00 [2]	18.00	21.00	24.00
5	15.00	17.50	20.00	20.60	22.50	25.00	30.00	35.00	40.00
10	30.00	35.00	40.00	41.20	45.00	50.00	60.00	70.00	80.00
12	36.00	42.00	48.00	49.44	54.00	60.00	72.00	84.00	96.00
15	45.00	52.50	60.00	61.80	67.50	75.00	90.00	105.00	120.00
20	60.00	70.00	80.00	82.40	90.00	100.00	120.00	140.00	160.00

[1] Best estimate without irrigation.
[2] Best estimate with irrigation.

Table C-2. Incremental Soybean Yield Increases Required to Breakeven on Irrigation Costs with Alternative Prices and Costs

Irrigation Costs [1]	Breakeven Yield at Price/Bushel dollars								
	3.00	3.50	4.00	4.12	4.50	5.00	6.00	7.00	8.00
dollars	bushels/acre								
10.00	3.3	2.9	2.5	2.4	2.2	2.0	1.7	1.4	1.3
25.00	8.3	7.1	6.3	6.1	5.6	5.0	4.2	3.6	3.1
35.00	11.7	10.0	8.8	8.5	7.8	7.0	5.8	5.0	4.4
40.00	13.3	11.4	10.0	9.7	8.9	8.0	6.7	5.7	5.0
45.00	15.0	12.9	11.3	10.9	10.0	9.0	7.5	6.4	5.6
50.00	16.7	14.3	12.5	12.1	11.1	10.0	8.3	7.1	6.3
55.00	18.3	15.7	13.8	13.3	12.2	11.0	9.2	7.9	6.9
60.00	20.0	17.1	15.0	14.6	13.3	12.0	10.0	8.6	7.5
65.00	21.7	18.6	16.3	15.8	14.4	13.0	10.8	9.3	8.1
70.00	23.3	20.0	17.5	17.0	15.6	14.0	11.7	10.0	8.8
75.00	25.0	21.4	18.8	18.2	16.7	15.0	12.5	10.7	9.4
80.00	26.7	22.9	20.0	19.4	17.8	16.0	13.3	11.4	10.0
85.00	28.3	24.3	21.3	20.6	18.9	17.0	14.2	12.1	10.6
90.00	30.0	25.7	22.5	21.8	20.0	18.0	15.0	12.9	11.3
95.00	31.7	27.1	23.8	23.1	21.1	19.0	15.8	13.6	11.9
100.00	33.3	28.6	25.0	24.3	22.2	20.0	16.7	14.3	12.5
110.00	36.7	31.4	27.5	26.7	24.4	22.0	18.3	15.7	13.8
125.00	41.7	35.7	31.3	30.3	27.8	25.0	20.8	17.9	15.6

1. Irrigation costs vary with the system used, and may represent annual capital costs, annual operating and maintenance costs, or annual total costs. For example, capital costs range from \$32 - \$77 and operating costs from \$25 - \$53 in the systems specified in Table 11.

Table C-3. Net Revenue Per Acre for Alternative Sets of Irrigation Costs, Yield Changes, and Prices, Soybeans

Irrigation Costs	Yield Change	Net Revenues				
		Dollars/Bushel				
		3.50	4.12	5.00	6.00	8.00
dollars	bushels	dollars				
25	5	-7.50	-4.40	0.00	5.00	15.00
	10	10.00	16.20	25.00	35.00	55.00
	12	17.00	24.44	35.00	47.00	71.00
	15	27.50	36.80	50.00	65.00	95.00
	20	45.00	57.40	75.00	95.00	135.00
50	5	-32.50	-29.40	-25.00	-20.00	-10.00
	10	-15.00	-8.80	0.00	10.00	30.00
	12	-8.00	-0.56	10.00	22.00	46.00
	15	2.50	11.80	25.00	40.00	70.00
	20	20.00	32.40	50.00	70.00	110.00
75	5	-57.50	-54.40	-50.00	-45.00	-35.00
	10	-40.00	-33.80	-25.00	-15.00	5.00
	12	-33.00	-25.56	-15.00	-3.00	21.00
	15	-22.50	-13.20	0.00	15.00	45.00
	20	-5.00	7.40	25.00	45.00	85.00
100	5	-82.50	-79.40	-75.00	-70.00	-60.00
	10	-65.00	-58.80	-50.00	-40.00	-20.00
	12	-58.00	-50.56	-40.00	-28.00	-4.00
	15	-47.50	-38.20	-25.00	-10.00	20.00
	20	-30.00	-17.60	0.00	20.00	60.00

Table C-4. Total Revenue Per Acre and Changes in Total Revenue Associated with Alternative Yield and Price Combinations, Dry Beans

	Total Revenue at Price/Hundredweight						
Yield	10.00	15.00	16.84	20.00	24.42	25.00	30.00
cwt.	dollars						
9	90.00	135.00	151.56	180.00	219.78	225.00	270.00
10	100.00	150.00	168.40	200.00	244.20	250.00	300.00
15	150.00	225.00	252.60	300.00	366.30	375.00	450.00
16	160.00	240.00	269.44	320.00 [1]	390.72	400.00	480.00
20	200.00	300.00	336.80	400.00	488.40	500.00	600.00
25	250.00	375.00	421.00	500.00 [2]	610.50	625.00	750.00

	Total Revenue at Price/Hundredweight						
Yield Increase	10.00	15.00	16.84	20.00	24.42	25.00	30.00
cwt.	dollars						
4	40.00	60.00	67.36	80.00 [2]	97.68	100.00	120.00
5	50.00	75.00	84.20	100.00	122.10	125.00	150.00
9	90.00	135.00	151.56	180.00	219.78	225.00	270.00
10	100.00	150.00	168.40	200.00	244.20	250.00	300.00
15	150.00	225.00	252.60	300.00	366.30	375.00	450.00

[1]Best estimate without irrigation.
[2]Best estimate with irrigation.

Table C-5. Incremental Dry Bean Yield Increases Required to Breakeven on Irrigation Costs with Alternative Prices and Costs

Irrigation Costs [1]	Breakeven Yield at Price/Hundredweight						
	dollars						
	10.00	15.00	16.84	20.00	24.42	25.00	30.00
dollars	cwt/acre						
10.00	1.0	0.7	0.6	0.5	0.4	0.4	0.3
25.00	2.5	1.7	1.5	1.3	1.0	1.0	0.8
35.00	3.5	2.3	2.1	1.8	1.4	1.4	1.2
40.00	4.0	2.7	2.4	2.0	1.6	1.6	1.3
45.00	4.5	3.0	2.7	2.3	1.8	1.8	1.5
50.00	5.0	3.3	3.0	2.5	2.0	2.0	1.7
55.00	5.5	3.7	3.3	2.8	2.3	2.2	1.8
60.00	6.0	4.0	3.6	3.0	2.5	2.4	2.0
65.00	6.5	4.3	3.9	3.3	2.7	2.6	2.2
70.00	7.0	4.7	4.2	3.5	2.9	2.8	2.3
75.00	7.5	5.0	4.5	3.8	3.1	3.0	2.5
80.00	8.0	5.3	4.8	4.0	3.3	3.2	2.7
85.00	8.5	5.7	5.0	4.3	3.5	3.4	2.8
90.00	9.0	6.0	5.3	4.5	3.7	3.6	3.0
95.00	9.5	6.3	5.6	4.8	3.9	3.8	3.2
100.00	10.0	6.7	5.9	5.0	4.1	4.0	3.3
110.00	11.0	7.3	6.5	5.5	4.5	4.4	3.7
125.00	12.5	8.3	7.4	6.3	5.1	5.0	4.2

1 Irrigation costs vary with the system used, and may represent annual capital costs, annual operating and maintenance costs, or annual total costs. For example, capital costs range from \$32 - \$77 and operating costs from \$25 - \$53 in the systems specified in Table 11.

Table C-6. Net Revenue Per Acre for Alternative Sets of Irrigation Costs, Yield Changes, and Prices, Dry Beans

Irrigation Costs	Yield Change	Net Revenues Dollars/cwt 15.00	16.84	20.00	25.00	30.00
dollars	cwt	dollars				
25	4	35.00	42.36	55.00	75.00	95.00
	5	50.00	59.20	75.00	100.00	125.00
	9	110.00	126.56	155.00	200.00	245.00
	10	125.00	143.40	175.00	225.00	275.00
	15	200.00	227.60	275.00	350.00	425.00
50	4	10.00	17.36	30.00	50.00	70.00
	5	25.00	34.20	50.00	75.00	100.00
	9	85.00	101.56	130.00	175.00	220.00
	10	100.00	118.40	150.00	200.00	250.00
	15	175.00	202.60	250.00	325.00	400.00
75	4	-15.00	-7.64	5.00	25.00	45.00
	5	0.00	9.20	25.00	50.00	75.00
	9	60.00	76.56	105.00	150.00	195.00
	10	75.00	93.40	125.00	175.00	225.00
	15	150.00	177.60	225.00	300.00	375.00
100	4	-40.00	-32.64	-20.00	0.00	20.00
	5	-25.00	-15.80	0.00	25.00	50.00
	9	35.00	51.56	80.00	125.00	170.00
	10	50.00	68.40	100.00	150.00	200.00
	15	125.00	152.60	200.00	275.00	350.00

Table C-7. Total Revenue Per Acre and Changes in Total Revenue Associated with Alternative Yield and Price Combinations, Wheat

	Total Revenue at Price/Bushel							
Yield	2.00	2.36	2.50	3.00	3.50	4.00	4.50	5.00
bushels	dollars							
30	60.00	70.80	75.00	90.00	105.00	120.00	135.00	150.00
40	80.00	94.40	100.00	120.00	140.00	160.00	180.00	200.00
46	92.00	108.56	115.00	138.00	161.00	184.00	207.00	230.00
50	100.00	118.00	125.00	150.00[1]	175.00	200.00	225.00	250.00
60	120.00	141.60	150.00	180.00	210.00	240.00	270.00	300.00
70	140.00	165.20	175.00	210.00[2]	245.00	280.00	315.00	350.00
75	150.00	177.00	187.50	225.00	262.50	300.00	337.50	375.00

	Total Revenue at Price/Bushel							
Yield Increase	2.00	2.36	2.50	3.00	3.50	4.00	4.50	5.00
bushels	dollars							
10	20.00	23.60	25.00	30.00[2]	35.00	40.00	45.00	50.00
15	30.00	35.40	37.50	45.00	52.50	60.00	67.50	75.00
20	40.00	47.20	50.00	60.00	70.00	80.00	90.00	100.00
25	50.00	59.00	62.50	75.00	87.50	100.00	112.50	125.00
30	60.00	70.80	75.00	90.00	105.00	120.00	135.00	150.00

[1] Best estimate without irrigation.
[2] Best estimate with irrigation.

Table C-8. Incremental Wheat Yield Increases Required to Breakeven on Irrigation Costs with Alternative Prices and Costs

Irrigation Costs [1]	Breakeven Yield at Price/Bushel (dollars)							
	2.00	2.36	2.50	3.00	3.50	4.00	4.50	5.00
dollars	bushels/acre							
10.00	5.0	4.2	4.0	3.3	2.9	2.5	2.2	2.0
25.00	12.5	10.6	10.0	8.3	7.1	6.3	5.6	5.0
35.00	17.5	14.8	14.0	11.7	10.0	8.8	7.8	7.0
40.00	20.0	16.9	16.0	13.3	11.4	10.0	8.9	8.0
45.00	22.5	19.1	18.0	15.0	12.9	11.3	10.0	9.0
50.00	25.0	21.2	20.0	16.7	14.3	12.5	11.1	10.0
55.00	27.5	23.3	22.0	18.3	15.7	13.8	12.2	11.0
60.00	30.0	25.4	24.0	20.0	17.1	15.0	13.3	12.0
65.00	32.5	27.5	26.0	21.7	18.6	16.3	14.4	13.0
70.00	35.0	29.7	28.0	23.3	20.0	17.5	15.6	14.0
75.00	37.5	31.8	30.0	25.0	21.4	18.8	16.7	15.0
80.00	40.0	33.9	32.0	26.7	22.9	20.0	17.8	16.0
85.00	42.5	36.0	34.0	28.3	24.3	21.3	18.9	17.0
90.00	45.0	38.1	36.0	30.0	25.7	22.5	20.0	18.0
95.00	47.5	40.3	38.0	31.7	27.1	23.8	21.1	19.0
100.00	50.0	42.4	40.0	33.3	28.6	25.0	22.2	20.0
110.00	55.0	46.6	44.0	36.7	31.4	27.5	24.4	22.0
125.00	62.5	53.0	50.0	41.7	35.7	31.3	27.8	25.0

1 Irrigation costs vary with the system used, and may represent annual capital costs, annual operating and maintenance costs, or annual total costs. For example, capital costs range from $32 - $77 and operating costs from $25 - $53 in the systems specified in Table 11.

Table C-9. Net Revenue Per Acre for Alternative Sets of Irrigation Costs, Yield Changes, and Prices, Wheat

Irrigation Costs	Yield Change	Net Revenues Dollars/Bushel 2.36	3.00	3.50	4.50	5.00
dollars	bushels	dollars				
25	10	-1.40	5.00	10.00	20.00	25.00
	15	10.40	20.00	27.50	42.50	50.00
	20	22.20	35.00	45.00	65.00	75.00
	25	34.00	50.00	62.50	87.50	100.00
	30	45.80	65.00	80.00	110.00	125.00
50	10	-26.40	-20.00	-15.00	-5.00	0.00
	15	-14.60	-5.00	2.50	17.50	25.00
	20	-2.80	10.00	20.00	40.00	50.00
	25	9.00	25.00	37.50	62.50	75.00
	30	20.80	40.00	55.00	85.00	100.00
75	10	-51.40	-45.00	-40.00	-30.00	-25.00
	15	-39.60	-30.00	-22.50	-7.50	0.00
	20	-27.80	-15.00	-5.00	15.00	25.00
	25	-16.00	0.00	12.50	37.50	50.00
	30	-4.20	15.00	30.00	60.00	75.00
100	10	-76.40	-70.00	-65.00	-55.00	-50.00
	15	-64.60	-55.00	-47.50	-32.50	-25.00
	20	-52.80	-40.00	-30.00	-10.00	0.00
	25	-41.00	-25.00	-12.50	12.50	25.00
	30	-29.20	-10.00	5.00	35.00	50.00

Table C-10. Total Revenue Per Acre and Changes in Total Revenue Associated with Alternative Yield and Price Combinations

Yield	Total Revenue at Price/Ton 25.00	30.00	33.00	35.00	40.00	45.00	50.00
tons	dollars						
2.5	62.50	75.00	82.50	87.50	100.00	112.50	125.00
3.0	75.00	90.00	99.00	105.00	120.00 [1]	135.00	150.00
3.5	87.50	105.00	115.50	122.50	140.00	157.50	175.00
4.0	100.00	120.00	132.00	140.00	160.00	180.00	200.00
4.5	112.50	135.00	148.50	157.50	180.00	202.50	225.00
5.0	125.00	150.00	165.00	175.00	200.00	225.00	250.00
5.5	137.50	165.00	181.50	192.50	220.00 [2]	247.50	275.00
6.0	150.00	180.00	198.00	210.00	240.00	270.00	300.00
6.2	155.00	186.00	204.60	217.00	248.00	279.00	310.00
6.5	162.50	195.00	214.50	227.50	260.00	292.50	325.00
7.0	175.00	210.00	231.00	245.00	280.00	315.00	350.00

Yield Increase	Total Revenue at Price/Ton 25.00	30.00	33.00	35.00	40.00	45.00	50.00
tons	dollars						
-0.5	-12.50	-15.00	-16.50	-17.50	-20.00	-22.50	-25.00
1.0	25.00	30.00	33.00	35.00	40.00	45.00	50.00
1.5	37.50	45.00	49.50	52.50	60.00	67.50	75.00
2.0	50.00	60.00	66.00	70.00	80.00 [2]	90.00	100.00
2.5	62.50	75.00	82.50	87.50	100.00	112.50	125.00
3.0	75.00	90.00	99.00	105.00	120.00	135.00	150.00
3.2	80.00	96.00	105.60	112.00	128.00	144.00	160.00

[1] Best estimate without irrigation.
[2] Best estimate with irrigation.

Table C-11. Incremental Alfalfa Yield Increases Required to Breakeven on Irrigation Costs with Alternative Prices and Costs

Irrigation Costs [1]	Breakeven Yield at Price/Ton						
	dollars						
	25.00	30.00	33.00	35.00	40.00	45.00	50.00
dollars	tons/acre						
10.00	0.4	0.3	0.3	0.3	0.3	0.2	0.2
25.00	1.0	0.8	0.8	0.7	0.6	0.6	0.5
35.00	1.4	1.2	1.1	1.0	0.9	0.8	0.7
40.00	1.6	1.3	1.2	1.1	1.0	0.9	0.8
45.00	1.8	1.5	1.4	1.3	1.1	1.0	0.9
50.00	2.0	1.7	1.5	1.4	1.3	1.1	1.0
55.00	2.2	1.8	1.7	1.6	1.4	1.2	1.1
60.00	2.4	2.0	1.8	1.7	1.5	1.3	1.2
65.00	2.6	2.2	2.0	1.9	1.6	1.4	1.3
70.00	2.8	2.3	2.1	2.0	1.8	1.6	1.4
75.00	3.0	2.5	2.3	2.1	1.9	1.7	1.5
80.00	3.2	2.7	2.4	2.3	2.0	1.8	1.6
85.00	3.4	2.8	2.6	2.4	2.1	1.9	1.7
90.00	3.6	3.0	2.7	2.6	2.3	2.0	1.8
95.00	3.8	3.2	2.9	2.7	2.4	2.1	1.9
100.00	4.0	3.3	3.0	2.9	2.5	2.2	2.0
110.00	4.4	3.7	3.3	3.1	2.8	2.4	2.2
125.00	5.0	4.2	3.8	3.6	3.1	2.8	2.5

1 Irrigation costs vary with the system used, and may represent annual capital costs, annual operating and maintenance costs, or annual total costs. For example, capital costs range from $32 - $77 and operating costs from $25 - $53 in the systems specified in Table 11.

Table C-12. Net Revenue Per Acre for Alternative Sets of Irrigation Costs, Yield Changes, and Prices, Alfalfa

Irrigation Costs	Yield Change	Net Revenues — Dollars/Bushel 25.00	33.00	40.00	45.00	50.00
dollars	bushels	dollars				
25	1.0	0.00	8.00	15.00	20.00	25.00
	1.5	12.50	24.50	35.00	42.50	50.00
	2.0	25.00	41.00	55.00	65.00	75.00
	2.5	37.50	57.50	75.00	87.50	100.00
	3.0	50.00	74.00	95.00	110.00	125.00
	3.2	55.00	80.60	103.00	119.00	135.00
50	1.0	-25.00	-17.00	-10.00	-5.00	0.00
	1.5	-12.50	-0.50	10.00	17.50	25.00
	2.0	0.00	16.00	30.00	40.00	50.00
	2.5	12.50	32.50	50.00	62.50	75.00
	3.0	25.00	49.00	70.00	85.00	100.00
	3.2	30.00	55.60	78.00	94.00	110.00
75	1.0	-50.00	-42.00	-35.00	-30.00	-25.00
	1.5	-37.50	-25.50	-15.00	-7.50	0.00
	2.0	-25.00	-9.00	5.00	15.00	25.00
	2.5	-12.50	7.50	25.00	37.50	50.00
	3.0	0.00	24.00	45.00	60.00	75.00
	3.2	5.00	30.60	53.00	69.00	85.00
100	1.0	-75.00	-67.00	-60.00	-55.00	-50.00
	1.5	-62.50	-50.50	-40.00	-32.50	-25.00
	2.0	-50.00	-34.00	-20.00	-10.00	0.00
	2.5	-37.50	-17.50	0.00	12.50	25.00
	3.0	-25.00	-1.00	20.00	35.00	50.00
	3.2	-20.00	5.60	28.00	44.00	60.00

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