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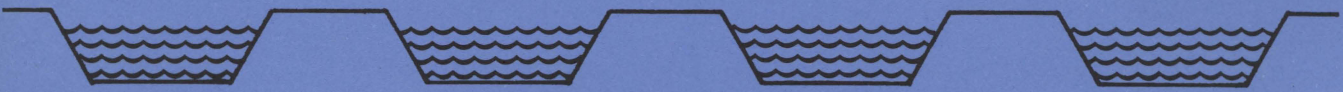
Economic Implications of Applying Effluent for Irrigation



in the Texas High Plains

THE TEXAS AGRICULTURAL EXPERIMENT STATION/Neville P. Clarke, Director/The Texas A&M University System/College Station, Texas

SUMMARY

Growing rural communities face pressure to provide services to their populations. Wastewater treatment represents one of the many services in which communities must invest. The choice of an appropriate treatment facility represents a major decision and hinges on such factors as technical feasibility, cost, and treatment effectiveness so that the community complies with the water quality standards embodied in the Clean Water Act. This study focuses on one particular treatment method, that of applying sewage effluent to land for purposes of agricultural production. The study area selected is the Southern High Plains region of Texas. Several scenarios involving two farm sizes, two storage capacities, irrigation with varying amounts of effluent, and irrigation under a combined effluent and groundwater regime were established and net returns maximized for each. To derive net benefits from effluent use, the net returns from irrigating with effluent were compared to those of dryland and groundwater irrigated farms. The results demonstrated increases in net returns of up to 200% using only effluent over a dryland scenario and up to 78% over one for groundwater irrigation. When net returns for scenarios using a mixture of both effluent and groundwater are compared to dryland and groundwater irrigated farms, the respective increases in returns are 170% and 65%.

Keywords: Wastewater/rural communities/sewage treatment/waste disposal

ECONOMIC IMPLICATIONS OF APPLYING EFFLUENT FOR IRRIGATION IN THE TEXAS HIGH PLAINS

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INTRODUCTION

Wastewater treatment through land application has been practiced for decades throughout the world. The soil, which acts as a biological filter, treats wastewater to the extent that effluent quality often equals that obtained through advanced treatment processes (Malhorta and Myers). This effluent quality factor has contributed to renewed interest in land application as communities strive to meet Federal Water Pollution Control Act discharge requirements. Other factors contributing to the interest in land application treatment processes; (2) lower costs for system operation and maintenance (O&M); and (3) prospects for utilizing effluent for crop irrigation in areas where irrigation can be practiced.

The use of effluent for irrigation can contribute economically to both the rural municipality and the farmer in semiarid and arid regions. Rural communities gain from lower O&M costs (Reed and Buzzel) and from lower treatment requirement levels. Under furrow and flood irrigation, primary treated wastewater can be applied to crops; secondary treatment is necessary for sprinkler and trickle irrigation systems to prevent nozzle clogging (Marsh et al.). A municipality may also earn revenue through sale of wastewater or through lease arrangements whereby farmers lease municipal land and agree to receive all effluent pumped by the municipality. Money earned from such arrangements can be applied to defray O&M costs of the treatment plant.

Farmers benefit from increased supplies of water for irrigation. Use of effluent permits the introduction of irrigated crops to areas accustomed to dryland production only and supplements surface and groundwater supplies in irrigated areas. Effluent also contains valuable nutrients essential to plant growth. The use of these available nutrients enhances crop yields and permits the reduction in use of purchased fertilizer inputs. Principally, however, the benefits to the farmer in a semiarid area result from the availability of an additional supply of water at a relatively low cost which can be used for irrigation. The primary objective of this research was to estimate the effect on net returns to farmers in semiarid regions who utilize effluent for irrigation and to identify the resultant cropping patterns of these farmers. This provides an indication of a farmer's ability to pay for effluent (benefits). It also suggests that smaller communities could use land application through irrigation as an alternative waste disposal method.

STUDY AREA

The Southern High Plains of Texas (Figure 1), was chosen as the study area to estimate net returns to farmers applying effluent for irrigation (Victurine). Average annual rainfall in the area ranges from 18 to 24 inches, sufficient for dryland production of many crops, including cotton, ,grain sorghum and wheat. These crops, as well as alfalfa, pasture, corn, and soybeans, are produced under irrigated conditions. Irrigation water is pumped from the Ogallala aquifer, which receives negligible recharge and thus, in effect, is being mined. The continually declining water level in the aquifer results in declining well yields, increased energy requirements for pumping, increased expenditures for energy and fuel, and the eventual economic exhaustion of the water supply for irrigation (Hardin and Lacewell).

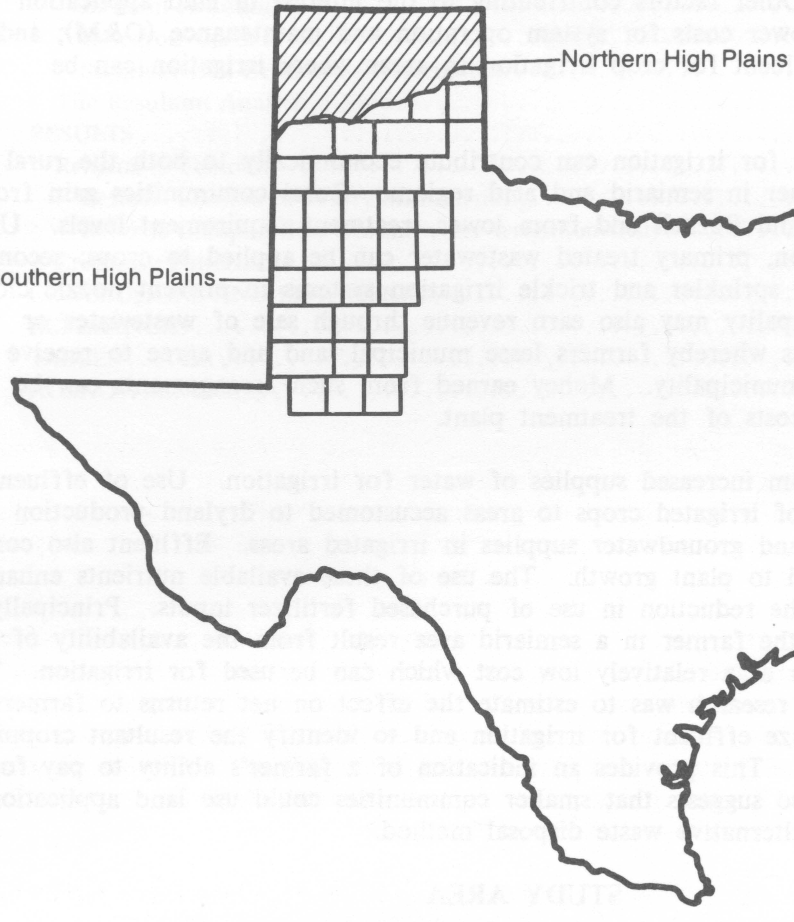

Figure 1. Map of the study area for land application.

Even with increasing pumping costs, irrigation remains economically attractive since yields can be increased substantially, and even more than doubled for some crops (Hardin and Lacewell). With irrigation, alfalfa, corn, and soybeans can be produced in a region that would not otherwise support these crops. Thus, the implications of this study on the use of municipal effluent for irrigation could be important throughout the Great Plains and in much of the western United States.

SELECTED REVIEW OF PREVIOUS RESEARCH

Since 1970 there have been several research efforts to investigate the economic and biological aspects of land application of effluent. The material summarized below was selected as representative of work focusing on potential returns to farmers from effluent irrigation. A more in-depth treatment of land application may be found in Victurine (1984).

EPA studies indicate effluent that has received only primary treatment can be used to flood or furrow irrigate grain for livestock feed, fiber crops, and pastureland (USEPA, 1981). However, the majority of systems send effluent through secondary treatment processes. Cantrell et al. report that where irrigation is done with sprinklers, secondary treatment is necessary to remove solids that may cause clogging of nozzles. Sutherland and Myers believe that waste stabilization ponds are the most cost-effective alternative for pretreatment in land application systems. Effluents from these ponds can be used in most types of irrigation systems. The total cost of land application of effluent, however, is dependent upon land costs and other capital expenditures.

Williams, Conner, and Libbey identified agricultural and revenue-generating benefits of land application. Small communities in Michigan received one-third of the revenue from a farmer who planted and harvested on municipal land treated with sewage effluent. The potential for income-generating agreements between farmers and the community should be considered before a design is chosen.

Several researchers have reported increased crop yields from the utilization of sewage effluent for irrigation. Day and Tucker compared yields from plots of barley, wheat, and oats irrigated with effluent containing an equivalent of 65 pounds of nitrogen, 50 pounds of phosphorus and 32 pounds of potassium per acre-foot to control plots receiving the same level of nutrients. They found that wheat yields from effluent irrigation increased 263% and oat yields, 249%. Barley yields increased also, but not nearly so dramatically due to barley's sensitivity to salts contained in the effluent.

Christiansen, Conner and Libbey evaluated total and net revenues from production of corn for grain, soybeans, dry beans, wheat, and alfalfa on farm sizes of 320 and 580 acres under various crop rotations. Total revenues of both sized farms irrigating with sewage effluent varied with cropping patterns, land use intensity, yields, and prices. Net revenues from irrigation were influenced by fertilizer cost savings and by compensatory arrangements established between the farmers and municipalities to share in the cost of installing irrigation systems. Results indicate total revenues increased for all crops, with crop rotations of corn and dry beans showing the largest increases. The smallest increases occurred with soybeans.

Land application offers the potential benefits of system cost savings, revenue earning capacities, and nutrient provision to crops. Moreover, land application represents an excellent treatment method considered better than can be achieved with a typical activated sludge plant (USEPA). Despite the benefits, costs do exist. Thomas, Ellis, and other researchers have noted increased levels of nitrogen in the soil and groundwater. Although the evaluation of nitrate contamination of groundwater is beyond the scope of this report, the mention of it is important, especially considering the increased attention given to the problem in the literature.

METHOD OF ANALYSIS

The Reneau Model

Estimation of net returns involved the use of a linear programming model modified for the specific purposes of this study (Reneau, Lacewell, and Ellis). Reneau's model was established to determine the effects of alternative irrigation technologies on agricultural production and returns for the Texas High Plains region. Conventional furrow and sprinkler irrigation schemes ranged from a single application to a preplant with five postplant irrigation applications on various crops commonly grown under irrigation in the region. The crops included in the Reneau model are: (1) dryland and irrigated cotton; (2) irrigated soybeans; (3) irrigated corn; (4) dryland and irrigated sunflowers; (5) dryland and irrigated grain sorghum; and (6) irrigated wheat. Commodity prices used for outputs were calculated using an average of the last 20 years' prices, stating them in 1982 dollars using the parity price index (Texas Crop and Livestock Reporting Service). The model permits the solution of numerous irrigation schemes to best represent the alternatives confronting a farmer facing scarce water supplies and high pumping costs.

Soils in the model were classified to take into account the effect of soil characteristics on crop yield. Similar soils were grouped based upon the texture, slope, and crop yield potential. The soil is divided into three texture classes according to its permeability and available water capacity, four slope categories, and a yield variable, which is used as a proxy for local micro-climate variations and those aspects of soil not accounted for by texture and slope. Nine soil categories for the Texas High Plains result from these soil classification procedures.

Water requirements of crops were determined assuming a basic usable plant water delivery rate of 6 inches per preplant and 3 inches per postplant irrigation. These base requirements were translated into the amount of water applied, accounting for irrigation system delivery efficiencies. Furrow irrigation systems are assumed to have an efficiency of 69%, while sprinklers have an efficiency of 80% (Reneau, Lacewell, and Ellis). All crop production activities, including required inputs, are based upon a one-acre land unit.

Modifications of the Reneau Model

The matrix of the crop and water use coefficients derived by Reneau formed the foundation for the study of the effects of land application of municipal effluent. From the base model, modifications were undertaken including the addition of two crops to the matrix, irrigated alfalfa and pasture. These crops were added to provide a crop cover to which water could be added throughout the year and thus productively dispose of the available effluent.

Alfalfa yields were determined using regional soil surveys and were assumed to be the same whether flood or sprinkler irrigation was employed. The values for the yields from soil surveys were scaled down by multiplying them by 0.8 to approximate what is being achieved by typical farmers in the region (Laughlin, Lacewell, and Moore). Alfalfa prices were obtained by taking a 10-year average of prices received by Texas farmers and stated in 1982 dollars using the parity price index (Texas Crop and Livestock Reporting Service). A price of $85 per ton was adopted for the analysis.

Pasture yields and prices were treated somewhat differently. Yields were obtained from soil surveys and were given in animal units per month (AUM). An AUM represents feed requirements for one month for a cow and her calf. Yields per acre were converted into the number of calves that could be grazed on each acre. Purchase and sale prices of cattle were determined in the same manner as those of alfalfa and presented in 1982 dollars. The purchase price of calves was subtracted from gross returns gained by the sale of steers to obtain a gross return of approximately $90.

Once the appropriate yield and price data for these crops were collected, production costs were calculated. Various sources were consulted to gather the necessary input cost information. The Texas Crop Enterprise Budgets provided average costs for seed, machinery, fertilizer, and other required inputs for both crops (Extension Economists - Management). These budgets also furnished the irrigation regimes for alfalfa and pasture. Rather than establish several scenarios with various postplant applications, water was applied in specific quantities over several months. Irrigated alfalfa received 48 inches of water between March and December, with 8 inches applied during the November-December period to utilize abundant effluent. Thirty-four inches were applied under sprinkler over the March to December period. For pasture, 38 inches of water were applied under both furrow and sprinkler irrigation regimes from March to November.

Production Scenarios

Several scenarios were established for the analysis of the net returns accruing to farmers who apply effluent to their crops. Each scenario was tested against one of four base scenarios. The base scenarios depicted net returns and cropping patterns for both a 320- and 640- acre farm under dryland and groundwater irrigated production schemes. The established scenarios were based on the two farm sizes, the amount of effluent available, pond storage capacity, and the availability of supplemental irrigation.

Effluent Availability. Several procedures were followed to obtain the necessary data to develop the aforementioned scenarios. Effluent availability was determined by using a regression equation for sewage flow estimation. The equation regressed monthly average sewage flow in millions of gallons on population and was derived from sewage flow data collected from 503 rural communities with fewer than 13,000 inhabitants. Twelve equations, one for each month, were derived, and water quantity was calculated by setting the value of the population parameter to 5,000 for one set of scenarios and 10,000 for the other. A detailed discussion of the study results at the municipal level are available in Victurine.

Since municipal effluent cannot always be immediately applied to the land, it is necessary to have storage capacity. For this analysis, reservoirs of sufficient size to hold 60 and 90 days of municipal effluent flow were selected. The amount of water that would flow into storage during a 60- or 90- day period was calculated using the regression equations previously mentioned. The maximum amount of flow for 1981, the year for which flow rates were available, occurred in October. These rates were used to provide an upper boundary on the amount of flow that could be expected. It is important to remember that these values represent average and not peak monthly flows. The average monthly values were thus multiplied by two and three to determine 60- and 90-day capacities, respectively.

The quantity of effluent that would need to be stored was then converted to acre-inches, and a reservoir depth of 15 feet was assumed. A 15-foot depth was chosen as a compromise between the use of a very large land area and the necessity of excavating a deeper pit. Although the compromise 15-foot depth was chosen for this analysis, any reasonable depth between 10 and 25 feet would suffice, the exact choice being dependent upon effluent flow. The ultimate choice lies with the proprietor, who should consider the difficulty and cost of deep excavation and the costs in terms of forgone production when large tracts of land are occupied by a reservoir.

Reservoir Costs. The determination of storage reservoir costs consisted of calculating the storage volume of a rectangular pit 15 feet deep and assigning an excavation cost of $2 per cubic yard (USEPA). Actual excavation volume was estimated by taking the area of the rectangle represented by the pond and multiplying it by one-half the proposed pond depth, or 7.5 feet. The fill is used to build up the sides of the pond to create the desired depth, hence excavation would proceed to only 7.5 feet. The total volume calculated is multiplied by $2 to obtain total pond cost.

The resultant capital cost of the pond represents a major investment which must be explained in terms of annual cost over its lifetime. Pond lifetime was assumed to be 30 years, and a 6% rate of interest, or discount rate, was chosen to reflect the cost of capital. The value of 6% represents a real rate of interest of approximately 3.5% for 1983, with 2.5% added to take risk into account (Council of Economic Advisers). The following formula can be used along with the present value interest factor of annuity tables to determine annual costs:

$$AC = \frac{PV}{PVIFA}$$

where

AC = the annualized cost;
PV = the present value in dollars; and
PVIFA = the present value interest factor of an annuity.

The PVIFA for a 30-year time horizon and 6% discount rate is 13.7648. The annualized costs derived from this equation are subtracted from net returns to demonstrate the effect of a large investment on farmer's profits.

Supplemental Groundwater Irrigation. The final aspect of the model preparation involved determining the amount of water that could be pumped from an aquifer and that would be supplemental to the available effluent. The amount of available water from wells was calculated using the following formula (Reneau, Lacewell, and Ellis):

$$WATPMP_i = 0.0528\ GPM\ (PDAY_i)\ P\%\ (WELL)$$

where:

$WATPMP_i$ = the amount of water in acre-inches pumped in period i
GPM = gallons of water pumped per minute per well;
$PDAY_i$ = the number of days in each water period;
P% = the percentage of time the pump operates (1 - down-time); and
WELL = the number of wells available.

Irrigation from groundwater was separated into 18 water periods of uneven length based on seasonal changes in crop water use. The water periods range in length between approximately 60 days for the two periods January-February and November-December and 10 days for June, July, and August, which are divided into three water periods each. March, April, and October each represent 30-day periods, while May and September are each divided into two 15-day periods. Down-time was assumed to be .15 and the number of wells was set to three (Reneau, Lacewell, and Ellis). The choice of number of wells represented a somewhat arbitrary decision. The average number of wells in the Southern High Plains of Texas is one for every 111 acres of cropland. A typical well flow is 1,000 gpm. Therefore, a 320-acre farm, on the average, would have three irrigation wells, while this number would double for a 640-acre farm. Since the major concern is testing the significance to net returns of a mixed effluent-well irrigation scheme, and since lesser quantities of groundwater would be used in conjunction with effluent in order to save money, only three wells were assumed throughout the study.

The Resultant Analytical Model

Essentially, two linear programming (LP) models were created, one using water provided by effluent only, the other using a combination of effluent and groundwater. In both cases, alfalfa and pasture were added to the Reneau model.

The right-hand side of the model possessed the following characteristics: (1) A specific quantity of effluent water was assigned to each of the 18 water periods depending upon the amount of sewage flow available during each month. (2) Water quantity was derived using the regression equations from the Victurine study and adjusting the quantity of water for the effects of evaporation losses from the storage reservoir. (3) Evaporation rates utilized for the calculations were taken from Dugas and represented monthly averages for the High Plains region. (4) Losses to evaporation were countered by precipitation. (5) Monthly precipitation rates were calculated using a 20-year average for the Lubbock region. The amount of precipitation was added to the amount of storage to offset some of the evapotranspiration losses. (6) The resultant water quantities were set as equalities so that the model would be forced to use the water, either distributing it to crops or to storage. (7) Pond storage capacity was set according to an average 60- or 90- day wastewater flow from treatment plants serving towns of populations of 5,000 and 10,000. (8) The amount of water entering storage could not exceed the established capacity; that is, water could not be added to storage once capacity was reached and thus had to be distributed to crops.

When supplemental water from pumping was used, the model was set up in the same manner except that the opportunity for pumping water from three wells beyond the effluent level was established. The amount of water from the wells was established as an inequality to allow the model to use only what was necessary to maximize net returns. Water could thus be drawn from both storage and wells to supply the quantities needed for irrigation during specific water periods. Table 1 provides a simplified version of the model to illustrate the basic structure of the LP model.

RESULTS

Analysis of land application of sewage effluent for irrigation at the farm level was conducted to estimate the impact on farmers' net returns and cropping patterns. The analysis focuses on the returns from having an assured source of water, and on the crops that provide the farmer his highest net returns given available land and water. Results are reported for several scenarios relative to farm size, pond storage capacity, and supplemental groundwater irrigation. The benefits for given scenarios are assessed as the increase in net returns over base scenarios. The base scenarios depict cropping patterns and net returns for both dryland and groundwater irrigated farms of 320 and 640 acres.

Net returns are simulated over 20 scenarios each delineated by population, farm size, reservoir storage capacity, and whether or not supplemental groundwater irrigation is practiced (Table 2). In scenarios C through F and K through N, water is assumed available from a sewage treatment plant serving a population of 5,000. This population assumption yields a specific flow of water. In C-F irrigation is practiced using effluent only, while in K-N effluent is complemented by water pumped from wells. Scenarios G through J and O through R are organized in the same fashion except that water availability is assumed to come from a community of 10,000.

Returns to Farmers

In all cases net returns above variable costs (NRVC) are higher for farms that irrigate than for those using dryland techniques. This emphasizes the importance of irrigation to the agriculture of the region. For a 320-acre farm, the lowest returns above variable costs are $24,368 for a dryland scenario. Returns increase to $41,238 when well irrigation is added, while the highest net returns for a 320-acre farm ($73,644) appear in scenario I where effluent is used without supplemental irrigation, 90 days storage is provided, and population is 10,000. The same scenario with a population of 5,000 renders only $59,345 in net returns.

The lowest net returns for a 320-acre farm are shown in scenario O: population is 10,000, supplemental irrigation is practiced, and there is a storage capacity of 60 days. Net returns above variable costs are $35,861, barely greater than those for a complete dryland scenario. Net returns above total costs are only $9,493, much below those for dryland.

As farm size increases to 640 acres, there is an appreciable increase in net returns. Net returns above variable costs for a dryland farm are the lowest ($48,916). As irrigation is added, net returns increase, reaching $80,378 when groundwater is used for irrigation and a high of $132,040 in scenario R for a combined effluent and groundwater irrigation scheme. The use of effluent for irrigation results in higher net returns than obtained when only groundwater is used in all but one scenario. Scenario D in Table 2 shows net returns of only $73,694, which is primarily due to the size of the farm and the limited amount of effluent available.

The highest returns for a farm that uses only effluent occurs under scenario J ($121,010). This scenario provides returns above total costs of $82,979, which are the largest of all scenarios shown in Table 2.

Returns Compared to Dryland Farming. The contribution to net returns which sewage effluent can make compared with dryland farming is demonstrated in Table 3. In columns 7 and 8, the net returns from the use of effluent from communities of 5,000 and 10,000 population are presented. NRVC range from a low of $11,493 in scenario O to a high of $83,124 in scenario R, with an average increase in NRVC of $31,550 for a 320-acre farm and $60,470 for one of 640 acres.

Although irrigation is important, its significance could diminish if adequate quantities of water are not available and efficient irrigation scheduling is not practiced. The effects of limited supplies of effluent on irrigation scheduling and subsequent net returns are demonstrated in Table 3. Under scenario O, NRVC are only $11,000 greater than for dryland. When fixed costs are added, net returns above total costs (NRTC) actually fall below those for a dryland farm of 320 acres. Farm size is simply too small for efficient utilizaton of both the quantity of effluent being delivered from a plant serving 10,000 inhabitants and the water available from three wells.

With elimination of groundwater irrigation, both NRVC and NRTC surpass $30,000 (scenario G). In addition, by increasing acreage to 640 acres (scenario P), net returns increase by more than $78,000 over variable costs and approximately $45,000 over total. This emphasizes that both the land and water constraints affect net returns.

Another factor that influences net returns is the storage capacity of the reservoir. The greater the storage, the greater the net returns, despite the additional storage costs which result from increased capacity. The more effluent a farmer can store, the greater his flexibility in applying it during periods of high crop water demand. There is an increase in net returns over variable costs when effluent is used without supplemental well irrigation on larger rather than smaller farms. These results can be observed by comparing scenarios C and G ($23,655 and $44,936, respectively) with F and J ($38,598 and $72,094, respectively).

Returns Compared to Groundwater Irrigation Only. When net returns from irrigation with effluent either alone or in combination with groundwater are compared with those where irrigation is done with groundwater only, increases in net returns occur in practically all cases (Table 3). In those scenarios with a population parameter of 5,000, net returns are higher than for well irrigation in all cases but one. In scenario D, effluent from a plant serving 5,000 inhabitants is used on a 640-acre farm with a 60-day storage, with the result that net returns above variable costs (NRVC) are over $6,600 lower than for a 640-acre farm irrigated with wells only. Net returns above total costs (NRTC) are greater for scenario D than for the dryland farm, however.

This specific outcome results from an insufficient quantity of water to irrigate such a large farm. For example, given scenario D, but changing population to 10,000, which implies increasing available effluent, NRVC surpass those for the base scenario shown in Table 2 by $20,407 (scenario H), an increase of over 25%. The hypothesis that low net returns are tied to insufficient effluent is further supported if net returns for these scenarios are compared to similar scenarios with larger stoarage capacity. Increasing storage changes negative NRVC in scenario D to positive NRVC under scenario F. Larger quantities of available water allow the farmer to allocate water to the highest value crops, which are generally the ones grown on the best soil with the largest number of postplant irrigations.

NRTC from the use of effluent compared to groundwater irrigation only are positive under all scenarios with a population parameter of 5,000. This results from the high cost of irrigation and the assumption that the effluent is made available at negligible cost to the producer. Well and pump costs are high enough so that even storage construction costs do not adversely affect the returns to a farm irrigated with effluent only. Furthermore, it is shown that earnings under a mixed groundwater and effluent irrigation regime increase, so the farmer can justify a mixed strategy to provide needed water in critical water periods.

The net returns for scenarios with a 10,000 population parameter vary only in magnitude from those found under a 5,000 population scenario. Once again, only one scenario displays negative net returns over the base represented by a 320-acre farm with irrigation wells. Negative NRVC occur under scenario O, the same scenario which demonstrated negative NRTC when compared to dryland farming. Increasing either the acreage (scenario P) or storage capacity (scenario Q) results in positive net returns.

Cropping Patterns

Table 4 represents cropping patterns for a 640-acre farm which receives effluent from a community of 10,000 inhabitants. This particular acreage-effluent combination was selected as illustrative of the changes in optimal cropping patterns when groundwater and/or effluent irrigation is utilized, compared to dryland cropping patterns. The table indicates the effects on crop choice connected with augmenting storage capacity and increasing available irrigation water supply. Where storage capacity is 60 days and irrigation is provided with effluent only, dryland cotton production predominates. An increase in storage capacity alters the pattern to only limited dryland acreage. Once supplemental groundwater irrigation is added to complement the effluent, no acreage is planted with dryland crops, and irrigated cotton, corn, wheat and alfalfa predominate. Comparison of the scenarios in Table 3 with those of Table 2 demonstrates that the highest net revenues accrue to farms with larger storage capacity which apply a mixed effluent-groundwater irrigation scheme.

CONCLUSIONS AND LIMITATIONS

Land application of wastewater can be an attractive alternative among sewage treatment options. In the Texas High Plains and other semiarid regions, the benefits from irrigating are indisputable. Use of effluent provides a very important source of irrigation water that has the potential to substantially increase net returns to the farmer who either has no access to water or who must pump it at great cost from the ground. Effluent can be used as the sole source of irrigation, or in combination with groundwater to increase available supplies. Caution should be exercised in planning to ensure that effluent is used efficiently. Irrigation scheduling is needed to ensure that water is not simply dumped on the land. The need for efficient irrigation scheduling signals the need for adequate storage capacity for the effluent. Sufficient storage ensures the availability of water for high crop demand periods as well as the prevention of the overflow of the reservoir. An adequate land area is also necessary to permit all effluent to be applied when necessary. The choice of crops facilitates year-round application, improves treatment effectiveness, and results in profits to the farmer.

Land application provides benefits to the farmers, but potential benefits are available to communities as well. Communities should be able to share in profits derived from effluent by establishing a method of charging. Such measures could include the outright sale of the wastewater or the leasing of municipal land to farmers on a several-year basis under the stipulation that they take all the effluent produced by the city. Communities also receive benefits in the form of reduced treatment costs for effluent. A thorough study of the benefits likely to accrue to the farmer from the use of effluent would aid in the determination of a fair sale price or leasing arrangement. The income derived from such arrangements could assist communities in defraying their costs of operation and maintenance and might even permit a municipality to pay for any land purchased for land application.

The research into the effects of land application of sewage effluent demonstrated certain limitations. In the analysis, effluent was considered as an additional source of water for irrigation, while other benefits from its use were ignored. These benefits include higher crop yields and lower fertilizer input costs due to the amounts of nitrogen, phosphorus, and potassium present in effluent. No yield increases were assumed in this study nor were input costs adjusted for savings in fertilizer. Studies which take these benefits into account would better evaluate the overall effects of irrigation with effluent. The study also failed to include the cost of any externalities which result from salt build-up in the soil or from possible nitrogen contamination of groundwater.

Delivery of the effluent from the plant to the farm is not evaluated. In some cases the municipality pays for the lines to deliver water to the farmer's field; in others, an agreement to share costs is arranged. At times the water is simply discharged to a municipal land which is leased to farmers, and the discharge lines are included in the cost of the treatment system. Since there is no single method for delivering effluent, it was assumed that farmers received the effluent free of charge. This assumption limits to some extent the direct use of the increase in net returns attributable to effluent as derived in this study. However, the increases in net returns estimated represent a maximum cost the farmer would be willing to pay for effluent.

Despite these limitations, results of this study indicate financial benefits are potentially available to producers in the semiarid region of the Texas High Plains. The magnitude of these financial benefits will, of course, be dependent upon specific arrangements with communities that might provide effluent for irrigation purposes. Further research is needed to identify arrangements acceptable to both the community and the producer and to account for and correct limitations previously mentioned.

REFERENCES

Cantrell, Robert P., Charles W. Wilson, F.E. Beckett, and F.A. Calvo. "A Technical and Economic Feasibility Study of the Use of Municipal Sewage Effluent for Irrigation." *Municipal Sewage Effluent for Irrigation*, F.E. Beckett and C.W. Wilson, eds., Louisiana Polytechnic University, 1968.

Christensen, L.A., L.J. Conner, and L.W. Libbey. *An Economic Analysis of the Utilization of Municipal Waste Water for Crop Production.* Michigan State University Agricultural Economics Report 292, November 1975.

Council of Economics Advisers. *Economic Report to the President.* United States Government Printing Office, Washington, D.C., 1983.

Day, A.D. and T.C. Tucker. "Production of Small Grains Pasture Forage Using Sewage Effluent as a Source of Irrigation Water and Plant Nutrients." *Journal of Agronomy* 54(1959):569–571.

Dugas, W.A. *Agro-Climatic Atlas of Texas, Part VI: Potential Evapotranspiration.* Texas Agricultural Experiment Station Misc. Pub. 1543, 1983.

Ellis, Boyd G., Earl A. Erikson, Lee W. Jacobs and Bernard D. Knezek. "Crop Management Studies at the Muskegon County Michigan Land Treatment System." *Land Treatment of Municipal Wastewater: Vegetation Selection and Management*, Frank M. D'Itri, ed., pp. 49–64. Michigan: Ann Arbor Science Publishers, 1982.

Extension Economists - Management. "Texas Crop Budgets." Texas Agricultural Extension Service, B-1241, 1982.

Federal Water Pollution Control Act of 1972, Public Law No. 92-500 86, Stat.

Hardin, Daniel C. and Ronald D. Lacewell. *Break-Even Investment in a Wind Energy Conversion System for an Irrigated Farm on the Texas High Plains.* Texas Water Resources Institute, Texas A&M University, 1981.

Laughlin, David H., Ronald D. Lacewell, and Donald S. Moore. "The Agricultural Benefits of Salinity Control on the Red River of Texas and Oklahoma." Texas Water Resources Institute, TR-112, December 1980.

Malhorta, S.K. and E.A. Myers. "Design, Operation and Monitoring of Municipal Irrigation Systems." *Journal Water Pollution Control Federation* (47)1975: 2627-2638.

Marsh, John, Michael Gravitz, David Zwick, and Sophie Ann Aoki. "Shopping for Sewage Treatment: How to Get the Best Bargain for Your Community or Home." Environmental Policy Institute and Clean Water Fund, 1980.

Reed, Sherwood C. and Timothy Buzzell. "Land Treatment of Wastewaters for Rural Communities." *Water Pollution Control in Low Density Areas*, William J. Jewell and Rita Swan, eds., pp. 23-39. New Hampshire: University Press of New England, 1975.

Reneau, Duane R. "Technological Response to Natural Resource Depletion: A Model of Crop Agriculture on the Texas High Plains." Ph.D. Dissertation, Texas A&M University, Natural Resource Working Paper Series. College Station, 1983.

Reneau, Duane, Ronald D. Lacewell and John R. Ellis. "Recursive Programming Model for Crop Production on the Texas High Plains." Texas Water Resources Institute, Technical Report TR-129, Texas A&M University. February, 1984.

Sutherland, Jefferey C. and Earl A. Myers. "Selection of Irrigation System Design." *Land Treatment of Municipal Wastewater: Vegetation Selection and Management*, Frank M. D'Itri, ed., pp. 19-34. Michigan: Ann Arbor Science Publishers, 1982.

Texas Crop and Livestock Reporting Service. "Texas Agricultural Cash Receipts, Prices Received and Paid by Farmers." United States Department of Agriculture, Austin, 1981.

Thomas, R.E. and James P. Law, Jr. "Soil Response to Sewage Effluent Irrigation." *Municipal Sewage Effluent for Irrigation*, F.E. Beckett and C.W. Wilson, eds., Louisiana Polytechnic University, 1968.

United States Environmental Protection Agency. *Needs Survey (1980): Cost Estimates for Construction of Publicly Owned Wastewater Treatment Facilities.* EPA 430/9-81-001, Washington, D.C., February 1981.

Victurine, Raymond F. "Estimating Costs and Benefits of Wastewater Disposal in Rural Communities," unpublished M.S. thesis, Department of Agricultural Economics, Texas A&M University, College Station, January 1984.

Williams, J.R., L.J. Conner, and L.W. Libbey. "Case Studies and Comparative Cost Analyses of Land and Conventional Treatment of Waste Water by Small Municipalities in Michigan." Michigan State University Agricultural Economics Report AER-329, October, 1977.

Table 1. Basic Format of the LP Model Developed For Effluent Irrigation.

Rows	Crops	Storage S_1	S_2	...	S_{18}	Irrigation P_1	P_2	...	P_{18}	Pond U	Constraint
NR_{vc}	C_{ij}									$-U_{ij}$	≥ 0
NR_{tc}	C_{2j}									$-U_{2j}$	≥ 0
Land 1	X_{3j} ...										$\leq \beta_1$ (a)
.	.										.
.	.										.
Land 9	X_{11j}..										$\leq \beta_9$
Water 1	X_{12j}..	1				-1					$= Eff_1$ (b)
Water 2	.	-1	1				-1				$= Eff_2$
.	.		-1	1				-1			.
Water 18	.			-1	1				-1		$= Eff_{18}$
Storage 1	X_{30j}	1									$\leq Pond_1$ (c)
Storage 2	.		1								$\leq Pond_2$
.	.			1							$\leq$.
Storage 18	.				1						$\leq Pond_{18}$
Pump 1	X_{48j}					1					$\leq$ Well Cap_1 (d)
Pump 2	.						1				$\leq$ Well Cap_2
.	.							1			$\leq$.
Pump 18	.								1		$\leq$ Well Cap_{18}
Tank										1 (e)	$= 1$

a. Quantity of soil available by specific soil type. Nine soil types were used.
b. Quantity of effluent available and which must be used per water period.
c. Capacity of the pond for storage in acre-inches.
d. Quantity of water that can be extracted from 3 available wells.
e. Procedure to subtract cost of pond from net returns.

Table 2. Annual Net Returns From Irrigation for Various Farm Scenarios.

	POPULATION		FARM SIZE (acres)		WELLS		STORAGE (days)		NRVC[a]	NRTC[b]
SCENARIO	5,000	10,000	320	640	Y	N	60	90		
BASE1			X			X			24,368	15,015
BASE2				X		X			48,916	15,015
A			X		X				41,238	20,813
B				X	X				80,378	46,378
C	X		X			X	X		48,023	31,527
D	X			X		X	X		73,694	57,102
E	X		X			X		X	59,345	40,681
F	X			X		X		X	87,514	58,145
G		X	X			X	X		69,304	46,318
H		X		X		X	X		100,785	67,178
I		X	X			X		X	73,644	46,417
J		X		X		X		X	121,010	82,979
K	X		X		X		X		52,626	26,289
L	X			X	X		X		115,345	72,438
M	X		X		X			X	55,365	29,538
N	X			X	X			X	117,735	73,947
O		X	X		X		X		35,861	9,493
P		X		X	X		X		126,983	74,960
Q		X	X		X			X	53,158	25,567
R		X		X	X			X	132,040	82,677

a. NRVC is the net returns above variable costs for each scenario.
b. NRTC is the net returns above total costs excluding land, management, and risk for each scenario.

Table 3. Annual Returns from Irrigating with Effluent for Several Production Scenarios.

	WELLS		FARM SIZE (acres)		STORAGE (days)		NET RETURNS OVER DRYLAND		NET RETURNS OVER IRRIGATED	
Scenario	Y	N	320	640	60	90	NRVC[a]	NRTC[b]	NRVC[c]	NRTC[d]
					Population = 5,000					
C		X	X		X		23,655	16,512	6,785	10,715
D		X		X	X		24,778	26,970	-6,684	10,715
E		X	X			X	34,977	25,666	18,107	19,868
F		X		X		X	38,598	28,013	7,136	11,758
K	X		X		X		28,254	11,274	11,384	5,476
L	X			X	X		66,429	42,306	34,967	26,051
M	X		X			X	30,997	14,524	14,127	8,726
N	X			X		X	68,819	43,815	37,357	27,560
					Population = 10,000					
G		X	X		X		44,936	31,303	28,066	25,505
H		X		X	X		51,869	37,046	20,407	20,791
I		X	X			X	49,276	31,402	32,406	25,604
J		X		X		X	72,094	52,847	40,632	36,592
O	X		X		X		11,493	-5,522	-5,377	11,320
P	X			X	X		78,067	44,828	46,605	28,573
Q	X		X			X	28,790	10,552	11,920	4,754
R	X			X		X	83,124	52,545	51,662	36,290

a. NRVC is the net returns above variable costs compared to a dryland farm.
b. NRTC is the net returns above total costs compared to a dryland farm.
c. NRVC is the net returns above variable costs compared to groundwater irrigation.
d. NRTC is the net returns above total costs compared to groundwater irrigation.

Table 4. Cropping Patterns in Acres for a 640 Acre Farm Under a Dryland and Several Irrigation Schemes for Scenarios in Table 2.

Population = 10,000																			
						COTTON						CORN		GR.SORG.	WHEAT		ALFALFA		PASTURE
Sc.	Storage (days)		Irr. Wells		Dry	0PP^a		1PP^b		2PP		5PP		3PP	4PP				
	60	90	Y	N		F^c	S^d	F	S	F	S	F	S	S	F	S	F	S	S
H	X			X	278		45	21	16		22				75	117	66		
J		X		X	52	61	2	70	200		26			66	99	8		56	
P	X		X							63	25	8	117		160	78		163	27
R		X	X							84	153	52	143			95		112	

a. 0PP refers to single pre-plant irrigation with no post-plant applications.

b. 1PP refers to a pre-plant with 1 post-plant application; the number preceeding the PP represents the number of post-plant applications.

c. F represents furrow or flood irrigation.

d. S represents sprinkler irrigation.

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