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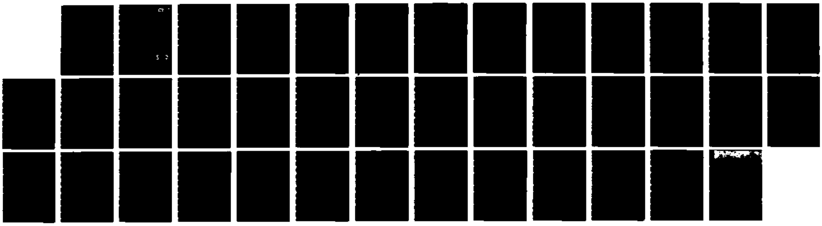

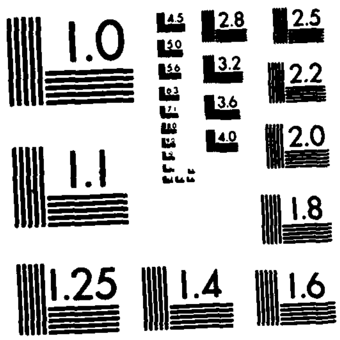

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Optimization model for land treatment planning, design and operation

Part II. Case study

J.A. Baron, D.R. Lynch and I.K. Iskandar

Prepared for
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A procedure to evaluate design and operating options for slow-rate land treatment systems is demonstrated. The nonlinear optimization model LTMOD is used to generate optimal monthly operating regimes (effluent application patterns) and to define optimal design configurations (combinations of storage capacity and irrigation area). The model is applied to a hypothetical slow-rate land treatment system in a cool, humid area with a forage crop, where the operation and design of the system is constrained by the potential for nitrogen renovation in the storage facility and in the soil-crop system. The cost properties over the

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range of optimal design alternatives are examined to deduce some general cost characteristics of slow-rate systems ranging from 0.5 to 10 mgd.

PREFACE

This report was prepared by Jaclyn A. Baron, graduate assistant, Dr. Daniel R. Lynch, Assistant Professor, both of Thayer School of Engineering, Dartmouth College, Hanover, New Hampshire, and Dr. Iskandar K. Iskandar, Research Chemist, Earth Sciences Branch, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire. The report is the second of a three-part series, "Optimization Model for Land Treatment Planning, Design and Operation." Part I (Baron et al. 1983) provides background information and a review of the land treatment optimization literature. This part presents a case study illustrating methods, results and sensitivity analysis. Details of the principal mathematical model and its realization in computer form (LTMOD) are presented in Part III (Baron and Lynch 1983).

This work has been supported by the U.S. Army Corps of Engineers under CWIS 31732, Land Treatment Management and Operation. This report was technically reviewed by Dr. A.O. Converse and Dr. T.J. Adler of the Thayer School of Engineering, Dartmouth College.

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OPTIMIZATION MODEL FOR LAND TREATMENT PLANNING, DESIGN AND OPERATION
PART II. CASE STUDY

Jaclyn A. Baron, Daniel R. Lynch and Iskandar K. Iskandar

OBJECTIVE

In this report the design and operation of a slow-rate land treatment system is examined. The case study involves a hypothetical facility in a cool, subhumid area where the primary objective is to minimize treatment costs. The principal analytical tool used is the nonlinear optimization model LTMOD (Baron and Lynch 1983). The intent of the case study is to illustrate the use of this model and its capabilities in land treatment studies, and to explore some general properties of land treatment design and operation problems.

LTMOD

The results reported here were generated by the nonlinear optimization model LTMOD. This model is an extension of the linear and dynamic programming models developed by Lynch and Kirshen (1981) and includes many of the basic features of these models in modified form. The principal physical, chemical and biological interactions (but not the economic features) of a slow-rate land treatment system are represented in LTMOD for a system comprising a storage lagoon with bypass option and a single-crop irrigation system (Fig. 1). An essential feature is the nonlinear nitrogen balance at the storage lagoon, permitting evaluation of the effect of lagoon management on the nitrogen renovation that occurs in this part of the system.

The model comprises a relatively simple set of equations, which are repeated for several periods over one year of operation and are sequentially linked. The principal mathematical constraints are:

1) Mass balances of water and nitrogen in lagoon storage during each period.
2) Mass balances of water and nitrogen at the irrigation site.
3) A limitation on soil drainage capacity at the irrigation site.
4) Environmental constraints on percolate nitrogen concentration during each operating period as well as on an annual average basis.
5) Specified crop response functions relating nitrogen uptake in any period to nitrogen applied during that period.

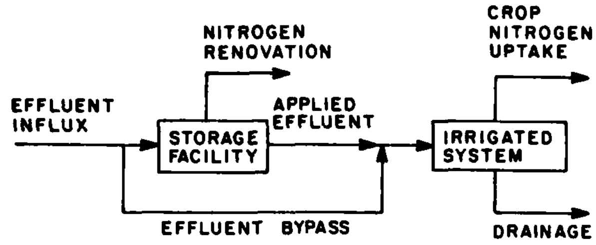

Figure 1. Simplified schematic of the land treatment system in LTMOD.

The model is suitable for use in a subhumid or humid climate where precipitation is normally sufficient to avoid a crop water deficit; it is assumed that the soil moisture storage does not change from one period to the next. The principal decision variables represented in LTMOD may be grouped into two categories: the operating schedule (the quantity of water from storage and/or bypass that is applied during each period) and design parameters (required irrigation area, storage volume and irrigation capacity).

Since the principal costs of a land treatment system are associated with the size of the storage lagoon and the irrigation area required, the optimization objective is to minimize a weighted sum of these two variables. In the application described here, one of these is held constant (e.g. land area), and LTMOD generates the minimum feasible value of the other (in this case, storage volume).

A one-month period is used, striking a balance between capturing the time-dependent behavior of the crop with respect to water and nitrogen requirements and uptake, and avoiding an excessive level of temporal detail requiring exorbitant data inputs. Furthermore, the leaching characteristics cannot be realistically represented accurately by a simple mass balance in shorter time spans, and the climatic parameters would lose meaning in the present deterministic framework. The monthly basis is also an appropriate time frame for making operating decisions.

The optimization is achieved by use of GRG2, a user-oriented, Fortran-coded optimization package developed in a joint effort by the University of Texas at Austin and Cleveland State University (Lasdon et al. 1978). The program solves nonlinear problems by the Reduced Gradient Method. The procedure can be started with either a feasible or infeasible set of initial values for the decision variables. The algorithm proceeds in two phases. In Phase 1 an objective function, which is a sum of constraint violations and optionally a fraction of the true objective function, is minimized. Phase 2 starts with the feasible solution that is either supplied by the user or found in Phase 1 and optimizes the true objective function. GRG2 computes first partial derivatives of each function (constraint) with respect to each variable at each point. These can be computed either by forward or central finite difference approximations or analytically if a subroutine is supplied by the user. The search direction is then determined by a variable metric method or by one of several conjugate gradient techniques from which the user can choose. A one-dimensional search is conducted in the indicated direction, the new solution point is found, and a new iteration begins. The program terminates when the Kuhn-Tucker optimality conditions are satisfied or when the fractional change in the objective function is small for several successive iterations. The solution indicates the value of each decision variable and whether it is basic, non-basic or superbasic, the value of each constraint and whether it is at a bound or free, and the reduced costs. Details of the LTMOD model are contained in Baron and Lynch (1983).

PHYSICAL CHARACTERISTICS OF THE SYSTEM

The model is applied to a hypothetical system with climate and crop data typical of central New Hampshire. The system configuration is similar to that in the case study by Reed and Bouzoun (1980) and draws on physical data from the study by Lynch and Kirshen (1981).

The monthly estimates of precipitation and evaporation for central New England are shown in Table 1. The soil is a sandy loam of moderate perme-

Table 1. Climatic data for Hanover, New Hampshire.

Month	Precipitation (cm)	Potential Evaporation (cm)
January	6.9	0.0
February	5.8	0.0
March	6.6	0.0
April	6.6	3.0
May	7.9	7.7
June	8.6	11.2
July	8.9	13.4
August	8.9	11.3
September	8.1	7.6
October	7.9	3.9
November	7.1	0.6
December	6.6	0.0

ability ($k = 1.25$ cm/hr) and a maximum hydraulic loading of approximately 20 cm/wk (Reed and Bouzoun 1980). A minimum storage capacity of 140 days is recommended in New England because of the cold conditions extending from mid-November through late March. Thus, with no winter application the application season is 225 days. During the winter months the precipitation is assumed to be snow, and the percolation of any precipitation occurring between these dates is deferred until April. In all other months the precipitation and effluent applied but not evapotranspired percolates in the same month. Irrigation efficiency, or the percent of applied effluent that does not evaporate or otherwise vanish before it reaches the soil-plant system and that is thus available for crop consumption and percolation, is assumed to be 100%.

With winter effluent application it has been shown that the thin ice cover created by spraying at the beginning of the cold season, when covered with snow and maintained until spring, can prevent the soil from freezing. In this case a quantity of water equal to the precipitation is assumed to percolate through the soil in each winter month, in addition to any effluent applied. The maximum drainage capacity of the soil is assumed to be unaltered during the cold period. This assumption is based on the successful winter application of 15 cm/wk at an experimental site in Hanover, New Hampshire (Iskandar et al. 1976). The minimum feasible storage capacity with the winter application option is set at one month's worth of the incoming effluent volume for purposes of flow equalization and emergency storage.

Thus, the range of feasible storage capacity and irrigation area options is bounded on one end by the minimum storage capacity based on the considerations described above, and on the other end by the minimum land area, defined by the maximum infiltration capability of the soil. For a 10-mgd system with no winter application, the minimum storage capacity is set at 5.352×10^6 m^3, and the minimum irrigation area (inserting 10 cm/wk maximum drainage to represent the half month of November) is 245 ha. With the winter application option the minimum storage capacity is 1.15×10^6 m^3, and the minimum irrigation area is 153 ha.

The nitrogen composition of the incoming effluent is 40 mg/L, a concentration typical of both primary and secondary municipal effluent. Nitrogen renovation in storage is assumed to follow first-order kinetics

(King 1978, Reed 1981). In all cases studied below, except those testing the sensitivity of the solutions to the nitrogen renovation potential in storage, the decay rate is taken as 0.0075 $days^{-1}$, yielding a 20% reduction in the nitrogen in the storage facility in each month during the period from April through November (Reed, in prep.). For testing the sensitivity to this parameter, an upper bound of 0.03 $days^{-1}$ is used, yielding a monthly nitrogen reduction of 60% (King 1978). In both cases the "warm" season decay rate is halved from December through March, based on data from a pond in Peterborough, New Hampshire (Reed, in prep.).

A mixed forage crop is grown on the entire irrigated area in all cases. The crop consumes moisture at the potential evapotranspiration rate throughout the growing season. This is likely to be the case in the northeast, where frequent precipitation, which normally precludes the need for irrigation, is supplemented by effluent application. The effluent applied under these conditions is expected to keep the soil near saturation over extended periods. The soil moisture conditions thus have no effect on crop yield in this case, as moisture deficits are highly unlikely. While crop yield depressions due to excess soil moisture may occur in land treatment systems, this effect is not accounted for in the present study.

The seasonal nitrogen uptake of the forage crop is represented by an exponential function fitted to experimental data:

$$N_p = 470 \, [1.0 - \exp(-b/470)]$$

where

N_p = seasonal nitrogen uptake (kg/ha)

b = applied nitrogen (kg/ha)

470 = maximum seasonal nitrogen uptake (kg/ha).

This functional form has classically been used to represent crop production functions and is known as the Mitscherlich equation in the agricultural literature. Comparison of these relationships to observed data is shown in Figure 2. This curve fits the available data quite adequately for the present purposes. The exponential form captures the high efficiency of nitrogen uptake in the nitrogen deficiency range, and the increased magnitude but lower efficiency of uptake at higher application levels.

The forage growing season extends from April to mid-September. The harvesting schedule producing the greatest seasonal nitrogen consumption

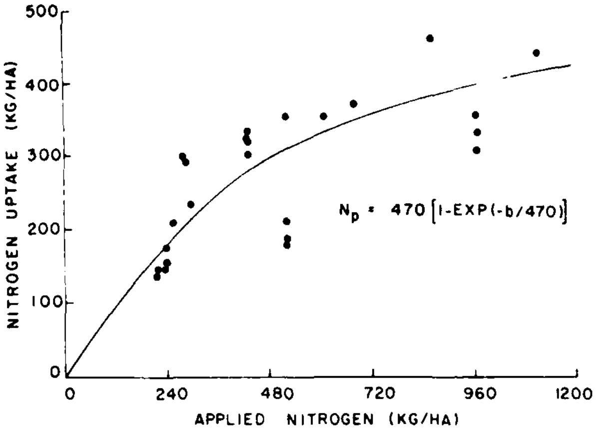

Figure 2. Comparison of seasonal forage nitrogen uptake function to experimental data. The data are from Larson et al. (1977), Clapp et al. (1978) and Palazzo and McKim (1978).

involves three cuttings: on or about July 1, August 15 and September 15 (Reed and Bouzoun 1980). The three cuts contain approximately 50%, 30% and 20% of the total seasonal forage nitrogen uptake, respectively. From these percentages and monthly uptake estimates in the Process Design Manual for Land Treatment of Municipal Wastewater (USEPA et al. 1981) based on data provided by Palazzo and Graham (1981), the portion of total seasonal uptake expected in each month was estimated (Table 2). The monthly percentages fluctuate due to the variable nitrogen uptake of the grasses at different points in their growing cycle. The monthly crop nitorgen uptake is assumed to parallel the total seasonal uptake behavior, and is represented by similar exponential functions in which the maximum seasonal uptake is multiplied by the appropriate monthly percentage.

Ammonia volatilization and denitrification at the irrigation site are assumed to be negligible. In slow-rate systems these losses have been found to range from negligible to 15%. The soil nitrogen storage is assumed to be in a state of equilibrium, and there is no net transfer from organic to inorganic species. Only the nitrogen applied in the effluent is available for crop uptake and leaching, and all of this nitrogen is available. The nitrogen applied but not consumed by crops in each month is assumed to leach in that same month during the period from April to

Table 2. Estimated monthly percentages of seasonal nitrogen uptake by forage.

Month	Percent
January	0
February	0
March	0
April	15
May	20
June	15
July	20
August	20
September	10
October	0
November	0
December	0

November. When winter application is considered, winter leaching characteristics are based on data from an experimental site in Hanover, New Hampshire (Iskandar et al. 1976), in which the applied nitrogen is adsorbed on the soil as ammonium in the cold months and leached as nitrate and ammonium in May and June. The concentration of the nitrogen in the percolate in the cold months at any effluent application level is fixed at the average value of 5 mg/L observed at the site. Of the remaining total winter application, 20% is assumed to leach in May, 40% in June, and 40% in July. These percentages are also estimated from the behavior of the experimental system.

SYSTEM COMPONENTS AND COSTS

The components of the slow-rate land treatment system include:

1) A partial-mix aeration cell for partial biological stabilization of the effluent for odor control, sized for an average detention time of three days. Pathogen die-off in storage is sufficient to require no disinfection or further pretreatment.

2) A storage reservoir 12 feet deep with an asphalt lining.

3) A center-pivot sprinkling system with a main pipe down the center of the site for transporting the effluent from storage.

4) Service roads and fencing surrounding the entire site.

5) Administrative and laboratory facilities.

6) Monitoring wells, 20 feet deep, on 500-feet centers, down gradient from site.

The facility requires enough land for the irrigated area plus 15% for roads and unused areas, a 50-foot buffer zone surrounding the site, and the pretreatment and storage facilities.

The total system costs include the capital and operating expenses associated with the components listed above, the cost of clearing and leveling the land (assumed to have brush and some trees), the price of the land, and engineering and legal fees. The cost of pumping and transporting effluent to the land treatment site are excluded. Many of these are fixed costs, so they do not affect the choice of the optimal storage-land combination. (These costs may, however, affect the attractiveness of land treatment over conventional treatment, which may be located closer to the wastewater source.) For simplicity it is assumed that profits from the sale of the forage balance the costs of its management and that the net revenue is zero.

The entire system may be sized and assessed knowing three design parameters: the irrigation area, the capacity of the storage facility, and the maximum monthly irrigation volume. Approximate pipe sizes are estimated based on a pumping head of 150 feet. Engineering and legal services are estimated to add 30% to the capital cost of the system. The financial life of the project is 20 years, and operating expenses are amortized over this period at a 7% interest rate. Slow-rate land treatment requires suitable farmland assumed to be priced at $2500/acre, with a 3% appreciation rate. The salvage value of the land is also amortized at 7%. All land treatment cost curves and data are from <u>Cost of Land Treatment Systems</u> (Reed et al. 1979).

All costs are updated to 1981 dollars based on the EPA Construction Cost Inflation Index. The costs were calculated using the program COSTLT (Appendix A).

CASE STUDY RESULTS

<u>Base case</u>

As a starting point a 10-mgd design was considered, using the hydrologic and climatic conditions elaborated above. The percolate nitrogen concentration was restricted to 10 mg/L or less on an annual average basis. No requirements were imposed on the monthly percolate quality, and the bypass option was not considered. LTMOD was used to find the minimum

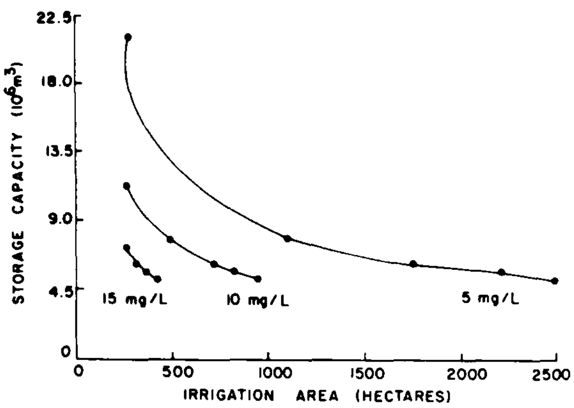

Figure 3. Optimal storage-land combinations for the base case (10 mgd). The annual average percolate nitrogen concentrations are limited to the values shown.

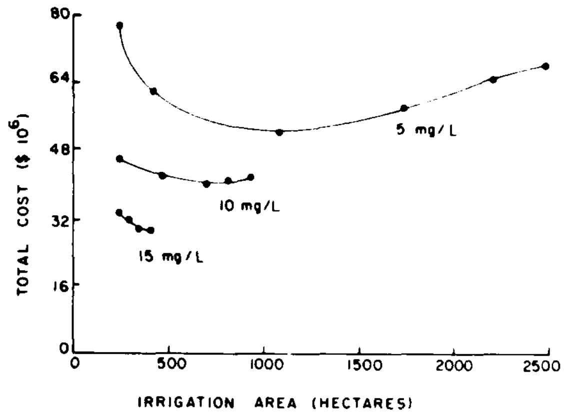

Figure 4. Cost of optimal design configurations for the base case (10 mgd). The annual average percolate nitrogen concentrations are limited to the values shown.

required storage capacity and the associated monthly operating schedule for a given irrigation area. Repeating this procedure for a range of values of irrigation area generated a set of optimal land-storage combinations, which are plotted in Figure 3. The minimum land area of 245 ha (based on soil drainage capacity) requires a storage capacity of 11.42×10^6 m^3 (302 days), and the minimum storage capacity of 5.35×10^6 m^3 (141 days) requires an irrigated area nearly four times as large, or 920 hectares.

When the land area is small, the curve is steep, requiring large increases in the storage capacity to further diminish the irrigated area; when the irrigated area is large, small increases in the storage capacity greatly reduce the required area. The mutual effects of storage and area are less drastic in the middle of the range. This is true for all of the situations considered here.

The total system costs associated with the design configurations in Figure 3 were calculated using COSTLT (Fig. 4). The lowest cost solution ($39.7 million) lies at an intermediate irrigation area of about 700 ha. Moreover, the change in the cost of the system does not vary by a large percentage (the variation is less than $1.5 million) over a wide range of land area options (from 470 to 930 ha) around this point. The cost variation over the entire range does not exceed $6 million, this being the penalty for choosing the smallest area rather than the lowest cost design.

Scale effects

The base-case, 10-mgd system is clearly on the large end of the spectrum, particularly for land treatment. Intuitively one might expect that the optimal storage-land combinations for the 10-mgd system may be scaled up or down and applied to systems of any other incoming flow rate. For example, if the incoming flow and the storage capacity are both cut by half, the residence time of the effluent in storage, and thus the potential for nitrogen renovation in storage, remains unchanged. The LTMOD equations (Baron 1982) confirm that there are no scale effects, i.e. the entire set of calculations scale linearly with incoming flow rate. Under these conditions, both the average residence time (the ratio of storage capacity to incoming flow rate) and the ratio of storage capacity to irrigation area are independent of facility size. Thus the optimal storage-land combinations presented in Figure 3 for the 10 mgd system may be normalized, and the resulting curve (Fig. 5) is applicable to any facility size.

Although the physical features scale linearly with size, the cost curves do not, and thus economic comparisons must be done with specific reference to facility size. Figures 6-8 illustrate the costs of the various designs for smaller facilities. The lowest cost designs are \$20.7, \$5.1 and \$3.1 million for the 5-, 1- and 0.5-mgd systems, respectively. Each minimum cost solution occurs at nearly the same storage-land ratio as did the minimum cost design of the 10-mgd system. The roughly parallel

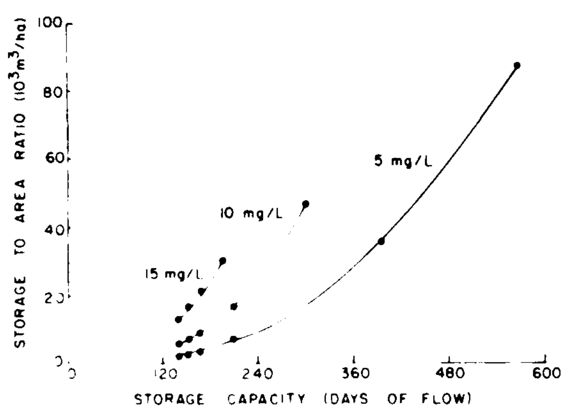

Figure 5. Normalized optimal storage-land ratios for slow-rate land treatment systems with constraints on the average annual nitrogen concentration in the percolate.

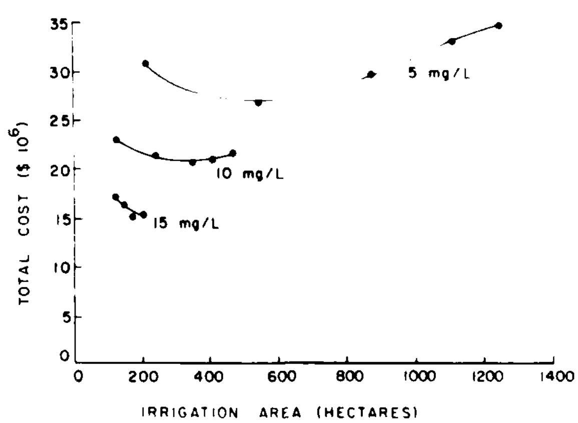

Figure 6. Cost of optimal design configurations for a 5-mgd system with constraints on the average annual nitrogen concentration in the percolate.

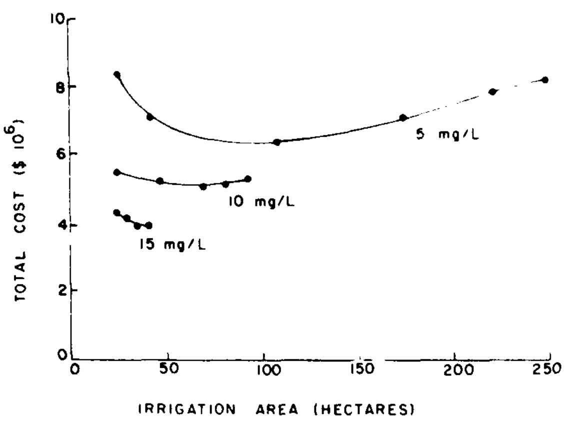

Figure 7. Cost of optimal design configurations for a 1-mgd system with constraints on the average annual nitrogen concentration in the percolate.

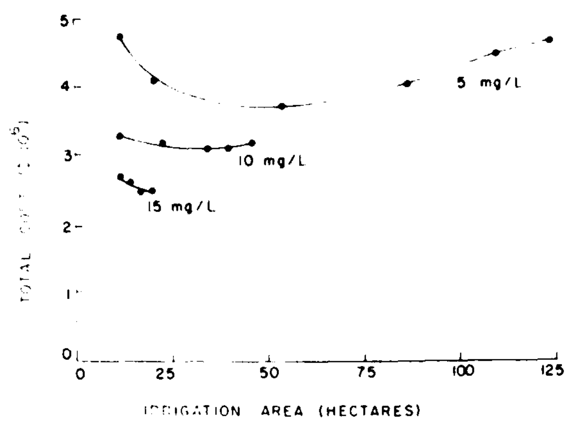

Figure 8. Cost of optimal design configurations for a 0.5-mgd system with constraints on the average annual nitrogen concentration in the percolate.

cost curves and the fact that the least-cost alternative occurs at similar storage-area ratios for the different system sizes are features shared by all the situations considered here.

Tightening the environmental constraints

The optimal design configurations for the 10-mgd facility with annual percolate nitrogen concentration limits at 5 and 15 mg/L are also shown in Figure 3. As the required level of water treatment is increased, the "tails" of the curve elongate; large increases in the storage capacity are required to reduce the land area when the area is small, and further reductions in a relatively small storage facility have an exaggerated effect on the required irrigated area. At the 5-mg/L level the storage required with the minimum land area is approximately twice that needed to meet the 10-mg/L constraint. The irrigated area with the minimum storage is over 2.5 times as large. The result is a larger variation in the costs along the range of alternatives. This variation is approximately $3 million for the 15-mg/L constraint and $16 million for the 5-mg/L constraint. As the required level of treatment is increased, there is also a distinct shift toward lowered costs with higher storage-land ratios. The lowering of costs with less land continue until the storage requirements become very steep, when the costs shoot up, resulting in the most expensive design in each case.

The costs associated with the 15- and 5-mg/L requirements are shown in Figure 4. The lowest cost designs for each of these cases are $29 million and $51.7 million, respectively. Thus, the increase in cost associated with removing each additional 5 mg/L from the percolate is a substantial $10 million.

Figure 5 shows the normalized physical results for the range of percolate quality constraints; the cost effects for 5.0-, 1.0- and 0.5-mgd facilities are shown in Figures 6-8.

The optimal design alternatives with monthly nitrogen concentration limits imposed in addition to the annual 10 mg/L constraint are shown in Figure 9. The elongation of the curves near the endpoints becomes even more prominent when the monthly constraints are tightened. The irrigated area associated with the minimum 140-day storage capacity is increased to roughly 1.5, 2.5 and 5 times the base case value for the 20-, 15- and 10-mg/L monthly constraints, respectively. The variation of cost (Fig. 10) along the range of alternatives is magnified, and the penalties for designing systems at other than the optimal point can be much more severe. The difference in cost between the "best" and "worst" configurations with the 10 mg/L monthly constraint is approximately $53 million, which is more than the total cost of the cheapest alternative.

The lowest cost solutions for all of the monthly constrained cases lie within the same narrow range of large storage-land ratios. Again, the cost

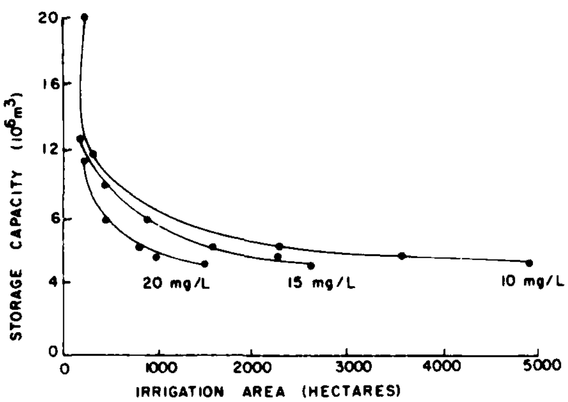

Figure 9. Optimal storage-land combinations for the 10-mgd system with monthly constraints on the nitrogen concentration in the percolate in addition to a 10-mg/L constraint on the average annual concentration.

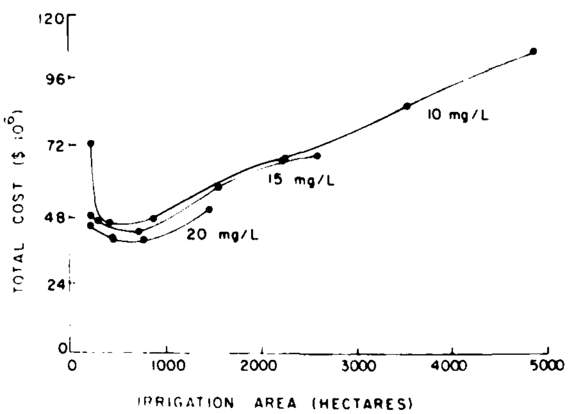

Figure 10. Cost of optimal design configurations for the 10-mgd system with monthly constraints on the nitrogen concentration in the percolate in addition to a 10-mg/L constraint on the average annual concentration.

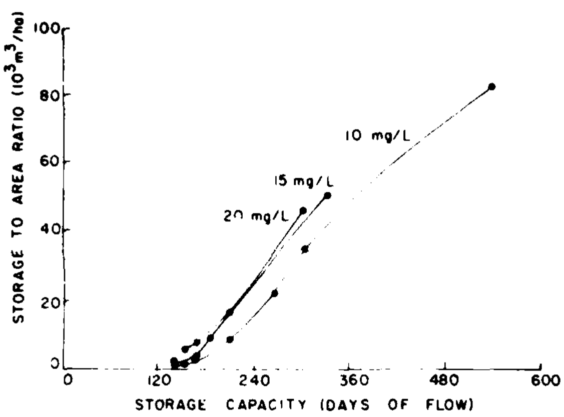

Figure 11. Normalized optimal storage-land ratios with monthly constraints on the nitrogen concentration in the percolate in addition to the 10-mg/L constraint on average annual concentration.

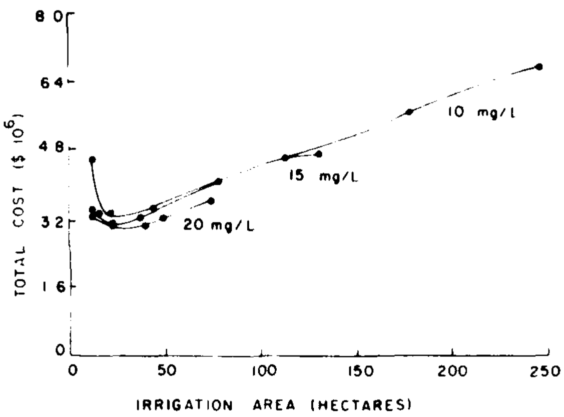

Figure 12. Cost of optimal design configurations for a 0.5-mgd system with monthly constraints on the nitrogen concentration in the percolate in addition to the 10-mg/L constraint on the average annual concentration.

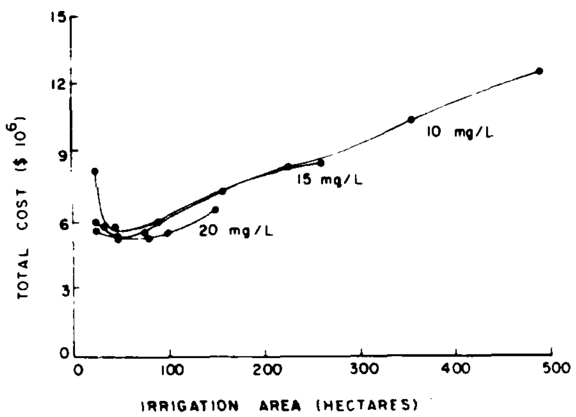

Figure 13. Cost of optimal design configurations for a 1-mgd system with monthly constraints on the nitrogen concentration in the percolate in addition to the 10-mg/L constraint on the average annual concentration.

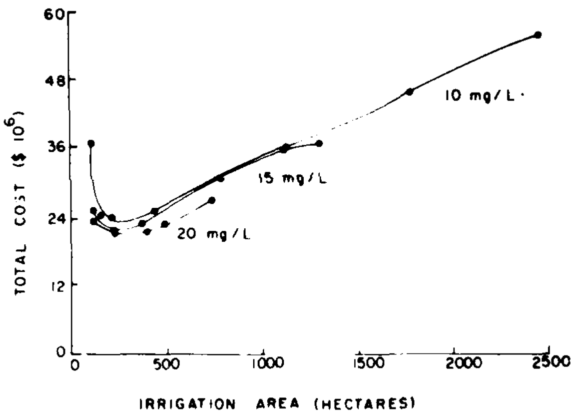

Figure 14. Cost of optimal design configurations for a 5-mgd system with monthly constraints on the nitrogen concentration in the percolate in addition to the 10-mg/L constraint on the average annual concentration.

decreases as the irrigation area becomes smaller, until a point is reached where the required storage shoots up sharply. Although the cost increases incurred by tightening the monthly constraints are tremendous when the area is large, the differences between the lowest cost solutions are less significant. The lowest cost designs range from $40.3 million with the 20-mg/L monthly constraint to $47 million at the 10-mg/L level.

The results for smaller plants show the same trends. The normalized storage-land curve is shown in Figure 11, and costs for smaller systems are shown in Figures 12-14.

Sensitivity to nitrogen renovation in storage

The optimal 10-mgd design configurations and their associated costs with a monthly 15-mg/L constraint and with higher estimates of the storage renovative capacity than in the base case are shown in Figures 15 and 16. As the storage renovative ability increases, the "tails" on the curves shrink, and at the highest renovation level the relationship of storage capacity to area is nearly linear over the entire feasible range. The cost variation over the range of alternatives ($6 million) is small compared to the cost variation of the base case alternatives ($27 million). The lowest cost solutions with the higher nitrogen renovation in storage are the ones that combine the required storage capacity with the smallest, or nearly the smallest, irrigation area. The lowest cost alternative with twice the storage renovative capacity ($32.3 million) is $11 million less and requires about 200 ha less area than the lowest cost solution with the base case conditions ($43.1 million).

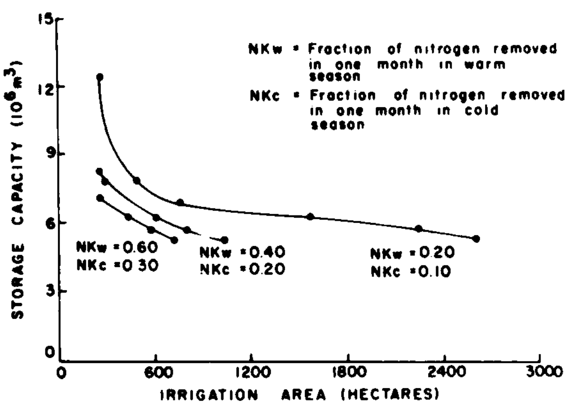

Figure 15. Optimal storage-land combinations for 10-mgd systems with varying potential for nitrogen renovation in storage with 10-mg/L annual and 15-mg/L monthly constraints on the nitrogen concentration in the percolate.

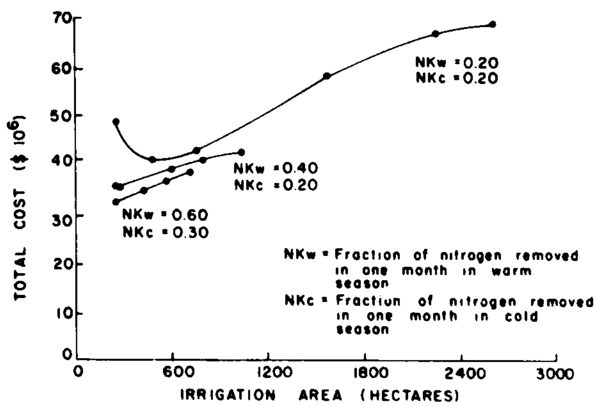

Figure 16. Cost of optimal design configurations for a 10-mgd system with varying potential for nitrogen renovation in storage with 10-mg/L annual and 15-mg/L monthly constraints on the nitrogen concentration in the percolate.

Benefits of the bypass option

The optimal design configurations and costs of the base case are compared with those obtained with bypass and winter operating options (with various environmental constraints) in Figures 17-24. When the nitrogen concentration in the percolate is constrained on an annual basis, the bypass is not used in the model solutions, and thus the option does not alter the design configurations or system costs. Even though the nitrogen applied in the effluent could be better synchronized with the crop nitrogen demand, the gain in treatment efficiency on the land is balanced by the loss of nitrogen renovation in storage. The renovation in storage is proportional to the concentration in the facility, which is maintained lower when it is bypassed. The bypass options become a bit more attractive when the monthly environmental constraints are imposed and tightened. The slightly lower nitrogen concentration maintained in the storage facility allows increased effluent application in periods of low crop nitrogen uptake. The bypass option reduces the area required when the storage facility is small. When the storage is large, the bypass makes little difference in the storage nitrogen concentration, and has negligible effects on the system configuration and costs. Since the lowest cost (and smaller area) designs lie near this end of the range, the option to bypass the storage facility seems to be of little consequence in improving land treatment design.

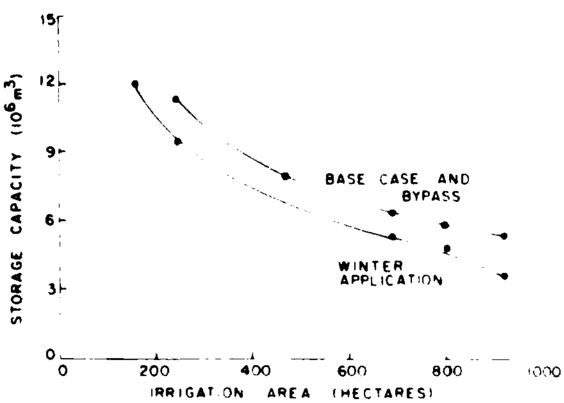

Figure 17. Optimal storage-land combinations for the base case, bypass and winter application options for a 10-mgd system with a 10-mg/L constraint on the nitrogen concentration in the percolate.

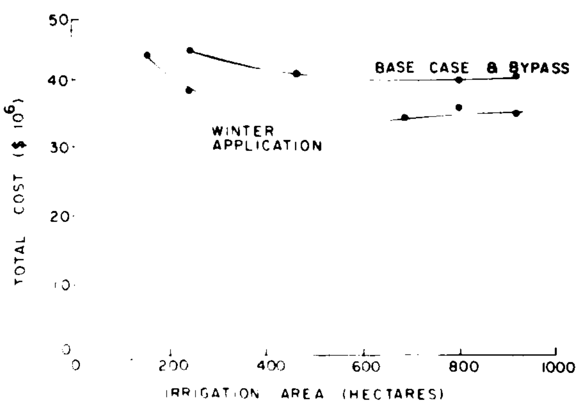

Figure 18. Cost of optimal design configurations for the base case, bypass and winter application options for a 10-mgd system with a 10-mg/L constraint on average annual nitrogen concentration in the percolate.

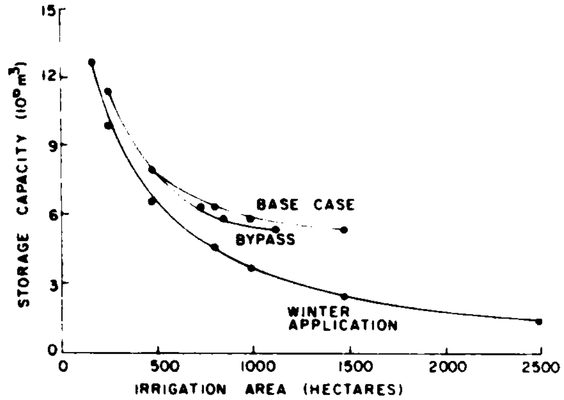

Figure 19. Optimal storage-land combinations for the base case, bypass and winter application options for a 10-mgd system with 10-mg/L annual and 20-mg/L monthly constraints on nitrogen concentration in the percolate.

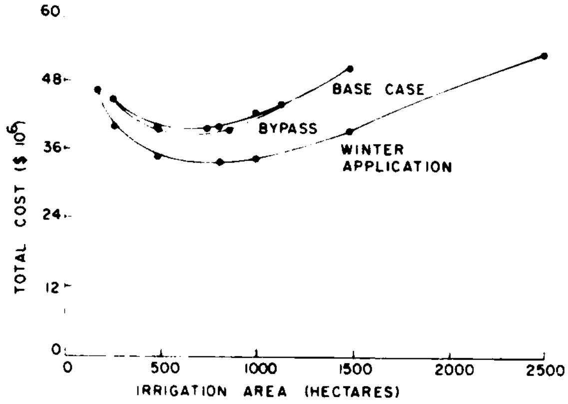

Figure 20. Cost of optimal design configurations for the base case, bypass and winter application options for a 10-mgd system with 10-mg/L annual and 20-mg/L monthly constraints on nitrogen concentration in the percolate.

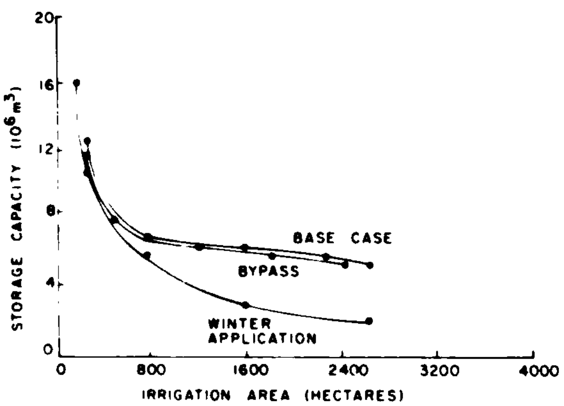

Figure 21. Optimal storage-land combinations for the base case, bypass and winter application options for a 10-mgd system with 10-mg/L annual and 15-mg/L monthly constraints on nitrogen concentration in the percolate.

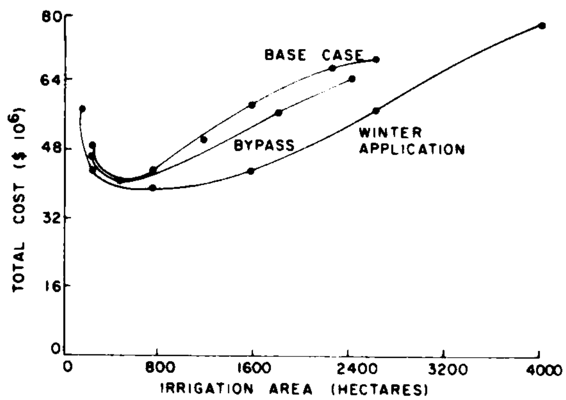

Figure 22. Cost of optimal design configurations for the base case, bypass and winter application options for a 10-mgd system with 10-mg/L annual and 15-mg/L monthly constraints on nitrogen concentration in the percolate.

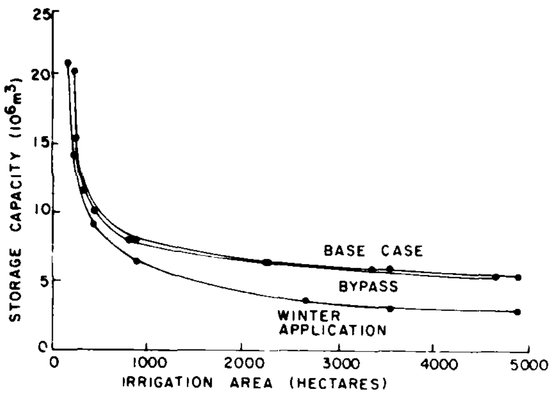

Figure 23. Optimal storage-land combinations for the base case, bypass and winter application options for a 10-mgd system with 10-mg/L annual and 10-mg/L monthly constraints on nitrogen concentration in the percolate.

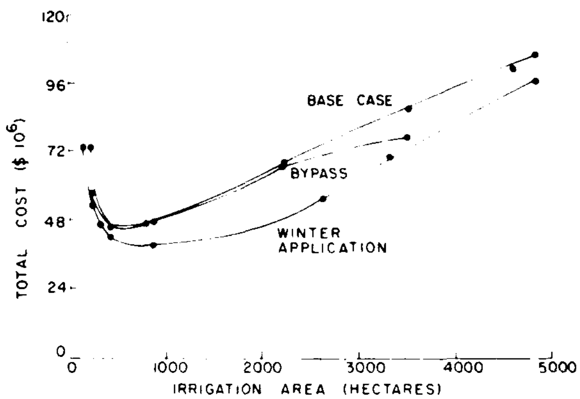

Figure 24. Cost of optimal design configurations for the base case, bypass and winter application options for a 10-mgd system with 10-mg/L annual and 10-mg/L monthly constraints on nitrogen concentration in the percolate.

Benefits of winter application

The model results indicate that if winter effluent application is at all feasible in an area, it is worth investigating. For the base case with an annual average 10-mg/L nitrogen constraint in the percolate, the lowest cost 10-mgd design with winter application is at least $5 million less than the $39.7-million cost without the winter option. Moreover, the cost of systems with small irrigation areas is decreased by the winter application. For example, the cost of the design using 245 ha (the minimum area without winter application) is decreased by $6 million to $39 million. This cost is in fact lower than the lowest cost (700 ha) base-case design (Fig. 25-28).

The winter application designs with the monthly nitrogen constraints maintain their superiority along the range of areas possible for the base case. In other words the storage needed at each irrigation area is significantly less and the costs are lower than without the winter application. In these cases the winter and base case curves are both shifted, so the lowest cost designs for both appear at the relatively high storage-land ratios. In contrast to the bypass option, the advantage of the winter options decreases as the monthly environmental constraints are imposed and tightened. This is because the winter application is limited by the

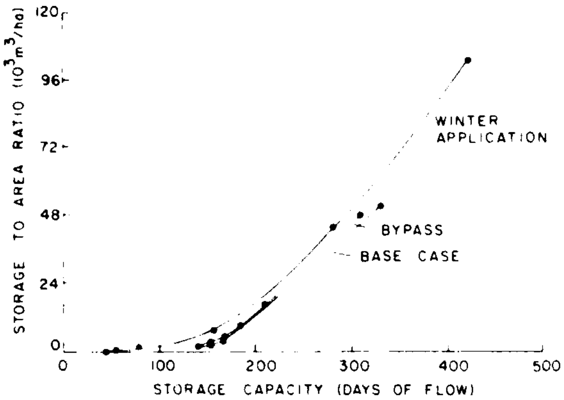

Figure 25. Normalized optimal storage-land ratios with 10-mg/L annual and 15-mg/L monthly constraints on nitrogen concentration in the percolate for the base case, bypass and winter application options.

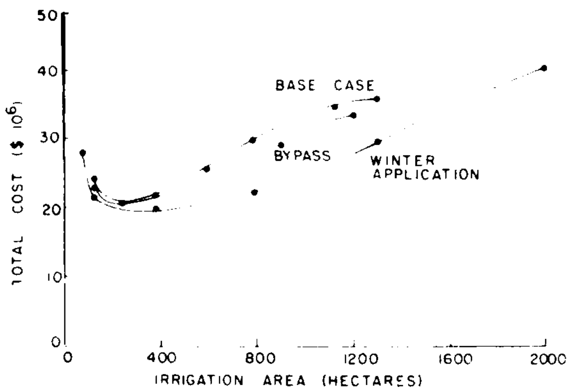

Figure 26. Cost of optimal design configurations for the base case, bypass and winter application options for a 5-mgd system with 10-mg/L annual and 15-mg/L monthly constraints on nitrogen concentration in the percolate.

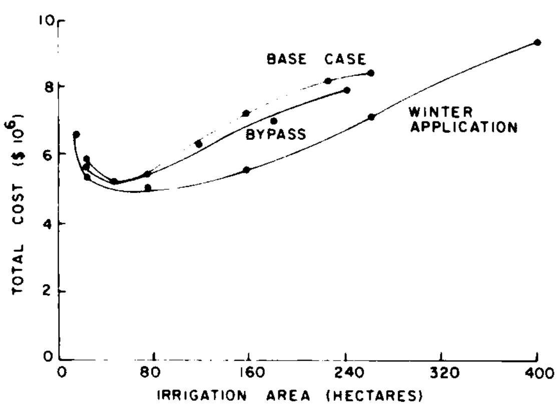

Figure 27. Cost of optimal design configurations for the base case, bypass and winter application options for a 1-mgd system with 10-mg/L annual and 15-mg/L monthly constraints on nitrogen concentration in the percolate.

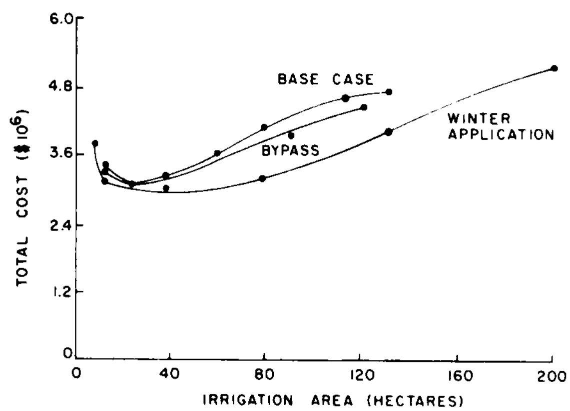

Figure 28. Cost of optimal design configuration for the base case, bypass and winter application options for a 0.5-mgd system with 10-mg/L annual and 15-mg/L monthly constraints on nitrogen concentration in the percolate.

tighter constraint on the early summer months, when a portion of the nitrogen applied in the winter is assumed to leach. With the winter application there is also a point (as in the base case) where further decreases in irrigation area must be accompanied by a large increase in storage capacity and cost. The designs using less irrigation area than would be possible without the winter application fall into this category. The designs utilizing less than the minimum 140 days of storage capacity required by the base case are also unattractive compared to the base case options and the other winter options because of the greatly expanded irrigation area that they require.

Breakdown of costs

Detailed breakdowns of the capital costs, operating expenses and present worth of the components for various optimal storage-land combinations of the base case with the 10-mg/L annual and the 15-mg/L monthly constraints on nitrogen concentration in the percolate are shown in Tables 3, 4 and 5 for 1-, 5- and 10-mgd systems, respectively. The storage facility, the irrigation system and the purchase of land are all major costs in designs with low storage-land ratios. As the storage-land ratio is increased and the lowest cost design is approached, the decrease in the costs of all of the components that depend on the area (especially the irrigation system) more than compensates for the increase in storage costs. Beyond the lowest cost point, the continued rise in storage costs overtakes the further decreases in the land-dependent components. At even moderately high storage-land ratios, the cost of the storage facility far exceeds the cost of any of the other individual land treatment components.

Operating costs are highly dependent on the area and continue to decrease along the entire range as the storage-land ratio increases. For the 10-mgd system with the minimum storage capacity, the operating costs account for 22% of the total. In the design with the minimum feasible irrigation area, the operating contribution shrinks to 11%. The reduction in the ratio of operating to capital costs is sufficiently large to cause the local share of the cost of the lowest cost design to be higher than the local share of the cost for the more expensive, higher storage design. (The local share is 15% of the capital cost plus 100% of the present worth of the operating cost.)

Table 3. Detailed costs of optimal design configurations for a 1-mgd system.

CONFIGURATION												
Storage capacity ($10^6 m^3$)(days)	0.5352(141)			0.6359(168)			0.700(185)			1.2556(332)		
Irrigation area (ha)	261.3			157.1			75.3			24.5		
Total land (ha)	327			207			112			66		
Irrigation capacity (in./wk)	1.5			3.9			4.7			7.5		
COSTS ($\$10^3$)	CAP*	OP*	PW*	CAP	OP	PW	CAP	OP	PW	CAP	OP	PW
Storage facility	1243	6	1303	1450	6	1517	1581	7	1653	2706	10	2815
Service roads and fencing	405	12	533	296	8	384	197	5	251	141	4	178
Administration and laboratory	111	15	271	111	15	271	111	15	271	111	15	271
Monitoring wells	15	2	40	12	2	32	9	1	23	7	1	18
Center-pivot sprinkler system	837	110	2002	466	71	1218	212	34	569	86	16	252
Site clearing and grading	670	-	670	441	-	441	252	-	252	158	-	158
Transmission from storage to site	269	0.7	276	209	0.5	214	144	0.4	148	82	0.2	84
Pumping from storage to site	419	33	768	541	50	1,069	397	30	715	293	17	467
Preapplication treatment	98	18	291	98	18	291	98	18	291	98	18	291
Capital subtotal	4066			3622			3000			3682		
Engineering and legal services	1220			1087			900			1105		
Land purchase	1074			681			368			218		
Total	6,360	197	8447	5390	171	7203	4269	111	5440	5005	80	5856
Local share of the cost			3040			2620			1816			1598

* CAP = Capital

OP = Operating

PW = Present worth

Table 4. Detailed costs of optimal design configurations for a 5-mgd system.

CONFIGURATION												
Storage capacity ($10^6 m^3$)(days)	2.676(141)			3.1795(168)			3.500(185)			6.27835(332)		
Irrigation area (ha)	1,307			786			377			123		
Total land (ha)	1,601			1,011			543			322		
Irrigation capacity (in./wk)	1.5			3.9			4.7			7.5		
COSTS ($\$10^3$)	CAP*	OP*	PW*	CAP	OP	PW	CAP	OP	PW	CAP	OP	PW
Storage facility	5,583	18	5,774	6,613	21	6,830	7,271	22	7,506	13,085	35	13,453
Service roads and fencing	1,327	50	1,857	926	33	1,272	582	19	781	401	12	527
Administration and laboratory	213	32	554	213	32	554	213	32	554	213	33	554
Monitoring wells	33	5	88	26	4	70	19	3	51	15	2	39
Center-pivot sprinkler system	4,911	455	9,728	2,845	289	5,903	1,264	151	2,865	349	58	957
Site clearing and grading	2,930	-	2,930	1,907	-	1,907	1,072	-	1,072	665	-	665
Transmission from storage to site	1,044	3	1,070	809	2	830	560	1	574	320	0.8	328
Pumping from storage to site	1,221	149	2,795	1,768	228	4,178	1,127	135	2,556	701	73	1,472
Preapplication treatment	260	63	922	260	63	922	260	63	922	260	63	922
Capital subtotal	17,522			15,367			12,369			16,007		
Engineering and legal services	5,257			4,610			3,711			4,802		
Land purchase	5,273			3,327			1,789			1,059		
Total	28,051	774	36,249	23,304	670	30,402	17,869	426	22,381	21,869	275	[illegible]
Local share of the cost			12,407			10,593			7,193			6,193

* CAP = Capital

OP = Operating

PW = Present worth

Table 5. Detailed costs of optimal design configurations for a 10-mgd system.

CONFIGURATION												
Storage capacity ($10^6 m^3$)(days)	5.352(141)			6.359(168)			7.000(185)			12.556(332)		
Irrigation area (ha)	2,613			1,571			753			245		
Total land (ha)	3,188			2,010			1,079			639		
Irrigation capacity (in./wk)	1.5			3.9			4.7			7.5		
COSTS ($\$10^3$)	CAP*	OP*	PW*	CAP	OP	PW	CAP	OP	PW	CAP	OP	PW
Storage facility	11,126	31	11,451	13,256	35	13,629	14,625	38	15,026	26,839	60	27,475
Service roads and fencing	2,333	97	3,364	1,593	62	2,251	974	35	1,341	656	22	885
Administration and laboratory	305	46	791	305	46	791	305	46	791	305	46	791
Monitoring wells	47	7	124	37	6	99	27	4	72	21	3	56
Center-pivot sprinkler system	10,121	852	19,147	5,965	537	11,652	2,718	278	5,663	778	104	1,880
Site clearing and grading	5,598	-	5,598	3,625	-	3,625	2,025	-	2,025	1,250	-	1,250
Transmission from storage to site	1,845	4	1,889	1,430	3	1,464	990	2	1,014	565	1	578
Pumping from storage to site	2,198	288	5,251	3,344	443	8,038	2,006	261	4,774	1,161	140	2,642
Preapplication treatment	433	111	1,610	433	111	1,610	433	111	1,610	433	111	1,610
Capital subtotal	34,006			29,989			24,103			32,007		
Engineering and legal services	10,202			8,997			7,231			9,602		
Land purchase	10,500			6,619			3,553			2,104		
Total	54,708	1,437	69,927	45,605	1,243	58,755	34,887	775	43,100	43,713	487	48,873
Local share of the cost			23,429			20,008			13,443			11,715

* CAP = Capital

OP = Operating

PW = Present worth

SUMMARY AND CONCLUSIONS

From the preceding analyses the following conclusions may be drawn:

1) Evaluating the full range of feasible design alternatives is important in sound slow-rate system planning. While the costs of different storage-land alternatives can vary quite significantly, the cost variation can be very small between design alternatives with very different land requirements and application rates. In general the lowest cost design configurations are between the two extremes of highest storage with lowest irrigation area and lowest storage with highest irrigation area. In most cases the lowest cost design had a relatively small irrigation area; thus, reducing the irrigation area (and increasing the capacity of the storage facility) in many cases will reduce the total system cost. The cost characteristics over the range of feasible design options were similar for small and large systems.

2) In many areas (humid regions in particular) land availability is at least as important as cost in planning and designing land treatment systems. The cost characteristics of a range of optimal storage-land configurations are useful in gauging the attractiveness of alternatives with very different resource requirements. Additionally, if the cost differences between dissimilar options are not large, non-economic reasons may become more important in making decisions.

3) The option to bypass the storage facility does not significantly improve slow-rate land treatment design possibilities. Although a bypass reduces the area required when the storage facility is small, the lowest cost designs have relatively high storage capacities, and the bypass option has little effect.

4) If winter application is at all feasible, it is an option well worth investigating. The storage capacity required with each particular irrigation area is lower when effluent is applied during the winter months, and winter application may result in considerable cost savings.

5) Tightening the environmental constraints has a large influence on the feasible slow-rate system designs and cost. The cost increases associated with lowering the permissible annual and monthly nitrogen concentrations in the percolate are significant, and they are exaggerated in the more expensive, suboptimal configurations.

In the course of this project, several areas have been identified in which further research would improve subsequent modeling efforts.

1) We need a deeper understanding of the behavior of the nitrogen applied to the soil-crop system during the winter. The adsorption and leaching characteristics should be related to the quantity and timing of nitrogen application.

2) We need more detailed representation of the soil moisture balance, especially in the winter. If effluent is not applied in the winter, what fraction of time is the soil frozen? What percentage of the winter precipitation is rain, and how much of the rain runs off? What percentage of the precipitation is snow and will percolate in the spring? If effluent is applied in the winter, how are the drainage properties of the system altered? Finally, how does the soil moisture balance interact with the nitrogen transformations?

3) In most cases, the more attractive design alternatives generated by the model involve less irrigation area, and thus higher effluent application rates, than have usually been associated with slow-rate systems. The behavior of the other contaminants in the system at these rates bear investigation to ensure that nitrogen remains the limiting environmental concern. The persistence of the crop grown on the site and its continuing ability to consume high amounts of nitrogen at high application rates is another area that should be thoroughly analyzed in a specific application.

4) The interactive use of LTMOD with simulation models that predict the behavior of water, nitrogen and contaminants in the soil system of slow-rate land treatment systems is called for in actual design work. At the least, simulation models should be used to check in detail the feasibility of results generated by LTMOD or any similar optimization model.

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APPENDIX A: COSTLT PROGRAM

```
COSTLT    30 Dec 82  15:41

* LAND TREATMENT COSTS
*
DIMENSION CAP(6)
DATA CAP(1),CAP(2),CAP(3),CAP(4),CAP(5),CAP(6) /1.0,.5,.2,.1,.05,.02/
DATA N /11/
PRINT 5, N
5 FORMAT(I3)
DATA SVOLO /5352000/
DATA AO /2965.2/
DATA PLAND /2500.0/
DATA APPMAX /2.4/
DATA CROPRO /317.2/
DATA MET /1/
DO 100 I=1,6
FLOW=10.0*CAP(I)
CROPR=CROPRO*CAP(I)
*
* STORAGE FACILITY
*
SVOLM=SVOLO*CAP(I)
SVOLG=SVOLM/3785.0
IF(SVOLG.LT.10.0)
A=5.09*(10.0**(.0232*LOG10(SVOLG)*LOG10(SVOLG)+.542*LOG10(SVOLG)))
B=5.24*(10.0**(.0105*LOG10(SVOLG)*LOG10(SVOLG)+.754*LOG10(SVOLG)))
C=7.92*(10.0**(-.0754*LOG10(SVOLG)*LOG10(SVOLG)+.559*LOG10(SVOLG)))
E=SVOLG*134.9*(10.0**(-.00305*LOG10(SVOLG)*LOG10(SVOLG)-.661*LOG10(SVOLG)))
F=SVOLG*70.8*(10.0**(.0419*LOG10(SVOLG)*LOG10(SVOLG)-.577*LOG10(SVOLG)))
ELSE
A=3.30*(10.0**(.0360*LOG10(SVOLG)*LOG10(SVOLG)+.651*LOG10(SVOLG)))
B=3.95*(10.0**(.0402*LOG10(SVOLG)*LOG10(SVOLG)+.814*LOG10(SVOLG)))
C=12.6*(10.0**(.106*LOG10(SVOLG)*LOG10(SVOLG)+.212*LOG10(SVOLG)))
E=SVOLG*151.3*(10.0**(-.00637*LOG10(SVOLG)*LOG10(SVOLG)-.643*LOG10(SVOLG)))
F=SVOLG*24.5*(10.0**(-.00515*LOG10(SVOLG)*LOG10(SVOLG)-.125*LOG10(SVOLG)))
ENDIF
SCAP=A+B+C
SCAPU=2.1657*SCAP
SOP=E+F
SOPU=.0021657*SOP
SOPAM=SOPU/.0944
PWSTOR=SCAPU+SOPAM
*
* LAND PURCHASE
*
AR=AO*CAP(I)
ARA=1.15*AR
ARB=((ARA*43562.97)**.5)+100
ARIRR=(ARB**2)/43562.97
ARSTOR=SVOLM/3.6576*.0002471
ARTOT=ARIRR+ARSTOR+9*CAP(I)
PWLAND=.000533*PLAND*ARTOT
*
* SERVICE ROADS AND FENCING
*
RDCAP=2.33*(10.0**(.00984*LOG10(ARTOT)*LOG10(ARTOT)+.474*LOG10(ARTOT)))
FNCAP=2.05*(10.0**(.0645*LOG10(ARTOT)*LOG10(ARTOT)+.420*LOG10(ARTOT)))
RAFCAPU=2.1657*(RDCAP+FNCAP)
RDOP=ARTOT*20.4*(10.0**(.0168*LOG10(ARTOT)*LOG10(ARTOT)-.559*LOG10(ARTOT)))
FNOP=ARTOT*56.2*(10.0**(.0683*LOG10(ARTOT)*LOG10(ARTOT)-.526*LOG10(ARTOT)))
RAFOPU=.0021657*(RDOP+FNOP)
RAFOPAM=RAFOPU/.0944
PWRAF=RAFCAPU+RAFOPAM
*
```

```
* ADMINISTRATIVE AND LABORATORY FACILITIES
*
IF(FLOW.GE.1.0)
ADMCAP=51.3*(10.0**(.115*LOG10(FLOW)*LOG10(FLOW)+.323*LOG10(FLOW)))
ELSE
ADMCAP=51.3*(10.0**(.307*LOG10(FLOW)*LOG10(FLOW)+.366*LOG10(FLOW)))
ENDIF
ADMCAPU=2.1657*ADMCAP
ADMOPL=FLOW*5129.0*(10.0**(.0337*LOG10(FLOW)*LOG10(FLOW)-.574*LOG10(FLOW)))
ADMOPM=FLOW*1820.0*(10.0**(.0440*LOG10(FLOW)*LOG10(FLOW)-.497*LOG10(FLOW)))
ADMOPU=.0021657*(ADMOPL+ADMOPM)
ADMOPAM=ADMOPU/.0944
PWADM=ADMCAPU+ADMOPAM
*
* MONITORING WELLS
*
WLNUM=((ARTOT*43562.97)**.5)/500.0
WLDEPTH=20.0
WLCAP=WLNUM*524.8*(10.0**(.244*LOG10(WLDEPTH)*LOG10(WLDEPTH)-.284*LOG10(WLDEPTH
WLCAPU=.0021657*WLCAP
IF(WLDEPTH.LT.40)
WLOPL=WLNUM*70.8*(10.0**(.0212*LOG10(WLDEPTH)*LOG10(WLDEPTH)+.0034*LOG10(WLDEPT
ELSE
WLOPL=WLNUM*7.21*(10.0**(-.153*LOG10(WLDEPTH)*LOG10(WLDEPTH)+.093*LOG10(WLDEPTH
ENDIF
WLOPM=WLNUM*2.44*(10.0**(.0522*LOG10(WLDEPTH)*LOG10(WLDEPTH)+.503*LOG10(WLDE
WLOPU=.0021657*(WLOPL+WLOPM)
WLOPAM=WLOPU/.0944
PWWL=WLCAPU+WLOPAM
*
* CENTER PIVOT SPRINKLING
*
IF(ARA.LT.300.0)
SPRCAP=14.45*(10.0**(.240*LOG10(ARA)*LOG10(ARA)-.203*LOG10(ARA)))
SPROPL=ARA*6026.0*(10.0**(.276*LOG10(ARA)*LOG10(ARA)-1.48*LOG10(ARA)))
SPROPP=ARA*27.5*(10.0**(.127*LOG10(ARA)*LOG10(ARA)-.614*LOG10(ARA)))
SPROPM=ARA*1.52*(10.0**(.136*LOG10(ARA)*LOG10(ARA)-.743*LOG10(ARA)))
ELSE
SPRCAP=0.072*(10.0**(-.056*LOG10(ARA)*LOG10(ARA)+1.46*LOG10(ARA)))
SPROPL=ARA*251.0*(10.0**(.023*LOG10(ARA)*LOG10(ARA)-.290*LOG10(ARA)))
SPROPP=ARA*5.0
SPROPM=ARA*12.0*(10.0**(.0226*LOG10(ARA)*LOG10(ARA)-.163*LOG10(ARA)))
ENDIF
SPRCAPU=2.1657*SPRCAP
SPROPU=.0021657*(SPROPL+SPROPP+SPROPM)
SPROPAM=SPROPU/.0944
PWSPR=SPRCAPU+SPROPAM
*
* SITE CLEARING - ROUGH GRADING
*
ARCLR=ARA+ARSTOR
CLRCAP=1.04*(10.0**(.0171*LOG10(ARCLR)*LOG10(ARCLR)+.806*LOG10(ARCLR)))
CLRCAPU=2.1657*CLRCAP
PWCLR=CLRCAPU
*
* TRANSMISSION STORAGE TO SITE
*
HEAD=150.0
IF(I.EQ.1)
PIPSZE=36.0
ELSE
ENDIF
IF(I.EQ.2)
PIPSZE=30.0
ELSE
ENDIF
```

```
IF(I.EQ.3)
PIPSZE=24.0
ELSE
ENDIF
IF(I.EQ.4)
PIPSZE=18.0
ELSE
ENDIF
IF(I.EQ.5)
PIPSZE=14.0
ELSE
ENDIF
IF(I.EQ.6)
PIPSZE=6.0
ELSE
ENDIF
TRCAPI=7.19*(10.0**(.471*LOG10(PIPSZE)*LOG10(PIPSZE)-.207*LOG10(PIPSZE)))
FTLEN=(ARA*43562.97)**.5
TRCAP=FTLEN*TRCAPI
TRCAPU=.0021657*TRCAP
TROPM=FTLEN*.0146*(10.0**(.279*LOG10(PIPSZE)*LOG10(PIPSZE)+.121*LOG10(PIPSZE)))
TROPU=.0021657*TROPM
TROPAM=TROPU/.0944
PWTR=TRCAPU+TROPAM
*
* PUMPING STORAGE TO SITE
*
PKFLW=(APPMAX*AR*43562.97)/(7.0*12.0*.133681*1000000.0)
AVFLW=.5*PKFLW
PUMCAP=109.6*(10.0**(.184*LOG10(PKFLW)*LOG10(PKFLW)+.324*LOG10(PKFLW)))
PUMCAPU=2.1657*PUMCAP
PUMOPL=AVFLW*1995.0*(10.0**(-.0333*LOG10(AVFLW)*LOG10(AVFLW)-.379*LOG10(AVFL
PUMOPP=AVFLW*42.0*HEAD
PUMOPM=AVFLW*239.9*(10.0**(.0032*LOG10(AVFLW)*LOG10(AVFLW)-.0618*LOG10(AVFLW)))
PUMOPU=.0021657*(PUMOPL+PUMOPP+PUMOPM)
PUMOPAM=PUMOPU/.0944
PWPUM=PUMCAPU+PUMOPAM
*
* PREAPPLICATION TREATMENT, PARTIAL MIX - AERATION POND
*
IF(I.EQ.1)
PRECAP=200.0
PREOP=10.0*(4000.0+1000.0+150.0)
ELSE
ENDIF
IF(I.EQ.2)
PRECAP=120.0
PREOP=5.0*(4000.0+1600.0+200.0)
ELSE
ENDIF
IF(I.EQ.3)
PRECAP=65.0
PREOP=2.0*(4000.0+3000.0+300.0)
ELSE
ENDIF
IF(I.EQ.4)
PRECAP=45.0
PREOP=1.0*(4000.0+4000.0+450.0)
ELSE
ENDIF
IF(I.EQ.5)
PRECAP=35.0
PREOP=.5*(4000.0+7000.0+600.0)
ELSE
ENDIF
IF(I.EQ.6)
```

```
PRECAP=25.0
PREOP=.2*(4000.0+20000.0+1000.0)
ELSE
ENDIF
PRECAPU=2.1657*PRECAP
PREOPU=.0021567*PREOP
PREOPAM=PREOPU/.0944
PWPRE=PRECAPU+PREOPAM
*
* SERVICE AND INTEREST AT 30% (SUBTOTAL CAPITAL EXCLUDING LAND)
*
SUBCAP=SCAPU+RAFCAPU+ADMCAPU+WLCAPU+SPRCAPU+CLRCAPU+TRCAPU+PUMCAPU+PRECAPU
SERCAP=.30*SUBCAP
*
* TOTALS
*
TOTCAP=SUBCAP+SERCAP+PWLAND
TOTOP=SOPU+RAFOPU+ADMOPU+WLOPU+SPROPU+TROPU+PUMOPU+PREOPU-CROPR
IF (MET.EQ.1)
TOTCOST=TOTCAP+TOTOP/.0944
ELSE
TOTCOST=PWSTOR+PWLAND+PWRAF+PWADM+PWWL+PWSPR+PWCLR+PWTR+PWPUM+PWPRE+SERCAP
ENDIF
CPERGAL=100.0*1000.0*TOTCOST/(FLOW*1000000.0*365.0*20.0)
*
PRINT 10, FLOW, ARTOT,SVOLG,TOTCAP,TOTOP,TOTCOST,CPERGAL
10 FORMAT(F5.1,1X,F10.3,2X,F10.3,2X,F10.3,2X,F10.3,2X,F10.3,2X,F5.3)
100 CONTINUE
END
*
*
```

END

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