TREATMENT OF CATTLE FEEDLOT RUNOFF USING A SPRAY-RUNOFF IRRIGATION SYSTEM WITH RECIRCULATION

by

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INTRODUCTION

One of the problems magnified by the trend towards larger capacity cattle feedlots is the handling of stormwater runoff. Miner (1967) stated that due to the high loading of organic matter and nitrogenous compounds, cattle feedlot runoff has a high water pollution potential.

Many states now require the installation of water pollution control facilities by feedlots that possess a water pollution potential. These facilities consist of a system of diversion structures that route all runoff from waste contributing areas to detention ponds.

The primary method to dispose of stored runoff has been to use the wastewater for irrigation. Eisenhauer (1973) states that while irrigated land disposal is widely practiced, certain limitations do exist such as those listed below:

1. In areas that have high rainfall, low evaporation, and low soil infiltration rates, land disposal may not be feasible from an economic and/or land availability viewpoint.

2. Monovalent cations, sodium and potassium, are present in cattle feedlot runoff. If applied to clay soils these cations, in excessive amounts relative to other cations, may cause the soil particles to disperse causing a reduction in the soil's intake rate.

3. Salt concentrations are high in cattle feedlot runoff. If these salts are applied to a soil and are not leached from the soil profile by rainfall or high quality irrigation water, the soil may become saline. This condition, if severe enough, may inhibit plant growth and seed germination.

Since the problem of low infiltration rate had been reported in Kansas especially in areas of higher rainfall, Eisenhauer (1973) attempted to determine the feasibility of treating cattle feedlot runoff with a spray-runoff irrigation system. Although treatment of the feedlot runoff did occur, the effluent produced was not of high enough quality for release to the environment.

The research reported in this thesis is a continuation of Eisenhauer's (1973) work. This study was conducted to determine the effect and feasibility of recirculating once-treated wastewater over a portion of the treatment area set aside for that purpose. It was hoped that an effluent of satisfactory quality for direct release would be produced.

REVIEW OF LITERATURE

An extensive review of pertinent literature was compiled by Eisenhauer (1973). In his literature review, he dealt with the following subjects:

1. The hydrology of, the pollution parameters associated with, and the management of cattle feedlot runoff.
2. Runoff treatment and disposal alternatives (irrigated land disposal, soil treatment systems, and spray-runoff irrigation systems).
3. Biological treatment (trickling filters and nitrogen removal).

Additions to his literature review are made in this thesis.

Pollution Parameters

The pollution parameters of interest in this investigation were: five day biochemical oxygen demand, BOD_5; chemical oxygen demand, COD; ammonia nitrogen, NH_3; Kjeldahl nitrogen; total phosphorous; total suspended solids, TSS: pH; and electrical conductivity, EC. All parameters except total suspended solids, pH, and electrical conductived were well covered by Eisenhauer (1973).

Total suspended solids, discussed by McKinney (1962), is a quantitative expression of the presence in water of the suspended material that is too large to pass through a fine-pore filter. Another expression, total solids, TS, includes dissolved material.

According to Sawyer and McCarty (1967) "pH is a term used rather universally to express the intensity of the acid or alkaline condition of a solution." The neutral position on the pH scale being 7.0, any pH value less than this indicates that the sample is acidic while a pH value greater than 7.0 indicates that the sample is alkaline.

The electrical conductivity of a solution was also discussed by Sawyer and McCarty (1967). A water sample's electrical conductivity is a dependable and quick measurement of its electrolyte concentration. The electrical conductivity is almost directly proportional to the ionic concentration of the total electrolytes.

Grass Filters

Spray-Runoff Treatment Systems

Although Eisenhauer (1973) could not find any investigations dealing with the application of animal wastes to grass filters, he did cite several cases in which food processing plant wastes were treated by a spray-runoff system.

In an effort to determine the feasibility of using such a system to treat beef cattle feedlot runoff, he installed a similar system at a feedlot in south central Kansas.

This system was installed on a field adjacent to the feedlot. The loam topsoil was underlain by a heavy clay layer, which in turn was over a shale layer. Two treatment areas, GI and GII, were monitored. GI had a land slope of about one percent while GII had a slope of about two percent. The treatment area was sown to a mixture of grasses.

Two tests were conducted from late spring to early fall of 1972. In both tests about 2.5 in. per week of effluent were applied to the plots. Test 1 ran from June 8 through July 28. During this period the loading rate was approximately 0.08 in./hour, iph, applied 8 hours per day, 4 days per week. Test 2 ran from August 24 through October 14. The operating schedule consisted of three 21-hour application periods per week with a loading rate of about 0.04 iph. About 29 in. of wastewater were applied to the treatment plot during the two tests although some waste water was applied before and after the tests.

Table 1. Characteristics of Applied and Effluent Wastewater from Grass Filter*

		Mean Concentrations			
		Applied		Effluent	
Parameter	Units	Minimum	Maximum	Minimum	Maximum
BOD_5	mg/l	252	358	131	201
Kjeldahl Nitrogen	mg/l as N	209	542	127	387
Ammonia Nitrogen	mg/l as N	77	165	42	87
Total Phosphorous	mg/l as PO_4	95	114	81	92

* Table taken from Eisenhauer (1973).

Eisenhauer (1973) pointed out that since one-third of the Kjeldahl nitrogen of the applied wastewater was in the form of ammonia, a high degree of nitrification would be necessary for suitable performance of the spray-runoff system.

The mean concentration reduction percentages of BOD_5, Kjeldahl nitrogen and ammonia nitrogen are illustrated in Figure 1. This graph points out that GII more effectively removed BOD_5 than did GI. The highest removals occurred during Test 2. However, the differences in BOD_5 and nitrogen removal between the two plots were not statistically significant at a 0.05 alpha level. This also was true when BOD_5 removals during Test 1 and Test 2 were compared. Although a significant difference in the mean Kjeldahl and ammonia nitrogen concentrations of the field effluents did exist between the two tests, Eisenhauer (1973) felt that it was due to a difference in the quality of water applied during the tests.

He suggested that adsorption to clay particles on the soil surface was the primary phosphorous removal mechanism. Therefore, a lower application rate should have improved phosphorous removal. This did occur as the phosphorous removal percentage increased from about five percent for both plots during Test 1 to 14 and 29 percent during Test 2 for GI and GII, respectively. However, only three samples were analyzed for total phosphorous during Test 2. Thus, the data may not be significant.

Only about 25 to 27 percent of the applied wastewater ran off the plots. In Eisenhauer's (1973) opinion, very little water moved through the clay subsoil. He felt that direct sprinkler evaporation and evapotranspiration should account for the remaining water.

Evaporation of the wastewater while undergoing treatment tended to reduce the concentration reductions of the parameters but increased their mass removals. Thus, mass reductions of 77 to 92 percent, 74 to 90 percent, and 81 to 90 percent were achieved for BOD_5, Kjeldahl

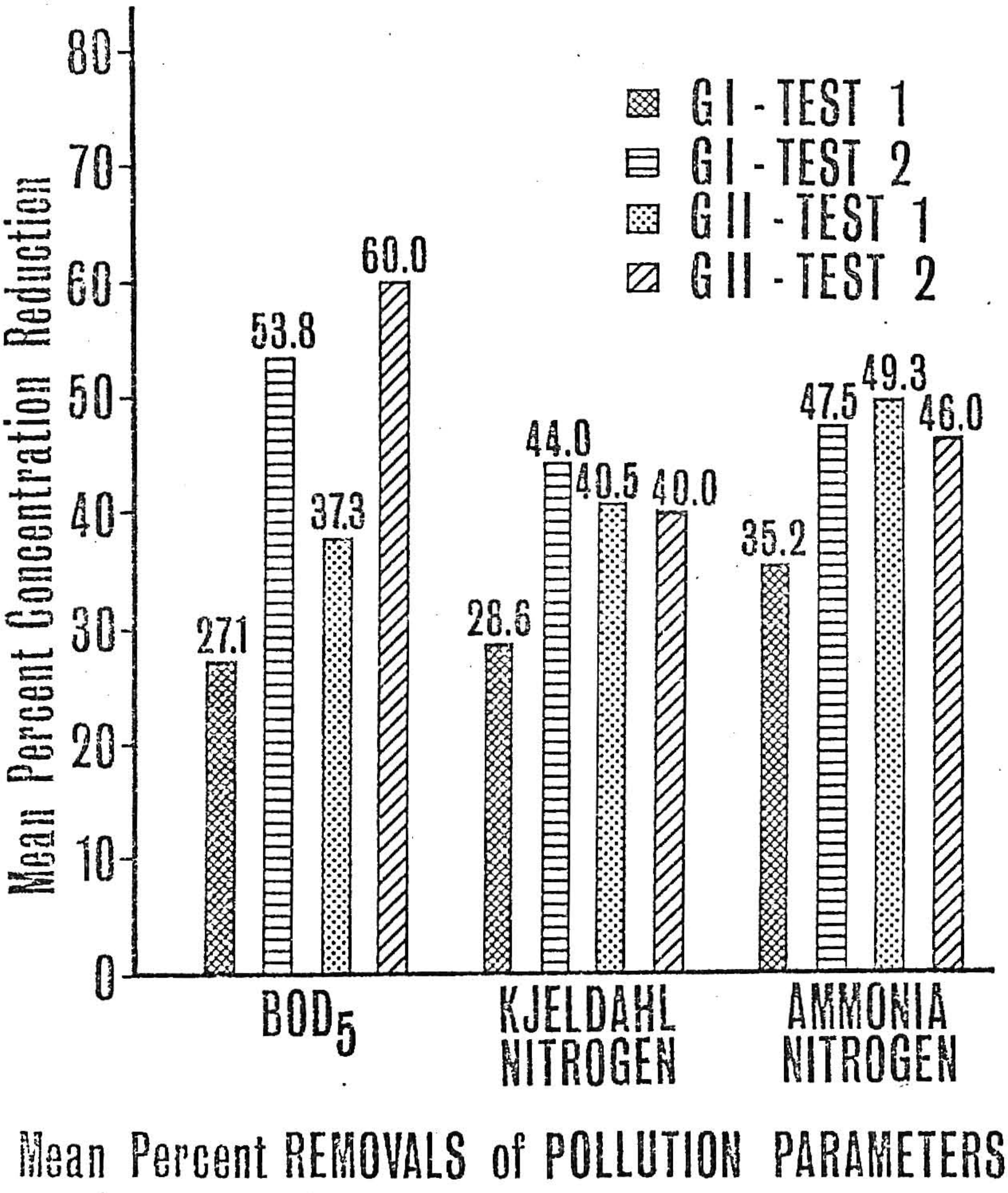

Figure 1. (Taken from Eisenhauer et al. (1973).)

nitrogen, and ammonia nitrogen, respectively.

The characteristics of rainfall runoff from the plots were such that the runoff would be of questionable quality for direct release to a stream. The author thought that the questionable quality of the rainfall runoff was due to soil erosion.

The author reached the following conclusions:

1. Although treatment of the feedlot runoff did occur, the field effluent was not of satisfactory quality to be released to surface waters. At the 0.05 alpha level there was no significant difference in the treatment occurring on plots with one and two percent slopes.

2. Rainfall runoff from the treatment plots was of questionable quality for release.

3. Although salt, sodium, and potassium, did accumulate in the soil profile during the period of study, no serious salinity or alkali hazards developed during the first season of operation.

Reeves (1973) designed and installed a similar system in Eastern Kansas on a 5.9 acre field with a landslope of about 3.5 percent. Two parallel terraces with about a 230-ft. spacing were constructed. The field was seeded with a K-31 fescue. Settled feedlot runoff was applied to this area. A hydraulic loading rate of .075 in./hour with an operating schedule of four hours per day was used. Two testing periods were used: October 24, 1972, to November 2, 1972, and May 30, 1973, to June 6, 1973. As shown in Table 2, about 85 percent removal of BOD_5 occurred during the May and June period. The ammonia content of the treated effluent was above 40 mg/l. Reeves (1973) believed that higher BOD_5 removals can be achieved but felt "there is a very real question if the future, federally imposed, state water quality standards can be met."

Table 2. Summary of Results*
(Average in mg/l of individual composite samples)

Date	Loading Time	Rate ac/ft/yr on entire field	BOD_5 inf.	BOD_5 eff.	Sus. Solids inf.	Sus. Solids eff.	NH_3 inf.	NH_3 eff.
10-24/10-26	4 hr/MTWT	31.0	780	380	1000	580	95	45
10-31/11-2	4 hr/TWT	23.3	950	480	2500	700	110	40
5-30/6-7	4 hr/MTWT	31.0	450	55	700	190	130	45

* Table taken from Reeves (1973).

Tertiary Treatment

The use of grass filters for tertiary treatment of biological filter effluents has been the subject of several investigations, Ward (1973) and Walker (1972). Effluent was applied through a perforated pipe at the top of a uniform slope. The effluent flowed downslope through the grass, to collection channels. Treatment occurred while the effluent flowed downslope. Ward (1973) felt that gravity flow of the waste was as effective as spray irrigation when the land was level.

As shown in Table 3, the treatment provided by the grass filter did result in an improvement in effluent quality, with an appreciable decrease in BOD_5, suspended solids, NH_3, and NO_3 concentrations.

Table 3. Analysis of Biological Filter Effluents Before and After Treatment on Grass Plots*

	Filter effluent (mg/l)				Grass plot effluent mg/l			
	BOD	SS	NH_3 (as N)	NO_3 (as N)	BOD	SS	NH_3 (as N)	NO_3 (as N)
Unit Serving 35 persons	17.2	19	23	24	6.2	6	0.5	16
Snap Samples	8.4	26	--	5.2	5.1	9	---	5.8
Unit Service 74 persons	12.8	22	1.8	17	5.1	9.2	1.5	17
(ave. of 9 snap samples)								
Range	7-19	5-35	0.3-8	9-20	2-9	4-21	0.3-6	10-19

* Table taken from Ward (1973).

Trickling Filters

The mechanics of organic removal in trickling filters were reviewed by Eisenhauer (1973). In his literature review he listed some of the factors that control BOD_5 removal in a trickling filter. These factors included the hydraulic and organic loading rate, the type of media used, the depth of the filter, the waste characteristics, and the temperature of the waste.

Inclined Plane Trickling Filter

The use of an inclined plane trickling filter to treat swine waste was studied by Mulkey and Smith (1972). Anaerobic swine lagoon effluent was applied to inclined planes. The organic removal performance, measured by BOD_5 removal, was determined for four plane lengths, on four slopes, at four flow rates. The samples were allowed to settle for a few minutes prior to dilution for the BOD_5 determinations.

The range of plane lengths, slopes, and flow rates were 2 to 8 ft., 2 to 8 degrees, and 0.48 to 0.96 gallons per hour per foot of plane width, respectively. Upon analysis the BOD reduction data yielded the following prediction equation:

$$\frac{S}{S_o} = \exp\left[-0.03 \frac{L}{Q}\right] \quad (1)$$

where:

S/S_o = BOD_5 concentration ratio

S = effluent BOD_5 concentration

S_o = influent BOD_5 concentration

L = inclined plane length in feet

Q = flow rate in gallons per hour per foot of plane width

Recirculation

With strong wastes it is necessary to recirculate part of the trickling filter effluent to obtain satisfactory treatment. The recirculation ratio, r, defined as the ratio of volume recirculated, R, to the volume of plant influent, I, is the common expression for recirculation. There are several theories pertaining to the effect that recirculation has on effluent quality.

Velz (1948), upon whose work much of the existing trickling filter theory is based, proposed the following theory: "The rate of extraction of organic matter per interval of depth of a biological bed is proportional to the remaining concentration of organic matter, measured in terms of its removability." This can be expressed mathematically as:

$$\frac{L_D}{L} = 10^{-kD} \qquad (2)$$

where: L = total removable portion of BOD

L_D = corresponding quantity of removable BOD remaining at depth D

D = depth of biological bed in feet

k = logarithmic rate of extraction

In his work, the effect of recirculation and two-stage series treatment was analogous to BOD removal through successive filter depths. Thus, a recirculation ratio of one has the same effect as passing the plant influent through a two-stage trickling filter system in which both filters are the same depth. The effect of either of these actions would be "tantamount to passing I once through two such successive depth intervals", where I is the volume of the plant influent.

The model proposed by Velz (1948) implied that recirculation has a greater effect on the filter effluent than did the models proposed by Howland (1958). The time of flow through the filter is important in both models. However, in the first model, the important concept is the average time of flow through the filter, while in the second model, the time of flow on one pass through the filter is important. Also in the second model it is assumed that the filter influent is a homogeneous liquid with an organic concentration equal to the weighted average organic concentration of the plant influent and the reciru-lated effluent. However, Howland (1958) felt that his theory, in the matter of recirculation, suggested questions that were left unanswered.

The Howland (1958) and Schulze (1960) models were modified by Eckenfelder (1961), who, considering a decreasing amount of BOD removal per unit of depth with increasing filter depth, developed the following model:

$$\frac{L_e}{L_o} \qquad \frac{1}{1 + K\frac{D^{(1-m)}}{Q^n}} \tag{3}$$

where: L_e = BOD_5 of filter effluent in milligrams per liter

L_o = BOD_5 applied to filter in milligrams per liter

K = constant for model = 2.5

D = filter depth in feet

m = constant = .33

n = constant = .5

Q = hydraulic through-put rate in million gallons per day

In this model recirculation is considered as having a dilution effect on the plant influent BOD as described by:

$$L_o = \frac{L_i + rL_e}{1 + r} \tag{4}$$

where: L_i = plant influent BOD in milligrams per liter

r = recirculation ratio

Combining equations 2 and 3 gives:

$$\frac{L_e}{L_i} = \frac{1}{(1+r)\left(1+2.5\,\frac{D^{.67}}{Q^{0.5}}\right) - r} \tag{5}$$

Equation 4 does not take into account any reduction in the "treatability" of the recirculated flow as does the empirically developed model on the National Research Council, NRC, (1946).

The NRC (1946) model is based upon the following equation:

$$E = \frac{1}{1 + K\left(\frac{W}{VF}\right)^{0.5}} \qquad (6)$$

where:

$E = \frac{L_o - L_e}{L_o}$ = filter efficiency

$K =$ 0.0085

$W =$ filter BOD_5 loading in pounds

$V =$ filter volume in acre-feet

$F =$ recirculation factor

The recirculation factor, F, is defined by:

$$F = \frac{\frac{r}{i} + 1}{\left[1 + (1-P)\frac{r}{i}\right]^2} \qquad (7)$$

where:

r = recirculation rate, in million gallons per day

i = plant influent rate, in million gallons per day

p = weighting factor

In this model recirculation is equivalent to the repeated passage of sewage through the filter. The weighting factor, p, approximately equal to 0.9 for sewage from military bases, reflects the reduced availability of organic matter on subsequent passes through a filter. This occurs because the filter growths extract the more easily biodegradable material first.

The efficiency of the second-stage filter in a two-stage trickling filter plant is also affected by the "treatability" of the effluent from the first-stage filter, which depends on the efficiency of the first-stage filter. By modifying Equation 6, it can be applied to second-stage filters in the following form:

$$E_2 = \frac{1}{1 + K \left[\frac{W'}{VF\ (1-E_1)}\right]^2} \qquad (8)$$

where:

E_2 = second-stage filter efficiency

E_1 = first-stage filter efficiency

K = 0.0085

W' = pounds of BOD_5 in the intermediate settling tank effluent, the second-stage filter BOD_5 load

B = second-stage filter volume in acre-feet

F = recirculation factor

Another empirical model, based on a multiple regression analysis of data from pilot and existing plants, was developed by Galler and Gotaas (1964). Their model was described by:

$$L_e = \frac{0.464 L_o^{1.19} (i+r)^{0.28} \left(\frac{Q}{A}\right)^{0.13}}{(1+D)^{0.67}\ T^{0.15}} \qquad (9)$$

where:

L_e = plant effluent BOD in milligrams per liter

L_o = filter influent BOD with recirculation, in milligrams per liter

r = recirculation rate in million gallons per day

i = plant influent rate in million gallons per day

Q = hydraulic through-put rate, in million gallons per acre per day

A = filter area in square feet

D = filter depth in feet

T = temperature in degrees Celsius

The effective gain in BOD removal due to recirculation was calculated as:

$$0.358L_o^{0.21}\left(\frac{Q}{I}\right)^{0.28} \tag{10}$$

where:

I = plant influent rate in million gallons per acre per day

A discrepancy existed between the calculated results obtained from these equations and the observed results. The authors felt this was the result of the seeding of the plant influent with organisms predominating in the filter being the most beneficial effect of recirculation.

Atkinson et al. (1963) used film flow in contact with a vertical wall as their model. Using this model they developed the following equation for BOD removal:

$$\frac{C_{AO}}{C_{AI}} = \frac{\exp\left[\dfrac{-K_A\, h\, WL}{Q\,(1+N)}\right]}{1+N-N\exp\left[\dfrac{-K_A\, h\, WL}{Q(1+N)}\right]} \qquad (11)$$

where:

C_{AO} = effluent concentration in pounds per feet^3

C_{AI} = influent concentration in pounds per feet^3

K_A = reaction rate constant

h = film thickness in feet

W = film width in feet

L = model length in feet

Q = flow rate in cubic feet per second

N = recirculation ratio

In this model recirculation is considered as having an effect on the flow regime and thus the flowing film thickness as well as a dilution effect. At higher recirculation rates a transition to turbulent flow occurs, which results in a slightly greater BOD reduction.

They developed the following equation for the effluent concentration from a number of filters in series:

$$\frac{C_{AO}}{C_{AI}}^{(X)} = \left[\frac{C_{AO}}{C_{AI}}^{(1)}\bigg|_{N}\right]^{X} \qquad (12)$$

where:

$C_{AO}^{(X)}$ = final effluent concentration from X number of filters in series

$C_{AO}^{(1)}$ = effluent concentration from first filter

N = recirculation ratio

X = number of filters in series

Thus, for a given recirculation ratio, the percentage concentration reduction in each filter of a series system is equal to that occuring in each of the other filters in the system.

In general, the Eckenfelder (1961) and the Galler-Gotaas (1964) models yield computed efficiencies that are closer to the observed efficiencies of trickling filters than do the other models. The NRC (1946), Eckenfelder (1961), and the Galler-Gotaas (1964) models all have a maximum practical recirculation ratio of about 4.

Photosynthetic Treatment of Wastes

As stated by Oswald and Gotaas (1957), "Photosynthesis is the most basic process of biology." By means of this process, plants which contain photosensitive pigments are able to produce, in the presence of sunlight, organic matter and liberate oxygen from inorganic matter and water. The process has been studied as a possible means of wastewater treatment.

Oxidation Ponds

An oxidation pond is primarily an aerobic treatment device although it may have anaerobic zones, in which case it becomes a facultative device. Pond depth is controlled by the minimum depth required to prevent weed growth, usually about 2 ft, and the amount of mixing desired, the shallow ponds having better mixing.

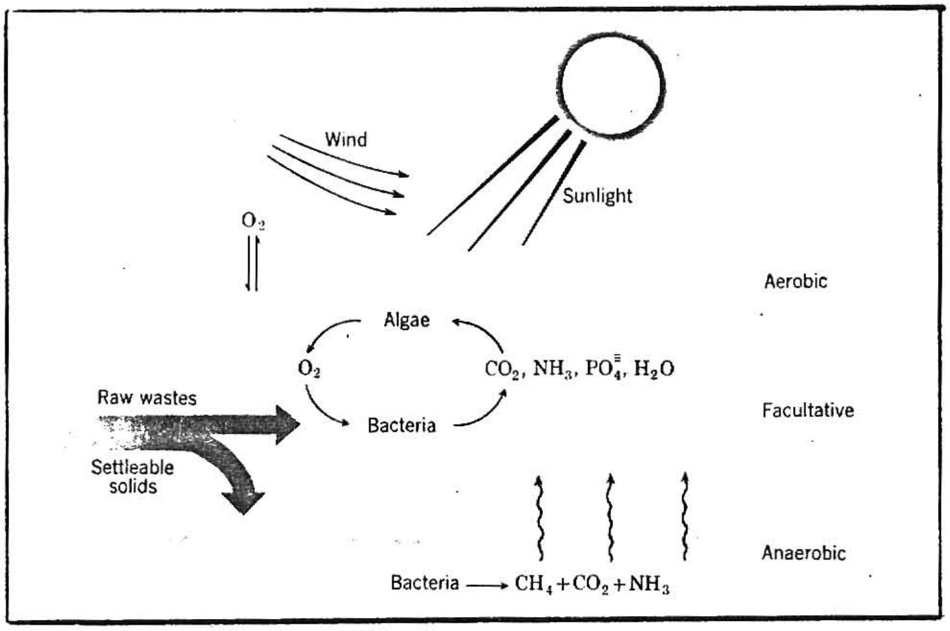

Figure 2. Schematic Diagram of Oxidation Pond (Taken from McKinney (1962).)

As shown in Figure 2, the organic matter is biologically oxidized by bacteria with carbon dioxide, ammonia nitrogen, orthophosphate, and water as the principal end products. These end products, with the addition of light energy, provide the principal elements needed for photosynthetic conversion into algal protoplasm. Oxygen is released in proportion to the amount of carbon dioxide reduced. The oxygen produced microbially plus the oxygen gained through surface aeration, provide the oxygen necessary for aerobic bacterial stabilization of the influent organic matter.

In wastes containing significant amounts of bicarbonates and carbonates, the algae use these materials as an additional source of carbon. Under these conditions, more oxygen may be released by the algae than is required by the bacteria, possibly leading to super-saturation of the water with oxygen.

According to Oswald and Gotaas (1957), oxidation ponds may be divided into two types, depending upon their source of oxygen. Type 1 ponds depend primarily upon surface reaeration for oxygen and are characterized by detention periods of greater than three weeks. Type 2 ponds are dependent upon photosynthesis to provide the oxygen necessary to oxidize the entering wastes. Thus, the ponds are said to undergo photosynthetic oxygenation. A Type 2 pond usually has a detention period of less than one week. This type of pond has a high rate of algae growth.

Algal Growth

Since algae assimilate inorganics, analysis of the algal biomass composition can determine the amount of inorganics extracted from the medium by the algae. The data in Table 4 indicate that the assimilation of 1 mg/l of phosphorous by algae would require the metabolism of from 33 to 78 mg/l of carbon and from 1 to 12 mg/l, or more, of nitrogen.

Bush et al. (1961) indicated that Chlorella preferred a medium which contained greater quantities of organic matter than did other species of algae. The maximum growth rates for Chlorella occur at water temperatures between 68° F and 86° F with growth inhibition occurring at water temperatures below 41° F and above 95° F. The optimum pH for algal growth is between 7.0 and 8.5 with higher or lower values inhibiting growth. During active photosynthesis a rapid

Table 4. Composition of Fresh Water Algae*

Element	Percent Total Dry Weight
Carbon	49.5 - 70.2
Oxygen	17.4 - 33.2
Hydrogen	6.6 - 10.2
Nitrogen	11.0 - 11.4
Phosphorous	0.9 - 1.5
Sulfur	.09
Magnesium	0.3 - 1.5
Chloride	.32
Calcium	0.0 - 1.5
Sodium	.30
Potassium	0.0 - 1.4

* Table taken from Bogan et al. (1960).

pH rise, up to pH 11, has been noted in many instances. This has been attributed to the removal of carbon dioxide from the medium.

Oswald (1972) stated that nitrogen may be utilized by algae in either the ammonia or nitrate form. However, Bush et al. (1961) indicated that Chlorella seemed to prefer the ammonia form. With domestic wastes, Oswald and Gotaas (1957) stated that the nitrogen content of a waste determined the practical upper limit of the algal cell concentration which developed in the waste. A rule-of-thumb for this limit was given as $C_c = 10 X N$, where C_c, the maximum algal cell concentration, and N, the nitrogen content of the waste, are expressed in the same units. This relationship assumes that 80 percent of the nitrogen in the waste is recovered and the algae cells are 8 percent nitrogen. This assumption was validated by Michel and Michel (1973), who found that Chlorella pyrenoidosa removed over 80 percent of the nitrogen present in a controlled, batch culture, bacterial-algal system.

The California Department of Water Resources (1971) states that algae use phosphorous in the orthophosphate form, PO_4. Since the phosphorous content of algae does not exceed 1.5 percent of the dry weight of the algae, it seldom is a limiting growth factor in sewage. Bogan et al. (1960) concluded that rapid biological extraction of PO_4 was possible with adequate amounts of light. Also, adsorption and coagulation seemed to be the primary removal mechanisms when large amounts of phosphate were removed rapidly. However, metabolic conversion was found to be the primary removal mechanism in oxidation ponds and sewage lagoons where removal rates were slower. For the algae in an oxidation pond 3 to 4 ft deep to biologically extract 5 mg/l of phosphorous, a detention time of 14 to 28 days would be required.

As shown in Table 4, carbon makes up a large percentage of the algal biomass. When cultured in sewage, algal growth is usually limited by the amount of carbon available. The needed carbon is primarily supplied by carbon dioxide, although many species are able to use bicarbonate as a carbon source. As previously stated, during active photosynthesis the pH may rise to 10 or more. If this occurs, the absorption of CO_2 by the culture is accelerated. Increasing the pH above 9 may cause some phosphate precipitation. Oswald et al. (1958) found that pH varied as a function of pond depth as follows:

5 cm, pH 10; 15 cm, pH 9; 30 cm, pH 7.5; 45 cm, pH 7.1. Based on this information, some pH precipitation probably occurred at depths less than 30 cm.

Bush et al. (1961) indicated that algae removed salts from water. He found that inorganic salts composed 25 to 28 percent of the dry weight of algal cells.

Algal Removal

Since algae extract inorganic elements from a wastewater, removing the algae from the wastewater would improve the quality of the wastewater. Some research has been conducted on the removal of algae from oxidation pond effluents.

In an effort to determine the algae contribution to BOD_5, COD, total phosphates, and total nitrogen, Shindala (1971) tested filtered and unfiltered samples of an oxidation pond effluent. He found that algae accounted for more than 50 percent of the total BOD_5, COD, and nitrogen, and less than 25 percent of the total phosphate content of the waste.

In a study of the effluent from the oxidation ponds of Stockton, California, Parker et al. (1973) found that the long term oxygen demand was principally associated with algae. They also felt that algal removal would effectively remove the nitrogen in the effluent because most of it was in the organic form associated with algae.

Oswald and Gotaas (1957) analyzed the effluent from a Type 2 oxidation pond. As the data in Table 5 shows, the BOD of the effluent is dependent upon the algae separation procedures. The more complete the separation, the greater the BOD reduction. These results were duplicated by McGarry and Tongkasame (1971) who found that a high rate oxidation pond with a loading of 200 lb BOD/acre/day, a 17.7 in. depth and a one day detention time, produced an effluent with a BOD of less than 10 mg/l after algae removal.

Table 5. Typical Values for BOD as a Function of Separation Procedure Following Photosynthetic Oxygenation*

Sample	Separating Procedure	BOD in mg/l	Percentage Removal
Influent	None	210	0
Pond	None	195	7
Tailing	Settling 1 hr.	105	50
Tailing	Lab. centrifuging 10 min. at 500 times gravity	25	88
Supernatant	Coagulation (followed by 30 min. settling)	9	96

* Table taken from Oswald and Gotaas (1957).

Bush et al. (1961) reported on dissolved solids removal in a shallow U-shaped algae pond 55 ft long. The water was constantly recirculated and CO_2 was supplied continuously to maintain the hydrogen ion concentration in the medium. Scenedesmus was the predominant algal species. This species clung to the sides and bottom of the pond. Thus, the effluent contained little algae. The algae utilized the bicarbonate ion as a carbon source as shown in Table 6 in addition to the carbon added in the CO_2 form. This test set-up reduced the total dissolved salts from 520 ppm to 265 ppm. However, Bush et al. (1961) noted that the algae must be harvested live to guarantee the removal of the salts stored in the cells from the water.

Table 6. *Range of Influent and Effluent Concentration and Percentage Removal of Ions**

Element	Influent ppm	Effluent ppm	Percentage Removal	Maximum Percentage Removal
Bicarbonate	200-320	80-180	50-80	90
Phosphate	5- 15	2- 9	19-68	76
Ammonia	4- 7	0- 2.5	63-90	93-100
Nitrate	2- 14	1- 4	27-60	
Organic Nitrogen	1- 5	0- 1.5	32-74	

* Table taken from Bush et al. (1961).

INVESTIGATION

Objectives

1. To determine the effectiveness of recirculating effluent from a spray-runoff irrigation system over a different part of the treatment area which was set aside for that purpose. This system was used to treat beef cattle feedlot runoff and the effectiveness of treatment was evaluated with respect to concentration reductions and total mass removals. This system, without recirculation, was designed by Eisenhauer (1973).

2. To monitor the chemical composition of the untreated feedlot runoff and the recirculated wastewater and thus determine their suitability for use as irrigation water.

3. To monitor the effects of the wastewater on the chemical properties of the soil through two seasons of operation.

4. To determine what type of relationship exists between the degree of treatment occurring and the distance that the waste flows downslope.

5. To examine the quality and quantity of rainfall runoff from the grass filter.

Theory

The theory of treating beef cattle feedlot runoff with a spray-runoff irrigation system is well presented by Eisenhauer (1973). He states that in the spray-runoff irrigation system, wastewater runs off the treatment area. Treatment of the waste occurs as it flows downslope over the biological mat that is formed on the soil surface. The cells that make up this mat utilize the organic material in the wastewater in the formation of new cell mass along with the end products of carbon dioxide and water. The primary nitrogen removal mechanism would probably be ammonia volitilization. In addition, the nitrogen present may undergo mineralization, nitrification, and possibly denitrification processes while the waste is flowing over the treatment area. Some of the suspended solid material in the feedlot runoff should settle out of solution while in the grass areas and decompose on the soil surface. Adsorption to soil particles probably will be the primary phosphate removal mechanism.

The above mechanisms are the primary pollutant removal processes that occur when untreated feedlot runoff is treated using a once-over spray-runoff irrigation system. However, if the portion of the applied waste that runs off the treatment plot is detained in a polishing pond and reapplied to a portion of the treatment area, additional pollutant removal mechanisms will be involved. It is felt that the once-over treatment process will reduce the BOD_5 of the feedlot runoff to such a level that aerobic conditions can predominate in the polishing pond. If this is the case, the polishing pond may act as an oxidation pond if the detention period is long enough for biological treatment to occur.

When the detention period is of sufficient length, the organic matter in the field effluent should be biologically oxidized by bacteria. Additionally, if sufficient light energy is available, algal growth will occur. The algae will assimilate some of the inorganic nitrogen, phosphate and salts contained in the pond water and, with the addition of carbon from either carbon dioxide or possibly bicarbonate and light energy, will synthesize additional algae cells. Some of the algae cells may settle out of suspension in the polishing pond and thus some of the inorganics will be removed from the water. Reapplying the wastewater contained in the polishing pond to a different part of the treatment area may result in additional reductions of the pollutant parameters.

The reapplication of wastes will provide additional time for organic material adsorption, ammonia volitilization, the mineralization, nitrifrication, and possibly denitrification of nitrogen, and for additional adsorption of phosphate to soil particles. This will also provide a means of removing algae cells from the recirculated wastewater. The removal of algae cells will result in the removal of some inorganic nitrogen, phosphate, and salts from the field effluent.

A block diagram of the system is shown in Figure 3. It was hypothesized that the system would operate in the following manner. Stored feedlot runoff would be applied to the treatment area. The effluent from this area would flow into the polishing pond. Additional treatment, similar to that which occurs in an oxidation pond, should occur there. Liquid from the polishing pond would be reapplied to a portion of the grass filter where additional biological treatment could occur and some of the algae should settle out of suspension and

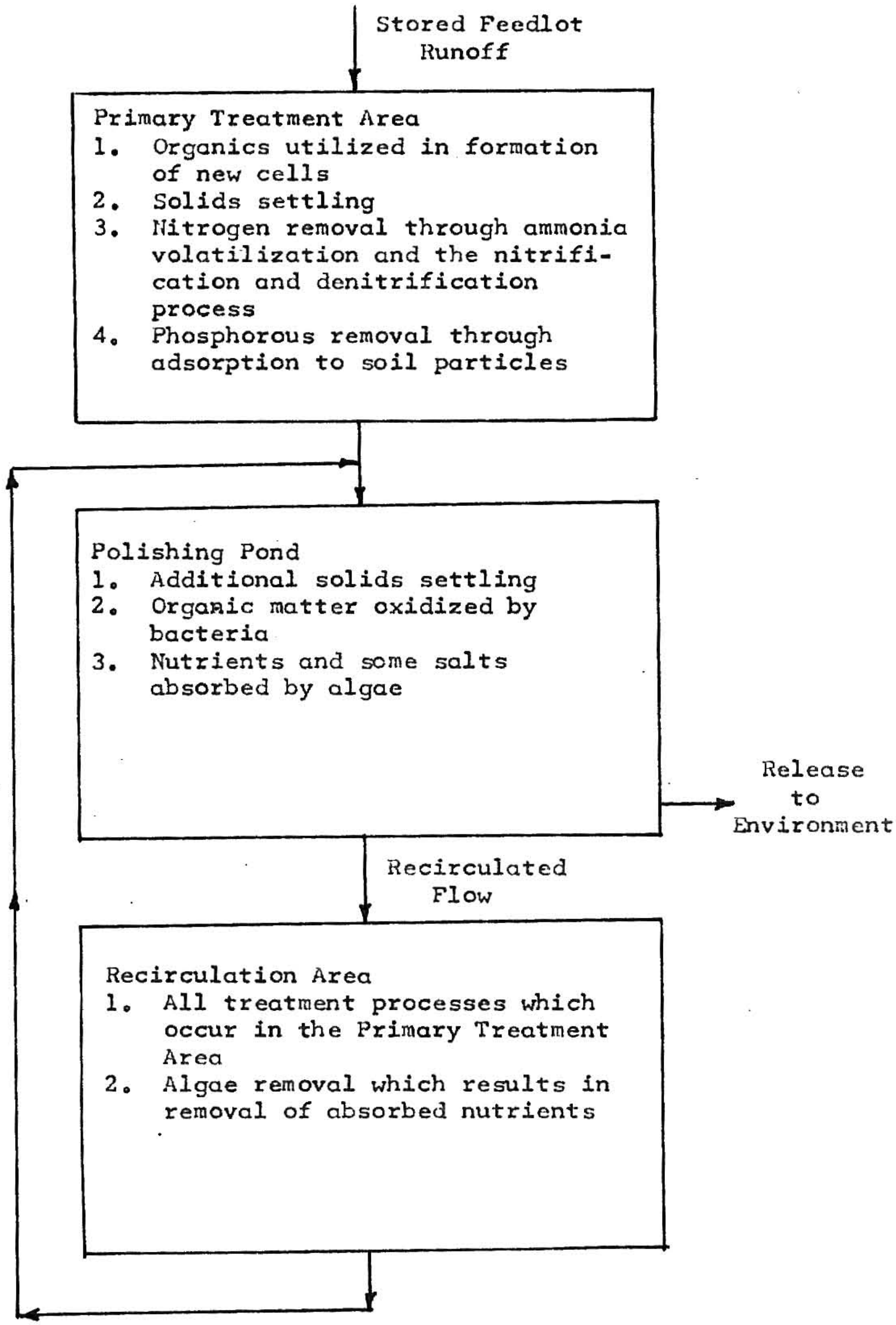

Figure 3. Block Diagram of Proposed Treatment System

decay on the soil surface. The effluent from the recirculation plot would dilute the effluent from the rest of the treatment area. It was hoped that after the system had reached an equilibrium condition, the effluent from the recirculation plot would be of such a quality that the fluid in the polishing pond would be of suitable quality to release to the environment.

The application rate of stored feedlot runoff, the recirculation rate, and the operating schedule will be selected so that the discharge from the polishing pond should be nearly continuous.

Method of Procedure

The research reported in this thesis was conducted at the Circle E Ranch division of Kansas Beef Industries, Inc., located in south central Kansas near Potwin. An open lot cattle feeding operation, Circle E has a one-time capacity of 22,000 head and a lot area of 100 acres. The feedlot presently has a runoff detention storage volume of approximately 100 acre-feet. This is sufficient to hold an average year's expected runoff as Bergsrud (1968) stated that the average annual runoff expected from a feedlot in this area is 11 in.

A spray-runoff irrigation system was designed and installed by Eisenhauer (1973) on a 10.9 acre field adjacent to the feedlot. A schematic diagram of this system is shown in Figure 4. The land slope varied from one to three percent. The soil profile was found to consist of a loam topsoil underlain by a clay subsoil at a depth which varied from 9 to 12 in. A shale layer was encountered at a depth which ranged from 18 in. to 3 ft.

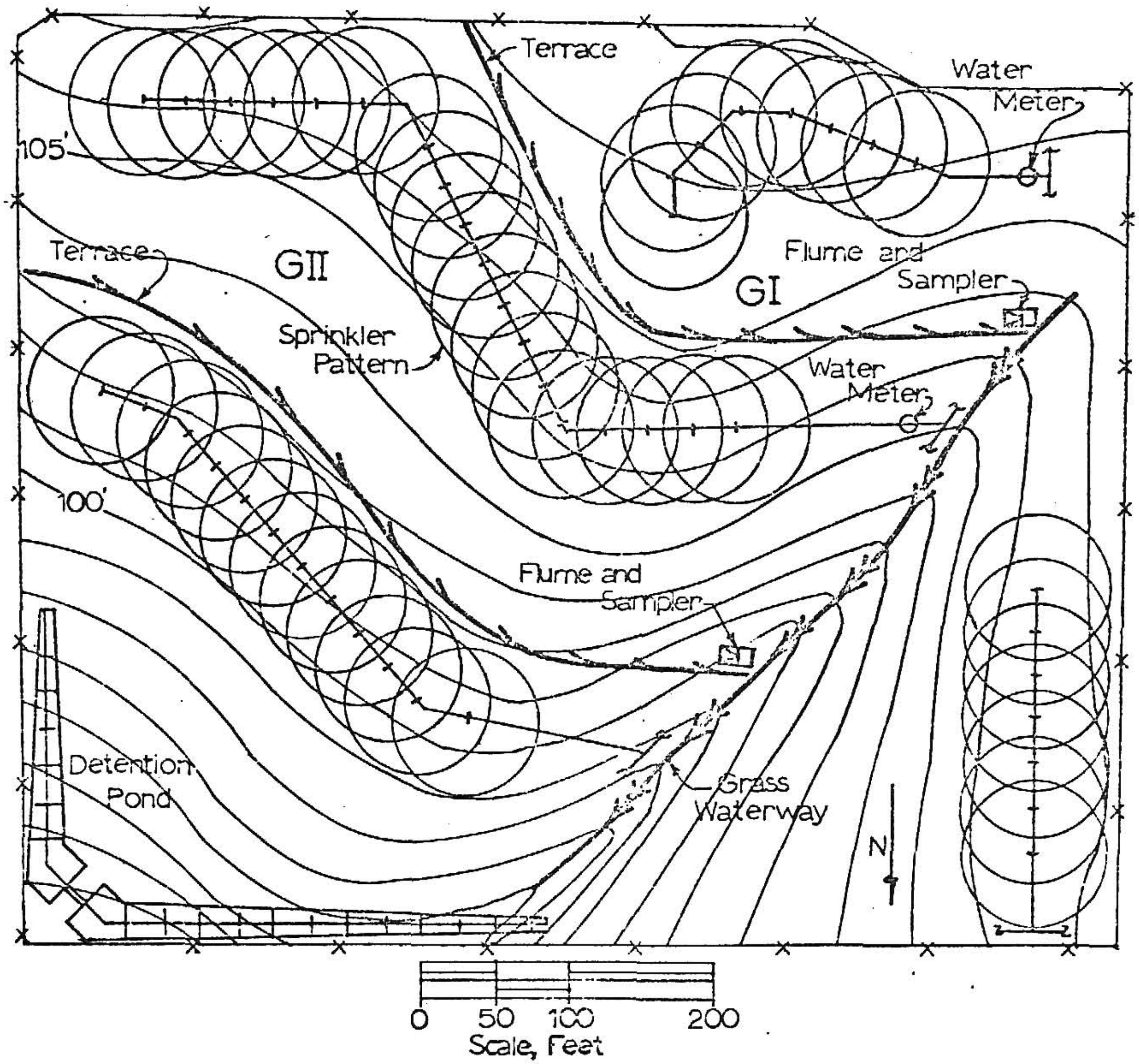

Figure 4. Plan View of Experimental Spray-Runoff System. (From Eisenhauer (1973).)

The treatment field was divided into four subwatersheds by two parallel terraces with a spacing of 200 ft. and a parabolic waterway into which the terraces discharged. The waterway discharged into a detention pond with a storage volume of 1.65 acre-feet. This pond received runoff only from the treatment area. The storage volume of the pond was designed to store at least the amount of runoff expected from two days of irrigation. The storage structure was considered a polishing pond in which further biological treatment and solids settling occurred. A concrete drop structure was installed in the earth fill dam of the detention pond. The terraces, waterway, and polishing pond were laid out and constructed with the aid of local Soil Conservation Service personnel.

Approximately 50 tons of wet manure per acre was applied to the treatment field during the fall of 1971. Prior to seeding the field to grass, the manure was incorporated into the soil.

In March 1972, the treatment field was seeded with a mixture of Reed canarygrass, tall fescue, tall wheatgrass, smooth bromegrass, and perennial ryegrass. It was expected that after high volumes of effluent had been applied, the more salt and moisture tolerant grasses would predominate.

Each of the four subwatersheds in the treatment area had a slope length of at least 160 ft. and usually 200 ft. A sprinkler lateral was installed on each watershed approximately 60 ft. from the watershed's upper boundary. A total of 45 three-foot risers were placed on the laterals at a spacing of 30 ft. Using a sprinkler head with a 100-ft. spray diameter, this arrangement provided a minimum length of run beyond the spray diameter of 50 ft. with most runs being from 90 to 100 ft.

The experimental studies were conducted on the two subwatersheds with terrace channel outlets, which allowed the quantity and quality of the applied and runoff water to be monitored. The upper plot, GI, has an area of 1.55 acres, a slope of about one percent, and contains 8 sprinkler heads. The second plot, GII, has a slope of about 2 percent, an area of 3.6 acres, and contains 19 sprinkler heads.

During the 1972 operating season, wastewater from a runoff storage pond adjacent to the treatment field was supplied to the irrigation system by a centrifugal pump powered by an internal combustion engine. The same pond and pump provided wastewater for all of the treatment area during part of the 1973 study. However, in early July 1973, a 7½ horsepower electric centrifugal pump was installed near the drop structure of the polishing pond to recirculate water from the polishing pond over GI. The rest of the treatment area was still supplied by the internal combustion engine powered centrifugal pump.

To evaluate total field effluent volume for each irrigation and rainfall event, runoff measuring flumes equipped with stage recorders were placed at the terrace outlet of each plot.

Rainfall was measured by three rain gauges placed in the treatment field. During the 1972 study, the quantity of water applied to each test plot was determined by four-inch water meters placed in the spray laterals. These meters were read at the end of each waste application. However, during the 1973 study, the water meter monitoring GII malfunctioned. Therefore, the volume of waste applied to GII was determined from estimated operating time and nozzle pressure data.

The first season of operation was monitored by Eisenhauer (1973). The research conducted during the second season of operation is reported in this thesis.

The system was operated from the early spring of 1973 to July 2, 1973, without any data being taken. From July 2, 1973, through July 13, 1973, the system was operated and monitored as a once-over treatment system. The application rates during this period were approximately .118 in. per hour, iph, and .07 iph for GI and GII, respectively, assuming a nozzle pressure of 37.5 psi and a 30 x 200 foot spacing. The system was operated for about five hours per day, six days per week.

From July 13 to July 16, 1973, GI received no feedlot runoff. During this period, the electrically powered, time-clock controlled, centrifugal pump was installed below the drop structure of the polishing pond.

From July 17 through August 21, both GI and GII were monitored. GII was operated in the same manner as it was from July 3 through July 13. The recirculated wastewater was applied to GI at a loading rate of .134 iph. The recirculation system's operating schedule consisted of a two-hour application period followed by a four-hour period when no waste was pumped. This cycle was repeated continuously. Assuming runoff percentages of 75 and 25 percent for GI and GII, respectively, the application rates and operating schedules were such that stored runoff would be sprayed on the treatment plot three times, the initial application plus twice over the recirculation plot, GI, before it flowed over the drop structure of the detention pond.

Composite samples of the wastewater applied to GI and GII were collected daily. The samples were caught by samplers placed in the spray pattern.

Composite samples of effluent from each plot were taken by flow-proportional samplers located below the flow measuring flumes of GI and GII. The sample from GII was collected at the end of each irrigation runoff event while the sample from GI was collected daily. Rainfall runoff samples from both plots were usually obtained by grabbing a sample of the water passing through the flow measuring flume.

From August 14 to August 21, 1973, five sets of water samples were taken at 0, 50, 70, 90, 110, and 130 ft. downslope from the spray laterals on GII and the subwatershed immediately south of the polishing pond. The water sample at each distance was composite of samples taken at four locations that were the same distance downslope from a spray lateral. These samples of water flowing downslope were collected by first digging a shallow hole in an area over which water flowed, allowing the water in the hole to clear, and then withdrawing a sample by means of an evacuated glass jug.

Soil samples were taken in the early spring of 1973, before the 1973 treatment season had begun, and after the study was completed in the early fall of 1973. Samples were taken under the spray pattern and downslope of the spray pattern on GI and GII. In addition, samples were collected from an area which received no wastewater. Three depth intervals were sampled, 0-6, 6-12, and 12-14 in.

All water samples were refrigerated at the feedlot until they could be transported to Manhattan. The samples were analyzed in the sanitary engineering laboratory, Department of Civil Engineering, Kansas State University.

All water samples were analyzed to determine the following parameters: COD, ammonia nitrogen, Kjeldahl nitrogen, and electrical conductivity. Additionally, the BOD_5, total phosphorus, and total suspended solids concentrations, and the pH were determined for all but the downslope samples. All wastewater analyses were conducted according to the methods given by the American Public Health Association (1965) with the modifications given below.

The seed material used for the BOD_5 determination was municipal sewage. This was an unacclimated seed which may have given lower values than what might be expected. Nitrification during the test was inhibited by the addition of Hach Nitrification Inhibitor Formula 2533. This removed the oxygen demand caused by nitrification. To reduce the number of BOD_5 determinations needed, several samples were combined for each BOD_5 test.

Ammonia nitrogen was determined using the techniques given by Orion Research (1972) and (1973).

Kjedahl nitrogen was determined by the micro-Kjeldahl digestion technique. The ammonia nitrogen present upon digestion was then determined.

Total phosphate determinations were made using the aminonaphthol-sulfonic acid method. The color development was measured with a spectrophotometer at a wavelength of 690 millimicrons. To reduce the number of total phosphate determinations, several samples were combined and the total phosphate concentration of the combined sample was determined.

Due to the length of time required to draw a portion of a sample through the filter paper the applied wastewater and irrigation runoff samples were divided into groups of about ten. Two samples were randomly selected from each group and combined. Three total suspended solids determinations were then conducted for each combined sample. The two closest results were averaged to determine the total suspended solids concentration of the combined sample.

Several wastewater and recirculation water samples, obtained throughout the study, were analyzed for the soluble cations, calcium, sodium, potassium, and magnesium. These values, along with the electrical conductivity of the sample, were used to evaluate the wastewater's quality as irrigation water. The analyses were conducted by the Soil Testing Laboratory, Kansas State University. An atomic adsorption method was used to determine the divalent cations, while a flame photometer technique was used for sodium and potassium. The cation-exchange-capacity was determined using an approximation method.

The soil samples were also analyzed at the Soil Testing Laboratory, Kansas State University. Salt-alkali, general fertility, and nitrogen tests were conducted for each sample.

Materials and Equipment

A 7½ horsepower electric centrifugal Berkley pump, model B2TPM, supplied water to GI. This pump was controlled by a Paragon time clock, model 1505-0.

A four-inch Sparling low pressure line meter with a normal flow range of from 60 to 400 gallons-per-minute, gpm, was used to measure the amount of water applied to GI. The meter was equipped with an instantaneous flow rate dial which read in gpm and a totalizer which gave the total volume of liquid passing through the meter in units of acre-in.

Rain Bird model 30-WS-TNT sprinkler heads were used throughout the 1973 operating season. The nozzles installed on GI had a 13/64 in. diameter with a spray diameter of 102 ft. and a discharge rate of about 8.3 gpm at 47 psi. The nozzles installed on the rest of the treatment area had a 5/32 in. diameter. These nozzles had a spray diameter of about 88 ft. and a discharge rate of about 4.3 gpm at an operating pressure of about 38 psi.

Wedge-shaped True-Chek rain gauges were used. These gauges are manufactured by Edwards Mfg. Co., Albert Lea, Minnesota, and measure rainfalls between 0.01 and 6.0 in.

Flow from the GI plot was measured by a 1.5 ft. H flume located in the terrace outlet of GI. According to the U.S. Department of Agriculture (1962), this flume measures flow rates between 0.011 and 5.33 cubic feet per second, cfs. The calibration curve for this flume, shown in Appendix A, was obtained by plotting on log paper the head existing in the flume in feet, measured with a rule having 0.01 ft. divisions, versus the flow rate through the flume, which was determined using a bucket and stopwatch. A 0.8 ft. HS flume measured the flow from the GII plot. This flume has a flow range of from 0.0003 to .457 cfs. A rating table given by the U.S. Department of Agriculture (1962) was used for the calibration curve of this flume. The larger flume was placed on GI because it could measure the runoff both from irrigation and high intensity rainfalls. Both runoff measuring flumes were equipped with Stevens Type F Model 61 water level recorders.

These float-activated recorders, equipped with 24-hour clocks, provided a stage hydrograph for each runoff event. A computer program was used to convert the stage hydrograph to a discharge hydrograph, which was further integrated by the program to obtain the total runoff volume.

A jug-and-funnel arrangement was used to obtain a sample of the applied water. Two samplers were placed 28 in. above ground level in the spray patterns on GI and GII. They were placed midway between two risers in each plot and were five and ten feet from the lateral. The contents of the two jugs on each plot were combined for analysis.

Flow-proportional samplers were used to collect runoff samples from GI and GII. A flow-splitting weir box split the flow one part in ten. A chute then delivered the smaller flow to a rotating slotted-cup sampler. Laboratory tests conducted by Eisenhauer (1973) showed that the weir box and sampling cup arrangement sampled 0.027 percent of the flow passing through the measuring flumes. For further information on this sampling system see Eisenhauer (1973).

Ammonia determinations were made using an Orion Research ammonia electrode, model 95-10, in conjunction with an Orion Research Specific Ion Meter, model 407.

Total suspended solids determinations were made using a Millipore filter holder and Millipore Type HA filter paper with a 0.45 micron pore size.

A Fisher Accumet, Expanded Scale Research Model 320 pH meter was used for pH determinations. This meter is manufactured by Fisher Scientific.

A Lab-Line Portable Lectro Mho-Meter, Model MC-1, Mark IV was used for electrical conductivity determinations. This instrument is manufactured by Lab-Line Instruments, Inc.

Color development for the phosphate determination was measured with a Model 101 UV-VIS Spectrophotometer manufactured by Hitachi, Ltd.

RESULTS AND DISCUSSION

Treatment of Feedlot Runoff

In this thesis, the amount of treatment which occurred in the various parts of the treatment system is expressed as a difference in the mean values of the parameters associated with the wastewaters sampled. These differences cannot be taken as an absolute expression of the amount of treatment occurring since the statistical significance of the differences was not determined.

Characteristics of Stored Feedlot Runoff

The wastewater applied to GII was feedlot runoff that had been stored in detention ponds. This water was analyzed and characterized by the minimum, maximum, mean, median, and standard deviation of the parameters of interest. As expected, the water was found to contain large amounts of organic material, nitrogenous compounds, phosphorous and suspended solids, and thus, was of low quality. Values for the parameters determined are given in Table 7. Examination of the data reveals that, in general, the values obtained in this study are lower than those reported by Eisenhauer (1973). This was attributed to the natural variability of feedlot runoff, although the author felt that the unusually wet early spring of 1973 somewhat affected the quality of the stored runoff.

Table 7. Quality of Wastewater Applied to GII

Parameter	Units	Number of Observations	Minimum	Maximum	Mean	Median	Standard Deviation
BOD_5	mg/l	13	122	156	140	148	14
COD	mg/l	16	872	1567	1257	1220	212
Ammonia Nitrogen	mg/l as N	17	61	140	106	110	22.0
Kjeldahl Nitrogen	mg/l as N	16	105	300	166	150	53
Total Phosphorous	mg/l as PO_4	12	30	69	49	46	17
Total Suspended Solids	mg/l	12	280	565	432	482	142
pH	pH units	17	7.5	8.1	7.9	8.0	.2
Electrical Conductivity	micromhos/cm	17	4300	5100	4650	4700	245

As reported by Eisenhauer (1973), about one-third of the Kjeldahl nitrogen contained in the wastewater applied to the treatment area during 1972 was in the form of ammonia nitrogen. With mean ammonia and Kjeldahl nitrogen concentrations of 106 and 166 mg/l as nitrogen, respectively, about two-thirds of the mean Kjeldahl nitrogen content of the applied water was in the ammonia nitrogen form during 1973. The mean ammonia nitrogen content of the applied waste was similar during both the 1972 and 1973 treatment seasons. However, the mean Kjeldahl nitrogen concentration was much lower during the 1973 operating season.

The mean BOD_5 and total phosphorous values of 140 and 49 mg/l, respectively, obtained during the summer of 1973 are about one-half those reported by Eisenhauer (1973).

The mean electrical conductivity of 4650 micromhos/cm indicates that the applied water had a high concentration of dissolved salts.

Characteristics of Once-Treated Wastewater

The field effluent from GII was analyzed to determine its quality. This water also was characterized by the minimum, maximum, mean, median, and standard deviation of the various parameters. The treatment efficiency, expressed as the difference in the means of the applied and effluent water, also was determined. Inspection of Table 8 reveals that although some treatment did occur, this water was of low quality.

With mean COD and BOD_5 values of 966 and 64 mg/l, respectively, approximately a 54 percent reduction in BOD_5 and a 23 percent reduction in COD occurred as the waste flowed over the treatment plot.

Table 8. Quality of Field Effluent, GII

Parameter	Units	Number of Obser-vations	Minimum	Maximum	Mean	Median	Standard Deviation	Difference in Means of Ap-plied and Ef-fluent Water
BOD_5	mg/l	11	43	92	64	60	18	-54%
COD	mg/l	14	675	1239	966	1012	191	-23%
Ammonia Nitrogen	mg/l as N	15	5.5	28.0	12.9	10.0	8.0	-88%
Kjeldahl Nitrogen	mg/l as N	15	31	94	53	50	16	-68%
Total Phosphorous	mg/l as PO_4	11	20	57	32	27	14	-35%
Total Sus-pended Solids	mg/l	10	170	280	236	280	57	-45%
pH	pH units	15	7.8	8.9	8.2	8.2	.4	+.3 units
Electrical Conduc-tivity	micro-mhos/cm	15	4100	5200	4917	4800	584	+ 6%

Eisenhauer (1973) reported that BOD_5 and COD reductions of 60 and 21 percent, respectively, occurred on this plot during one test.

Ammonia and Kjeldahl nitrogen concentrations were reduced to 12.9 and 52 mg/l, respectively. These concentrations represent decreases of 88 and 68 percent for ammonia and Kjeldahl nitrogen, respectively. Ammonia volatilization was thought to be the primary ammonia removal mechanism. Over 80 percent of the Kjeldahl nitrogen reduction can be attributed to ammonia nitrogen loss, which suggests that some nitrification did occur.

With an effluent concentration of 32 mg/l as orthophosphate, the total phosphorous concentration was reduced 35 percent in the treatment area. The primary phosphorous removal mechanism is thought to have been adsorption to soil particles on the surface of the treatment area.

The mean electrical conductivity of the field effluent was 4917 micromhos/cm, which represents a six percent increase over the electrical conductivity of the applied water. The increase was caused by an increase in the concentration of dissolved salts, which can be attributed to some evaporation of the water as it flowed downslope.

A 45 percent decrease in total suspended solids occurred on GII, which was attributed to the settling of suspended matter as the applied water ran over the treatment plot. However, the mean total suspended solids concentration of 235 mg/l in the effluent from GII was not low enough to permit it to be released to the environment.

Although the pH of the effluent was 0.3 pH units higher than the pH of the applied wastewater, it was still below pH 9.5, the pH level at which the hydroxl-ion concentration begins to have a toxic effect on the biomass present. An increase in pH is characteristic of the treatment process which occurs in trickling filters.

Characteristics of Recirculated Wastewater

Water from the polishing pond was recirculated over GI. It was assumed that the quality of any water flowing over the drop structure of the polishing pond would be the same as that of the portion recirculated. This treatment system was visualized as treating feedlot runoff to such a degree that once the system had come to equilibrium, the water flowing over the drop structure of the polishing pond would be of high enough quality to release to the environment. Adequate data do not exist for the transitory period to predict precisely when the system reached an equilibrium condition. The data we have suggest that the system came to equilibrium from one to two weeks after it was placed in operation. It appeared as though the system had reached equilibrium by August 1, 1973. Thus, samples taken between August 1 and August 20, 1973, were analyzed. Algae cells were observed in the recirculated water. These cells would contribute to the BOD_5, COD, nitrogen, phosphorous and total suspended solids of the water applied to GI. No attempt was made to determine the species or mass of the algae cells present.

The water recirculated after the system had reached a steady state condition was characterized by the minimum, maximum, mean, median, and standard deviation of the various pollution parameters. The differences that existed between the mean values of the parameters associated with the field effluent from GII and those associated with the recirculated water were calculated. The differences that existed between the mean values of the parameters associated with the stored feedlot runoff and those associated with the recirculated flow were also calculated. The latter difference represented the overall treatment efficiency of the proposed system.

Inspection of Table 9 reveals that although the recirculated water was of better quality than was the effluent from GII, it was still of low quality.

Dilution of the field effluent from GII with the higher quality effluent from GI was primarily responsible for the quality increase. Some treatment may have occurred in the polishing pond but adequate data was not taken to determine this.

With mean BOD_5 and COD values of 37 and 659 mg/l, respectively, approximately six percent of the material contributing to the COD can be biochemically degraded in five days or less. These values represent overall mean concentration reductions of 74 and 48 percent for the BOD_5 and COD values, respectively.

Mean ammonia and Kjeldahl nitrogen concentrations were reduced to 5.7 and 33 mg/l, respectively, while total phosphorous was reduced 58 percent to 21 mg/l. Any settling in the polishing pond of suspended soil particles, to which phosphorous had been adsorbed, would result in a decrease in the total phosphorous concentration.

The mean total suspended solids concentration was 69 percent lower in the recirculated flow than in the field effluent from GII. This reduction was attributed to dilution and additional settling which took place in the polishing pond, although the algae found in the recirculated flow would tend to increase this parameter. The mean

Table 9. Characteristics of Recirculated Flow

Parameter	Units	Number of Observations	Minimum	Maximum	Mean	Median	Standard Deviation	Difference in Means*	Difference in Means**
COD	mg/l	12	535	833	659	652	93	-32%	-48%
BOD_5	mg/l	8	24	62	37	34	16	-42%	-74%
Ammonia Nitrogen	mg/l as N	12	1.2	8.0	5.7	5.9	1.9	-56%	-95%
Kjeldahl Nitrogen	mg/l as N	12	24	52	33	31	7	-38%	-80%
Total Phosphorous	mg/l as PO_4	8	18	22	21	21	2	-34%	-58%
Total Suspended Solids	mg/l	8	63	155	74	63	32	-69%	-83%
pH	pH units	12	7.9	8.6	8.3	8.3	.2	+.1 unit	+.4 unit
Electrical Conductivity	micromhos/cm	11	3850	4900	4286	4400	312	-13%	-8%

*Difference in means of field effluent from GII and recirculated water applied to GI.

**Difference in means of stored runoff applied to GII and recirculated water applied to GI.

total suspended solids concentration of 74 mg/l in the recirculated flow represented an overall treatment efficiency of about 83 percent.

The electrical conductivity of the recirculated liquid was 4286 micromhos/cm which is 13 percent lower than that of the field effluent from GII. The decrease was caused by a reduction in dissolved salts which took place in the polishing pond. The author feels that the decrease in dissolved salts may be attributed to the assimilation of dissolved salts by algae in the polishing pond, even though no data is available to support this theory.

The mean values of the BOD_5, total suspended solids, ammonia and Kjeldahl nitrogen, and total phosphate data indicate that this water, and thus the water in the polishing pond was of low quality.

Characteristics of Field Effluent, GI

The field effluent from the recirculation plot, GI, was characterized by the minimum, maximum, mean, median, and standard deviation of the various pollution parameters. Again, the samples analyzed were collected after August 1, 1973. The differences in the means of the parameters associated with the water applied to, and those associated with the field effluent from GI were calculated. In addition the differences in the means of the parameters associated with the stored feedlot runoff and those associated with the effluent from GI were calculated. Had the system been designed so that this effluent could have been directly released, the latter difference would have represented the overall treatment efficiency of the system. Part of the treatment occurring on GI was attributed to algal removal from the recirculated waste. However, no data was taken which would allow the proportion of treatment attributable to algal removal to be calculated.

Inspection of Table 10 reveals that the mean BOD_5 and COD values for the effluent from GI were 17 and 635 mg/l, respectively. A 54 percent reduction in mean BOD_5 values occurred on each plot, GI and GII. Thus, it appears that the BOD_5 "treatability" of the recirculated water is the same as that of the stored feedlot runoff. This agrees with the models proposed by Velz (1948) and Atkinson et al. (1963). Comparison of the mean BOD_5 and COD values of the applied and effluent water from GI suggests that the only reduction in COD occurring on GI was due to BOD_5 removal. Had the effluent from GI been released, the system's overall concentration reductions would have been 88 and 50 percent for BOD_5 and COD, respectively.

The effluent from GI had a mean Kjeldahl nitrogen concentration of 25 mg/l. Of this, 2.6 mg/l was in the form of ammonia nitrogen. The mean Kjeldahl nitrogen concentration in the effluent from GI was 85 percent less than the mean concentration which existed in the stored runoff. The mean ammonia nitrogen concentration was reduced by 98 percent. Over 70 percent of the Kjeldahl nitrogen reduction was attributed to ammonia nitrogen loss. Therefore, other nitrogen removal mechanisms were involved, probably the nitrification and subsequent denitrification processes.

Total phosphorous did not exhibit a significant concentration reduction while flowing over the recirculation plot. Removal of algae from the water would result in lower concentrations of phosphorous but any erosion of the soil surface would result in soil particles being carried off the plot in the effluent. Phosphorous adsorbed to these particles would contribute to the effluent's total phosphorous content. The mean total phosphorous concentration of the effluent from GI was

Table 10. Quality of Field Effluent, GI

Parameter	Units	Number of Observations	Minimum	Maximum	Mean	Median	Standard Deviation	Difference in Means*	Difference in Means**
BOD_5	mg/l	8	16	17	17	17	.5	-54%	-88%
COD	mg/l	12	410	750	635	659	91	-4%	-50%
Ammonia Nitrogen	mg/l as N	11	1.4	4.3	2.6	2.6	1.0	-54%	-98%
Kjeldahl Nitrogen	mg/l as N	12	19	35	25	26	4	-24%	-85%
Total Phosphorous	mg/l as PO_4	8	17	24	20	19	3	-5%	-59%
Total Suspended Solids***	mg/l	....	....	....	18	....	....	-76%	-96%
pH	pH units	12	8.0	8.8	8.5	8.6	.2	+.2 unit	+.6 unit
Electrical Conductivity	micromhos/cm	12	3300	5200	4483	4650	570	+5%	-4%

*Difference in means of water applied to, and field effluent from GI.

**Difference in means of water applied to GII and field effluent from GI.

***Only one representative composite sample was analyzed.

59 percent lower than that of the stored runoff, but the effluent's concentration of 19 mg/l would cause this water to be of questionable quality to release to surface waters. Effluent from municipal waste treatment plants that do not have phosphorous removal facilities, contain approximately the same total phosphorous concentration.

The mean pH value increased about 0.2 pH units as the waste flowed over GI, with the pH of the effluent being about 0.6 pH units higher than that of the stored runoff. An increase in pH is typical of the type of reactions thought to be taking place in the polishing pond and on the treatment plots.

The electrical conductivity of the wastewater increased as it flowed over GI. The percentage increase in electrical conductivity was about the same on GI and GII, five and six percent, respectively. Since the waste exhibited a decrease in electrical conductivity while in the polishing pond, the mean electrical conductivity of the runoff from GI of 4650 micromhos/cm was about four percent lower than the mean of the water applied to GII.

Mean total suspended solids decreased about 76 percent on GI. The mean total suspended solids of this effluent was 96 percent less than that of the stored feedlot runoff. However, the effluent's total suspended solid concentration of 18 mg/l is not statistically significant since only one sample was analyzed, a composite of two samples chosen at random from a group of eight.

It appears that the effluent from GI would meet the proposed standards for municipal wastewater of 30 mg/l of BOD_5 and 30 mg/l of total suspended solids. Nutrient concentrations may preclude release, although settling of this effluent may result in additional concentration decreases.

Runoff Percentage

During the 1973 operating season, the recirculation system was operated continuously from July 17 through August 21. During that period, 24.4 in. of recirculated waste was applied to GI. Nonetheless, because of recorder malfunctions and the author's inability to distinguish between rainfall and irrigation runoff, runoff data was available for only 14 days. As shown in Table 11, a total of about 9.8 in. of wastewater was applied on the 14 days. Of this, 3.2 in., or about 33 percent ran off GI. The runoff percentage was much lower than was expected.

Table 11. Quantity of Applied Wastewater and Field Effluent

Plot	Total Number of Irrigation Days	Total Amount Applied (IN.)	Number of Days with Runoff Data Available	Amount Applied with Run-off Data Available (IN.)	Amount of Runoff (IN.)	Percent Runoff for Available Data
GI	34	24.4	14	9.8	3.2	32.6
GII	27	7.5	13	3.5	.5	14.6

The quantity of water applied to, and the effluent from GII was monitored from July 3, 1973, through August 21, 1973. Stored wastewater was applied to this plot on 27 days during this period. However the four-inch water meter in the spray lateral on GII malfunctioned. Therefore, an estimate of the amount of water applied daily was made using estimated nozzle pressures and recorded pumping times. Using this estimation method, about 7.5 in. of feedlot runoff was applied to GII during this period. Owing to the reasons previously mentioned, runoff data was available for only 13 days. It was estimated that about 3.5 in. of water was applied to GII on the 13 days. Of the applied water, .5 in. ran off GII, which yielded a runoff percentage of about 15 percent. Again, this was much lower than expected, as Eisenhauer (1973) reported that 25 to 27 percent of the applied water ran off the plots, although he used lower application rates.

The water loss must be accounted for by direct sprinkler evaporation, crop consumptive use, and evaporation which took place as the water flowed downslope. In addition, some water may have moved through the soil profile. This is suggested by the soil tests that indicated leaching took place between treatment seasons.

Mass Removals

The treatment efficiency of a system can also be defined in terms of the mass removal of various parameters. To calculate the mass removal that occurs on a given plot, the quantity and quality of the applied and effluent water must be known. The total mass of a given parameter that is applied to, or flows from a plot can then be determined on a pounds-per-acre-per-day basis.

Since GI had a much higher hydraulic loading rate, the weekly BOD_5 loading rate of GII was only slightly higher than that of GI. Weekly COD and total phosphorous loading rates were actually higher for GI than for GII. As the result of high concentration reductions of nitrogen on GII, the weekly nitrogen loading rate was almost twice as high for GII as for GI.

In general, mass reductions were attributed to the concentration reductions occurring on the plots and the physical transport of material into the soil by infiltrating wastewater. Table 12 gives the mass

Table 12. Mass Reductions

Parameter	Plot	Total Amount of Wastewater Applied (ac-in)	Days with Needed Data Available	Amount of Wastewater Applied with Needed Data (ac-in)	Pounds per acre Applied	Pounds per acre per week Applied	Pounds per acre Off	Mass Removal (%)
BOD_5	GI	37.8	7	7.6	43	6	5	88
	GII	26.9	11	9.8	84	8	3	96
COD	GI	37.8	9	9.8	912	101	272	70
	GII	26.9	11	9.8	749	68	50	93
Kjeldahl Nitrogen	GI	37.8	9	9.8	46	5.3	10	78
	GII	26.9	11	9.8	101	9.2	2	98
Ammonia Nitrogen	GI	37.8	9	9.8	8	.9	9	89
	GII	26.9	12	10.8	81	6.8	9	99
Total Phosphorous	GI	37.8	7	7.6	25	3.6	5	80
	GII	26.9	11	9.8	26	2.4	2	92

removal percentages for the following parameters: BOD_5; COD; Kjeldahl nitrogen; ammonia nitrogen; and total phosphorous. The mass reductions occurring on GI and GII, respectively, are: 88 and 96 percent for BOD_5; 70 and 93 percent for COD; 78 and 98 percent for Kjeldahl nitrogen; 89 and 99 percent for ammonia nitrogen; and 80 and 92 percent for total phosphorous. The mass removal of any given parameter was higher for water applied to GII. This was due to the small portion of the applied wastewater which ran off of GII and the lesser degree of treatment that occurred on GI.

Effect of Slope Length

In an attempt to determine the effect that the slope length had on the quality of the field effluent, samples were taken at various distances downslope from the spray laterals on GII and the subwatershed immediately south of the polishing pond. The quality of the downslope samples was characterized by the range, mean, median, and standard deviation of their ammonia and Kjeldahl nitrogen concentrations, their COD's and electrical conductivities. This data is presented in Table 13. The author feels that the data given in this section should be used only to determine general trends, as the sampling procedure used allowed the samples to be easily contaminated with excess suspended matter.

A statistical analysis of the data by an AARDVARK computer program revealed that at the 0.05 alpha level, the only parameter which exhibited any statistically significant difference in mean values, at the various distances downslope, was Kjeldahl nitrogen.

Mean Kjeldahl nitrogen concentrations were reduced from 104 mg/l

Table 13. Quality of Downslope Samples

Parameter	Units	Distance Down-slope	Number of Data Points	Maximum	Minimum	Mean	Median	Standard Deviation
Ammonia Nitrogen	mg/l as N	0'	5	74	26	48	50	20
		50'	5	47	26	37	38	10
		70'	5	46	26	37	42	9
		90'	5	44	27	34	32	7
		110'	5	43	28	33	32	6
		130'	5	40	19	29	28	8
Kjeldahl Nitrogen	mg/l as N	0'	5	118	78	104	105	16
		50'	5	125	74	104	110	19
		70'	5	100	84	93	95	6
		90'	5	100	86	92	92	5
		110'	5	94	68	82	81	9
		130'	5	104	50	79	83	20
Electrical Conductivity	micro-mhos/cm	0'	5	4700	4200	4540	4600	207
		50'	5	5000	4400	4660	4700	261
		70'	5	5200	4400	4780	4800	335
		90'	5	5300	4100	4700	4900	524
		110'	5	5300	4300	4780	4900	390
		130'	5	5400	4400	4900	5000	436
COD	mg/l	0'	5	1437	1150	1343	1386	113
		50'	5	1475	1220	1316	1300	95
		70'	5	1395	1150	1265	1285	100
		90'	5	1314	1035	1179	1160	116
		110'	5	1285	1085	1190	1210	91
		130'	5	1314	829	1103	1060	202

at the lateral to 79 mg/l 130 ft. downslope. The largest decreases occurred from 50 to 70 ft. and from 90 to 110 ft. downslope with no decrease occurring less than 50 ft. downslope.

Mean ammonia nitrogen concentrations ranged from 48 mg/l at the lateral to 29 mg/l 130 ft. downslope. The greatest decrease in this parameter occurred between 0 and 50 ft. downslope. Ammonia nitrogen loss was attributed primarily to ammonia volatilization. Ammonia volatilization appears to be the major nitrogen removal mechanism with some mineralization, nitrification, and possibly some dentrifrication occurring.

The mean COD values generally decreased as the distance downslope increased. Mean COD values ranged from 1343 mg/l at the spray lateral to 1103 mg/l 130 ft. downslope. The general decrease in COD values was expected because as the distance of overland flow increases, the time that the waste is in contact with the biological mass on the soil surface also increases. This allows more of the organic material present in the waste to be utilized by the biomass in the formation of new cell nass. Also, it is possible that more of the suspended solids settled out of solution at the greater slope lengths.

The mean electrical conductivities of the downslope samples ranged from 4540 micromhos/cm at the spray lateral to 4900 micromhos/cm 130 ft. downslope from the spray lateral. The general increase in electrical conductivity was attributed to an increase in the total salt concentration of the waste as it flowed downslope, which was thought to be caused by evaporation of some of the wastewater. The reduction in electrical conductivity that occurred between 70 and 90 feet downslope could not be explained.

It appears that waste treatment is still occurring 130 ft. downslope. Therefore, longer slope lengths may produce greater concentration reductions.

Rainfall Runoff

Rainfall runoff from the treatment area is of interest because it may not be of high enough quality to release to the environment. This was found to be true by Eisenhauer (1973). If the rainfall runoff is of low quality, a detention facility would be required.

As shown in Table 14, a total of 5.0 in. of rainfall occurred during the period of study, which occurred as 10 rainfall events. No runoff volume data is available for the rainfall runoff from GI while the rainfall runoff volume from GII is known for only one event. The lack of data was the result of stage recorder malfunctions and the author's inability to differentiate between rainfall and irrigation runoff. For the one rainfall event, about 17 percent of the rainfall ran off GII. That seems fairly low but no rainfall intensity data was taken. Thus, it may have been a low intensity storm.

Table 14. Quantity of Rainfall and Percent Rainfall Runoff

Plot	Number of Rainfall Events	Total Rainfall (IN.)	Number of Events with Rainfall Runoff Data Available	Rainfall with Runoff Data Available (IN.)	Percent Runoff
GI	10	5.0	0	0	----
GII	10	5.0	1	1.5	16.8

Some of the samples of rainfall runoff analyzed for the various pollution parameters may have been slightly contaminated with irrigation runoff. If all these samples were eliminated, very few samples would have been available for analysis. Rainfall runoff samples were also characterized by the range, mean, median and standard deviation of the various pollution parameters.

As shown in Table 15, unsettled rainfall runoff from the treatment area was of low quality.

Mean BOD_5 values for runoff from both GI and GII were 29 mg/l, while mean COD values were 480 and 517 mg/l for GI and GII, respectively. The data implies that only about 6 percent of the material contributing to the COD can be biologically degraded in 5 days. The BOD_5 values may have been higher had an acclimated seed been used. Values for BOD_5 and COD are somewhat lower than those reported by Eisenhauer (1973). He reported a range of mean BOD_5 values from 45 to 53 mg/l for GI and GII, respectively, and a range of mean COD values from 593 to 852 mg/l.

The mean Kjeldahl nitrogen concentrations for rainfall runoff from GI and GII, respectively, were 23 and 25 mg/l. Since the mean ammonia nitrogen concentrations were 4.4 and 6.9 mg/l for rainfall runoff from GI and GII, respectively, the organic nitrogen concentrations of rainfall runoff from both plots were about the same.

With mean total phosphorous concentrations of 25 and 37 mg/l for GI and GII, respectively, rainfall runoff from both plots had a higher mean total phosphorous concentration than did the field effluent that occurred during the waste treatment process.

Table 15. Quality of Rainfall Runoff

Parameter	Units	Plot	Number of Data Points	Maximum	Minimum	Mean	Median	Standard Deviation
BOD_5	mg/l	GI	6	52	13	29	28	18
		GII	5	49	14	29	19	17
COD	mg/l	GI	6	719	197	480	468	178
		GII	5	800	240	517	518	210
Ammonia Nitrogen	mg/l as N	GI	6	6.9	2.5	4.4	4.2	1.6
		GII	5	9.2	4.4	6.9	6.0	2.2
Kjeldahl Nitrogen	mg/l as N	GI	6	41	11.5	23	20	10.6
		GII	5	36	11	25	25	10.6
Total Phosphorous	mg/l as PO_4	GI	6	34	17	25	27	7
		GII	4	46	29	37	36	8
Total Suspended Solids	mg/l	GI	4	180	95	116	96	42
		GII	4	160	49	107	109	48
Electrical Conductivity	micro-mhos/cm	GI	6	4050	1290	3182	3475	984
		GII	4	4500	2450	3712	3950	954
pH	pH units	GI	6	8.8	8.0	8.4	8.4	.32
		GII	4	8.6	8.0	8.4	8.4	.24

The mean total suspended solids concentrations were 116 and 107 mg/l for rainfall runoff from GI and GII, respectively. This is one of the parameters which suggest that unsettled rainfall runoff from the treatment area was the environment.

The total salt concentration of the runoff from GI is probably less than that of runoff from GII. This is suggested by the mean electrical conductivities of 3182 and 3712 micromhos/cm for runoff from GI and GII, respectively.

The data presented indicate that the rainwater picks up considerable impurities from the treatment plots. This probably can be attributed to the erosion and transport of soil particles and organic matter from the treatment area. The tendancy for rainfall runoff from GII to be of lower quality than that from GI possibly may be the result of applying a higher strength waste to GII.

Suitability of the Wastewaters for Irrigation

Salt and Cation Concentrations of the Wastewaters

To determine the suitability of the applied and the recirculated wastewater for irrigation purposes, samples of the water applied to GI and GII were analyzed to determine their electrical conductivities and their potassium, sodium, calcium, and magnesium concentrations. These cation concentrations were used to determine the sodium-adsorption ratio and the soluble-sodium percentage of the wastewaters.

As shown in Table 16, the wastewaters had high mean electrical conductivities, 4286 and 4650 micromhos/cm for the recirculated water and the water applied to GII, respectively. Mean concentrations of

Table 16. Salt and Cation Concentrations of Applied Wastewater

Parameter	Units	Plot	Number of Data Points	Maximum	Minimum	Mean	Median	Standard Deviation
Electrical Conductivity	micro-mhos/cm	GI	11	4900	3850	4286	4400	312
		GII	17	5100	4300	4650	4700	245
Potassium	mg/l	GI	5	525	475	505	500	21
		GII	5	550	450	510	525	38
Sodium	mg/l	GI	5	770	550	712	735	92
		GII	5	770	475	704	770	129
Calcium	mg/l	GI	5	99	86	90	88	5
		GII	5	122	90	110	117	14
Magnesium	mg/l	GI	5	123	115	118	118	3
		GII	5	133	120	128	128	5
Soluble Sodium Percentage	Percent	GI	5	56.0	46.8	53.3	54.6	3.7
		GII	5	55.9	40.0	51.0	53.4	6.3
Sodium Adsorption Ratio	None	GI	5	13.2	8.7	11.8	12.2	1.8
		GII	5	12.3	7.1	10.9	11.7	2.2

potassium were 505 and 525 mg/l for wastewater applied to GI and GII, respectively. The mean concentrations of calcium and magnesium were, respectively, 90 and 118 mg/l in the water applied to GI, and 110 and 128 mg/l in the feedlot runoff applied to GII. Both the feedlot runoff from storage and the recirculated wastewater had high sodium concentrations with mean concentrations of 704 and 712 mg/l, respectively. The higher sodium concentration found in the recirculated water was reflected in its higher calculated soluble-sodium percentage and sodium-adsorption ratio. The recirculated water's sodium-adsorption ratio and soluble-sodium percentage were 11.8 and 53.3 percent, respectively, while the same quantities were slightly lower in the stored feedlot runoff, 10.9 and 51.0 percent, respectively.

Using the mean sodium-adsorption ratios and the mean electrical conductivities of the wastewaters, their suitability as irrigation water was determined by referring to the irrigation water classification chart given by the U.S. Salinity Laboratory Staff (1954). The chart is shown in Appendix B. Using this classification method, the feedlot runoff and the recirculated water were both very saline and were high to very high in sodium. Thus, the waters were not suitable for irrigation under most conditions. The only conditions where sustained use of this water is practical is on salt tolerant crops in areas with permiable soil and excellent subsurface drainage when chemical amendments such as gypsum are added to reduce the sodium hazard to low or medium. If these practices are not followed, the soils may become saline and/or disperse. Thus, both the feedlot runoff and water recirculated from the polishing pond should be used as irrigation water with caution.

Since spray-runoff irrigation systems are meant to be installed in areas with low soil permiability and/or poor subsurface drainage, extreme caution should be used with this system to insure its continued operation.

The soil should be carefully monitored to follow the salt and sodium balance in the soil so that it doesn't disperse or become saline. Some leaching should occur between treatment periods and thus partially alleviate the problems associated with applying very saline water which is also high to very high in sodium.

Effect of Wastewater on the Chemical Properties of the Soil

Soil samples were taken before and after both seasons of operation to monitor the chemical changes occurring in the soil profile. All determinations except the cation-exchange-capacity, have an accuracy range of ± 5 percent. The cation-exchange-capacity is accurate within ± 10 percent. The 1973 study period ended August 21, but the soil samples were not taken until early October 1973. During this period the treatment area received about 9.1 in. of rain, which may have resulted in some leaching. Thus, the chemical analysis of the soil samples taken in October 1973, may not indicate the true soil chemistry changes that occurred during the 1973 treatment season.

The soil analysis of the checkplot, to which no feedlot runoff was applied, is shown in Table 17. High initial concentrations of some parameters can be attributed to the manure applied in the fall of 1971. The parameters determined exhibited the following overall trends from the spring of 1972 to the spring of 1973: soluble sodium, exchangeable-sodium percentage, electrical conductivity of the soil

Table 17. Soil Analysis of Check Plot*

Parameter (units)	Date Sampled	Depth (In.) 0-6	6-12	12-24
Soluble Sodium (meq/100 gm)	Spring 1972	.33	.39	.51
	Fall 1972	...	...	...
	Spring 1973	.07	.12	.26
	Fall 1973	.12	.14	.44
Exchangeable Sodium (meq/100 gm)	Spring 1972	.48	.72	1.44
	Fall 1972	...	...	...
	Spring 1973	.33	.75	1.43
	Fall 1973	.46	.76	1.12
Approximate Cation Exchange Capacity (meq/100 gm)	Spring 1972	22.3	21.0	24.7
	Fall 1972	...	...	...
	Spring 1973	22.5	22.7	26.9
	Fall 1973	24.0	25.0	27.4
Exchangeable Sodium Percentage (%)	Spring 1972	2.15	3.43	5.83
	Fall 1972	...	...	...
	Spring 1973	1.16	2.82	4.35
	Fall 1973	1.90	3.04	4.07
Electrical Conductivity (millimhos/cm)	Spring 1972	2.82	1.99	1.34
	Fall 1972	...	...	...
	Spring 1973	.74	.53	.75
	Fall 1973	.88	.62	.74
pH (pH units)	Spring 1972	6.0	5.8	6.4
	Fall 1972	6.2	6.1	6.6
	Spring 1973	6.3	6.0	6.7
	Fall 1973	6.7	6.2	6.8
NH_4 (PPM)	Spring 1972	29.9	20.6	11.3
	Fall 1972	10.1	4.3	4.3
	Spring 1973	10.1	6.9	4.9
	Fall 1973	11.6	6.1	5.8
NO_3 (PPM)	Spring 1972	105.1	109.9	65.3
	Fall 1972	90.8	80.8	80.8
	Spring 1973	18.5	5.5	15.3
	Fall 1973	13.9	7.2	12.1
Exchangeable Potassium (meq/100 gm)	Spring 1972	.9	.6	1.5
	Fall 1972	4.1	.7	.6
	Spring 1973	3.1	.8	.6
	Fall 1973	2.7	.9	.7
Available Phosphorous (PPM)	Spring 1972	222	58	24
	Fall 1972	148	32	17
	Spring 1973	225	26	10
	Fall 1973	225	50	25

* Data for Spring and Fall of 1972 taken from Eisenhauer (1973).

saturation extract and ammonium and nitrate nitrogen decreased in all depth increments sampled; exchangeable sodium decreased in all but the 6-12 in. increment; the cation exchange capacity and pH generally increased in all depth increments; and exchangeable potassium initially increased, then decreased in the top 6 in., and showed an overall decrease in the 6-12 in. interval. An increase in many parameters occurred between the spring and fall of 1973. The author could find no explanation for the increase as no waste had been applied to this area. Even with the increase, the parameters for the check plot were all lower than the corresponding parameters for samples taken from the treatment area.

Tables 18 and 19 show the results of the soil analysis for treatment areas GI and GII, respectively. Eisenhauer (1973) noted that the following parameters increased on both plots during the 1972 study: electrical conductivity of the soil saturation extract, cation exchange capacity, pH, exchangeable potassium, exchangeable sodium, soluble sodium and exchangeable sodium percentage, with the most abrupt increases occurring in the top six inches of soil. Using the classifications given by the U.S. Salinity Laboratory Staff (1954), which classify a soil as saline if its electrical conductivity exceeds four millimhos/cm, only the top six inches of the soil profile of each plot was classified as saline. He went on to state that no serious salinity or alkali hazards developed after one year of operation. He again used the classification given by the U.S. Salinity Laboratory Staff (1954) which classifies a soil as alkali if its exchangeable sodium percentage exceeds 15 percent.

It was expected that some leaching would occur between treatment

Table 18. Soil Analysis of GI*

Parameter (units)	Date Sampled	Depth (In.) 0-6	6-12	12-24
Soluble Sodium (meq/100 gm)	Spring 1972	0.3	0.3	0.5
	Fall 1972	1.1	1.0	0.3
	Spring 1973	0.6	0.6	0.6
	Fall 1973	1.0	0.9	0.7
Exchangeable Sodium (meq/100 gm)	Spring 1972	0.5	0.5	0.9
	Fall 1972	0.9	0.4	1.2
	Spring 1973	1.1	1.3	1.3
	Fall 1973	1.5	1.1	1.1
Approximate Cation Exchange Capacity (meq/100 gm)	Spring 1972	22.9	18.7	24.2
	Fall 1972	25.2	24.0	25.5
	Spring 1973	24.7	22.8	24.5
	Fall 1973	25.2	25.4	27.5
Exchangeable Sodium Percentage (%)	Spring 1972	2.0	3.0	3.5
	Fall 1972	3.6	1.8	4.8
	Spring 1973	2.4	3.1	2.7
	Fall 1973	5.9	4.3	3.9
Electrical Conductivity (millimhos/cm)	Spring 1972	2.3	2.0	2.0
	Fall 1972	4.4	3.3	2.6
	Spring 1973	2.5	2.2	2.2
	Fall 1973	3.4	2.6	2.1
pH (pH units)	Spring 1972	6.7	6.4	6.4
	Fall 1972	7.6	7.1	6.7
	Spring 1973	7.2	6.7	6.3
	Fall 1973	7.5	7.0	6.8
NH_4 (PPM)	Spring 1972	41	30	20
	Fall 1972	20	12	6
	Spring 1973	17	11	10
	Fall 1973	15	8	8
NO_3 (PPM)	Spring 1972	72	74	85
	Fall 1972	24	13	39
	Spring 1973	50	19	16
	Fall 1973	29	12	8
Exchangeable Potassium (meq/100 gm)	Spring 1972	2.3	1.2	0.7
	Fall 1972	8.0	3.9	0.8
	Spring 1973	6.4	3.1	1.0
	Fall 1973	7.2	2.3	0.9
Available Phosphorous (PPM)	Spring 1972	244	82	30
	Fall 1972	246	99	35
	Spring 1973	255	77	26
	Fall 1973	262	75	44

* Data for Spring and Fall of 1972 taken from Eisenhauer (1973).

Table 19. Soil Analysis of GII*

Parameter (units)	Date Sampled	Depth (In.) 0-6	6-12	12-24
Soluble Sodium (meq/100 gm)	Spring 1972	0.4	0.3	0.2
	Fall 1972	0.6	0.4	0.2
	Spring 1973	0.4	0.4	0.4
	Fall 1973	0.8	0.7	0.6
Exchangeable Sodium (meq/100 gm)	Spring 1972	0.6	0.6	0.7
	Fall 1972	1.3	1.3	0.9
	Spring 1973	1.0	1.4	1.1
	Fall 1973	0.9	1.0	0.8
Approximate Cation Exchange Capacity (meq/100 gm)	Spring 1972	25.2	23.6	24.9
	Fall 1972	26.8	26.4	27.6
	Spring 1973	24.9	24.5	26.7
	Fall 1973	28.8	27.2	27.8
Exchangeable Sodium Percentage (%)	Spring 1972	2.2	2.5	2.7
	Fall 1972	4.7	4.7	3.3
	Spring 1973	2.2	3.8	2.7
	Fall 1973	3.1	3.9	2.9
Electrical Conductivity (millimhos/cm)	Spring 1972	2.8	2.1	2.0
	Fall 1972	4.0	2.7	2.2
	Spring 1973	1.8	1.5	1.6
	Fall 1973	3.6	3.3	3.0
pH (pH units)	Spring 1972	6.6	6.3	6.5
	Fall 1972	7.7	7.2	6.6
	Spring 1973	7.2	6.9	6.5
	Fall 1973	7.5	7.3	7.0
NH_4 (PPM)	Spring 1972	53	40	21
	Fall 1972	20	12	9
	Spring 1973	14	9	7
	Fall 1973	16	13	10
NO_3 (PPM)	Spring 1972	93	70	75
	Fall 1972	34	8	13
	Spring 1973	36	19	12
	Fall 1973	42	14	8
Exchangeable Potassium (meq/100 gm)	Spring 1972	2.6	1.3	1.1
	Fall 1972	9.6	5.3	2.4
	Spring 1973	6.5	3.9	1.5
	Fall 1973	5.4	3.5	1.4
Available Phosphorous (PPM)	Spring 1972	329	188	132
	Fall 1972	300	104	43
	Spring 1973	302	72	30
	Fall 1973	281	75	62

* Data for Spring and Fall of 1972 taken from Eisenhauer (1973).

seasons. This expectation was realized as the following parameters showed reductions in some or all of the depth intervals studied between the fall of 1972 and the spring of 1973: soluble sodium, cation exchange capacity, exchangeable sodium, soil saturation extract's electrical conductivity, pH, ammonium nitrogen, exchangeable potassium and available phosphorous. Only the electrical conductivity of the soil saturation extract, soil nitrogen in the ammonium and nitrate ion forms and available phosphorous were generally lower in value in the spring of 1973 than they were in the spring of 1972. Thus, although most parameters decreased between the fall of 1972 and the spring of 1973, only three were reduced to levels below those existing prior to the application of any wastewater.

Using the classifications given by the U.S. Salinity Laboratory Staff (1954) for saline and alkali soils, no salt or alkali hazard existed in any portion of the plot in the spring of 1973.

As expected, the value of some of the parameters increased during the 1973 operating season. The following parameters increased in value from the spring to the fall of 1973: soluble sodium, pH, cation-exchange-capacity, exchangeable sodium, and electrical conductivity. Excluding the pH, the increases were most pronounced at the shallower depths. In addition, an increase in ammonia nitrogen was noted in samples taken from GII. This increase occurred primarily in the deeper layers as did an increase in available phosphorous.

Up to a 100 percent increase in soluble sodium was noted during the 1973 treatment season, with up to a 230 percent increase occurring during the first two years of operation. Possibly due to the addition of organic material to the soil, the cation-exchange-capacity generally increased slightly during both seasons of operation. From the spring of 1972 to the fall of 1973 this parameter increased about 15 percent. The overall rise in soil pH was probably caused by addition of the higher pH wastewater.

The overall reduction of nitrogen after two years of operation was attributed to losses through plant use, nitrification, denitrification and possibly leaching of the nitrogen added to the soil by the manure applied in the fall of 1971.

Using the classification for soil salinity given by the U.S. Salinity Laboratory Staff (1954) which classifies a soil as saline if its electrical conductivity exceeds four millimhos/cm, no salinity hazard existed in the treatment area. However, considerable leaching may have occurred before the soil was sampled in the fall of 1973. Thus, a salinity hazard may have existed prior to the rainfall. The increases in the electrical conductivity of the soil saturation extracts of samples from all three depth intervals indicate that the potential for salinity problems exists. Thus, the soil should be periodically sampled and analyzed to warn of an approaching salinity hazard.

The U.S. Salinity Laboratory Staff (1954) classifies a soil as alkaline if the soil's exchangeable-sodium percentage exceeds 15 percent. Using this classification method, an alkali problem did not exist in the treatment area after two years of operation. The classification method does not take into account the effect of exchangeable potassium on soil alkalinity, but this parameter is thought to have only a slight or no adverse effect on soil physical properties. Nevertheless, as with the salinity problem, the potential for alkali problems does exist as the exchangeable sodium percentage increased in the top 12 in. of soil on GI to a higher level during the second season of operation than it had during the first season. Again, it must be remembered that it is possible some leaching occurred before the samples were taken in the fall of 1973. Therefore, the soil should also be periodically checked to warn of possible alkali conditions.

Miscellaneous Observations

Since the runoff percentages for GI and GII were much lower than originally anticipated, no wastewater flowed over the drop structure of the polishing pond. In effect, the system functioned as a disposal system rather than a treatment system. Nonetheless, it was felt that the treatment data obtained in this study would not have been significantly different had there been a discharge from the polishing pond.

On several occasions, sprinkler risers broke off the spray lateral, which resulted in "slug" loadings of the system with untreated feedlot runoff. It is not known how much this affected the treatment system. Some plugging of the spray nozzles was also noted.

No noticeable odor problems developed during treatment although it would be very hard to determine due to the treatment area's proximity to the feedlot.

A definite color change was noted as the wastewater flowed through the various portions of the system. The stored feedlot runoff was initially a dark reddish-brown when applied to GII. Samples of the effluent from GII exhibited no discernable change in color from the applied water. A noticeable color change occurred in the polishing pond. Samples of the recirculated water applied to GI were light in color and had a greenish tinge because of the presence of algae. At times these samples were a bright emerald green. As the water flowed over GI some additional color change occurred, with the effluent samples from GI being somewhat clearer and of a lighter shade of green.

Some ponding occurred on GI and in the terrace channel of GII. It was assumed that anaerobic conditions existed in these areas but it is not known if the treatment efficiency of the system was adversely affected.

The thin biological mat mentioned by Eisenhauer (1973) was again observed. This mat could be peeled from the soil surface, and when subjected to dry conditions, would crack and roll up. No attempt was made to study the mat.

Some channeling occurred as the wastewater flowed downslope. The channels were wide, in excess of 50 ft. Channeling probably reduced the treatment efficiency of the grass filter. Increased slope lengths would accentuated the channeling problem.

No more flies were present in the treatment area than were present in other areas around the feedlot. However, the treatment area proved to be very conducive to the breeding of mosquitoes.

The system was shut down on August 21, 1973. As soon as the area had dried sufficiently, the grass was cut with a tractor-mounted rotary mower and allowed to dry. It was then raked and baled. During September, about 9.1 in. of rainfall occurred. In early October, the author observed a complete loss of the grass stand in some areas,

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THIS IS AS RECEIVED FROM THE CUSTOMER.

primarily under the spray lateral on GII. A partial loss also occurred downslope from this lateral. Little or no regrowth occurred in affected areas after the grass was cut, although a lush growth was noted in areas which received no wastewater. A narrow strip of grass along the spray lateral, which had not been closely cut, did survive, which led the author to believe that the close mowing of the grass may have been partly responsible for the loss of the stand. Another possibility is that the stand of perennial grasses had been lost previously and a stand of annual grasses had replace it. This would explain the lack of regrowth after mowing.

CONCLUSIONS

1. Treatment of beef cattle feedlot runoff took place on the grass filter system. Had water flowed over the drop structure of the polishing pond as proposed, it would probably not have been suitable for release to a stream though, based upon the quality of the wastewater recirculated after the system had reached equilibrium. The BOD_5 and total suspended solids data for the effluent of the recirculation plot suggest that it may be possible to release it to the environment. Nevertheless, nutrient levels of this effluent may preclude release.
2. Mass reductions were greater for GII than for GI, which was attributed to the greater degree of treatment occurring on GII and the small proportion of the applied water which ran off GII.
3. Unsettled rainfall runoff from both plots probably was not suitable for release to a stream. Erosion and transport of soil particles and surface litter by the rainwater was blamed for the low quality

of the rainfall runoff. In general, the rainfall runoff from GII was more highly polluted than was the runoff from GI.

4. Although the cattle feedlot runoff and the recirculated water were classified as posing very high salt and sodium hazards when used as irrigation water, no salt or alkali hazards existed in the treatment area after two years of operation. Accumulation of salt, sodium, and potassium occurred though. Some leaching of salts and cations took place between treatment seasons. Nevertheless, the chemical properties of the soil in the treatment area should be monitored to warn of approaching salinity or alkalinity problems.
5. Most of the treatment efficiency versus distance of flow downslope data were not statistically significant at the 0.05 alpha level because of poor sampling techniques. In general, it appeared that treatment efficiency increased as distance of flow downslope increased.

SUMMARY

The problems associated with handling rainfall runoff have been magnified by the trend towards larger capacity open feedlots. In order to prevent pollution of nearby surface waters, many states require rainfall runoff from feedlots be diverted to detention facilities. The runoff remains in these facilities until it can be treated to such a quality that it can be released to the environment or until it can be disposed of in such a manner that no stream contamination occurs. Since no economical or practical treatment method exists, runoff water is handled primarily by land disposal. However, especially in areas with low soil infiltration rates, irrigation disposal is not always a practical alternative.

In an attempt to develop an economical and effective alternative to land disposal of these wastes, Eisenhauer (1973) installed a spray-runoff irrigation system at a 22,000 head capacity feedlot in south central Kansas. In this type of system, waste is applied at the top of a uniform grassed slope by sprinkler nozzles at a rate which results in a high proportion of the applied waste flowing off the treatment area. As the water flows overland, some of the impurities in the water are utilized for food and energy sources by the mass of biological organisms which develop on wetted grass and soil areas.

The system was installed on a 10.9 acre field adjacent to the feedlot. The landslope of the field varied from one to three percent. The area was divided into four subwatersheds by two parallel terraces with a 200 ft. spacing, and a waterway into which the terraces drained. The waterway discharged into a 1.65 acre-foot detention pond. One spray lateral was installed on the upper portion of each watershed. A total of 45 sprinklers were installed on the laterals at a spacing of 30 ft. Each of the nozzles had a spray diameter of about 100 ft. Two subwatersheds were studied, one with an area of 3.6 acres and the other had an area of 1.55 acres. The loam topsoil was underlain by a clay layer and was seeded to a mixture of Reed canarygrass, tall fescue, tall wheatgrass, smooth bromegrass, and perennial ryegrass. Equipment was installed so that the quantity and quality of the wastewater applied to, and the effluent from each of the plots could be determined. Although treatment of the waste occurred, the effluent from the plots was of low quality.

In an effort to produce a treated effluent that could be released to a stream, the research reported in this thesis was undertaken. The previously described system was modified so that water from the detention pond could be recirculated over the 1.55 acre plot. Originally, the recirculation system was designed so that overflow of the detention pond would occur almost continuously. It was hoped that after the system had reached an equilibrium condition, the quality of the water overflowing the detention pond would be high enough so that it could be released directly. It was assumed that the quality of the overflow water would be identical to that of the portion recirculated. The water applied to, and the effluent from both areas were monitored so that their quantity and quality could be determined. Water from the detention pond was applied at instantaneous and weekly rates of 0.134 in.-per-hour and 7.5 in.-per-week, respectively. Stored feedlot runoff was applied at instantaneous and weekly rates of 0.07 in.-per-hour and 2.1 in.-per-week, respectively.

The mean BOD_5 concentration was reduced 54 percent on each of the study areas. The reductions in the mean concentrations ranged from 54 to 88 percent for ammonia nitrogen, from 24 to 68 percent for Kjeldahl nitrogen, from 5 to 35 percent for total phosphorous and from 45 to 76 percent for total suspended solids. For all parameters except total suspended solids, the lower reduction in mean concentrations occurred on the recirculation plot.

The mean concentrations of BOD_5, ammonia nitrogen, Kjeldahl nitrogen, and total suspended solids were 74, 95, 80, and 83 percent lower, respectively, in the water in the detention pond than in untreated feedlot runoff. However, the liquid was still of questionable quality. The effluent from the recirculation plot exhibited higher overall concentration reductions with mean concentrations of BOD_5, ammonia nitrogen, Kjeldahl nitrogen, and total suspended solids that were 88, 98, 85, and 96 percent, respectively, lower than the corresponding mean concentrations found in the stored feedlot runoff. Based on the proposed standards for municipal wastewater of 30 mg/l of BOD_5 and 30 mg/l of total suspended solids, this water may be of sufficient quality to release, but nutrient concentrations may preclude it. Treatment occurring on the recirculation plot was attributed to the utilization of impurities as a food and energy source by the biomass present, and to the removal of the algae present in the recirculated flow.

For the season, only about 33 and 15 percent of the water applied ran off the recirculation plot and the 3.6 acre test plot, respectively. Because runoff percentages were much lower than anticipated, no overflow of the detention pond occurred. The low runoff percentages also resulted in high mass reductions of the parameters as the waste flowed over the treatment area. Unsettled rainfall runoff was of low quality.

An attempt was made to determine the effect of slope length on treatment efficiency. However, probably because of poor sampling techniques, the differences in treatment efficiencies were not statistically significant at the 0.05 alpha level. In general, treatment was still occurring 130 ft. downslope but longer slope lengths would accentuate channeling problems.

The untreated feedlot runoff and the recirculated waste posed very high salinity and alkalinity hazards when used as irrigation water. Although accumulations of salts, sodium, and potassium were found in the soil profile, no salinity or alkalinty problems existed after two years of operation.

SUGGESTIONS FOR FUTURE RESEARCH

The treatment system as proposed did not result in a high quality polishing pond effluent. However, the results of the study indicate that effluent from the recirculation plot may be of high enough quality to release. The study suggested several questions and left several others unanswered. Therefore, the following studies would provide useful information:

1. Methods of increasing the overall treatment efficiency of the system need to be evaluated. This includes a study of a system designed to release effluent directly from a recirculation plot. The value of additional settling of the recirculation plot effluent should be determined. Other possible studies include the determination of optimum slope lengths, operating schedules, and application rates for treating feedlot runoff. Determination of the optimum number of recirculations of polishing pond liquid would also be valuable.
2. A study should be set up so that the treatment provided by the polishing pond can be evaluated.
3. Tests should be conducted to determine the proportion of the treatment occurring on the recirculation plot that can be attributed to algae removal.

4. Studies to determine the movement and quality of soil water should be undertaken to evaluate the system's potential for polluting groundwater.

5. Continued monitoring of soil chemical and physical properties is needed to determine the effects of continued application of these wastes.

6. The reasons for the loss of the stand of grass on part of the treatment area needs to be more fully determined.

7. A biological study of the treatment area may provide information useful in determining the type of treatment taking place.

8. Determination of the dissolved oxygen levels in the effluent from the treatment area may be important in determining the suitability of field effluent for release.

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APPENDICES

APPENDIX A

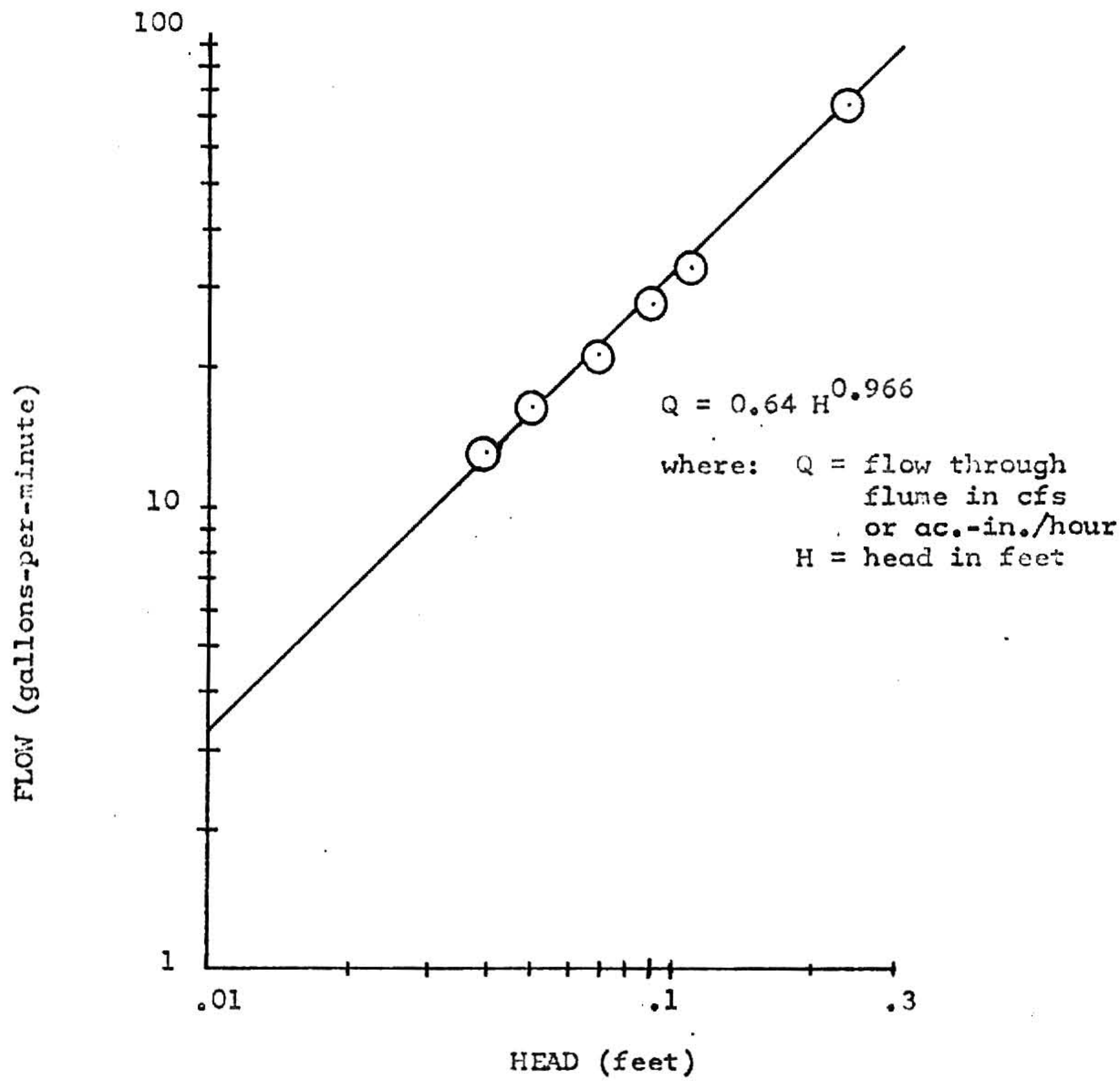

Figure 5. Calibration Curve for 1.5-foot H Flume

APPENDIX B

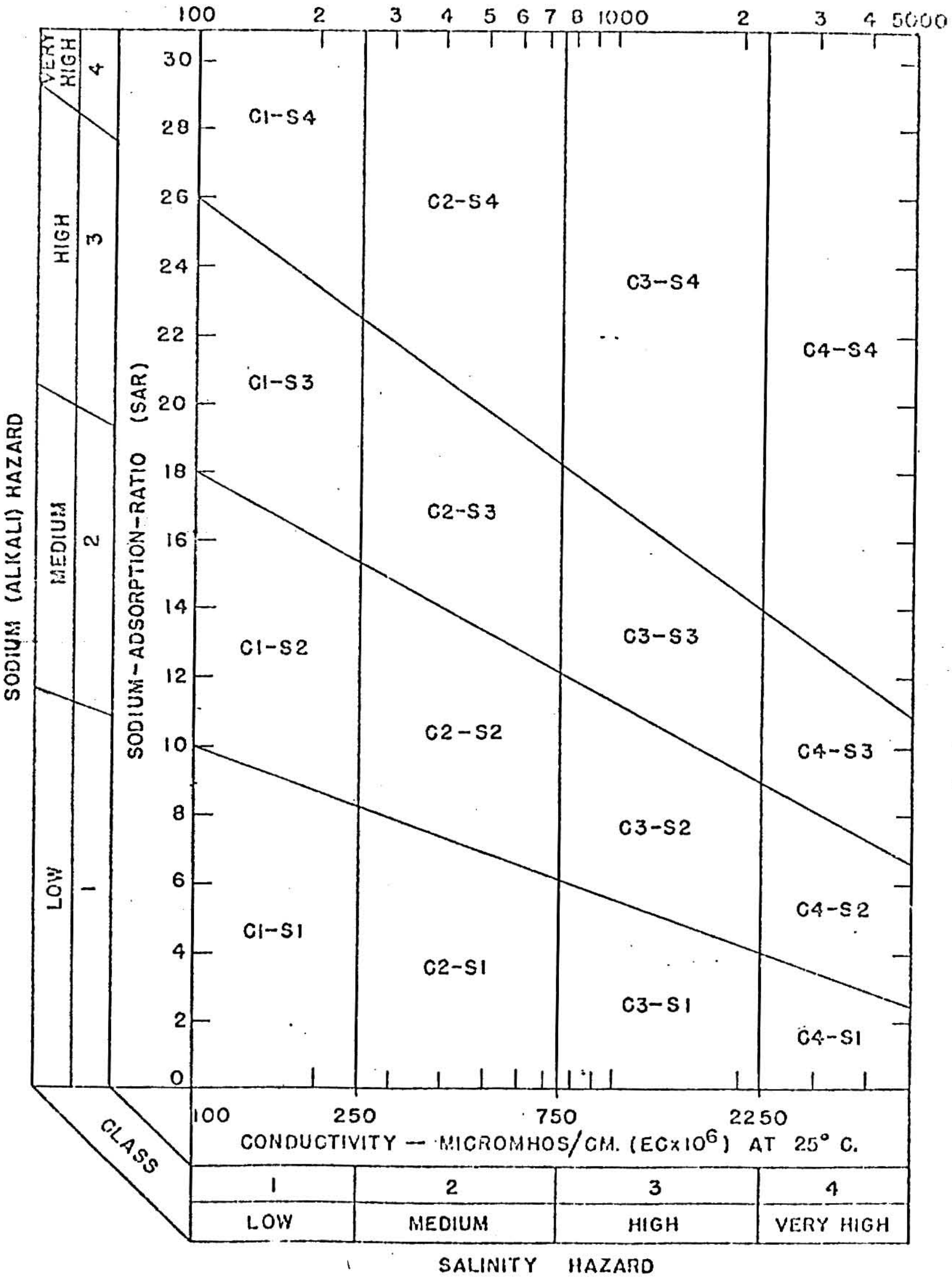

Figure 6. Irrigation Water Classification Diagram (Taken from U.S. Salinity Laboratory Staff (1954).)

TREATMENT OF CATTLE FEEDLOT RUNOFF USING
A SPRAY-RUNOFF IRRIGATION SYSTEM WITH RECIRCULATION

by

JOHN ANDREW KRAMER

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Stormwater runoff from cattle feedlots poses a pollution hazard. To reduce this hazard, many states require that rainfall runoff from feedlots be held in detention facilities. Although land disposal by irrigation has been the prevalent method of handling the water, this disposal method is not applicable in all cases.

To evaluate its use as an alternative to land disposal, Eisenhauer (1973) installed a spray-runoff irrigation system on a 10.9 acre field in south central Kansas in the spring of 1972. With this system, wastewater is applied by sprinkler nozzles at the top of a uniform grassed slope at a rate which exceeds the intake rate of the soil. As the waste flows over the soil, impurities in the water are used for food and energy by the mass of biological organisms which develop on the wetted grass and soil. The field had a land slope that varied from one to three percent and was seeded with a Reed canary and tall fescue mixture. The field was divided into four subwatersheds by two parallel terraces on 200-foot centers and a waterway into which the terraces drained. The waterway drained into a detention pond. Forty-five sprinkler heads applied feedlot runoff to the field. Although treatment occurred, the effluent from the treatment area was not of suitable quality to release.

In early July, 1973, the system was modified so that liquid from the detention pond could be recirculated over part of the treatment area. The detention pond was visualized as overflowing almost continuously. It was hoped that after the system had reached equilibrium, the overflow water would be of sufficient quality to release. Stored feedlot runoff and recirculated liquid were applied at 2.1 and 7.5 in./week, respectively. Results indicate that recirculation of detention pond liquid improved the quality of the water in the pond. Although the mean concentrations of BOD_5, Kjeldahl nitrogen, and total suspended solids were about 75 percent lower in the detention pond water than in the raw feedlot runoff, the pond water was still of questionable quality to release. Mean concentrations of the pollution parameters in the recirculation plot effluent were about 90 percent lower than those in the stored feedlot runoff. Mean BOD_5 and total suspended solids concentrations suggest that this effluent may be suitable for release, but nutrient concentrations may preclude it. Treatment occurring on the recirculation plot was attributed to the utilization of impurities for food and energy by the biomass, and to the removal of algae present in the recirculated flow. Since runoff percentages were much lower than anticipated, no water overflowed the pond. It appeared that treatment increased as distance of flow downslope increased, although the results were not statistically significant. No salt or alkali hazards existed after two years of operation even though accumulations of salt, sodium, and potassium were found in the soil profile.