TREATMENT AND DISPOSAL OF CATTLE FEEDLOT RUNOFF USING A SPRAY-RUNOFF IRRIGATION SYSTEM

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INTRODUCTION

The cattle feeding industry has been greatly expanded in the State of Kansas during the last decade. The Kansas Board of Agriculture (1970) and (1972) noted a marked increase in fat cattle marketed between 1964 and 1971, 1,031,000 head in 1964 and 1,966,000 head in 1971. Also, the number of feedlots with a capacity greater than 1,000 head is on the increase, 63 and 128 for the years 1964 and 1971 respectively. The year by year increases are shown in Table 1.

Table 1. Growth of Cattle Feedlots in Kansas*

Year	1964	1965	1966	1967	1968	1969	1970	1971
No. of Fat Cattle Marketed (1000 Head)	1031	857	1162	1321	1332	1674	1890	1966
No. of Lots with Capacity Greater than 1000 Head	63	88	93	100	100	126	132	128

*Table taken from Kansas Board of Agriculture. (1970) and (1972)

The increase in fat cattle production has been accompanied by an increase in the water pollution potential of cattle feedlot wastes. Loehr (1968) noted that an average 950 pound steer will produce 60 pounds of wet manure per day. Although not all of the manure produced reaches a stream, the pollution potential of rainfall runoff from the feedlot is of concern. Miner (1967) stated that cattle feedlot runoff has a high water pollution potential due to the strong concentrations of organic matter and nitrogenous compounds present in the runoff. Smith (1965) reported that of the 27 pollution caused fish kills in Kansas in 1964, 15 were caused primarily by the runoff of commercial livestock feed operations. Therefore, the handling of these liquid wastes has been of concern the past few years.

The Kansas State Department of Health (1967) requires that a feedlot with a capacity of 300 head or more, or one having a water pollution potential, must register with them. Then the department determines if water pollution control facilities are needed. Control facilities usually are retention ponds that intercept surface runoff from all waste contributing areas. The Department of Health (1967) regulations say "Wastes may be used for irrigation or spread on land surface and mixed with the soil in a manner which will prevent runoff of wastes." Other methods of handling the runoff, such as waste treatment facilities, will be permitted providing effective water pollution control is accomplished.

The most common method for removing the liquid wastes from the retention ponds has been irrigated land disposal. This practice has been adapted due to some of the shortcomings of biological treatment such as the following suggested by Loehr (1968):

1. Lack of understanding of the waste characteristics.
2. Magnitude of the problem.
3. Economic constraints.

The first two points given above indicate that conventional type waste treatment facilities are not readily adaptable to cattle feedlot runoff because of their difference in characteristics and concentrations relative to municipal sewage.

Although land disposal is widely adapted, there are limitations such as those listed below:

1. If the soil has a low infiltration rate, it may not be economically feasible to use this method and/or sufficient land may not be available for complete disposal.

2. Sodium and potassium ions are present in cattle feedlot runoff. It these monovalent cations are applied to clay soils in excessive amounts relative to other cations they may cause the soil particles to disperse, and thus, cause a reduction in the infiltration rate of the soil.

3. Salt concentrations are high in cattle feedlot runoff and if those added salts are not leached from the soil profile by rainfall or irrigation water, the soil may become saline. If this condition is severe enough, it may inhibit seed germination and plant growth.

The problem pertaining to low infiltration rate has been reported in Kansas, especially in areas of higher rainfall. That was the reason for undertaking the research reported in this thesis. The study was conducted to determine the feasibility of using a spray-runoff irrigation system for treatment of cattle feedlot runoff. This type of system is a combination of land disposal and biological treatment and has been used to treat canning plant wastes as reported by Gilde (1968).

REVIEW OF LITERATURE

Feedlot Runoff

The design of any type of waste treatment facility requires knowledge of the quantity and quality of the material to be treated.

Hydrology. The amount of runoff for a given storm and the amount to be expected in an average year are both important in the design of pollution abatement facilities. Miner (1967) stated that before runoff begins, surface storage must be satisfied. For two small test feedlots on 2% slopes at Manhattan, Kansas, the values of surface storage ranged from 0.06-0.6 inches. Gilbertson et al. (1971) reported similar figures of 0.4-0.5 inches for small feedlots near Mead, Nebraska.

Investigators have been in good agreement on the amount of runoff to expect from a given storm. Miner et al. (1966) felt that the soil cover complex number was a good method for describing runoff producing surfaces. This number, sometimes called the runoff curve number, takes into account: soil type, land use, treatment of practice, and hydrologic condition. To compute the amount of runoff to expect from a given storm once the runoff curve number is determined, the following equation reported by Schwab et al. (1966) can be used:

$$Q = \frac{(I - 0.2S)^2}{I + 0.8S} \tag{1}$$

where:

Q = Direct runoff in inches

I = Rainfall in inches

$S = \frac{1000}{CN} - 10$

CN = Runoff curve number

Miner et al. (1966) found that by plotting runoff versus rainfall the soil cover complex numbers that best fit his data were 91 and 94 for unsurfaced and concrete lots respectively. Bergsrud (1968) empirically chose the identical number of 91 for a soil cover complex number for unsurfaced lots. He also stated that if adjusted for antecedent moisture conditions, the values would be 80 and 98 for dry and wet conditions respectively. Fields (1971) found that the values of 91 and 93 best fit his data from unsurfaced lots at Pratt, Kansas. The reason for discrepancy was explained by differences in conveyance losses that occurred before the runoff reached the flow measuring devices.

Regression equations which describe the runoff that can be expected from a given storm are given in Table 2. The equations reveal that runoff volume is a function of rainfall and land area and that a surface storage condition must be satisfied before runoff occurs.

Table 2. Regression Equations for Predicting Runoff from Non-surfaced Cattle Feedlots

Year	Lot Slope (%)	Regression* Equation	Source
1968	6	R=0.93P-0.407	Swanson et al. (1971)
1969	6	R=0.446P-0.05	Swanson et al. (1971)
1970	6	R=0.493P-0.06	Swanson et al. (1971)
1968	3-9	R=0.531P-0.135	Gilbertson et al. (1971)
1970	1.3	R=0.57P-0.412	Fields (1971)
1970	1.0	R=0.593P-0.128	Fields (1971)

*R = Runoff in inches
P = Rainfall in inches

The total volume of runoff that can be expected at a specific location during an average year depends upon the amount of rainfall and how it is distributed. Bergsrud (1968) made use of the soil cover complex number and 30 years of rainfall data from 12 locations throughout Kansas to develop a map showing the amount of runoff that can be expected throughout the State for the average year. Swanson et al. (1970) concluded that you can expect two to three times more runoff from cattle feedlots than from adjacent crop land. Gilbertson (1970) found that the ratio of runoff to total precipitation was about 0.33. He went on to say that animal density and land slope had very little effect if any on the expected amount of runoff.

Pollution parameters. The pollution parameters of concern in this thesis are: biochemical oxygen demand, BOD; chemical oxygen demand, COD; Kjeldahl nitrogen; ammonia nitrogen; phosphorus; and solid material.

Sawyer and McCarty (1967) define BOD as "the amount of oxygen required by bacteria while stabilizing decomposable organic matter under aerobic conditions." The BOD is a good measure of the actual effect an organic waste will have on the receiving water. The oxygen requirement of the BOD can lower the dissolved oxygen of a stream below the amount required for aquatic life. The major limitation of using BOD as a pollution indicator is the amount of time required to perform the test. Theoretically an infinite amount of time would be required to completely measure all BOD but Sawyer and McCarty (1971) report that 70 to 80 percent of the ultimate can be measured in five days. This is the common meaning of BOD.

Gilbertson et al. (1971) report that the BOD of feedlot runoff ranges from 370 to 600 milligrams-per-liter, mg/l., for summer runoff and from 1600 to 7900 mg/l. for winter runoff. Madden and Dornbush (1970) found that snow-melt in South Dakota had a mean BOD of 2332 mg/l.

The COD is a measure of the oxygen required to completely oxidize an organic waste to carbon dioxide and water. This oxidation takes place in the presence of strong oxidizing agents and acid conditions. The COD test does not differentiate between biodegradable and non-biodegradable organic matter. Therefore, it does not have the same advantage of measuring the true effects on the receiving water as BOD. The major advantage of COD is that only about 3 hours are required to perform the test as compared to the 5-day incubation period required for the BOD test. Sawyer and McCarty (1967) and Eckenfeldar (1970) report that for a given type of waste there will be a correlation between COD and BOD. Thus, once this correlation is developed, the COD test can be run for an estimate of BOD.

Fields (1971) found COD values for rainfall runoff in the range from 1514 to 14,309 mg/l. with a mean of 6111 mg/l. from a 32.8 acre area of study.

The snowmelt runoff for the same area ranged from 7299 to 35,764 mg/l. with a mean of 13,767 mg/l. The high concentrations in the snowmelt runoff were attributed to the higher solids content of snowmelt runoff and less biodegradation on the lot surface during winter months. Miner et al. (1966) report COD values in the range from 1900 to 8900 mg/l. for simulated rainfall runoff from a non-surfaced lot. Swanson et al. (1971) found the COD for rainfall runoff from lots in eastern Nebraska ranged from 144 to 12,790 mg/l. Madden and Dornbush (1970) report that snowmelt runoff in South Dakota had a mean COD concentration of 8408 mg/l.

The COD/BOD ratio reported by Gilbertson et al. (1971) ranged from 6.1 to 21.3 and 13.0 to 16 for winter and summer runoff, respectively. Miner (1967) found a mean COD/BOD quotient of 9.5 for 48 samples.

The Kjeldahl nitrogen test consists of two steps, (1) conversion of the organic nitrogen present to ammonia by a digestion process and, (2) measuring all ammonia present by a standard ammonia test. Therefore, Kjeldahl nitrogen refers to the sum of organic nitrogen plus ammonia. Bartholomew (1965) reported that organic nitrogen is converted to ammonia by the microbiological transformation called mineralization. The water pollution potential of the ammonia formed by this transformation is probably of more concern than the organic nitrogen itself.

Balakrishnan and Eckenfelder (1969) stated that the two primary concerns of ammonia nitrogen are, (1) the oxygen required during the conversion of ammonia to nitrites and further to nitrates, and (2) the nutrient value of the nitrates formed is considered a possible stimulant for algal blooms which are undesirable in recreation and potable waters. A more detailed study of the production of nitrates from ammonia will be reported later in this thesis.

Fields (1971) reported mean Kjeldahl nitrogen concentrations of 494 mg/l. and 1033 mg/l. for rainfall and snowmelt runoff respectively. A somewhat lower mean Kjeldahl nitrogen concentration of 573 mg/l. was reported by Madden (1970) for snowmelt runoff. Miner et al. (1966) found Kjeldahl nitrogen ranged from 50 to 540 mg/l. for simulated and natural rainfall. Gilbertson et al. (1971) suggest that Kjeldahl nitrogen ranged from 65 to 555 mg/l. and 1429 to 5765 mg/l. for summer and winter runoff, respectively.

Gilbertson et al. (1971) found that ammonia concentrations in winter runoff were much higher than for summer. The ranges found were from 670 to 2028 mg/l. and 26 to 82 for winter and summer runoff, respectively.

Phosphates, like nitrates, are plant nutrients and stimulate algal blooms. In the total phosphorus test, all forms of phosphorus are broken down and measured in the form of ortho-phosphates. Fields (1971) states that the mean phosphate content was 87 and 209 mg/l. for rainfall and snowmelt runoff, respectively. The mean value reported by Madden and Dornbush (1970) was 98.1 mg/l. for snowmelt runoff. Swanson et al. (1971) found a wide range of phosphorus concenration in cattle feedlot runoff, 0-771 mg/l. He went on to say that the concentration was a function of the amount of solids transported from the feedlot.

Total solids refer to the residue that remains upon evaporation at 103-105 degrees Centigrade, ^{o}C. This differs from total suspended solids in that total solids include dissolved matter. Volatile solids refer to the loss of weight after ignition at $600^{o}C$. These are generally interpreted as organic material and are reported as a percentage of total solids. Cattle feedlot runoff generally contains a high concerntration of solid material. For non-surfaced lots the percent volatile is generally low due to the soil material carried in the runoff. The mean total solids content found by Fields (1971) was 7528 mg/l. with a volatile percentage of 51.3 percent. These values were for rainfall runoff. Snowmelt runoff was somewhat higher with a mean value of 19,308 mg/l. The volatile percentage was 57.5 percent. Swanson et al. (1971) reported a range of total solids from 1800 to 21,800 mg/l. and a volatile percentage from 19.6 to 75 percent. A mean value of total solids reported by Madden and Dornbush (1970) was 10,008 mg/l. for snowmelt runoff. Miner et al. (1966) studied only suspended solids and reported a range from 1100 to 7000 mg/l. and a volatile percentage of 39 percent. This was for the non-surfaced lot.

Miner et al. (1966) indicated that cattle feedlot runoff was most concentrated during (1) warm weather, (2) low rainfall rates, and (3) a moist surface condition. A first look at the results reported above indicate a discrepancy on when to expect a more concentrated waste. This is explained by the fact that Miner was working only with rainfall runoff. The laws of solubility were his explanation to the higher concentrations during the conditions listed above. The studies reported by Madden et al. (1970), Fields (1971), and Gilbertson et al. (1971) included snowmelt runoff. Fields (1971) states that the runoff from snowmelt was from 2 to 2 1/2 times as "strong" as rainfall runoff. Gilbertson et al. (1971) reported concentrations ten times higher for snowmelt runoff. As indicated before this was attributed to more solids in snowmelt runoff and less biodegradation on the lot surface. Gilbertson et al. (1970) found winter-thaw runoff contained 10 tons of solids per acre-inch while rainfall runoff carried only 1.6 tons per acre-inch.

Managing cattle feedlot runoff. The first step towards reducing the pollution caused by cattle feedlot runoff is to minimize the potential as much as possible. Miner (1967) mentioned that minimizing the pollution potential could be accomplished by diverting all runoff away from areas adjacent to the lot and by maintaining the best lot drainage possible. He went on to say that the manure pack had very little effect on the runoff quality.

Solids removal is the second step for reducing the pollution potential of runoff water. Gilbertson et al. (1970) investigated two methods of solids removal which they called the "continuous flow system" and the "batch system". Both methods were efficient in removing the solids from the runoff, but the continuous flow system had the advantage of being easier to manage. Butchbaker et al. (1971) pointed out that other methods available for solids removal other than those listed above include broad basin terraces and low slope ditch systems.

The solids removal system generally is followed by some type of liquid detention structure to prevent the runoff from entering surface waters. Detention structures or holding ponds usually are built as such and not designed as lagoons for wastewater treatment. However, some treatment will take place in such a structure due to the action of anaerobic organisms and additional solids settling. Loehr (1967) states, "the purpose of anaerobic lagoons is the destruction and stabilization of organic matter rather than water purification." Loehr went on to report data on effluent quality from several holding ponds sampled by the Kansas State Department of Health. These data are presented in Table 3. These data indicate the high degree of variability that can be expected among lagoons. The samples were taken from lagoons throughout the State of Kansas and the exact conditions would have to be evaluated to determine why the variability occurred.

Manges (1971) reported on a small test lagoon which received direct runoff from a 1.72 acre pen near Pratt, Kansas. The effluent at the 6 inch depth had a COD of 6000 mg/l. in early June. By August 15 the COD had been reduced to 2000 mg/l. There was no rainfall during this period. The reduction was attributed to solids settling. The total solids content increased from 4000 to 7000 mg/l. over this period which was mostly due to the concentrating effect of evaporation.

Table 3. Quality of Water From Several Cattle Feedlot Runoff Holding Ponds in Kansas*

	FEEDLOT			
Parameter	A	B	C	D
Cattle on Feed	9000	2000	4000	3000
BOD_5 (mg/l)	2500-5500	72-330	700	2800
NH_3 (mg/l)	220-400	22-82	---	225
pH	7.0	7.8	---	6.7

*Table taken from Loehr (1967).

The question that should be asked at this point is "What should be the fate of the effluent held in runoff holding ponds?"

Runoff Treatment and Disposal Alternatives

Butchbaker et al. (1971) give a diagram which shows runoff handling alternatives. The authors state that the most common methods for ultimate disposal are irrigated land disposal and evaporation. The authors go on to say that evaporation ponds might be a good method for disposal in areas where the evaporation minus rainfall exceeds 40 inches during the average year. Controlled discharge to a stream was also mentioned as an alternative but the authors state that at the present time there is no practical system available to treat feedlot runoff to this degree.

Irrigated land disposal. Irrigation disposal is the most common method available for handling animal wastes. Thomas and Law (1968) listed the following four reasons for applying wastewater to the land.

1. Crop growth.
2. Conservation of water and nutrients.
3. Treatment of wastewater.
4. Reduction of pollution load.

The authors stated that most soil systems are designed for the purpose of wastewater disposal and not necessarily to enhance crop growth, although, crop growth is a secondary benefit.

Water quality should be considered when designing disposal systems so that crop growth and soil structure can be maintained. One water quality parameter usually considered is the salinity of the liquid. Salinity is usually measured by the electrical conductivity of the solution. Hayward and Bernstein (1968) state that an increase in the salinity of the soil solution will be accompanied with an increase in osmotic pressure which restricts the uptake of water by plant roots. This may restrict seed germination and plant growth.

The amount and proporation of cations present is another basic water quality parameter. Wilcox (1958) suggests that the relationship between the monovalent cation sodium and divalent cations calcium and magnesium is an important irrigation water quality consideration. The relationship is usually defined by the sodium adsorption ratio as shown below:

$$SAR = \frac{Na^{+}}{\left[\frac{Ca^{++} + Mg^{++}}{2}\right]^{\frac{1}{2}}} \qquad (2)$$

where:

SAR = Sodium adsorption ratio

Na^{+} = Sodium in meq/l.

Ca^{++} = Calcium in meq/l.

Mg^{++} = Magnesium in meq/l.

The concentrations of the cations used in Equation 2 are expressed in milli-equivalents per liter, meq/l. The reason for defining a relationship between sodium and the divalent cations is that is the relative proportion of sodium to the divalent cations is high, the sodium will replace calcium and magnesium cations on the soil exchange complex. If this condition is severe enough, the soil particles will disperse. This dispersion causes a reduction in a soil's ability to take in water and air.

Travis (1970) states that it might be possible that potassium has effects similar to that of sodium. This fact has not been well established because potassium is not highly abundant in most irrigation water supplies. The recent emphasis on waste disposal will probably generate more interest on the subject.

The United States Salinity Laboratory (1954) has produced a chart that can be used to determine the suitability of a water for irrigation purposes. This chart takes into consideration both the sodium adsorption ratio and the electrical conductivity of the water in question.

Many authors have reported using irrigation systems for disposal of various types of wastes; Hunt (1954), Henry et al. (1964), Kardos (1968), Phillip (1971), McKee (1967), and Vercher (1965). The types of wastes included municipal sewage, dairy plant wastes, meat packing plant wastes, insulation board mill plant wastes, and paper mill wastes. The types of soils included sandy silt, silt loam, silty clay loam, and fine sandy loams. The slopes were highly variable, from 1 to 6 percent. The predominant crop used was Reed canary grass because of its high moisture tolerance, high salt tolerance, long growing season, and perennial growth. Application rates varied from 35 to 80 inches per year with weekly loading rates from 1 to 2 inches. Most systems were highly efficient in removing nitrogen, phosphorus, and potassium. This removal was attributed to both the crops ability for nutrient removal and the high fixing capacity of soils for phosphorus. Some authors warned of killing the crop by over irrigation. The literature also cautioned about salt accumulations and increased sodium percentages on the soil exchange complex. Groundwater pollution potential also should be taken into consideration when applying wastes to the land.

Travis et al. (1971) investigated applying feedlot runoff lagoon water to bare soil columns. Four types of soils were studied; loam, silty clay loam, clay loam, and silt loam. In all cases the infiltration rate of the soils was reduced to zero after application of the lagoon water. Only 13.3 cm. of the water had been applied to the clay loam soil before it sealed. A simulant containing concentrations of sodium, potassium, ammonium, calcium, and magnesium similar to that of cattle feedlot runoff also was tried to determine if the sealing was due to soil dispersion or due mainly to plugging by organic matter present in the wastewater. The infiltration rates of the finer textured soil went to zero upon application of the simulant. This indicated that the cations were responsible for some of the sealing which occurred by the addition of the wastewater. After application of the wastewater, all the soils were classified alkali (sodium hazard). Also, the electrical conductivity of the saturation extract from the top 15 cm. of all columns had increased more than 200 percent. The study suggested the potential hazards of applying feedlot runoff to soils.

Manges (1971) reported on irrigated corn with cattle feedlot runoff. The treatments used were 0, 2, 4, 8, and 16 inches of effluent per year. No commercial fertilizer was added to the plots. Well water was used for supplemental irrigation. For the second year of study, the maximum corn forage yield was found on the 4-inch treatment. He proposed that the salts were the reason for reduced yields on higher treatments. An increase in electrical conductivity of the saturation extract supported the hypothesis. The yield of the 4-inch treatment surpassed that of both the check plot and the 2-inch treatment because of the nutrient deficiency. Accumulations of both divalent and monovalent cations were reported plus an increase in available phosphorus. Table 4 shows the yield results from various treatments for the first two years of study.

Table 4. Yield Response of Corn to the Application of Feedlot Runoff*

Treatment Inches	Forage Yield[1] Tons/Acre 1970	1971
0	18.7	14.8
2	20.3	19.8
4	21.9	22.4
8	23.7	19.0
16	26.7	17.2

*Table taken from Manges (1971).

[1]Yields corrected to 70% moisture. Average of four replications.

It might be concluded then that irrigation disposal can be successf[illegible] if good management practices are followed. Not only should the water quality parameters be checked, but the type of soil and how well it is drained should be considered.

Soil treatment systems. Soil treatment systems differ from disposal systems in that their purpose is to treat wastewater to a degree that would be allowable for release to surface waters or groundwater. They utilize the tremendous capacity present in the soil mantle for microbial growth plus the nutrient removal potential of the soil and crop.

Robeck et al. (1964) report the treating of septic tank effluent in 3-foot sand lysimeters. The system was successful in removing both organic material and coliform organisms. The coliform removal was attributed to adsorption in the soil mantle. They stated that the soil should be of low enough permeability so that dissolved and suspended organic material will be retained long enough for treatment by aerobic organisms. Resting periods were required so that air would become available to the organisms. The authors listed some guidelines to follow in the design and operation of such a system:

1. Soil should have 0.5 to 1 percent organic matter for adsorption capacity.
2. The effective soil size should be from 0.1-0.3 mm. (medium to fine sand).
3. Depth to groundwater should be at least 10 feet.
4. After development for one month, the loading rate should be 3 gpd per square foot. This is equivalent to about 4.8 inches per day.
5. Applications should be spread out over three to six periods per day.
6. Do not operate in weather conditions below $40^{o}F$.

A tile drainage system is sometimes required for systems such as the one listed above for continuous operations. Gilde (1968) reported such a system at a Campbell Soup canning plant. The 5 to 7 foot soil mantle removed 95 percent of the initial 635 mg/l. BOD concentrations. The effluent from the tile drains was received by a final polishing pond.

An experimental soil treatment system was used to treat effluent from an anaerobic swine lagoon at Iowa State University. This work was presented by Koelliker and Miner (1970), Vanderholm and Beer (1970), and Koelliker et al. (1971). A sprinkler irrigation system was used to spread the waste on the soil.

The soil was a silty clay loam and the plots were on a gentle slope. A tile drainage line passed through the center of each 40 x 60 foot plot at a depth of 4 feet. The plots were seeded to fescue grass. The grass was mowed periodically but was not removed from the field.

The authors reported the following removals: COD, 79-93%; total phosphorus, 90-97%; total nitrogen, 48-67%. The analysis was done on samples collected from the tile drains. The loading rates were from 13.8 to 31.4 inches per year.

The COD removal was due to physical filtering and biological treatment. They reported as high as 50% COD removals in the top three inches of the soil.

The phosphorus removal was attributed to adsorption to the aluminum and iron ions associated with the clay fraction of the soil and to crop use. Over a three-year period 1700 pounds of phosphorus had been applied per acre.

The nitrogen removal was due to biological nitrification-denitrification and crop use. Ammonia accounted for 90% of the nitrogen applied. The majority of the nitrogen detected in tile drainage was in the form of nitrates. Denitrification was thought to be the limiting process. The soil rooting depth was low because of the high moisture conditions. The authors warned that since the rooting depth was low and COD removal was high in the upper layers of the soil, the organic substrate necessary for dentrification at the deeper depths may have been limited to the soil organic matter only. The authors suggested that not over 600 pounds of nitrogen be applied per acre per year. This would allow an application of 6 to 12 inches per year for the particular waste they were working with. They considered the anaerobic swine waste similar to cattle feedlot runoff. A suggestion was to store the waste in holding ponds as long as possible for maximum ammonia loss by volatilization.

The purpose of the foregoing discussion on land disposal and soil treatment systems is to point out methods available for feedlot runoff disposal and some of the limitations to such systems. The author concludes that these types of systems might not be applicable under some of the following conditions:

1. A limited amount of land available for disposal.
2. The land available does not have adequate water intake rates for complete disposal.
3. The land available is not well drained and is highly susceptable to saline and alkali conditions.
4. A high groundwater pollution potential present in the area available for disposal.

Spray-runoff irrigation systems. Spray-runoff systems (grass filters) might be considered a combination of biological treatment and irrigation disposal. The author was unable to find cases where this type of system has been applied to animal wastes. Wilson (1967) reported using grass filtration for sediment removal from flood waters. Luley (1963) reported using the spray-runoff technique where preliminary investigations of a site had revealed that irrigation disposal was not practical. During the investigation it was noticed that waste was seeping from the ground at one end of a storage lagoon. The water then flowed down a 100-foot waterway covered with dense honeysuckle to a small stream. Tests revealed that there was a reduction of COD in the wastewater as it flowed through the grass. The reduction was sufficient to meet Pennsylvania Sanitary Water Board standards for complete treatment. The authors concluded that the treatment that took place was similar to that which takes place in a trickling filter.

Porges and Hopkins (1955) reported on one of the earlier grass filter systems. The system was designed to treat wastes from a beet sugar plant at Bayard, Nebraska. Water usage at the plant was about 5.2 million gallons per day, mgd. The treatment field had an area of about 160 acres. The wastewater was delivered to the field by a trapezoidal flume and distributed on the field by four-inch pipes through the wall of the flume. The field was essentially level but some channeling did occur. Average detention time in the field was 14 hours. The average BOD of the applied wastewater was 483 mg/l. and the field effluent had a concentration of 158 mg/l., a 67 percent reduction. Suspended solids were reduced 99 percent from the beginning concentration of 5215 mg/l. The average runoff volume was 81 percent of that applied, which increased the mass removal efficiency of the BOD to 73 percent. Samples collected within the field revealed that BOD reductions were 48 to 60 percent at 450 and 900 feet downslope from the flume respectively.

The BOD was in the form of both soluble and suspended material. Biological investigations revealed the presence of algae, fungi, protozoa, and other life forms in the grass thatch and on the surface of the soil. The authors noted "The growth of various forms of life must have been at the expense of materials in the sugar beet wastes, which were utilized in formation of protoplasm as well as metabolic processes." The median dissolved oxygen concentration of the runoff was zero. The authors felt that not all of the biological treatment capabilities were realized. They concluded that if field leveling and terracing were done, the effective area and detention time would be increased. This would give the advantage of additional biological treatment.

The system described by Luley (1963) had similar characteristics to the one reported above except the wastewater was spread on the land by a sprinkler irrigation system. The soil type was a clay shale mixture underlain by a shale layer at 1 to 2 feet. This combination allowed for a very low infiltration rate. The land slope varied from 2 to 12 percent. Spray laterals were spaced 200 to 500 feet apart. Three nozzle sizes were used, 3/8, 9/16, and 3/16 inches. The larger nozzle delivered 32 gallons per minute, gpm., over a 135 foot spray diameter. The smaller nozzles discharged about 4 gpm and were spaced between the larger nozzles. The 52-acre treatment field was planted to Reed canary grass and honeysuckle. The system was used to treat wastes from a canning plant on a year round basis. During the peak period the plots handled 1.25 mgd. The system was operated for 24 hours and then the plots were rested for two to three days. The idea was to treat the waste by spraying it on the surface of the ground in quantities small enough to spread over the surface yet large enough to cause surface runoff.

Treatment results showed a BOD reduction of 92.7 percent, from 1095 mg/l. to 80 mg/l. On a mass removal basis a 97.3 percent BOD reduction was reported. During periods of dry weather only 37 percent of the applied water ran off. The authors warned "extreme caution was necessary to be certain that the waste moved over the ground slowly, that the waste was spread as thinly over the surface of the slopes as possible, and that erosion of the ground was prevented." Treatment efficiency was reduced during the winter but stream standards were not violated.

Bendixen et al. (1969) studied another spray-runoff system that is used to treat wastes from a tomato processing plant in northwest Ohio. The top-soil of the 165-acre disposal field had a fairly high infiltration rate but was underlain by a low permeability subsoil. This situation yielded a poorly drained soil. The topography was graded to a uniform slope of about 5 percent. The slopes were divided with collection waterways to provide 100 to 200 foot runs. Spray laterals were placed at the top of each slope with riser spacings from 20 to 40 feet. The general operating procedure was to spray six hours and rest six hours on a continuous basis. The slopes were planted to Reed canary, seaside bent, and red top grasses.

The treatment field was monitored during the years 1961 to 1965. The average flow was 24,260 gpd/acre (0.9 inches per day) which yielded about 46 inches per year. The volume of runoff was about 49 percent of the wastewater applied. This figure included runoff from rainfall. When adjusted for the rainfall which occurred, only 30 percent of the total liquid applied (rainfall plus irrigation) appeared as runoff.

Treatment results revealed a reduction of COD from 526 mg/l. to 100 mg/l., an 81 percent reduction. On a mass removal basis this percentage increased to 83.7 percent.

The results from the monitoring program encouraged more detailed studies of the system. These studies were made on three sub-watersheds. One contained the remnants of an old tile drain system. The fate of the liquid applied on the tile drained watershed and the non-tile drained watersheds respectively was: spray evaporation, 6 and 5 percent; evapo-transpiration, 30 and 29 percent; tile drainage, 20 and 0 percent; runoff, 16 and 41 percent; soil storage, 5 and 12 percent; and deep percolation, 23 and 13 percent. Infiltration rates declined as the season progressed but recovered between seasons.

The treatment results of the detailed study are shown in Table 5.

The nitrogen applied was mostly in the organic form while that which ran off was about 1/2 ammonia and 1/2 organic bound. The tiled watershed had a lower percent runoff and also appeared to yield better removals of most constituents. Although the quality of the applied water varied considerably throughout the season, the quality of the runoff was fairly constant. The hydraulic loading rate had very little effect on concentration reduction, but

Table 5. Results of Spray-Runoff System Treating Cannery Plant Waste*

PARAMETER	CONCENTRATIONS IN APPLIED WATER (mg/l)	CONCENTRATIONS REMOVAL (%) TILED	CONCENTRATIONS REMOVAL (%) NON-TILED	MASS REMOVAL (%) TILED	MASS REMOVAL (%) NON-TILED
COD	916	82	71	95	81
BOD	548	--	66	--	85
T-N	30	73	61	93	73
PHOSPHATES	10.7	39	45	84	65
SS	274	88	82	97	89
TOTAL VOLATILE SOLIDS	161	31	20	--	--

*Table taken from Bendixen et al. (1969).

did alter the mass removal efficiency because of the higher runoff percentages produced by the increased loading rate.

Rainfall runoff accounted for 30 percent of the total runoff volume and 35 to 55 percent of the COD, nutrients, and suspended solids that were removed from the plots.

Finally, the authors compared the pollution load of the spray-runoff watershed to that of a normal agricultural watershed in that area. On a pounds per-acre-per-year basis the pollution potential of both types of watershed were about equal.

The most classical study of the spray-runoff treatment process was reported by Law et al. (1969a), Law et al. (1969b) and Thomas et al. (1970) and was made reference to by Gilde (1968). The system was designed to treat wastes from a Campbell Soup Company canning plant at Paris, Texas. The 400-acre disposal field handles 3.2 mgd. Terraces were spaced 200 to 300 feet apart on the one to six percent slopes. Spray laterals were placed at the top of each slope. A total of 77 spray laterals containing 700 sprinklers made up the spray system. The schedule during the five to six cooler months was 6 hours on and 18 hours off, while for the remaining warmer months it was 8 hours on, 16 hours off. Reed canary, tall fescue, and red top grasses were planted on the slopes. The topsoil varied from a sandy loam to a clay loam but the subsoil was clay throughout the area.

A 12-month detailed study was made on four watersheds in the treatment area ranging in size from 1.5 to 3.9 acres. The total area studied was 11.4 acres. During this period, waste was applied to the experimental areas for 43 weeks and a total of 181 acre-feet of liquid were applied. Rainfall accounted for 24 percent of the liquid applied while the wastewater spray accounted for the remaining 76 percent. A water balance accounted for 93 percent of the total liquid received by the plots. Of the total liquid accounted for, 18 percent was lost through evaporation processes, 61 percent returned as runoff, and 21 percent was lost to deep soil percolation. On a monthly basis, the amount of liquid returning as runoff ranged from 42 to 71 percent.

The mean concentrations in the applied water were 806, 572, 17.2, 7.4, and 245 mg/l. for COD, BOD, total nitrogen, total phosphorus, and total suspended solids, respectively. The concentration removal percentages were 91, 98, 84, 42, and 94 for the above parameters, respectively. Mass removal percentages were from 92 to 99 for the oxygen demanding substances, 86 to 93 for the nitrogenous compounds, and 50 to 65 for total phosphorus.

The sprinklers used on the system had a 100-foot spray diameter. This allowed for waste to be spread on about 40 percent of the treatment area. The authors stated that phosphorus removals could be increased by spreading over 75 percent of the land.

Soil and soil water samples were evaluated. The soil samples showed an increase in both the level of salinity and the exchangeable sodium percentages. The soil water samples taken at the 3-foot depth revealed that phosphorus and nitrogen were being removed in the soil profile and that groundwater pollution was not a hazard.

Short term supplemental studies were made to explain some unanswered questions. These are summarized below:

1. The optimum length of slope from the spray perimeter to the collection ditch is from 40 to 120 feet.

2. Only 30 to 40 percent of the pollution parameters were removed by physical filtering, thus, microbial activity was significant in the treatment process.

3. Resting periods were required frequently because of a reduction in treatment efficiency. Only 11 to 12 days are needed for full recovery. Upon restarting the system, several weeks are required to regain treatment efficiency.

4. For the first 10 days after restarting a system, nitrates were high in the runoff water. This was due to nitrification. At the end of 17 days, the nitrates in the runoff had gone to zero. The authors concluded dentrification to the gaseous forms was the fate of the nitrate.

Gilde (1968) suggests that the best operating procedure is to apply 4 hours per day, usually 2 hours at a time with rest periods in between. He goes on to say that treatment can take place during winter months even when microbial activity is low. The organic material is adsorbed to the surface litter faster than it is stabilized during the cold months. Upon the return of warm weather, the microbial populations build rapidly and decompose the accumulated waste material. Good management practices are required to prevent odor problems during this period.

Biological Treatment

The biological treatment referred to in this thesis will mainly refer to aerobic systems which means that the process occurs in the presence of free oxygen. Anaerobic systems do not require free oxygen. Also, the bacteria which are referred to will be heterotrophic organisms. Heterotrophs require organic material for their carbon source and energy. McKinney (1962) states that heterotrophic bacteria may be broken down into three groups; aerobes, anaerobes, and facultative. The facultative group will utilize free oxygen when available but can carry on metabolism when free oxygen is not available.

Biological treatment occurs when the organic material in a wastewater is adsorbed to the cell surfaces of microorganisms. A portion of the adsorbed matter is then assimilated to additional cell protoplasm. The majority of the remaining material is oxidized to the end products carbon dioxide and water. The latter process is accompanied with a release of energy which is necessary for cell growth. The process is shown in the diagram below as reported by Eckenfelder (1970):

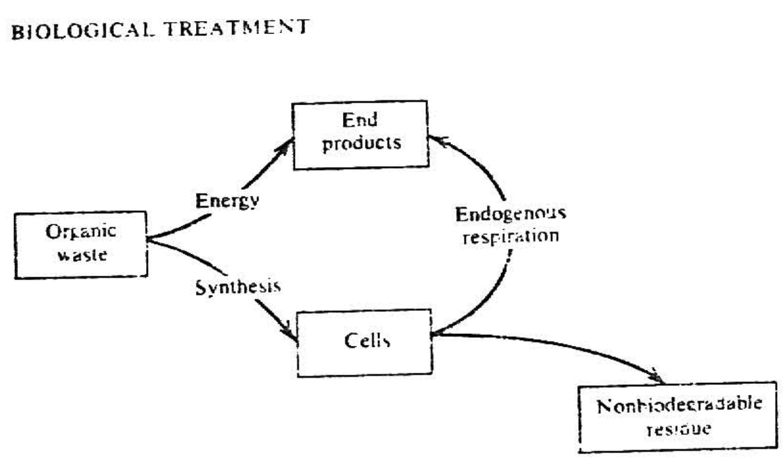


Figure 1. The Mechanism of Aerobic Biological Oxidation. (Taken from Eckenfelder (1970).)

The endogenous phase shown on the diagram refers to the degradation of some of the existing cells. This process is believed to occur simultaneously with the synthesis of new cells as reported by McKinney (1962).

Trickling filters. Aerobic systems are the most common type of systems used for waste treatment. Activated sludge, trickling filters, and oxidation ponds are the predominant aerobic systems. Trickling filters will be discussed in this thesis because the action of the spray-runoff system is believed to be similar to that which occurs in a trickling filter.

Trickling filters are made up of three components: (1) a media for biological growth, (2) a distribution system to spray the waste over the media, and (3) a final sedimentation system to remove biological growth that sloughs off of the media. The media are usually rock material that ranges in size from one to four inches in diameter. The average depth of the packing is usually six feet for municipal sewage treatment plants. Maier et al. (1967) had this to say about the media or packing, "it acts as a support for biological growth (slime layer) and serves a filler with connecting void spaces so that liquid and air can flow through the bed simultaneously (generally concurrent)." He goes on to state "the trickling filter is a contacting device which facilitates adsorption of waste matter and oxygen by the slime layer from the liquid and air."

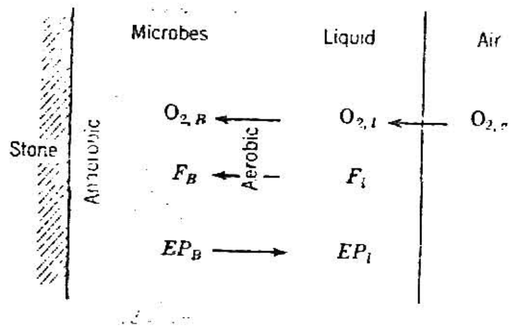
McKinney (1962) states that although the trickling filter is called an aerobic device, facultative action probably describes the system more closely. Aerobic bacteria predominate during the early stages of development of the filter, but as the slime layer thickens, an anaerobic layer developes at the interface of the microbial layer and the filter media. Thus, the bacteria in the filter include aerobic, anaerobic, and facultative types.

Maier et al. (1967) report that the slime layer consists of a matrix of zooleal bacteria, other forms of bacteria, fungi, protozoa, and algae. Most sanitary engineers feel that bacteria are the most important form of life present under normal temperature conditions. Lackey et al. (1956) state that other life forms are desirable because they keep the bacteria growth rate high and the thickness of the slime layer small.

McKinney (1962) explains the basic mechanics of a trickling filter. As the applied liquid surges over the filter media, a thin water layer will form a coating over the microbial layer. Oxygen will be absorbed by the thin water layer due to a partial pressure difference at the water and air interface. One method for the oxygen to reach the microbial surface is by diffusion due to concentration differences. However, this is a very slow process. The best method for oxygen transfer is by the creation of turbulance which causes the replacement of the oxygen-saturated surface layer by an unsaturated lower layer. This phenomena is called surface renewal and is the key to oxygen transfer.

The incoming organic waste flows over the microbial layer. The flowing liquid mixes with the bound water layer and if the organic concentration in the bound water layer is lower than that of the moving water, the organic matter will be transferred from the flowing wastes to the fixed water layer. In effect the transfer is due to dilution. The organic matter present in the fixed water layer is then absorbed by the cells present in the microbial layer. Treatment will continue as long as the microbes are able to metabolize the organic substrate at the same rate as it is supplied to them. A schematic diagram of the microbial activity is shown in Figure 2.

The microbial mass adheres to the rock surface as a result of Van der Waals forces of attraction for two surfaces. The surface allows the



O_2 = Oxygen

F = Food

EP = End Products

Figure 2. Schematic Representation of the Microbial Activity of a Trickling Filter. (Taken from McKinney (1962).)

microorganisms to expand in only one direction, out from the media surface. As the layer thickens, anaerobic endogenous metabolism occurs at the interface of the filter media. The end product of this metabolism are organic acids, aldehydes, and alcohols which diffuse to the outer layer. The efficiency of the filter is reduced under these conditions if the rate of anaerobic metabolism is too high because the outer layer of microorganisms are receiving organic matter from both sides. As the endogenous metabolism continues, the anaerobic cells die and lyse. This destroys the attractive forces to the media surface and thus, the microbial growth drops from the media. The most efficient filters have very thin microbial layers. Schroepfer et al. (1952) noted that worms and larvae facilitate the sloughing of microbial material also.

Schroepfer et al. (1952), McKinney (1962), Maier et al. (1967) listed some of the factors which control BOD removal in a trickling filter:

1. Hydraulic and organic loading rate.

2. Type of media used.

3. Depth of filter.

4. Waste characteristic.

5. Temperature of the waste.

The hydraulic loading rate is an indication of the time of retention of the wastewater in the filter. This factor is important in that adsorption and biological degradation are time dependant. The organic loading rate also determines whether the microorganism can remove the organic material at the rate it is applied. McKinney (1962) reports that typical hydraulic loading rates are from 2 to 4 million gallons per acre per day for low rate filters. Organic loading rates range from 10 to 20 pounds of BOD_5 per 1000 cubic feet of filter volume.

The type of media used are usually characterized by the specific surface of the media, in other words, the amount of surface area of media per unit volume. This factor influences the hydraulics of the bed, the ventilation, and the contact area.

The depth of the filter is also related to the retention time and contact area. Theoretically an infinite depth would be required to remove all the BOD but the biological activity is the greatest at the top 2 to 3 feet of most filters.

The characteristic of the waste determines its biodegradability. One important factor is pH of the substrate. McKinney (1962) reports that near neutral conditions are most favorable for biological growth. The hydrogen-ion concentration exerts a toxic effect on most microorganisms below a pH of 4.0 and likewise, the hydroxl-ion concentration has a toxic effect above a pH of 9.5.

McKinney (1962) states that the rate of microbial growth doubles with every 10°C increase in temperature up to about 35°C. Most microorganisms do not grow below freezing temperatures because approximately 80 percent of the biological cells are water which, freezes and prevents further reaction. Schroepfer et al. (1952) found in a study of trickling filters treating municipal sewage that the filter efficiency increased with increasing temperature. The authors went on to say that fungi and protozoa are more prevalent during the winter months when bacteria are at a lower level.

Few biological systems have been used for treating animal wastes. Bridgham et al. (1966) used a trickling filter to treat a dairy manure slurry. The purpose was to provide an effluent suitable for use in flushing gutters of dairy barns without violating sanitary milk production codes and one suitable to be released to a stream. The authors used filters two feet in diameter and four feet deep with a three to five-inch stone media. The three filters used had primary and secondary settling basins. The variables considered were organic loading rate and influent temperatures. Each test was run for eight weeks. Some of the results are listed in Table 6.

Table 6. Performance of Trickling Filter Treating Dairy Wastes*

FILTER	A		B		C	
INFLUENT TEMP. (°F)	BOD[1] LOADING	EFFLUENT BOD (mg/l)	BOD[1] LOADING	EFFLUENT BOD (mg/l)	BOD[1] LOADING	EFFLUENT BOD (mg/l)
65	12.2	143	21.6	373	7.2	82
55	12.8	241	22.0	653	6.6	128
45	9.7	384	17.2	747	5.8	180

*Table taken from Bridgham et al. (1966).

[1]lbs/1000 ft.^{3}/day

The applied BOD_5 values ranged from about 600 to 2400 mg/l. Both loading rate and temperature had a great effect on the quality of the effluent. The lowest BOD_5 value in the effluent, 82 mg/l. came from the lowest loading rate and the highest temperature.

Nitrogen removal. Nitrogen is one of the most difficult elements to remove from wastewaters. Samples (1967) stated that one of the four methods available for nitrogen removal is by the microbial nitrification-denitrification process.

As stated earlier in the thesis, the microbial transformation from the organic form of nitrogen to ammonia is called mineralization. Samples (1967) stated that this process can be accomplished by numerous types of organisms. Sawyer and McCarty (1967) attribute mineralization to saprophytic bacteria. The authors went on to say that the breakdown occurs under both aerobic and anaerobic conditions.

The complete conversion from ammonia to nitrate is called nitrification. The formation of nitrates is an intermediate step. The nitrification process is shown in Equations 3 and 4.

$$2\ NH_3 + 3\ O_2 \xrightarrow{\text{Nitrosomonas}} 2\ NO_2^- + 2\ H^+ + 2\ H_2O \qquad (3)$$

$$2\ NO_2^- + O_2 \xrightarrow{\text{Nitrobactor}} 2\ NO_3^- \qquad (4)$$

The equations reveal that nitrification is an aerobic process. The complete conversion requires about 4.6 parts of oxygen for ever, part of nitrogen. Heukelekian (1942) states that the nitrosomonas and nitrobactor are autotrophic organisms. These differ from the heterotrophic type mentioned earlier in that they obtain their energy from the oxidation of inorganic compounds and their carbon source is either carbon dioxide or carbohydrates.

Heukelekian (1942) listed some of the factors which affect the rate of nitrification:

1. Presence of adequate numbers of nitrifiers.
2. Ample supply of free oxygen.
3. Ample supply of ammonia.
4. A supply of carbon dioxide.
5. The proper pH level.

Balakrishnan and Eckenfeldar (1969a) state that the autrotrophic nitrifiers have a slower growth rate than heterotrophs, thus, longer retention times are required in sewage treatment plants when nitrification is the goal.

Eckenfeldar (1967) suggests that nitrification occurs at all levels of dissolved oxygen, but that the rate is oxygen dependant below levels of 3.0 mg/l. The author was referring to the activated sludge process. Heukelekian (1942) said that if the dissolved oxygen level falls below 0.2 to 0.7 mg/l. in an activated sludge plant, complete aerobic conditions may not exist in the floc. The author went on to say that nitrification will take place in the presence of organic matter providing there is sufficient nitrifying flora present and that the oxygen demand of the carbonaceous material does not cause an oxygen deficiency.

Alexander (1965) stated that the optimum pH for the nitrosommonas is from 7 to 9 while that for the nitrobactor is between a wide range, from 5 to 10. The author also said that the optimum temperature for nitrification is from 30 to 35^{o}C, that it rarely occurs above 40^{o}C, and the rate is slow at 2^{o}C.

Balakrishnan and Eckenfeldar (1969b) studied nitrification in trickling filters. The authors stated that organic removal usually occurs in the top few feet of the filter while nitrification occurs in the bottom part of the filter. The authors were working with a water that had an ammonia concentration from 2 to 17 mg/l. The dissolved oxygen was always above 2.0 mg/l. They found that the following relationship describes the percent removal of ammonia that you can expect.

$$\text{Percent nitrification} = 1 - e^{-KD/Q^n} \quad 100 \qquad (5)$$

where

K = Reaction constant related to specific surface.

D = Depth.

Q = Hydraulic loading rate.

n = Constant related to specific surface and configuration.

From their studies with 6-foot models, the authors found an increase in nitrification from 52 to 72 percent by decreasing the loading rate from 30 to 10 million gallons per acre per day. They went on to say that higher nitrification can be achieved by either increasing the depth or reducing the hydraulic loading rate.

They also concluded that temperature has a great effect on nitrification. This can be shown by the change in reaction constant K.

$$K_t = K_{20}(1.085^{T-20}) \qquad (6)$$

where

K_t = Reaction constant at some temperature, T

K_{20} = Reaction constant at 20°C.

Although it was stated earlier that aerobic processes will be the major type of treatment discussed, the facultative anaerobic reaction called dentrification deserves some mention. Samples (1967) defines dentrification as, "the process of reduction of nitrate and possibly nitrite with the liberation of molecular nitrogen and, in some instances, nitrous oxide." The use of nitrification followed by dentrification is probably one of the most promising methods available for complete nitrogen removal. Balakrishnan and Eckenfeldar (1969c) reported from 80 to 90 percent nitrogen removals with this type of process. The initial nitrogen concentration was from 25 to 30 mg/l.

One of the major drawbacks of such a process is that an organic substrate is necessary for an energy source of the heterotrophic organisms. Broadbent and Clark (1965) also stated that another way in which organic matter affects denitrification is that it reduces the dissolved oxygen level to where denitrification can occur. Balakrishnan and Eckenfeldar (1969c) found that denitrification was completely inhibited at dissolved oxygen levels of 6 mg/l. This occurs because anaerobic conditions are required before the heterotrophs use nitrates as the hydrogen acceptor.

Bremner and Shaw (1958) studied denitrification in soils and found that the rate increased rapidly with temperature from 2 to 25°C. From that point the increase was not as rapid but the optimum temperature was reported to be 60°C. No dentrification was found at a temperature of 70°C.

Bremner and Shaw (1958) found that denitrification in soil was slow at a pH below 6.0 and quite high at a pH from 8.0 to 8.6.

Murphy (1970) used a stone media biofilter to treat water from indoor fish tanks. The interesting thing to note was that at the startup of his filter, he found a gradual buildup of nitrates for the first 15 days of operation. This was attributed to nitrification of the ammonia present in the fish wastes. However, during the second 15 days of operation, a reduction of nitrates was shown. This was explained as follows: as the thickness of the microbial layer on the filter media increased, the interlayer became anaerobic.

The anaerobic heterotrophs then used the nitrates as a hydrogen acceptor. Thus, denitrification was occurring at the interface of the microbial mass and the filter media. This was a good example of nitrification-denitrification occurring in the same system.

Chang et al. (1971) studied the decomposition of dairy wastes in laboratory aeration units. They used a diluted manure waste and aerated it for 40 days. The authors reported refractory organic nitrogenous compounds were present after aeration and stated that they were not readily biodegradable. The authors also found that nitrification did not take place until 10 to 20 days after aeration started. They reported other forms of nitrogen loss during the aeration study. For one test, ammonia volatilization was accredited for about 45 percent of the nitrogen not accounted for while the remaining 55 percent was attributed to dentrification.

INVESTIGATION

Objectives

1. To examine the effectiveness of a spray-runoff irrigation system for treating cattle feedlot runoff under different land slopes and loading conditions. This will be evaluated in terms of both concentration reductions and total mass removal.

2. To check the quantity and quality of rainfall runoff from the treatment area.

3. To check the chemical composition of cattle feedlot runoff with regard to irrigation water quality and examine its effects on the chemical properties of the soil.

4. To determine the worth of a polishing pond for further treatment of the effluent from the spray-runoff system.

5. To examine the quality of the soil water.

Theory

The theory of a spray-runoff system treating cattle feedlot runoff is to apply the wastewater by sprinkler irrigation nozzles placed at the top of a grassed slope at a rate such that a high percentage returns as overland flow. The treatment that takes place in the grass thatch and on the soil surface is due to the growth of microorganisms in these areas. Therefore, the mechanism of treatment is similar to that which occurs in a trickling filter. As pointed out in the review of literature, this type of system has been successfully applied to treating canning plant wastes. Some of these wastes had higher concentrations of BOD_5 than can be expected for cattle feedlot runoff, however, this is not to say that the organic material in cattle feedlot runoff can be decomposed at the same rate as that in the canning plant wastewaters. Also, none of the authors reported using a spray-runoff system for removal of high concentrations of nitrogen compounds common in cattle feedlot runoff.

The hypothesis for this experiment is that the organic material can be removed from cattle feedlot runoff by a spray-runoff treatment system. Organic material in solution will be adsorbed to the bio-mass present and utilized in the formation of additional cell mass and the end products, carbon dioxide and water. Also, it is expected that the nitrogen present in feedlot runoff, which will primarily be the organic or ammonia form, will undergo the mineralization, nitrification, and possibly denitrification processes in the treatment area. The mechanism for phosphate removal will be limited to adsorption to the soil particles. Suspended solid material will settle out in the grass areas and decompose on the soil surface. There may be some biological mass that sloughs off of the treatment area as is the case for trickling filters. A polishing pond may be required to allow the bio-mass to settle out of the effluent.

The impact of raindrops during rain storms may erode the surface litter from the treatment area. Therefore, rainfall runoff may also contain high concentrations of organic impurities but, these probably could be settled out in runoff detention facility. Thus, a polishing pond may serve for this purpose also.

If the quality of the water in the polishing pond does not meet stream standards, recycling may be required. The block diagram shown in Figure 3 shows the layout and operation of a spray-runoff system for treatment of cattle feedlot runoff.

The operation of such a system over a number of years will require that the physical and chemical properties of the soil are maintained at a level such that plant growth is not inhibited. Thus, salinity of the soil solution must not exceed the tolerance of the crop. Also, the reduction of infiltration rate caused by soil dispersion may limit the amount of water available to the plant. Therefore, the soil properties should be checked frequently to determine if they have come to an equilibrium with their environment.

The spray-runoff system probably will be most applicable when other types of disposal and soil treatment systems are not feasible. Generally, this infers that the soil type will be one of a low infiltration rate and one having poor drainage. However, the quantity and quality of the water lost to deep soil percolation may be an important factor in regard to groundwater pollution.

Method of Procedure

The project was conducted at the Circle E Ranch Division of Kansas Beef Industries, Inc., located near Potwin, Kansas. Circle E is an open lot cattle feeding operation which has a one-time capacity of 22,000 head and a total lot

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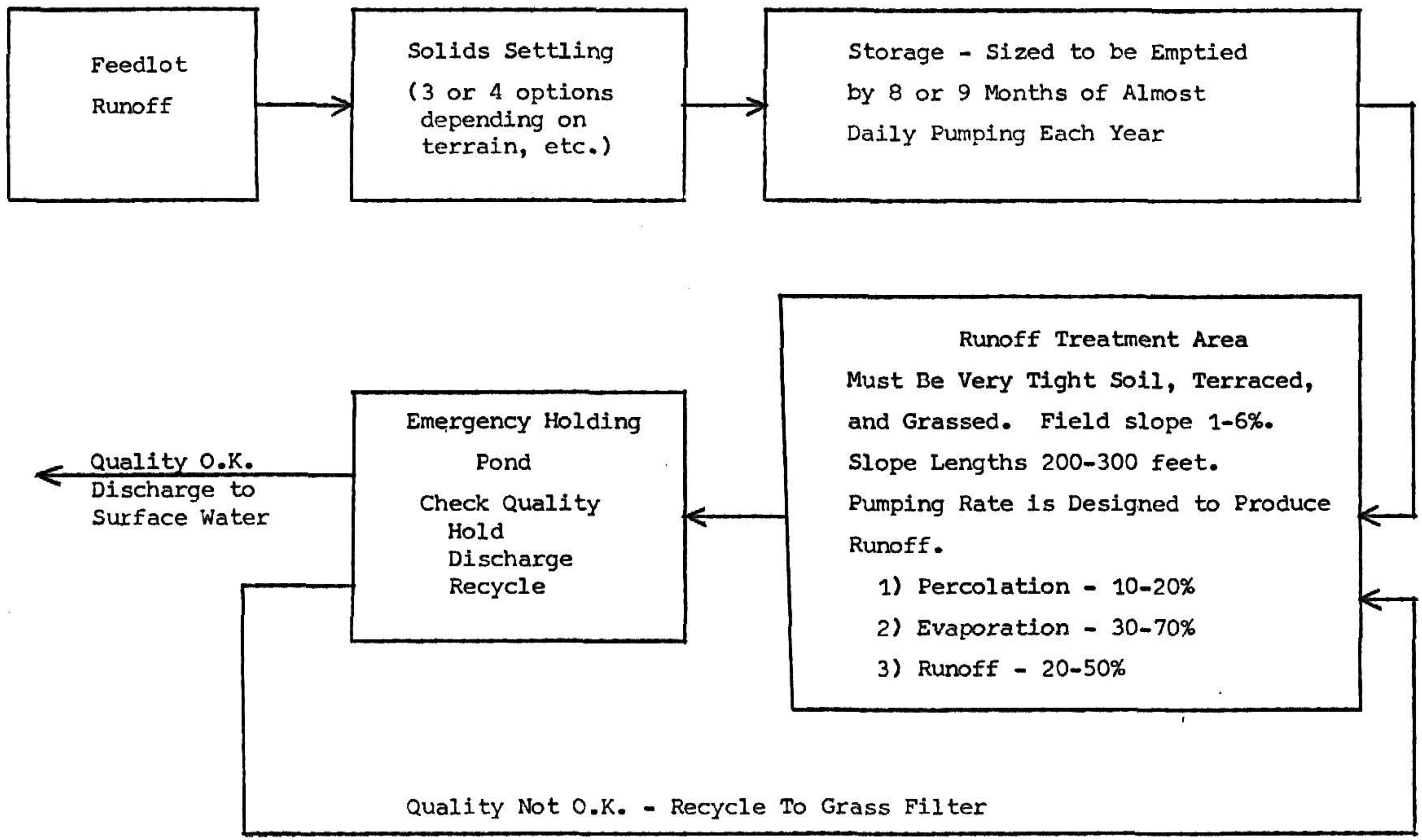

Figure 3. Block Diagram of Layout and Operation of Spray-Runoff System for Treatment of Cattle Feedlot Runoff

area of about 100 acres. According to Bergsrud (1968) the average annual runoff from a feedlot in this area is about 11 inches. At the present time, the feedlot has a runoff detention storage volume of approximately 100 acre-feet.

A spray-runoff system was designed and installed on a 10.9 acre field which is adjacent to a runoff holding pond. The land slope on the treatment field varies from 1 to 3 percent. The soil was characterized as a loam topsoil underlain by a clay subsoil at a depth of 9 to 12 inches. The soil depth ranges from 18 inches to 3 feet and is underlain by a shale layer.

Two parallel terraces were constructed on the field with a spacing of approximately 200 feet. This particular spacing was chosen on the basis of the information reported by Law et al. (1969a) and also the layout of the field lent itself to this arrangement. These terraces drain into a parabolic waterway which further discharges into a detention pond. This pond has storage volume of 1.65 acre-feet and receives runoff only from the treatment field. The pond was designed to store at least the amount of runoff expected from 2 days or irrigation. The facility was considered a polishing pond for further biological treatment and solids settling. A concrete drop structure was installed in the earth fill dam of the detention facility. The terraces, waterway, and polishing pond were laid out and constructed with the aid of local Soil Conservation Service personnel.

During the fall of 1971, the treatment field received about 50 tons of wet manure per acre. The manure was incorporated into the soil prior to planting the field to grass.

The treatment area was seeded with a Reed canarygrass, tall fescue, tall wheatgrass, smooth bromegrass, and perennial ryegrass mixture during March 1972. It is anticipated that when the grass is fully developed and has been exposed to high volumes of effluent spray, the brome and ryegrass will diminish and leave the more salt and moisture tolerant grasses.

The terrace layout allowed for four individual watersheds on the treatment field. Each slope has a slope length of at least 160 feet and usually 200 feet. Sprinkler laterals were installed on the treatment field at a distance of 60 feet from the upper boundary of each watershed. Three-foot risers were placed on the laterals at a spacing of 300 feet. A total of 45 were placed on the treatment field. Assuming a 100-foot spray diameter sprinkler head, the above arrangement gives a minimum length of run beyond the spray diameter of 50 feet and usually 90 to 100 feet. A plan view of the entire layout is shown in Figure 4.

Wastewater from the runoff holding pond adjacent to the treatment field was supplied to the irrigation system by a centrifugal pump powered by an internal combustion engine.

The experimental study was conducted on the two watersheds with terrace outlets. This allowed for complete monitoring of the quantity and quality of both the applied water and the runoff water. The upper plot, GI, has a slope of about one percent and an area of 1.55 acres. Eight sprinkler heads were installed in this plot. The second plot, GII, has an area of about 3.6 acres and contains 19 sprinkler heads. The slope of this plot is 2 percent.

The quantity of the 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 application. Three raingauges were placed in the 10.9 acre watershed so that a good measurement of rainfall could be made.

Runoff measuring flumes were placed at the terrace outlets of each plot. These were equipped with stage recorders so that total runoff volume could be evaluated for each application and rainfall event.

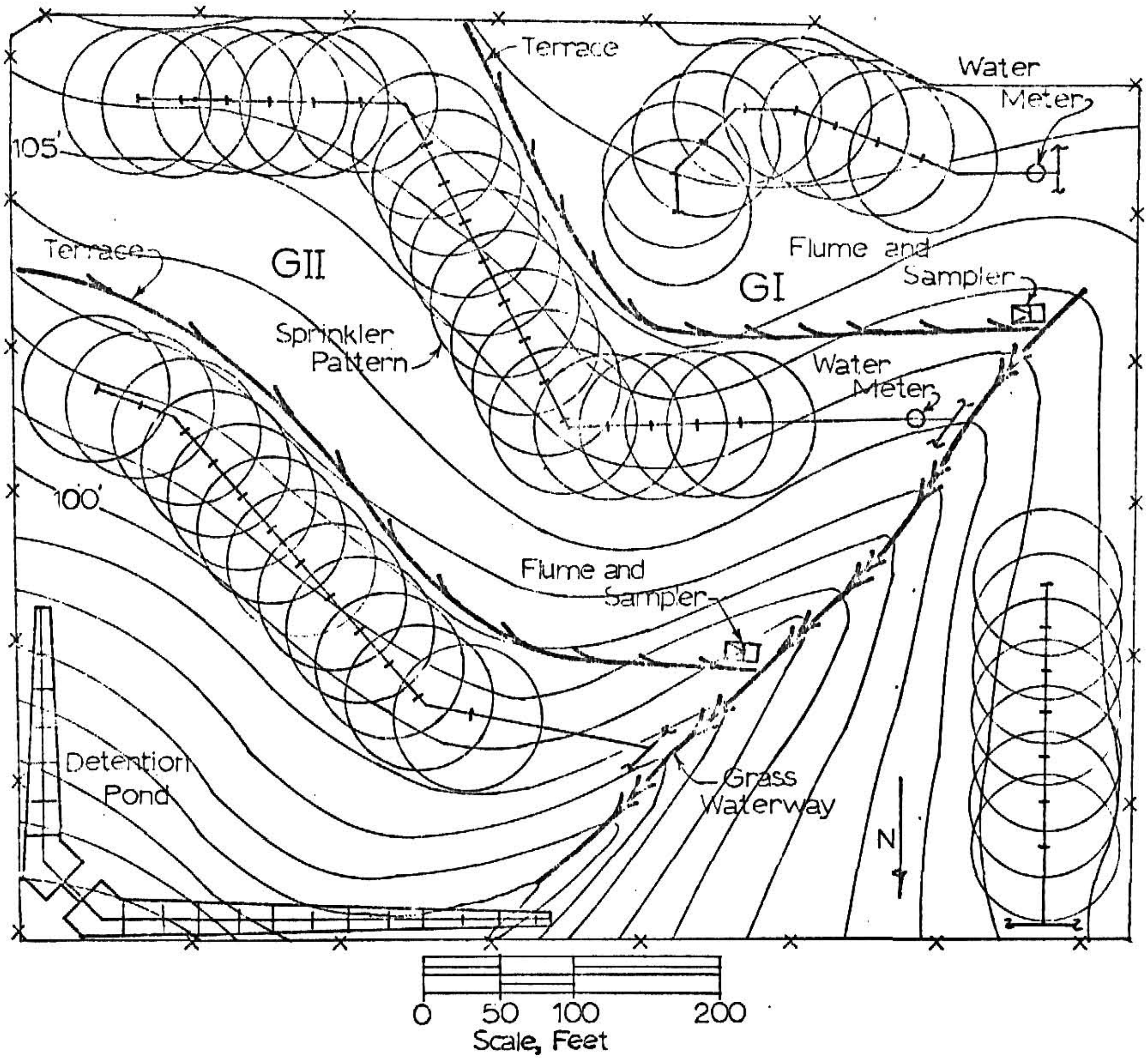

Figure 4. Plan View of Experimental Spray-runoff System.

The system was monitored from late spring to early fall of 1972. Two hydraulic loading rates were evaluated during this period. Test 1 began on June 8 and continued through July 28. During this period, the system was operated eight hours per day, four days per week. The application rate was 0.08 inches per hour, iph, or about two and one-half inches per week. A rest period of four weeks followed Test 1. Test 2 began on August 24 and continued through October 14. During this test the wastewater was applied in three 21-hour periods per week. The loading rate was 0.04 iph. which gave about the same weekly loading rate as Test 1, but only one-half the instantaneous loading rate. The schedule for Test 1 was chosen on the basis of the 8-hours on, 16-hours off method suggested by Law et al. (1969a). In hope of improving the results of Test 1, the author chose the schedule for Test 2 arbitrarily, assuming the instantaneous loading rate has an effect on the treatment efficiency of the system. The 2-hours on, 2-hours off schedule indicated by Gilde (1968) appeared more satisfactory to the author but the internal combustion pumping plant did not lend itself to this arrangement.

Composite samples of the applied water were collected each day of application from each test plot, GI and GII. These samples were caught in samplers placed in the spray pattern of each plot.

Composite runoff samples were caught by flow proportional samplers placed below the flow measuring flumes on each plot. These samples were collected at the end of each runoff event. Rainfall runoff samples usually were collected by grabbing a sample of the water passing through the flume.

Grab samples were collected biweekly (sometimes more frequently) from the polishing pond. These were taken from the six-inch depth. Also, several samples of the soil water were collected from soil water sampling tubes placed at a depth of nine inches.

All samples collected 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.

The following parameters were checked on the water samples collected: BOD_5, COD, Kjeldahl nitrogen, and ammonia nitrogen. In addition, total phosphorus, pH, electrical conductivity, total solids, and volatile solids were evaluated on all samples except the soil water samples. The analyses were done according to the methods given by the American Public Health Association (1965) with the exception of the modifications given below.

Municipal sewage was used as seed material for the BOD_5 test. This was not an acclimated seed which may have given lower values than might be expected. Nitrification was inhibited during the test by the acidification method suggested by Hurwitz et al. (1947). This allowed for a differentiation between the carbonaceous oxygen demand and the oxygen demand caused by nitrification. A relationship between COD and BOD_5 was developed so the lengthy BOD_5 test would not have to be run on each sample.

Kjeldahl nitrogen was determined by the micro-Kjeldahl digestion technique. The ammonia present upon digestion was determined by the direct nesslerization method. The color development was measured with a spectrophotometer at a wavelength of 410 millimicrons.

The aminonaphtholsulfonic acid method was used for total phosphate determinations. The color development was measured with a spectrophotometer at a wavelength of 690 millimicrons.

Suspended solids determinations were not made because the small concentrations found in the wastewater did not allow for a good measurement.

The soluble cations calcium, magnesium, sodium, and potassium were determined for several wastewater samples collected early in the study. This analysis was done at the Soil Testing Laboratory, Kansas State Universtiy. Sodium and potassium were determined by a flame photometer technique while an atomic adsorption method was used for the divalent cations. These values, along with the electrical conductivity, were used to evaluate the wastewater with regard to irrigation water quality.

Soil samples were taken prior to application of wastewater to the plots. These were collected from both beneath the spray pattern and downslope from the spray perimeter of each test plot. Three layers were sampled, 0-6, 6-12, and 12-24 inches. The samples were analyzed at the Soil Testing Laboratory, Kansas State University. Salt-alkali and general fertility tests were made on the samples. Following the completion of Test 2 in October the soil was sampled again in the same manner as above to determine any chemical changes that had taken place due to the application of the wastewater.

Materials and equipment. The sprinkler heads utilized for Test 1 were Rain Bird model 30-WS-TNT with 5/32 inch nozzles. These nozzles had a discharge rate of about five gallons per minute, gpm., at a pressure of 50 pounds per square inch, psi., and a spray diameter of 90 feet. Rain Bird model 20E-TNT heads were used for Test 2. The 7/64 inch nozzles used had a discharge rate of about two and one-half gpm at a pressure of 50 psi. The spray diameter was 80 feet. The discharge rates of five and two and one-half gpm. allowed for application rates of 0.08 and 0.04 iph., respectively. This was assuming a 30 X 200 foot spacing and an operating pressure of 50 psi.

Four-inch Sparling low pressure line meters were used to measure the amount of water applied to the two plots. These meters had a normal flow range from 60 to 400 gpm. They were equipped with a flow rate dial which registered in gpm. and a totalizer which indicated the total volume passing through the meter in units of acre-inches.

The raingauges used were wedge-shaped Tru-Chek gauges, manufactured by Edwards Mfg. Co., Albert Lea, Minnesota. These gauges measure rainfalls between 0.01 and 6.0 inches.

A 1.5 foot H flume was installed at the terrace outlet of the GI plot. 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 GII plot was instrumented with an 0.8-foot HS flume. The flow range of this flume is from 0.0003 to 0.457 cfs. The larger flume was placed on the GI plot because of its capability of handling both irrigation runoff and high intensity rainfalls. Thus a measurement of both types of runoff events could be made on the GI plot. A removable flood gate was placed in the wing wall of the flume on the GII plot for release of runoff rates exceeding the maximum discharge rate of the HS flume.

Both runoff measuring flumes were equipped with Stevens Type F Model 61 water level recorders. These float-activated recorders were equipped with 24-hour electric clocks. Thus, for each runoff event a stage hydrograph was obtained. A computer program was used to convert the stage hydrograph to a discharge hydrograph. The program further integrated the discharge hydrographs to obtain total runoff volume. The rating tables given by the U.S. Department of Agriculture (1962) were used for the calibration curve of each flume.

The apparatus used to obtain a sample of the applied water was made up of a jug-and-funnel arrangement. Two samplers were placed in the spray pattern of each plot at a height of 28 inches above the ground. They were placed midway between two risers in each plot and spaced at five and twenty feet from the lateral. The contents of the two jugs in each plot were combined for analysis.

The flow proportional samplers used to collect runoff samples were made up of two components, a flow splitting weir box and a slotted-cup arrangement.

The weir boxes contained two Cipolleti weirs, one having a crest length nine times that of the other weir. This allowed the flow to be split one part in ten. Laboratory tests revealed that this phenomena was true up to head readings equal to one-half the crest length of the smaller weir. However, the flow at this head was greater than that expected in the field. The weir crests in the box which received flow from the GI plot had lengths of 2.7 and 0.3 feet. The crest lengths in the weir box on the GII plot were 1.8 and 0.2 feet.

The flow from the smaller weir was carried in a chute to the slotted-cup sampler. The slotted-cup arrangement operates on the same principle as the Coshocton-type runoff samplers reported by Parsons (1954) except the motion occurs in the vertical plain rather than the horizontal plain. The sampling cup passes beneath the chute three times per minute. The sample caught is deposited in a sample collection barrel as the cup travels in a circular motion. The cup has a slot width of three-eighths inch and follows a two and one-half foot circular path.

Laboratory tests revealed that the weir box and sampling-cup arrangement collected a sample which was 0.027 percent of flow passing through the measuring flumes. A schematic diagram of the layout of the flow measuring and sampling equipment is shown in Figure 5.

The soil water sampling tubes were built in a similar way to the type used by Wagner (1962). They were made of a PVC pipe with a porous ceramic cup attached to the end. A vacuum was applied to the pipe for about an hour to pull a sample into the tube. The vacuum was supplied by using evacuated glass jugs. The samples collected from each plot were combined to have enough for analysis.

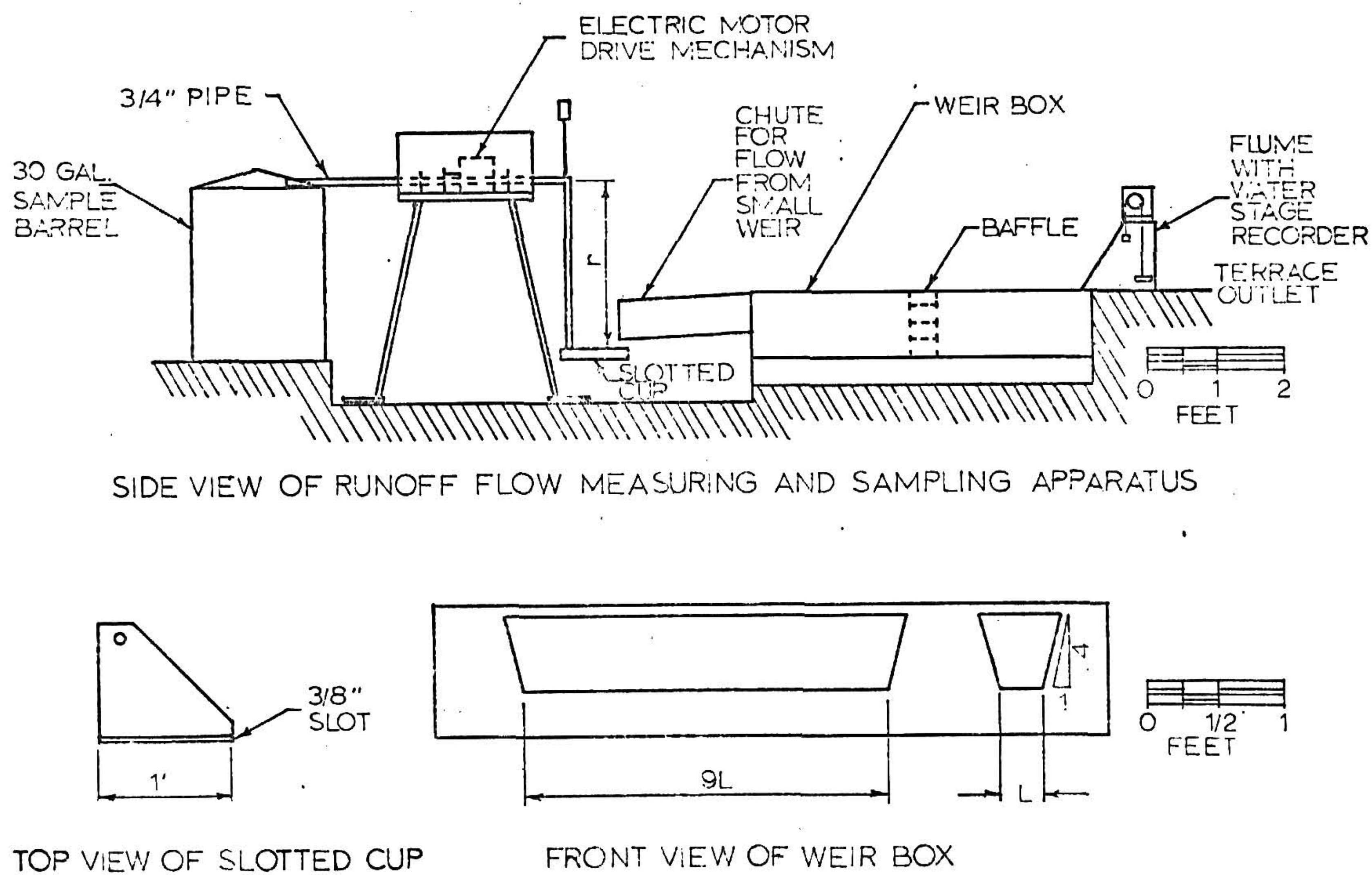

Figure 5. Flow Measuring and Sampling Apparatus at Terrace Outlets.

The pH was measured with a meter manufactured by Fisher Scientific. The model name was Fisher Accumet pH Meter, Expanded Scale Research Model 320.

A Model 101 UV-VIS Spectrophotometer manufactured by Hitachi, Ltd., was used to measure color development for the ammonia and phosphate determinations.

Electrical conductivity measurements were made with a Lab-Line Portable Lectro Mho-Meter, Mark IV, manufactured by Lab-Line Instruments, Inc.

RESULTS AND DISCUSSION

COD-BOD_5 Relationship

A relationship between COD and BOD_5 was developed to avoid performing the BOD test on all samples. A regression analysis was made for 24 samples. A log-log curve fit the data best. The regression equation and actual data points are shown in Figure 6. The correlation coefficient of 0.71 is significant at a 0.01 alpha level. This indicated there is a correlation between COD and BOD_5. The regression equation was used to estimate BOD_5 for all samples except those having a COD less than 1350 mg/l. or greater than 2400 mg/l. which was the range of values used in the regression analysis.

Removal of Pollution Parameters

Characteristics of applied wastewater. The quality of the wastewater applied was characterized by the range, mean, median, and standard deviation of the pollution parameters. These data, grouped according to plot, parameter, and test number, are shown in Tables 7 to 10.

The tabulated results confirm the high water pollution potential of cattle feedlot runoff. In addition to oxygen demanding organic material, there also are high concentrations of Kjeldahl-nitrogen, ammonia-nitrogen, and phosphates. Mean COD values ranged from 1799 to 2199 mg/l. These values

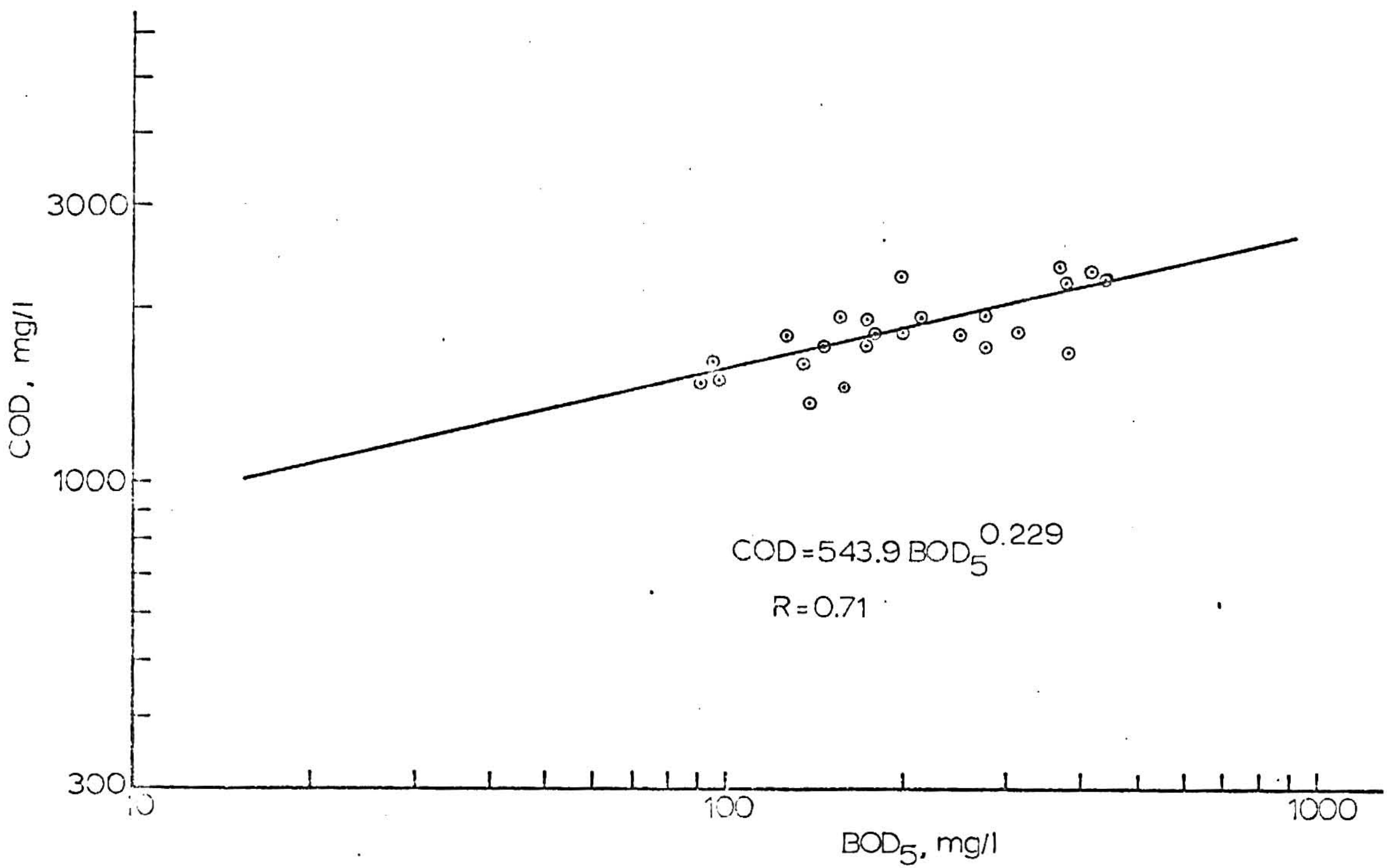

Figure 6. COD-BOD Relationship

Table 7. Quality of Applied Wastewater, GI, Test 1

Parameter	Units	Number of Observations	Minimum	Maximum	Mean	Median	Standard Deviation
COD	mg/l	25	1128	2464	1831	1870	366
BOD_5	mg/l	20	80	664	276	255	181
Kjeldahl Nitrogen	mg/l as N	15	176	1072	542	405	313
Ammonia Nitrogen	mg/l as N	18	66	269	150	126	64
Total Phosphorus	mg/l as PO_4	10	84	110	95	93	10
Total Solids	mg/l	25	3248	5243	4598	4750	536
Percent Volatile Solids	Percent	25	32	45	39	40	4
pH	pH Units	25	7.5	8.3	7.9	7.9	0.2

Table 8. Quality of Applied Wastewater, GI, Test 2.

Parameter	Units	Number of Observations	Minimum	Maximum	Mean	Median	Standard Deviation
COD	mg/l	15	1791	2677	2199	2244	284
BOD_5	mg/l	8	200	655	358	299	165
Kjeldahl Nitrogen	mg/l as N	15	51	369	237	216	93
Ammonia Nitrogen	mg/l as N	15	40	197	87	78	40
Total Phosphorus	mg/l as PO_4	3	88	114	103	108	14
Total Solids	mg/l	15	3125	5495	4755	4845	553
Percent Volatile Solids	Percent	15	30	44	37	40	11
pH	pH Units	15	7.6	8.1	7.8	7.8	0.2

Table 9. Quality of Applied Wastewater, GII, Test 1.

Parameter	Units	Number of Observations	Minimum	Maximum	Mean	Median	Standard Deviation
COD	mg/l	25	1350	2404	1799	1798	309
BOD_5	mg/l	19	53	666	252	233	179
Kjeldahl Nitrogen	mg/l as N	15	168	1072	507	421	300
Ammonia Nitrogen	mg/l as N	18	57	283	165	143	75
Total Phosphorus	mg/l as PO_4	10	75	118	97	96	16
Total Solids	mg/l	25	2967	5265	4516	4577	584
Percent Volatile Solids	Percent	25	32	46	39	40	3
pH	pH Units	25	7.5	8.6	8.0	8.0	0.3

Table 10. Quality of Applied Wastewater, GII, Test 2.

Parameter	Units	Number of Observations	Minimum	Maximum	Mean	Median	Standard Deviation
COD	mg/l	18	1461	2520	2086	2082	333
BOD_5	mg/l	11	61	617	322	282	179
Kjeldahl Nitrogen	mg/l as N	17	57	358	209	216	96
Ammonia Nitrogen	mg/l as N	17	31	161	77	67	34
Total Phosphorus	mg/l as PO_4	3	105	120	114	118	8
Total Solids	mg/l	17	3052	5617	4764	4837	568
Percent Volatile Solids	Percent	17	32	47	39	41	4.8
pH	pH Units	17	7.2	8.3	7.8	7.9	0.3

are somewhat lower than usually found in "fresh" runoff as reported in the review of literature. Low concentrations of suspended solids, caused by good settling, explains the lower COD and indicates that a large portion of the organic material is in the dissolved form.

Mean BOD_5 concentrations of the applied wastewater ranged from 252 to 358 mg/l. Use of an acclimated seed might have given higher results but, these data appear to be within the range to be expected considering the low suspended solids content.

With regard to oxygen demanding organic material, it appears that the wastes applied during Test 2 were the more concentrated. The natural variation of the quality of cattle feedlot runoff is probably the only explanation for the difference.

Mean Kjeldahl nitrogen concentrations ranged from 209 to 542 mg/l. in the applied water. Although these values are similar to those reported by Fields (1971) for cattle feedlot runoff, they are 10 to 20 times higher than the values reported by Law et al. (1969b) for the canning plant wastewater. This indicates a marked difference between the two types of wastewater and probably will be significant factor in using the spray-runoff system for treating cattle feedlot runoff.

About one-third of the Kjeldahl nitrogen was in the form of ammonia for the applied wastewater. The mean values ranged from 77 to 165 mg/l. This indicates a high degree of nitrification is necessary for satisfactory performance of the spray-runoff system.

Contrary to the COD and BOD_5 data, the nitrogen compounds of the applied water had higher concentrations during Test 1 compared to Test 2. Again, the high variability and unpredictability of cattle feedlot is probably the only explanation.

Mean total phosphorus values were in a narrow range from 95 to 114 mg/l. Again, as was the case for nitrogen, these concentrations are at least ten-fold those found in the canning plant wastewater as indicated by Law et al. (1969b). Since the canning plant study indicated that concentration reductions of total phosphorus were lower than all other parameters, total phosphorus may be an important factor when considering use of a spray-runoff system.

Total solids, mainly in the form of dissolved solids, were high in the applied water. The mean volatile percentage of the total solids ranged from 37 to 39 percent which indicates that a significant portion of the solids is non-organic material. A high percent of this material is probably colloidal clay eroded from the feedlot surface.

The pH of the wastewater ranged from 7.8 to 8.0. This indicates that the pH is favorable for the type of biological activity anticipated.

Characteristics of treated effluent. The quality of the effluent from the treatment field was characterized by the range, mean, median, standard deviation, and the change relative to the mean concentrations of the applied wastewater. These data, grouped according to plot, parameter, and test number, are shown in Tables 11 to 14.

The results indicate that there were reductions of most constituents but the field effluent still was of poor quality. Mean COD concentrations ranged from 1641 to 1835 mg/l. For both tests, the COD was higher in the effluent from GI. Mean changes in concentration ranged from 0.2 to minus 21 percent. The plus 0.2 percent indicates that the water actually increased in COD. This occurred during Test 1 and may have been due to the manure that had been applied to the plots before seeding. Higher concentrations reductions occurred during Test 2 for both plots.

Table 11. Quality of Field Effluent, GI, Test 1.

Parameter	Units	Number of Observations	Minimum	Maximum	Mean	Median	Standard Deviation	Change in Mean
COD	mg/l	23	1440	2468	1834	1791	296	+0.18%
BOD_5	mg/l	20	71	382	201	175	102	-27.1%
Kjeldahl Nitrogen	mg/l as N	13	153	638	387	325	143	-28.6%
Ammonia Nitrogen	mg/l as N	16	33	170	97	81	45	-35.2%
Total Phosphorus	mg/l as PO_4	10	70	102	90	96	12	-4.6%
Total Solids	mg/l	22	4173	6185	5034	5087	589	+9.5%
Percent Volatile Solids	Percent	22	30	43	37	37	3	-2.2
pH	pH Units	23	7.8	8.8	8.2	8.1	0.3	+0.3

Table 12. Quality of Field Effluent, GI, Test 2.

Parameter	Units	Number of Observations	Minimum	Maximum	Mean	Median	Standard Deviation	Change in Mean
COD	mg/1	15	1538	2510	1835	1768	293	-16.6%
BOD_5	mg/1	8	94	281	166	145	72	-53.8%
Kjeldahl Nitrogen	mg/1 as N	16	39	337	133	115	84	-44.0%
Ammonia Nitrogen	mg/1 as N	16	14	104	47	41	27	-45.7%
Total Phosphorus	mg/1 as PO_4	3	78	94	88	93	9	-14.3%
Total Solids	mg/1	16	4240	5245	4760	4758	369	+0.1%
Percent Volatile Solids	Percent	16	31	41	36	36	3	-0.5
pH	pH Units	16	7.7	8.4	8.1	8.2	0.2	+0.3

Table 13. Quality of Field Effluent, GII, Test 1.

Parameter	Units	Number of Observations	Minimum	Maximum	Mean	Median	Standard Deviation	Change in Mean
COD	mg/l	24	1016	2567	1641	1608	343	-8.8%
BOD_5	mg/l	19	31	454	158	130	115	-37.3%
Kjeldahl Nitrogen	mg/l as N	13	110	515	301	255	151	-40.5%
Ammonia Nitrogen	mg/l as N	16	13	153	84	81	38	-49.3%
Total Phosphorus	mg/l as PO_4	10	72	110	92	96	13	-4.6%
Total Solids	mg/l	22	2943	5765	4757	4862	727	+5.3%
Percent Volatile Solids	Percent	22	34	42	37	37	2	-2.0
pH	pH Units	24	7.8	8.7	8.2	8.2	0.3	+0.2

Table 14. Quality of Field Effluent, GII, Test 2.

Parameter	Units	Number of Observations	Minimum	Maximum	Mean	Median	Standard Deviation	Change in Mean
COD	mg/l	19	846	1969	1648	1711	238	-21%
BOD_5	mg/l	11	71	198	131	121	43	-60%
Kjeldahl Nitrogen	mg/l as N	17	21	200	127	124	50	-40%
Ammonia Nitrogen	mg/l as N	18	11	72	42	40	20	-46%
Total Phosphorus	mg/l as PO_4	3	69	91	81	83	11	-29%
Total Solids	mg/l	18	3308	5487	4668	4638	498	-2%
Percent Volatile Solids	Percent	18	30	40	35	36	4	-3.7
pH	pH Units	19	7.7	8.3	8.1	8.1	0.2	+0.3

BOD concentrations also were high in the runoff water. Mean values ranged from 131 to 201 mg/l. Again, more favorable results were obtained from GII. The mean concentration changes ranged from minus 27 to minus 60 percent. The higher concentration reduction occurred during Test 2. BOD concentration reduction percentages were higher than COD concentration reductions because of the high non-biodegradable fraction of the COD.

Mean Kjeldahl nitrogen ranged from 127 to 387 mg/l. in the field effluent. For both tests, runoff from GII contained the lower concentrations. Higher concentrations occurred from Test 1 but this probably was due to the high concentrations applied during that test. Concentration reductions ranged from 29 to 44 percent. The results from GII indicated that on a percent concentration reduction basis there was not much difference between Test 1 and Test 2. The opposite occurred on GI, Test 2 giving the higher percent removal. Removal of Kjeldahl nitrogen would ultimately depend on nitrification. The data suggests then that nitrification did occur but high concentrations of Kjeldahl nitrogen remained in the field effluent.

Like Kjeldahl nitrogen, ammonia nitrogen remained high in the field effluent. Mean concentrations ranged from 42 to 97 mg/l. Again, lower concentrations were found in theeffluent from GII than those found in the effluent from GI for both tests. Mean percent concentration reductions ranged from 35 to 49 percent. Percent concentration reductions were about the same for both tests on GII but the results from GI were better for Test 2. This is similar to what occurred with the Kjeldahl nitrogen. No reasonable explanation for this could be determined.

Removal of total phosphorus is probably due mainly to adsorption to the clay particles on the soil surface. This suggests that removal could be increased by allowing more time for adsorption to occur or by spreading the waste over more area. Since the area was fixed in this situation, it was felt that the instantaneous loading rate would be the only mechanism available to alter phosphorus removal. Thus, the author anticipated higher percent removals during Test 2. However, since low percent removals occurred during Test 1 and time was limiting, the author chose to make only three analyses for total phosphorus during Test 2. This should be considered when looking at the results.

Mean total phosphorus concentrations ranged from 81 to 92 mg/l. in the field effluent. The concentration reductions were about five percent for both plots during Test 1 but increased to 14 and 29 percent for GI and GII, respectively during Test 2. As stated above, the increase was anticipated for Test 2 but due to the limited number of samples taken, this information may not be significant. However, the results do suggest that phosphorus may be a parameter which limits the adaptability of the spray-runoff system for treatment of cattle feedlot runoff.

Total solids concentrations were high in the field effluent and if anything, increased in the treatment area. Mean concentrations ranged from 4668 to 5036 mg/l. As was the case for the applied wastewater, suspended solids were low and were not measured. Mean concentration changes ranged from plus 9.5 percent to minus 2.02 percent. Increases in total solids were probably due to the concentrating effect of evaporation and possible due to erosion of soil particles from the treatment field. This would explain why the gain in total solids was lower for Test 2 because the grass was more developed during that test which would inhibit soil erosion.

The mean percent volatile solids ranged from 35 to 37 percent in the field effluent. There was a decrease in the percent volatile during the treatment process which indicates that erosion of soil particles might have occurred.

Statistical analysis. The effects of land slope and days on the variables, BOD_5, Kjeldahl nitrogen, and ammonia nitrogen, were measured with a two-way analysis of variance statistical model. Since the data from Test 1 and Test 2 could be grouped according to days, the effects of the two test conditions could also be measured.

The water quality data from each plot was grouped for both tests and an analysis was made to determine if both plots were receiving the same quality of water. The analysis revealed that this was true for all three parameters.

Next, an analysis was made to determine if the quality of the field effluent was statistically different from each plot. The analysis indicated that there was no difference in the mean values of the three parameters between plots at an alpha level of 0.05. However, the difference in BOD_5 data was significant at an alpha level of 0.059. GII yielded lower mean BOD_5 concentrations.

From the above analysis then, there was no significant difference between the degree of treatment obtained under the two land slope conditions at a 0.05 alpha level. However, the high degree of natural variability in the data, as well as that caused by sampling and laboratory errors, may have masked the true difference between the treatment results of the two plots. The author felt this was especially true in the case of the BOD_5 data.

To compare the effect of loading rate, the data from both plots were combined and grouped for each test. First the quality of the water applied was run to determine if there was any significant difference between tests. There was no significant difference between the mean BOD_5 of the applied water for both tests but there was for the Kjeldahl nitrogen and ammonia nitrogen.

The field runoff water was then compared in the same manner. Even though Test 2 appeared to yield more favorable treatment, the results indicated no significant difference between the mean BOD_5 for both tests at a 0.05 alpha level. This was determined by comparing F values. The F calculated was 4.01 while the critical value at an alpha level of 0.05 was 4.32. Even if the difference had been statistically significant, the analysis would not have necessarily indicated the difference between loading conditions because the grass was more developed during Test 2 and environmental conditions were not necessarily the same for both tests. There was a significant difference in the mean Kjeldahl nitrogen and ammonia nitrogen of the field effluent between the two tests. However, this was probably due to the difference in the quality of water applied for these tests.

The above analysis suggests that the constraints on the design of the experiment did not allow for a good comparison between loading rates.

Mass removal of pollution parameters. Another method for evaluating treatment efficiency is on a mass removal basis. This is possible if both concentration and flow volume data are available for applied and runoff water. Using this information the total amount of a given parameter can be evaluated on a pounds-per-acre-per-day basis by use of the appropriate conversion factors.

Table 15 shows the total amount of wastewater applied to each plot for each test. The table also shows the amount of runoff that occurred on the days with data available. The missing data which occurred on 13 of the 48 irrigation days, was caused by days when the recorder malfunctioned or by days when rainfall and irrigation occurred on the same day and the runoff caused by each could not be differentiated. The table indicates that about 13 inches of wastewater was applied to each plot during Test 1. About 16 inches was applied during Test 2. The amount applied to GI during Test 2 was an estimate from the amount applied to GII because the flow meter was not operating within the flow range suggested in the specifications. The estimate was made by multiplying the amount of water applied to the GII plot by the ratio of the number of sprinklers on GI to the number on GII.

For the total season, only about 25-27 percent of the applied wastewater ran off. This was based on the days with data available. The percent runoff was somewhat lower than anticipated but continuous operation throughout the season probably would yield higher runoff percentages. The author felt that very little water moved through the clay subsoil. This would suggest that the remaining water was lost through direct sprinkler evaporation and evapotranspiration.

Table 15. Amount of Wastewater Applied and the Percent Runoff.

	GI			GII		
	Test 1	Test 2	Total	Test 1	Test 2	Total
Amount Applied (In.)	13.0	16.4	29.4	12.7	16.0	28.7
Number of Irrigation Days	29	19	48	29	19	48
Number of Days with Runoff Data Available	22	13	35	23	12	35
Percent Runoff for Days with Runoff Data Available	29.2	21.6	25.6	22.8	31.8	26.6

Table 16 shows the mass reductions of three parameters, BOD_5, Kjeldahl nitrogen, and ammonia nitrogen. As was the case for the runoff percentages, data were not available for each day of application due to lack of runoff hydrographs or samples not taken. The table indicates mass reductions of 77-92 percent for BOD_5, 74-90 percent for Kjeldahl nitrogen, and 81-90 percent

Table 16. Mass Reductions of BOD_5 and Nitrogen

Parameter Plot Test	Total Amount Applied (ac-in)	Amount with Data Available (ac-in)	Pounds Per Acre Applied	Pounds Per Acre Off	Percent Mass Removal
BOD_5					
GI Test 1	20.1	14.2	565	131	76.8
Test 2	25.4	6.9	407	32	92.2
GII Test 1	45.8	28.3	422	61	85.6
Test 2	57.9	18.1	456	47	89.6
Kjeldahl Nitrogen					
GI Test 1	20.1	17.8	1895	302	84.1
Test 2	25.4	12.5	482	49	89.8
GII Test 1	45.8	35.4	1636	194	88.1
Test 2	57.9	25.9	295	78	73.6
Ammonia Nitrogen					
GI Test 1	20.1	17.8	445	81	81.9
Test 2	25.4	12.5	157	17	89.1
GII Test 1	45.8	38.8	488	51	89.6
Test 2	57.9	25.9	141	26	81.2

for ammonia nitrogen. These reductions are due to both concentration reductions and the amount carried into the soil by the infiltrating water. This suggests then that to increase mass removal you can either increase the treatment efficiency or decrease the percent runoff. Since the purpose of the spray-runoff system is to give an alternative to irrigation disposal, increasing the treatment efficiency would be the logical suggestion.

Rainfall Runoff

The quantity and quality of rainfall runoff may be an important factor when considering the layout of a spray-runoff system. If the runoff water is of too poor quality for direct release to a stream, a detention facility may be required. Since the treatment area is covered with organic litter it is possible that rainfall runoff could contain considerable amounts of impurities.

Table 17 shows the total amount of rainfall which occurred during the period of study and the percent runoff on the days where runoff records were available. The reason for not having a complete record of runoff data is the same as that of the irrigation runoff. A total of 10.97 inches of rainfall fell during the period of study. This occurred in 21 events and the largest event, 1.76 inches, occurred on August 30. The table indicates that only 16-17 percent of the rainfall ran off for the events when records were available. The low runoff percentage is probably explained by the fact that the largest event which had runoff information available was 0.83 inches. There was no storm intensity data taken to compliment the rainfall data. High runoff percentages could be expected for high volume and high intensity storms since the treatment area usually is fairly wet.

Samples of rainfall runoff were taken by grabbing a sample of the water passing through the flow measuring flumes. The samples were taken in this

Table 17. Rainfall and Rainfall Runoff Percent.

	GI	GII
Total Rainfall (In.)	10.97	10.97
Amount of Rainfall with Runoff Record Available	5.20	4.32
Percent Runoff for Rainfall with Runoff Record Available	15.7	17.1

manner because the sample barrels used to collect irrigation runoff usually had a small amount of residue remaining in them after they were drained. It was felt that this residue might bias the results.

Tables 18 and 19 show the characteristics of the rainfall runoff water. The water was characterized by the method used for the wastewater. The data indicates that the rainfall runoff contains considerable concentrations of most pollution parameters and would be of questionable quality for release to a stream. Generally speaking, the water from the GII plot was of poorer quality than that from GI. This may be due to the higher erosion potential of the steeper slope.

Mean COD concentrations ranged from 593 to 852 mg/l. Manges (1971) reported somewhat lower COD values, 100 to 600 mg/l. for rainfall runoff from furrow irrigation disposal plots. Mean BOD_5 concentrations ranged from 45 to 53 mg/l. This indicates that less than 10 percent of the COD is in the form of five-day biodegradable material. The BOD_5 concentrations are a small amount higher than can be expected in the effluent of a trickling filter treating municipal sewage.

Mean Kjeldahl nitrogen concentrations were high in the rainfall runoff, 80 to 109 mg/l. for GI and GII, respectively. Ammonia accounted for about

Table 18. Quality of Rainfall Runoff, GI.

Parameter	Units	Number of Observations	Minimum	Maximum	Mean	Median	Standard Deviation
COD	mg/l	6	239	886	593	585	243
BOD_5	mg/l	4	29	76	49	45	20
Kjeldahl Nitrogen	mg/l as N	8	15	259	104	80	83
Ammonia Nitrogen	mg/l as N	8	8	38	21	19	10
Total Phosphorus	mg/l as PO_4	8	19	60	34	34	13
Total Solids	mg/l	8	918	3078	2079	2082	621
Percent Volatile	Percent	8	26	44	38	39	6

Table 19. Quality of Rainfall Runoff, GII.

Parameter	Units	Number of Observations	Minimum	Maximum	Mean	Median	Standard Deviation
COD	mg/l	6	616	1161	852	867	188
BOD_5	mg/l	4	28	78	53	54	22
Kjeldahl Nitrogen	mg/l as N	8	12	302	130	109	87
Ammonia Nitrogen	mg/l as N	8	5	68	27	25	20
Total Phosphorus	mg/l as PO_4	8	23	60	33	29	12
Total Solids	mg/l	8	984	3602	2338	2193	868
Percent Volatile Solids	Percent	8	30	46	39	40	5

one-fourth of the Kjeldahl nitrogen, mean values being 21 to 27 mg/l. for GI and GII, respectively. The nitrogen data, combined with the BOD_5 information, indicates that the water is of questionable quality for direct release to a stream.

Mean total phosphorus concentrations were 34 to 33 mg/l. for GI and GII, respectively. This suggests that the rainfall runoff carries less than one-third the amount of total phosphorus as the irrigation runoff.

Total solids concentrations were high in the rainfall runoff. Mean values were 2080 and 2338 mg/l. for GI and GII, respectively. This suggests that the rainfall runoff is picking up considerable quantities of impurities from the treatment area. The percent volatile solids were only 38 and 39 mg/l. for GI and GII, respectively. This would indicate that colliodal clays and other non-volatile material accounts for a high percentage of the solid material.

Effects of Wastewater on the Soil

The applied wastewater was characterized with regard to irrigation water quality. This was done by measuring the electrical conductivity and the concentrations of the four cations, sodium, potassium, calcium, and magnesium. The concentrations of the four cations were then used to calculate the soluble-sodium percentage and the sodium-adsorption ratio. These data are shown in Table 20.

Generally speaking, the table suggests that the wastewater applied was of very poor quality from an irrigation water standpoint. The water was high in dissolved salts which was indicated by high electrical conductivity, mean value of 3900 micromhos-per-centimeter. The water was also exceptionally high in sodium and potassium. The mean concentrations were 801 and 869 mg/l.

Table 20. Salt and Cation Concentrations of Applied Wastewater.

Parameter	Units	Number of Observations	Minimum	Maximum	Mean	Median	Standard Deviation
Electrical Conductivity	mmhos/cm	81	2.7	5.9	3.9	3.9	0.6
Sodium	mg/l	8	740	870	801	800	35
Potassium	mg/l	8	400	1000	869	925	196
Calcium	mg/l	8	38	85	56	49	18
Magnesium	mg/l	8	43	91	81	86	16
Soluble Sodium Percentage	Percent	8	49	66	53	52	5
Sodium Adsorption Ratio	None	8	14.5	18.9	16.0	15.8	1.3

for sodium and potassium, respectively. The mean calculated values of soluble-sodium percentage and sodium-adsorption ratio were 52 percent and 16, respectively.

Using the mean sodium adsorption ratio and mean electrical conductivity, the water was classified according to the chart given by the U.S. Salinity Laboratory Staff (1954). The chart shown in Appendix A yielded a classification of C4-S4. According to the U.S. Salinity Laboratory Staff (1954) the C4-S4 classification means that the water is very saline and very high in sodium and is unsatisfactory for irrigation purposes under almost all circumstances. The exception might be on a highly permeable soil which is well drained, used in conjunction with soil amendments such as gypsum and used on a highly salt tolerant crop.

The above analysis indicates that cattle feedlot runoff should be used as irrigation water with caution. Since the spray-runoff system is meant for regions where the soil is of low permeability and/or poorly drained, the soil properties should be monitored to ascertain that crop growth can be maintained over a long period of use.

Soil sampling was done prior to the application of the wastewater and again following the irrigation period. The results of the soil analysis are shown in Tables 21 and 22. The results were similar to what was anticipated after the application of the wastewater. Increases occurred for the following parameters; electrical conductivity of the soil saturation extract, cation exchange capacity, pH, exchangeable potassium, exchangeable sodium, soluble sodium, and exchangeable sodium percentage. Generally, the increases occurred at all depths sampled but were most abrupt in the top six inches of soil. The most significant changes were in the electrical conductivity and the exchangeable cations, sodium and potassium. The electrical conductivity of the top

Table 21. Soil Analysis of GI.

Depth (In.)	0-6		6-12		12-24	
Date Sampled	Spring	Fall	Spring	Fall	Spring	Fall
Cation Exchange Capacity (meq/100 gm)	22.9	25.2	18.7	24.0	24.2	25.5
Exchangeable Potassium (meq/100 gm)	2.3	8.0	1.2	3.9	0.7	0.8
Exchangeable Sodium (meq/100 gm)	0.5	0.9	0.5	0.4	0.9	1.2
Exchangeable Sodium Percentage (%)	2.0	3.6	3.0	1.8	3.5	4.8
Soluble Sodium (meq/100 gm)	0.3	1.1	0.3	1.0	0.5	0.3
Electrical Conductivity (mmhos/cm)	2.3	4.4	2.0	3.3	2.0	2.6
pH	6.7	7.6	6.4	7.1	6.4	6.7
NH_4 (PPM)	41	20	30	12	20	6
NO_3 (PPM)	72	24	74	13	85	39
Available Phosphorus (PPM)	244	246	82	99	30	35

Table 22. Soil Analysis of GII.

Depth (In.)	0-6		6-12		12-24	
Date Sampled	Spring	Fall	Spring	Fall	Spring	Fall
Cation Exchange Capacity (meq/100 gm)	25.2	26.8	23.6	26.4	24.9	27.6
Exchangeable Potassium (meq/100 gm)	2.9	9.6	1.3	5.3	1.1	2.4
Exchangeable Sodium (meq/100 gm)	0.6	1.3	0.6	1.3	0.7	0.9
Exchangeable Sodium Percentage (%)	2.2	4.7	2.5	4.7	2.7	3.3
Soluble Sodium (meq/100 gm)	0.4	0.6	0.3	0.4	0.2	0.2
Electrical Conductivity (mmhos/cm)	2.8	4.0	2.1	2.7	2.0	2.2
pH	6.6	7.7	6.3	7.2	6.5	6.6
NH_{4}(PPM)	53	20	40	12	21	9
NO_{3}(PPM)	93	34	70	8	75	13
Available Phosphorus (PPM)	329	300	188	104	132	43

six inches increased over 140 percent on both plots. Also, the exchangeable sodium and potassium doubled and tripled, respectively, in the top six inches on both plots.

According to the U.S. Salinity Laboratory Staff (1954), a soil is classified saline if the electrical conductivity exceeds four millimhos-per-centimeter. Only the top six inches of each plot could be considered saline. This indicates then that a serious salinity hazard has not developed after one year of irrigation with the runoff water but that over a number of years such a condition could develop. Leaching caused by precipitation between applica-periods and in the off season may prolong the time before a salinity hazard developes.

The exchangeable sodium percentage of the soil did not increase above five percent with the addition of the wastewater. The U.S. Salinity Laboratory Staff (1954) classifies an alkali soil as one have an exchangeable sodium percentage above 15 percent. This suggests then that a serious alkali hazard has not developed after one year of operation but again, application of the wastewater over a long period of time could lead to such a problem. It is also fair to mention that the effect of exchangeable potassium was not considered part of the alkali hazard since the true effects of potassium on soil properties are not well established. However, the accumulation of exchangeable potassium may have similar effects as exchangeable sodium and probably should be considered when evaluating the soil properties.

As mentioned above, increases were found in the cation exchange capacity and the soil pH. The cation exchange capacity probably increased because of the addition of organic material to the soil. The addition of wastewater with a pH of about 8.0 to the originally acid soil explains the rise in soil pH.

Soil nitrogen, in the forms of the ammonium and nitrate ions, decreased at least 50 percent during the test period. The author contributes the high initial values to the manure that had been applied to the plots prior to planting the grass. The nitrogen losses were probably due to nitrification, denitrification, plant use, and possibly by some leaching.

Polishing Pond and Soil Water Data

Problems were encountered when trying to evaluate the treatment results of the polishing pond. This was due mainly to the dilution caused by rainfall runoff. Since runoff information was not available on all rainfall events, the effect of dilution could not be evaluated. Therefore the sample data from the pond was inconclusive. This data is available in Appendix C.

Only four soil water samples were taken during the period of study. The results of the analysis of these samples are shown in Appendix B.

Discussion of Miscellaneous Observations

During Test 2, operational problems occurred when using the smaller nozzle. Plugging of the nozzles, caused by suspended solid material (usually dead water bugs), was a frequent occurrence. This suggests then that the larger nozzle would be a more practical size to use.

The cattle feedlot runoff appeared to be dark brown in color. By visual observation, there was little, if any, loss of color during the treatment process.

There appeared to be a small layer of biological growth on the surface of the soil. This was especially evident during Test 2. When the layer was allowed to dry, it would crack and roll up, exposing the surface of the soil. There were no microscopic examinations made of the surface layer.

Ponding occurred in a small depression on GI and also in the terrace channel of GII. Anaerobic conditions were probably prevalent in these areas and their occurrence might have decreased the effectiveness of the treatment area.

Odors produced during the spraying operation were not detected. The fact that the treatment field is adjacent to the feedlot and runoff holding ponds makes this a difficult parameter to evaluate.

CONCLUSIONS

1. Cattle feedlot runoff contains high concentrations of both oxygen demanding material and the nutrients, nitrogen and phosphorus. Treatment of the feedlot runoff was accomplished using the spray-runoff system but the system did not produce a satisfactory effluent for release to surface waters. Under the test conditions, there was no significant difference between the treatment results from the plots with one and two percent slopes at a 0.05 alpha level. The experiment was not designed adequately to compare the effects of loading rate on the treatment efficiency.
2. Mass removal of the pollution parameters is more encouraging. Removals as high as 90 percent of the applied BOD_5 and nitrogen can be accomplished.
3. Rainfall runoff from the treatment field carries polluted material. Although concentrations are considerably lower than the irrigation return flow, the rainfall runoff may not be of high enough quality for release.
4. Due to high salt and monovalent cation concentrations, the cattle feedlot runoff used in this study was classified unacceptable for normal irrigation purposes. Accumulations of salt, sodium, and potassium were found in the soil profile after 29 inches of the wastewater had been applied. However, no serious hazards had developed after the first year of operation.

5. No conclusive results were available from the polishing pond and soil water data.

SUMMARY

The expansion of the cattle feeding industry in the State of Kansas has been accompanied with an increase in the water pollution potential of open beef feedlots. The runoff caused by rainfall from an open feedlot contains high concentrations of organic and nutrient material. State regulations require that feedlots which have a water pollution potential must retain the surface runoff until it can either be disposed of or has been treated to sufficient quality for release. At the present state of the art, there are no economic or reliable waste treatment systems that will treat cattle feedlot runoff to the degree required for release. Therefore, land disposal by irrigation methods has been the prevalent method for handling the liquid wastes. Due to high salt and monovalent cation concentrations, the practice of disposing cattle feedlot runoff onto the land should be approached with caution. Also in areas of high rainfall and heavy soils, land disposal may not be a practical solution. The purpose of the research reported in this thesis was to evaluate an alternative, the spray-runoff system, to the present land disposal practices.

Spray-runoff systems have been successfully applied to treating wastes from fruit and vegetable processing plants. The spray-runoff method is a special case of sprinkler irrigation disposal systems. The general principle is to apply the wastewater at the top of a uniform grassed slope by sprinkler nozzles at a rate such that a high percent returns as overland flow. Masses of biological organisms develop in the wetted grass and soil areas. Since the biological organisms utilize certain impurities in the water as a food and energy source, the water is treated as it flows over the grass slopes. The principle is similar to that which occurs in a trickling filter system. The treated water is then carried off the field by terrace channels and either released or recycled depending upon the degree of treatment desired.

An experimental spray-runoff system was installed at a 22,000 head feedlot in south central Kansas. The 10.9 acre treatment field contained four sprinkler laterals on which 100 foot spray diameter sprinkler heads were installed. Two parallel terraces spaced on about 200 foot centers were constructed to carry the water between laterals off the field. Two plots were used for experimental study. The land slopes of the 1.6 and 3.6 acre plots were one and two percent, respectively. The loam soil was seeded to a grass mixture of Reed canarygrass and tall fescue. Flow measuring and sampling equipment were installed so that both quantity and quality of the applied wastewater and the runoff water could be evaluated. Two different instantaneous loading rates were used, 0.04 and 0.08 inches per hour. The system was operated during the summer and early fall of 1972 with a weekly loading rate of two inches.

Concentration reductions ranged from 27 to 60 percent for BOD_5, 29 to 44 percent for Kjeldahl nitrogen, and 35 to 49 percent for ammonia nitrogen. No significant differences in treatment were found between the two test plots. Physical limitations on the experimental design did not allow for a good comparison between loading rates. The field effluent was not of high enough quality for direct release under any of the test conditions. During the total season, only 25 to 27 percent of the applied wastewater ran off. Due to the low runoff percentage, mass removal percentages ranged from 77 to 97, 74 to 90, and 81 to 90 for BOD_5, Kjeldahl nitrogen, and ammonia nitrogen, respectively. The rainfall runoff from the treatment field also contained considerable amounts of pollution causing material and was of questionable quality for release to surface waters. After application of 29 inches of the wastewater to the treatment field, accumulations of salt, sodium and potassium were found in the soil profile. However, only the top six inches of the soil on both plots were classified as saline and neither of the plots developed alkali conditions after the first season of operation. Further study will be required to determine if crop growth can be maintained under the operating conditions used.

SUGGESTIONS FOR FUTURE RESEARCH

Although the spray-runoff system did not produce a satisfactory effluent for direct release to surface waters, the system would be a valuable alternative for handling cattle feedlot runoff if the treatment efficiency could be increased. There are many unanswered questions on how the system should be designed and operated to increase the treatment efficiency and how this information could be utilized in areas of different soil and hydrologic conditions. Therefore, the author feels that future study should be made on the topics listed below.

1. Methods for increasing the treatment efficiency should be studied. Possible alternatives include increasing the length of flow, recycling the effluent, and finding some optimum operating schedule.
2. Mathematical formulas which could predict effluent quality under certain design and operating conditions would be helpful. These should contain sufficient information so that they could be used in areas with different soil and hydrologic conditions. A more detailed study of the hydrology of the system may be required for this.
3. Continued study of the soil chemical and physical properties should be done to determine if crop growth can be maintained after several years

of operation. The changes in the soil properties may also influence the hydrology of the system.

4. A more detailed study should be made of the soil water to establish if groundwater pollution is being avoided.

5. More work should be done to determine the merits of a polishing pond for further treatment and how such a pond should be designed.

6. Biological investigations of the treatment area may be important to determine what type of treatment is taking place. Information of this type may be important to consider when trying to improve the treatment efficiency of the system.

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APPENDICES

APPENDIX A

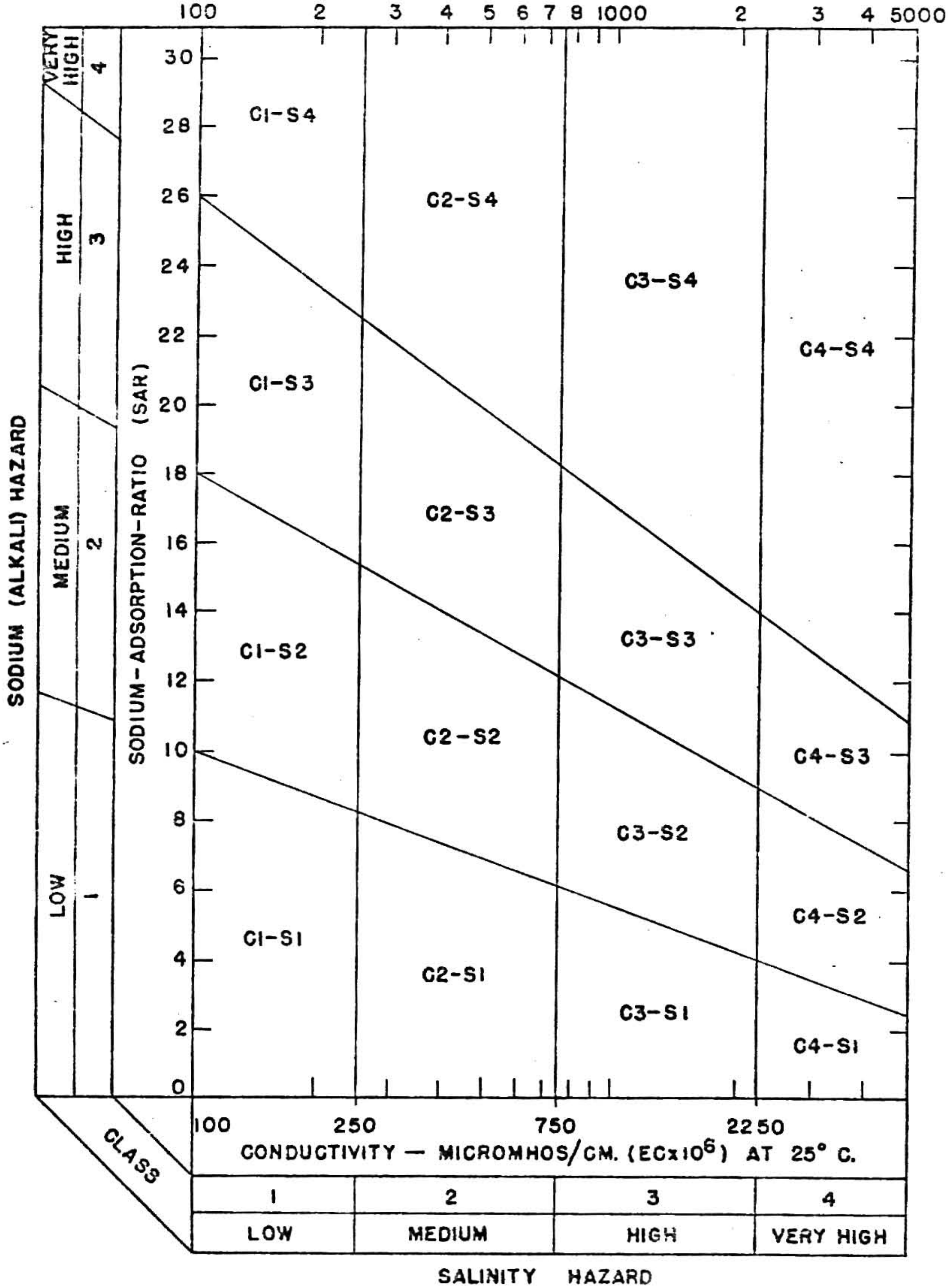

Figure 7. Irrigation water classification chart.

APPENDIX B

SOIL WATER DATA

Parameter	Average Values for Each Sampling Event*
COD (mg/l.)	345
	804
	866
	631
BOD_5 (mg/l.)	66
	99
Kjeldahl-N (mg/l.)	25
	21

*Samples from each plot were combined.

APPENDIX C

POLISHING POND DATA

DATE	COD	BOD	TS	PVS	T-P	T-N	NH_3
6-16	1055		3570	34	48	425	114
6-23	1161		3880	40	50	459	84
6-30	1455		4287	37	51	364	70.2
7-13	1215	58.5	3922	35	46.8	102.8	46.7
7-20	1396	115	3744	40	62.4	83.0	45.3
8-30	588	51	2387	34	30.0	38.4	25.5
9-12	1496	112	4002	34	60.4	82.8	22.8
9-26		163			84.0		

TREATMENT AND DISPOSAL OF CATTLE FEEDLOT RUNOFF USING A SPRAY-RUNOFF IRRIGATION SYSTEM

by

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The water pollution caused by stormwater runoff from cattle feedlots is of high concern. To reduce this pollution, regulatory agencies require that detention facilities be built to retain the runoff from entering surface waters. Although disposal onto the land by irrigation methods have been the prevalent practice for removing stored water from the detention ponds, this scheme is not applicable under all circumstances. An experimental study was made to examine the spray-runoff technique as a possible alternative to the present disposal practices.

The spray-runoff method is a special adaption of sprinkler irrigation. These systems have been successfully applied to treating wastewaters from fruit and vegetable processing plants. Sprinkler nozzles are used to apply the wastewater at the top of a uniform grassed slope. The rate of application is higher than the intake rate of the soil so that some of the applied water runs off. As the water passes through the grass and soil areas, mass of biological organisms develop. These microorganisms utilize the impurities in the water as a food and energy source, and in turn, reduce the pollution potential of the water. The water is carried off the field by terrace channels and either released or recycled depending upon the degree of treatment desired.

An experimental 10.9 acre spray-runoff system was installed at a feedlot in south central Kansas. Forty-five sprinkler heads with a 100-foot spray pattern were used to apply cattle feedlot runoff to the treatment field. The land slope varied from one to three percent. The field was seeded with a Reed canary and tall fescue grass mixture. Parallel terraces spaced on 200-foot centers were constructed on the field. Two inches of wastewater were applied per week during the summer and early fall of 1972.

Experimental results indicated that treatment did take place on the field slopes but the effluent from the system was not of high enough quality for release. Concentration reductions were approximately 50 percent for BOD_5 and Kjeldahl nitrogen under the most favorable conditions. Less than 30 percent of the applied wastewater ran off of the treatment area. Due to the low runoff percentage, mass reductions of the pollution parameters were in the range from 75 to 90 percent. Stormwater runoff from the treatment area also carried pollutants and was of questionable quality for release to a stream. After 29 inches of the wastewater had been applied, accumulations of salt, sodium and potassium were found in the soil profile.