Manure and Wastewater Management Systems for Open Lot Dairy Operations

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Abstract. *Dairy industry expansion using open lot designs has impacted water quality and groundwater usage in parts of Central Texas. Field research was conducted at commercial dairy farms in Erath County, Texas, to develop improved design criteria for storage, treatment, and land application systems for open lot dairies. Water use and wastewater from milking parlors were monitored along with rainfall runoff from open lots. Water use for milk sanitation and manure removal averaged 148 L per cow per day. Two-stage anaerobic lagoon systems achieved higher solids and nutrient removal efficiencies than a combination of settling basin and one-stage anaerobic lagoons. The two-stage anaerobic lagoon system with 81- to 118-day hydraulic retention time reduced concentrations of volatile solids (VS), chemical oxygen demand (COD), and total kjeldahl nitrogen (TKN) in dairy wastewater from milking parlors by 80 to 82%, 90 to 93% and 55 to 73%, respectively. Solids settling basins reduced VS, COD, and TKN concentrations in wastewater by 35 to 45%, 27 to 47%, and 14 to 24%, respectively. As compared to second-stage lagoon effluent, open lot runoff was higher in K, but similar in TKN and P concentrations and contained a greater proportion of fixed solids. Analysis showed that anaerobic lagoon effluent and open lot runoff were good sources of available plant nutrients.*
Keywords. *Livestock waste, Water quality, Lagoons, Pollution control, Effluent.*

Expansion of the dairy industry has occurred in Texas, New Mexico, Oklahoma, and other states in the South Central United States during the 1980s and thus far into the 1990s. This area has historically had many small dairy farms with sufficient land to maintain low animal densities on pastures except during milking. Several trends are evident with this expansion: large herd sizes with dairies over 500 head are now commonplace; an influx of dairy operators from California, Arizona, the Netherlands, and other areas; increasing water use for sanitation and manure removal; and use of an open lot dairy concept.

Production of dairy cattle in open lots or corrals has been a common practice in the desert Southwest, where evaporation minus rainfall (i.e., moisture deficit) is 1300 to 1500 mm (50 to 60 in.) or more per year. This concept readily fits into the arid climatic conditions of west Texas and Eastern New Mexico where open lot cattle feedlots and dairies have been operated successfully for decades. Welchert et al. (1990) described several types of waste management systems utilized by open lot dairies.

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However, use of open lot dairies in higher rainfall regions such as Central or East Texas (for example) without adequate design compensation for higher moisture conditions can result in problems caused by higher runoff volumes and chronic mud conditions especially in above-average rainfall periods. For instance, the 25-year, 24-h rainfall event in north central Texas near Stephenville-Dublin is 185 to 190 mm (7.3 to 7.5 in.) per 24-h period, about twice the value near El Paso, Texas-Las Cruces, New Mexico. Using procedures of Phillips (1981), which takes into account antecedent surface moisture conditions, it can be predicted that an unpaved lot in North Central Texas will yield about 230 mm (9 in.) of runoff per year as compared to just 38 mm (1.5 in.) in the El Paso-Las Cruces area for the same open lot surface area. In Northeast Texas, Arkansas, and Louisiana, the predicted annual runoff is about 380 mm (15 in.) per year—10 times greater than the El Paso area.

Moisture excreted with manure can be a major factor in open lot management where moisture deficit approaches zero. Moisture excretion rates from a 635 kg (1400 lb) dairy cow amounts to about 0.17 ha-mm (0.165 acre-in.) per year, which equates to an effective precipitation rate of 305 mm (12 in.) per year on an open lot surface with a stocking density of 56 m^2 (600 ft^2) per head (fig. 1) (ASAE, 1988). Attempts to compensate for low moisture deficit by increasing lot size will increase runoff volume and yield marginal benefit in terms of reduced effective precipitation (fig. 1). Hence in higher rainfall/humid areas, other types of dairy practices including pasture operations and free stall barns are preferable to open lots.

Objectives and Scope

A number of interagency research and demonstration projects have been initiated since 1988 in response to the

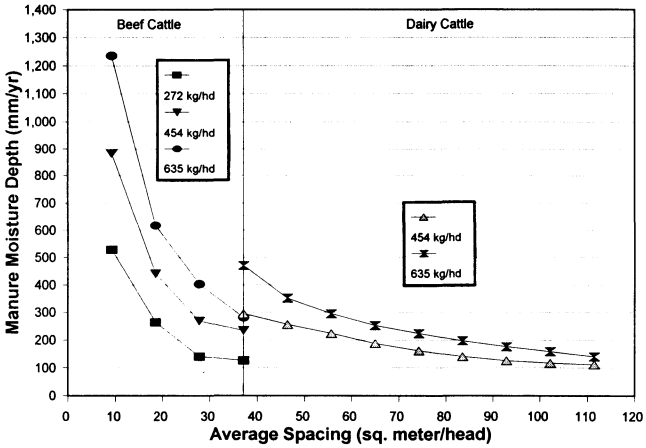

Figure 1–Calculated moisture production in manure from dairy and beef cattle in open lots as function of live body weight and animal spacing (values calculated from ASAE, 1988).

concerns about water quality degradation due to open lot dairies. A common goal of these projects is to obtain and disseminate data and information related to the design and evaluation of dairy waste management practices. The results of these studies will aid producers, engineers, planners, and regulatory officials in the refinement and adoption of appropriate practices for water quality protection.

The specific objectives of the project as reported in this article were to:

- Determine the water use for sanitation, manure management, and cow watering at typical dairy farms in Erath County, Texas, in order to improve design criteria for water supply and wastewater management systems and supply input data for any future groundwater management policy for the region.
- Provide design information and guidelines for wastewater management systems for storage, treatment, and land application of manure and wastewater from the milking center and feeding lanes.
- Identify and evaluate best management practices for land disposal of dairy manure and wastewater.

The equipment and procedures used to achieve these objectives and the data obtained are described in the following sections.

Equipment and Procedures

Description of Dairy Facilities: Wastewater and Runoff Monitoring

Wastewater quality data were collected at three dairy farms in Erath County in North Central Texas during 1989-1991. The dairies were typical of dairies being built in Texas, New Mexico, Oklahoma, and elsewhere in the South Central United States. The dairies ranged in size from 280 to 850 cows (Holsteins) in the milking herd. The primary sources of wastewater at these three dairies were: milking parlor, milking equipment, milk storage tank, cattle holding (or drip) shed, open lots or corrals, traffic lanes, feeding lanes or bunks, and working alleys or chutes. Shades were provided in the dairy corrals. In each case, liquid manure and wastewater from the milking facility were collected in holding ponds and lagoons, and irrigation systems were utilized for disposal. Runoff from open lots was collected either in separate detention ponds (Dairies A and J) or in the wastewater treatment/storage lagoons (Dairy B). Dairy B utilized concrete settling basins for partial removal of settleable solids. Solid manure was collected by tractor-mounted scrapers and spread on pasture or cropland, either on-site or off-site, without stockpiling at the dairies. The experimental equipment and procedures for each dairy are described in the project completion report (Sweeten and Wolfe, 1993). The sampling and analytical procedures were conducted according to an EPA and state approved quality assurance/quality control plan (Sweeten et al., 1991).

Dairy A. A 375-cow dairy with an average of 281 cows in milking herd; primary and second stage anaerobic lagoons 4900 and 3100 m^3 (172,000 and 108,000 ft^3), respectively; tertiary lagoon 21 500 m^3 (759,000 ft^3) for open lot runoff and lagoon effluent storage; cattle sprinkler pre-washers in holding/drip shed; manual wash and flushing of milking parlor.

The milking and dry cattle were fed in open lots with two watersheds established for monitoring runoff 1.0 and 1.6 ha (2.5 and 4.0 acre) using 0.46 and 0.61 m (1.5 and 2.0 ft) type-H flumes equipped with Stevens type-F stage recorders and ISCO model 2900 discrete water samplers. In-line water meters 38 and 51 mm (1.5 and 2.0 in.) were installed to measure water usage for the milking parlor including the flush system, the sprinkler cow washer system, and the cattle drinking water.

Dairy B. A 950-cow open lot dairy on 65 ha (160 acre) and with cows manually washed following pre-rinsing with a sprinkler cow-washer system in the holding shed; milking herd size of 650 to 850 cows. Wastewater from a plate cooler, vacuum pump, and milking equipment was collected in a sump and was recycled through the cow pre-wash and the flush system. Concrete feeding alleys were flushed at the start of the study, but then were tractor-scraped to conserve water and preserve lagoon capacity. Monitoring systems were installed on Dairy B to evaluate wastewater production and quality (type-H flume and automatic sampler), open lot runoff (two type-H flumes and samplers), and water consumption (eight water meters).

Liquid manure and wastewater from the milking parlor were routed by gravity flow into a 0.67 m (2.2 ft) deep dual-chambered concrete settling basin with 10:1 ramps on each end. The East Chamber was 5.5 × 14.6 m (18 ft × 48 ft); the West Chamber was 9.1 × 18.3 m (30 ft × 60 ft) and decanted through slotted plank outlet and perforated 200 mm (8 in.) diameter corrugated plastic riser into the primary lagoon/holding pond. Wastewater and runoff collected in the two lagoons were irrigated onto 48 ha (120 acre) of coastal bermudagrass pasture with a sandy loam soil.

Open lots covered 6.5 ha (16 acre) including feeding and cattle alleys and shade structures. Runoff flowed through the settling basin into the primary lagoon/holding pond 22 800 m^3 (806,000 ft^3) capacity, and any overflow entered a second holding pond 10 200 m^3 (362,000 ft^3) liquid capacity. A separate settling basin collected runoff from the two north dry lots, with supernatant drained through a perforated riser pipe entered the second holding pond. Runoff from three dry lots (south side) did not enter a settling basin, but rather discharged directly into the primary lagoon/detention pond.

Dairy J. Double eight-stall milking facility for an average herd of 540 milking Holstein cows with flush and sprinkler pre-washer systems that used fresh water. Total area of open lots was 5.3 ha (13 acre) or 103 m^2 (1100 ft^2) per head, including alleys and intermittent-use utility pens and pastureland occupied 65.2 ha (161 acre).

Monitoring systems used for demonstration and evaluation were located on this dairy to evaluate water consumption (three in-line meters), wastewater production and quality (type-H flume and automatic sampler), and open lot runoff (one type-H flume and sampler).

Wastewater from the milking barn and holding pen flowed by gravity into the primary lagoon [liquid volume of 6800 m^3 (240,000 ft^3)]. A second-stage lagoon of 8500 m^3 (300,000 ft^3) liquid capacity was designed by SCS in connection with obtaining a TWC permit and was installed during the last year of the study (TWC, 1987). The second-stage lagoon collected direct overflow from the primary lagoon and provided storage, further treatment, and a pumping station for land application by irrigation. The drainage area for the runoff monitoring flume was 1.25 ha (3.06 acre).

Water Use on Dairy Farms

Eleven dairy farms in Erath County within the Upper North Bosque River Watershed were selected for involvement in the water use study from November 1989 through the spring of 1992. The 11 dairy farms (which included Dairies A, B, and J) ranged in size from 150 to 1,300 cows in the milking herds. Ten of these dairies represented open lot confinement facilities typical of new and expanding dairies in North Central and West Texas, and one of the dairy farms (Dairy E) utilized free-stall barn facilities for the milking herd, with dry cows and heifers kept in open lots. The dairies are described further in Sweeten and Wolfe (1993).

Thirty-nine brass water meters, 38, 51, and 76 mm (1.5, 2.0, and 3.0 in.) in size, were installed on water supply pipe lines to directly measure the water use in the milking barns and, in many cases, the cattle corrals on the 11 dairies.

The main indicator of water use was liters (gallons) per cow per day in the milking herd. This was computed by dividing the incremental water use between weekly or semi-weekly meter readings by the product of the average number of cows milked and the number of days (i.e., 24-h time periods) since the preceding meter readings.

Results and Discussion

Milking Parlor Wastewater, Settling Basins, and Lagoons

The data sets from wastewater and runoff monitoring obtained from this study were unique for each of the three dairies. The data set for Dairy A covered the longest continuous time period (18 January 1989 to 19 August 1991). The data for Dairy B illustrated the effects of operational changes at the dairy during the sampling period (30 June 1989 to 27 August 1991). Analytical results for Dairy J encompassed the period 21 February 1990 to 19 August 1991. The results for each dairy are discussed below, with data summarized in tabular form for all analyzed constituents and discussed in more depth for seven important parameters: total solids (TS), volatile solids (VS), volatile suspended (nonfilterable) solids (VSS), chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), phosphorus (P), and electrical conductivity (EC).

Dairy A. Primary and Second-stage Lagoons. For purposes of estimating manure production that would enter the primary lagoon at Dairy A, the adjusted cow liveweight was approximately 29 000 kg (63,000 lb), assuming 612 kg (1350 lb) liveweight per cow and 4-h per cow-day in the confinement buildings. Using the TAEX MANURE Worksheets (Sweeten et al., 1989), a theoretical amount of volatile solids entering the primary lagoon was calculated as 309 kg (680 lb) per day based on ASAE (1988) standard manure production values for the mean plus one standard deviation. Unit volumes of the primary and secondary lagoons (liquid operating volume per unit of cow liveweight) were approximately 0.17 and 0.10 m^3/kg (2.7 and 1.7 ft^3/lb). The estimated theoretical volatile solids loading rate in the primary lagoon was 0.063 $kg/day/m^3$ (0.0040 $lb/day/ft^3$) which is at the upper end of the range recommended by the Texas Agricultural Extension Service.

Mean concentrations of constituents in the milking parlor wastewater, the primary lagoon effluent, and the second-stage lagoon effluent for a 31-month period (42 to 48 sampling events) are shown for Dairy A in table 1. The average of 281 cows were in the milking herd during the monitoring period. Volatile solids concentrations decreased from 3444 ± 1961 mg/L in the milking parlor wastewater to 966 ± 551 mg/L in the primary lagoon effluent and 681 ± 332 mg/L in the second-stage lagoon effluent that was applied to coastal bermudagrass pasture. Total suspended solids (TSS) constituted 52.0% of the total solids. Volatile suspended solids (VSS) were 2,017 ±

Table 1. Concentrations of milking parlor wastewater and lagoon effluent, Dairy A, Erath County, Tex., 1/18/89 to 8/19/91

		Milking Parlor, n = 48		Primary Lagoon Effuent, n = 42		Second-Stage Lagoon Effuent, n = 45	
Constituent	Units	Avg	S.D.	Avg	S.D.	Avg	S.D.
Total solids	(mg/L)	5541	2903	2088	960	1644	381
Fixed solids	(mg/L)	2096	1289	1123	441	963	140
Volatile solids	(mg/L)	3444	1961	966	551	681	332
Filt. solids	(mg/L)	2474	1827	1294	304	1196	154
Filt. fixed solids	(mg/L)	1221	903	789	165	774	112
Filt. volatile solids	(mg/L)	1248	988	505	205	423	105
Total susp. solids	(mg/L)	2884	1716	839	858	480	370
Susp. fixed solids	(mg/L)	870	848	347	470	204	138
Susp. volatile solids	(mg/L)	2017	1370	501	427	278	346
COD	(mg/L)	6397	4444	1480	1497	650	243
Nitrogen	(mg/L)	259.8	383.0	171.7	27.1	117.3	42.4
Nitrate	(mg/L)	0.6	0.7	1.6	4.5	4.7	14.5
Ammonium	(mg/L)	248.1	368.1	161.4	24.8	116.5	25.6
Organic	(mg/L)	24.2	22.9	9.9	7.5	6.3	2.9
Phosphorus	(mg/L)	85	172	53	94	39	79
Potassium	(mg/L)	435	943	288	559	285	549
Calcium	(mg/L)	238	342	178	313	144	271
Magnesium	(mg/L)	98.5	168	97.1	194.1	93.4	183.4
Sodium	(mg/L)	193	398	149	302	146	282
Manganese	(mg/L)	2.87	10.21	0.67	0.88	0.41	0.55
Chloride	(mg/L)	258	173	158	81	149	66
Iron	(mg/L)	12.4	19.6	3.2	3.9	2.1	2.9
pH		7.22	0.60	7.56	0.63	7.84	0.31
Salinity Data:							
EC, Elec. Cond.	(dS/m)	3.70	3.22	2.82	0.46	2.42	0.38
SAR*		2.36	1.81	1.97	1.20	2.09	1.14
SSP†		20.90	6.11	20.70	2.60	21.94	1.96

* SAR – Sodium absorption ratio.
† SSP – Soluble sodium percentage.

1370 mg/L (or 36.4% of total solids) and decreased to only 278 ± 346 mg/L in the second-stage lagoon effluent. The chemical oxygen demand (COD) decreased from 6397 ± 4,444 mg/L in milking parlor wastewater to 1480 ± 1,497 mg/L in primary lagoon effluent, and to just 650 ± 243 mg/L in second-stage lagoon effluent. The concentrations of these parameters varied between sampling dates, especially with the milking parlor wastewater.

The ratio of COD to TS, a measure of digestion (treatment) efficiency, decreased from 1.15 in the raw wastewater to 0.71 and 0.40 in the primary and second-stage lagoon effluent, respectively. The digestion of volatile solids was evident in the decreased VS/TS ratio from 0.62 in the raw wastewater to 0.46 and 0.41 in the primary and second-stage lagoon effluent, respectively.

The primary anaerobic lagoon produced excellent reductions in concentrations of TS (62.3%), VS (72.0%), suspended volatile solids (75.2%), and COD (76.9%) as shown in table 2. The second-stage lagoon provided lower reduction efficiencies than the primary lagoon for these parameters, but was nevertheless effective. Overall concentration reductions, due to both lagoons as compared to the raw wastewater, were: TS (70.3%), VS (80.2%), VSS (86.2%), and COD (89.8%).

Table 2. Dairy A, concentration reductions (%) in wastewater from milking parlor through primary and second-stage lagoon system, 1/18/89 to 8/19/91

Constituent	Primary Lagoon Treatment, MP-PL* (%)	Second-Stage Lagoon Treatment, PL-SL* (%)	Overall Two-Stage Lagoon System, MP-SL* (%)
Total solids	62.3	21.3	70.3
Fixed solids	46.4	14.2	54.1
Volatile solids	72.0	29.5	80.2
Filt. solids	47.7	7.6	51.6
Filt. fixed solids	35.4	2.0	36.7
Filt. volatile solids	59.5	16.3	66.1
Total susp. solids	70.9	42.8	83.4
Susp. fixed solids	60.2	41.1	76.5
Susp. volatile solids	75.2	44.5	86.2
COD	76.9	56.1	89.8
Nitrogen	33.9	31.7	54.9
Nitrate	–162.7	–201.9	–693.3
Ammonium	35.0	27.8	53.0
Organic	59.1	36.7	74.1
Phosphorus	38.1	25.7	54.1
Potassium	33.9	1.0	34.5
Calcium	25.4	19.0	39.5
Magnesium	1.4	3.8	5.2
Sodium	22.9	1.7	24.2
Manganese	76.5	39.5	85.8
Chloride	38.8	6.0	42.5
Iron	74.2	33.8	82.9
pH	–4.7	–3.8	–8.7
Salinity Data:			
EC, Elec. Cond.	23.8	14.1	34.6
SAR†	16.4	–6.1	11.3
SSP‡	1.0	–6.0	–5.0

* Percent reductions were computed as follows:
MP-PL – (milking parlor concentration minus primary lagoon effluent concentration) divided by milking parlor concentration.
PL-SL – (primary lagoon effluent concentration minus second-stage lagoon effluent concentration) divided by primary lagoon effluent concentration.
MP-SL – (milking parlor concentration minus second-stage lagoon effluent concentration) divided by milking parlor concentration.
† SAR – Sodium absorption ratio.
‡ SSP – Soluble sodium percentage.

Overall nutrient reductions through the two-stage lagoon system were large, with N, P, and K losses of 54.9, 54.1, and 34.5%, respectively (table 2). Higher nutrient losses occurred in the primary lagoon than in the second-stage lagoon. Most of the TKN (94% or more), throughout the system, was in the ammonium form (table 1). The mean concentrations of nutrients from the second-stage lagoon effluent were 117 ± 42 mg/L total N, 39 ± 79 mg/L total P, and 285 ± 549 mg/L total K (table 1).

The EC values averaged 2.82 ± 0.46 dS/m and 2.42 ± 0.38 dS/m in primary and second-stage lagoon effluent, respectively. These EC values were due mainly to the presence of ionic forms of plant nutrients as opposed to sodium and chloride, which typically cause soil salinity problems of irrigation waters. There did not appear to be a sodium hazard with land application of this lagoon effluent.

Seasonal variation of the constituent concentrations is important, especially for planning irrigations with the second-stage lagoon effluent. For the primary lagoon effluent, there were statistically significant differences in mean concentrations of TS, VS, VSS, TKN, and EC due to season. The concentration of TKN was significantly different (greater) during the winter as compared to the fall and spring. The concentrations of TS, VS, VSS, and EC were significantly greater during the spring than during the summer.

The mean seasonal TKN concentration of the second-stage lagoon effluent varied from 80.4 mg/L (summer) to 145.5 mg/L (winter) which is equivalent to 0.080 to 0.146 kg/m^3 (18 to 33 lb/acre-in.). Thus, if a crop required a total nitrogen application of 225 kg N/ha (200 lb N/acre), approximately 150 to 280 mm (6.1 to 11.0 in.) of effluent could be irrigated onto the crop annually. The lower concentrations occurred in the spring, summer, and fall when irrigation is most commonly practiced.

Sludge accumulation in the primary lagoon was measured at 17 locations using a hollow calibrated rod from a rowboat to determine (a) total liquid depth (pointed end) and (b) sludge depth (flat disk end). The maximum liquid depth was 4.27 m (14.0 ft) and the average liquid depth was 2.0 ± 1.24 m (6.65 ± 4.07 ft). The measured depth of sludge was surprisingly low, ranging from 0 to 0.61 m (0 to 2.0 ft) and averaging 0.29 ± 0.14 m (0.94 ± 0.46 ft). Hence, 14% of the lagoon depth was occupied by sludge. Projecting this average sludge depth across the lagoon bottom area indicates the lagoon was only 12% full of sludge (600 m^3 or 24,000 ft^3) after 12 years of operation without sludge removal or pumping from the primary lagoon, which shows very high solids digestion efficiency of this mature lagoon. The apparent rate of sludge accumulation was approximately 0.18 m^3 (6.3 ft^3) per cow per year, which is much lower than indicated in ASAE (1991) design standards for anaerobic lagoons.

Dairy B. Settling Basin and Primary Lagoon. Initially, wastewater from the milking parlor was discharged down a feeding alley for flushing purposes and then into the primary lagoon. The two-chambered settling basin became operational in October 1989. At the end of January 1990, Dairy B instituted a water conservation and recycling system, which reduced its fresh water use by 68%. There was a change in mass loading from the milking parlor wastewater as well in that concrete aprons behind the feed alley with head lock stanchions that were flushed were now scraped, thus keeping manure solids and spilled feed out of the settling basin and primary lagoon. The effects of these changes on the milking parlor wastewater concentrations and the primary lagoon were evident in the primary lagoon monitoring results Sweeten and Wolfe (1993). After about April, 1990, the concentrations of constituents in the lagoon returned to lower values and remained there. From both outward appearances and sampling results, it appears that the lagoon adjusted to the reduced hydraulic and organic (volatile solids) loading.

Concentrations of constituents in the milking parlor wastewater, settling basin, and effluent from the primary lagoon from 10 May 1990 to 27 August 1991 are summarized in table 3 for 35, 25, and 31 sampling events, respectively.

Volatile solids concentrations decreased from 4775 ± 4001 mg/L in the milking parlor wastewater to 3111 ± 1712 mg/L in the settling basin outflow and to 2999 ± 2680 mg/L in the primary lagoon supernatant. Similarly, the COD decreased from 8363 ± 6215 mg/L in the milking parlor wastewater to 6086 ± 4004 mg/L in the settling basin outflow and to 5467 ± 4971 mg/L in the primary lagoon. Total Kjeldahl nitrogen was reduced from 403 ± 419 mg/L in milking parlor wastewater to 305 ± 114 mg/L in settling basin outflow and to 282 ± 106 mg/L in the primary lagoon supernatant. Total phosphorus and potassium remained about constant at 54 to 58 mg/L and 372 to 401 mg/L, respectively, through the system. Electrical conductivity decreased slightly from 4.74 ± 3.39 dS/m in milking parlor wastewater to 4.29 ± 1.19 dS/m in settling basin outflow and to 4.14 ± 1.16 dS/m in lagoon supernatant. Concentrations of TS, VS, COD, VSS, TKN, and EC in milking parlor wastewater and lagoon supernatant were higher at Dairy B than at Dairy A.

Table 3. Summary of concentrations of milking parlor wastewater and lagoon supernatant, Erath County, Tex., Dairy B, 5/10/90 to 8/27/91

		Milking Center, n = 35		Settling Basin Outflow, n = 25		Primary Lagoon Supernatant, n = 31	
Constituent	Units	Avg	S.D.	Avg	S.D.	Avg	S.D.
Total solids	(mg/L)	7065	5185	5127	2852	5068	3563
Fixed solids	(mg/L)	2290	1380	2016	1232	2069	1114
Volatile solids	(mg/L)	4775	4001	3111	1712	2999	2680
Filt. solids	(mg/L)	3212	2096	29S0	853	2735	780
Filt. fixed solids	(mg/L)	1510	1030	1358	411	1377	453
Filt. volatile solids	(mg/L)	1699	1097	1592	489	1358	457
Total susp. solids	(mg/L)	3817	4149	2179	2576	2333	3163
Susp. fixed solids	(mg/L)	794	763	659	1144	692	853
Susp. volatile solids	(mg/L)	3068	3449	1506	1505	1687	2411
COD	(mg/L)	8363	6215	6086	4004	5467	4971
Nitrogen	(mg/L)	403	419	305	114	282	106
Nitrate	(mg/L)	0.74	1.9	0.3	0.3	1.0	2.4
Ammonium	(mg/L)	356	421	305	105	267	106
Organic	(mg/L)	35	39	27	14	22	11
Phosphorus	(mg/L)	54	35	58	36	55	28
Potassium	(mg/L)	401	281	372	111	398	148
Calcium	(mg/L)	215	106	227	181	203	128
Magnesium	(mg/L)	89	29	98	30	89	20
Sodium	(mg/L)	154	101	132	35	136	44
Manganese	(mg/L)	1.25	0.82	1.2	0.7	1.1	0.8
Chloride	(mg/L)	132	84	177	37	135	52
Iron	(mg/L)	7	4	11	27	17	62
pH		8.07	0.3	7.6	0.4	7.7	0
Salinity Data:							
EC, Elec. Cond.	(dS/m)	4.74	3.39	4.29	1.19	4.14	1.16
Total cations	(mg/L)	853	513	931	126	795	129
Total anions	(mg/L)	3226	3310	3070	988	2676	677
Total salts	(mg/L)	4079	3806	4001	1059	3304	1121
SAR*		2.3	1.3	2.0	0.4	2.1	0.4
SSP†		19.7	3.4	16.2	3.8	19.3	2.4

* SAR = Sodium absorption ratio.
† SSP = Soluble sodium percentage.

Computed concentration reductions due to the settling basin and primary lagoon (table 4) indicated that the concentrations of TS decreased by 27.4%, VS decreased by 34.9%, VSS by 50.9%, COD by 27.2%, and TKN by 24.3% through the settling basin. Sampling problems may have contributed to very low apparent concentration reductions in the primary lagoon. On most sampling dates, it was not feasible to sample the primary lagoon effluent overflow due to low flow conditions. On those occasions, the primary lagoon contents (supernatant) were sampled. The reductions listed in the last column of table 4 show the efficiency of the overall system (settling basin and primary lagoon) to be 28.3% for TS, 37.2% for VS, 45.0% for VSS, 34.6% for COD, and 29.9% for TKN.

The ratio of COD to TS decreased slightly from the raw wastewater (1.18) to the primary lagoon effluent (1.08) (table 3). Some settling or digestion of VS was evident in the decreased VS/TS ratio from 0.68 in the raw wastewater to 0.59 in the primary lagoon effluent.

High peak efficiencies that can be obtained from a properly designed and operated settling basin are illustrated by data from two consecutive sampling dates in May 1991, when it was evident from rainfall records that runoff was not causing any interference. The average concentrations reductions outflow versus inflow for these two dates were

Table 4. Wastewater and lagoon effluent reductions, Dairy B, 5/10/90 to 8/27/91

Constituent	Settling Basin Treatment, MP-SB* (%)	Primary Lagoon Treatment, SB-PL* (%)	Overall System MP-PL* (%)
Total solids	27.43	1.16	28.27
Fixed solids	11.96	−2.60	9.67
Volatile solids	34.85	3.59	37.19
Filt. solids	8.15	7.30	14.86
Filt. fixed solids	10.08	−1.39	8.82
Filt. volatile solids	6.30	14.71	20.09
Total susp. solids	42.92	−7.09	38.87
Susp. fixed solids	17.08	−5.10	12.86
Volatile susp. solids	50.90	−11.95	45.03
COD	27.22	10.18	34.63
Nitrogen	24.31	7.34	29.87
Nitrate	63.83	−272.96	−34.91
Ammonium	14.31	12.69	25.18
Organic	20.66	21.42	37.66
Phosphorus	−6.11	4.28	−1.57
Potassium	7.15	−7.02	0.63
Calcium	−5.43	10.85	6.00
Magnesium	−10.29	9.11	−0.25
Sodium	13.99	−3.18	11.25
Manganese	8.39	6.15	14.03
Chloride	−34.28	23.76	−2.37
Iron	−55.38	−56.60	−143.32
pH	6.49	−1.56	5.03
Salinity Data:			
EC, Elec. Cond.	9.61	3.55	12.81
SAR†	15.01	−6.79	9.23

* Percent reductions were computed as follows:
MP-SB = (milking parlor concentration minus settling basin concentration) divided by milking parlor concentration.
SB-PL = (settling basin concentration minus primary lagoon concentration) divided by settling basin concentration.
MP-PL = (milking parlor concentration minus primary lagoon concentration) divided by milking parlor concentration.
† SAR = Sodium absorption ratio.

as follows: TS = 80%, VS = 82%, VSS = 92%, COD = 81%, TKN = 81%, and P = 37%.

Dairy J. Primary and Second-stage Lagoons. At Dairy J, assuming 4 h/cow-day in the milking center and 612 kg (1350 lb) per head, the adjusted cow liveweight was approximately 55 300 kg (122,000 lb). Accordingly, lagoon liquid operating volumes per unit of cow liveweight were approximately 0.12 and 0.15 m^3/kg (2.0 and 2.5 ft^3/lb), and the theoretical volatile solids loading rate in the primary lagoon was 0.09 $kg/day/m^3$ (0.0054 $lbs/day/ft^3$).

The existing primary lagoon at Dairy J was probed on 18 September 1990 to determine the sludge depth. The measurements were made at 19 points within the lagoon from a rowboat using a 6.1 m (20 ft) long hollow PVC rod calibrated to 0.3 m (0.5 ft) with one end pointed to detect the clay bottom and the other end with a flat disk 130 mm (5 in.) diameter to detect the sludge layer. The maximum liquid depth near the center of the lagoon was 3.7 to 4.6 m (12 to 15 ft) under present operating conditions. Average measured liquid depth was 1.8 ± 1.1 m (5.9 ± 3.5 ft), and the average sludge depth was 0.43 ± 0.33 m (1.4 ± 1.1 ft). This indicates that 24% of the depth of the primary lagoon was occupied by sludge after 12 years of continuous dairy operation. Again, this is below the values indicated in the ASAE (1991) design standard.

Wastewater from the milking parlor from Dairy J was sampled on 36 events (24-h each) from 27 February 1990 to 19 August 1991. The number of cows in the milking herd averaged 540 head. The primary lagoon effluent was sampled on 41 occasions within this period and the second-stage lagoon was sampled seven times when supernatant was present. Overflow into the second-stage lagoon was not always present because primary lagoon effluent was used for irrigation of coastal bermudagrass. Milking center wastewater concentrations for Dairy J were very similar to the values found for Dairy A, discussed earlier (table 5). Concentrations of total solids in the milking parlor wastewater averaged 4808 ± 2495 mg/L, of which an average of 64.8% was volatile solids (3116 ± 2009 mg/L) and 35.2% was fixed solids or ash (1,692 ± 606 mg/L), as shown in table 5. The total filterable (dissolved) solids represented less than half of the total solids and were almost evenly divided between fixed and volatile fractions. By contrast, the total suspended (nonfilterable) solids (TSS) of 2569 ± 1952 mg/L, which represented 53.4% of the total solids concentration, were composed primarily (75%) of the volatile suspended solids fraction (VSS). The VSS concentration averaged 1933 ± 1672 mg/L. Chemical oxygen demand (COD) averaged 5553 ± 3830 mg/L which indicated a COD/TS ratio of 1.15 (which is identical to Dairy A).

Table 5. Concentrations of milking parlor wastewater and lagoon effluent, Dairy J, Erath County, Tex., 2/27/90 to 8/19/91

		Milking Parlor, n = 36		Primary Lagoon, n = 41		Second-Stage Lagoon, n = 7	
Constituent	Unit	Avg	S.D.	Avg	S.D.	Avg	S.D.
Total solids	(mg/L)	4808	2495	3551	2793	1497	251
Fixed solids	(mg/L)	1692	606	1686	1246	948	209
Volatile solids	(mg/L)	3116	2009	1865	1876	549	106
Filt. solids	(mg/L)	2238	793	1603	889	979	125
Filt. fixed solids	(mg/L)	1059	395	888	444	656	142
Filt. volatile solids	(mg/L)	1179	443	715	605	323	79
Total susp. solids	(mg/L)	2569	1952	1953	2254	831	920
Susp. fixed solids	(mg/L)	634	335	797	980	293	158
Susp. volatile solids	(mg/L)	1933	1672	1150	1484	225	125
COD	(mg/L)	5553	3830	3619	4859	394	192
Nitrogen	(mg/L)	267.1	153.3	192.8	117.3	71.8	37.6
Nitrate	(mg/L)	0.8	3.2	0.8	2.4	4.2	7.3
Ammonium	(mg/L)	249.1	154.8	182.4	120.0	117.6	0.0
Organic	(mg/L)	20.0	12.5	13.6	10.3	4.5	*
Phosphorus	(mg/L)	38	28	35	18	3	*
Potassium	(mg/L)	299	153	257	122	202	38
Calcium	(mg/L)	230	87	193	116	81	24
Magnesium	(mg/L)	88	61	70	14	59	7
Sodium	(mg/L)	104	52	108	91	115	137
Manganese	(mg/L)	1.01	0.65	4.69	23.88	0.16	0.18
Chloride	(mg/L)	165.03	63.87	137.90	60.67	*	*
Iron	(mg/L)	6.03	3.44	4.65	6.36	0.76	0.96
pH		7.49	0.37	7.57	0.47	7.92	0.32
Salinity Data:							
EC, Elec. Cond.	(dS/m)	3.68	1.49	3.00	0.84	2.00	0.29
SAR†		1.52	0.75	1.42	0.57	2.21	2.52
SSP‡		14.61	3.90	15.05	3.73	*	

* Data not available
† SAR = Sodium absorption ratio.
‡ SSP = Soluble sodium percentage.

Nutrient concentrations in the raw wastewater included total nitrogen (TKN) of 267 ± 153 mg/L, of which 249 ± 155 mg/L (or 93%) was in the ammonium form; phosphorus and potassium levels were 38 ± 28 and 299 ± 53 mg/L, respectively. Electrical conductivity was 3.68 ± 1.49 dS/m.

The primary lagoon supernatant and/or effluent overflow showed considerably lower concentrations of most parameters as follows. Total solids averaged 3551 ± 2793 mg/L; VS were 1865 ± 1876 mg/L; TSS were 1953 ± 2254 mg/L; VSS were 1150 ± 1484 mg/L; COD was 3619 ± 4859 mg/L; TKN was 193 ± 117 mg/L; and P was 35 ± 18 mg/L. These values represented concentration reductions (table 6) in the primary lagoon of 26.1% TS, 40.1% VS, 39.4% filterable volatile solids, 24.0% TSS, 40.5% VSS, 34.8% COD, 27.8% TKN, and 7.9% P.

Relatively large reductions in constituent concentrations apparently occurred in the second-stage lagoon. Overall apparent concentration reductions in the two-stage system (table 6) were 68.9% TS, 82.4% VS, 88.3% VSS, 92.9% COD, and 73.1% TKN. The COD/TS ratio of second-stage lagoon effluent was only 0.26 while the VS/TS ratio was 0.37; these values are less than values for the second lagoon at Dairy A.

The mean concentrations of nutrients in second-stage lagoon effluent at Dairy J were 118 mg/L ammonia nitrogen and 202 mg/L potassium, while phosphorus was very low at only 3 mg/L. Sodium and chloride concentrations were 100 to 200 mg/L; electrical conductivity was 2.0 to 3.0 dS/m; and sodium absorption ratio (SAR) was 2.2. Irrigation with lagoon effluent at Dairy J would not be limited by salinity considerations.

Comparison of Fertilizer Value and Salinity of Lagoon Effluent at Dairies A, B, and J

The mean fertilizer nutrient and salinity concentrations of primary and second-stage lagoon effluent at the three dairy farms are compared in table 7. The range of values indicates the importance of considering varying nutrient concentrations when planning irrigation systems for open lot dairies. In primary lagoon effluent, the mean concentrations of TKN, ammonia-nitrogen, and potassium at Dairies A and J were similar and were lower than for Dairy B. The variability of these nutrient concentrations in effluent underscores the importance of sampling at each dairy to accurately plan application rates. The primary lagoon effluent at the three farms contained an average of 216 ± 58 mg/L TKN, 48 ± 11 mg/L P, and 314 ± 74 mg/L K (49, 11, and 71 lb/acre-in.) of TKN, phosphorus, and potassium, respectively. Second-stage lagoon effluent

Table 6. Dairy J, concentration reductions (%) in wastewater from milking parlor through primary and second-stage lagoon system, 2/27/90 to 8/19/91

Constituent	Primary Lagoon Treatment, MP-PL* (%)	Second-Stage Lagoon Treatment, PL-SL* (%)	Overall Two-Stage Lagoon System, MP-SL* (%)
Total solids	26.1	57.8	68.9
Fixed solids	0.3	43.8	44.0
Volatile solids	40.1	70.6	82.4
Filt. solids	28.4	38.9	56.3
Filt. fixed solids	16.1	26.1	38.0
Filt. volatile solids	39.4	54.8	72.6
Total susp. solids	24.0	57.5	67.7
Susp. fixed solids	–25.8	63.3	53.8
Susp. volatile solids	40.5	80.4	88.3
COD	34.8	89.1	92.9
Nitrogen	27.8	62.8	73.1
Nitrate	2.6	–445.5	–431.1
Ammonium	26.8	35.5	52.8
Organic	31.9	66.9	77.5
Phosphorus	9.6	90.1	91.0
Potassium	14.0	21.6	32.5
Calcium	15.9	58.3	65.0
Magnesium	21.1	15.6	33.4
Sodium	–3.7	–5.9	–9.8
Manganese	–361.9	96.6	84.1
Chloride	16.4	†	†
Iron	22.9	83.6	87.4
pH	–1.1	–4.5	–5.7
Salinity Data:			
EC, Elec. Cond.	18.5	33.3	45.7
SAR‡	6.9	–55.8	–45.1
SSP§	–3.0	†	†

* Percent reductions were computed as follows:
MP-PL = (milking parlor concentration minus primary lagoon concentration) divided by milking parlor concentration.
PL-SL = (Primary lagoon concentration minus second-stage lagoon concentration) divided by primary lagoon concentration.
MP-SL = (milking parlor concentration minus second-stage lagoon concentration) divided by milking parlor concentration.
† Data not available.
‡ SAR = Sodium absorption ratio.
§ SSP = Soluble sodium percentage.

concentrations had about half the nutrient concentrations of primary lagoon effluent with an average of 95 ± 32, 21 ± 25, and 244 ± 59 mg/L (21, 5, and 55 lb/acre-in.) of TKN, phosphorus, and potassium, respectively.

The electrical conductivity, which reflects a complex mixture of organic and inorganic compounds, averaged 3.32 dS/m in primary lagoon effluent and 2.21 dS/m in second-stage lagoon effluent (table 8). Elements contributing to soil salinity (sodium and chloride) were not found at excessive levels in these wastewaters. Sodium absorption ratio averaged just 1.8 and 2.2 in primary and second-stage lagoon effluent, respectively.

Water Use on Dairy Farms

Water use at the 11 dairy farms varied widely, depending on the type of manure removal system and other factors. The greatest variable was the use of sprinkler cow washer systems and/or flush systems versus manual manure removal.

The total amount of fresh water used for sanitation and manure removal (table 9) averaged 149.9 L (39.6 gal) per cow per day. The mean value for each farm ranged from 46.5 to 261.8 L (12.3 to 69.2 gal) per cow per day.

The average water use for milking parlors and adjacent holding sheds without flush systems or cow washers (i.e., manual cleanup) averaged just 75.2 ± 53.2 L (19.9 ± 14.0 gal) per cow per day. By contrast milking parlors and holding sheds with sprinkler cow washers used an average of 178.4 ± 66.8 L (47.1 ± 17.7 gal) per cow per day. The water use for separately metered sprinkler cow washers (including fresh water and recycled water) averaged 132.7 ± 50.2 L (35.1 ± 13.3 gal) per cow per day of which fresh water use averaged 104.5 ± 60.9 L (27.6 ± 16.1 gal) per cow per day for the five dairies.

The data indicate that sprinkler cow washers increased fresh water use by about 104 L (27.5 gal) per cow per day, an increase of 137% over manual washing. Therefore, it appears that a dairy waste management system with and without sprinkler cow washers should be designed for approximately 75 and 190 L (20 and 50 gal) per cow per day of fresh water use, respectively, to convey manure into the system. The water used for cattle drinking water troughs on seven farms averaged 108.6 ± 45.4 L (28.7 ± 12.0 gal) per cow per day.

One of the farms (Dairy B) reduced fresh water use from 302 L (79.9 gal) to only 96.9 L (25.6 gal) per cow per day, an average of 205.5 L (54.3 gal) per cow per day savings or a reduction of 68%. The 163 000 L (43,000 gal) per day savings was achieved by maximizing the recycling of water from vacuum pumps and plate cooler through the sprinkler cow washer systems and by tractor-scraping rather than flushing of feeding lanes.

For four of the farms (Dairies A, C, I, and J), data collected in this study were utilized by USDA-SCS

Table 7. Comparison of average fertilizer nutrient concentrations in lagoon effluent and supernatant, Dairies A, B, and J

	Nitrogen, Total (mg/L)	Ammonia Nitrogen (mg/L)	Phosphorus, Total (mg/L)	Potassium (mg/L)
A. Primary lagoon				
Dairy A (n = 42)	172 ± 27	161 ± 25	53 ± 94	288 ± 559
Dairy B (n = 31)	282 ± 106	267 ± 106	55 ± 28	398 ± 148
Dairy J (n = 41)	193 ± 117	182 ± 120	35 ± 18	257 ± 122
Average (mg/L)	216	203	48	314
Average (lbs/ac-in.)	49	46	11	71
B. Second-stage lagoon				
Dairy A (n = 45)	117 ± 42	116 ± 26	39 ± 79	285 ± 549
Dairy J (n = 7)	72 ± 38	118 ± 0	3 ± 4	202 ± 38
Average (mg/L)	95	117	21	244
Average (lbs/ac-in.)	21	27	5	55

Table 8. Comparison of average salinity indicators in lagoon effluent or supernatant, Dairies A, B, and J

Location	Electrical Conductivity (dS/m)	Chloride, Cl (mg/L)	Sodium, Na (mg/L)	Sodium Absorption Ratio, SAR
A. Primary lagoon				
Dairy A (n = 42)	2.82 ± 0.46	158 ± 81	149 ± 302	1.97 ± 1.20
Dairy B (n = 31)	4.14 ± 1.16	135 ± 52	136 ± 44	2.90 ± 0.35
Dairy J (n = 41)	3.00 ± 0.84	138 ± 61	108 ± 91	1.42 ± 0.57
Average	3.32	144	131	1.83
B. Second-stage lagoon				
Dairy A (n = 45)	2.42 ± 0.38	149 ± 66	146 ± 282	2.09 ± 1.14
Dairy J (n = 7)	2.00 ± 0.29	--	115 ± 137	2.21 ± 2.52
Average	2.21	149	131	2.15

Table 9. Average fresh water used for sanitation and manure removal, 11/89 to 4/92

Dairy	Avg. No. Cows	Average (L/cow/day)	Comments
A	281	211.6 (55.9 gal)	Cow washers and milking parlor
B	809	115.4 (30.5 gal)	Main barn and filling of recycle tank
C	149	259.3 (68.5 gal)	Cow washer and milking parlor
D	155	46.5 (12.3 gal)	Milking parlor and manual cleaning
E	1030	261.9 (69.2 gal)	Milking parlor, flush tank, and sprinkler tank
F	949	141.5 (37.4 gal)	Cow washers and milking parlor
G	327	204.0 (53.9 gal)	Milking parlor, cow washers, manual washdown, equipment and bulk tank
H	1514	166.5* (44.0 gal)	Milking parlor, cow washers and cow drinking water measured, less estimated drinking water use
I	293	56.8 (15.0 gal)	Milking barn
J	540	109.0 (28.8 gal)	Milking barn equipment wash, manual cleanup and barn flush, holding pen flush tank, and cow washers
K	186	76.4 (20.2 gal)	Milking barn and manual holding pen washdown
Average	567	149.9 (39.6 gal)	
S.D.	449	76.8 (20.3 gal)	

* Value for Dairy H was calculated rather than directly measured.

engineers to estimate water use for manure removal and sanitation and to calculate process-generated wastewater volumes and design of lagoon systems. This information was used to prepare Natural Resource Conservation Commission permit applications for the dairy farms.

Hydraulic Retention Times

The hydraulic retention times (HRTs) in the primary lagoons at Dairies A, B, and J were estimated using the average total daily water use plus the estimated wet manure volume entering the lagoons. The HRTs in primary lagoons at Dairies A, B, and J were estimated at 81, 119, and 110 days, respectively. For this purpose the primary lagoon at Dairy B was partitioned into a primary lagoon treatment (operating) volume of 11 100 m^3 (391,000 ft^3) and a runoff storage volume of 11 700 m^3 (415,000 ft^3).

Discussion

Average water use rates for the three dairies were used to project the annual volume of milking parlor wastewater and the amount of solids, COD, and nutrients generated in the milking center and the amount potentially available for land application of treated lagoon effluent. The total wastewater volumes were estimated to be 21 700, 34 000, and 21 500 m^3 (211, 331, and 209 acre-in.) per year, respectively, for Dairies A, B, and J.

The annual TS, VS, TSS, and COD loads from the milking center were determined by multiplying the mean concentrations of milking parlor wastewater by the average annual water use projections. The resulting loads (average for the three dairy milking centers) were as shown in table 10.

Considering that cows are in confinement roughly one-sixth of the time, these values would appear to account for most of the theoretical nitrogen and phosphorus production as predicted from the ASAE (1988) standard values for manure production.

Losses of solids, COD, and nutrients reduced the potential loading rates of these constituents that would be subject to land application as irrigated effluent. On a per cow basis, averaged for the three dairy farms, the annual amounts of constituents remaining following primary and secondary lagoon treatment were computed (table 10).

Open Lot Runoff Quality

The quality of the runoff sampled at the three dairies is summarized for Dairies A, B, and J, in figures 2 and 3. The average concentrations of TS, VS, and COD (fig. 2) for the five runoff sampling stations showed that runoff from Dairy J had lower constituent concentrations than runoff for Dairies A and B. This may have been related to a lower stocking density at Dairy J. For Dairies A and B, average runoff concentrations ranged from 5169 to 7853 mg/L TS; from 1897 to 2892 mg/L VS; and from 2635 to 4248 mg/L COD. In fact, the TS concentrations of the runoff were similar to the average concentrations of the milking parlor wastewater, which were 5541 mg/L for Dairy A and 7065 mg/L for Dairy B. However the runoff contained more soil particles (ash or fixed solids) and presented a lower organic load on lagoons and holding ponds. This is evidenced in lower values of VS/TS ratio for the open lot runoff (0.35 to 0.44) as compared to milking parlor wastewater. Similarly, the COD/TS ratio was considerably lower for the runoff (0.50 to 0.64) than for the milking parlor wastewater (about 1.17).

Relatively consistent nutrient concentrations were obtained from runoff monitoring on the five open lot watersheds. The average concentrations of N, P, and K nutrients in the open lot runoff varied from 54 to 109 mg/L TKN, from 18 to 35 mg/L P, and from 377 to 912 mg/L K (fig. 3).

Table 10. Total annual constituent loads per cow from milking center wastewater and effluent from primary and secondary lagoons (average of three dairy farms), Erath County, Tex.

Constituent	Milking Center Wastewater* (kg/yr)	Primary Lagoon (kg/yr)	Secondary Lagoon (kg/yr)
Total solids	305 ± 119	180	63
Volatile solids	197 ± 71	100	24
Total suspended solids	162 ± 60	86	26
Chemical oxygen demand	355 ± 137	182	21
Total Kjeldahl nitrogen	15.8 ± 4.8	10.7	5.0
Total phosphorus	3.4 ± 2.7	2.3	1.2

* Mean ± one standard deviation.

SUMMARY

An applied research and demonstration project was conducted at three open lot dairy farms in Erath County, Texas. Three dairies (Dairies A, B, and J) with an average of 281, 809, and 540 cows in the milking herd, respectively, were instrumented to monitor quantity and quality of wastewater from the milking parlors and holding shed. Runoff from open lots was also monitored. The purpose of the project was to determine the effectiveness of the wastewater management systems in reducing concentrations of water quality parameters. All three dairies had lagoon systems (primary and/or secondary). One of the dairies (Dairy B) utilized a settling basin ahead of the primary lagoon to pre-treat open lot runoff and milking parlor wastewater. At Dairies A and J, rainfall runoff was routed directly into holding ponds rather than into the primary and secondary treatment lagoons. A study of water use at 11 dairy farms in Erath County was also made using 39 in-line water meters.

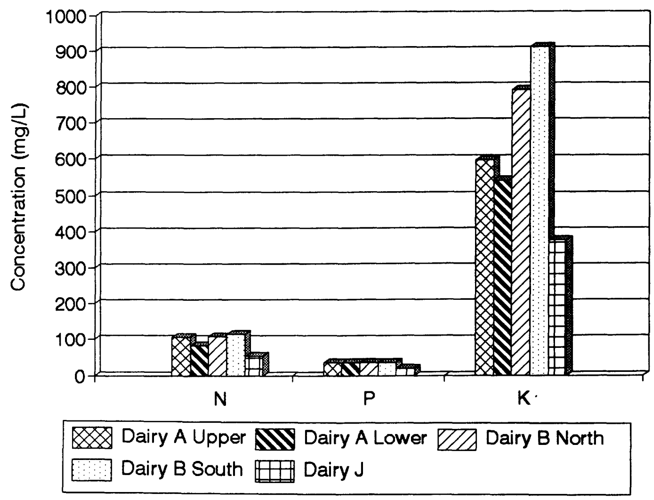

Figure 3–Average concentrations of nitrogen (TKN), phosphorus (P), and potassium (K) in runoff from open lots at Dairies A, B, and J, Erath County, Tex.

CONCLUSIONS

Analyses of the data lead to the following conclusions:

- Concentrations of the constituents in dairy wastewater from milking parlors varied widely between sampling events. Many samples of wastewater and lagoon effluent are required to accurately characterize the wastewater from the milking parlor and hence to calculate reductions in constituents due to the dairy waste management system.
- Properly sized and operated settling basins can remove a high percentage of settleable constituents, which must be removed regularly from the basins to maintain their efficiency of removal.
- Solids settling basins varied widely in performance over time and between systems. The range of performance in terms of average constituent removal (i.e., treatment efficiency) ranged from: 27.4 to 32.8% TS, 34.9 to 44.8% VS, 50.9 to 59.0% VSS, 27.2 to 46.5% COD, and 14.2 to 24.3% TKN. However, measured reductions in phosphorus concentrations averaged less than 2% overall, but measured as high as 37% in two tests. Removal of constituents before they reach the lagoons may decrease the required size of lagoons, but it appears to reduce the opportunity for concentration reductions in the lagoon.
- Two-stage anaerobic lagoon systems (primary and secondary lagoons) significantly reduced the concentrations of constituents in dairy wastewater. Properly-designed and operated two-stage treatment lagoon systems, having hydraulic retention times of 81 to 118 days and theoretical volatile solids loading rates of 0.063 to 0.090 kg/day/m^3 (0.0040 to 0.0054 lb/1000 ft^3), achieved consistent removal efficiencies of 68.9 to 70.3% TS, 80.2 to 82.4% VS, 86.2 to 88.3% VSS, 89.8 to 92.9% COD, 54.9 to 73.1% TKN, and 54.1 to 91.0% total P.
- In two-stage lagoon systems, the primary lagoon accounted for most of the percentage reductions in solids-related constituents and chemical oxygen demand, while the second-stage lagoons accounted for nearly the same percentage nutrient losses as did the primary lagoons.
- Constituent removal efficiencies were lower in the system at Dairy B consisting of a solids settling basin and a primary lagoon that received both rainfall runoff and milking parlor wastewater and that was operated as a holding pond with fluctuating water levels rather than as a treatment lagoon system with steady state conditions.
- The depth of settled solids (sludge) present in primary treatment lagoons at Dairies A and J were measured at 14 and 24%, respectively, of the total liquid operating depth after more than 12 years of continuous operation which was less than sludge accumulation values predicted in the ASAE (1991) design standard for anaerobic lagoons.
- Dairy lagoon effluent is a good source of available plant nutrients with relatively low potential for soil

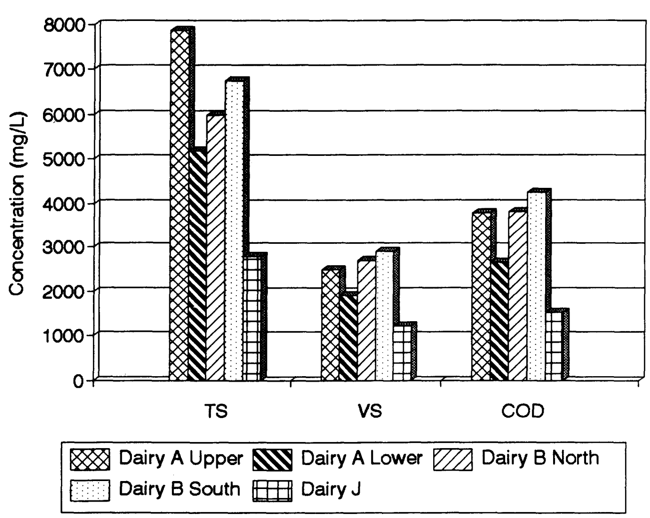

Figure 2–Average concentrations of TS, VS, and COD in runoff from open lots at Dairies A, B, and J, Erath County, Tex.

salinity. (1) Nutrient concentrations of primary lagoon effluent at three farms averaged 216 ± 58 mg/L TKN, 48 ± 11 mg/L P, and 314 ± 74 mg/L K. Over 90% of the TKN was in the ammonium form. (2) Nutrient concentrations of second stage lagoon effluent were 95 ± 32, 21 ± 25, and 244 ± 59 mg/L, for TKN, phosphorus, and potassium, respectively. (3) Salinity indicators in primary and secondary lagoon effluent included electrical conductivity, which ranged from 2.00 ± 0.21 to 4.14 ± 1.16 dS/m in lagoon effluent for the three dairy farms. (4) Higher concentrations of TKN in second stage lagoon effluent were found in winter than in summer months. (5) The levels of constituents in the secondary or second-stage lagoons were relatively consistent over time, which should facilitate planning for land application of the effluent.

- Water use for manure removal and sanitation ranged from 46.5 to 261.8 L (12.3 to 69.2 gal)/cow/day, with an average of 148.2 L (39.6 gal)/cow/day. The biggest variable was the use of sprinkler cow-washers, which increased average fresh water use by 104 L (27.5 gal)/cow/day or more than 140%.
- One of the dairies devised a way to reduce water use by 204 L (54 gal)/cow/day, and on an average all 11 dairies reduced water use by 7.6 L (2 gal)/cow/day during the study.
- Estimated annual manure loading rates from milking centers into lagoons, on a per-cow per-year basis, were reasonably consistent with values predicted from the ASAE manure production standard using the assumptions of 4 h/day in confinement and 612 kg (1350 lb) per head cattle liveweight.
- As compared to milking center wastewater, runoff from four watersheds consisting of open lots at Dairies A and B had similar concentrations of TS (5169 and 7853 mg/L, respectively), VS (1897 and 2982 mg/L), and COD (2635 and 4248 mg/L). However, runoff contained a greater proportion of soil particles and less volatile solids than did the milking parlor wastewater. Runoff from one watershed at Dairy J was below these levels of concentrations, perhaps due to a lower animal stocking rate.
- Open-lot runoff contained nutrient concentrations ranging from 54 to 109 mg/L TKN, 18 to 35 mg/L P, and 377 to 912 mg/L K. Open lot runoff was higher in K than second-stage lagoon effluent, but was similar in TKN and P concentrations.
- Data collected from the water use study on 11 dairy farms can be used to estimate both the milking center wastewater volume and water use requirements on typical open-lot dairies for the South Central United States.
- Data collected from the wastewater monitoring and runoff monitoring phases of the project on three farms can be used to design anaerobic treatment lagoon systems and land application systems for similar dairies in the South Central United States. The data are also useful for estimating the effectiveness of widely prescribed best management practices for open lot dairies in terms of water quality protection.

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