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The Expanding Dairy Industry: Impact on Ground Water Quality and Quantity With Emphasis on Waste Management System Evaluation for Open Lot Dairies

J.M. Sweeten
M.L. Wolfe

Texas Water Resources Institute

Texas A&M University

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by

John M. Sweeten
Associate Department Head
Professor and Extension
Agricultural Engineer-Waste Management
Department of Agricultural Engineering
Texas A&M University
College Station, Texas

and

Mary Leigh Wolfe
Associate Professor
Agricultural Engineering Department
Virginia Polytechnic Institute and State University
Blacksburg, Virginia

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THE EXPANDING DAIRY INDUSTRY: IMPACT ON GROUND WATER QUALITY AND QUANTITY WITH EMPHASIS ON WASTE MANAGEMENT SYSTEM EVALUATION FOR OPEN LOT DAIRIES

John M. Sweeten[1] and Mary Leigh Wolfe[2]

INTRODUCTION

Major expansion of the dairy industry has occurred in the last 12 years in North Central Texas, especially in Erath County. For several decades, this area has been the location of small dairy farms with sufficient land to maintain low animal densities on pastures except during milking operations. Today, however, new dairy operations are typically much larger (500-1,000 or more head) and maintain milking and dry cattle in open lots or corrals on small areas relative to the number of cows, in a manner that is similar to practices in the desert Southwest. Typical animal spacings in open lots are 56 m^2 (600 ft^2) per cow. Large amounts of water are used for manure removal and milk sanitation, resulting in significant volumes of process-generated wastewater.

Concern has increased regarding the potential for ground and surface water quality degradation due to the increasing number and size of open lot dairies, particularly in the Upper North Bosque River watershed (Erath and Hamilton Counties, Texas). The outcropping of the Paluxy Formation within the watershed, which acts as a recharge zone for the Trinity Aquifer group, has led to concern about the quality of ground water in the watershed.

The Upper North Bosque River (stream segment 1226) flows through the center of Erath County and eventually enters a municipal water supply reservoir before entering the Brazos River at Waco. This stream segment has been characterized as the state's major "known problem" for

[1] Associate Department Head, Professor and Extension Agricultural Engineer-Waste Management, Department of Agricultural Engineering, Texas Agricultural Extension Service, Texas A&M University, College Station, Texas.

[2] Associate Professor, Department of Agricultural Engineering, Virginia Polytechnic Institute and State University, Blacksburg, Virginia. Formerly, Associate Professor, Department of Agricultural Engineering, Texas A&M University, College Station, Texas.

agricultural nonpoint source water quality pursuant to 1988 and 1990 assessments under Section 319 of the Federal Clean Water Act (TWC, 1988). Animal confinement operations, specifically dairy operations, were identified as primary contributors to the problem.

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

OBJECTIVES AND SCOPE

The applied research and demonstration project described in this report was initiated in 1988 with funding from the Texas Water Resources Institute and the Texas Agricultural Extension Service, Texas A&M University System. The overall objective of the project was to evaluate dairy waste management systems in North Central Texas. The specific objectives of the project were:

1. To assess the potential impact of the rapidly growing dairy industry on ground water use and quality of the Trinity Group Aquifer;
2. To develop technologies to prevent point and nonpoint pollutants from dairies from entering receiving waters;
3. To determine the water use for sanitation, manure management and cow watering at typical dairy farms in Erath County, Texas;
4. To 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 so that this information can be used in developing waste management plans and permit applications for dairy facilities;

5. To determine typical water requirements for dairies in regard to any future surface or ground water management policy for the region;

6. To develop technical guidelines for dairy operators for water conservation and disposal of wastewater and solid manure; and

7. To identify and evaluate best management practices for land disposal of dairy manure and wastewater.

The equipment and procedures used to achieve these objectives are described in following sections. The data are presented and discussed. Conclusions and recommendations are made based on the data. The report begins with a summary of regulatory considerations relative to environmental (water and air) quality protection by confined animal operations and a description of dairy waste management system alternatives.

REGULATORY CONSIDERATIONS

Water Quality Protection

According to Texas Water Commission (TWC, 1987) and United States Environmental Protection Agency (USEPA, 1976 and 1991) regulations, dairies are included in the definition of "feedlots" or "concentrated animal feeding operations", and are considered to be "point sources" of water pollution that are subject to state and federal regulations. A point source is a discrete conveyance structure for wastewater, and can be a confinement building, feedlot surface, pipe, channel, ditch, or irrigation distribution system. Following distribution, land-applied manure creates the potential for nonpoint source pollution (NPS), which includes rainfall runoff from fields, forests or pasturelands.

In April 1987, the Texas Water Commission (TWC, 1987) adopted a regulation that stated the following no-discharge policy: "...there shall be no discharge of waste and/or wastewater from concentrated animal feeding operations into the waters in the state, but rather that these materials shall be collected and disposed of on agricultural land." The TWC definition of a feedlot/concentrated animal feeding operation contains four visually-determined conditions necessary for a facility to be regulated and be considered a point source: (a) an enclosure--corral or building; (b) presence of livestock; (c) feeding of those livestock; and (d) sufficient animal density to prevent crop and forage growth. Those characteristics integrate the effects of factors such as animal density, animal species, soils, slope and management practices. In addition, the USEPA definition contains an additional criterion that animals be fed or maintained for a total of 45 days or more in any 12 month period (USEPA, 1976).

The TWC regulation requires livestock and poultry producers to obtain a permit if they have more than 250 milking cows (or 1000 beef cattle, 1500 swine, 600 horses, 6000 sheep or goats or 30000 laying hens) in a concentrated animal feeding operation. Operators of smaller facilities are regulated by rule and must meet the same requirements of the TWC regulations for keeping manure and wastewater out of streams.

Specifically, TWC (1987) requires producers to protect surface and ground water and to apply manure and wastewater on land. Required surface water protection measures consist of diverting off-site drainage around the feeding facility, constructing a detention pond with at least the minimum required storage capacity for manure and process-generated wastewater, and constructing adequate runoff storage capacity.

Holding ponds and lagoons are essential for capturing rainfall runoff and process-generated wastewater and preventing its discharge into streams. Texas Water Commission (TWC) regulations specify minimum criteria that should be used to determine the size of such structures and the adequacy of soils used to form the bottom and sides of the structures. Systems for runoff control, wastewater treatment and storage and irrigation should be designed by a professional engineer.

Rainfall runoff from open lots and other manure contaminated surfaces must be collected in holding ponds designed to contain all runoff from the 25-year, 24-hour duration storm, plus accumulated sediment and process generated wastewater. The minimum required storage capacity for process-generated wastewater ranges from 6 to 60 days for different locations in the state (west to east Texas, respectively). Runoff holding ponds and lagoons must be located outside of the 100-year flood plain. Irrigation, evaporation or some combination of the two is necessary to dewater these structures sufficiently to restore the design capacity for rainfall runoff within 21 days after a rain. Holding ponds and lagoons must be sealed with at least 0.30 m (1 ft) of compacted clay that meets the TWC specifications based on soils engineering tests, which include Atterburg limits (liquid limit $\geq$ 30 percent and plasticity index $\geq$ 15 percent), a sieve analysis (more than 30 percent passing a No. 200 mesh sieve), and in most cases a saturated soil hydraulic conductivity less than 1×10^{-7} cm/sec.

A water balance based on monthly inflows of wastewater, rainfall and runoff and on monthly outflows of evaporation and irrigation is generally required in designs for recent permits to confirm the adequacy of lagoon and holding pond capacity and adjust it if necessary. Similarly, a nutrient balance, using predicted crop uptake rates and soil nutrient status, is needed to determine proper application rates and the amount of land needed for application and utilization of manure and wastewater. Computer programs are available to help the designer in planning and designing a system for manure and wastewater management, sizing the ponds/lagoons, and determining land requirements (Sweeten et al., 1989; Baird, 1990).

The TWC (1990) adopted additional regulations in June, 1990 that required all 2,100 dairies in Texas to register with the TWC. In addition, the TWC stipulated that certain best management practices (BMPs) be adopted on those dairies that do not need to get a permit at this time, i.e. those dairies with less than 250 head in the milking herd. One category of BMPs deals with decreasing lot runoff volume to reduce the size of required holding ponds and irrigation facilities. This can be done by diverting clean runoff around the facility with ditches and terraces, installing roof gutters, covering open lots with roofs and reducing open lot surface area. The latter may necessitate surfacing pens or collecting manure more frequently and abandoning pens that do not allow wastewater collection. A second category of BMPs deals with decreasing wastewater volume by properly maintaining the watering system, reducing water used for cooling or cleanup, and recycling wastewater from lagoons and holding ponds in lieu of using fresh water. A third category of BMPs is aimed at capturing rainfall runoff according to TWC stipulated design criteria and uniformly applying collected runoff on land. As an interim measure, until a permit is issued, the dairy is to install and manage runoff control facilities to contain at least 70 percent of the potential runoff from the 25-year, 24-hour storm. Some leeway is given for multiple storms within a 7-day period. A fourth BMP category calls for minimizing solid manure transport by locating manure stockpiles (if used) away from waterways, installing adequate manure storage structures, using appropriate rates and timing for manure application, providing grass filter strips along waterways, and using off-site areas for manure application. The fifth BMP specified is the protection of ground water by locating lagoons and ponds at least 46 m (150 ft) from water wells and leaving a buffer area around water wells.

In summary, the TWC must approve engineering applications and issue permits to manage and dispose of animal manure and wastewater for dairies with over 250 head in the milking herd

(TWC, 1987). All dairy operations must register with the TWC and install and operate systems in a manner consistent with the stated "no-discharge" policy (TWC, 1987; 1990).

Under the USEPA regulations, a dairy needs a permit if it may have a discharge and the operation has: (a) more than 700 mature dairy cows, including milkers and dry cows and it discharges off-premises, or (b) more than 200 mature dairy cattle and discharges either to a stream that flows through or alongside the operation or through a human-made conveyance, such as a ditch, pipe or flushing system. Smaller dairies may also be required to obtain a permit if they have substantial potential for water pollution. An operation is considered to discharge if manure-contaminated wastewater will leave the premises under rainfall conditions less than the 25-year frequency, 24-hour duration storm. Dairy operators are not held responsible for discharges which occur because of rainfall events greater than the 25-year, 24-hour storm.

The USEPA and the TWC have very similar water pollution control regulations for dairy operations. Under the USEPA regulations, a feeding operation that has never had or will not have a discharge does not need a permit. At the time of this reporting, the USEPA region 6 is considering a general permit program for dairies above the 200 and 700 head criteria if they could have a discharge from a human-made conveyance device from an event less than the 25-year, 24-hour storm.

Air Quality Protection

Water pollution is not the only environmental consideration for dairy operators. A construction permit and, subsequently, an operating permit from the Texas Air Control Board are also required for dairies that will exceed 1,000 head of cattle in confinement (including non-lactating dairy and replacement heifers). The Texas Clean Air Act (Section 382.051) states "Before work is begun on the construction of a new facility or a modification of an existing facility that may emit air contaminants, the person planning the construction or modification must obtain a construction permit from the board" (TACB, 1991). "Construction" is broadly interpreted as anything other than site clearance or site preparation. Specifically, the first excavation into the prepared soil surface is considered "start of construction" that requires a permit for the dairy facility. TACB Standard Exemption No. 62 specifically exempts "livestock animal feedlots designed to feed less than 1000 animals" from the requirement to obtain a construction permit.

Dairy operations, including manure and wastewater management systems, should be designed and managed to control odor and dust to comply with the nuisance regulation pursuant to the Texas Clean Air Act. Odor control involves application of a combination of practices that constitute Best Available Control Technology that is economically achievable (BACT) as demonstrated by state-of-the-art design and operation within an industry. As it applies to Central Texas dairy operations, BACT includes proper site selection; correct animal spacing; frequent manure collection from milking parlors, holding sheds or pens, alleys, and open lots; adequate treatment and storage facilities including, as appropriate, solids separation to reduce organic solids loading rates on lagoons, runoff detention ponds, treatment lagoons (one or more stages) with relatively low volatile solids and hydraulic loading rates (ASAE Standards, 1993a); irrigation systems using treated effluent of sufficient quality (i.e. low odor intensity and offensiveness); and land application of solid/semi solid manure at relatively low loading rates followed by soil incorporation where appropriate. Odor or dust control practices are discussed in more detail in other sources (Sweeten, 1982; ASAE Standards, 1993b; and Sweeten, 1992).

DAIRY WASTE MANAGEMENT SYSTEM ALTERNATIVES

Several types of waste management systems are utilized by open lot dairies (Welchert et al., 1990). Solid manure from open-dirt surface dairy corrals is collected with a tractor loader or box scraper at frequent intervals and stockpiled prior to land application. Liquid manure from milking parlors, paved holding pens or sheds, and paved feeding alleys, as well as open-lot runoff, is normally routed to one or more treatment lagoons or holding (detention) ponds where the effluent and solids are collected and stored for a design time period for limited primary and secondary treatment while awaiting disposal by land application[3]. Many dairies also use settling basins, static screens or other types of separation devices for removal of coarse fibrous solids and nutrient recovery ahead of lagoons or holding ponds. This prolongs the effective life of the structure before sludge removal is necessary and facilitates lagoon management including irrigation.

Ground water can be contaminated by leachate from holding (detention) ponds and lagoons, by infiltration beneath open lot surfaces, or by improper land disposal of wastewater and solid manure at rates that exceed plant nutrient requirements. Sweeten (1990) provided information regarding effects of and management practices for open lot dairies and feedlots to protect ground water. The TWC (1987) specified regulatory criteria for lining of detention ponds and lagoons. Application of excessive amounts of manure and wastewater, especially on sites with aquifer outcrops and/or on soil types that have porous subsoils, could potentially result in contamination of shallow aquifers. Uncontrolled runoff can transport manure constituents (nutrients, pathogens, organic matter) directly into surface streams or across aquifer recharge areas, thereby impairing surface water quality. However, when adequate waste management systems are installed and managed according to the no-discharge requirements, surface and ground water pollution potential are greatly reduced and opportunities for beneficial reuse of nutrients and organic matter are maximized.

[3] Refer to Appendix A for definitions of terms regarding livestock waste management systems.

Proper system design is essential to meeting regulations and reducing pollution. Pasture operations or confinement buildings such as free stall barns are usually preferable to open lots in high rainfall areas. It is generally inadvisable to construct dairies that rely on open lot feeding systems in areas where the moisture deficit is zero or negative (i.e. annual precipitation plus predicted manure moisture deposition approaches or exceeds annual evaporation). This is because the additional moisture excreted in manure will virtually assure a wet open lot surface. Dairy cattle typically excrete an annual volume of moisture equivalent to 2.68 ha-mm per 1000 kg (or 0.118 ac-in per 1000 lbs) liveweight (ASAE Standards, 1993c). Consequently, with a typical dairy cow size of 635 kg (1,400 lbs) per head and open lot spacing of 56 m^2 (603 ft^2) per head, the depth of moisture in fresh manure will be approximately 304 mm (12 in) per year[4]. Annual rates of moisture excreted in dairy cattle manure, calculated as a function of dairy cattle size and spacing, are shown in Figure 1.

The average annual lake surface evaporation and precipitation for Stephenville (Erath County), Texas are 1830 and 737 mm (72 and 29 in) per year, respectively (Larkin and Bomar, 1983), yielding an annual moisture deficit of 1093 mm (43 in) per year. This compares with an annual moisture deficit of 330 mm (13 in) per year in Hopkins County, the state's second leading dairy county, where annual lake surface evaporation and precipitation are 1400 and 1070 mm (55 and 42 in) per year, respectively, and a moisture deficit of about 1520 mm (60 in) per year in El Paso County. The relationship between annual moisture deficit for these three counties and moisture production in manure is illustrated in Figure 1. Spacings less than about 55 ft^2/head (600 ft^2/head) could lead to excess moisture production in Hopkins County.

Average annual runoff volume can be estimated as a percentage of annual rainfall (Phillips, 1981) at approximately 20 to 25 percent for unpaved lots and 30 to 35 percent for paved

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4 Conversion factors used in this report are given in Appendix B.

lots. For example, an unpaved open lot in El Paso County will produce an average of 38 mm (1.5 in) of runoff per year. In the Stephenville/Fort Worth area, the average runoff volume is projected at about 230 mm (9 in) per year, or six times the volume in El Paso, for the same open lot area. By contrast, an open lot operation in northeast Texas (Texarkana) or southeast Texas (Houston) would be expected to produce an average of 380 to 430 mm (15 to 17 in) of runoff per year. Hence, higher runoff volumes, and the potential mud problems, make open lots much less attractive than free stall barns or pasture operations in humid climates.

Constructing holding ponds and lagoons according to the TWC standards represents only part of the system design. It is also essential to have a pumping and irrigation system to dispose of effluent. The irrigation system should be able to handle the suspended solids load while furnishing adequate discharge capacity and pressure and covering the land area required by nutrient and water balances.

Since the TWC regulations require that the storage capacity in holding ponds for runoff be restored by pumping within 21 days after each rain, this often means that irrigation must begin before soil moisture has been depleted to the point normally requiring irrigation. Therefore, the irrigation system should be able to deliver relatively light, uniform applications to dewater holding ponds, yet prevent runoff and illegal discharge of tailwater. Practices that improve soil infiltration rates, such as deep chiseling of clay pan soils, conservation tillage or furrow diking, may be advisable in many cases.

A holding pond designed strictly for runoff collection should be completely dewatered to re-establish the designed runoff capacity soon after rainfall. On the other hand, lagoons designed both for runoff retention and for treatment and storage of process-generated wastewater should be pumped down to the permanent treatment level soon after rainfall.

Livestock feeders should monitor and record the amount of wastewater stored in lagoons and holding ponds and keep records of the dewatering and irrigation operations. Simple staff gauges (i.e., vertical calibrated rods) will show the depth of wastewater in the structures. Engineers can prepare a chart that relates water depth to liquid volume. Markers should be placed at the levels where the operator needs to start and stop pumping (dewatering).

Application rates for lagoon effluent and open feedlot runoff should be selected with respect to seasonal and annual nutrient salt and hydraulic loading criteria. Guidelines for selection of proper application rates for solid manure, lagoon effluent, and runoff with respect to soil testing results are provided in Gilbertson et al. (1979) and Sweeten et al. (1991a).

The Texas State Soil and Water Conservation Board (TSSWCB) lists the following Best Management Practices (BMPs) for livestock feeding operations considered to be nonpoint pollution sources, i.e. generally those with insufficient cow numbers to be considered a point source (TWC and TSSWCB, 1988):

1. Proper location of livestock concentrations;
2. Proper management of solid and liquid manure;
3. Runoff control; and
4. Land disposal of wastes.

The TSSWCB is the designated state agency responsible for agricultural and silvicultural nonpoint source water quality management. This designated responsibility applies to livestock operations considered to be nonpoint sources.

Site selection is one of the most important factors in preventing water and air quality problems from livestock feeding facilities. Key factors to consider in site selection are listed in Table 1. Proper site selection includes consideration of topography, slope, location relative to flood plains, geology, land area available for manure and wastewater applications, land use, and proximity to neighbors and prevailing wind direction.

EQUIPMENT AND PROCEDURES

Description of Dairy Facilities: Wastewater and Runoff Monitoring

Wastewater quality data were collected at four dairy farms in Erath County in North Central Texas during 1988, 1989, 1990 and 1991. The dairies ranged in size from 280 to 1,900 cows (Holsteins) in the milking herd. The primary sources of wastewater at these four 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 or in wastewater treatment/storage lagoons. Two of the farms utilized concrete settling basins for partial removal of settleable solids. At all four dairies, 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 individually in the following paragraphs.

Dairy M: A wastewater settling basin study was conducted in 1988 at Dairy M, which had 1,900 cows that were kept in open corrals and fed in head-lock feeding aprons along paved alleys. The cattle were milked three times per day in two double 16 herringbone milking parlors following rinsing in a drip shed using sprinkler cow washers. During feeding, the cattle stood on a 3 m (10 ft) wide concrete apron behind the head-lock stanchions. This apron was tractor-scraped daily, solid manure was collected on a weekly basis from the corrals, and solid and semi-solid manure was hauled to nearby pasture land. The open lot portion of the dairy occupied approximately 10 ha (25 ac). The milking parlor floor was flushed using a mixture of fresh water and recycled rinsate from the milking equipment and bulk tank.

All wastewater from the milking parlor and drip shed, as well as any rainfall runoff, was channeled into a 0.9 m (3 ft) deep, 24 m (80 ft) long settling basin. The basin had two compartments operated in parallel, each with 330 m^3 (11,700 ft^3) capacity. Settled solids were removed with a wheel loader. Overflow from the settling basin entered the anaerobic treatment/storage lagoon from which it was irrigated with a big-gun sprinkler onto pasture land. The study at this dairy involved sampling inflow and outflow from the concrete settling basin and pumped effluent from the storage/treatment lagoon on four occasions. Flow rates were not measured.

Dairy A: A study involving a two-stage anaerobic lagoon and open lot runoff was established at Dairy A, which milked an average of 281 cows in a double 8 herringbone milking parlor twice daily in 4 groups. Each group of cattle was pre-washed using a sprinkler cow washer system in the holding/drip shed. Inside the milking parlor, cow udders, grates, floors, and walls were manually washed by pressure hoses. Final cleanup was provided by flushing once per day using two 1900 L (500 gal) flush tanks. Longitudinal slopes of the milking parlor and holding shed floors were 0.5 and 2.0%, respectively. All dairy wastewater from the cow pre-wash sprinklers in the holding shed, the milking parlor, the milk storage tank, and the milking equipment was routed through a 0.46 m (1.5 ft) galvanized metal type-H flume into a 1900 L (500 gal) conical-bottom concrete sump. The flume was equipped with a Stevens type-F water level (float-stage) recorder and an ISCO Model 2900 discrete water sampler, programmed to sample wastewater at 5 minute intervals when the liquid depth exceeded 0.03 m (0.1 ft). The wastewater in the sump drained by gravity through a 20 cm (8 in.) diameter, 125 m (410 ft) long

PVC pipeline into a primary lagoon and a second-stage lagoon in series with capacities of approximately 4,900 and 3,100 m^3 (172,000 and 108,000 ft^3), respectively.

The total number of Holstein cows, milking and dry, averaged 375 head with heifers included. Two wells near the milking barn, approximately 120 m (400 ft) deep, supplied fresh ground water for the operation. The area of the dairy which supported the monitoring studies consisted of approximately 8.9 ha (22 ac) which contained the milking center, feeding pens, holding pens, and waste management facilities.

The milking and dry cattle were fed in open lots with a total of 260 m (850 ft) of fence line feed bunk space. Watersheds for monitoring runoff were established in the two largest open lots, which included all the fence line bunk space. An upper watershed, with an area of approximately 1 ha (2.5 ac) drained into a 0.46 m (1.5 ft) type-H flume equipped with a Stevens type-F stage recorder and an ISCO Model 2900 discrete water sampler. Average watershed slope was 2.5% from the milking parlor to the flume 310 m (1020 ft) away. The lower watershed consisted entirely of a dairy corral and had a net drainage area of 1.6 ha (4 ac) diverted into a 0.61 m (2.0 ft) Plasti-Fab type-H flume, equipped with a Stevens type-F stage recorder and Model 2900 ISCO sampler. Average watershed slope was 3.2% over a distance of 384 m (1260 ft) from the milking parlor. In-line water meters with 38 and 51 mm (1.5 and 2.0 in) nominal sizes from Badger Meter Co. were installed to measure water usage for the milking parlor including the flush system, the sprinkler cow washer system, and the cattle drinking water. An SCS-designed runoff and wastewater holding pond with a capacity of 21,500 m^3 (759,000 ft^3) was installed in Spring, 1991 to collect open lot runoff and overflow from the second-stage lagoon.

Dairy B: This 950-cow open lot dairy was built in 1987 on 65 ha (160 ac) and consisted of a double 16 herringbone milking parlor in which cows were manually washed following pre-rinsing with a sprinkler cow washer system in the holding shed. Dairy B had 650 to 850 cows in holding pond with 10,200 m^3 (362,000 ft^3) liquid capacity. Runoff from 5 of the 8 cattle feed pens passed through concrete settling basins prior to entering the primary lagoon. Settling basin A (north) collected runoff from the two north dry lots. Supernatant that drained from this settling basin through a perforated riser pipe entered the second holding pond. Settling basin B (dual-chambered), shown in Figure 3, collected runoff from the 3 central dry lots. Runoff from the 3 dry lots on the south side of the dairy did not enter a settling basin but rather discharged directly into the primary lagoon/detention pond.

Runoff was monitored through two 0.9 m (3 ft) depth type-H flumes set near the northwest and southwest corners of the open lots (Figure 2). The total drainage areas of open lots and drainage channels that entered these measuring flumes and sampling stations were 4.29 and 2.29 ha (10.59 and 5.66 ac), respectively, for the north and south runoff flumes. These flumes were equipped with flow-activated ISCO samplers (Model 2900) programmed to place 3 or 4 subsamples into each of the 24 one liter sample bottles at 5-minute intervals, according to the duration of the runoff event.

Water meters were placed in a shed at the main pumping facility in pipe lines going to the following destinations:

1. Milking barn
2. Fresh water to fill recycle tank
3. Vacuum pump
4. Platecooler (recycled to sprinkler tank)
5. Sprinkler (recycled water only)
6. Cow drinking water troughs - Pens #1, #2, and #3
7. Cow drinking water troughs - Pens #4, #5, and #6
8. Cow drinking water troughs - Pens #7 and #8

A flow diagram of the water use and distribution system that has evolved is shown in Figure 4.

Dairy J: This dairy operation included a double 8-stall milking facility accommodating an average of 540 milking Holstein cows on two times milking per day basis. The dairy consisted of 74.9 contiguous ha (165 ac), plus additional permanent pasture within a mile. According to a SCS technical design report prepared for Dairy J, the milking center and open dry lots occupied 7.3 ha (18 ac) and pastureland occupied 65.2 ha (161 ac). Total area of open lots was 5.3 ha (13 ac). Hence, approximate gross cow spacing in the open lots was 102.7 m^2 (1100 ft^2) per head, including alleys and intermittent-use utility pens. The total area draining into runoff holding ponds including barn area, drylots, feeding lanes, cattle alleys, grassed waterways and pond surfaces was 12.8 ha (31.7 ac). Two wells, approximately 140 m (460 ft) deep, supplied fresh ground water for the operation and were located near the milking barn and next to the hay storage barn.

Wastewater holding facilities consisted of a single-stage manure treatment lagoon and two runoff holding ponds. Monitoring systems used for demonstration and evaluation were located on this dairy to evaluate water consumption, wastewater production and quality, and open lot runoff. Water meters were placed in pipe lines providing fresh water for:

1. Milking barn--manual cleaning
2. Holding pen--flush tank
3. Sprinkler cow washers--80 spray-head Rain Jet #415 nozzles, 12 impact sprinklers with 5 mm (3/16 in) nozzles, and 18 Tee-Jet #8005-E mister sprinklers.

Wastewater from the milking barn and holding pen was collected and conveyed by gravity through a 0.46 m (1.5 ft) depth type-H flume equipped with an ISCO Model 2900 water sampler and Stevens type-F (float type) stage recorder before entering the primary lagoon. The primary lagoon had a liquid volume of approximately 6800 m^3 (240,000 ft^3). For runoff monitoring, a

0.61 m (2 ft) depth type-H flume equipped with a digital runoff flow recorder was placed southwest of the west holding lots. The drainage area for this runoff monitoring flume was 1.25 ha (3.06 ac). A second-stage lagoon of 8,500 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. 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.

Analytical Procedures: Wastewater and Runoff Monitoring

Manure, wastewater, and runoff samples were collected in the field at sampling sites identified in the preceding discussion. These samples were either stored in a frozen condition prior to shipment or transported within 2 days of collection to Texas A&M University, 290 km (180 miles) away, where samples were then stored in a freezer. Prior to analysis, samples were thawed, mixed, composited, divided into split samples, and analyzed by two laboratories: (a) Water and Wastewater Laboratory, Agricultural Engineering Department, and (b) Extension Soil and Water Testing Laboratory.

The sampling plan, sample handling procedures, and analytical procedures are described in more detail in a Quality Assurance/Quality Control Plan developed in conjunction with the Texas State Soil and Water Conservation Board as part of a related project (Sweeten et al., 1991c; Moore and Davis, 1991). Samples were analyzed for the following parameters:

1. Water and Wastewater Laboratory, Agricultural Engineering Department--analyses included solids (total, fixed, and volatile), chemical oxygen demand (COD), and total Kjeldahl nitrogen (ammonia and organic). Most of the wastewater samples were also partitioned into filterable and non-filterable solids including fixed and volatile fractions of each. Solid or semi-solid manure samples were analyzed for moisture, ash, and total Kjeldahl nitrogen. The results of the manure analyses are

outside the scope of this project and will be reported elsewhere. All analyses in this laboratory were performed according to Standard Methods for Examination of Water and Wastewater (APHA, 1989).

2. Extension Soil and Water Testing Laboratory--analyses included nitrate, nitrite, phosphorus (total), potassium, iron, sulfate, manganese, pH, sodium, calcium, magnesium, chloride, carbonate, bicarbonate, and conductivity. The sodium absorption ratio (SAR) and soluble sodium percentage (SSP) were calculated.

The values from individual samples were averaged for each sampling date. Mean values for a specified time interval from these averages were calculated across sampling dates. Comparisons were made between daily means, seasonal means, and overall means to determine the effectiveness of the treatment systems.

Dairy Farm Water Use

Eleven dairy farms in Erath County within the Upper North Bosque River Watershed were selected for involvement in the water use study. The study was initiated in November 1989 and continued through spring 1992. The 11 dairy farms ranged in size from 150 to 1,300 cows in the milking herds. Most of these dairies represented open lot confinement facilities typical of new and expanding dairies in North Central and West Texas. One of the dairy farms (Dairy E) utilized free-stall barn facilities for the milking herd, while dry cows and heifers were kept in open lots. Dairies A, B, and J were described in a previous section of this report. Appendix C contains a general description of Dairies C, D, E, F, G, H, I, and K that were also involved in the water use study.

Thirty-nine brass water meters from Badger Meter Co. 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 meters, 38, 51, and 76 mm (1.5, 2.0, and 3.0 in) in size, were installed between November 1989 and March 1990 by a commercial plumber, with the number on each dairy ranging from 1 to 8. The meters were removed in the summer and fall 1992.

Funds for purchase and installation of the water meters came from two sources: (a) Texas Water Development Board (75%)--grants to the Upper Leon Soil and Water Conservation District, Dublin, Texas and the Bosque Soil and Water Conservation District, Stephenville, Texas; and (b) the Texas Water Resources Institute, Texas Agricultural Experiment Station, Texas A&M University (25%).

Functional use of the fresh water being metered was determined from farm owners/managers and by direct observation. Following installation of the meters, observations were taken one or two times per week by a technician employed by the Bosque and the Upper Leon Soil and Water Conservation Districts, using grant funds supplied by the Texas State Soil and Water Conservation Board. Meter readings consisted of directly recording the digital totalizer which indicated the cumulative gallons of water that had flowed through the meter. Incremental water use since the previous reading was then calculated.

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

The number of cows was determined by interviewing the farm managers or using monthly Dairy Herd Improvement Association (DHIA) records. Eight of the farms (Dairies A, C, D, E, F, G, I, and J) were on the DHIA record system during the study period.

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 four dairies. The data for Dairy M were limited with either 3 or 4 sampling dates for each component of the waste management system, and fewer constituents were measured. Sampling dates included in the data summaries for Dairies A, B, and J are shown in Table 2. The data set for Dairy A covered the longest continuous time period (January 18, 1989 to August 19, 1991). The data for Dairy B illustrated the effects of operational changes at the dairy during the sampling period (June 30, 1989 to August 27, 1991). Analytical results for Dairy J encompassed the period February 21, 1990 to August 19, 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 (non-filterable) solids (VSS), chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), phosphorus (P), and electrical conductivity (EC).

Dairy M--Settling Basin and Lagoon

The results for Dairy M are summarized in Table 3, including the average and standard deviation of the concentration of each constituent measured and the apparent reduction in concentrations by the settling basin and primary lagoon. The settling basin provided appreciable removal efficiency for solids-related parameters from liquid dairy manure and wastewater in that 32.8% of the TS, 44.8% of the VS, 59% of the VSS, and 46.5% of the COD were removed from the wastewater stream by the settling basin. However, nutrient removal was generally less and results were more erratic. An average reduction of 14.2% TKN and almost no removal (1.5%) of P were measured.

Inflow to the single-stage primary anaerobic lagoon was sampled at the settling basin outflow. Effluent from the anaerobic lagoon that followed the settling basin was sampled from an irrigation pipeline riser outlet. The pumped lagoon effluent at Dairy M contained an average of 152 mg/L N, 28 mg/L P, and 180 mg/L K (Table 3). The anaerobic lagoon provided much lower reduction of VS, VSS, and COD than might be expected with reductions of 12.4, 29.7 and 14.4%, respectively. These results may have been caused by removal of readily settleable and digestible solids in the settling basin before lagoon treatment and also a relatively short hydraulic retention time in the lagoon. However, since entering flow rates were not measured, the hydraulic retention time of the settling basin and lagoon could not be determined. Several constituent concentrations, including N, P, K, EC and SAR, increased through the lagoon. The method of sampling from the lagoon may have influenced these results. The lagoon contents were agitated through the pumping process, perhaps entraining sediments, while the settling basin samples were withdrawn from steady flow. The sample size was too small to be conclusive, indicating the need for more intensive sampling.

Dairy A--Primary and Second-Stage Lagoons

At Dairy A, assuming 4 hours per cow-day in the confinement buildings, the adjusted cow liveweight was approximately 29,000 kg (63,000 lbs), for purposes of estimating manure production that would enter the primary lagoon. Using the TAEX MANURE worksheet (Sweeten et al., 1989), a theoretical amount of volatile solids entering the primary lagoon was calculated to be 309 kg/day (680 lbs/day) based on standard manure production values (ASAE, 1988) including the mean plus one standard deviation. Unit volumes of the two lagoons, in terms of 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 $lbs/day/ft^3$).

Mean concentrations of constituents in the milking parlor wastewater, the primary lagoon effluent, and the second-stage lagoon effluent for a 31-month period are shown for Dairy A in Table 4. The average number of cows in the milking herd during the monitoring period was 281. Volatile solids concentrations decreased from 3,444 ± 1,961 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 2017 ± 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 6,397 ± 4,444 mg/L in milking parlor wastewater to 1,480 ± 1,497 mg/L in primary lagoon effluent, and to just 650 ± 243 mg/L in second-stage lagoon effluent.

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.

Reductions in constituent concentrations due to the system components are shown in Table 5. 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%). 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%).

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 5). 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 4). 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 4).

Conductivities were moderate to high as compared to typical irrigation water (<2000 μmhos/cm) but were relatively low for livestock waste treatment lagoons (Payne et al., 1985; Lindemann et al., 1985). EC values averaged 2,819 ± 461 μmhos/cm and 2,420 ± 377 μmhos/cm 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.

The data in Table 4 are averages for the entire sampling period. The average concentrations of the constituents on each sampling date offer further insight into the performance of the waste management system over time. Values of TS, VS, VSS, COD, TKN, and EC, for each sampling date are plotted versus time in Figures 5a, 5b, and 5c. The trend of the data is similar in each of the plots. The characteristics of the milking parlor wastewater varied much more over time than those of either lagoon. The concentration of each of the four constituents was nearly always greatest in the milking parlor wastewater, much less in the primary lagoon effluent, and slightly less in the second-stage lagoon effluent. The noticeable peak concentrations in the primary lagoon effluent from approximately December 16, 1989 (day 350) through mid-April (day 475) may be attributed to decreased microbial activity. Also the peak values in March could be caused by spring warming and turnover of primary lagoon contents. Conversely, greater reductions of TS, VS, VSS, and COD occurred in warmer months.

Seasonal variation of the constituent concentrations is important, especially for planning irrigations with the second-stage lagoon effluent. Average seasonal concentrations of TS, VS, TKN, and COD are illustrated in Figures 6a and 6b. For the milking center wastewater, summer concentrations were lowest; winter concentrations were highest; and fall and spring were in between. In the primary and second-stage lagoon effluent, the lowest concentrations of COD, TKN, TS, and VS generally occurred in the summer which could be expected due to higher rates of digestion.

Statistical analyses were conducted for seven constituents to determine the effect of season. The results are summarized in Table 6. All statistical tests were conducted at an α-level of 0.05. Season did not significantly affect the concentrations of the constituents in the milking parlor wastewater. 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 characteristics of the second-stage lagoon effluent are important in completing the dairy waste management system design which includes land application of the second-stage lagoon effluent. To properly utilize effluent, it is essential to know the constituent concentrations of the effluent, particularly nutrients and salts. High variability throughout the year would complicate scheduling irrigations with effluent.

Seasonality caused significant differences in the mean concentrations of 4 of the 7 constituents for the second-stage lagoon effluent, specifically, COD, TKN, EC, and nitrate-nitrogen (Table 6). 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 0.080-0.146

kg/m^3 (18 to 33 lb/ac-in). Thus, if a crop required a total nitrogen application of 225 kg N/ha (200 lb N/ac), 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 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 at 17 measuring locations was 2.00 ± 1.24 m (6.56 ± 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). Projecting this average sludge depth across the lagoon bottom area indicates the lagoon was only 12% full of sludge (600 m^3 or 21,000 ft^3) after 12 years of operation without sludge removal or pumping from the primary lagoon. This further substantiates the data showing high solids digestion efficiency of this mature lagoon. The apparent rate of sludge accumulation was approximately 0.18 m^3/cow/year (6.3 ft^3/cow/year).

The runoff detention pond that was designed by SCS and installed in early 1991 displaced the lower watershed flume so that further runoff sampling was not conducted for the lower watershed. The new detention pond had a total drainage area of 9.88 ha (24.41 ac). The design capacity of 20,900 m^3 (738,000 ft^3 or 16.94 ac-ft) was comprised of 14,300 m^3 (504,000 ft^3 or 11.58 ac-ft) for runoff from the 25 year, 24 hour storm; 2,560 m^3 (90,600 ft^3 or 2.08 ac-ft) of additional runoff storage; 1,230 m^3 (91,500 ft^3 or 2.10 ac-ft) of process wastewater storage (overflow from the second lagoon); and 1,455 m^3 (51,400 ft^3 or 1.18 ac-ft) of sludge storage. The as-constructed capacity (Stanford, 1990) was 21,500 m^3 (759,000 ft^3 or 17.42 ac-ft). The design included a monthly water-balance calculation with rainfall, runoff (inflow), water surface evaporation, and crop demand for 18.2 ha (45 ac) of bermudagrass with an average loading rate of 293 m^3/year (2.85 ac-in/ac/year). The water budget verified that the 25 year, 24 hour storage allocation will be maintained throughout the design cycle of the wettest 10 years on record (Baird, 1990).

Dairy B--Settling Basin and Primary Lagoon

The average number of cows in the milking herd during the monitoring period was 809 cows. When Dairy B was first instrumented, the settling basin had not been installed. Wastewater from the milking parlor was discharged down a feeding alley into a bunker and into a 305 mm (12 in) PVC pipeline which discharged through a type-H flume and then into the primary lagoon. The settling basin was operational by October 1989. This necessitated changing the location of the flume used to sample milking parlor wastewater because the path of inflow was altered. At the end of January 1990, Dairy B instituted a water conservation and recycling system, which reduced its fresh water use by 68%. The reduced flow affected the operation of the flume associated with the milking parlor wastewater, which together with installation of a 254 mm (10 in) PVC pipeline to convey the milking parlor wastewater directly from the parlor to the settling basin, resulted in the flume being out of operation from late January through April 1990. By May 1990, the pipeline had been installed and the flume relocated to its present position immediately upstream from the settling basin. In addition, there was a change in mass loading from the milking parlor wastewater. Prior to water recycling, concrete aprons adjacent to (behind) the feed alley were flushed. After water recycling was implemented, the aprons were scraped, thus preventing the manure solids and spilled feed from entering the settling basin and primary lagoon.

The effects of these changes on the milking parlor wastewater concentrations and the primary lagoon can be seen from Figures 7a, 7b, and 7c, which show average daily values of TS, VSS, COD, VS, TKN, and EC versus time. There is a noticeable increase in the constituent concentrations in the primary lagoon from approximately December 15 (day 350) to about April 25, 1990 (day 480) which corresponds closely to the time period during which recycling of water began and the flow route of the milking parlor wastewater was being adjusted. During the latter part of this period, the previously overloaded lagoon was warming, likely mixing due to gas production and lifting solids from the bottom. The water level in the lagoon was probably lower as well because of less wastewater from the milking parlor. After about April 25, 1990, the concentrations of constituents in the lagoon returned to lower values and remained there. It appears that the lagoon adjusted to the change in hydraulic and organic (volatile solids) loading.

The instrumentation was entirely functional after May 1990. The data prior to May 10, 1990 were summarized in discrete time segments during the overall sampling period in a previous paper (Wolfe and Sweeten, 1991), and that analysis will not be repeated here. Concentrations of constituents in the milking parlor wastewater, settling basin, and effluent from the primary lagoon from May 10, 1990 to August 27, 1991 are summarized in Table 7.

From May 10, 1990 to August 27, 1991, volatile solids concentrations decreased from 4,775 ± 4,001 mg/L in the milking parlor wastewater to 3,111 ± 1,712 mg/L in the settling basin outflow and to 2,999 ± 2,680 mg/L in the primary lagoon supernatant (Table 7). Similarly, the COD decreased from 8,363 ± 6,215 mg/L in the milking parlor wastewater to 6,086 ± 4,004 mg/L in the settling basin outflow and to 5,467 ± 4,971 mg/L in the primary lagoon. Total Kjeldahl nitrogen was reduced from 403 ± 419 mg/L in milking parlor wastewater to 305 ± 115 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 4,743 ± 3,387 μmhos/cm in milking parlor wastewater to 4,287 ± 1,188 μmhos/cm in settling basin outflow and to 4,135 ± 1,160 μmhos/cm 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.

Computed concentration reductions due to the settling basin and primary lagoon (Table 8) 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 reduction in the primary lagoon. On some sampling dates, it was not feasible to sample the primary lagoon 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 8 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. These reductions are generally less than those measured for the primary lagoon alone at Dairy A. A longer period of data collection may be required to better evaluate the system at Dairy B.

The ratio of COD to TS decreased slightly from the raw wastewater (1.18) to the primary lagoon effluent (1.08) (Table 7). 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.

Data from two consecutive sampling dates in May, 1991, when it was evident from rainfall records that runoff was not causing any interference, illustrate the high efficiency that can be obtained from a properly designed and operated settling basin (Table 9). While inflow concentrations were variable, outflow concentrations were steady. The average reductions for these two dates were 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 hours per cow-day in the milking center and 610 kg/hd (1350 lbs/hd), the adjusted cow liveweight was approximately 55,100 kg (122,000 lbs). 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). The theoretical volatile solids loading in the primary lagoon was 595 kg/day (1,310 lbs/day), which provided a theoretical VS loading rate of 0.09 kg/day/m^3 (0.0054 lbs/day/ft^3).

The existing primary lagoon at Dairy J was probed on September 18, 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 at 0.3 m (1 ft) intervals. One end of the PVC rod was pointed to reach and detect the clay bottom of the lagoon. The other end had a flat disk 130 m (5 in) diameter that provided resistance when the disk reached the top of the sludge layer. A depth probing was made with the pointed end of the rod, and then with the disk end of the rod. Depth estimates were made to the nearest 0.15 m (0.5 ft). 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 $\pm$ 1.1 m (5.9 $\pm$ 3.5 ft). The measured sludge depth ranged from 0.0 to 1.2 m (0.0 to 4.0 ft). Average sludge depth was 0.43 $\pm$ 0.33 m (1.4 ft $\pm$ 1.1 ft). This data indicates that the primary lagoon was almost 25% full of sludge after 12 years of continuous dairy operation.

Wastewater from the milking parlor from Dairy J was sampled on 36 days (24-hour periods) from February 27, 1990 to August 19, 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 7 times when supernatant was present. Effluent from the primary lagoon was used for irrigation of coastal bermudagrass throughout the study so that overflow into the second-stage lagoon was not always present. Solids and nutrient levels decreased in concentration through treatment in the primary and second-stage lagoons, while the pH increased (Table 10). Average daily concentrations of TS, VS, VSS, COD, TKN, and EC in milking center wastewater and primary lagoon effluent are shown in Figures 8a, 8b and 8c. The concentration of each consituent varies appreciably over time. The primary lagoon concentrations are more variable at this dairy than at Dairy A.

Milking center wastewater concentrations for Dairy J were very similar to the values found for Dairy A, discussed earlier. Concentrations of total solids in the milking parlor wastewater averaged 4,808 ± 2,495 mg/L, of which an average of 64.8% was volatile solids (3,116 ± 2,009 mg/L) and 35.2% was fixed solids or ash (1,692 ± 606 mg/L), as shown in Table 10. 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 (non-filterable) solids (TSS) of 2,569 ± 1,952 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 1,933 ± 1,672 mg/L. Chemical oxygen demand (COD) averaged 5,553 ± 3,830 mg/L which indicated a COD/TS ratio of 1.15 (which is identical to Dairy A).

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 3,680 ± 1,490 μmhos/cm.

The primary lagoon supernatant and/or overflow showed considerable reduction in the lagoon of most parameters. Total solids averaged 3,551 ± 2,793 mg/L; VS were 1,865 ± 1,876 mg/L; TSS were 1,953 ± 2,254 mg/L; VSS were 1,150 ± 1,484 mg/L; COD was 3,619 ±

4,859 mg/L; TKN was 193 ± 117 mg/L; and P was 35 ± 18 mg/L. These parameters were higher than levels in primary lagoon effluent at Dairy A. These values represented concentration reductions (Table 11) 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. The digestion efficiency of the primary lagoon is further illustrated by the COD/TS ratio that was reduced slightly to 1.02, while the VS/TS ratio decreased from 0.65 in milking parlor wastewater to 0.53 in the primary lagoon effluent.

Relatively large reductions in constituent concentrations occurred in the second-stage lagoon. 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. Overall concentration reductions in the two-stage system (Table 11) were 68.9% TS, 82.4% VS, 88.3% VSS, 92.9% COD, and 73.1% TKN.

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. Irrigation with lagoon effluent at Dairy J would not be limited by salinity considerations. Sodium and chloride concentrations were 100-200 mg/L; electrical conductivity was 2,000-3,000 μmhos/cm; and sodium absorption ratio (SAR) was approximately 2.

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

The mean fertilizer nutrient concentrations of primary and second-stage lagoon effluent at the three dairy farms are compared in Table 12. 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 are similar and are 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, 48 ± 11, and 314 ± 74 mg/L (49, 11, and 71 lbs/ac-in) of TKN, phosphorus, and potassium, respectively. Second-stage lagoon 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 lbs/ac-in) of TKN, phosphorus and potassium, respectively.

A comparison of salinity values for the three dairies is shown in Table 13. The electrical conductivity, which reflects a complex mixture of organic and inorganic compounds, averaged 3,318 μmhos/cm in primary lagoon effluent and 2,210 μmhos/cm in second-stage lagoon effluent. Elements contributing to soil salinity (sodium and chloride) were not found at excessive levels in these wastewaters, and sodium absorption ratio averaged just 1.83 and 2.15 in primary and second-stage lagoon effluents, respectively.

Water Use on Dairy Farms

Water use at the eleven dairy farms varied widely, depending in part on the type of waste removal system employed. The greatest variable appeared to be the use of sprinkler cow washer systems and flush systems as opposed to manual removal of manure.

Results, expressed as gallons per cow per day, are summarized in Table 14, including the average, standard deviation, minimum, and maximum for each meter on all farms. The functional use of the meters is also identified. The average water use for specific functions within the dairy farms was compiled. The total amount of fresh water used for sanitation and manure removal is shown in Table 15. It averaged 149.8 L (39.59 gal) per cow per day. The mean value for each farm ranged from 46.5 to 261.8 L (12.28 to 69.17 gal) per cow per day.

Table 16 shows the average water use for milking parlors and adjacent holding sheds without flush systems or cow washers (i.e. manual cleanup). The average water usage was 75.2 ± 53.1 L (19.86 ± 14.02 gal) per cow per day. Milking parlors and holding sheds with sprinkler cow washers used an average of 178.4 ± 66.8 L (47.13 ± 17.65 gal) per cow per day, as shown in Table 17. The water use for sprinkler cow washers (including fresh water and recycled water) (Table 18) averaged 132.7 ± 50.2 L (35.06 ± 13.27 gal) per cow per day. However, fresh water use averaged only 104.6 ± 60.9 L (27.64 ± 16.09 gal) per cow per day for the five dairies.

On four farms, the combined fresh water use for milking parlor, holding shed with sprinkler cow washers, and cow drinking water troughs averaged 302.5 ± 63.7 L (79.91 ± 16.83 gal) per cow per day (Table 19). The water used for cattle drinking water troughs on 7 farms averaged 108.4 ± 45.4 L (28.65 ± 11.99 gal) per cow per day (Table 20).

For Dairy H, total fresh water use from both wells was 274.9 L (72.62 gal) per cow per day (Table 19). However, functional water use could not be determined because the water meter readings included not only the milking center with cow washers but also the cattle watering troughs, and several additional meters would have been needed to isolate the functional water uses. However, by assuming an average value of 108.4 L (28.65 gal) per cow per day for cattle drinking water use, as obtained from the other 7 dairies (Table 20), an estimate of approximately 167 L (44 gal) per cow per day for the milking center at Dairy H was obtained, which is 12% greater than the average.

The data in Tables 16, 17 and 18 indicate that sprinkler cow washers increased fresh water use by 103.2 to 104.6 L (27.27 to 27.64 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 75.7 and 189.3 L (20 and 50 gal) per cow per day of fresh water use, respectively, to convey manure into the system.

Specialized water uses that were separately metered included the following:

1. Vacuum pump (Dairy B)--55.1 ± 30.7 L (14.55 ± 8.12 gal) per cow per day.

2. Plate cooler (Dairy B)--165.5 ± 29.0 L (43.73 ± 7.67 gal) per cow per day.

3. Calf barn, cleanup, calf watering and occasional dry cow watering (Dairy F)--42.9 ± 35.6 L (11.34 ± 9.41 gal) per cow per day.

Graphs showing daily water usage for each meter at Dairies A, B, and J are shown in Appendix D. During the study, one of the farms (Dairy B) reduced fresh water use by an average of 205.5 L (54.3 gal) per cow per day, a reduction of 68%. This 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. This saved a total of more than 163 m^3 or 163,000 L (43,000 gal) per day. This water savings would be sufficient to operate two more dairies of a similar size and design.

A comparison of this data with earlier reports (Pope, 1992; Sweeten et al., 1990) indicated decreasing trends in water use for the last 12 months of the study at half of the dairies and slight increases at the other half of the dairies. Overall, the fresh water use decreased slightly throughout the study.

At the beginning of this study, all eleven dairies had systems for collecting, storing, and land applying solid manure and wastewater from the milking parlor and some also had runoff control systems. Most of the dairies either had a Texas Water Commission (TWC) permit or obtained technical assistance and obtained a TWC permit during this study. The resulting modifications to the existing waste management facilities included additional lagoons or runoff control structures that were planned and/or installed while the study was in progress.

For four of the farms (Dairies A, C, I, and J), data collected in this study were utilized by SCS 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 Texas Water Commission permit applications for the dairy farms.

Milking Parlor Wastewater Volumes

Hydrographs of milking parlor wastewater were measured in 0.46 m (1.5 ft) type-H flumes using either (a) a Stevens type-F float stage recorder (Dairies A and J) operated at 2:1 gear ratio for two consecutive 12 hour periods or (b) an ISCO Model 2870 bubbler stage recorder operated for a 24-hour period. There were inherent errors in this process. In particular, sedimentation of suspended solids within the approach sections, throat sections, and settling wells of the type-H flumes interfered with accurate measurement. For example, the holes interfacing the flume throat section and the stilling well frequently plugged, restricting liquid interchange and/or these solids sometimes accumulated in the stilling well holding the float above the instantaneous water line. A solids mat that settled on top of the bubbler tube outlet very likely increased pressure and the apparent liquid depth readings.

Typical hydrographs of 12 and 24-hour sampling periods for Dairies A, B, and J are shown in Figures 9, 10, 11, 12, 13, and 14. Water levels fluctuated rapidly under impulses of flushing, manual washing, or sprinkler cow-washing events. It can be difficult to obtain representative water samples from such fluctuating flow with a water-level actuated sampler. Some of the recorded variability in the constituent concentrations in the milking center wastewater is probably due to this difficulty.

Results for each dairy for the sampling period are shown in Table 21 (Dairy A), Table 22 (Dairy B), and Table 23 (Dairy J). For example, at Dairy A, the 45 events (24 hours each) recorded from January 18, 1989 through September 24, 1991 produced a measured wastewater volume of 41.11 $\pm$ 18.61 m^3/day (1452.0 $\pm$ 657.4 ft^3/day) with a range of 4.35 to 101.07 m^3/day (153.7 to 3569.8 ft^3/day). The mean wastewater discharge volume was equivalent to an average of 0.15 m^3/cow/day (38.65 gal/cow/day) (for 281 cows average) which was 31% below the fresh water usage for manure removal and sanitation of 0.21 m^3/cow/day (55.94 gal/cow/day).

At Dairy B, the measured daily wastewater volume for the August 1990 to March 1992 period (Table 22) ranged 30-fold from 59.26 to 1748.48 m^3/day (2,093 to 61,754 ft^3/day), and the mean value was 514.48 $\pm$ 456.93 m^3/day (18,171 $\pm$ 16,138 ft^3/day). The mean value is equivalent to a manure and wastewater production of 0.64 m^3/cow/day (168 gal/cow/day), which is 450% higher than the measured daily water use of just 0.12 m^3/cow/day (30.47 gal/cow/day). Hence, the inaccuracy of the uncalibrated bubbler meter and H-flume combination, operating in liquid dairy cattle manure with a heavy suspended solids load, is immediately suspect.

The results from Dairy J are presented in Table 23. The float stage recorder produced average values of 94.86 $\pm$ 107.92 m^3/day (3,349.1 $\pm$ 3,811 ft^3/day) and a range of 26.57 to 580.32 m^3/day (939 to 20,496 ft^3/day). The mean wastewater volume is equivalent to 0.18 m^3/cow/day (46.4 gal/cow/day), which is 61% above the measured volume of fresh water use of 0.109 m^3/cow/day (28.75 gal/cow/day).

Daily fluctuations in flume-measured wastewater volumes are shown in Figure 15 (Dairy A and J) and Figure 16 (Dairy B). The data for Dairy A shows more consistency than the other two dairies.

Hydraulic Retention Times

The hydraulic retention times (HRT's) in the primary lagoons at Dairies A, B, and J were estimated using two approaches. The first approach was to divide the liquid volume of the lagoons by the average total daily water use plus the estimated wet manure volume entering the lagoons. The latter was based on wet manure production for 4 hours per day in confinement per cow as calculated using ASAE Standards (1993c) data (mean plus one standard deviation). The average value of water use and cow numbers shown in Table 15 were used for this purpose. As a result, the HRT's in primary lagoons at Dairies A, B, and J were estimated at 81 days, 119 days, and 110 days, respectively. For Dairy B, the primary lagoon was partitioned into a 25 year, 24 hour runoff storage volume of 11,700 m^3 (415,000 ft^3) and a primary lagoon operating volume of 11,000 m^3 (391,000 ft^3).

The second approach for calculating HRT involved dividing the liquid volume of these lagoons by the average daily milking center volumes measured with H-flumes (Tables 21, 22 and 23). The resulting estimates of HRT were as follows: Dairy A, 118 days; Dairy B, 22 days; and Dairy J, 99 days. The wide discrepancy between the HRT's calculated by the two methods for Dairy B further indicates the suspect nature of the flume-measured wastewater volumes in Table 22.

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. From data in Table 15, volumes of wastewater for Dairies A, B, and J were projected at 77, 42, and 40 m^3 (0.75, 0.41 and 0.39 ac-in) per cow per year, respectively. The total wastewater volumes were estimated to be 21,700, 34,000, and 21,500 m^3 (211, 331, and 209 ac-in) per year, respectively, for Dairies A, B and J.

The annual total solids, volatile solids, total suspended solids, and chemical oxygen demand loads from the milking center were determined by multiplying the mean concentrations of milking parlor wastewater (Tables 4, 7, and 10) by the average annual water use projections. The resulting values are shown in Appendix E. For total solids, annual loads were as follows: Dairy A, 120,000 kg TS/yr (265,000 lbs/yr); Dairy B, 240,000 kg TS/yr (530,000 lbs/yr); and Dairy J, 103,000 kg/yr (227,000 lbs/yr). Similarly, the annual loading of volatile solids from the milking center wastewater was: Dairy A, 74,800 kg VS/yr (165,000 lbs/yr); Dairy B, 163,000 kg VS/yr (358,000 lbs/yr); and Dairy J, 66,800 kg VS/yr (147,000 lbs/yr). The total suspended solids loads averaged 53% of the total solids load for the 3 dairies and were projected to be 62,600 kg TSS/yr (138,000 lbs/yr); 130,000 kg TSS/yr (286,000 lbs/yr), and 55,100 kg TSS/yr (121,000 lbs/yr) for Dairies A, B, and J. The chemical oxygen demand load was estimated from the monitoring results to be 139,000 kg/yr (306,000 lbs/yr) from Dairy A; 285,000 kg/yr (628,000 lbs/yr) from Dairy B; and 119,000 kg/yr (262,000 lbs/yr) from Dairy J.

The average annual loading rates from milking centers on a per cow basis for the 3 dairies were estimated as follows (Table E-1):

1. Total solids--285 kg/cow/yr (628 lbs/cow/yr)
2. Volatile solids--187 kg/cow/yr (411 lbs/cow/yr)
3. Total suspended solids--152 kg/cow/yr (335 lbs/cow/yr)
4. Chemical oxygen demand--311 kg/cow/yr (734 lbs/cow/yr)

The average annual nutrient loading rates from the milking center wastewater was likewise estimated by the above procedure (Table E-2). Estimated TKN and P production from the measurements and projections were as follows:

1. Dairy A--5600 kg TKN/yr (12,400 lbs/yr) and 1,800 kg P/yr (4,100 lbs/yr)
2. Dairy B--13,700 kg TKN/yr (30,200 lbs/yr) and 1,800 kg P/yr (4,100 lbs/yr)
3. Dairy J--5,600 kg TKN/yr (12,000 lbs/yr) and 800 kg P/yr (1,800 lbs/yr)

These values averaged out to 15 kg TKN/cow/yr (34 lbs/cow/yr) and 2.8 kg P/cow/yr (6.1 lbs/cow/yr). Considering the fact that each cow is 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 Standards (1993c) 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. The remaining amounts of solids (total, volatile, and total suspended) and COD for the primary lagoon and second-stage lagoon effluent are shown in Table E-3. These values essentially reflect the percent reductions reported earlier in Tables 5, 8, and 11.

On a per cow basis, averaged for the 3 dairy farms, the annual amounts of constituents remaining following primary lagoon treatment were as follows (Tables E-3 and E-4):

1. Total solids--180 kg/cow/yr (398 lbs/cow/yr)
2. Volatile solids--100 kg/cow/yr (221 lbs/cow/yr)
3 TSS--86 kg/cow/yr (189 lbs/cow/yr)
4. COD--182 kg/cow/yr (400 lbs/cow/yr)
5. TKN--10.7 kg/cow/yr (23.6 lbs/cow/yr)
6. P--2.3 kg/cow/yr (5.1 lbs/cow/yr)

Results for second-stage lagoons at Dairies A and J were as follows:

1. TS--62 kg/cow/yr (138 lbs/cow/yr)
2. VS--24 kg/cow/yr (54 lbs/cow/yr)
3. TSS--26 kg/cow/yr (57 lbs/cow/yr)
4. COD--21 kg/cow/yr (46 lbs/cow/yr)
5. TKN--5.0 kg/cow/yr (11 lbs/cow/yr)
6. P--1.2 kg/cow/yr (2.7 lbs/cow/yr)

From the concentrations of total Kjeldahl nitrogen in primary lagoon effluent (Table 12), the soil loading rates of TKN were projected to be 3,730 kg/yr (8,230 lbs/yr), 9,565 kg/yr (21,090 lbs/yr), and 4,137 kg/yr (9,122 lbs/yr) for Dairies A, B, and J, respectively. This is equivalent to annual TKN soil loading rates per cow of 13.3, 11.8, and 7.7 kg (29.3, 26.1, and 16.9 lbs) per cow per year, respectively, for an average of 10.9 kg (24.1 lbs) TKN per cow per year in lagoon effluent resulting from the milking parlor ("process generated") wastewater. The amount of nitrogen that would be contained in second-stage lagoons would be about half these amounts for primary lagoon effluent. Similarly, phosphorus content of primary lagoon effluent was projected at 1,150 kg/yr (2,540 lbs/yr), 1,870 kg/yr (4,130 lbs/yr), and 750 kg/yr (1,660 lbs/yr) for Dairies A, B, and J, respectively. This is equivalent to annual soil loading rates of phosphorus of 4.1, 2.3, and 1.4 kg (9.0, 5.1, and 3.1 lbs) per cow per year.

Similarly, in second-stage lagoon effluent for Dairies A and J, projected soil loading rates (Table E-4) for TKN were 2,540 kg per yr (5,600 lbs per yr) and 1,540 kg per yr (3,400 lbs per yr), respectively, which is equivalent to 9.0 kg (19.9 lbs) and 2.8 kg (6.3 lbs) per cow per year. For phosphorus the projected soil loading rates in second-stage lagoon effluent were 846 kg per yr (1,867 lbs per yr) and 150 kg per yr (331 lbs per yr), which is equivalent to 3.0 kg (6.6 lbs) and 0.28 kg (0.61 lbs) per cow per year.

Ground Water Quality

Ground water was sampled from the water supply wells at the tap at the 11 dairies on April 19, 1990. Laboratory analysis was provided by the Extension Water Testing Laboratory in College Station. Results are shown in Table 24. None of these wells produced ground water that exceeded the level of 10 mg/L nitrate-nitrogen established as a drinking water standard by the USEPA and adopted by the Water Hygiene Division, Texas Department of Health and, subsequently, the Texas Water Commission. The average nitrate concentration was 1.2 ± 1.6 mg/L while the range was 0.0 to 4.35 mg/L. Water quality at all these wells was good to excellent as evidenced by low nitrate, salinity, and other mineral elements. Electrical conductivity averaged 904 ± 82 μmhos/cm. Analysis was not obtained on bacterial indicator organisms.

The same water supply wells and distribution system were re-sampled on July 2, 1992, more than 2 years after the initial sampling event. Samples were taken when the producing wells (used daily) were in operation. As shown in Table 25, nitrate concentrations were even lower at the second sampling event: average of 0.81 ± 1.10 mg/L NO_3-N, with a range of 0.10 to 3.17 mg/L. Electrical conductivity was also lower this time, ranging from 322 to 655 μmhos/cm and averaging 438 ± 86 μmhos/cm, and SAR values were only 0.54 ± 0.19. A comparison of ground water quality for both sampling dates (Table 26) shows that these farms have a good to excellent ground water supply for human or livestock consumption and for irrigation of crops from the standpoint of nutrients, salts and other minerals. There was no evidence of ground water quality degradation in these wells near operating dairy farms.

Open Lot Runoff Quality

The quality of the runoff sampled at the three dairies is summarized in Tables 27, 28, and 29 for Dairies A, B, and J, respectively. The average concentrations of TS, VS, and COD are plotted in Figure 17 for the five runoff sampling stations. In general, the runoff from Dairy J had the lowest constituent concentrations, while Dairies A and B had similar concentrations. This may have been related to a lower stocking rate on that portion of the open lots at Dairy J that was monitored compared to those at Dairies A and B. For Dairies A and B, average concentrations ranged from 5,169 to 7,853 mg/L TS; from 1,897 to 2,892 mg/L VS; and from 2,635 to 4,248 mg/L COD. The TS concentrations of the runoff were similar to the average concentrations of the milking parlor wastewater, which were 5,541 mg/L for Dairy A and 7,065 mg/L for Dairy B. However, the composition of the solids was different. The VS/TS ratio for the open lot runoff averaged 0.35 at Dairy A and 0.44 at Dairies B and J. These values are less than the milking parlor wastewater ratios of about 0.65. Similarly, the COD/TS ratio was considerably lower for the runoff (0.50 for Dairy A, 0.64 for Dairy B, 0.55 for Dairy J) than for the milking parlor wastewater (about 1.17). These ratios indicate that the runoff contained more soil particles (ash or fixed solids) and also required much less treatment.

The average concentrations of N, P, and K are plotted in Figure 18 for the five runoff sampling stations. The average concentrations of these 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.

SUMMARY AND CONCLUSIONS

Summary

The objective of this project was to determine the effectiveness of dairy wastewater management systems in reducing pollutant concentrations. The practices studied included solids settling basins and lagoon systems (primary and/or secondary). Data were collected at four dairies in North Central Texas (Erath County) to characterize the raw wastewater from milking parlors and to determine the reductions in concentrations of pertinent water quality parameters due to the settling basins and lagoons. At one dairy with 1,900 cows, periodic grab sampling was used to determine the treatment efficiency of a shallow concrete settling basin. Concentration reductions of 32.8% TS, 44.8% VS, 59.0% VSS, 46.5% COD, and 14.2% TKN were measured for the settling basin.

Subsequently, three other 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 parlor and holding shed. Runoff from open lots was also monitored.

Dairy A had a properly functioning two-stage anaerobic lagoon system that was adequately sized relative to its volatile solids loading rate of 0.064 kg VS/day/m^3 (0.0040 lbs VS/day/ft^3) and hydraulic retention time of 81-118 days. Overall concentration reductions due to the primary and secondary lagoons were determined as follows: 70.3% TS, 80.2% VS, 86.2% VSS, 89.8% COD, and 54.9% TKN. Sludge accumulation after more than 12 years of continuous operation was less than 14% which is remarkably low.

During the monitoring period, Dairy B constructed a settling basin and implemented a water recycling system that significantly affected the characteristics of the wastewater and subsequent reductions in concentrations. Overall system reductions for the period during which both the settling basin and the primary lagoon/detention pond were in operation (15 months) were 28.3% TS, 37.2% VS, 45.0% VSS, 34.6% COD, and 24.9% TKN as compared to wastewater from the milking parlor. The lower removal efficiencies may have reflected in part the additional loading of manure solids and soil particles from open lot runoff, a backlog of solids that had accumulated prior to settling basin construction, and an inherently lower digestion efficiency of combination lagoons/runoff detention ponds. The data also showed that removal efficiencies for the settling basin alone were as high as 80% TS, 82% VS, 92% VSS, 81% COD, 81% TKN and 37% P on two consecutive sampling days.

Concentrations of milking center wastewater and primary lagoon effluent for Dairy J were similar to values found at Dairy A in terms of solids (total, volatile, total suspended, and volatile suspended), chemical oxygen demand, and total Kjeldahl nitrogen. Reductions in concentrations in milking parlor wastewater through the primary lagoon were 26.1% TS, 40.1% VS, 40.5% VSS, 34.8% COD, and 27.8% TKN, which was less than for Dairy A. However, overall concentration reductions in the two-stage system were much higher: 68.9% TS, 82.4% VS, 88.3% VSS, 92.9% COD, and 73.1% TKN. Sludge accumulation in the primary lagoon was 25% after 12 years of operation.

Nutrient concentrations of primary lagoon effluent were higher at Dairy B than at Dairies A and J, and the three farms had an average nutrient content of 216, 48, and 314 mg/L (49, 11, and 71 lbs/ac-in) of total N, total P and total K. Second-stage lagoon effluent concentrations at Dairies A and J were further reduced to 95, 21 and 244 mg/L (21, 5, and 55 lbs/ac-in) of total N, total P and total K, respectively.

A study of water use at eleven dairy farms in Erath County was made using 39 in-line water meters that were installed beginning in November, 1989. Data compiled from November 1989 through April, 1992 showed that an average of 148 L (39.16 gal) of water/cow/day was used for sanitation and manure removal inside the milking parlors and holding sheds, including the use of fresh water for manual cleanup, flush systems, and/or sprinkler cow washers. However, there was considerable variation in water usage depending upon whether flush systems and/or sprinkler cow washers were used and other factors. The minimum water use for sanitation and manure removal averaged 46.48 L (12.28 gal)/cow/day while the maximum was 261.8 L (69.17 gal)/cow/day.

The cow washers required an average of 132.7 L (35.06 gal)/cow/day including recycled water (or 104.6 L (27.64 gal)/cow/day fresh water) and represented the single biggest component of water use. Sprinkler cow washers increased water use by almost 140 percent above water use for a manually-washed milking parlor and holding shed. 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.

Conclusions

Analyses of the data lead to the following conclusions:

1. Concentrations of the constituents in dairy wastewater from milking parlors vary over time. Numerous samples of wastewater and lagoon effluent are required to accurately characterize reductions in constituents due to a dairy waste management system.

2. 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.

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3. Solids settling basins varied 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.

4. A two-stage anaerobic lagoon system (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 110 days and theoretical volatile solids loading rates of 0.063 to 0.090 kg/day/m^3 (0.0040 to 0.0054 lbs/day/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 phosphorus.

5. The minimum standards of the Texas Water Commission provide for a minimum net effective storage capacity of 24 days for lagoons in Erath County. This would result in very low reduction of constituents.

6. The results from Dairies A and J confirm and validate the ASAE design standard (ASAE Standards, 1993a) for anaerobic lagoons, specifically, the requirement for enough volume to provide adequate treatment. In contrast, the lagoon at Dairy B was designed as a holding pond and showed much lower reductions, i.e., less treatment.

7. In two-stage lagoon systems, the primary lagoon accounted for most of the reductions in solids-related constituents and chemical oxygen demand, while the second-stage lagoons accounted for nearly the same nutrient losses as did the primary lagoons.

8. Dairy lagoon effluent is a good source of available plant nutrients with relatively low potential for soil salinity.

    a. Nutrient concentrations of primary lagoon effluent at three farms averaged 216 $\pm$ 58 mg/L TKN, 48 $\pm$ 11 mg/L P, and 314 $\pm$ 74 mg/L K. Over 90% of the TKN was in the ammonium form.

    b. Nutrient concentrations of second stage lagoon effluent were 95 $\pm$ 32, 21 $\pm$ 25, and 244 $\pm$ 59 mg/L, for TKN, phosphorus, and potassium, respectively.

    c. Salinity indicators in primary and secondary lagoon effluent included electrical conductivity, which ranged from 2,000 $\pm$ 209 to 4,135 $\pm$ 1,160 μmhos/cm in lagoon effluent for the three dairy farms.

    d. Higher concentrations of TKN in second stage lagoon effluent were found in winter than in summer months.

    e. 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.

9. The volumes of settled solids (sludge) present in primary treatment lagoons at Dairies A and J were measured at 14 and 25%, respectively, of the total liquid volume after more than 12 years of continuous operation.

10. Water use for manure removal and sanitation ranged from 46.5 to 261.8 L (12.28 to 69.17 gal)/cow/day, with an average of 148.2 L (39.16 gal)/cow/day. The biggest variable was the use of sprinkler cow washers, which increased water use by 150%. Data from the water use study can be used for design of dairy waste management systems with similar configurations in North Central Texas.

11. Ground water sampled at wells ranging in depth from 30 to 151 m (100 to 490 ft) on 11 dairy farms was not contaminated by nutrients or mineral elements on either sampling date.

12. Measurement of daily wastewater volume from milking centers using a Type-H flume produced erratic results. This method produced estimates of wastewater volume that ranged from 30% below to 450% above the measured volume of water used for sanitation and manure removal on these 3 dairy farms.

13. Estimated annual manure loading rates from milking centers into lagoons, on a per-cow per year basis, were as follows: 285 kg (628 lbs) TS, 187 kg (411 lbs) VS, 152 kg (335 lbs) TSS, 116 kg (257 lbs) VSS, 311 kg (734 lbs) COD, 15 kg (34 lbs) TKN, and 2.8 kg (6.1 lbs) P. These values are reasonably consistent with values predicted from the ASAE manure production standard using the assumptions of 4 hours per day in confinement and 635 kg (1,400 lbs) per head cattle liveweight.

14. As compared to milking center wastewater, runoff from open lots at Dairies A and B had similar concentrations of TS (5,169 and 7,853 mg/L, respectively), VS (1,897 and 2,982 mg/L), and COD (2,635 and 4,248 mg/L), indicating that runoff contained a greater proportion of soil particles. Runoff at Dairy J was below these levels of concentrations, perhaps due to a lower animal stocking rate.

15. 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.

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Table 1. Optimum site selection factors for open feedlots and dairies (Sweeten et al., 1991b)

TOPOGRAPHY
- good slope for drainage, 3-5 percent
- slope direction--away from buildings or working corrals
- aspect--west or south facing slopes
- elevation--above the 100-year flood plain
- near top of ridge or hill--avoid subsurface water flow

SOILS

Building site and corrals
- firm, stable subsoil--high coefficient of uniformity (clay through pebbles)
- medium texture topsoil
- low shrink-swell potential
- moderately well-drained
- restrictive layer--below 2 to 3 ft

Holding ponds and lagoons
- clay subsoil--permeability 1 x 10^{-7} cm/sec to meet TWC requirements
- forms stable embankments

Land application of manure/wastewater
- good soil depth (3 ft)
- absence of restricting layer in root zone
- moderate permeability and drainage
- medium texture
- good nutrient holding capacity

GEOLOGY
- deep aquifer
- restrictive layer above water table
- moderate texture soil material

WATER QUANTITY AND QUALITY
- good ground water quality
- absence of recharge features
- adequate water supply
- facilities 150 ft from wells
- facilities ¼ mile from surface water

WIND AND ATMOSPHERIC VARIABLES
- down wind from neighbors (optimum wind direction)
- 0.5 to 2 miles from rural neighbors or towns, depending on size
- good dispersion features

AESTHETICS
- visual barrier
- compatible land uses

LAND AREA
- sufficient to achieve nutrient balance (N,P)
- reasonable haul distance
- neighboring farmer demand for manure/wastewater
- appropriate distance from waterways (approximately 100 ft)

ACCESSIBILITY
- good roads
- feedstuffs supply
- labor and market access

UTILITIES
- 3-phase electricity
- absence of major oil, gas or electric transmission lines

Table 2. Sampling dates for dairy milking parlor wastewater and runoff included in data summaries

Location	Date	No. Events
Dairy A		
• Milking Parlor	01/18/89 - 08/19/91	48
• Primary Lagoon Effluent	04/07/89 - 08/28/91	42
• Second-Stage Lagoon Effluent	04/07/89 - 08/28/91	45
• Upper Flume, drylot runoff	02/16/89 - 08/14/91	21
• Lower Flume, drylot runoff	08/08/89 - 06/22/91	33
Dairy B		
• Milking Parlor	05/10/90 - 08/27/91	35
• Settling Basin Outflow	05/10/90 - 08/27/91	20
• Primary Lagoon Effluent	05/10/90 - 08/27/91	31
• North Flume, drylot runoff	08/02/89 - 08/12/91	55
• South Flume, drylot runoff	11/22/89 - 08/12/91	49
Dairy J		
• Milking Parlor	02/27/90 - 08/19/91	36
• Primary Lagoon	02/27/90 - 08/19/91	41
• Second-Stage Lagoon	05/28/91 - 08/19/91	7
• Drylot Runoff Flume	02/21/90 - 08/11/91	31

Table 3. Milking parlor wastewater, settling basin outflow, and lagoon effluent concentrations, Dairy M, 1988

Constituent	Units	Milking Parlor Wastewater		Settling Basin Outflow		MP-SB† Reduction (%)	Lagoon Effluent		SB-L† Reduction (%)	Overall† Reduction (%)
		Average n=4	Std. Dev.	Average n=4	Std. Dev.		Average n=3	Std. Dev.		
Total Solids	mg/L	2,985	1,244	2,007	336	32.8	1,884	339	6.1	36.9
Volatile Solids	mg/L	2,028	796	1119	169	44.8	980	309	12.4	51.7
Volatile Susp. Solids	mg/L	1,401	51	574	5	59.0	403	339	29.7	71.2
COD	mg/L	4,269	2,279	2,283	760	46.5	1,955	981	14.4	54.2
Nitrogen	mg/L	170	152	146	37	14.2	152	65	-4.0	10.8
Phosphorus	mg/L	23.7	5.0	23.3	3.8	1.5	27.6	7.0	-18.3	-16.5
Potassium	mg/L	169	163	151	44	10.8	180	7	-19.2	-6.3
Salinity Data:										
EC, Elec. Cond.	μmhos/cm	2,021	1,253	1,575	984	22.1	2,009	213	-27.5	0.6
SAR, Sodium Absorption Ratio		1.64	0.92	1.69	0.83	-2.7	1.83	0.78	-8.8	-11.8

† Percent reductions were computed as follows:

MP-SB = (milking parlor concentration minus settling basin concentration) divided by milking parlor concentration
SB-L = (settling basin concentration minus lagoon concentration) divided by settling basin concentration
Overall = (milking parlor concentration minus lagoon concentration) divided by milking parlor concentration

Table 4. Concentrations of milking parlor wastewater and lagoon effluent, Dairy A, Erath County, Texas, 1/18/89-8/19/91

Constituent	Units	Milking Parlor, n=48		Primary Lagoon Effluent, n=42		Second-Stage Lagoon Effluent, n=45	
		avg	std dev	avg	std dev	avg	std dev
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., µmhos/cm		3700	3220	2819	461	2420	377
SAR, Sodium Absorption Ratio		2.36	1.81	1.97	1.20	2.09	1.14
SSP, Soluble Sodium Percentage		20.90	6.11	20.70	2.60	21.94	1.96

Table 5. Concentration reductions (percent) in wastewater from milking parlor through primary and second-stage lagoon system, Dairy A, Erath County, Texas, 1/18/89-8/19/91

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, Sodium Absorption Ratio	16.4	-6.1	11.3
SSP, Soluble Sodium Percentage	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

Table 6. Mean seasonal concentrations of selected constituents and results of statistical analyses, Dairy A, Erath County, Texas, 1/18/89-8/28/91

Location	Constituents	Units	Fall	Winter	Spring	Summer	pr>F
Milking Center	Total Solids	mg/L	5468a	6360a	5658a	4681a	0.5601
	Volatile Solids	mg/L	3660b	3940b	3715b	2536b	0.2726
	Suspended Volatile Solids	mg/L	2429c	2062c	2195c	1447c	0.5164
	COD	mg/L	5989d	7431d	7328d	4516d	0.2969
	Nitrogen	mg/L	219.7e	375.3e	282.0e	147.5e	0.5182
	Electrical Conductivity	µmhos/cm	3390f	4574f	3808f	2917f	0.6424
	Nitrate-Nitrogen	mg/L	0.6g	0.7g	0.7g	0.4g	0.7301
Primary Lagoon	Total Solids	mg/L	1764a	2208ab	2656b	1567a	0.0194
	Volatile Solids	mg/L	778de	1117dc	1276c	629e	0.0102
	Suspended Volatile Solids	mg/L	361fg	592fg	719f	260g	0.0621
	COD	mg/L	1073h	1960h	2054h	685h	0.0794
	Nitrogen	mg/L	157.6j	190.3i	179.8ij	157.6j	0.0158
	Electrical Conductivity	µmhos/cm	2966kl	2833kl	3018k	2544l	0.0487
	Nitrate-Nitrogen	mg/L	4.2m	3.0m	0.3m	1.3m	0.3078
Second-Stage Lagoon	Total Solids	mg/L	1578a	1741a	1685a	1571a	0.6982
	Volatile Solids	mg/L	622b	736b	690b	659b	0.9281
	Suspended Volatile Solids	mg/L	327c	286c	239c	337c	0.9259
	COD	mg/L	739de	877d	650fe	495f	0.0006
	Nitrogen	mg/L	129.6g	145.5g	132.9g	80.4h	0.0001
	Electrical Conductivity	µmhos/cm	2510i	2496i	2653i	2126j	0.0003
	Nitrate-Nitrogen	mg/L	3.3kl	15.1k	0.3l	4.1kl	0.1455

Note: Means followed by the same letter in a row are not different at a significance level of $\alpha = 0.05$.

Table 7. Summary of concentrations of milking parlor wastewater, settling basin outflow, and lagoon supernatant, Dairy B, Erath County, Texas, 5/10/90-8/27/91

Constituent	Units	Milking Center n=35		Settling Basin Outflow n=25		Primary Lagoon Supernatent, n=31	
		avg	std dev	avg	std dev	avg	std dev
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	2950	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	0.746	1.93	0.3	0.3	1.006	2.355
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	0.817	1.2	0.7	1.078	0.759
Chloride	mg/L	132	84	177	37	135	52
Iron	mg/L	7	4	11	27	17	62
pH		7.60	0.51	7.6	0.4	7.67	0
Salinity Data:							
EC, Elec. Cond. µmhos/cm		4743	3387	4287	1188	4135	1160
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, Sodium Absorption Ratio		2.3	1.3	2.0	0.4	2.09	0.3518
SSP, Soluble Sodium Percentage		19.710	3.411	16.2	3.8	19.26	2.3735

Table 8. Wastewater and lagoon effluent reductions, Dairy B, Erath County, Texas, 5/10/90-8/27/91

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, Sodium Absorption Ratio	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 concentrationminus primary lagoon concentration) divided by milking parlor concentration

Table 9. Constituent concentrations and reductions for settling basin, Dairy B, Erath County, Texas, for two selected dates, 5/91

Constituent	Units	May 7, 1991			May 21, 1991			Average % Reduction
		Inflow Conc.	Outflow Conc.	% Reduction	Inflow Conc.	Outflow Conc.	% Reduction	
Total Solids	mg/L	13,640	3,388	75	23,650	3,600	85	80
Volatile Solids	mg/L	8,610	2,070	76	18,197	2,227	88	82
Suspended Volatile Solids	mg/L	5,345	635	88	14,997	727	95	92
COD	mg/L	15,843	3,966	75	31,046	3,894	88	81
Total Nitrogen	mg/L	1,483	322	78	377	283	25	52
Phosphorus	mg/L	58	43.7	25	131.0	66.6	49	37

Table 10. Concentrations of milking parlor wastewater and lagoon effluent, Dairy J, Erath County, Texas, 2/27/90-8/19/91

Constituent	Units	Milking Parlor, n=36		Primary Lagoon, n=41		Second-Stage Lagoon, n=7	
		avg	std dev	avg	std dev	avg	std dev
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†	
Organic	mg/L	20.0	12.5	13.6	10.3	4.5†	
Phosphorus	mg/L	38	28	35	18	3	4
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.	μmhos/cm	3680	1490	3000	840	2000	289
SAR, Sodium Absorption Ratio		1.52	0.75	1.42	0.57	2.21	2.52
SSP, Soluble Sodium Percentage		14.61	3.90	15.05	3.73	‡	

† One sample
‡ Data not available

Table 11. Concentration reductions (percent) in wastewater from milking parlor through primary and second-stage lagoon system, Dairy J, Erath County, Texas, 2/27/90-8/19/91

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, Sodium Absorption Ratio	6.9	-55.8	-45.1
SSP, Soluble Sodium Percentage	-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 concentraiton
‡ Data not available

Table 12. Comparison of average fertilizer nutrient concentrations in lagoon effluent and supernatant, Dairies A, B, and J, Erath County, Texas

	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 13. Comparison of average salinity indicators in lagoon effluent or supernatant, Dairies A, B, and J, Erath County, Texas

Location	Electrical Conductivity μmhos/cm	Chloride, Cl mg/L	Sodium, Na mg/L	Calcium, Ca mg/L	Magnesium, Mg, mg/L	Sodium Absorption Ratio, SAR
A. Primary Lagoon						
Dairy A (n = 42)	2819 ± 461	158 ± 81	149 ± 302	178 ± 313	97 ± 194	1.97 ± 1.20
Dairy B (n = 31)	4135 ± 1160	135 ± 52	136 ± 44	203 ± 128	89 ± 20	2.90 ± 0.35
Dairy J (n = 41)	3000 ± 840	138 ± 61	108 ± 91	193 ± 116	70 ± 14	1.42 ± 0.57
Average	3318	144	131	191	85	1.83
B. Second-Stage Lagoon						
Dairy A (n = 45)	2420 ± 377	149 ± 66	146 ± 282	144 ± 271	93 ± 183	2.09 ± 1.14
Dairy J (n = 7)	2000 ± 289	--	115 ± 137	81 ± 24	59 ± 7	2.21 ± 2.52
Average	2210	149	131	113	76	2.15

Table 14. Average measured water use on dairy farms, Erath County, Texas, 11/89-4/92

Dairy No.		Use of Water	Meter #	Total No, n	Water Volume, gal/cow/day			
					Mean	Std. Dev.	Min.	Max.
A	1	Cow washers and water troughs	4611	212	75.60	18.39	21.94	215.74
	2	Milking parlor	4612	214	10.98	2.84	5.84	25.64
	3	Cow washers	2662	168	44.96	49.77	0.00	378.79
B	1	Main barn	4617	219	16.26	16.85	3.40	81.61
	2	Fresh water to fill recycle tank	4619	166	14.21	11.77	0.00	36.47
	3	Vacuum pump	6449	135	14.55	8.12	0.00	28.91
	4	Platecooler (recycled to sprinkler tank)	4620	182	43.73	7.67	1.65	58.06
	5	Sprinkler (recycled water only)	9001	218	28.02	8.86	11.09	54.64
	6	#1, #2, & #3 Pens, cow drinking water troughs	4614	219	28.72	7.43	10.15	59.74
	7	#4, #5, & #6 Pens, cow drinking water troughs	4621	216	23.23	8.23	6.34	94.29
	8	#7 & #8 Pens, cow drinking water	4613	219	37.62	10.00	5.06	82.04
C	1	Milking parlor and cow washers	4623	128	68.46	17.47	11.22	117.27
	2	Cow drinking water troughs	4625	128	31.27	7.47	14.43	86.69
D	1	Milking parlor, manual cleaning	4574	132	12.28	12.07	1.39	139.82
	2	Cow drinking water troughs	4575	133	48.67	22.29	20.05	290.81
E	1	Milking parlor, equip., Plate cooler, vac. Pump, compressor, etc.	4626	118	50.61	17.86	32.44	227.56
	2	Flush tank (fresh water)	4618	119	0.31	0.71	0.00	4.51
	3	Sprinkler tank inflow (fresh)	4616	108	18.25	5.68	0.01	30.24
	4	Sprinkler cow washers (outflow)	9000	118	27.37	3.09	6.89	37.60
	5	North freestall, cow lot, heifer pen	4624	118	34.24	6.99	4.37	58.61
	6	South freestall, barn & dry lot	4615	118	23.03	4.71	14.75	43.31
F	1	Milking parlor & cow washers	4622	111	37.36	13.99	0.19	59.00
	2	Water troughs	4568	121	23.33	7.76	5.86	41.22
	3	Calf barn (drinking & manual cleanup) & dry cow watering	4569	120	11.34	9.41	0.92	71.63
G	1	Milking parlor, sprinkler cow washers	4572	107	45.42	8.09	25.58	69.74
	2	Milking parlor, manual wash down and equipment	8777	124	4.76	1.29	0.54	10.00
	3	Milking parlor, equipment & bulk tank	8774	124	3.75	1.44	0.46	11.77
	4	Cow drinking water, 3 pens	8773	101	14.64	5.81	4.49	63.62
	5	Cow drinking water, 3 pens	8776	123	7.24	2.36	3.76	27.99
	6	Cow drinking water, 1 pen	8778	100	2.51	1.77	0.00	13.81
H	1	Well #1, main water storage tanks, milking parlor & cow watering	8983	119	40.56	9.85	13.72	64.22
	2	Well #2, main water storage tanks, milking parlor & cow watering	4436	108	32.06	10.87	9.08	54.33
	3	Milking parlor, line a	4570	113	32.34	8.81	8.20	47.84
I	1	Milking barn	8775	125	15.04	3.83	0.00	25.47
J	1	Milking barn equipment wash, manual clean up, & barn flush	8770	204	7.73	2.45	0.41	37.60
	2	Flush tank, holding pen	8772	205	5.68	3.07	0.10	19.78
	3	Cow washers	8771	188	15.34	7.20	0.00	34.24
K	1	Milking barn	4577	115	9.90	4.94	2.15	37.04
	2	Holding pen washdown, manual	4578	91	10.25	8.45	0.78	84.28

Table 15. Average fresh water used for sanitation and manure removal on dairy farms, Erath County, Texas, 11/89-4/92

Dairy	Average No. Cows	Average (gal/cow/day)	Comments
A	281	55.94	Cow washers and milking parlor
B	809	30.47	Main barn and filling of recycle tank
C	149	68.46	Cow washer and milking parlor
D	155	12.28	Milking parlor and manual cleaning
E	1030	69.17	Milking parlor, flush tank, and sprinkler tank
F	949	37.36	Cow washers and milking parlor
G	327	53.93	Milking parlor, cow washers, manual washdown, equipment and bulk tank
H	1514	43.97†	Milking parlor, cow washers and cow drinking water measured, less estimated drinking water use from Table 20
I	293	15.04	Milking barn
J	540	28.75	Milking barn equipment wash, manual cleanup and barn flush, holding pen flush tank, and cow washers
K	186	20.15	Milking barn and manual holding pen washdown
Average	567	39.59	
Std Dev	449	20.33	

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

Table 16. Water use in milking parlor and holding shed without cow washers, Erath County dairy farms, 11/89-4/92

Dairy No.	Ave. No. Cows (Range)	Meter No.	Fresh Water Use, gal/cow/day			Comments
			Mean	Std. Dev.	Range	
A	281 (247 - 303)	612	10.98	2.84	5.84 - 25.64	Manual cleanup and flush
B	809 (601 - 924)	617	16.26	16.85	3.40 - 81.61	Declining water use due to water conservation practices
D	155 (149 - 158)	574	12.28	12.07	1.39 - 139.82	Manual cleanup
E	1030 (958 - 1075)	626	50.61	17.86	32.44 - 227.56	Includes plate cooler and vac. pump
		618	0.31	0.71	0.0 - 4.51	Flush tank, fresh water only
			50.92	--	--	
I	293 (235 - 321)	775	15.04	3.83	0.00 - 25.47	Manual cleanup
J	540 (513 - 560)	770	7.73	2.45	0.41 - 37.60	Manual cleanup
		772	5.68	3.07	0.10 - 19.78	Flush tanks
			13.41	--	--	
K	186 (159 - 210)	577	9.90	4.94	2.15 - 37.04	Milking barn, manual cleanup
		578	10.25	8.45	0.78 - 84.28	Holding pen, manual cleanup
			20.15	--	--	
Average	446		19.86	14.02	0.00 - 232.07	

Table 17. Water use in milking parlor and holding shed, with sprinkler cow washers, Erath County dairy farms, 11/89-4/92

Dairy No.	Ave. No. Cows (Range)	Meter No.	Fresh Water Use, gal/cow/day			
			Mean	Std. Dev.	Range	Comments
C	149 (137 - 160)	623	68.46	17.47	11.22 - 117.27	
F	949 (850 - 991)	622	37.36	13.99	0.19 - 59.00	
G	327 (311 - 336)	572	45.42	8.09	25.58 - 69.74	Cow washers
		777	4.76	1.29	0.54 - 10.00	
		774	3.75	1.44	0.46 - 11.77	
			53.93			
J	550 (531 - 560)	770	7.73	2.45	0.41 - 37.60	
		772	5.68	3.07	0.10 - 19.78	
		771	15.34	7.20	0.00 - 34.24	
			28.75			
Average	491		47.13	17.65	0.19 - 117.27	

Table 18. Separate water use for sprinkler cow-washer systems, Erath County dairy farms, 11/89-4/92

Dairy No.	Ave. No. Cows	Water Source	Water Use, gal/cow/day			
			Meter No.	Mean	Std. Dev.	Range
A	281	Fresh	662	44.96	49.77	0.00 - 378.79
B	809	Fresh	619	14.21	11.77	0.00 - 36.47
		Recycle	001	28.02	8.86	11.09 - 54.64
E	1030	Fresh only	616	18.25	5.68	0.01 - 30.24
		Total, Fresh & Recycle	000	27.37	3.09	6.89 - 37.60
G	327	Fresh	572	45.42	8.09	25.58 - 69.74
J	540	Fresh	771	15.34	7.20	0.00 - 34.24
Average	590			35.06	13.27	0.00 - 378.79

Table 19. Combined fresh water use in milking parlor, holding shed (with sprinkler cow washers), and cow drinking troughs, Erath County dairy farms, 11/89-4/92

Dairy No.	No. Cows, Average	Water Use, gal/cow/day				
		Meter No.	Mean	Std. Dev.	Range	Comments
A	281 (247 - 303)	611 612	75.60 10.98 86.58	18.39 2.84 --	21.94 - 215.74 5.84 - 25.64	
C	149 (137 - 160)	623 625	68.46 31.27 99.73	17.47 7.47 --	11.22 - 117.27 14.43 - 86.69	
F	949 (850 - 991)	622 568	37.36 23.33 60.69	13.99 7.76 --	0.19 - 59.00 5.86 - 41.22	
H	1514 (1504 - 1525)	983 436	40.56 32.06 72.62	9.85 10.87 --	13.72 - 64.22 9.08 - 54.33	Well #1 Well #2
Average	722		79.91	16.93	6.05 - 241.38	

Table 20. Water use for cow drinking water troughs, Erath County dairy farms, 11/89-4/92

Dairy No.	Ave. No. Cows	Water Use, gal/cow/day				
		Meter No.	Mean	Std. Dev.	Range	Pens Served
A	281	611	30.64†	--	--	All
B	338	614	28.72	7.43	10.15 - 59.74	#1, 2, 3
	338	621	23.23	8.23	6.34 - 94.29	#4, 5, 6
	260	613	37.62	10.00	5.06 - 82.04	#7, 8
	936		29.86	--	--	
C	149	625	31.27	7.47	14.43 - 86.69	All
D	155	575	48.67	22.29	20.05 - 290.81	All
E	562	624	34.24	6.99	4.37 - 58.61	North freestall & lots
	598	615	23.03	4.71	14.75 - 43.31	South freestall & lots
	1160		28.64	--	--	
F	949	568	23.33	7.76	5.86 - 41.22	All
G	150	773	14.64	5.81	4.49 - 63.62	3 pens
	150	776	7.24	2.36	3.76 - 27.99	3 pens
	50	778	2.51	1.77	0.00 - 13.81	1 pen
	350		8.13	--	--	
Average	568		28.65	11.99	5.86 - 290.81	

† By subtraction

Table 21. Daily milking center wastewater volume measured through type-H flume and float stage recorder, Dairy A, Erath County, Texas

Dates	Times		Elapsed Time hrs	Total Discharge Volume Measured		
	Start	End		gal.	ft^3	m^3
1989						
01/18-01/19	18:15	14:30	20.25	5876	785.5	22.24
03/15-03/16	11:00	08:45	21.75	8779	1173.6	33.23
03/29-03/30	12:35	09:15	20.67	10377	1387.2	39.28
04/12-04/13	10:15	08:45	22.50	14294	1910.8	54.10
05/10-05/11	11:45	16:45	29.00	19907	2661.2	75.35
05/23-05/24	10:45	09:25	22.67	26704	3569.8	101.07
06/21-06/22	10:05	10:15	24.17	13663	1826.5	51.71
07/05-07/06	10:10	09:15	23.08	17487	2337.7	66.19
07/18-07/19	11:25	09:30	22.08	19468	2602.5	73.69
08/15-08/16	11:30	10:30	23.00	10257	1371.2	38.82
08/29-08/30	22:10	10:40	12.50	13769	1840.6	52.12
09/14-09/15	11:45	09:10	21.42	6644	888.2	25.15
09/28-09/29	10:00	10:30	24.50	13640	1823.4	51.63
10/12-10/13	09:00	09:05	24.08	15827	2115.8	59.91
11/02-11/03	10:00	10:00	24.00	4625	618.3	17.51
11/16-11/17	08:00	07:30	23.50	8139	1088.0	30.81
11/30-12/01	08:00	07:30	23.50	8842	1182.0	33.47
12/14-12/15	08:00	07:30	23.50	5738	767.1	21.72
12/28-12/29	08:30	08:20	23.83	7487	1000.9	28.34
1990						
01/11-01/12	08:30	07:00	22.50	7727	1032.9	29.25
01/25-01/26	08:00	07:50	23.83	10128	1353.9	38.33
02/08-02/09	08:30	08:30	24.00	9947	1329.7	37.65
03/07-03/08	08:30	08:15	23.75	10409	1391.5	39.40
03/20-03/21	09:15	07:30	22.25	8743	1168.8	33.09
04/03-04/04	07:30	07:30	24.00	11917	1593.1	45.11
04/17-04/18	07:15	07:15	24.00	10063	1345.2	38.09
05/01-05/02	08:15	07:15	23.00	16929	2263.1	64.08
05/15-05/16	07:45	06:30	22.75	8897	1189.4	33.68
06/05-06/06	07:30	06:30	23.00	11706	1564.9	44.31
06/20-06/21	07:30	07:30	24.00	21095	2820.0	79.84
07/18-07/19	07:00	06:45	23.75	8892	1188.7	33.66
08/14-08/15	07:30	07:30	24.00	11167	1492.8	42.27
08/28-08/29	07:30	06:00	22.50	6982	933.4	26.43
10/24-10/25	10:00	10:00	24.00	7035	940.4	26.63
11/26-11/27	10:00	07:30	21.50	8489	1134.8	32.13
12/629-12/30	09:00	08:00	23.00	9254	1237.1	35.03
1991						
01/22-01/23	10:15	08:15	22.00	11069	1479.7	41.90
03/04-03/05	10:00	07:45	21.75	10086	1348.3	38.18
04/02-04/03	10:00	07:15	21.25	6896	921.9	26.10
04/29-04/30	09:00	09:15	24.25	14985	2003.2	56.72
06/18-06/19	08:00	06:45	22.75	11956	1598.3	45.25
07/24-07/25	09:00	07:45	22.75	11073	1480.2	41.91
08/19-08/20	10:30	07:45	21.25	1150	153.7	4.35
09/16-09/17	08:15	09:00	24.75	2055	274.7	7.78
09/23-09/24	10:30	08:00	21.50	8595	1149.0	32.53
No. Events Recorded, n			45	45	45	45
Mean			22.85	10862	1452.0	41.11
Standard Deviation			2.12	4918	657.4	18.61
Range:						
Maximum			29.00	26704	3569.8	101.07
Minimum			12.50	1150	153.7	4.35

Table 22. Daily milking center wastewater volume measured with type-H flume and bubbler flow meter, Dairy B, Erath County, Texas, 5/10/90-3/24/92

Dates	Times		Elapsed Time hrs	Total Discharge Volume Measured		
	Start	End		gal.	ft^3	m^3
1990						
08/21-08/22	08:30	09:30	25.00	20840	2785.9	78.88
10/17-10/18	11:00	08:00	21.00	31753	4244.8	120.19
10/31-11/01	07:00	07:30	24.50	15657	2093.0	59.26
11/13-11/14	08:30	12:15	26.25	56671	7575.8	214.50
12/04-12/05	10:00	09:15	23.25	191309	25574.3	724.11
12/17-12/18	09:00	08:00	23.00	147952	19778.3	560.00
1991						
01/14-01/15	07:30	12:30	29.00	461948	61753.5	1748.48
04/02-04/03	09:00	09:30	24.50	189791	25371.4	718.36
07/01-07/02	08:00	07:15	23.25	313473	41905.2	1186.50
11/05-11/06	10:00	08:15	22.25	76674	10249.8	290.21
12/02-12/03	07:15	08:00	24.75	150582	20129.9	569.95
12/16-12/17	09:00	09:30	24.50	281453	37624.8	1065.30
1992						
01/13-01/14	10:30	08:45	22.75	70049	9364.2	265.14
01/19-01/20	10:15	09:00	22.75	91739	12263.7	347.23
02/17-02/18	08:00	10:00	26.00	77145	10312.8	291.99
03/02-03/03	09:30	08:00	22.50	56454	7546.8	213.68
03/23-03/24	07:00	06:30	23.50	77253	10327.2	292.40
No. Events Recorded, n			17	17	17	17
Mean			24.04	135926	18170.7	514.48
Standard Deviation			1.87	120722	16138.1	456.93
Range:						
Maximum			29.00	461948	61753.5	1748.48
Minimum			21.00	15657	2093.0	59.26

Table 23. Daily milking center wastewater volume measured with type-H flume and float stage recorder, Dairy J, Erath County, Texas, 2/20/90-3/31/92

Dates	Times Start	Times End	Elapsed Time hrs	Total Discharge Volume Measured gal.	ft³	m³
1990						
02/20-02/21	08:30	08:45	24.25	9236	1235	34.96
02/27-02/28	09:00	09:00	24.00	153311	20496	580.32
03/28-03/29	09:30	09:15	23.75	29424	3934	111.37
04/10-04/11	09:30	09:45	24.25	7021	939	26.57
04/11-04/12	09:00	10:15	25.25	9051	1210	34.26
04/24-04/25	08:00	08:00	24.00	18732	2504	70.90
05/08-05/09	08:30	07:30	23.00	15114	2021	57.21
05/23-05/24	08:30	07:15	22.75	11645	1557	44.08
06/12-06/13	08:00	07:30	23.50	13655	1825	51.68
06/26-06/27	07:30	07:45	24.00	73051	9766	276.52
07/09-07/10	07:30	06:30	23.00	14109	1886	53.40
07/31-08/01	08:00	07:30	23.50	18297	2446	69.25
08/07-08/08	07:30	07:15	23.75	122496	16377	463.68
08/21-08/22	07:30	07:15	23.75	19397	2593	73.42
09/17-09/18	09:45	11:30	25.75	11946	1597	45.22
10/09-10/10	08:30	08:00	23.50	16569	2215	62.72
10/23-10/24	09:30	07:00	21.50	11323	1514	42.86
11/06-11/07	10:00	07:30	21.50	13036	1743	49.34
11/19-11/20	08:30	07:30	23.00	13292	1777	50.31
12/26-12/27	08:30	07:45	23.25	22027	2945	83.37
1991						
02/05-02/06	08:45	07:45	23.00	45876	6133	173.65
02/19-02/20	09:00	07:30	22.50	19722	2636	74.65
03/12-03/13	08:45	09:00	23.75	21183	2832	80.18
03/25-03/26	07:00	07:30	24.50	36835	4924	139.42
04/09-04/10	09:45	08:30	22.75	9029	1207	34.18
04/22-04/23	08:15	08:30	24.25	25653	3429	97.10
05/13-05/14	08:00	09:30	25.50	27362	3658	103.56
05/27-05/28	09:00	08:00	23.00	23658	3163	89.55
06/10-06/11	09:45	08:45	23.00	16927	2263	64.07
06/24-06/25	09:45	07:00	21.25	24333	3253	92.10
07/09-07/10	09:00	08:30	23.50	16187	2164	61.27
07/23-07/24	08:00	09:00	25.00	15508	2073	58.70
08/06-08/07	08:45	08:15	23.50	9219	1232	34.89
08/19-08/20	08:45	07:00	22.25	17473	2336	66.13
09/16-09/17	09:15	07:30	22.25	20581	2752	77.90
10/08-10/09	08:45	07:30	22.75	12080	1615	45.72
11/25-11/26	09:45	07:00	21.25	22290	2980	84.37
12/09-12/10	08:30	08:15	23.75	13334	1783	50.47
1992						
01/06-01/07	08:30	07:45	23.25	13396	1791	50.70
02/24-02/25	07:30	09:30	26.00	18092	2419	68.48
03/09-03/10	08:00	08:00	24.00	15765	2108	59.67
No. Events Recorded, n			41	41	41	41
Mean			23.70	25054	3349	94.86
Standard Deviation			1.11	28504	3811	107.92
Range:						
Maximum			26.00	153311	20496	580.32
Minimum			21.25	7021	939	26.57

Table 24. Summary report of water analysis, well water sampled at 11 dairy farms in Erath County, Texas, 4/19/90

Constituent	Dairy A	Dairy B	Dairy C	Dairy D	Dairy E	Dairy F	Dairy G	Dairy H	Dairy I	Dairy J	Dairy K	Mean	Std. Dev.
Nitrate-Nitrogen, mg/L	0.84	0.07	4.35	0.85	0.81	0.83	0.67	0.10	0.29	4.23	0.00	1.20	1.60
Calcium, mg/L	68.5	71.5	103.9	76.1	81.9	66.7	81.4	73.5	63.2	74.6	80.5	76.5	10.9
Magnesium, mg/L	28.0	31.0	4.0	26.0	26.0	28.0	34.0	35.0	34.6	35.0	39.0	29.1	9.4
Sodium, mg/L	22.1	33.3	12.7	19.6	21.0	24.5	15.5	37.2	18.7	16.0	18.5	21.7	7.5
Potassium, mg/L	1.95	2.9	0.01	1.97	2.10	2.3	2.28	2.75	2.65	1.09	2.49	2.04	0.84
Manganese, mg/L	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.0	0.0	0.00	0.00
Boron, mg/L	0.01	0.0	0.0	0.0	0.01	0.0	0.02	0.03	--	0.03	0.0	0.01	0.01
Bi-Carbonate, mg/L	329.0	321.2	274.2	321.2	329.0	344.7	368.2	360.3	352.5	399.5	368.2	324.6	33.1
Sulfate, mg/L	9.4	18.7	18.7	6.2	6.2	12.5	21.8	43.7	12.8	15.6	34.3	18.2	11.6
Chloride, mg/L	17.0	20.9	8.5	17.0	17.0	16.0	12.4	24.9	8.9	12.8	12.4	15.3	5.0
pH	7.70	8.00	7.30	7.50	7.20	7.50	7.40	7.50	7.40	7.50	7.40	7.49	0.21
Hardness, gr/gal	6.69	7.16	6.45	6.94	7.28	8.59	8.02	7.66	7.02	7.72	8.45	7.27	0.63
SALINITY DATA:													
Specific-Conduct, µmhos/cm	846	921	790	770	871	892	951	1029	902	995	979	904	82
Total Cations, mg/L	120.5	138.4	120.6	123.7	131.0	121.5	133.2	148.4	119.1	126.7	140.4	129.4	9.7
Total Anions, mg/L	356.1	360.8	301.4	344.5	352.3	373.1	402.4	428.9	374.2	427.9	414.9	367.0	54.1
Total Salts, mg/L	476.7	499.2	422.0	468.1	483.3	494.6	535.6	577.3	493.3	554.6	555.4	505.5	45.8
SAR†	0.50	0.71	0.29	0.43	0.44	0.56	0.30	0.76	0.41	0.32	0.35	0.46	0.16
SSP‡	14.27	18.81	9.10	12.46	12.70	15.77	8.88	19.64	11.83	9.50	9.94	12.99	3.78

† Sodium absorption ratio
‡ Soluble sodium percentage

Table 25. Summary report of water analysis, well water sampled at 11 dairy farms in Erath County, Texas, 7/2/92

Constituent	Dairy A	Dairy B	Dairy C	Dairy D	Dairy E	Dairy F	Dairy G	Dairy H	Dairy I	Dairy J	Dairy K	Mean	Std. Dev.
Nitrate-Nitrogen, mg/L	0.68	0.10	2.81	0.58	0.61	0.43	0.27	0.10	0.10	3.17	0.10	0.81	1.10
Calcium, mg/L	30	25	52	29	26	29	34	26	23	34	60	33.4	11.8
Magnesium, mg/L	26	26	4	22	25	28	28	24	20	23	37	23.9	7.9
Sodium, mg/L	20	29	12	18	19	16	14	23	11	13	17	17.2	5.6
Potassium, mg/L	51	4	3	2	3	3	3	3	3	2	3	7.3	14.5
Manganese, mg/L	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
Boron, mg/L	0.17	0.18	0.12	0.16	0.15	0.16	0.12	0.13	0.10	0.13	0.19	0.14	0.03
Bi-Carbonate, mg/L	208.7	194.7	132.1	180.8	208.7	222.6	229.5	146.1	187.8	208.7	313.0	203.0	47.3
Sulfate, mg/L	12.7	19.1	22.3	6.4	6.4	12.7	19.1	31.8	12.7	9.5	35.0	17.1	9.6
Chloride, mg/L	18	25	9	14	11	11	9	20	11	13	14	14.1	5.0
pH	7.20	7.30	7.00	7.30	7.40	7.40	7.30	7.20	7.20	7.10	7.80	7.29	0.21
Hardness, gr/gal	4.25	3.96	3.42	3.81	3.92	4.39	4.68	3.83	3.27	4.20	7.06	4.25	1.02
SALINITY DATA:													
Specific-Conduct, μmhos/cm	450	446	344	403	421	439	487	452	332	384	655	438	86
Total Cations, mg/L	127	84	71	71	73	76	79	76	57	69	117	81.8	21.1
Total Anions, mg/L	239	239	163	201	226	246	258	198	212	231	362	234	50
Total Salts, mg/L	366	323	234	272	299	322	337	274	269	300	479	316	65
SAR†	0.62	0.94	0.42	0.60	0.62	0.48	0.41	0.76	0.40	0.31	0.37	0.54	0.19
SSP‡	14.97	26.55	14.81	19.13	19.41	15.28	12.99	23.00	14.29	10.67	10.79	16.54	4.99

† Sodium absorption ratio

‡ Soluble sodium percentage

Table 26. Average values of constituents in well water sampled at 11 dairy farms, Erath County, Texas, 4/19/90 and 7/2/92

Analysis	April 19, 1990		July 2, 1992	
	Mean	Std. Dev.	Mean	Std. Dev.
Nitrate-Nitrogen, mg/L	1.20	1.60	0.81	1.10
Calcium, mg/L	76.5	10.9	33.5	11.8
Magnesium, mg/L	29.1	9.4	23.9	7.9
Sodium, mg/L	21.7	7.5	17.2	5.6
Potassium, mg/L	2.04	0.84	7.27	14.5
Manganese, mg/L	0.00	0.00	0.01	0.00
Boron, mg/L	0.01	0.01	0.14	0.03
Bi-Carbonate, mg/L	324.6	33.1	203.0	47.3
Sulfate, mg/L	18.2	11.6	17.1	9.6
Chloride, mg/L	15.3	5.0	14.1	5.0
pH	7.49	0.21	7.29	0.21
Hardness, gr/gal	7.27	0.63	4.25	1.02
SALINITY DATA:				
Specific-Conduct, μmhos/cm	904.0	8.2	438.1	86.1
Total Cations, mg/L	129.4	9.7	81.8	21.1
Total Anions, mg/L	367.0	54.0	234.1	50.1
Total Salts, mg/L	505.5	45.8	315.9	65.4
SAR†	0.46	0.16	0.54	0.19
SSP‡	12.99	3.78	16.54	4.99

† Sodium absorption ratio

‡ Soluble sodium percentage

Table 27. Constituent concentrations of open lot runoff, Dairy A, Erath County, Texas, 2/16/89-8/14/91

Constituent	Units	Upper Flume		Lower Flume	
		avg	std dev	avg	std dev
Total Solids	mg/L	7853	6837	5169	1823
Fixed Solids	mg/L	5374	5847	3272	1304
Volatile Solids	mg/L	2480	1184	1897	673
Filt. Solids	mg/L	3458	1422	2934	1173
Filt. Fixed Solids	mg/L	1985	900	1779	692
Filt. Volatile Solids	mg/L	1460	560	1156	514
Total Susp. Solids	mg/L	3920	7226	2224	1704
Susp. Fixed Solids	mg/L	2917	6106	1495	1304
Susp. Volatile Solids	mg/L	1016	1133	790	547
COD	mg/L	3783	1525	2635	1040
Nitrogen	mg/L	105.8	48.8	82.5	47.5
Nitrate	mg/L	2.0	6.2	1.9	4.3
Ammonium	mg/L	68.7	39.7	59.9	41.7
Organic	mg/L	18.4	8.3	19.2	15.5
Phosphorus	mg/L	33	13	35	18
Potassium	mg/L	598	260	540	193
Calcium	mg/L	187	147	130	64
Magnesium	mg/L	77	41	74	21
Sodium	mg/L	204	113	224	87
Manganese	mg/L	1.37	0.80	0.98	0.52
Chloride	mg/L	276	98	355	186
Iron	mg/L	20.1	31.0	30.4	52.3
pH		7.62	0.30	7.58	0.26
Salinity Data:					
EC, Elec. Cond.	μmhos/cm	3210	1720	3740	1370
SAR, Sodium Absorption Ratio		2.66	1.16	3.85	1.41
SSP, Soluble Sodium Percentage		21.13	6.01	26.81	4.99

Table 28. Constituent concentrations of open lot runoff, Dairy B, Erath County, Texas, 8/2/89-8/12/91

Constituent	Units	North Flume		South Flume	
		avg	std dev	avg	std dev
Total Solids	mg/L	5979	2247	6726	3017
Fixed Solids	mg/L	3285	1236	3834	1827
Volatile Solids	mg/L	2692	1129	2892	1353
Filt. Solids	mg/L	4206	1784	4725	1974
Filt. Fixed Solids	mg/L	2379	1021	2786	1157
Filt. Volatile Solids	mg/L	1827	795	1939	881
Total Susp. Solids	mg/L	1773	1455	2002	2301
Susp. Fixed Solids	mg/L	906	864	1048	1525
Susp. Volatile Solids	mg/L	865	714	953	967
COD	mg/L	3817	1895	4248	1748
Nitrogen	mg/L	108.8	51.5	115.0	60.4
Nitrate	mg/L	1.9	4.7	1.5	3.7
Ammonium	mg/L	78.3	44.6	78.7	41.3
Organic	mg/L	26.2	12.2	27.8	12.8
Phosphorus	mg/L	35	17	33	12
Potassium	mg/L	790	464	912	363
Calcium	mg/L	190	110	159	114
Magnesium	mg/L	142	286	109	47
Sodium	mg/L	235	85	260	110
Manganese	mg/L	0.78	0.39	1.00	0.51
Chloride	mg/L	373	182	475	273
Iron	mg/L	14.4	10.6	16.6	16.9
pH		7.51	0.31	7.57	0.24
Salinity Data:					
EC, Elec. Cond.	μmhos/cm	4640	1770	5270	1910
SAR, Sodium Absorption Ratio		3.36	1.27	4.00	1.65
SSP, Soluble Sodium Percentage		22.03	4.14	22.69	4.50

Table 29. Constituent concentrations of open lot runoff, Dairy J, Erath County, Texas, 2/21/90-8/11/91

Constituent	Units	North Flume	
		avg	std dev
Total Solids	mg/L	2776	903
Fixed Solids	mg/L	1564	568
Volatile Solids	mg/L	1212	426
Filt. Solids	mg/L	2040	552
Filt. Fixed Solids	mg/L	1165	343
Filt. Volatile Solids	mg/L	875	252
Total Susp. Solids	mg/L	736	753
Susp. Fixed Solids	mg/L	399	489
Susp. Volatile Solids	mg/L	338	346
COD	mg/L	1526	484
Nitrogen	mg/L	53.6	34.9
Nitrate	mg/L	0.5	1.3
Ammonium	mg/L	32.6	18.2
Organic	mg/L	10.4	4.1
Phosphorus	mg/L	18	18
Potassium	mg/L	377	106
Calcium	mg/L	109	58
Magnesium	mg/L	57	16
Sodium	mg/L	114	46
Manganese	mg/L	0.48	0.28
Chloride	mg/L	249	107
Iron	mg/L	6.86	5.40
pH		7.46	0.23
Salinity Data:			
EC, Elec. Cond.	μmhos/cm	2622	742
SAR, Sodium Absorption Ratio		2.03	0.56
SSP, Soluble Sodium Percentage		19.50	3.17

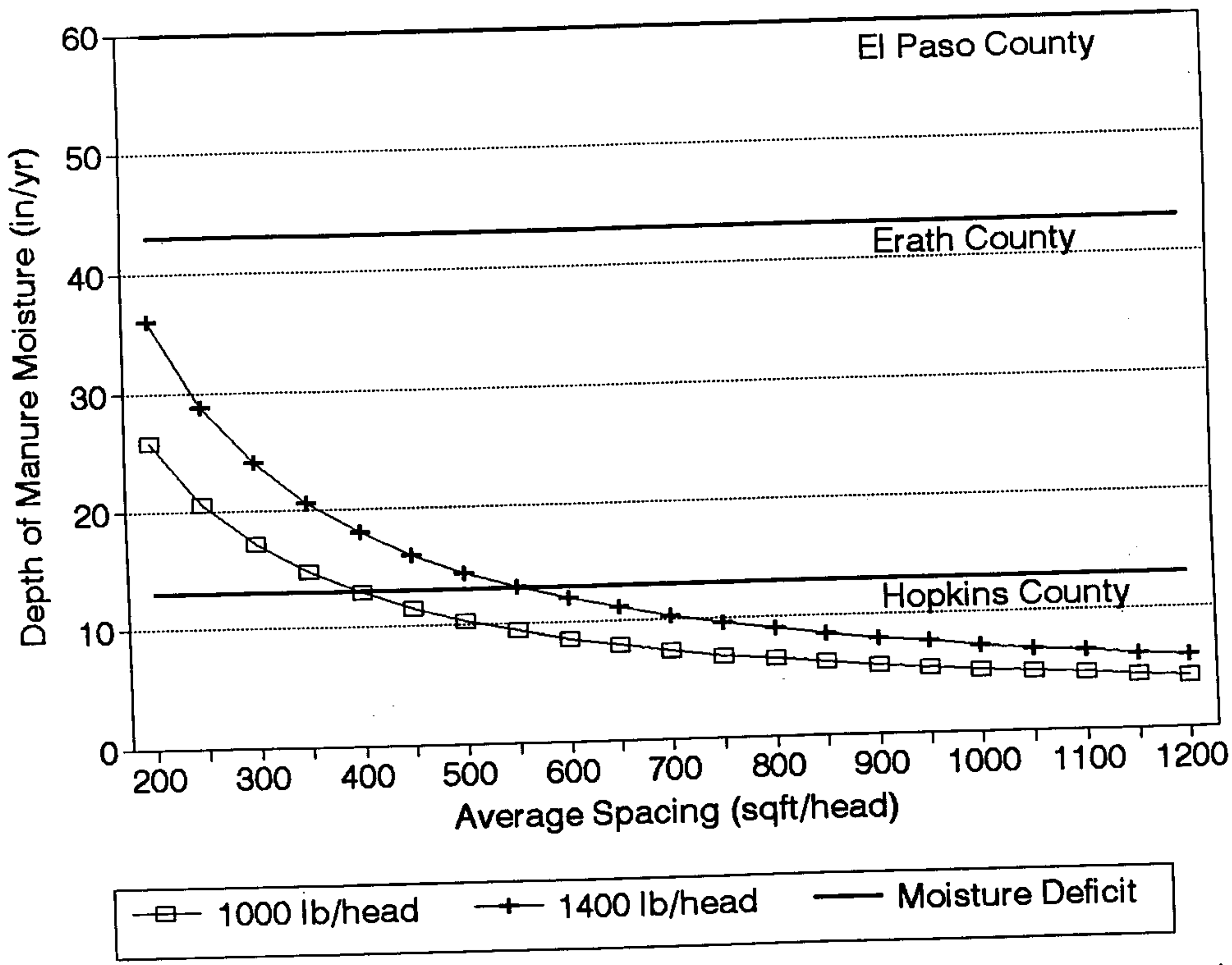


Figure 1. Calculated moisture production in manure from dairy cattle in open lots as function of live body weight and animal spacing.

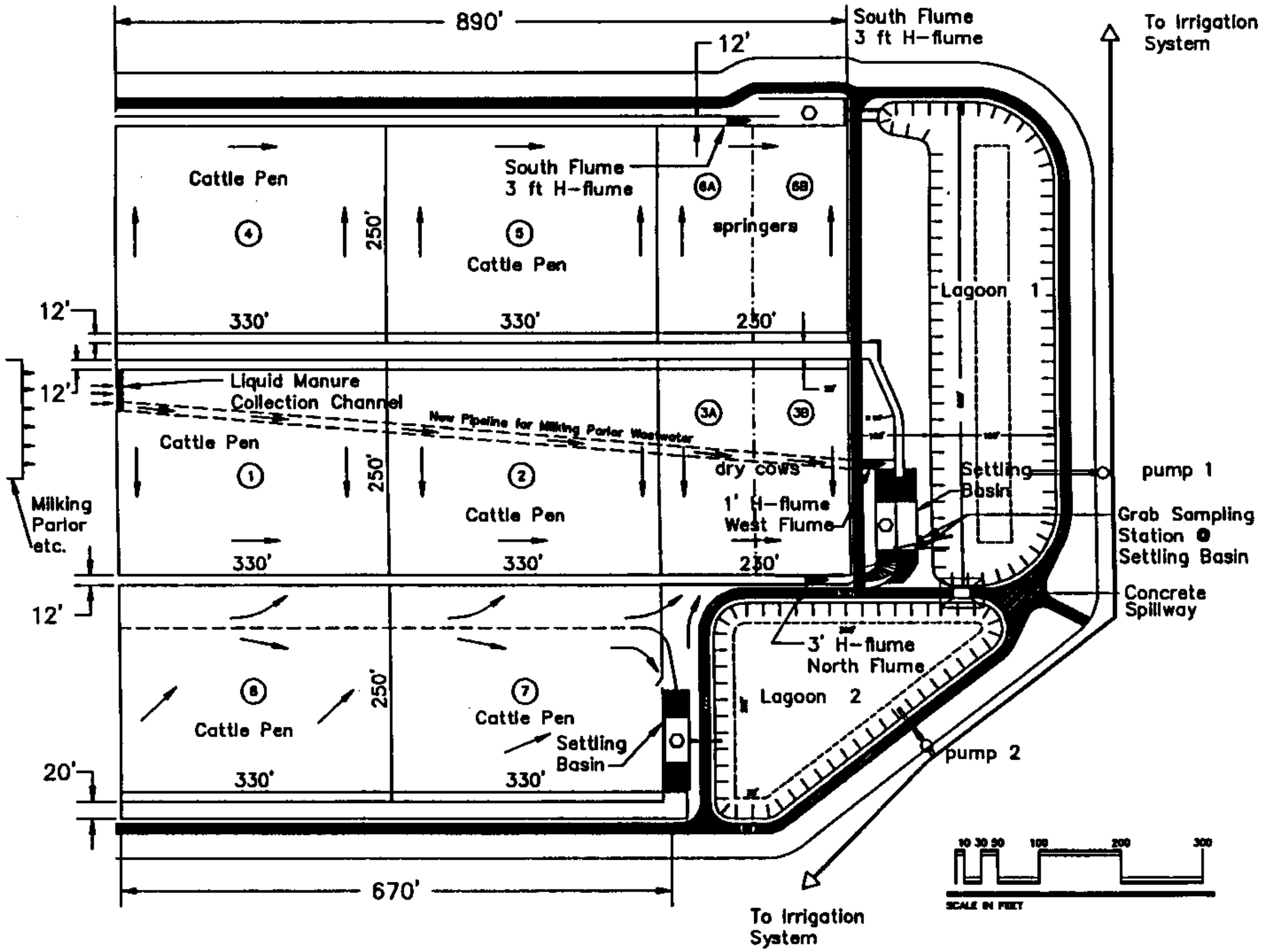


Figure 2. Layout of corrals, lagoons and settling basins at Dairy B.

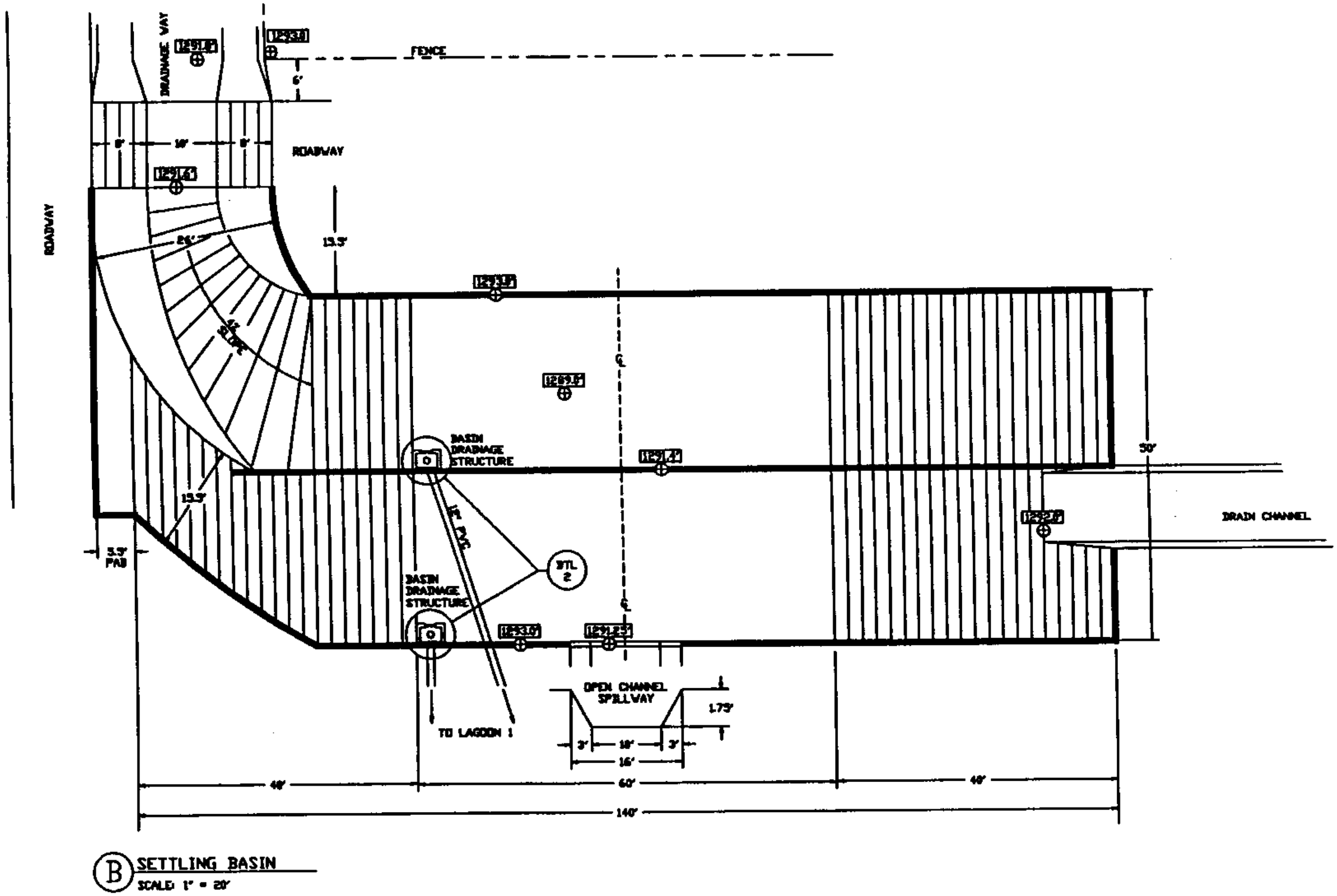


Figure 3. Design layout of the dual-chambered settling basin installed at Dairy B in 1989, with drive-through design for wheel loader operation.

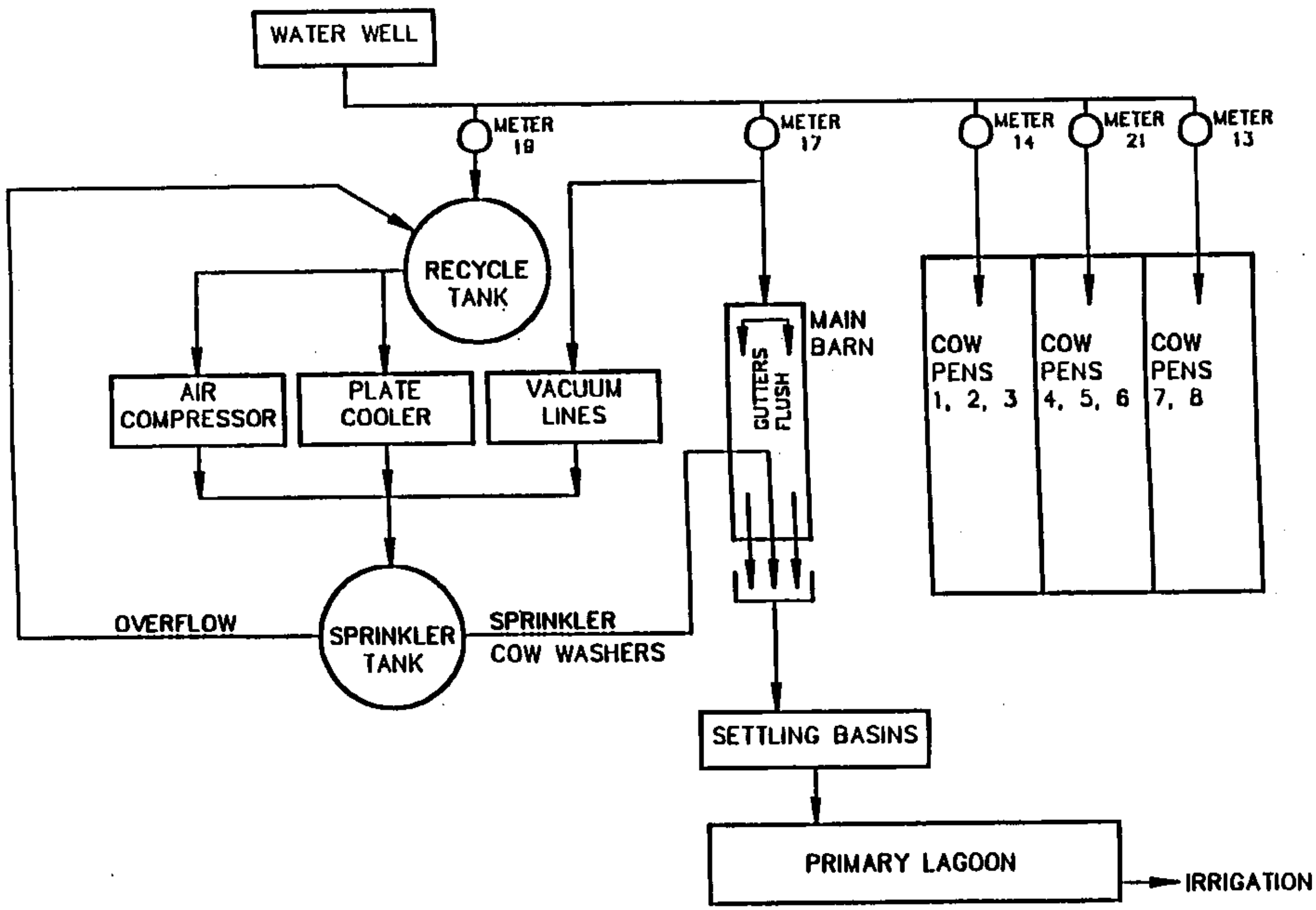
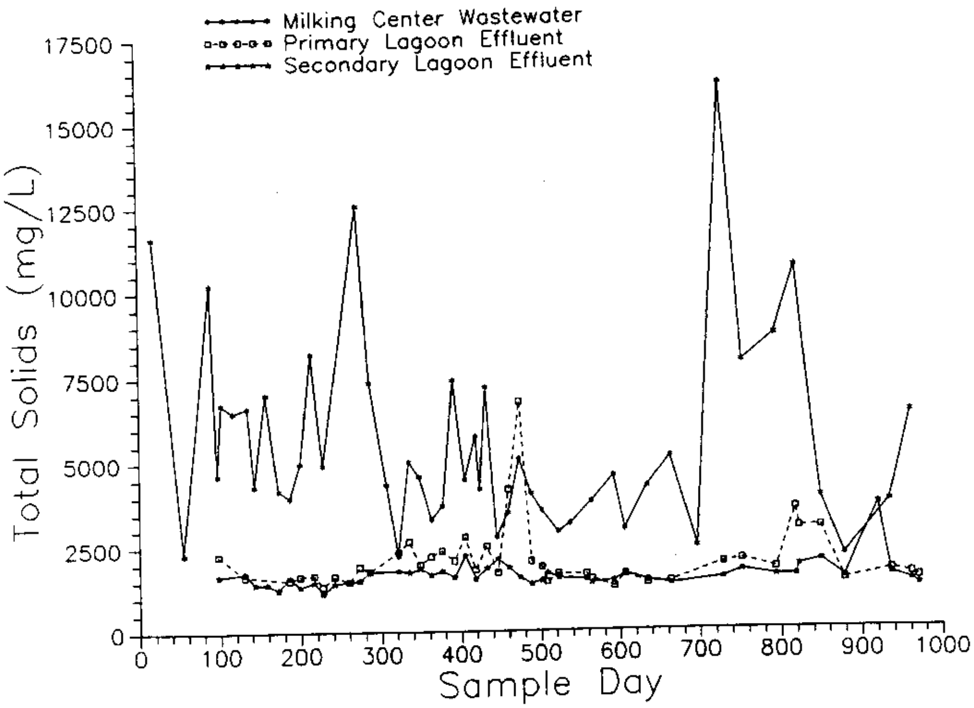


Figure 4. Schematic diagram of fresh water distribution and reuse system along with water meter placement at Dairy B.



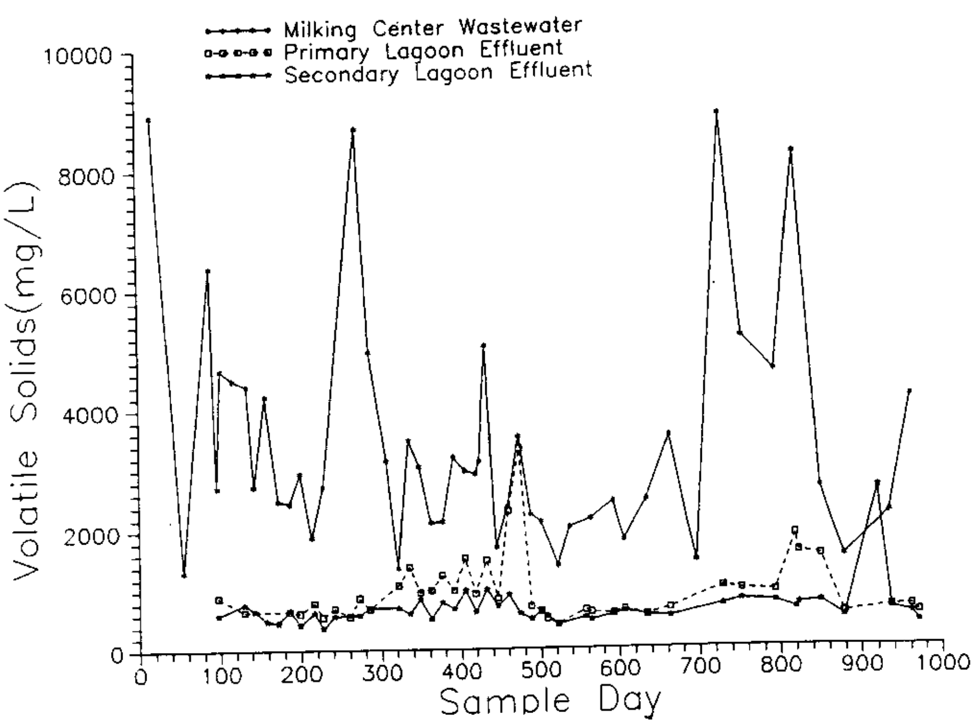
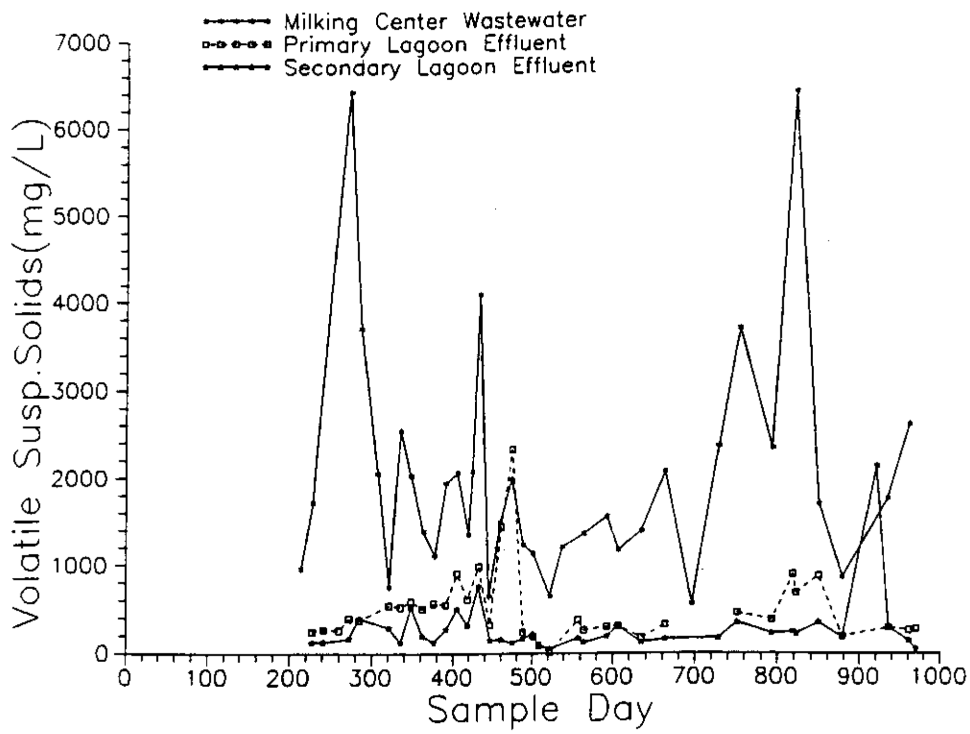


Figure 5a. **Average daily concentrations of milking center wastewater and lagoon effluent at Dairy A--total solids (TS) and volatile solids (VS), 1/18/89-8/19/91 (day 0 = 1/1/89).**



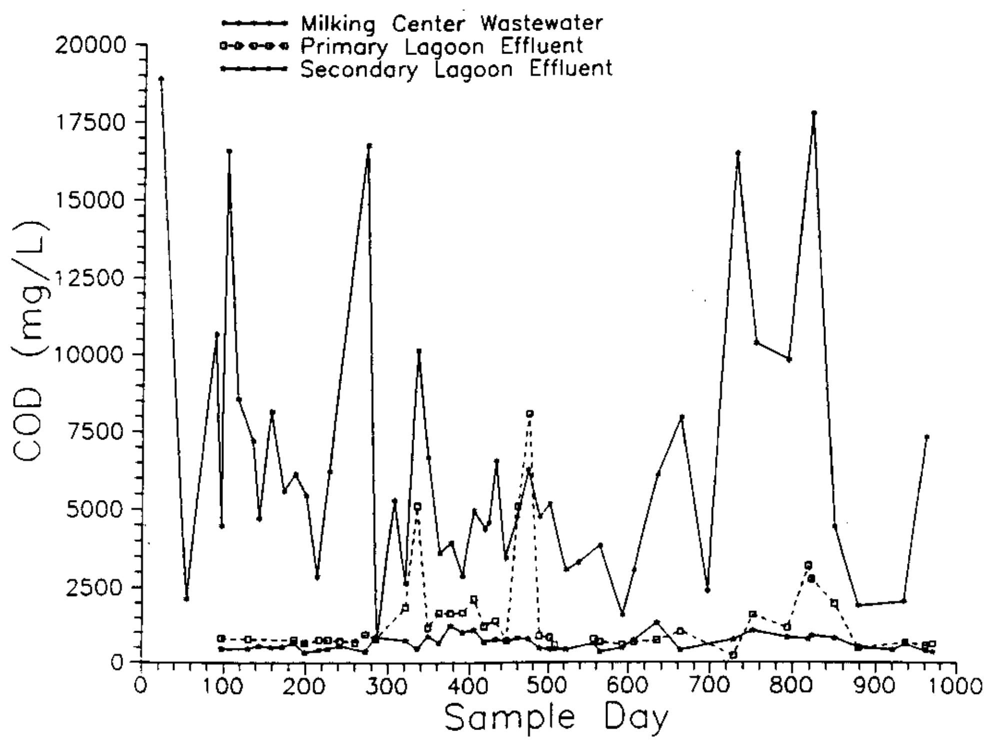
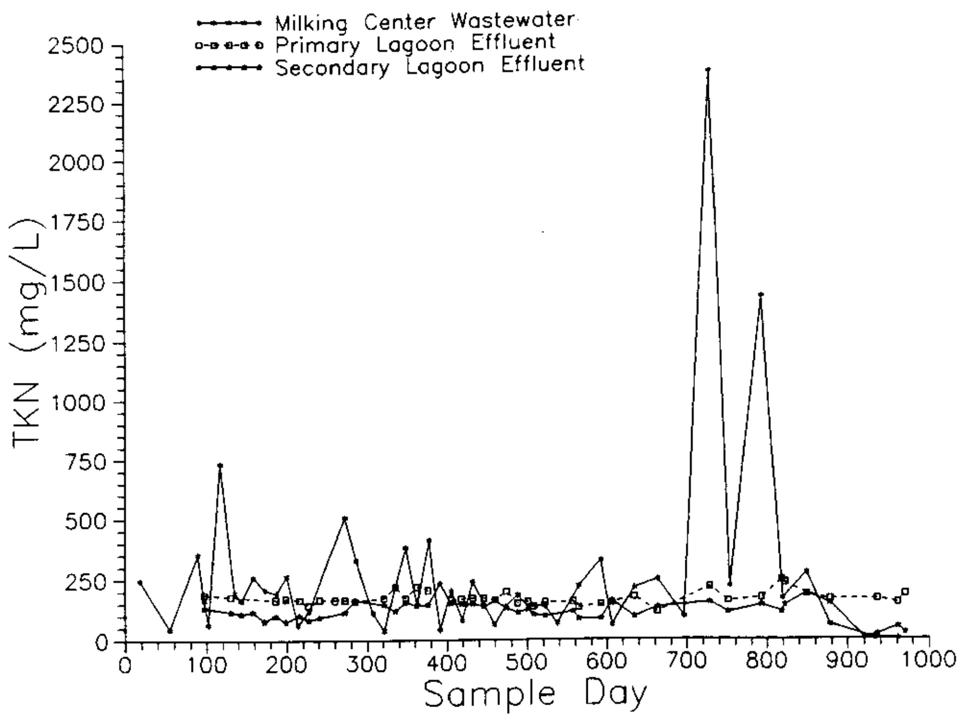


Figure 5b. Average daily concentrations of milking center wastewater and lagoon effluent at Dairy A--volatile suspended solids (VSS), and chemical oxygen demand (COD) 1/18/89-8/19/91 (day 0 = 1/1/89).



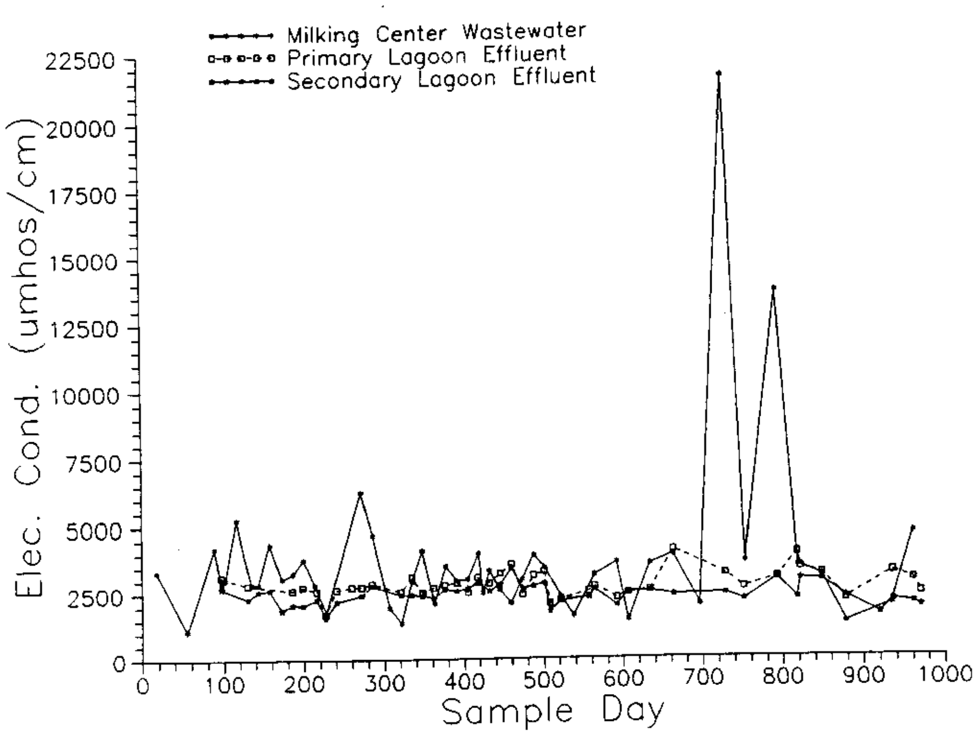


Figure 5c. **Average daily concentrations of milking center wastewater and lagoon effluent at Dairy A--total Kjeldahl nitrogen (TKN) and electrical conductivity (EC), 1/18/89-8/19/91 (day 0 = 1/1/89).**

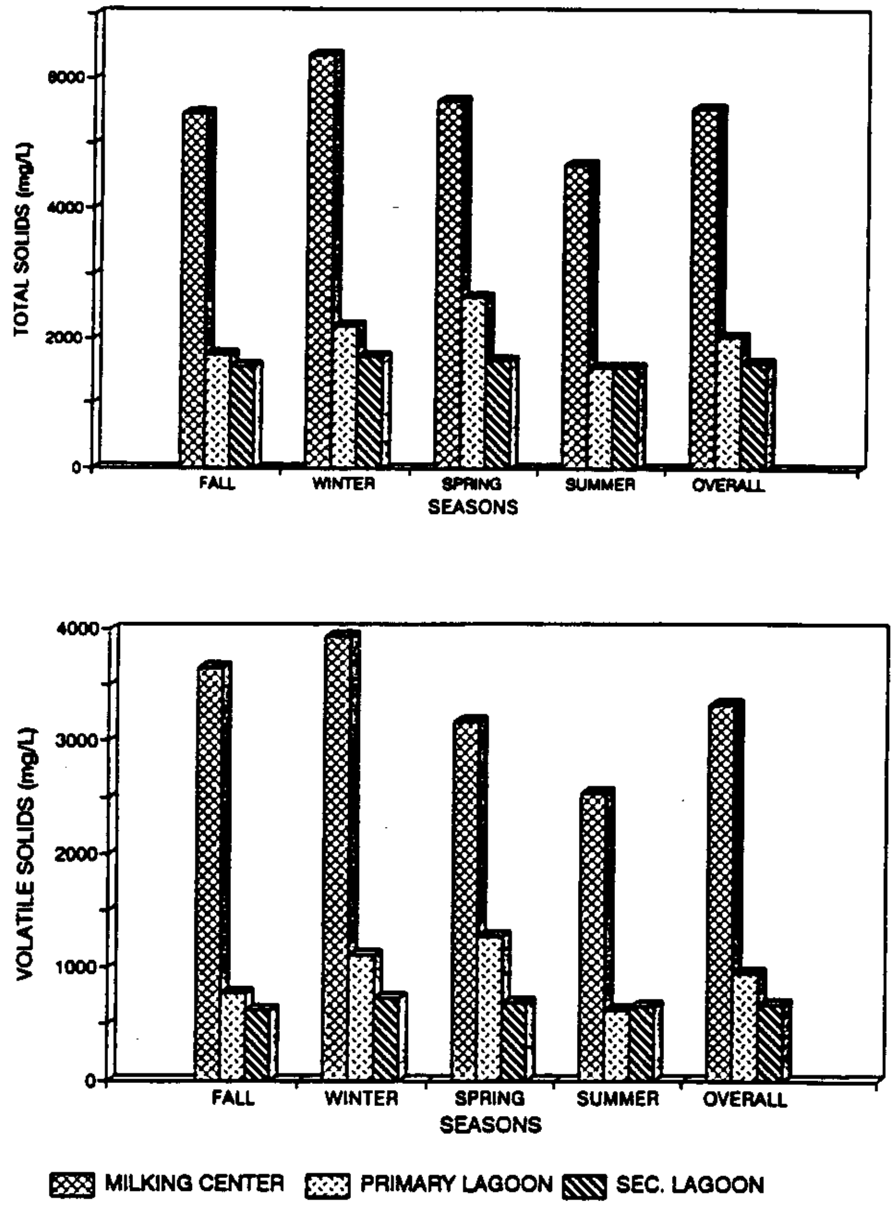


Figure 6a. Average seasonal concentrations measured at Dairy A for total solids and volatile solids.

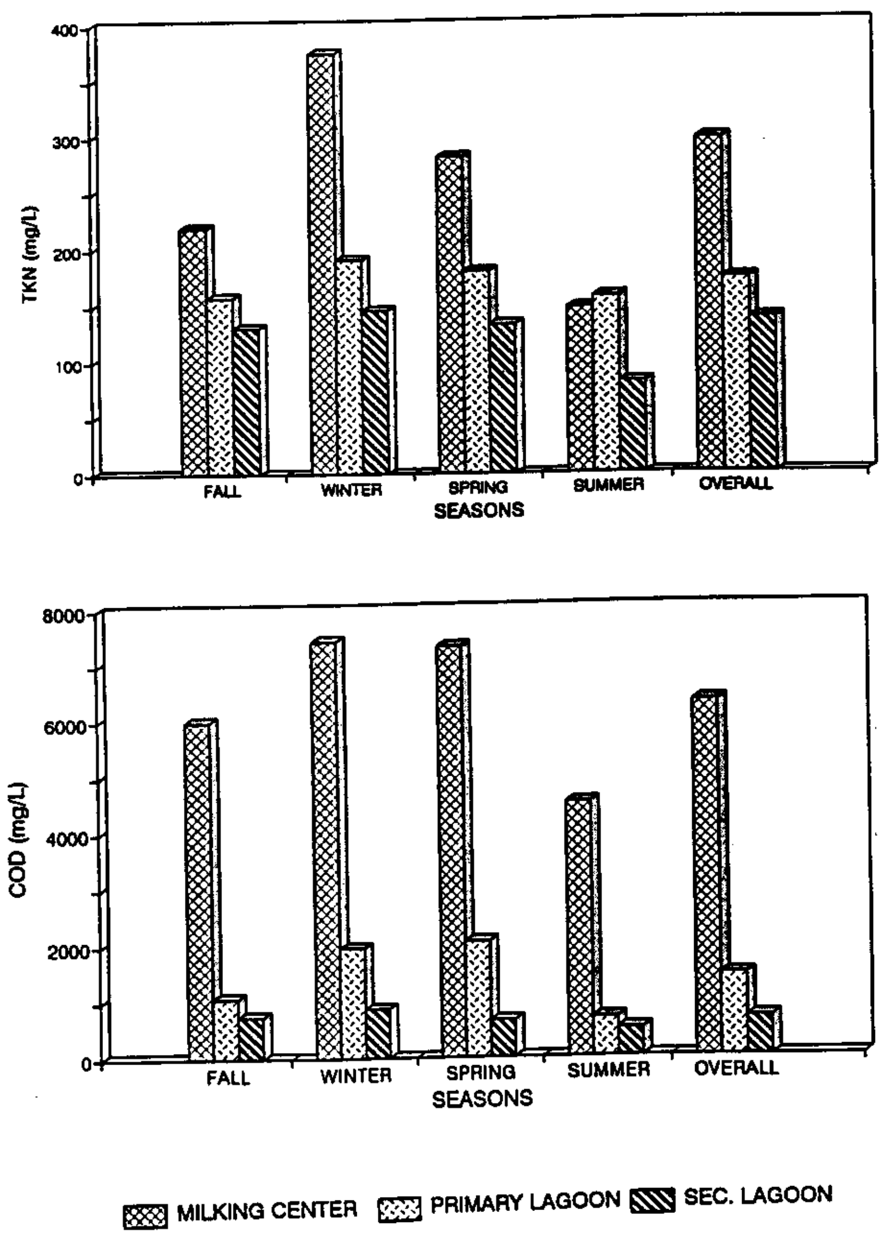


Figure 6b. Average seasonal concentrations at Dairy A of total Kjeldahl nitrogen (TKN) and chemical oxygen demand (COD).

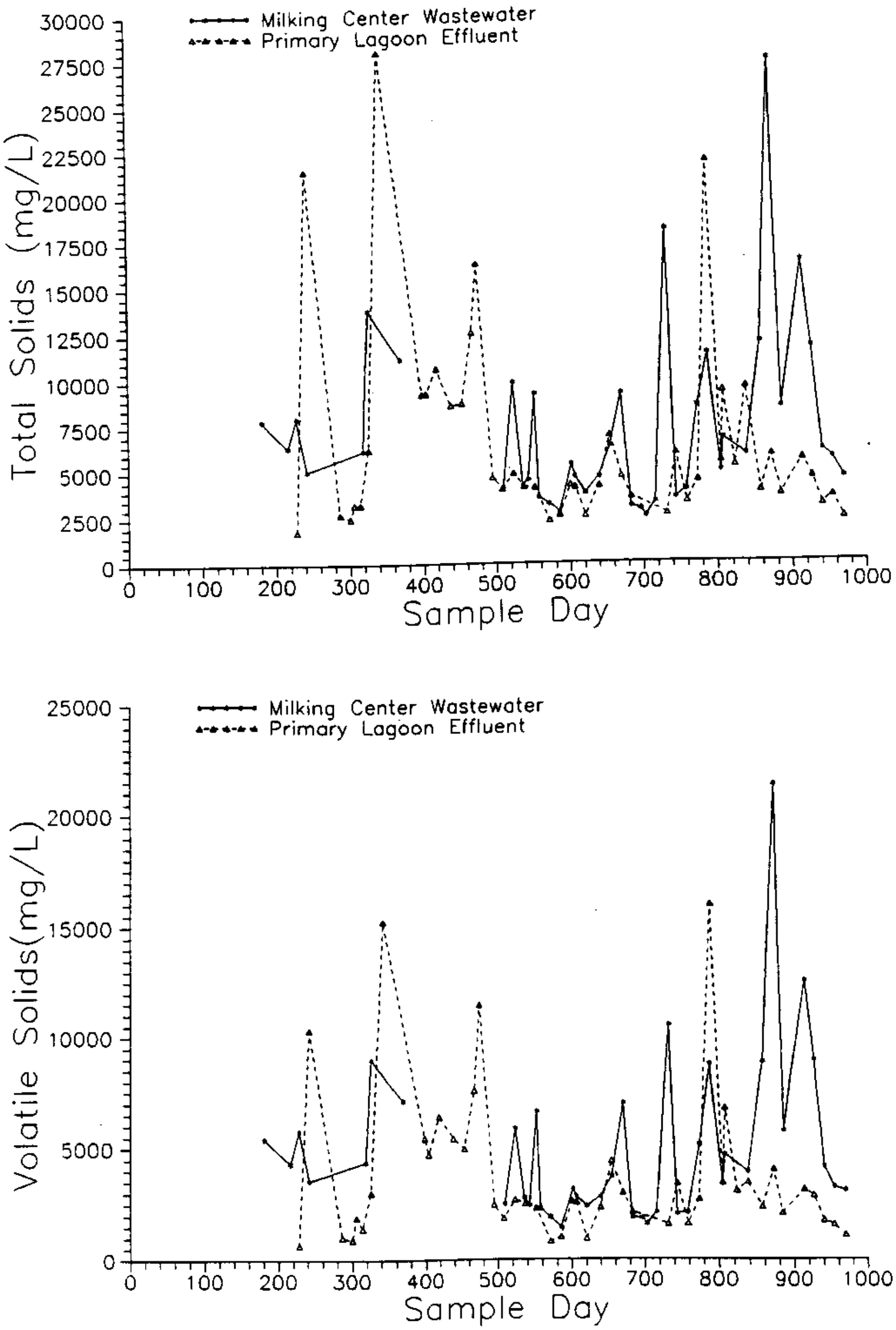
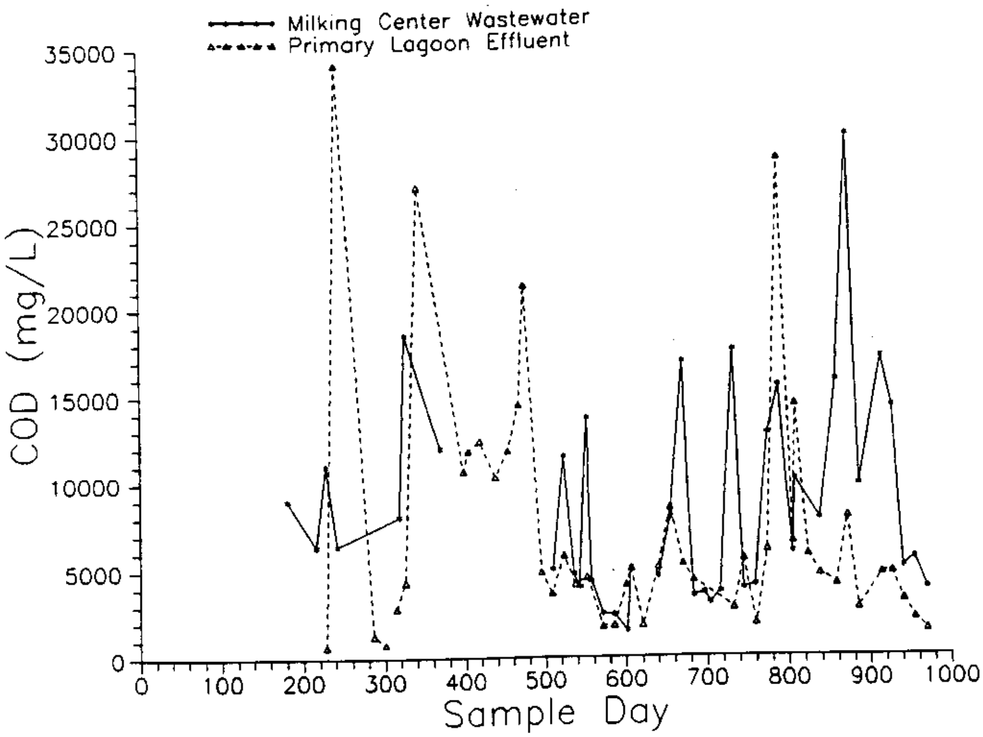


Figure 7a. Average daily concentrations of milking center wastewater and primary lagoon effluent at Dairy B--total solids (TS) and volatile solids (VS), 6/30/89-8/27/91 (day 0 = 1/1/89).



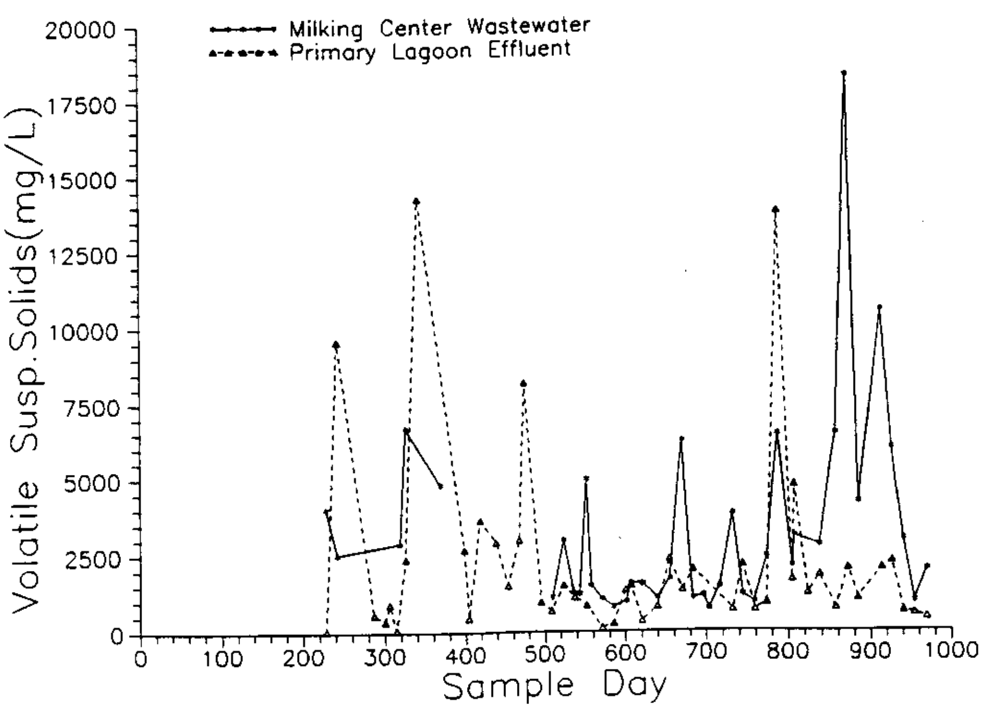
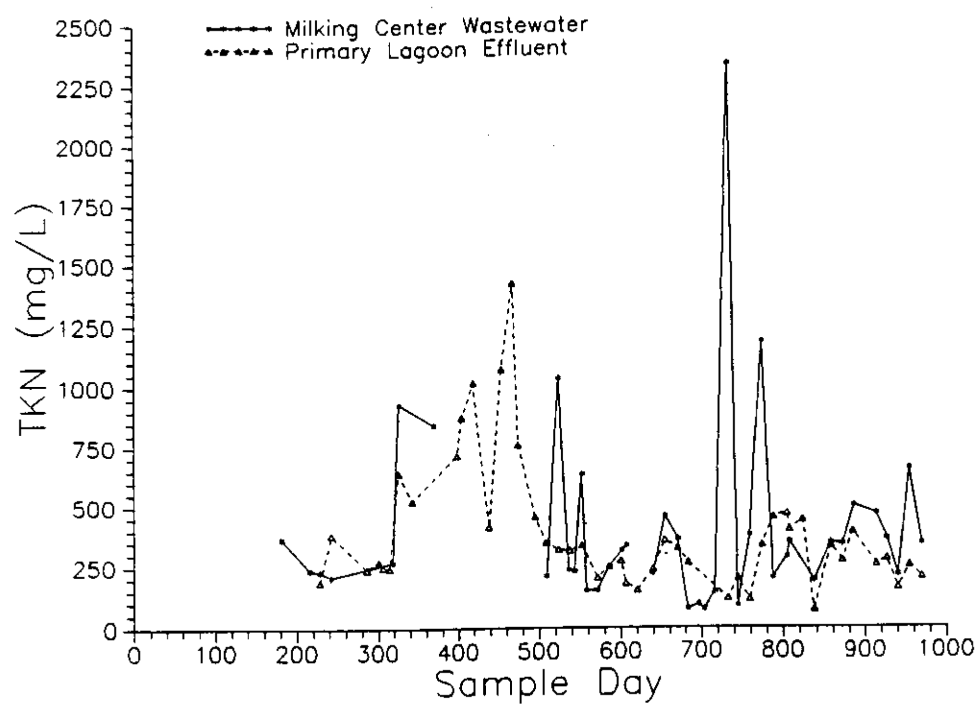


Figure 7b. **Average daily concentrations of milking center wastewater and primary lagoon effluent at Dairy B--chemical oxygen demand (COD) and volatile suspended solids (VSS), 6/30/89-8/27/91 (day 0 = 1/1/89).**



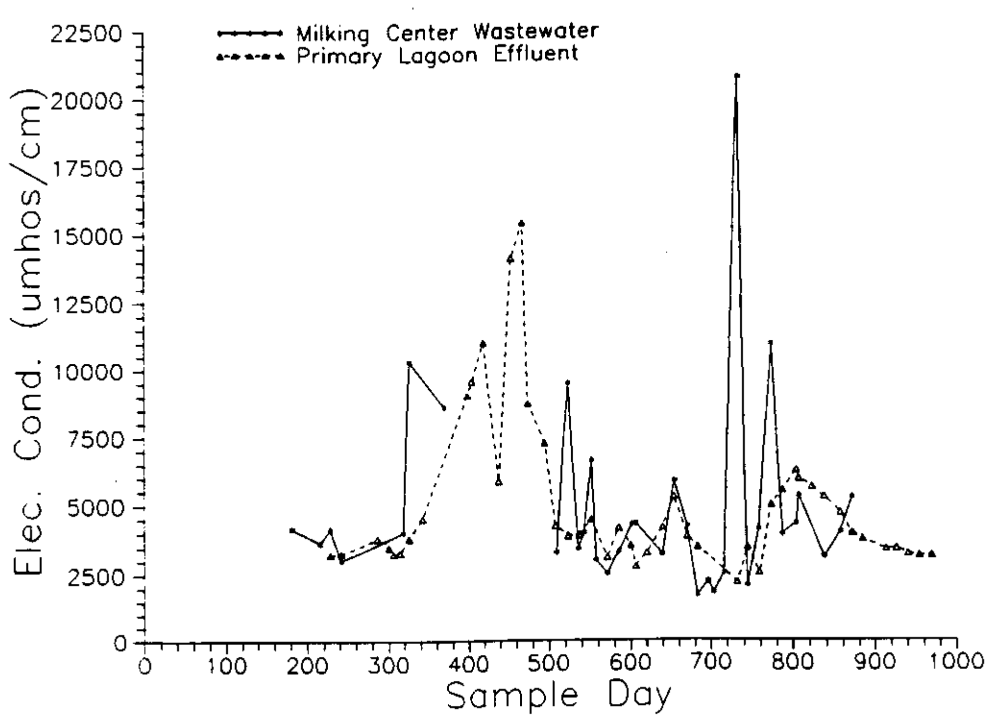


Figure 7c. Average daily concentrations of milking center wastewater and primary lagoon effluent at Dairy B--total Kjeldahl nitrogen (TKN), and electrical conductivity (EC), 6/30/89-8/27/91 (day 0 = 1/1/89).

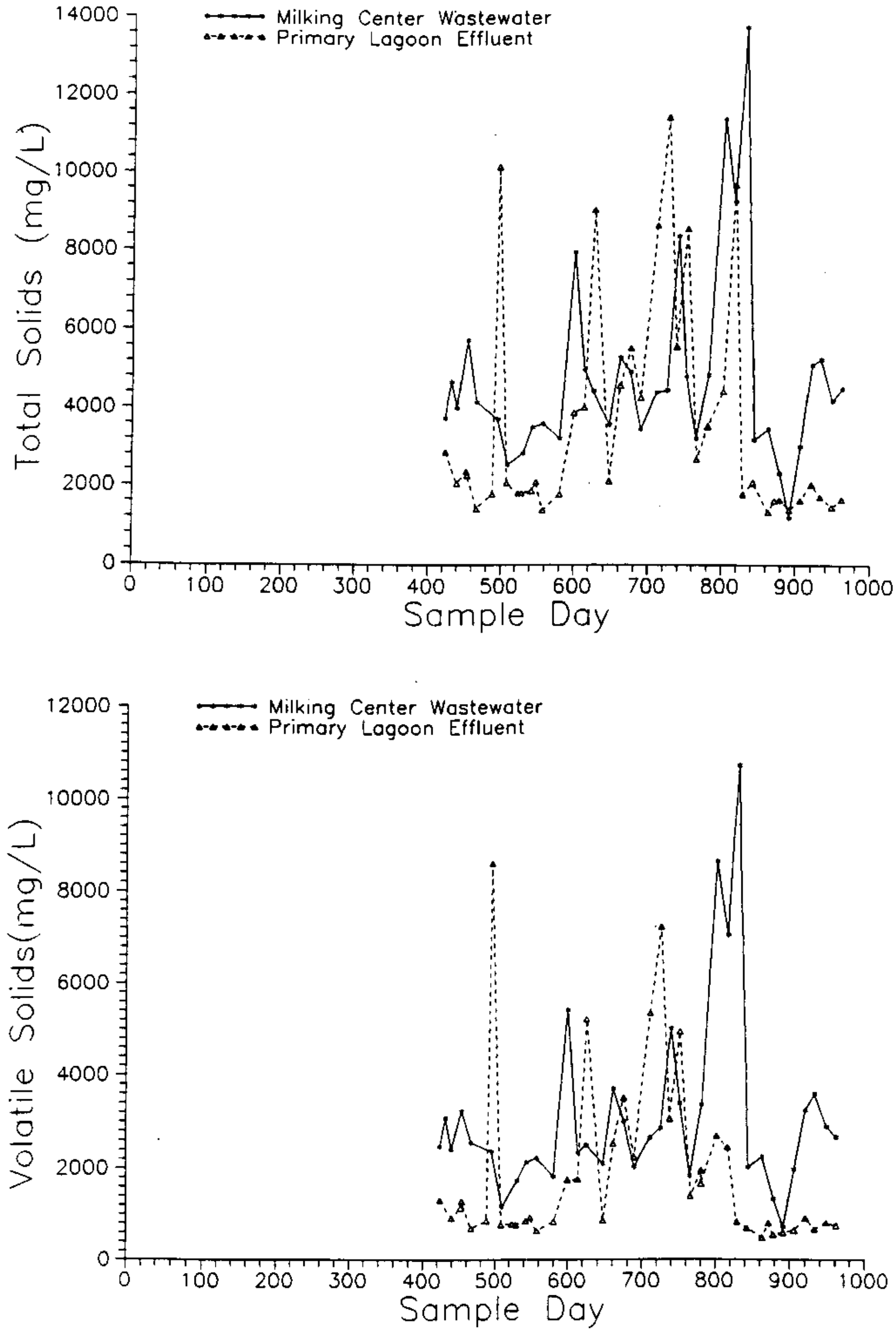
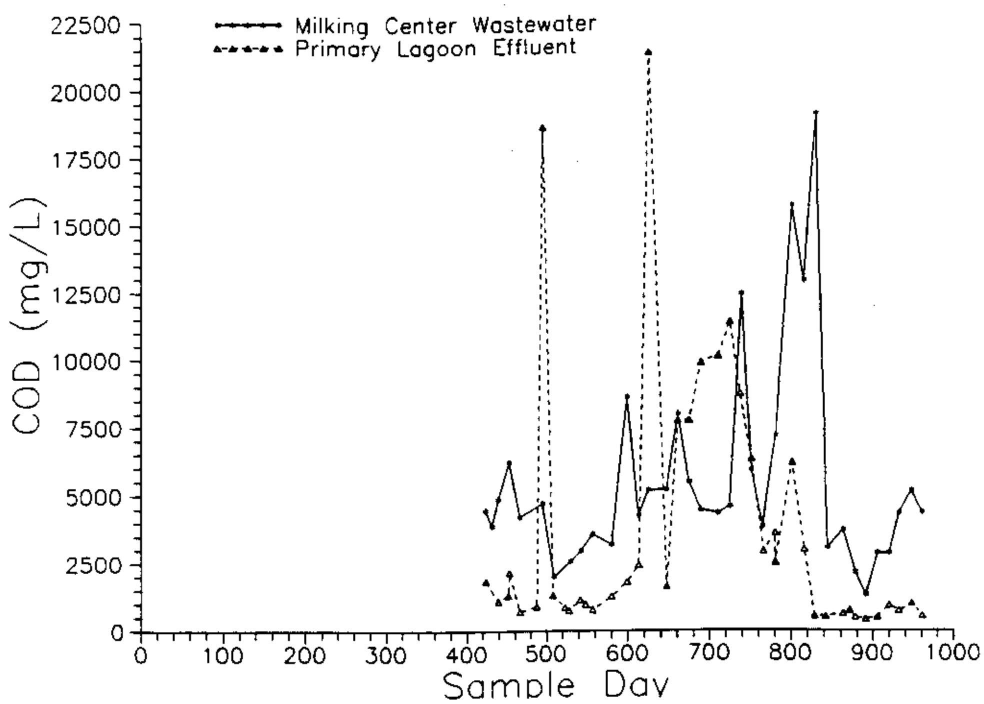


Figure 8a. Average daily concentrations of milking center wastewater and primary lagoon effluent at Dairy J--total solids (TS) and volatile solids (VS), 2/27/90-8/19/91 (day 0 = 1/1/89).



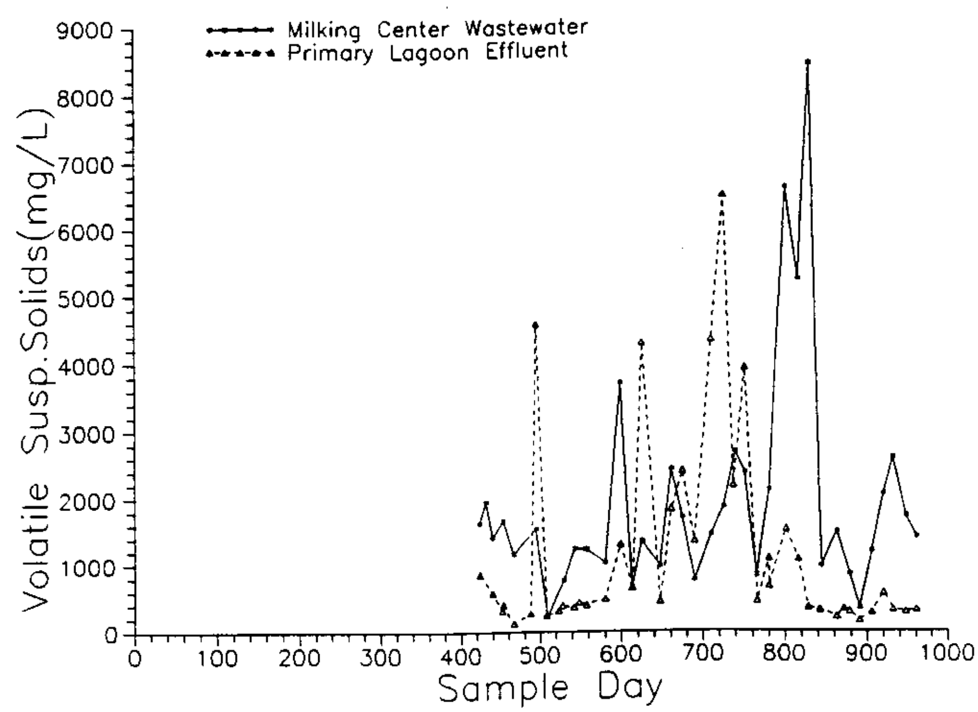
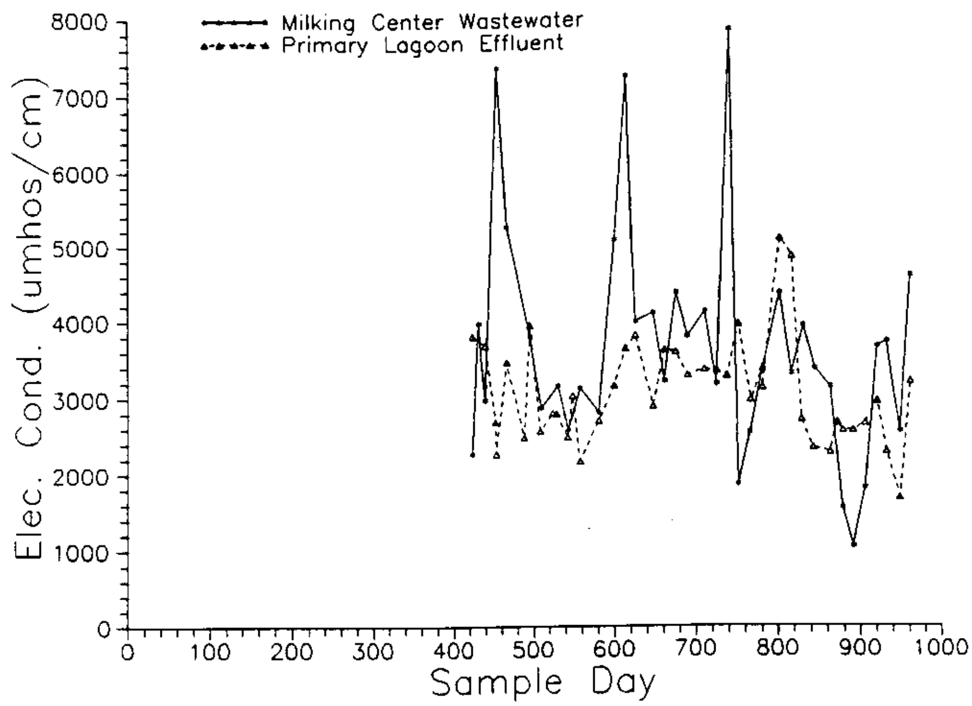


Figure 8b. Average daily concentrations of milking center wastewater and primary lagoon effluent at Dairy J--chemical oxygen demand (COD) and volatile suspended solids (VSS), 2/27/90-8/19/91 (day 0 = 1/1/89).



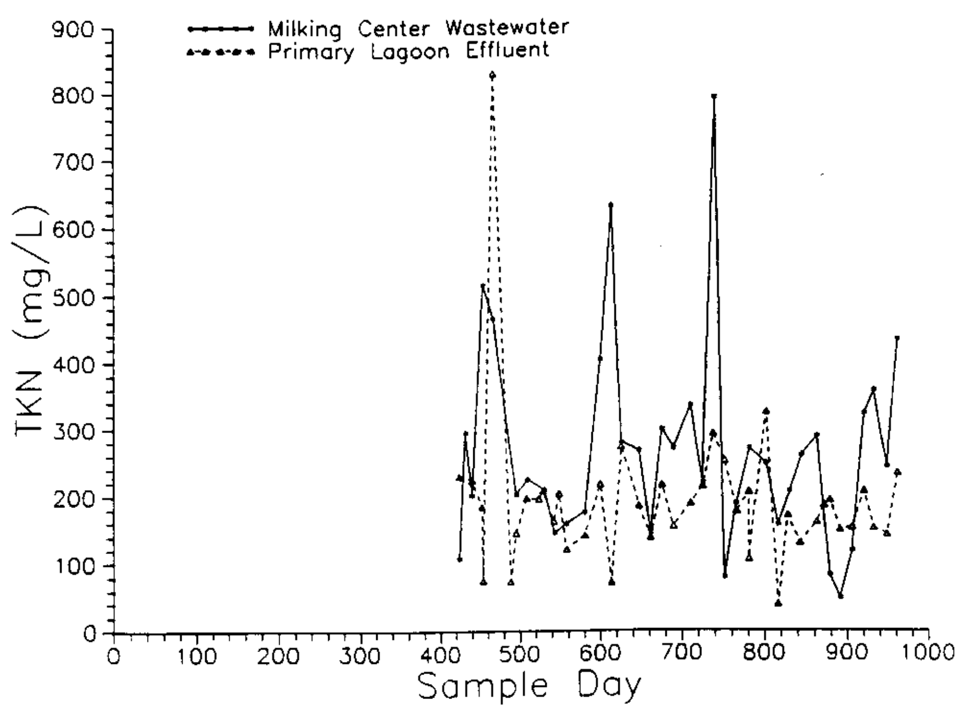


Figure 8c. Average daily concentrations of milking center wastewater and primary lagoon effluent at Dairy J--electrical conductivity (EC) and total Kjeldahl nitrogen (TKN), 2/27/90-8/19/91 (day 0 1/1/89).

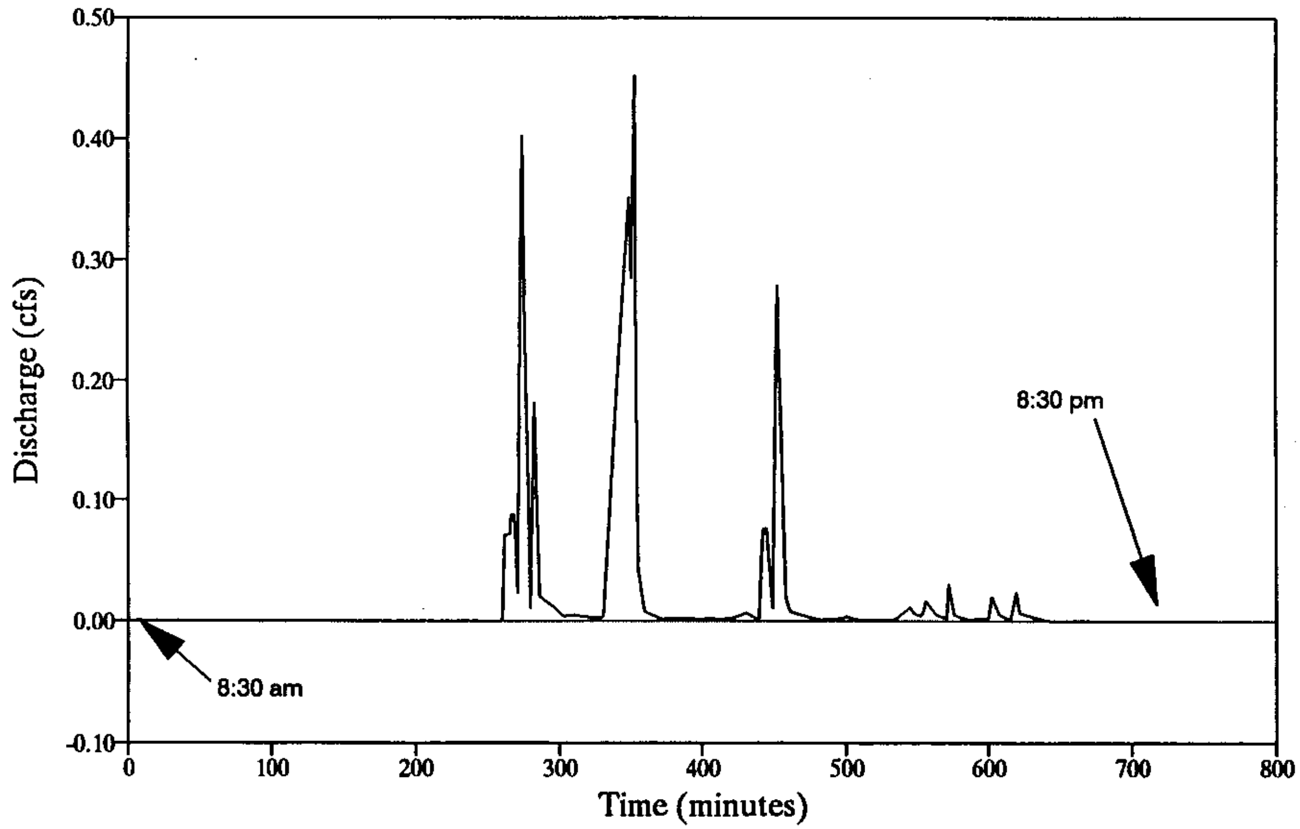


Figure 9. Hydrograph (12 hours) of milking center wastewater at Dairy A, February 8, 1990; Peak flow of 12.8 L/s (0.45 cfs) and total flow volume of 19.6 m^3 (5188 gal or 694 ft^3) measured with float-type stage recorder in 0.46 m (1.5 ft) type-H flume.

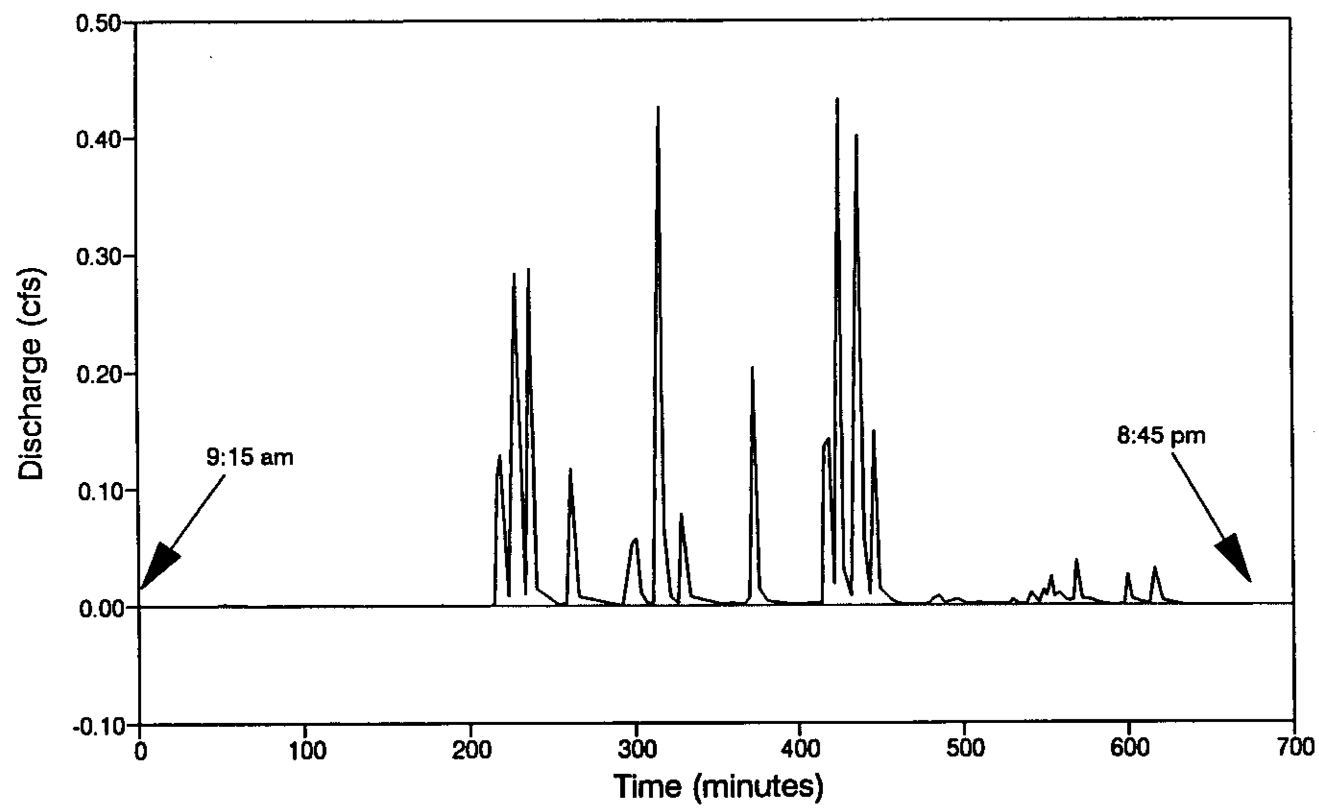


Figure 10. Hydrograph (12 hours) of milking center wastewater at Dairy A, March 20, 1990; Peak flow of 12.2 L/s (0.43 cfs) and total flow volume of 20.6 m^3 (5450 gal or 729 ft^3) measured with float-type stage recorder in 0.46 m (1.5 ft) type-H flume.

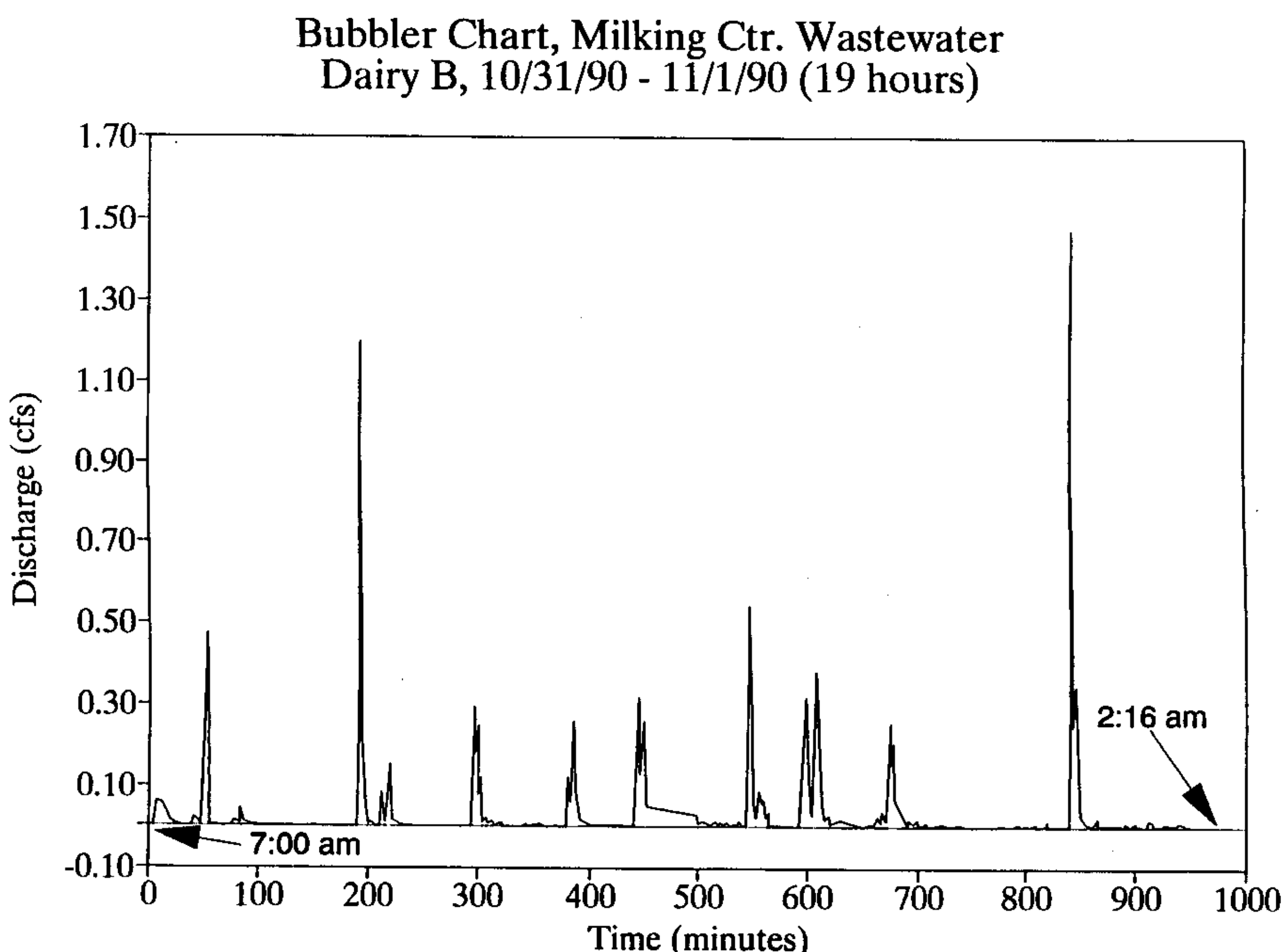


Figure 11. Hydrograph (19 hours) of milking center wastewater at Dairy B, October 31 to November 1, 1990; Peak flow of 41.7 L/s (1.47 cfs) and total flow volume of 59.3 m^3 (15,700 gal or 2,093 ft^3) measured with bubbler-type stage recorder in 0.46 m (1.5 ft) type-H flume.

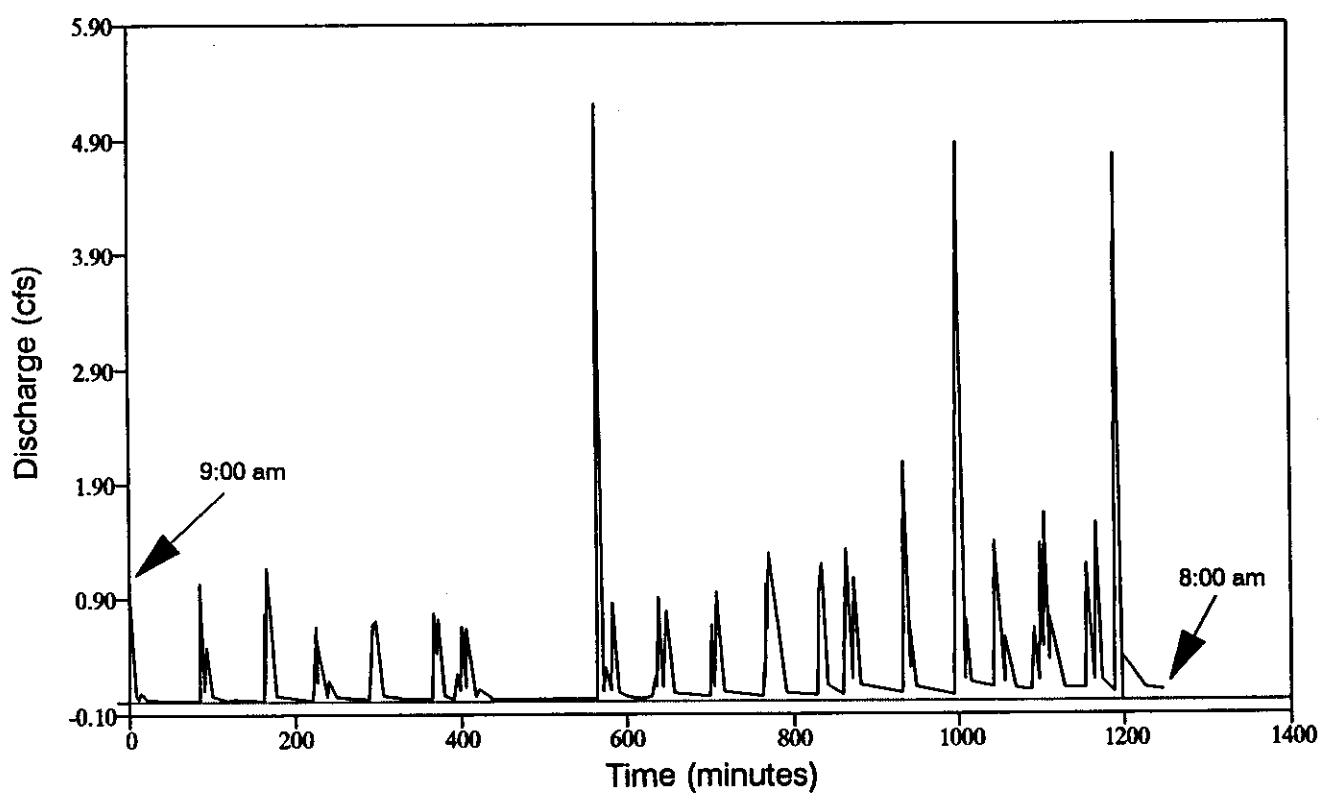


Figure 12. Hydrograph (24 hours) of milking center wastewater at Dairy B, December 17-18, 1990; Peak flow of 147.4 L/s (5.21 cfs) and total flow volume of 560 m^3 (148,000 gal or 19,800 ft^3) measured with bubbler-type stage recorder in 0.46 m (1.5 ft) type-H flume.

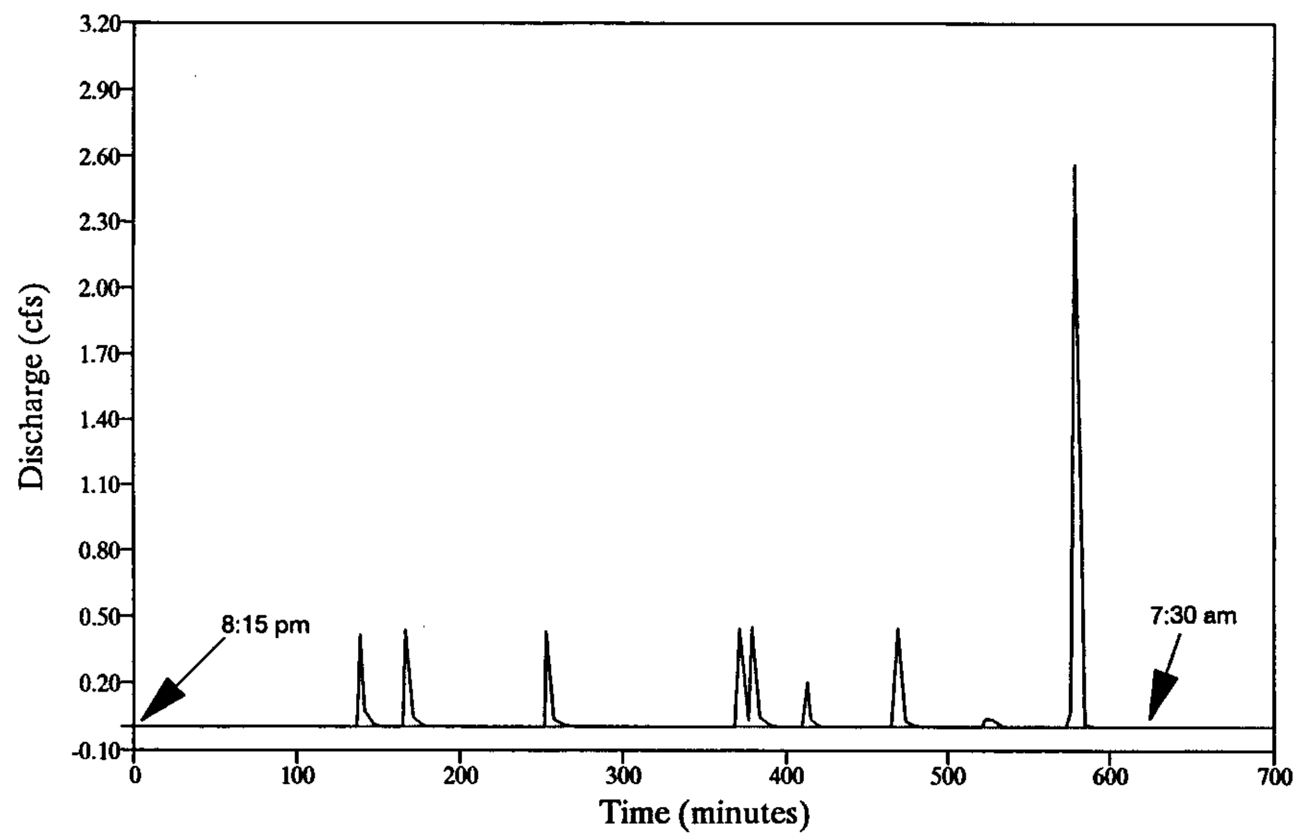


Figure 13. Hydrograph (12 hours) of milking center wastewater at Dairy J, May 8-9, 1990; Peak flow of 72.6 L/s (2.56 cfs) and total flow volume of 38.5 m^3 (10,200 gal or 1,360 ft^3) measured with float-type stage recorder in 0.46 m (1.5 ft) type-H flume.

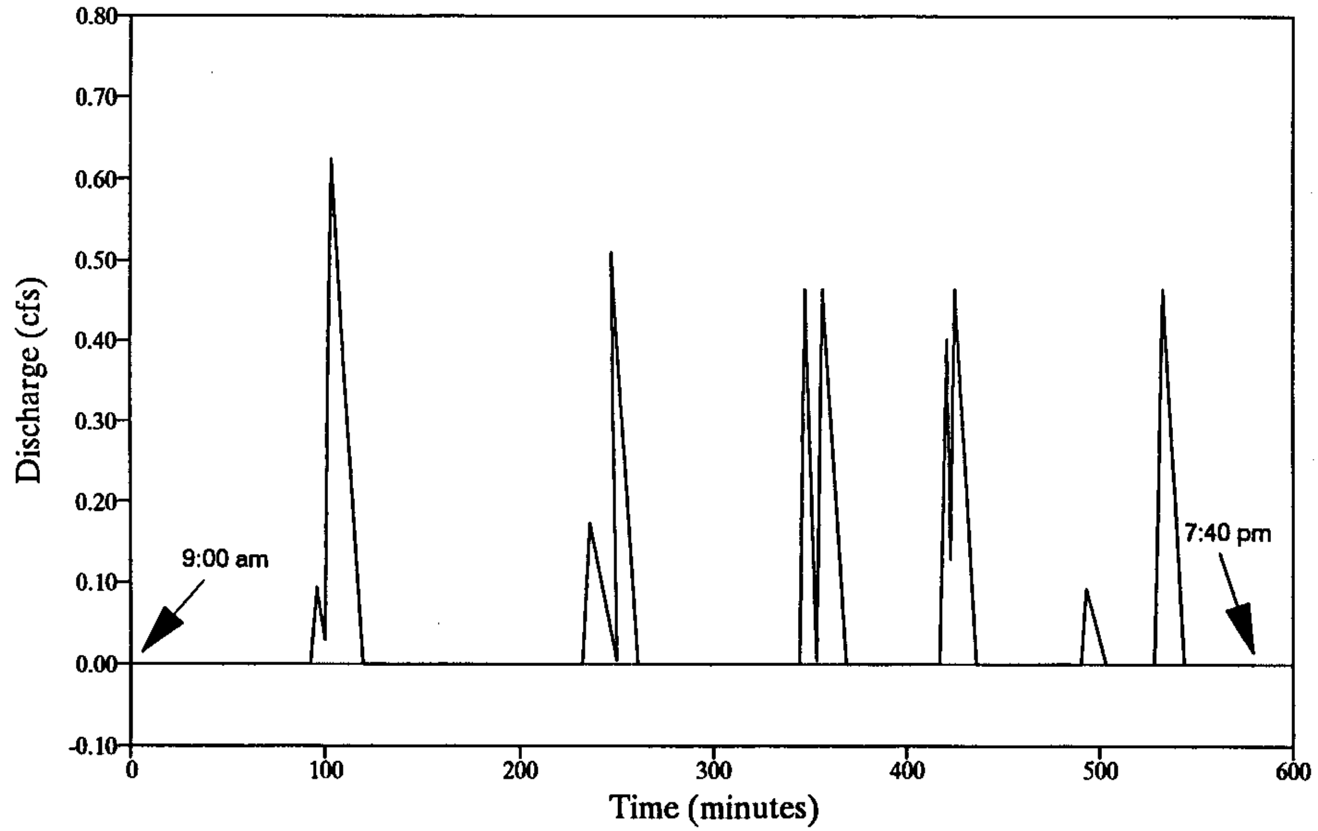


Figure 14. Hydrograph (12 hours) of milking center wastewater at Dairy J, May 27, 1990; Peak flow of 17.7 L/s (0.63 cfs) and total flow volume of 43.5 m^3 (11,500 gal or 1,537 ft^3) measured with float-type stage recorder in 0.46 m (1.5 ft) type-H flume.

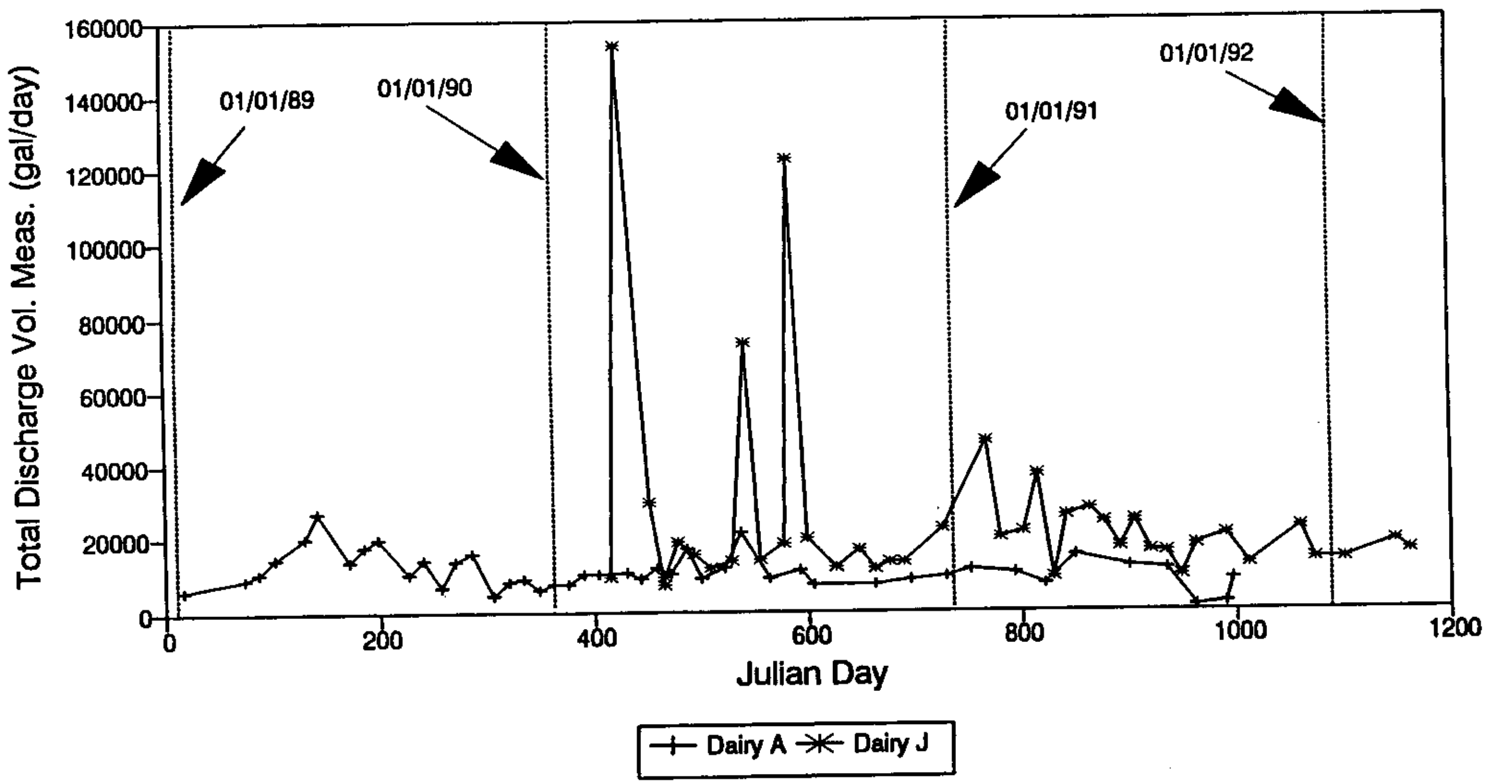


Figure 15. Total milking parlor wastewater volume measured in 0.46 m (1.5 ft) Type-H flume with float-type stage recorder at Dairies A and J, January, 1989-March, 1992.

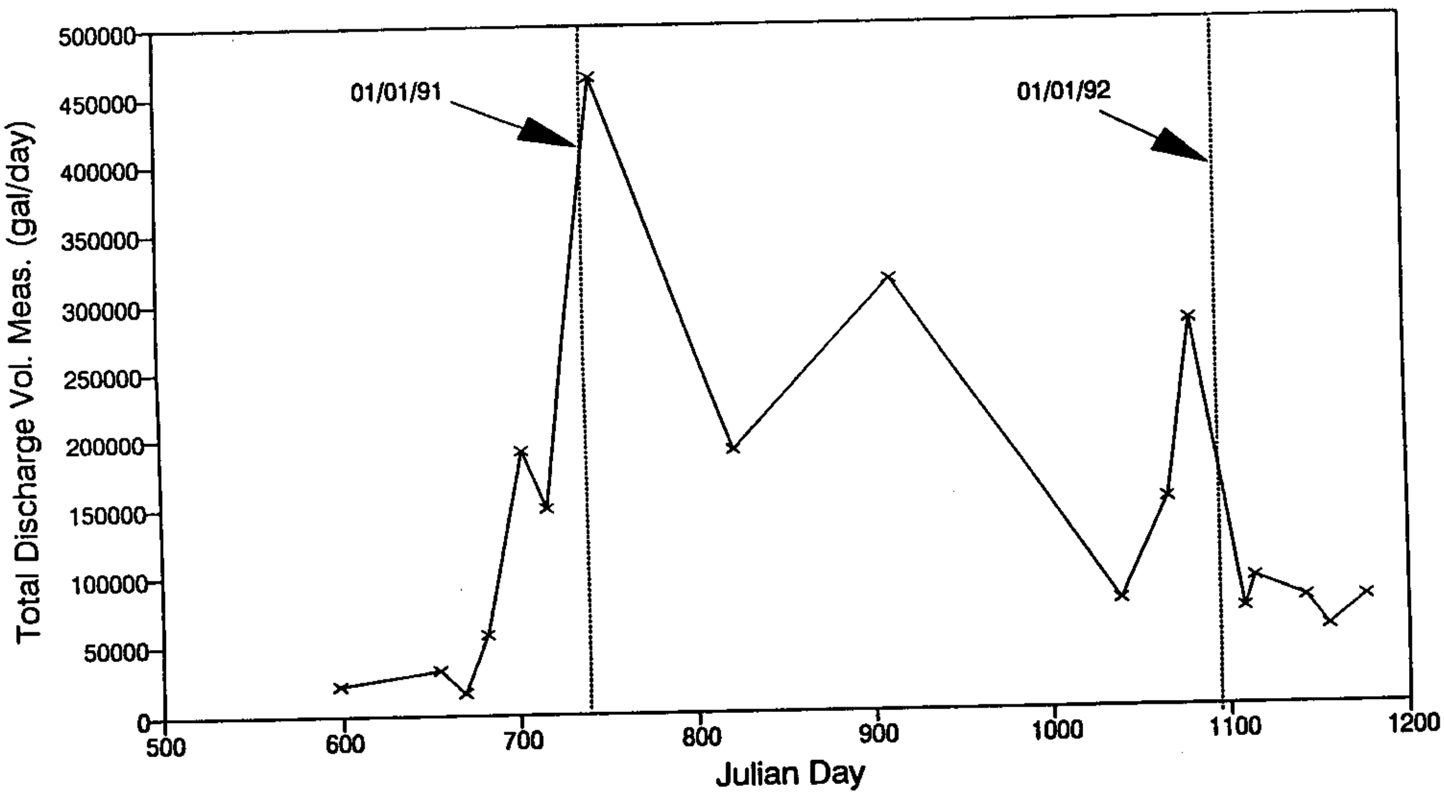


Figure 16. Total milking parlor wastewater volume measured in 0.46 m (1.5 ft) Type-H flume and bubbler-type liquid level recorder at Dairy B, August 1990-March, 1992.

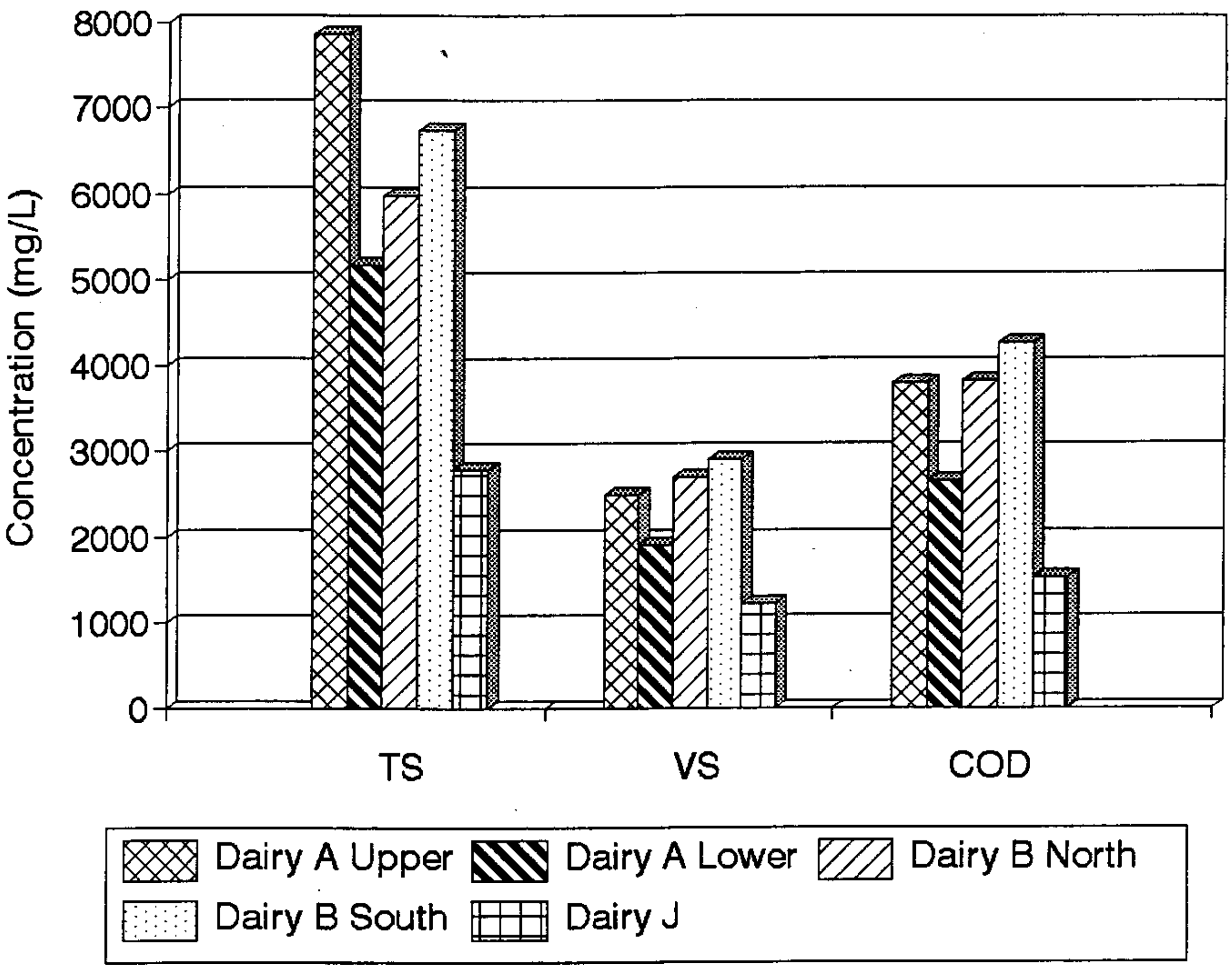
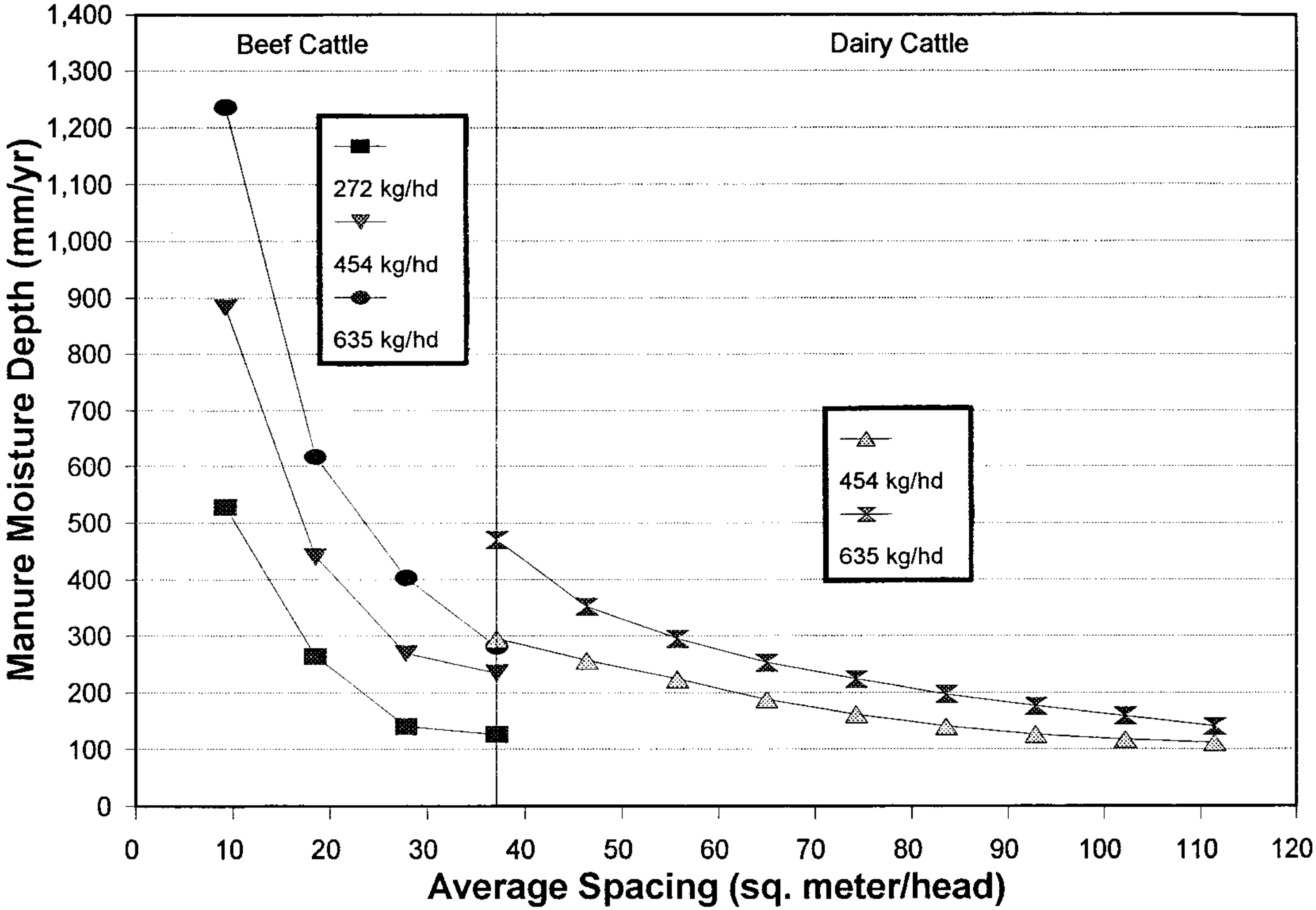


Figure 17. Average concentrations of total solids, volatile solids and chemical oxygen demand in runoff from open lots at Dairies A, B, and J, Erath County, Texas.


Manure Moisture Depth (mm/yr)
1,400
1,300
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
0
Beef Cattle
Dairy Cattle
272 kg/hd
454 kg/hd
635 kg/hd
454 kg/hd
635 kg/hd
0
10
20
30
40
50
60
70
80
90
100
110
120
Average Spacing (sq. meter/head)

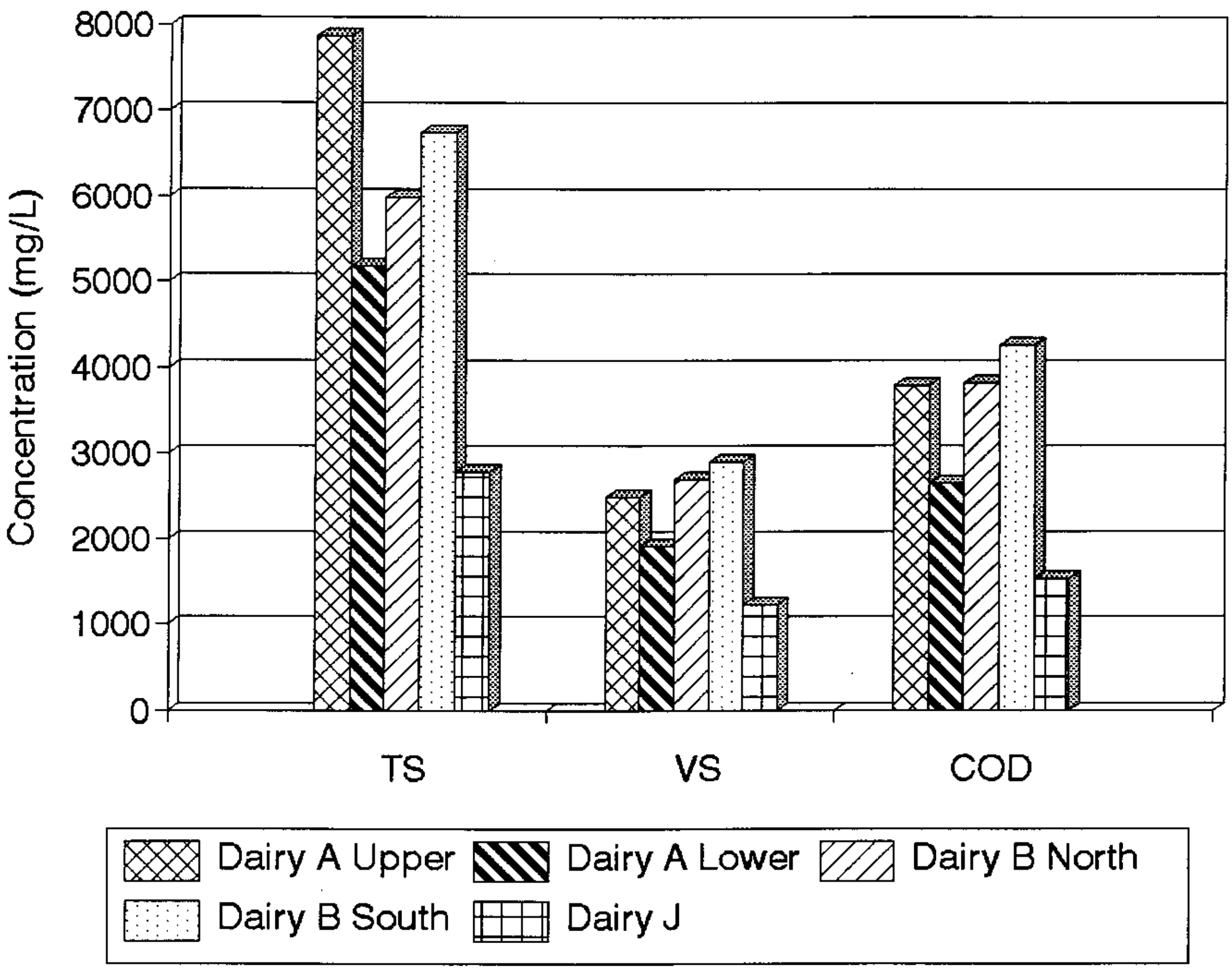


Figure 17. Average concentrations of total solids, volatile solids and chemical oxygen demand in runoff from open lots at Dairies A, B, and J, Erath County, Texas.

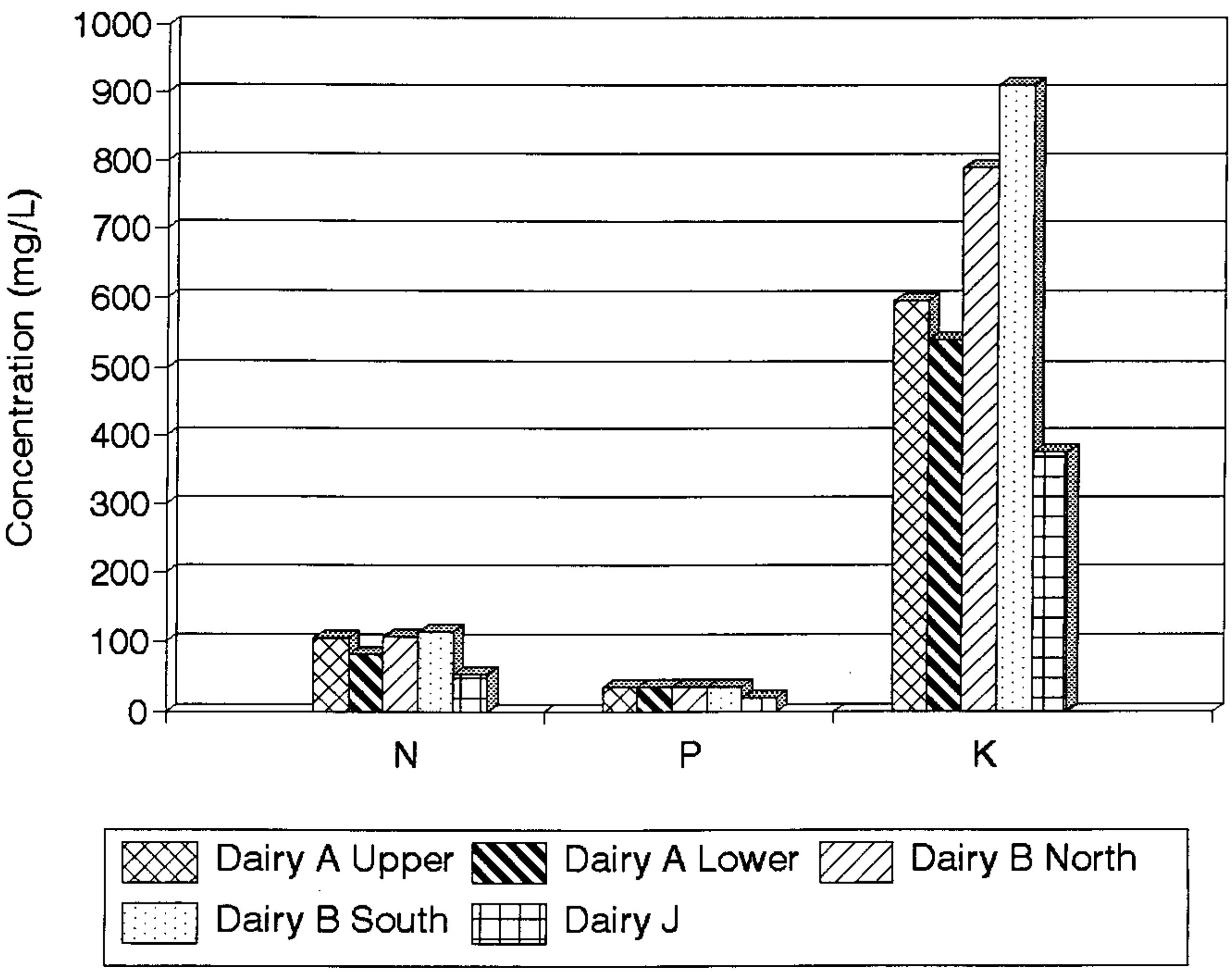


Figure 18. Average concentrations of nitrogen (TKN), phosphorus (P), and potassium (K) in runoff from open lots at Dairies A, B, and J, Erath County, Texas.

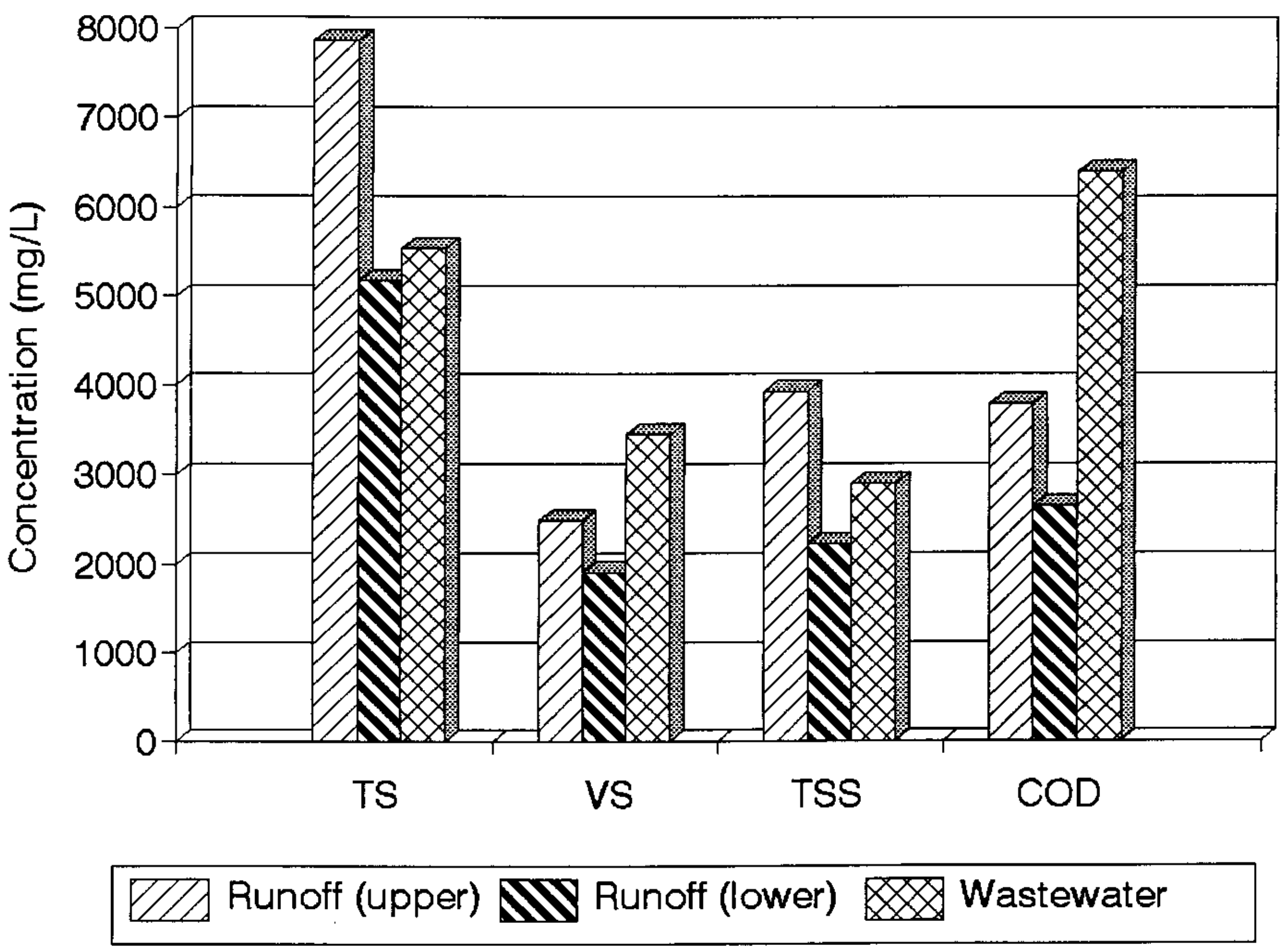


Figure 19. Comparison of open lot runoff and milking parlor wastewater concentrations of solids and chemical oxygen demand at Dairy A.

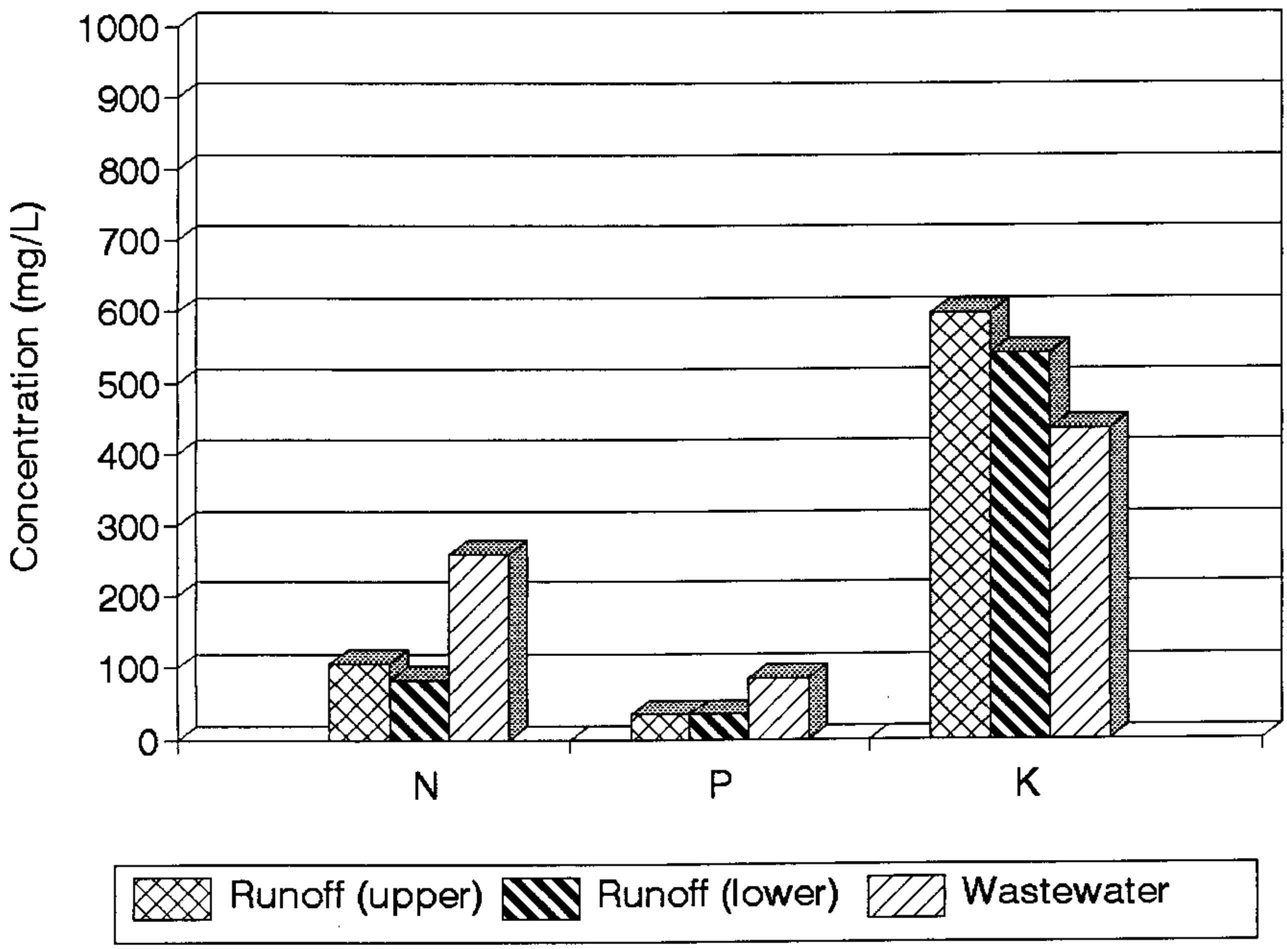


Figure 20. Comparison of open lot runoff and milking parlor wastewater nutrient concentrations, Dairy A.

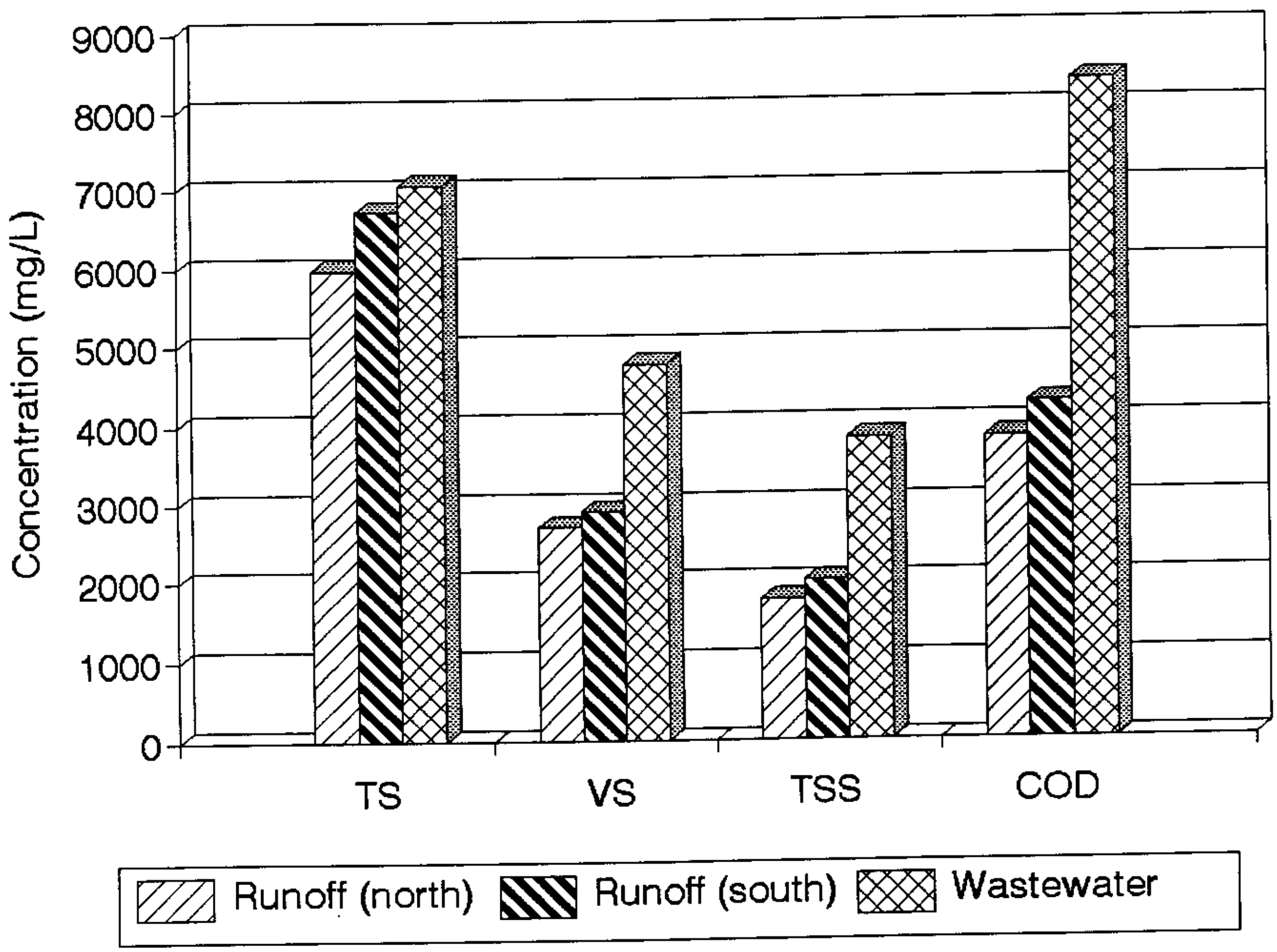


Figure 21. Comparison of open lot runoff and milking parlor wastewater concentrations of solids and chemical oxygen demand at Dairy B.

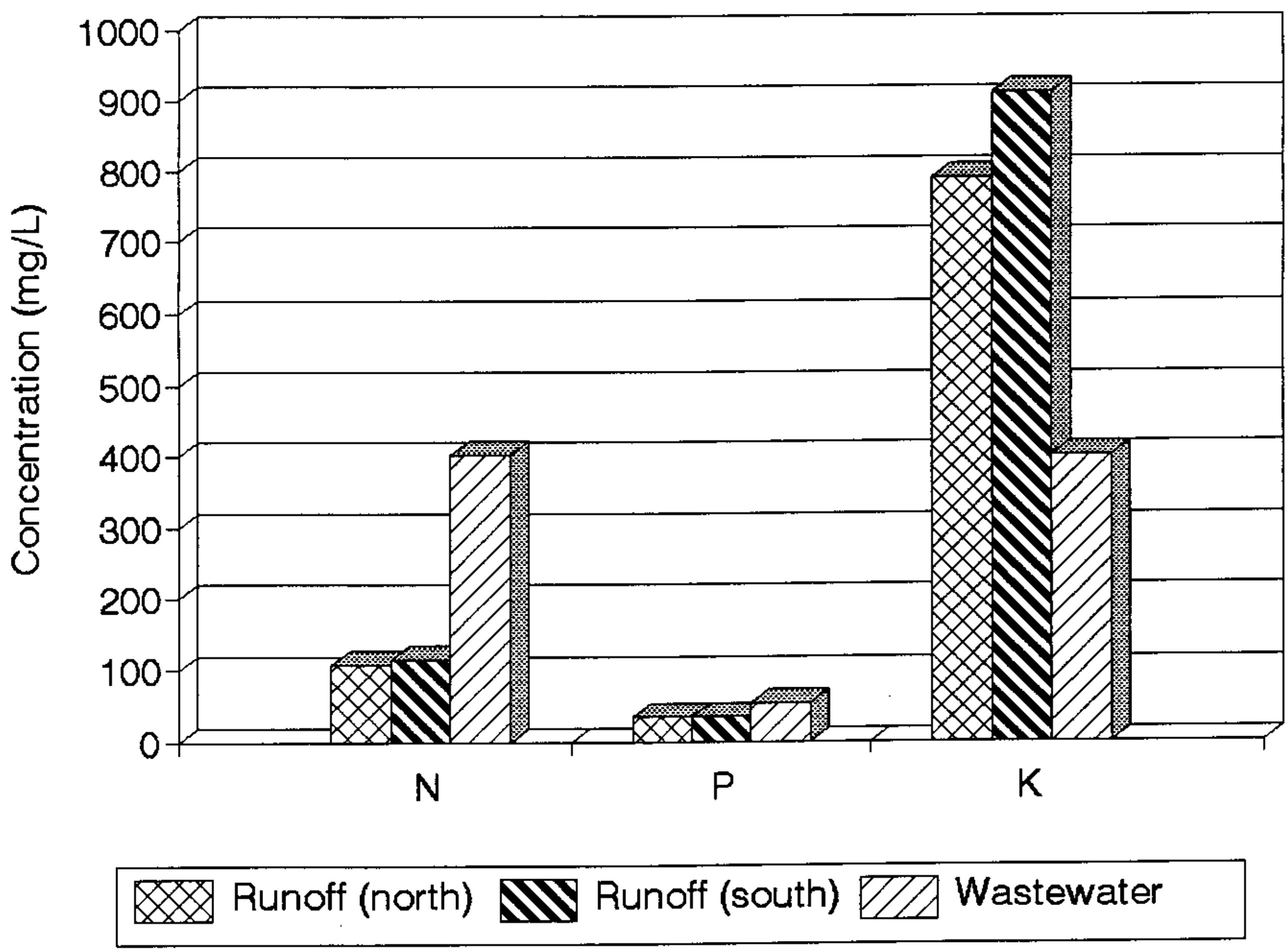


Figure 22. Comparison of open lot runoff and milking parlor wastewater nutrient concentrations, Dairy B.

APPENDIX A

DEFINITIONS OF SELECTED TERMS, FROM
ASAE STANDARD # S292.4
AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS

Definitions of Selected Terms, Used in This Report
From "Uniform Terminology for Rural Waste Management"
S292.4, ASAE Standard, American Society of Agricultural Engineers, 1990

2.15 **Anaerobic bacteria**: Bacteria not requiring the presence of free or dissolved oxygen. Facultative anaerobes can be active in the presence of dissolved oxygen, but do not require it.

2.16 **Anaerobic decomposition**: Reduction of the net energy level of organic matter by anaerobic microorganisms in the absence of oxygen.

2.27 **Chemical oxygen demand (COD)**: A measure of the oxygen-consuming capacity of inorganic and organic matter present in water or wastewater. It is expressed as the amount of oxygen consumed from a chemical oxidant in a specified test. It does not differentiate between stable and unstable organic matter and thus does not necessarily correlate with biochemical oxygen demand.

2.36 **Detention pond**: An earthen structure constructed to store runoff water and other wastewater until such time as the liquid many be recycled onto land. Sometimes called holding ponds or waste storage ponds.

2.37 **Detention time**: The time wastes are subjected to a stabilization process or held in storage.

2.39 **Digestion**: Usually refers to the breakdown of organic matter in water solution or suspension into simpler or more biologically stable compounds, or both. In anaerobic digestion organic matter may be decomposed to soluble organic acids or alcohols and subsequently converted to such gases as methane and carbon dioxide. Complete decomposition of organic solid materials to gases and water by bacterial action alone is never accomplished.

2.42 **Earthen storage basin**: An earthen structure usually with sloping sides and a flat floor, constructed to store semi-solid, slurry or liquid manure. Also called a waste storage pond.

2.43 **Effluent**: The discharge of wastewater or other liquid, treated or untreated.

2.48 **Fertilizer value**: An estimate of the value of commercial fertilizer elements (N, P, K) that can be replaced by manure or organic waste material. Usually expressed as dollars per ton of manure or quantity of nutrients per ton of manure.

2.49 **Fixed solids**: The portion of the total solids remaining as an ash or residue when heated at a specific temperature and time (usually 600 °C for at least one hour).

2.53 **Flushing system**: A system that collects and transports or moves waste material with the use of water such as in washing of pens and flushing confinement livestock systems.

2.56 **Holding pond**: (See detention pond.)

2.63 **Influent**: Water, wastewater, or other liquid flowing into a reservoir, basin, or treatment plant, or any unit thereof.

2.65 **Lagoon**: An earthen structure for the storage and biological treatment of wastewater. Lagoons can be aerobic, anaerobic, or facultative depending on their loading and design.

2.66 **Land application**: Application of manure, sewage sludge, municipal wastewater and industrial wastes to land either for ultimate disposal or for reuse of the nutrients and organic matter for their fertilizer value.

2.73 **Loading rate**: The quantity of material added per unit volume or unit area per unit time.

2.74 **Manure**: The fecal and urinary excretion of livestock and poultry. Sometimes referred to as livestock waste. This material may also contain bedding, spilled feed, water or soil. It may also include wastes not associated with livestock excreta, such as milking center wastewater, contaminated milk, hair, feathers, or other debris. Manure may be described in different categories as related to solids and moisture content.

2.74.1 **Liquid manure (thin slurry)**: Manure which has had sufficient water added so that it can be pumped easily. Normally fibrous material such as chopped straw or waste hay is not present.

2.74.3 **Semi-solid manure**: Manure which has had some bedding added or has received sufficient air drying to raise the solids content such that it will stack but has a lower profile than solid manure and seepage may collect around the outside.

2.74.4 **Solid manure**: Manure which has had sufficient bedding or soil added, or has received sufficient air drying to raise the solids content to where it will stack with little or no seepage.

2.80 **Milking center wastes**: The wastewater containing milk residues, detergents, and manure which is generated in a milking center.

2.107 **Sludge**: The precipitate or settled solids from treatment, coagulation, or sedimentation of water or wastewater.

2.111 **Solids content**: (1) The sum of the dissolved and suspended constituents in water or wastewater. (2) The residue remaining when the water is evaporated away from a sample of sewage, other liquids, or semi-solid masses of material and the residue is then dried at a specified temperature (usually 102 °C for 24 hours); usually stated in milligrams per liter or percent solids.

2.115 **Supernatant**: The liquid standing above a sediment or precipitate after settling or centrifuging.

2.116 **Suspended solids**: (1) Solids that are in water, wastewater, or other liquids, and which are largely removable by filtering or centrifuging. (2) the quantity of material filtered from wastewater in a laboratory test, as prescribed in APHA Standard Methods for the Examination of Water and Wastewater.

2.123 **Volatile solids**: That portion of the total solids driven off as volatile (combustible) gases at a specified temperature and time (usually 600 °C for at least 1 hour).

2.124 **Volatile suspended solids (VSS)**: That portion of the suspended solids driven off as volatile (combustible) gases at a specified temperature and time (usually 600 °C for at least 20 minutes).

APPENDIX B

SELECTED CONVERSION FACTORS

Selected Conversion Factors

	English to Metric	Metric to English
a.	Yield:	
	1 lb/ac = 1.120 kg/ha	1 kg/ha = 0.8922 lbs/ac
	1 lb/ac = 0.00112 Mg/ha	1 Mg/ha = 892.2 lbs/ac
b.	Irrigation Water Use Efficiency:	
	1 lb/ac-in = 0.004410 kg/m^3	1 kg/m^3 = 226.7 lb/ac-in
	1 lb/ac-in = 0.04410 kg/ha-mm	1 kg/ha-mm = 22.67 lb/ac-in
c.	Water Volume:	
	1 ac-in = 10.28 ha-mm	1 ha-mm = 0.0973 ac-in
	1 ac-in = 102.8 m^3	1 m^3 = 0.00973 ac-in
	1 in = 25.4 mm	1 mm = 0.03937 in
	1 ac-ft = 1,233 m^3	1 m^3 = 0.000811 ac-ft
d.	Pressure/Tension:	
	1 psi = 6.9 kPa	1 kPa = 0.145 psi
	1 bar = 10,200 kg/m^2 = 100 kPa	1 kg/m^2 = 9.8 x 10^{-5} bars
	1 centibar (cb) = 1 kPa	1 kPa = 1 cb
e.	Pumping Rate:	
	1 gpm = 0.0631 L/s	1 L/s = 15.9 gpm
f.	Soil Bulk Density:	
	1 lb/ft^3 = 0.0160 Mg/m^3	1 Mg/m^3 = 62.45 lb/ft^3

English to English	Metric to Metric
1 ac-in = 27,154 gal	1 ha-mm = 10 m^3
1 ac-in = 3,630 ft^3	

APPENDIX C

DESCRIPTION OF DAIRIES C, D, E, F, G, H, I AND K
AND FUNCTIONAL LOCATIONS OF WATER METERS

Description of Dairies

The eleven dairies in Erath County, Texas that cooperated in a large-scale water use demonstration lie in the Upper North Bosque River Hydrologic Unit Project area. The average herd size was 567 head, with a range of 149 to 1514 milking cows. Following is a brief description of these dairy farms, waste management systems, water use, and monitoring activities, exclusive of Dairies A, B, and J which were described in the Methods, Equipment and Procedures Section of this report. Water use data for each of these dairies are summarized in the Results section of this report.

Dairy C

Dairy C consisted of a double six-stall milking facility accommodating an average of 149 milking head on three times milking per day basis. Dry cows and heifers were not included in this demonstration. One well approximately 30 m (100 ft) deep supplied fresh ground water for the operation and was located near the milking barn. Wastewater holding facilities consisted of an underground concrete holding tank. The wastewater was irrigated onto pasture using a liquid manure pump and a big-gun sprinkler. The dairy facilities consisted of approximately 4 ha (10 ac) including the milking center, feeding, holding, and waste management facilities.

Monitoring systems used for demonstration and evaluation were located on this dairy to evaluate water use and consumption and indirectly obtain an estimate of wastewater production. Water meters were placed in flow lines going to: (1) milking parlor and cow washers; and (2) cow drinking water troughs.

An improved waste management system that will provide more storage was designed by SCS-USDA and installed by the dairyman during the study, along with obtaining a TWC permit.

Dairy D

Dairy D consisted of a double-eight-stall milking facility accommodating an average of 155 milking head on two times milking per day basis. Total number of cows (milking and dry) averaged 240 head with heifers included. One well approximately 140 m (460 ft) deep supplied fresh ground water for the operation and was located west of the milking barn. Wastewater holding and treatment facilities consisted of a single-stage lagoon. The milking center, feeding, holding, and waste management facilities occupied approximately 1.8 ha (4.5 ac). A runoff holding pond was designed by SCS-USDA to collect both open-lot runoff and overflow from the primary lagoon and to provide for irrigation.

Monitoring systems used for demonstration and evaluation were located on this dairy to evaluate water consumption and indirectly to estimate wastewater production. Water meters were placed near the well. Meters were located in pipe lines going to the milking parlor (manual cleanup) and cow drinking water troughs.

Dairy E

Dairy E consisted of a double 12-stall milking facility accommodating an average of 1,030 milking head on two times milking per day basis. This dairy also had two free-stall barns that were flushed. Total number of cows, milking and dry, averaged 1,450 head, including heifers. Two wells approximately 143 m (470 ft) deep supplied fresh ground water for the operation and were located next to the feed commodities barn and on the side of the milking barn. Waste water holding facilities consisted of primary and secondary lagoons for manure and wastewater treatment accompanied by a settling basin to remove settleable solids materials. A large sump pump station, mechanical agitator and static screen were installed during the study to replace the settling basin for solids removal.

Water meters used for demonstration and evaluation were located on this dairy to evaluate water consumption. The meters were placed at the main pumping facility in pipe lines going to:

1. Milking Parlor, Equipment, Plate Cooler, Vacuum Pump, and Compressor
2. Flush Tank (Fresh Water)
3. Sprinkler Tank Inflow (Fresh)
4. Sprinkler Cow Washers (Outflow)
5. North Freestall, Cow Lot, Heifer Pen
6. South Freestall, Barn and Dry Lot

Dairy F

Dairy F consisted of a double 15-stall milking facility accommodating an average of 949 milking head on two times milking per day basis. Total number of cows, milking and dry, averaged approximately 1,200 head with heifers included. Two wells approximately 122 m (400 ft) deep supplied fresh ground water for the operation and were located by the milking barn and calf barn. Wastewater holding facilities consisted of a single-stage manure and wastewater storage pond/lagoon. The area of the dairy which supported the monitoring program consisted of approximately 12 ha (30 ac) that contained milking, feeding, holding, and waste management facilities.

Water meters used to evaluate water consumption and wastewater production were placed at each well and in the pump room at the milking barn. Meters were located in flow lines going to:

1. Milking Parlor and Cow Washers
2. Water Troughs
3. Calf Barn (Drinking and Manure Cleanup) and Dry Cow Watering

Dairy G

This operation included a double six-stall milking facility accommodating an average of 327 milking head on two times milking per day basis. Dry cows and heifers were not included in this demonstration. Two wells approximately 88 m (290 ft) deep supplied fresh ground water for the operation and were located on the south side of the milking barn near the holding lots. Waste water holding facilities consisted of primary and secondary waste treatment and storage lagoons.

The dairy facility consisted of approximately 4.9 ha (12 ac) which included the milking, feeding, holding, and waste facilities.

Water meters used to evaluate water consumption and provide an indirect measure of wastewater production were located in flow lines going to:

1. Milking Parlor Manual Washdown, Line A
2. Milking Parlor Manual Washdown, Line B
3. Milk Barn, Equipment
4. Cow Drinking Water, 3 Pens
5. Cow Drinking Water, 3 Pens
6. Cow Drinking Water, 1 Pen

Dairy H

This operation included a double 16-stall milking facility accommodating an average of 1,514 milking head on two times milking per day basis. Total number of cows, milking and dry, averaged 1,650 head including heifers. Two wells approximately 122 m (400 ft) deep supplied fresh ground water for the operation and were located near two residences approximately 244 m (800 ft) west of the milking barn. Wastewater holding facilities consisted of primary and secondary waste lagoons. The dairy facility consisted of approximately 16 ha (40 ac) including the milking, feeding, holding, and waste management facilities.

Water meters used to evaluate water consumption were placed at each well and in the milking barn. Meters were located in flow lines going to:

1. Residence, Cattle Holding Pen and Milking Parlor
2. Milking Parlor (Line A) and Cow Watering
3. Milking Parlor (Line B)

Dairy I

This operation included a double 8-stall milking facility accommodating an average of 293 milking head on two times milking per day basis. Dry cows and heifers were not included in the demonstration. Two wells approximately 41 m (300 ft) deep supplied fresh ground water for the operation and were located near the dairy barn. Wastewater holding facilities consisted of primary, secondary, and tertiary waste water treatment lagoons. The milking, feeding, holding, and waste management facilities were located on approximately 15 ha (37 ac).

Only one water meter was located on this dairy to evaluate water consumption and wastewater production. This meter was located in the flow line going to the milking barn from the well.

Dairy K

Dairy K included a double 8-stall milking facility accommodating an average of 186 milking head on two times milking per day basis. Total number of cows, including both milking and dry, averaged 186 head. Two wells approximately 122 m (400 ft) deep supplied fresh ground water for the operation and were located near a residence and next to the milking barn. Waste water holding facilities consisted of primary and secondary waste treatment and storage lagoons. The dairy facility occupied approximately 5.7 ha (14 ac) which contained the milking center, feeding lots, holding shed, and waste management facilities.

Water meters used for demonstration and evaluation were located on this dairy to evaluate water consumption and wastewater production. Water meters were placed in flow lines going to: (1) milking barn; and (2) holding pen manual washdown.

APPENDIX D

GRAPHS OF DAILY WATER USE THROUGH

WATER METERS--DAIRIES A, B, AND J

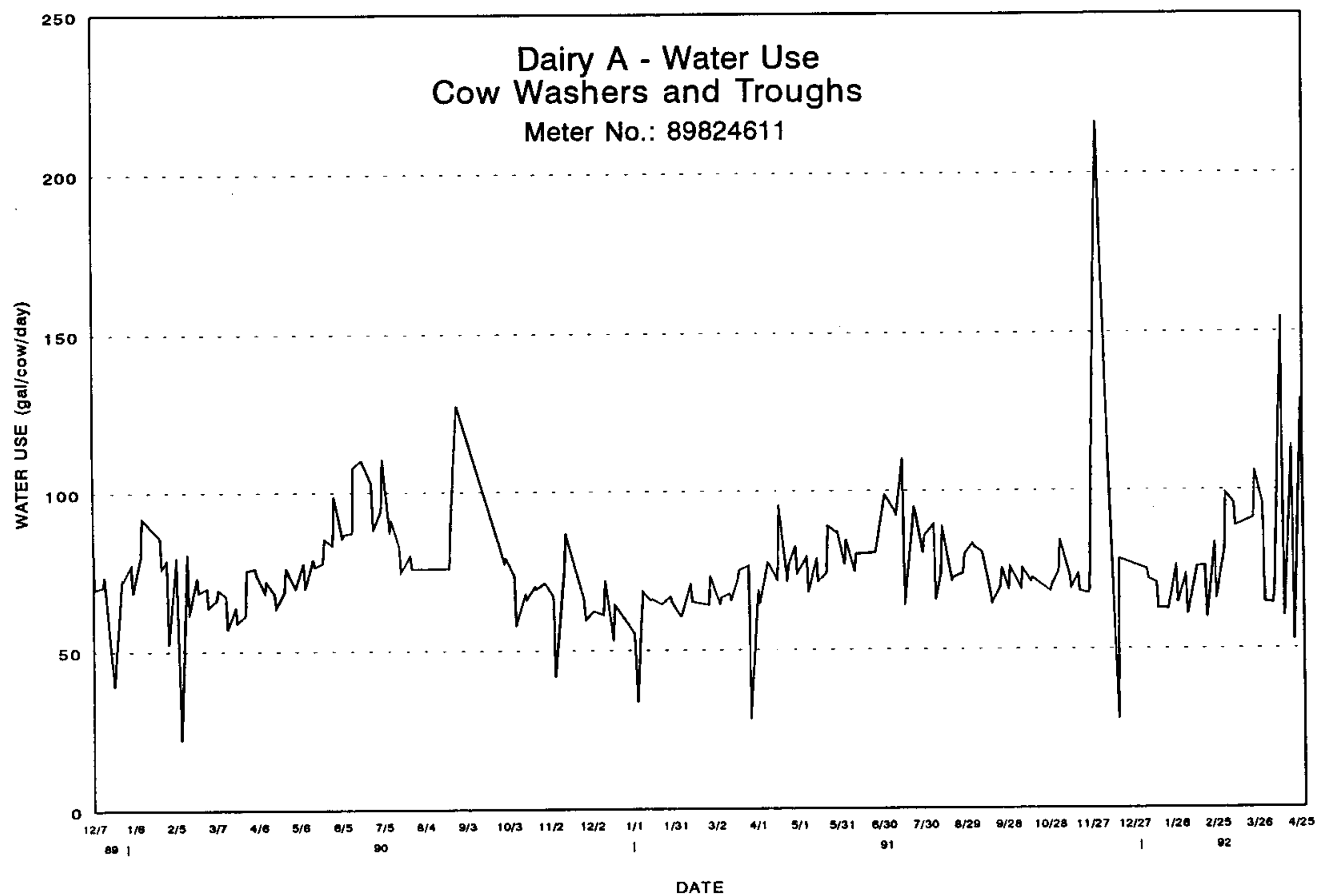


Figure D-1. Measured daily water use per cow for sprinkler cow washers and water troughs combined at Dairy A, December, 1989-April 1992. Mean ± standard deviation = 286.1 ± 69.6 L/day (75.60 ± 18.39 gal/day).

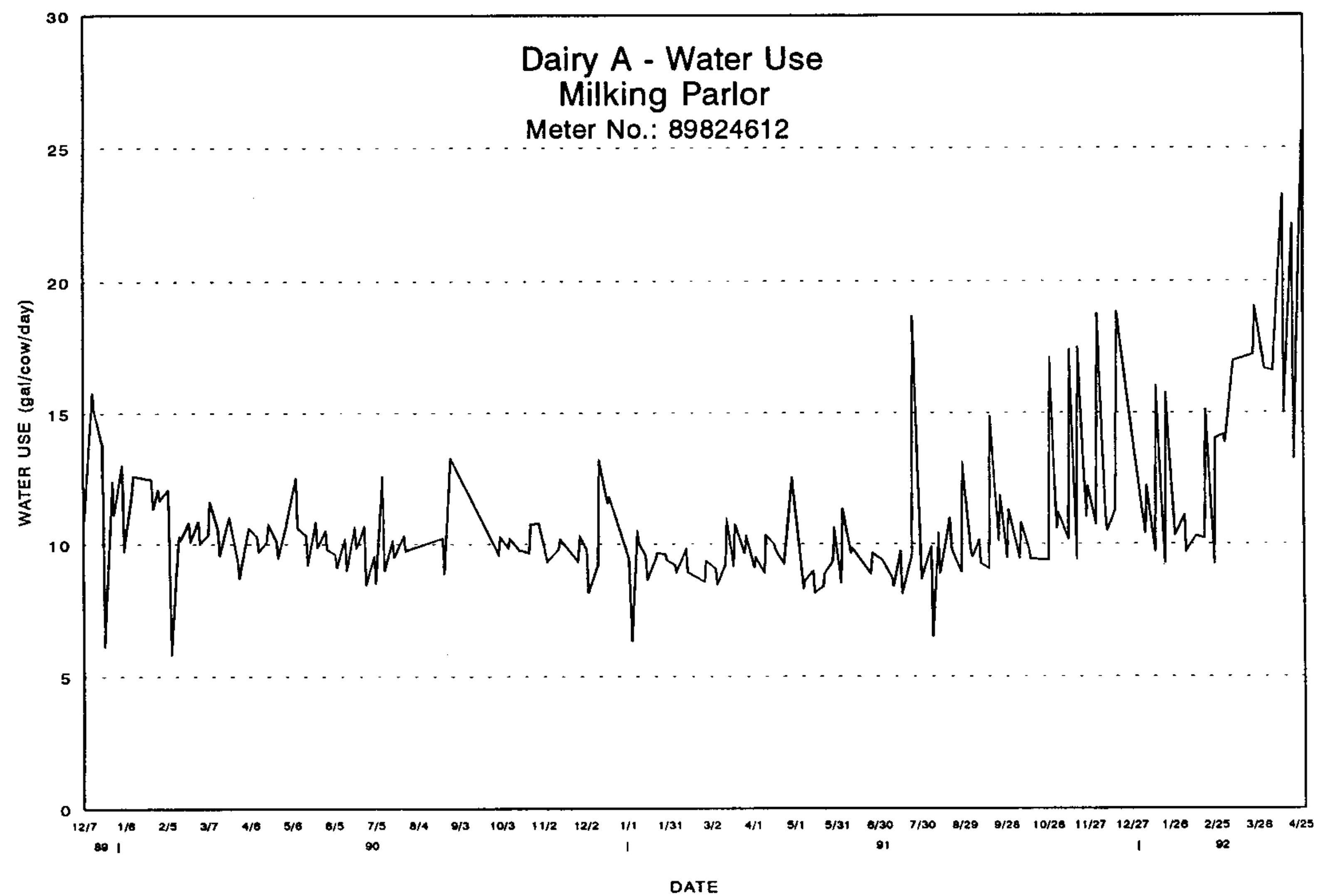


Figure D-2. Measured daily water use per cow for the milking parlor at Dairy A, December, 1989-April, 1992. Mean ± standard deviation = 41.6 ± 10.7 L/day (10.98 ± 2.84 gal/day).

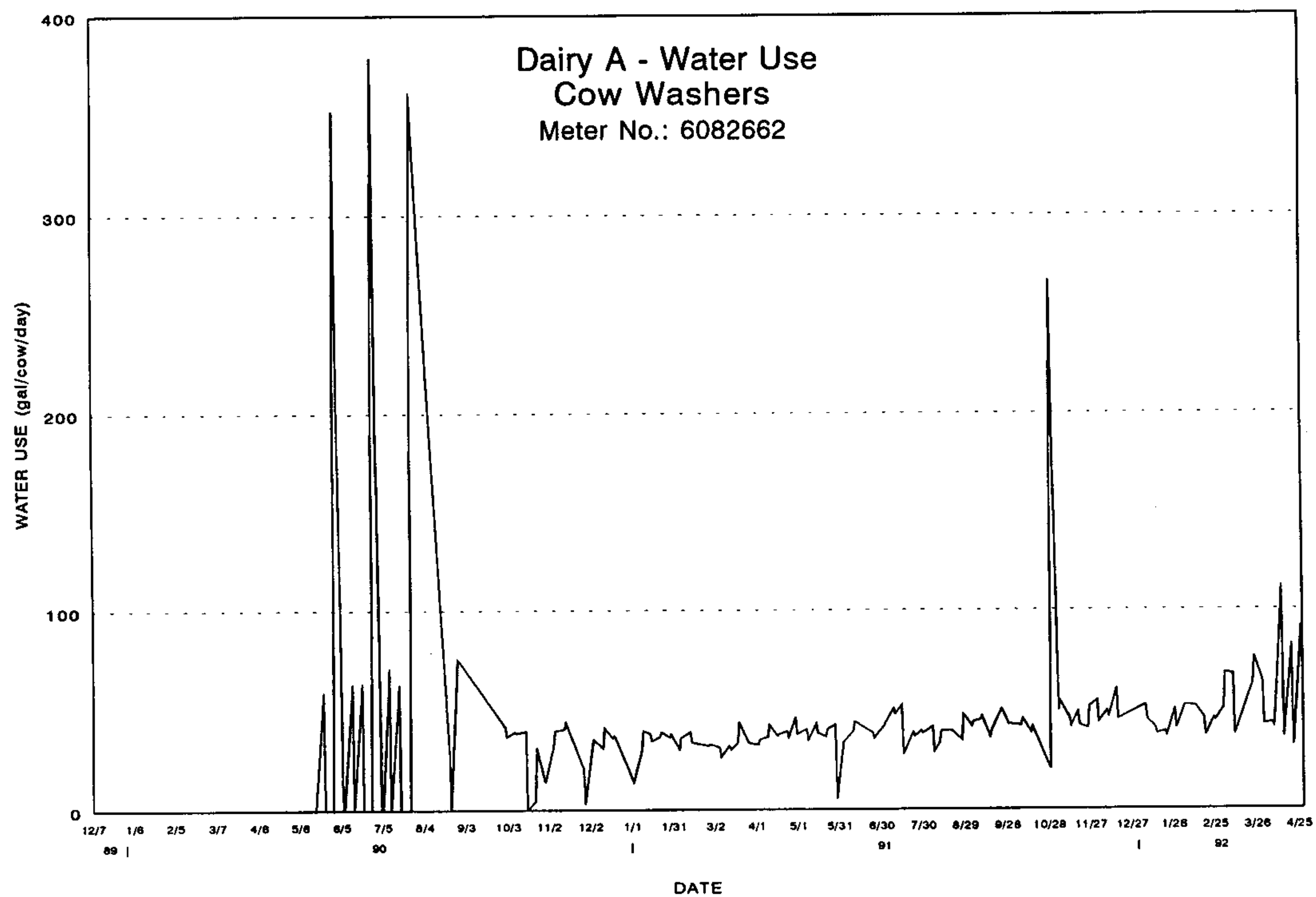


Figure D-3. Measured daily water use per cow for sprinkler cow-washers only at Dairy A, May, 1990-April, 1992. Mean ± standard deviation = 170.2 ± 188.4 L/day (44.95 ± 49.77 gal/day).

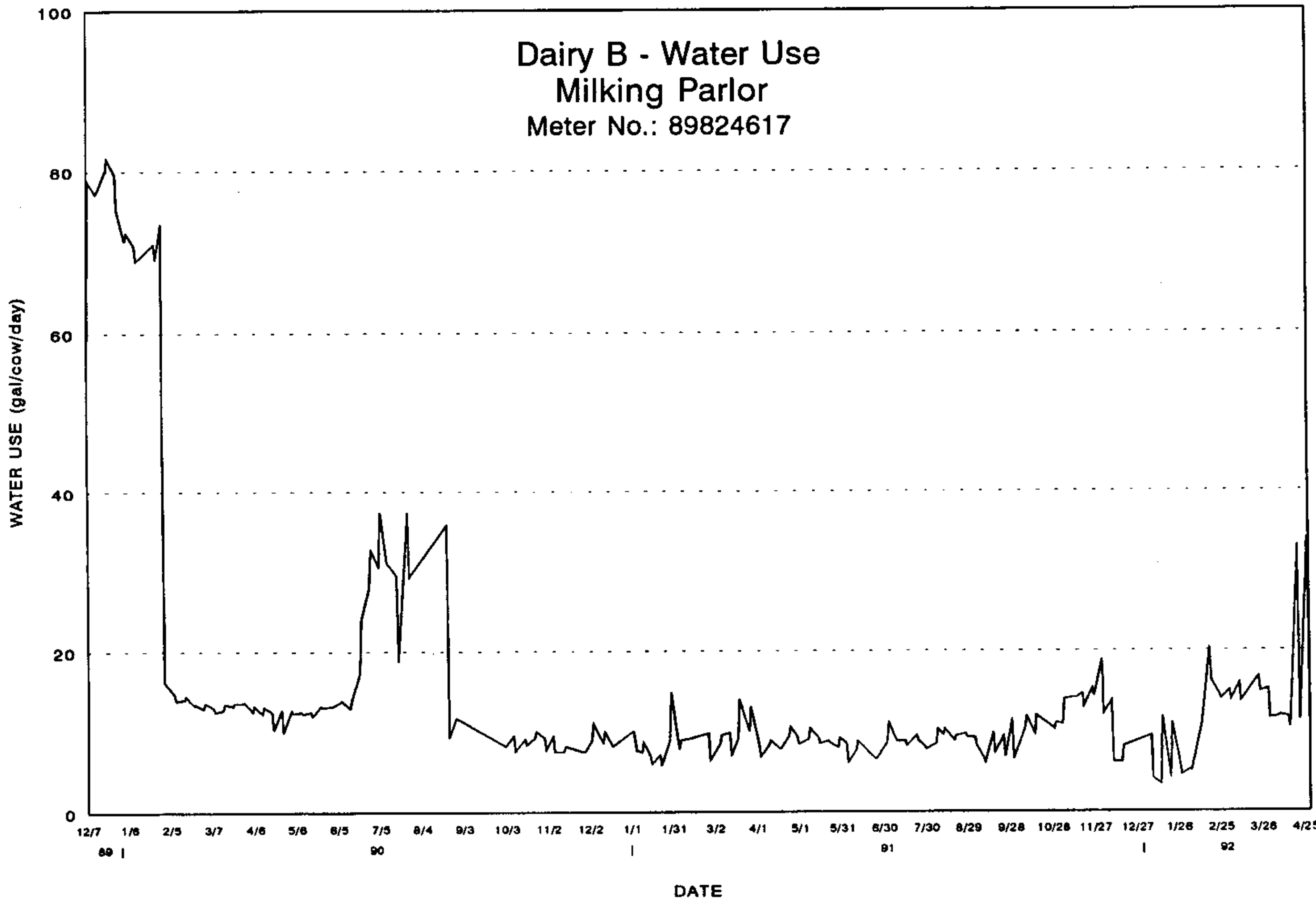


Figure D-4. Measured daily fresh water use per cow for the milking parlor ("main barns") at Dairy B, December, 1989-April, 1992. Mean $\pm$ standard deviation = 61.5 $\pm$ 63.8 L/day (16.26 $\pm$ 16.85 gal/day).

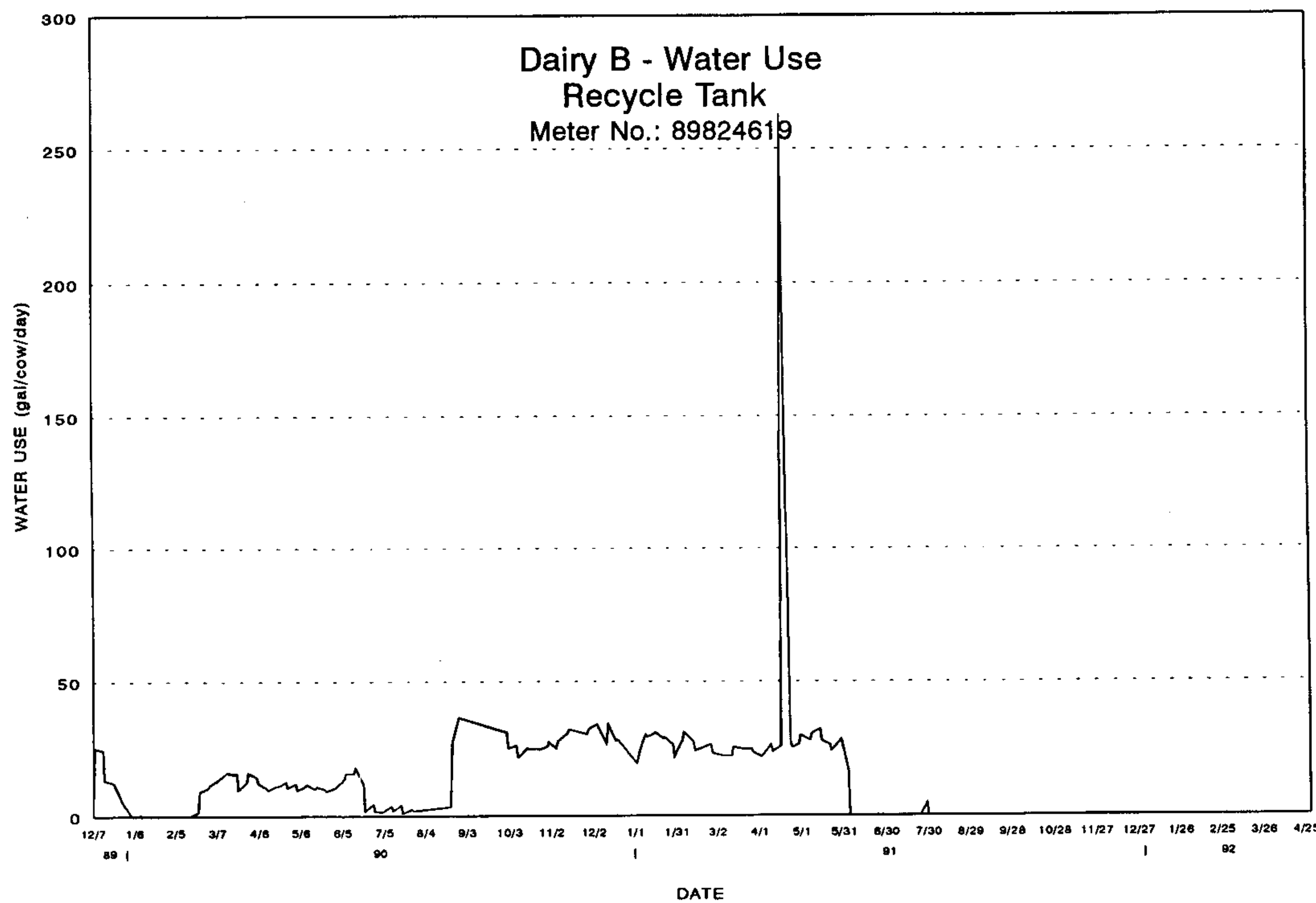


Figure D-5. Measured daily fresh water use per cow for the recycle tank at Dairy B, December, 1989-April, 1992. Mean ± standard deviation = 53.8 ± 44.5 L/day (14.21 ± 11.77 gal/day).

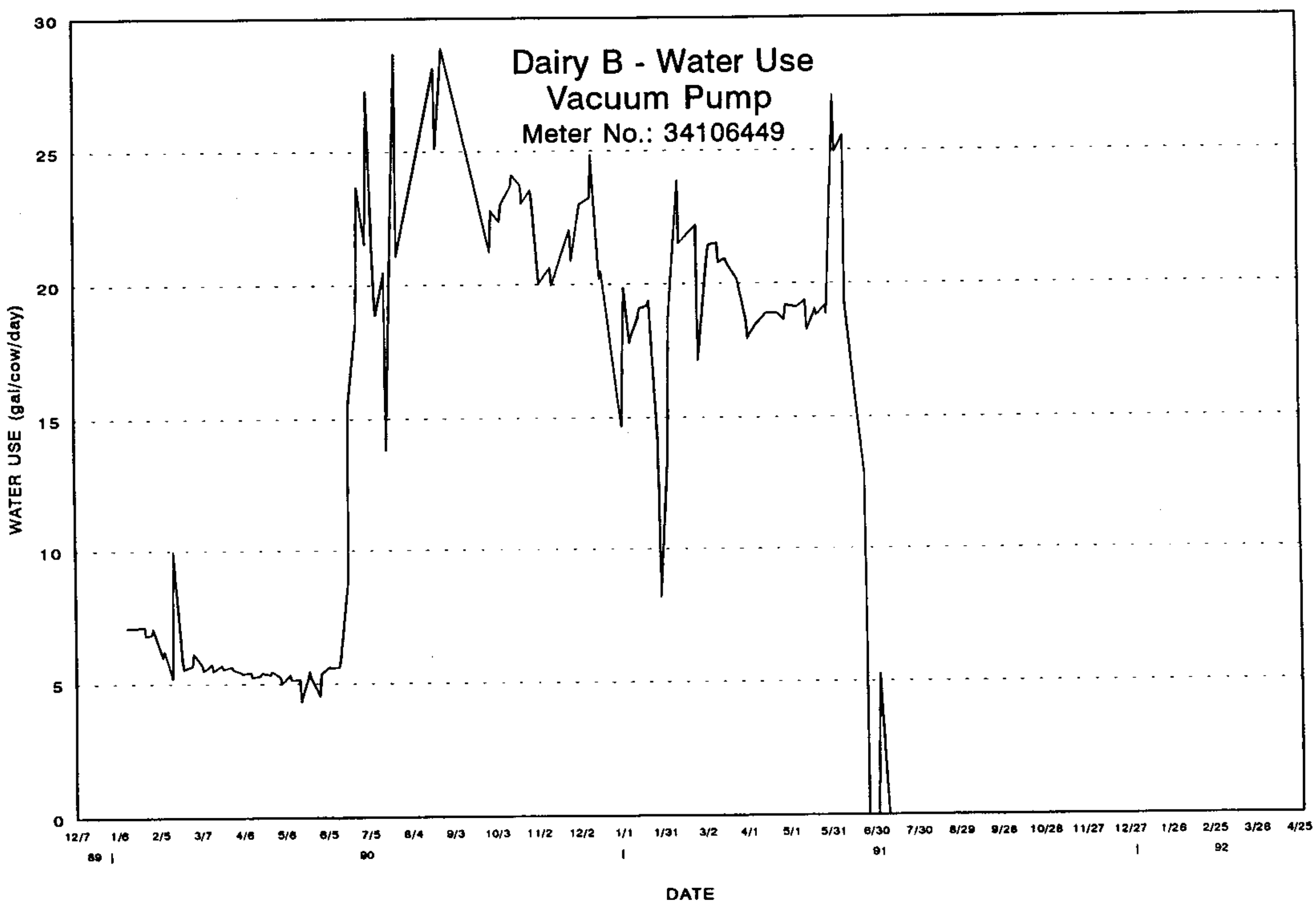


Figure D-6. Measured daily fresh water use per cow for the vacuum pump at Dairy B, December, 1989-June, 1991 (subset of milking parlor fresh water use). Mean ± standard deviation = 55.1 ± 30.7 L/day (14.53 ± 8.12 gal/day).

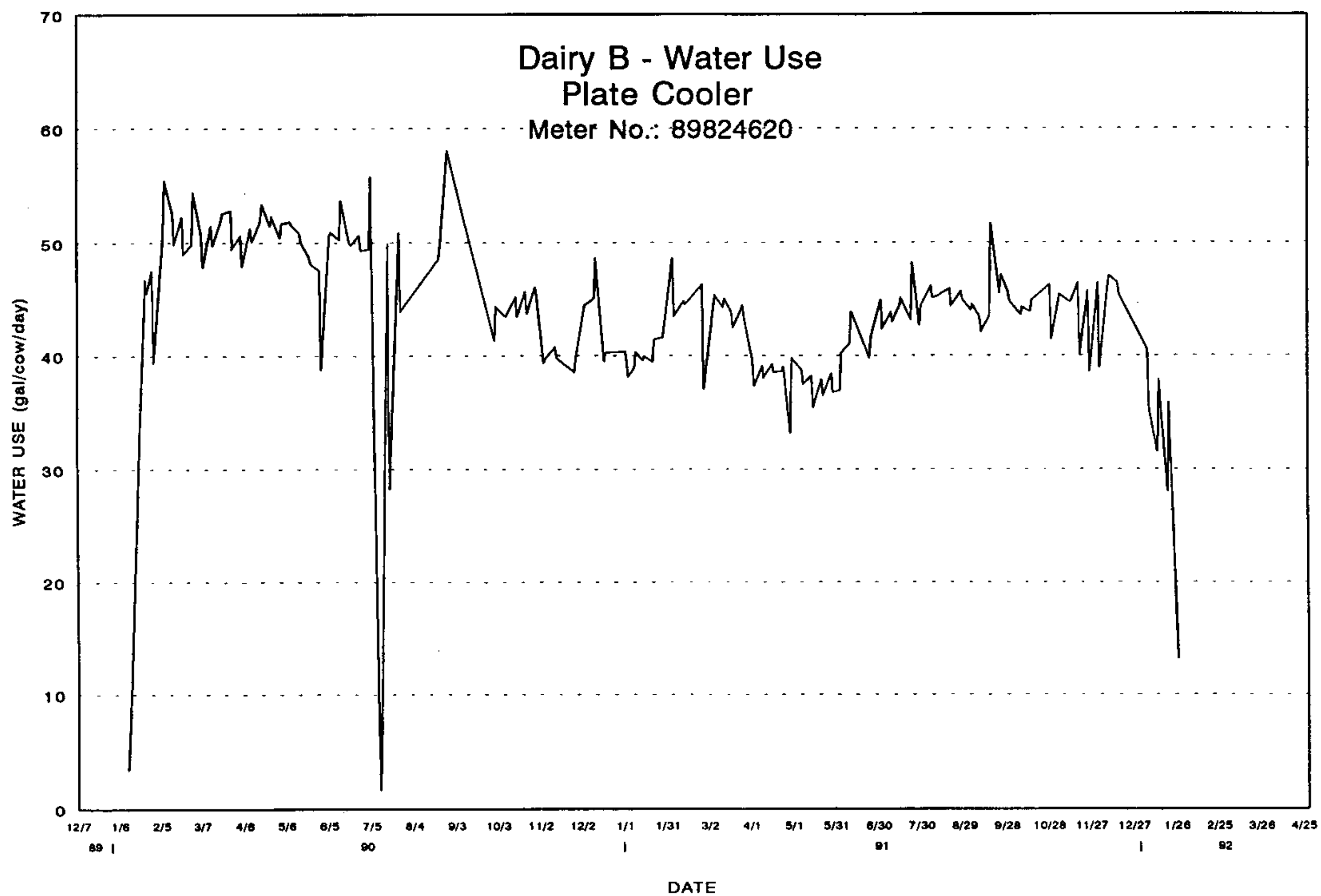


Figure D-7. Measured daily water use per cow for the plate cooler (using a blend of fresh water and recycled water from the recycle tank) at Dairy B, January, 1990-January, 1992. Mean ± standard deviation = 165.5 ± 29.0 L/day (43.73 ± 7.67 gal/day).

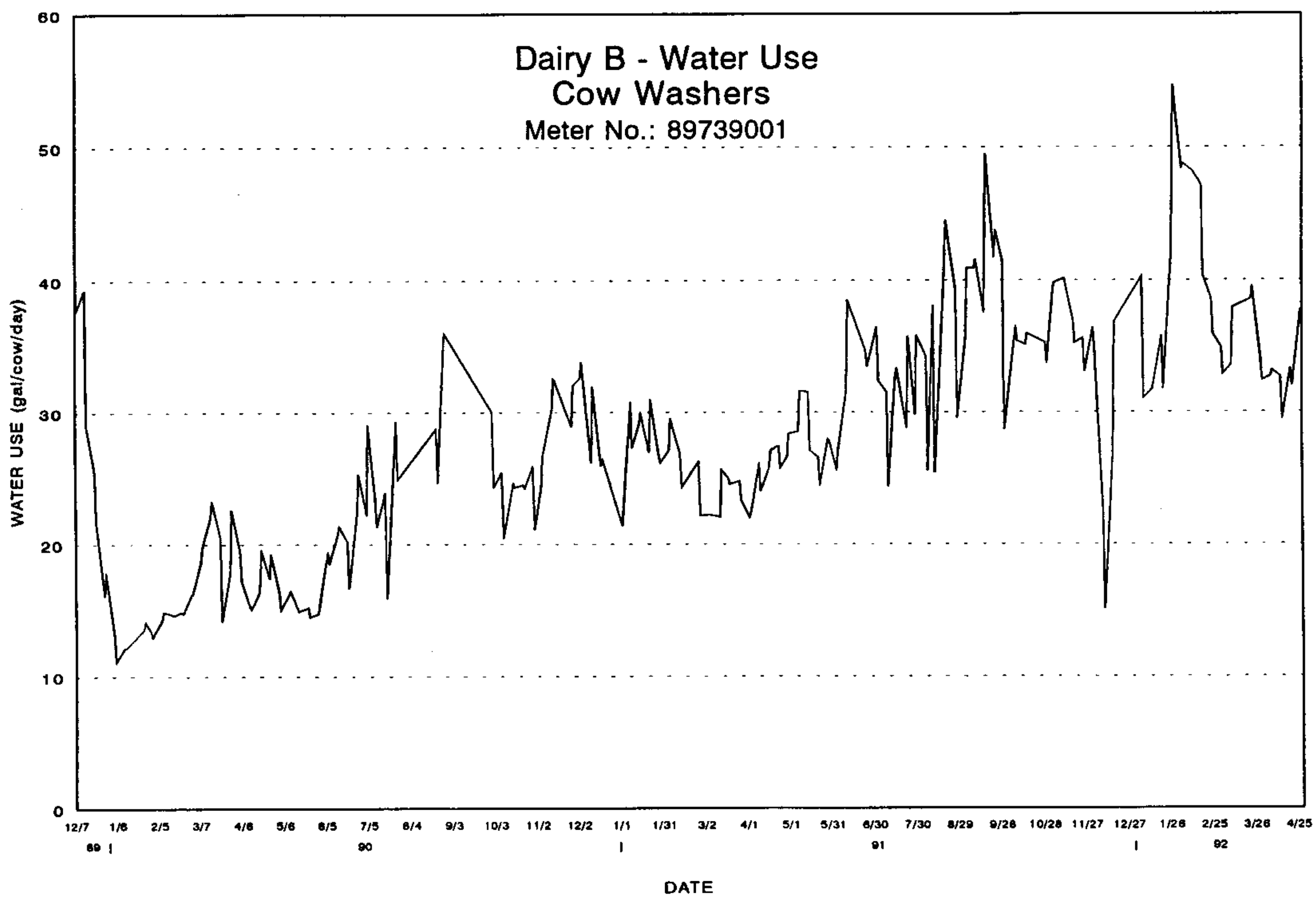


Figure D-8. Measured daily water use per cow for the sprinkler cow-washers, using recycled water, Dairy B, December, 1989-April, 1992. Mean $\pm$ standard deviation = 106.1 $\pm$ 33.5 L/day (28.02 $\pm$ 8.86 gal/day).

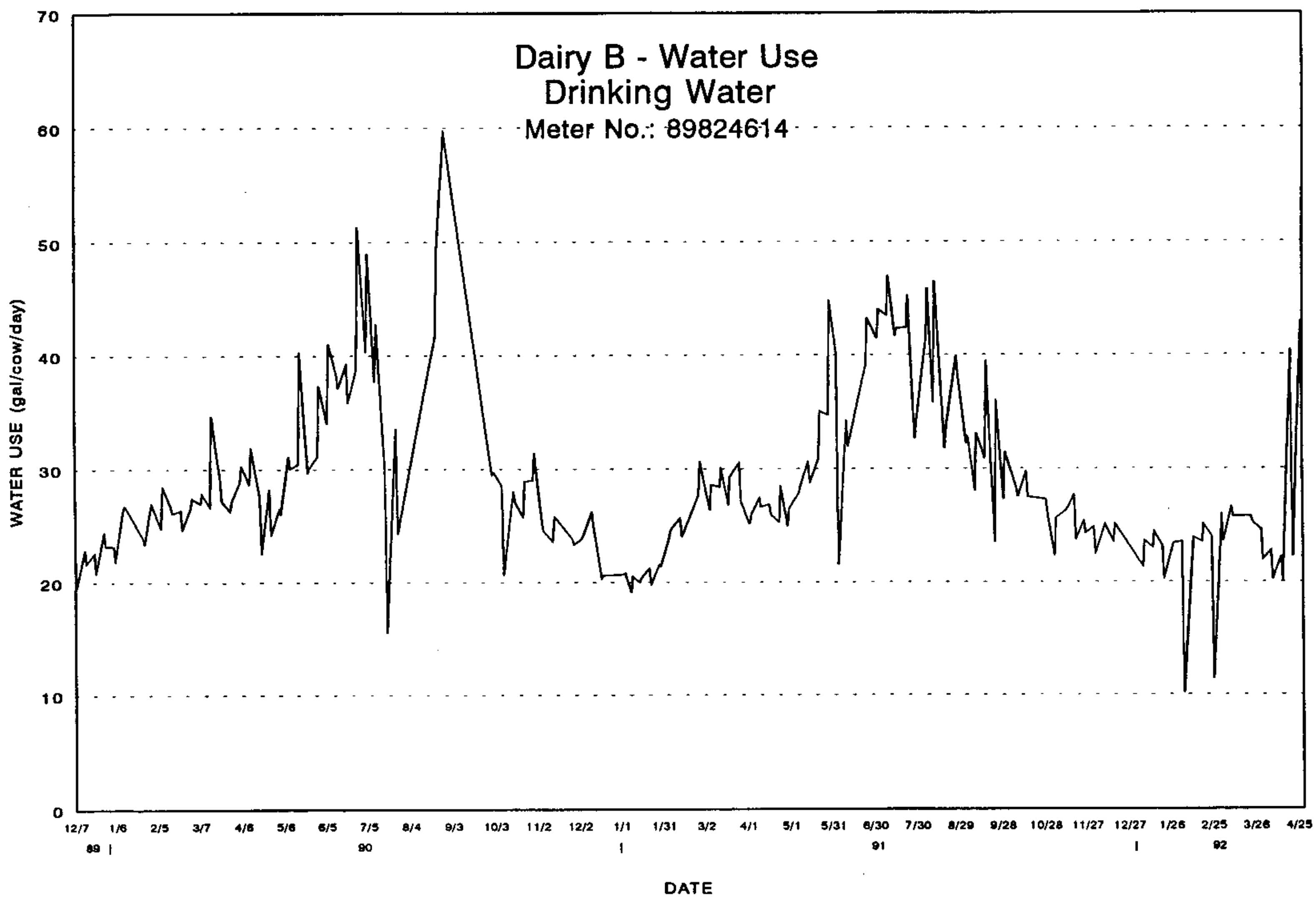


Figure D-9. Measured daily drinking water use per cow for pens 1, 2, and 3 at Dairy B, December, 1989-April, 1992. Mean ± standard deviation = 108.7 ± 28.1 L/day (28.72 ± 7.43 gal/day).

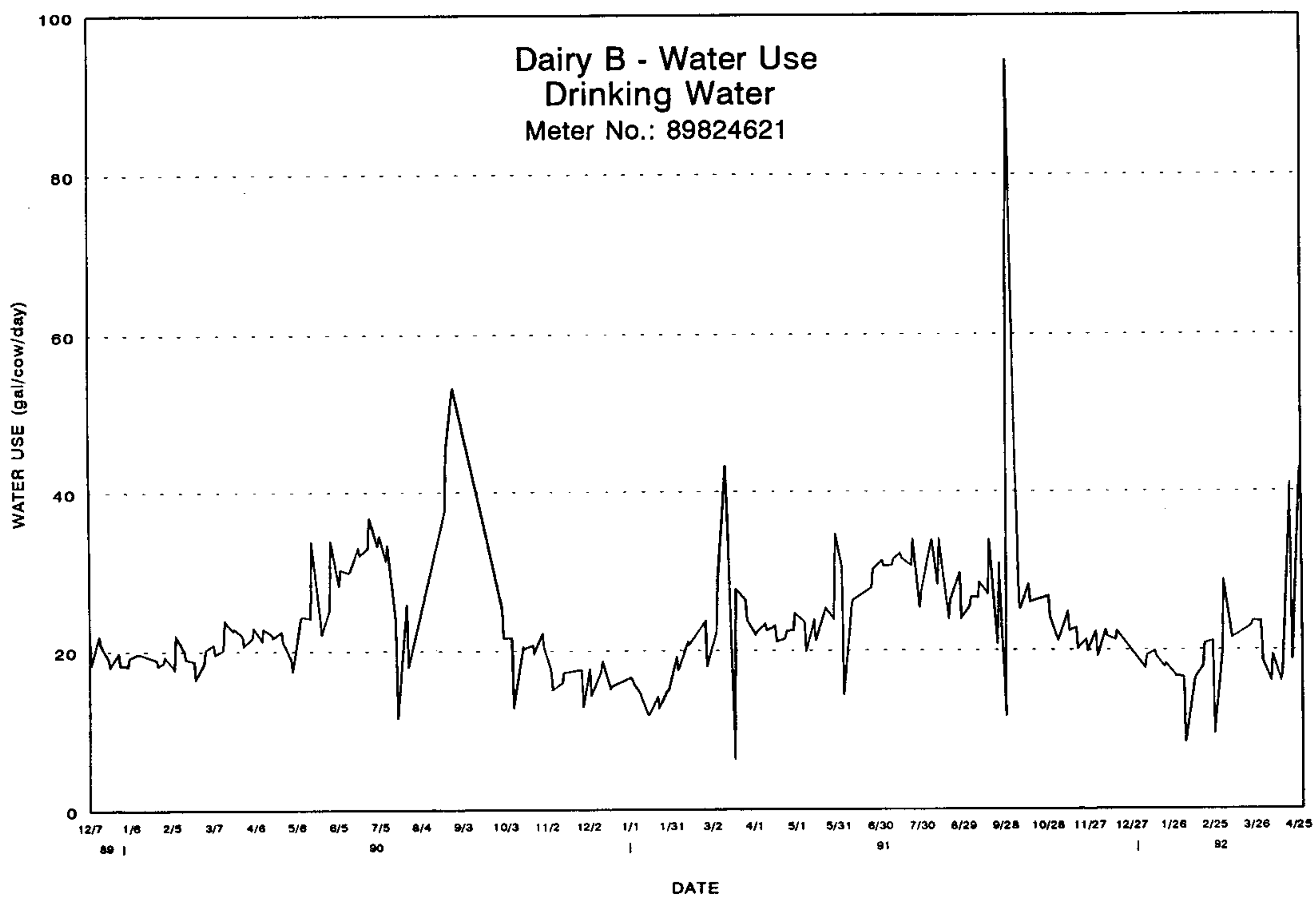


Figure D-10. Measured daily drinking water use per cow for pens 4, 5, and 6 at Dairy B, December, 1989-April, 1992. Mean ± standard deviation = 87.9 ± 31.2 L/day (23.23 ± 8.23 gal/day).

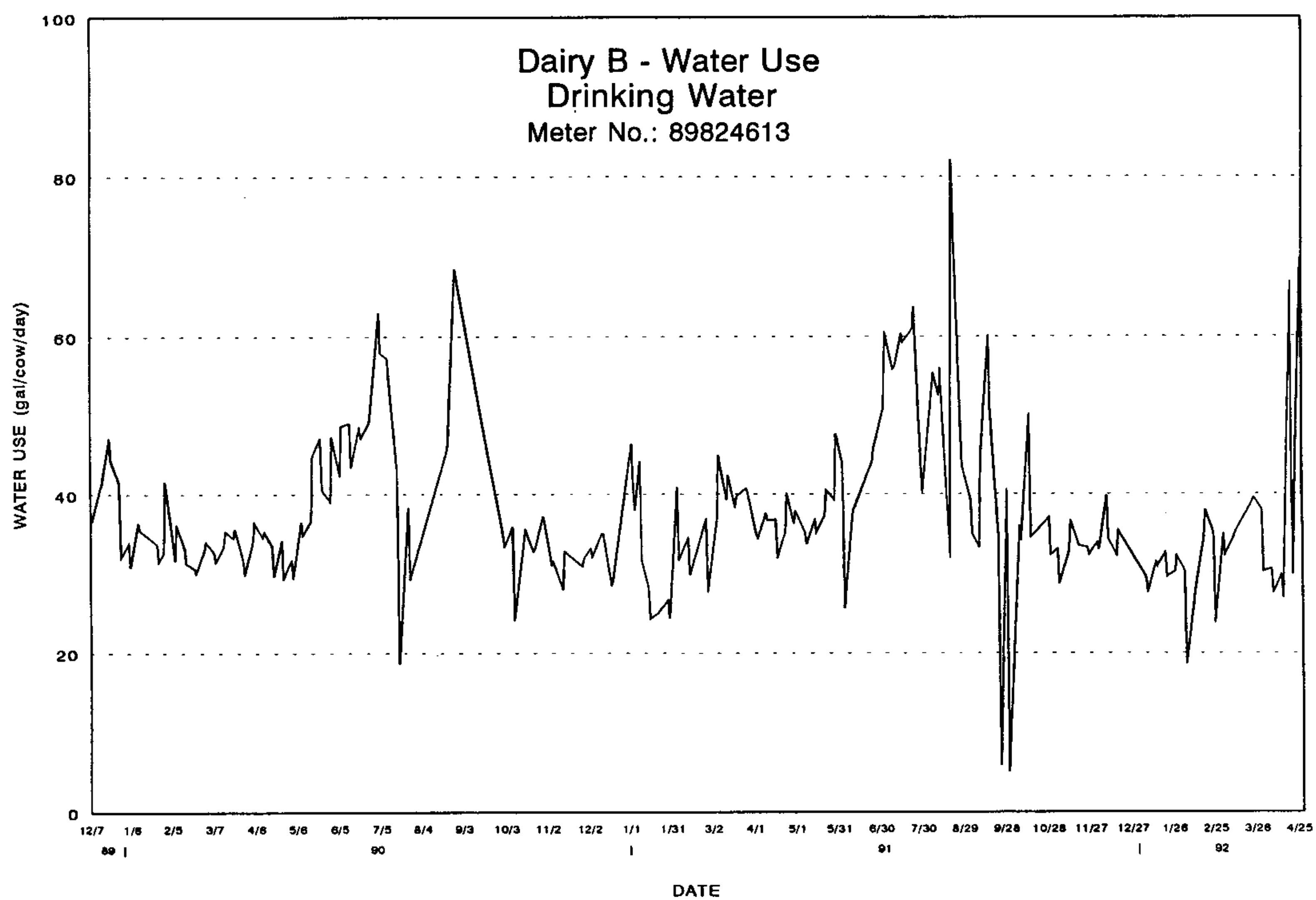


Figure D-11. Measured daily drinking water use per cow for pens 7 and 8 at Dairy B, December, 1989-April, 1992. Mean ± standard deviation = 142.4 ± 37.9 L/day (37.62 ± 10.00 gal/day).

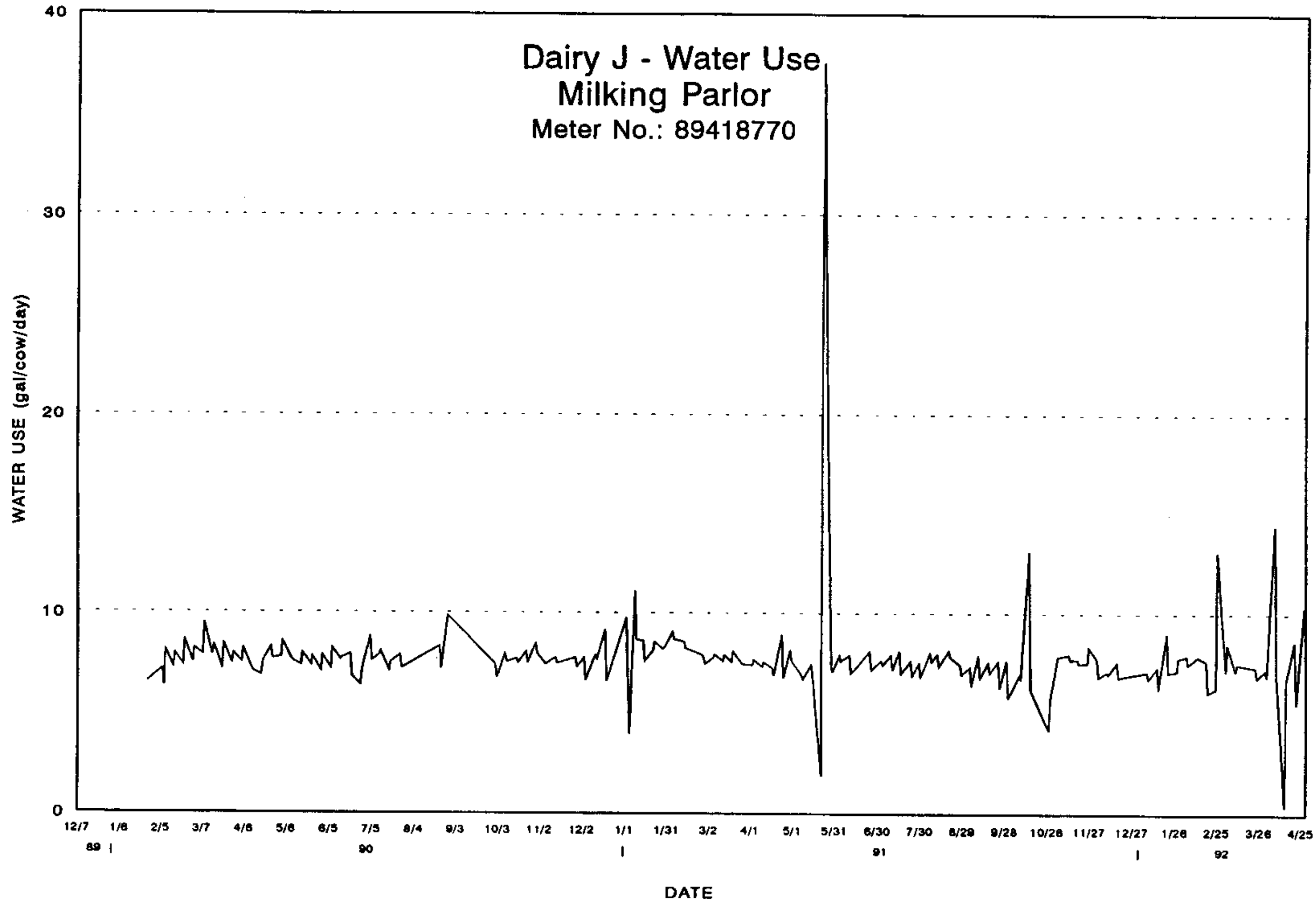


Figure D-12. Measured daily fresh water use per cow for milking parlor manual cleanup, equipment wash, and barn flushing at Dairy J, January 1990-April, 1992. Mean ± standard deviation = 29.3 ± 9.3 L/day (7.73 ± 2.45 gal/day).

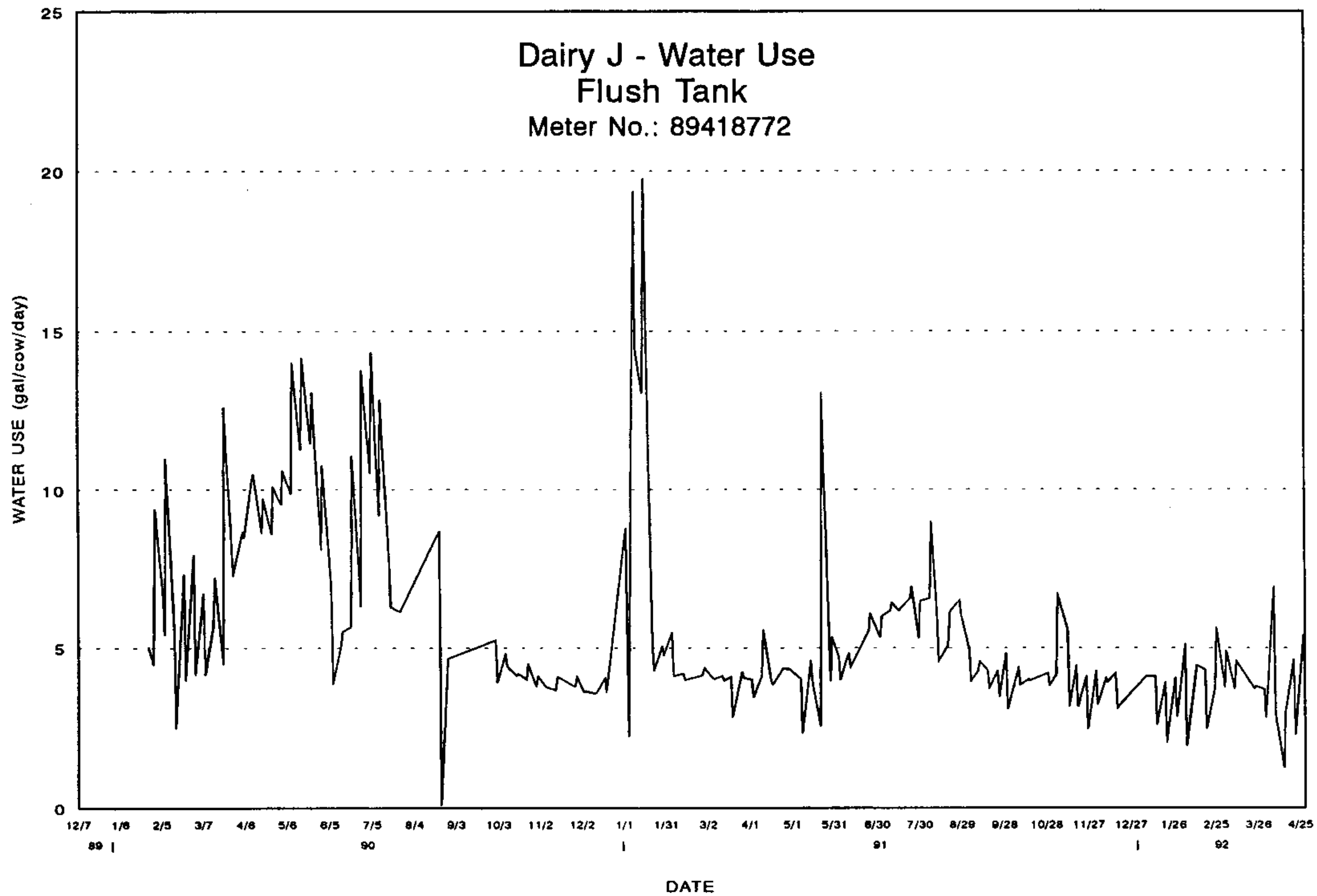


Figure D-13. Measured daily fresh water use for the flush tank in the holding pen at Dairy J, January 1990-April, 1992. Mean ± standard deviation = 21.5 ± 11.6 L/day (5.68 ± 3.07 gal/day).

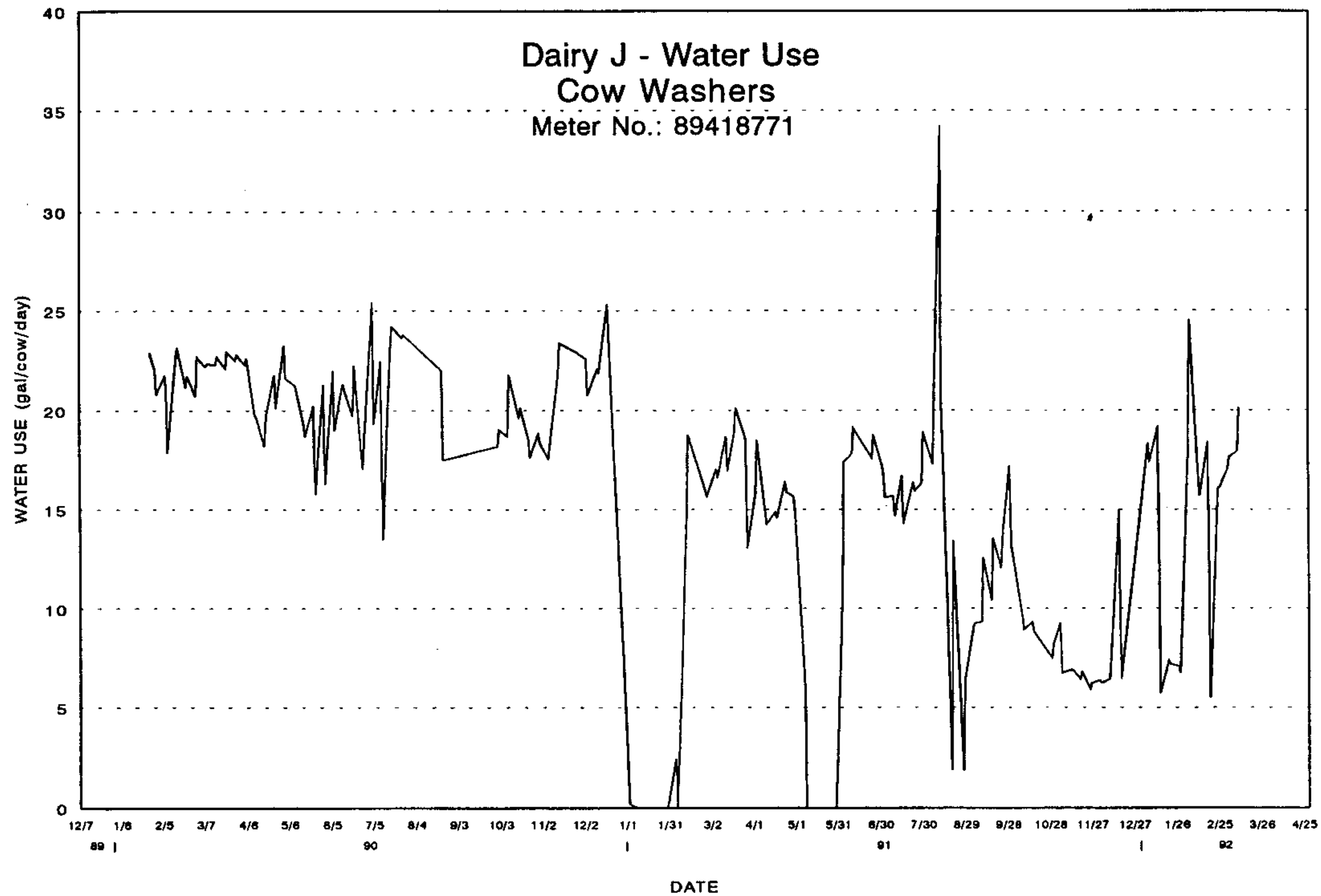


Figure D-14. Measured daily fresh water use for the sprinkler cow washers at Dairy J, January 1990-April, 1992. Mean ± standard deviation = 58.1 ± 27.3 L/day (15.34 ± 7.20 gal/day).

APPENDIX E

PROJECTED ANNUAL LOADING OF SOLIDS, COD, AND NUTRIENTS FROM MILKING CENTERS AND FROM LAGOONS

Table E-1. Projected annual solids load in wastewater from milking center into the anaerobic lagoons at Dairies A, B, and J

	No. Head	Average Water Use Rate			Total Solids			Volatile Solids			Total Suspended Solids			COD		
		gal/ cow-day	Ac-in/yr	m^3/yr	mg/L	lbs/yr	kg/yr	mg/L	lbs/yr	kg/yr	mg/L	lbs/yr	kg/yr	mg/L	lbs/yr	kg/yr
Dairy A	281	55.94	211.3	21,720	5,541	265,190	120,267	3,444	164,830	74,750	2,884	138,027	62,597	6,397	306,157	138,847
Dairy B	809	30.47	331.3	34,060	7,065	530,150	240,430	4,775	358,313	162,540	3,817	286,426	129,898	8,363	627,555	284,605
Dairy J	540	28.75	208.7	21,450	4,808	227,280	103,070	3,116	147,300	66,800	2,569	121,438	55,074	5,553	262,493	119,045
Mean	543	38.39	250.4	25,740	5,804	340,870	154,590	3,778	223,480	101,350	3,090	181,964	82,523	6,771	398,735	180,832
Mean per cow	--	--	--	--	--	628	285	--	411	187	--	335	152	--	734	333

Table E-2. Projected annual nutrient load in wastewater from milking center into anaerobic lagoons at Dairies A, B, and J

	No. Head	Average Water Use Rate			Nitrogen, TKN			Phosphorus, P		
		gal/cow-day	ac-in/yr	m^3/yr	mg/L	lbs/yr	kg/yr	mg/L	lbs/yr	kg/yr
Dairy A	281	55.94	211.3	21,720	260	12,443	5,643	85	4,068	1,844
Dairy B	809	30.47	331.3	34,060	403	30,241	13,714	54	4,052	1,838
Dairy J	540	28.75	208.7	21,450	267	12,626	5,726	38	1,796	815
Mean	543	38.39	250.4	25,740	312	18,437	8,361	59	3,305	1,499
Mean per cow	--	--	--	--	--	34	15	--	6.1	2.8

Table E-3. Projected annual solids in effluent from anaerobic lagoons at Dairies A, B, and J

	No. Head	Average Water Use Rate			Total Solids			Volatile Solids			Total Suspended Solids			COD		
		gal/ cow-day	Ac-in/yr	m^3/yr	mg/L	lbs/yr	kg/yr	mg/L	lbs/yr	kg/yr	mg/L	lbs/yr	kg/yr	mg/L	lbs/yr	kg/yr
Dairy A	281	55.94	211.3	21,720												
•Primary					2,088	99,931	45,320	966	46,232	20,967	839	40,154	18,210	1,480	70,832	32,123
•Second-Stage					1,644	78,681	35,683	681	32,592	14,781	480	22,973	10,418	650	31,109	14,108
Dairy B	809	30.47	331.3	34,060												
•Primary					5,068	380,300	172,472	2,999	225,043	102,060	2,333	175,067	79,395	5,467	410,241	186,050
Dairy J	540	28.75	208.7	21,450												
•Primary					3,551	167,858	76,126	1,865	88,160	39,982	1,953	92,319	41,868	3,619	171,072	77,584
•Second-Stage					1,497	70,764	32,093	549	25,952	11,769	831	39,282	17,815	394	18,625	8,447
Mean	543	38.39	250.4	25,740												
•Primary					3,569	216,030	97,973	1,943	119,810	54,336	1,708	102,513	46,491	3,522	217,382	98,586
•Second-Stage					1,571	74,723	33,888	615	29,272	13,275	656	31,128	14,117	522	24,867	11,278
Mean per cow																
•Primary	543	--	--	--	--	398	180	--	221	100	--	189	86	--	400	182
•Second-Stage	411	--	--	--	--	138	62	--	54	24	--	57	26	--	46	21

Table E-4. Projected annual nutrient yield from primary and second-stage anaerobic lagoons

	No. Head	Average Water Use Rate			Nitrogen, TKN			Phosphorus, P		
		gal/cow -day	ac-in/yr	m^3/yr	mg/L	lbs/yr	kg/yr	mg/L	lbs/yr	kg/yr
Dairy A	281	55.94	211.3	21,720						
•Primary					172	8,232	3,733	53	2,537	1,151
•Second-Stage					117	5,600	2,539	39	1,867	846
Dairy B	809	30.47	331.3	34,062						
•Primary					262	21,090	9,565	55	4,128	1,872
Dairy J	540	28.75	208.7	21,453						
•Primary					193	9,122	4,137	35	1,655	751
•Second-Stage					72	3,403	1,543	7	331	150
Mean	543	38.39	250.4	25,745						
•Primary					216	12,800	5,810	47.7	2,770	1,259
•Second-Stage					95	4,502	2,041	23	1,099	498
Mean per cow										
•Primary	543	--	--	--	--	23.6	10.7	--	5.1	2.3
•Second-Stage	411	--	--	--	--	11.0	5.0	--	2.7	1.2