Characterize Physical and Chemical Properties of Manure in California Dairy Systems to Improve Greenhouse Gas Emission Estimates

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Prepared for the California Air Resources Board and the California Environmental Protection Agency

Submitted by:
University of California, Davis One
Shields Avenue Davis, CA 95616
and University of California
Agriculture and Natural Resources

Prepared by:
Dr. Deanne Meyer (principal investigator), Jennifer Heguy, Betsy Karle and
Dr. Peter Robinson

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Proposed research does not use human or animal subjects

Disclaimer

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ABSTRACT

The current California methane inventory identifies 25% of emissions are from dairy manure. It is important to know the amount of dairy manure deposited onto and collected from concrete surfaces and ultimately stored in anaerobic conditions. For most California facilities, how animals are housed determines current manure collection and storage options. The objectives of this project were to analyze San Joaquin Valley dairies and determine how many facilities and cattle reside in the two predominant housing systems: non-freestall (drylot) and freestall. San Joaquin Valley Air District Permits were evaluated. Approximately 32%, 62% and 6% of permitted mature cows could reside on non-freestall, freestall or mixed housing dairies based on data obtained in 2016. These results need to be updated given recent attrition in dairy facility numbers. This information was used to identify cooperating facilities for in-depth analysis of waste stream distribution (liquid versus solid). A two pronged field campaign ensued on four cooperating San Joaquin Valley dairy farms: 2 freestall; 2 non-freestall (drylot) facilities. Animal residence time on concrete in winter, spring, and summer was monitored. Lactating cattle at two freestall dairies were on concrete 78.2 or 69.8% of time. Lactating cattle at two non-freestall dairies were on concrete 31.0 and 37.0% of time. Non-lactating animals (dry cows, replacement heifers if present) were on concrete between 21.0 and 35.6% of time. Farm specific animal husbandry management is responsible for higher percent of time on concrete in some freestall facilities. Monthly in-depth analysis of waste stream distribution at these same four dairies yielded tremendous variability in volatile solids concentration within and between farms, and within and between flushes within farm. Liquid manure was used for flushing lanes on three dairies. Volatile solids entered the liquid stream in water reused from the dairy pond. Volatile solids were in dried manure (with or without almond shells) used for bedding. Volatile solids were excreted from cattle and collected in their housing area, transfer lanes (from housing to milking parlor) and at the milking parlor. Volatile solids concentration increased in samples after collecting manure from concrete surfaces in animal housing areas. The tendency was for volatile solids concentrations to decrease as liquids went through gravity separation system (three dairies) and a two stage mechanical separation system (one dairy). One dairy vacuumed manure and volatile solids concentration was near 10%. The vacuum system studied did not collect manure from transfer lanes or the milking parlor. Chemical analysis varied of liquid manure ponds sampled quarterly at multiple locations and depths. Design of a sampling protocol to measure volatile solids flow within a specific dairy must be site specific and likely has great uncertainty. Multiple sets of data collection are needed to adequately describe variability in manure stream flow due to seasonal changes in animal husbandry and weather conditions. Combined these projects provide insightful information on estimates for percent of lactating cows housed in freestalls and no-freestall facilities and percent of time on concrete for lactating and non-lactating cattle. This information is important to further refine the greenhouse gas inventory and fine tune percent of manure collected exposed to anaerobic conditions. The results are also informative for evaluation of Alternative Manure Management Practice calculations and to understand how to design sampling protocols to evaluate effectiveness of Alternative Manure Management Practices implemented.

EXECUTIVE SUMMARY

Background

Key assumptions are used by the California Air Resources Board (CARB) to estimate greenhouse gas (GHG) inventory. The percent of volatile solids (VS) entering anaerobic storage or treatment conditions in either liquid storage or liquid/slurry gravity separation systems are key in estimating dairy manure emissions inventory and efficiency of manure management mitigation measures. Anaerobic conditions exist in liquid and liquid/slurry storage. This project identifies frequency of use of the two primary housing types (freestall and non-freestall) by facilities and number of permitted cows and solid liquid separation technique. The project also identifies the percent time animals are on concrete to estimate percent of manure collected through the liquid stream. Field evaluation of VS flow in liquid streams on commercial dairies serves to better understand liquid stream control points. This is informative to CARB staff managing the inventory analyses. Understanding how animals are housed and how much time they spend on concrete is useful to CARB as the current assumption that 59% of VS go to anaerobic ponds has not been evaluated for the San Joaquin Valley. Understanding the use of gravity separation systems will inform CARB regarding the assumption that 20% of VS are in a liquid/slurry system where the assumed maximum methane (CH_4) producing capacity (B_0) is 33%. Understanding manure stream management is also useful for CARB staff responsible for modifying the calculator associated with the Alternative Manure Management Program. Although the focus of this project is VS flow, yet, from a dairy manure management perspective the fixed solids (inert) are also important from an operational perspective. These solids may precipitate out, reducing flow through pipes and altering equipment functionality.

Objectives and methods

The first task (Chapter 1) was to evaluate existing San Joaquin Valley Air Pollution Control District (SJVAPCD) dairy permit data to identify dairy demographics in the San Joaquin Valley: facilities and animals housed in non-freestall (open lot) versus freestall facilities. Mechanical or gravity solid liquid separation may occur prior to entering the liquid storage system. Results provide information related to permit records from the SJVAPCD used to define demographics of dairy herds and cattle (potential maximum number of animals) in the San Joaquin Valley.

The second task was to develop and deploy a survey and analysis of freestall and non-freestall facilities to quantify total and volatile solids (TS, VS) and nitrogen (N) flows from excretion through storage using existing information on dietary composition and digestibility, dairy housing design, and facility manure flow. A two-pronged field campaign ensued on four cooperating San Joaquin Valley dairy farms: 2 freestall and 2 non-freestall facilities. Chapter 2 provides results from determining animal residence time on concrete in winter, spring/fall, and summer seasons. Animal residence time on concrete was monitored by counting animals in sentinel pens at 1.5 hour increments for 24 hours. Feed information was obtained and digestibilities determined.

Chapter 3 provides results from monthly in-depth analysis of waste stream distribution at these same four dairies (July 2017 through June 2018). This occurred to understand how herd specific management decisions alter manure collected in the liquid stream. Liquid manure was reused for flushing lanes on three dairies. Volatile solids entered the liquid stream 1) in water reused from the dairy pond, 2) excreted from cattle and collected in their housing area, transfer lanes (from housing to milking parlor) and at the milking parlor, and 3) as bedding (dried manure with or without almond shells).

Results

Herd distribution baseline demographic data from 2016 identified approximately 32%, 62% and 6% of permitted milking cows in the SJVAPCD could reside on non-freestall, freestall or a combination of freestall and non-freestall (mixed) housing for mature cattle. All herds >500 head should have SJVAPCD permits, and some smaller herds do have SJVAPCD permits. Twenty-five percent of mature cattle (milking and dry) were in 52% of herds, which had less than 1,500 mature cattle each. Twenty-six percent of mature cattle were in 9% of herds, containing more than 4,000 mature cattle per herd. The remaining 49% of mature cattle were in facilities between 1,500 and 4,000 mature cattle, comprising 39% of herds (Table E1). Facilities may have multiple management practices in place to remove solid particles from their liquid streams. Facility permits identified presence of mechanical separators only representing 7%, 21% and 22% of mature cattle on non-freestall, freestall, and mixed facilities. These same facility permits identified only some type of gravity separation system present on 47%, 42% and 42% of mature cattle on non-freestall, freestall, and mixed facilities. Mature cattle at facilities with both mechanical and gravity separation systems present represented 10%, 25% and 27% of cattle associated with the three housing types.

Table E1 Demographic distribution of SJVAPCD permit data by percent of mature cows.

Mature cow herd size	Herds		Mature cows	
	Number	Percent	Number	Percent
< 1,500	521	52	471,221	25
1,500 to 4,000	391	39	922,301	49
>4,000	85	9	491,781	26
Total	997	100	1,885,303	100

Analysis of animal residence time on concrete was monitored in winter, spring/fall, and summer. Lactating cattle at the two freestall dairies were on concrete 78.2 and 69.8% of time. In both herds managers restricted animal access to open lots due to weather conditions. It is likely these values do not represent the lower limit of time lactating cattle may spend on concrete in freestall facilities. Lactating cattle at the two non-freestall dairies were on concrete 31.0 and 37.0% of time. Non-lactating animals (dry cows, replacement heifers if present) were on concrete between 21.0 and 35.6% of time. These represent reasonable ranges for non-lactating animals to be on concrete.

Monthly in-depth analysis of waste stream distribution yielded variability in VS concentration within and between farms, and within and between flushes within farm. Volatile solids entered the liquid stream in flush water, bedding (dried manure with or without almond shells), and manure excreted on concrete. The VS concentration decreased as liquids went through gravity separation (three dairies) and a two stage mechanical separation system (one dairy). One dairy vacuumed manure. The vacuum system studied did not collect manure from transfer lanes or the milking parlor. Chemical analysis varied of liquid manure ponds sampled quarterly at multiple locations and depths. Conditions in all ponds were not optimal for methane production. Design of a sampling protocol to measure VS flow within a specific dairy must be site specific and likely has great uncertainty associated with it. Multiple sets of data collection are needed to adequately describe variability in manure stream flow due to seasonal changes in animal husbandry and weather conditions.

Conclusions

Dairy manure methane is a result of manure being handled, stored and treated under anaerobic conditions. This study identified that 76% of permitted dairy cattle in the San Joaquin Valley are on 48% of dairies, with 26% of cattle on the largest 9% of dairies (more than 4,000 mature cattle). SJVAPCD Permit data indicate 57%, 67% and 69% of non-freestall, freestall, and mixed facilities have gravity separation systems to separate solids from liquid stream. Considerable ambiguity existed for producers to describe manure management techniques at the time permits were completed. Frequency of cleanout of gravity separation systems needs to be identified. Systems with longer duration between clean out likely have similar methane forming potential as anaerobic ponds and not as similar to "liquid/slurry" B_0. Lactating cattle at the two freestall dairies were on concrete 78.2 and 69.8% of time. Based on field observations, these values do not represent the lower limit of time lactating cattle may spend on concrete in freestall facilities. Lactating cattle at the two non-freestall dairies were on concrete 31.0 and 37.0% of time. Non-lactating animals (dry cows, replacement heifers if present) were on concrete between 21.0 and 35.6% of time. These represent reasonable ranges for non-lactating animals to be on concrete. Detailed analysis of liquid streams on dairies indicated variability within herd sampling events and over time. Housing design and animal management are responsible for large differences in manure potentially collected in a liquid stream (percent of time on concrete). For permitted lactating cattle in the San Joaquin Valley c. 54% of manure would enter the liquid stream (anaerobic lagoon or liquid/slurry storage). The remaining c. 46% would be deposited in open lots and remain in solid storage. This does not account for solids removed from liquid streams.

Combined, these tasks provide insightful information on estimates for percent of manure collected through flush/scraped systems and variability in sampling liquid manure streams. This information is important for evaluation of Alternative Manure Management Practice calculations. It is important to evaluate each practice to determine if the practice will treat all or just part of the manure stream and modify calculations as needed. It is important to understand how manure stream variability contributes to the need to design sampling protocols to evaluate effectiveness of implemented Alternative Manure Management Practices.

Future research is needed to remove facilities no longer in business due to facility closure. A more detailed analysis of individual facilities is needed to determine if gravity separation systems are present and if they are managed with frequent (4 to 8 week) or infrequent (6 months to over 12 months) cleanout. The analysis should also include an analysis of mechanical separators to determine if they are functional.

Chapter 1 Demographics of dairy herds and use of manure treatment technologies in the San Joaquin Valley.

Abstract

Information related to how lactating cows are housed is crucial to verify assumptions used in greenhouse gas emission inventories and identify potential mitigations based on implementation of dairy digesters or alternative manure management practices. Permit records from the SJVAPCD were used to define demographics of dairies and dairy cattle in the San Joaquin Valley. These permit numbers represent the maximum number of animals which may be associated with individual dairies. All herds >500 head should have SJVAPCD permits, and some smaller herds do have SJVAPCD permits. Herd distribution baseline demographic data from 2016 identified approximately 32%, 62% and 6% of permitted milking cows in the SJVAPCD could reside on non-freestall, freestall or a combination of freestall and non-freestall housing for mature cattle. Twenty-five percent of mature cattle (milking and dry) were in 52% of herds. These herds had less than 1,500 mature cattle each. Twenty-six percent of mature cattle were in 9% of herds. These herds had more than 4,000 mature cattle. The remaining 49% of mature cattle were in facilities between 1,500 and 4,000 mature cattle. This represented 39% of herds. Facilities may have multiple management practices in place to remove solid particles from their liquid streams. Facility permits identified presence of mechanical separators only representing 7%, 21% and 22% of mature cattle on non-freestall, freestall, and mixed facilities. These same facility permits identified only some type of gravity separation system present on 47%, 42% and 42% of mature cattle on non-freestall, freestall, and mixed facilities. Mature cattle at facilities with both mechanical and gravity separation systems present represented 10%, 25% and 27% of cattle associated with the three housing types. Lastly, facilities that did not identify solid separation capability represented 37%, 11% and 9% of mature cattle at the three facility types identified. Inconsistencies exist in differentiation between gravity separation systems (settling basins, settling ponds, weeping walls), and storage and treatment ponds or lagoons in SJVAPCD permits. These descriptions did not differentiate between volatile solids (VS) remaining in a gravity separation system for a short duration (crust cleaned out at frequent intervals, i.e. 4 to 8 weeks) or those cleaned out at less frequent intervals (6 to 12 months or longer). Herd descriptive information by housing type and manure separation practices is important to estimate percent of VS entering anaerobic storage/treatment ponds. This is informative to CARB staff managing the inventory analyses and those associated with calculating mitigation reductions through installation of anaerobic digesters and alternative manure management practices.

Introduction

California has ambitious targets to reduce greenhouse gas (GHG) emissions by 40% from 2013 levels for dairy manure (SB 1383, 2016). Detailed inventory of GHG contributors is needed. Key assumptions used by the CARB to estimate GHG inventory from dairy manure include: 1) under optimum conditions B_0 is 0.24 cubic meters of CH_4 produced per 1 kg of volatile solids (VS) excreted by dairy cows and 0.17 cubic meters of CH_4 produced per 1 kg of volatile solids (VS) excreted by dairy heifers (USEPA, 2009); 2) 75% of B_0 is realized (on average, year-round) for liquid systems where liquids are stored in anaerobic ponds; 3) 59% of dairy cow VS go to anaerobic ponds; 4) 33% of B_0 is realized (on average, year- round) for liquid / slurry or deep pit storage or treatment systems (gravity separation systems); 5) 20% of dairy cow VS go to liquid/slurry systems. The percent of VS entering anaerobic storage or treatment conditions in either liquid storage (assumption 3) or liquid/slurry gravity separation systems (assumption 5) are key in estimating dairy manure emissions inventory. These assumptions contribute to the emissions inventory modelling and are baseline data used to estimate efficiency of manure management mitigation measures. The VS entering anaerobic storage ultimately converted to CH_4 and CO_2, captured and used as biogas are key in the Dairy Digester Research Development Program (DDRDP). The VS prevented from entering anaerobic storage/treatment conditions are key to determining effectiveness of mitigations associated with the Alternative Manure Management Program (AMMP). Both the DDRDP and AMMP quantification methodology and calculator tools rely on general assumptions for VS collected to determine five (AMMP) or ten (DDRDP) year efficacy of GHG reductions from participating facilities. This project serves to ground truth assumptions of VS flows through dairies by evaluation of estimates of VS excretion and deposition on a surface that is collected and transferred to the liquid or slurry storage structures and through measurements of liquid streams.

California's dairy industry has 1,331 commercial dairy farms with a total 1,735,350 dairy cows (CDFA, 2018a). No single source of information is available regarding herd numbers, animal housing type for mature (lactating and dry) cattle and manure treatment systems. The design of manure collection systems vary by animal housing type. All California dairies generate liquid manure from the milking parlor. This includes water used for udder hygiene, to clean milk contact surfaces and to wash down the milking barn area. Federal and State regulations prescribe mandatory equipment and barn cleaning required to maintain Grade A status. Milk barn water generation was highly variable in the Central Valley (Meyer et al., 2006). Once milk is harvested it goes through plate coolers for heat exchange to transfer heat from milk (chill) to water or propylene glycol before milk enters the bulk tank. Inclusion of ice chillers on dairies during the last 15 years has reduced the fresh water needed to cool milk and ultimately reduced the total volume of the liquid waste stream.

Many parameters exist on dairy facilities that may affect the amount of time animals stand on concrete feed lanes or travel lanes used to get to and from the milking parlor: goals of management, feed lane orientation (north-south versus east-west), presence or absence of animal soakers on feed line, condition of animal corrals (dry or muddy), attention to fly control (grooming of corrals, cleaning of curb and crossover areas in flushed lanes), class of animal (lactating, dry, replacement), temperature (range and number of hours above 20.5 C), and precipitation.

Manure is collected in solid, liquid, or slurry form. Dairies in the Central Valley utilize two primary methods to house lactating animals (Meyer et al., 2011) and these types of housing predetermine manure collection options. Freestall facilities provide an open barn structure typically joined with a corral or open lot. The barn roof covers a drive through feeding lane as well as animal housing. Freestalls are open cubicles that provide sufficient space for animals to rest comfortably on a clean, dry environment and minimize injuries to animals. These are aligned in a row with individual stalls perpendicular to the feeding lane. Cubicles are aligned so animals on one side of the barn are parallel to one another and they are nose to nose with animals on the opposite side of their cubicle. Freestalls are usually bedded with dried manure. Sand is an alternative, which is not available or is cost prohibitive in most locations. Almond shells or rice hulls may be used to extend dried manure use. Animals are fed along feedlines in freestall facilities. Total average residence time of animals in freestall housing area will vary between herds and within herd between seasons. Freestall flooring is concrete. Dairy operators have herd specific protocols to manage animal access to the open lot or corral associated with each pen of animals in freestall barns. Feed bunk soakers are on automatic timers to soak cattle throughout the hotter part of each day. On-cycle frequency and duration are site specific. Typically, manure is collected from the freestall floor via flush system with reused liquid manure from the dairy storage or treatment pond or lagoon. Some facilities scrape or vacuum manure.

Manure collected from freestall facilities is either in a liquid form (flushed) or in a slurry to solid form (vacuumed or scraped). If scraped, the manure and bedding are likely less than 10% VS based on previous work (unpublished). Personnel at each dairy manage animals and the facility to maximize animal health given their local conditions. Freestall facility managers may restrict or prohibit animal access to open lots during specific weather or lot conditions. Examples include restricting animal access to lots during foggy days when lots are unable to dry out sufficiently. Also, restrictions occur during hot weather. The objective of the manager to keep cattle out of moist environments then increases animal TOC to 100%. In other situations, animals have free access to open lots associated with freestalls. Cattle may choose to go out to the open lots or use freestalls. Utilization of freestalls increases TOC as manure deposited when standing or lying down in freestalls ends up on a concrete lane that is flushed or scraped. Moisture content of both the solid (open lot or scraped lane) and liquid (flushed concrete area) manure streams is a function of how much manure is collected, temperature, wind speed, precipitation, presence or absence of animal soakers for cooling, and quantity of bedding tracked out of freestall beds daily. Small amounts of feed end up in the waste stream.

Non-freestall facilities have open lots with shades available for mature cattle. Feed bunk fence line soakers and shade cloth extending over the feeding area (where animal feed is deposited for consumption) are used for heat abatement. Concrete areas where cattle stand to eat may be flushed, scraped or seldom cleaned. Flooring in pens for mature cattle are cleaned at least daily. Flooring in pens where replacement stock reside may be cleaned less frequently.

Many agencies permit and inspect dairies, yet none have a readily available database to provide the needed information to delineate manure management flow pathways. Dairies are permitted by the Department of Food and Agriculture (CDFA) for sale of milk. CDFA is the primary inspection agency responsible for inspecting dairy farms. Fresno, Sonoma, Tulare, Kings, Imperial, San Joaquin, and Stanislaus Counties have local agencies inspect dairy farms. These inspections focus on food safety and animal housing areas.

Nine Regional Water Quality Control Boards exist in California. Many of these have issued Individual or General Waste Discharge Requirements (Regions 2, 5, 6, 7, 8, 9) or Conditional Waivers of Waste Discharge Requirements (Region 1). These agencies inspect dairies at different frequencies (from annually to greater than five years). Most dairies in California reside in the Central Valley Regional Water Quality Control Board (Region 5). Annual Reports associated with Region 5 Requirements contain information specific to the regulatory reporting requirement. The reports are lengthy (50 to 150 pages).

The SJVAPCD also permits dairies. Dairy operators implement mitigation measures for each permit unit to reduce volatile organic compound emissions for dairy feed, silage, freestall barns, corrals, milking parlors, solid manure, liquid manure, and land application activities. Dairies in the San Joaquin Valley produced 89.2% of California's milk in 2017 (CDFA, 2018a).

Task 1 objective was to summarize data currently available regarding dairy demographics and use of manure management technologies.

Materials and Methods

A public records request was used to obtain permit information for dairy facilities with Rule 4570 Permits from the SJVAPCD. These permits represent the maximum number of animals which may be associated with individual dairies and not necessarily the actual numbers of animals present. These permits identify manure management practices potentially in use at farms. Duplicate or incomplete records (insufficient information on mature cattle) were removed. Narrative discussions for each permit unit (feed storage, animal housing, milking parlor, liquid manure and solid manure) were used to identify presence of mechanical separators, storage ponds or lagoons, anaerobic digesters, weeping walls, settling basins, or processing pits. The number of storage ponds or lagoons and processing pits (if present) were identified. Also identified was presence of aerator, dewatering press, deep drying, sand management, parlor type, and use of flush, scrape or vacuum collection of manure. Use of compost, covered manure stockpiles, and solid manure used for bedding was identified on some facilities. Information associated with the Notice of Intent submitted by the same facilities (2005) covered under the General Order for Waste Discharge Requirements for Existing Milk Cow Dairies (Central Valley Regional Water Quality Control Board) were compared to the animal numbers identified in the SJVAPCD permits.

Results

The data set obtained from the SJVAPCD in 2016 was initially developed in 2014. Results presented here are not current due to attrition of dairies since these data were obtained and evaluated. 997 SJVAPCD permitted dairies were identified with information related to mature herd size and manure management technologies used. Mature cow herd size limit (maximum milking and dry cows allowed) ranged from 218 to 14,780 cows. All dairies under 500 cows did not have permits.

The milking parlor is used by each lactating cow two to three times a day depending on herd management practices. Parlors identified on dairy farms included: parallel (248), herringbone (448), parabone (29), rotary (70), walk through (7), polygon (1), side open (6), trigon (1) and flat barn (278). Of interest is that 193 facility permits identified the only parlor available was a flat barn. 27 of these facilities have mature cow range between 1,500 and 4,000. The remaining flat barn facilities had less than 1,500 mature cattle.

Mature cows predominantly reside on facilities with freestall (62%) or mixed (6) housing (both freestall and non-freestall accommodations available for mature cattle). Some 32% of mature cows reside on facilities with no freestalls for mature cattle (Table 1.1). These facilities are permitted to contain in total 1,885,303 mature cows.

Table 1.1 Herds and mature cow number and percent by mature cow housing type.				
	Herds		Mature cows	
Housing	Number	Percent	Number	Percent
Freestalls	637	64	1,168,175	62
Non-freestall	305	31	605,956	32
Mixed	55	6	111,172	6
Non-freestall facilities include 312 facilities that did not include “freestalls” in their housing definition. Mixed contains both freestall and non-freestall housing for mature cows. Rounding errors associated with columns that do not add to 100%.				

Herd and mature cow populations were evaluated to identify herd sizes that contained upper and lower quartile of mature cows permitted (Table 1.2). Approximately one half of the mature cows reside in herds that range in size from 1,500 to 4,000 mature cows. Twenty-five percent of cows are in herds with less than 1,500 mature cows. Twenty-six percent of mature cows reside in herds with more than 4,000 mature cows. Non-freestall facilities contain 30%, 32% and 34% of mature cows permitted in herds that have less than 1,500 mature cows, between 1,500 and 4,000 mature cows, or more than 4,000 mature cows. Distribution of herd by housing type is presented in Figure 1.1.

Table 1.2 Demographic distribution by percent of mature cows.				
	Herds		Mature cows	
Mature cow herd size	Number	Percent	Number	Percent
< 1,500	521	52	471,221	25
1,500 to 4,000	391	39	922,301	49
>4,000	85	9	491,781	26
Total	997	100	1,885,303	100

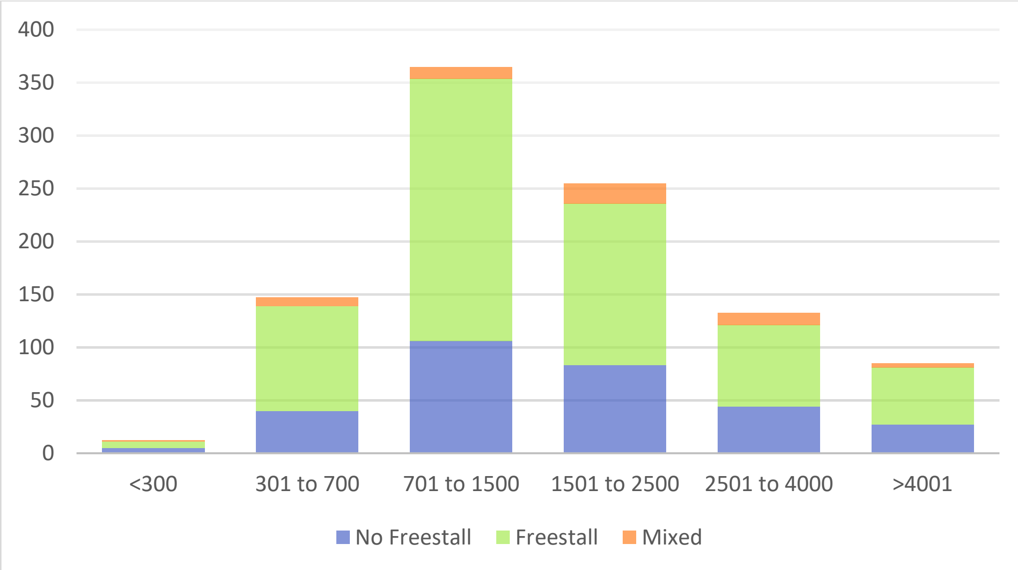

Figure 1.1 Frequency distribution of mature cattle herd size by type of housing for 997 dairies.

Method of manure collection included: flush (732), scrape (404) and vacuum (13). Zero, one, two or all three manure collection practices were identified on: 221, 406, 367, and 3 farms. The vacuum systems were predominantly associated with freestall dairies (8) compared to non-freestall dairies (5). Solid manure storage included: stock piles (943), covered manure stock piles (73) and composting (273).

Removal of solids from a liquid stream may be accomplished by either mechanical separation or gravity separation systems (settling ponds, pits or basins or weeping walls) (Table 1.3). Retention time and clean out frequency varies within gravity separation systems. Permit information did not identify frequency of cleanout. 373 dairies (37%) identified the presence of mechanical separator technology. The majority of dairies with mechanical separators (322 dairies; 86%) were associated with freestall or mixed housing for mature cows. 51 dairies (14%) with mechanical separators were located on facilities with no freestalls. There was no difference in herd size by housing type for facilities with mechanical separators: non-freestall (μ 1868, σ 1648), freestall (μ 2631, σ 1718).

Gravity separation system(s) only (settling basin(s) and weeping wall technology) was associated with 47%, 42% and 42% of non-freestall, freestall and mixed facilities. These facilities represented 16, 23 and 2% of overall permitted mature cow population. Use of settling basins with or without mechanical separator was permitted for 57, 67 and 69% of herds permitted for non-freestall, freestall and mixed facilities. Gravity separation systems are present to manage manure from 21, 55, and 4% of total permitted cows residing on non-freestall, freestall and mixed facilities.

Storage ponds were identified on 647 facilities. At least one storage pond or treatment lagoon was identified on 549 of facilities.

Table 1.3. Demographics of housing type by solid liquid separation system. Percent of column represented in parenthesis ( ) under each numeric value for each category. Percent of all herds and all cows represented in brackets [ ] in each cell.

	Non-freestall		Freestall		Mixed	
Solid liquid separation	Herds	Mature cows	Herds	Mature cows	Herds	Mature cows
Only mechanical	22 (7%) [2%]	49,327 (8%) [3%]	133 (21%) [13%]	227,751 (20%) [12%]	12 (22%) [1%]	26,868 (24%) [1%]
Only settling basin	142 (47%) [14%]	300,606 (50%) [16%]	270 (42%) [27%]	441,051 (38%) [23%]	23 (42%) [2%]	37,049 (33%) [2%]
Both settling basin and mechanical	29 (10%) [3%]	84,859 (14%) [5%]	162 (25%) [16%]	415,934 (36%) [22%]	15 (27%) [2%]	38,838 (35%) [2%]
Neither	112 (37%) [11%]	171,164 (28%) [9%]	72 (11%) [7%]	83,439 (7%) [4%]	5 (9%) [<1%]	8,417 (8%) [<1%]
Total	305	605,956	637	1,168,175	55	111,172

Additional manure treatment technologies were identified on some facilities. Few dairies (6) in the San Joaquin Valley had anaerobic digesters when data were obtained. Weeping wall separation systems were identified (17 dairies) and are included above with the gravity separation system. Additional practices included: processing pits (39 dairies), aerators (19 dairies), dewatering press (17 dairies), deep drying pit (1 dairy), and sand management (11 dairies).

Discussion

The focus of this analysis was on herds permitted by the SJVAPCD as dairy cattle in the San Joaquin Valley produce 89.2% of milk in California (CDFA, 2018a). Manure production is a function of milk production (ASABE, 2005), so this focus highlights manure management for the key dairy area of California.

The 997 records associated with distinct dairies from the 2016 data file represented fewer dairies than CDFA recorded for 2017. Smaller dairies (<500 cows) were not all included in SJVAPCD permits. Economic instability has resulted in attrition of dairies. Some records were removed from the analysis as Region 5 records indicated some facilities were not currently in use or were replacement heifer operations with no mature animal present. SJVAPCD records represent a potential of 1,885,303 mature cattle. This value is greater than 1,543,110, the actual number of cattle identified in 2017 for the San Joaquin Valley (CDFA, 2018a). Permits identified maximum number of animals for a facility at the time of application rather than the number actually present. For example, if a facility had 1,500 mature cows but was capable of housing 1,750 mature cows, the SJVAPCD permit was issued for 1,750 mature cows (lactating and dry). Comparison of herd numbers from the SJVAPCD permit to Region 5 maximum number of mature cattle served as a validation of the SJVAPCD data. Additional queries were done for facilities with abnormally higher mature cows in SJVAPCD permits when compared to Region 5 herd sizes. In some cases, these differences represented a change in facility structure and management (e.g. merger or expansion).

Milking parlors are expensive capital investments. Parallel and rotary parlors have been more common during installations in the last two decades. Older facilities have flat barn only, walk through, polygon, side open or trigon parlors. These were parlors of choice in the 1970s and early 1980s. Herringbone parlors were more commonly installed in the late 1970s, 1980s and 1990s. Spikes in energy costs in 2008 and associated poor return on investment in the dairy sector since 2008 are likely responsible for fewer parlor upgrades and replacements since that time. It is not known if dairies that have not been able to upgrade milking facilities will have the financial ability and interest to implement alternative manure management practices.

Water use associated with milk harvest process varies (Meyer, et al., 2006). Management of sprinkler pen use is essential to minimize water used to harvest milk and subsequent water entering the liquid manure system. The more dilute the liquid (California dairy effluent often runs 1% total solids (TS); Meyer and Price, 2012), the more challenging it is to remove solids from the liquid stream. In addition, these very dilute systems require large volumes for storage.

Knowing how many animals potentially reside in each housing type is important to estimate emissions inventory. Forty-eight percent of permitted cattle in Tulare County are on freestall facilities. San Joaquin Valley Air Pollution Control District-wide, roughly two-thirds of herds and cattle reside in freestall facilities. A manure management survey was conducted in 2007 of dairy producers and managers in Tulare (largest dairy county in California) and Glenn (outside the San Joaquin Valley) counties (Meyer et al., 2011). In 2007, freestalls were housing lactating cows in 37% of herds responding. In the current data set 43% of herds in Tulare County reported using freestalls.

Freestall barns provide flexibility to modify the ambient environment to ameliorate heat stress during summer months with the use of soakers. Freestall housing also provides the opportunity to restrict animal access to corrals during times when manured lots are moist or very hot. Preventing animal access is key on some facilities to maintain excellent animal health and food safety. This management decision does have implications on the manure stream. When animals are restricted from lounging in corrals, all manure generated during that time will be collected in the liquid (flush) or slurry (vacuum or scrape) stream.

Results from the SJVAPCD data indicate 81% of dairies have the ability to use some method of solid liquid separation. This compares with the 2007 survey where 71% of operators responding indicated use of some method of solid liquid separation. Reflecting back to a survey conducted in 1995 (Morse Meyer et al., 1997) use of some type of solid liquid separation was reported on 54% of dairies surveyed. Use of gravity separation system as the only source of separation occurred on 47, 42 and 42% of non-freestall, freestall, and mixed housing dairies within the SJVAPCD jurisdiction. A total of 32% of dairies reported gravity separation systems only in the 2007 survey. Mechanical separators as the only source of solid liquid separation were reported in 16% (Meyer et al., 2007) of herds compared with 11% (Meyer et al., 2011). The trend for more solid liquid separation capabilities is present since the 2007 survey. Facility permits identified presence of mechanical separators only representing 7%, 21% and 22% of mature cattle on non-freestall, freestall, and mixed facilities. Mature cattle at facilities with both mechanical and gravity separation systems present represented 10%, 25% and 27% of cattle associated with the three housing types. It is unclear if the systems are fully operational as SJVAPCD permits identify what is present on farms, and mechanical separators may be present and not used. Results herein related to gravity separation systems identify that great improvements to reduce methane emissions may be achieved by modifying clean out frequency given that 45% (23% only settling basin + 22% both settling basin and mechanical separator) of facilities with cows in freestalls in the SJVAPCD use gravity separation systems as part of their solid liquid separation.

The different methods of separation impact how completely VS are digested to end products of methane and carbon dioxide. It is not possible to differentiate management of different gravity separation systems from SJVAPCD permits or Region 5 Annual Reports. Additional work is necessary, and being conducted at this time, to identify if other processes may be deployed to determine frequency of solids removal. Additional research is needed, and being conducted, to verify use of mechanical separators on a select group of dairies in the San Joaquin Valley.

The less frequent the clean out interval is for solid liquid separation systems, the greater the potential for the VS in these systems to emit methane. In a recently published study, methane yields from animal housing normalized by VS loading from liquid manure storage varied significantly: 1.7 and 3.5 times greater when compared to another dairy during the summer and winter measurement periods (Arndt et al., 2018). Frequency of cleanout of solids in gravity separation systems varies. Producers using systems with frequent cleanout (every four to eight weeks) often employ staff to handle removed solids so these may air dry. Often solids are distributed over a drying surface and regularly harrowed to expedite drying while controlling fly habitat. Dried solids are stockpiled for later use as either animal bedding or land applied fertilizer. Solids from systems cleaned out less frequently (six month intervals or longer) may be stockpiled for drying, and handled when labor is available during opportunities to land apply. A crust forms on these piles when they exist for extended periods.

Reuse of dried manure for bedding reintroduces VS into the liquid stream. The 2007 study identified 79% of Tulare county farms used dried manure (solids separated from liquid stream and or corral solids) for bedding in freestalls and 66% reported use of these bedding resources on non-freestall dairies (i.e., building mounds in corrals). Arndt et al., (2018) reported use of 2.5 to 3.5 kg VS per head per day for bedding. Daily VS output per head per day (assume 40 kg daily milk production) is 7.6 kg per head per day (assume 8.9 kg TS per head per day and 85% of TS are VS). Reintroduction of 2.5 to 3.5 kg VS per head per day is an increase of 33 to 46% of the VS produced daily by cattle. Given their work was conducted in Jersey cattle and milk production was less, this reintroduction value would be markedly greater as a function of all VS entering the liquid stream. Research should be conducted on commercial farms and through modelling to quantify VS flow through reuse of separated solids and to determine if these solids are merely delaying methane formation, displacing other organic materials from being used for bedding and forming methane, or being partially degraded aerobically and, therefore, reducing their methane forming potential.

Conclusions

The objective of evaluating current dairy demographics was to inform the selection of facilities for field campaign work and to identify if modifications should be considered in emissions inventory calculations. Not more than five dairy facilities would be selected for the field campaign associated with this project. At least two of these should be non-freestall facilities. The above results would suggest including facilities that are non-freestall, with and without gravity separation (these two types of facilities represent 84% of non-freestall herds), and freestalls with only gravity separation or both mechanical and gravity separation systems present (representing 67% of freestall facilities and 69% of mixed facilities). A logical fifth facility would be freestall, preferentially with gravity separation.

More clear definitions of solid-liquid separation systems would improve usefulness of permit data. Delineation between presence of separation equipment and actual use would be informative.

Inventory calculations may benefit from differentiating between the short versus long term cleanout frequency in gravity separation systems. Ultimate fate of VS removed from either mechanical or gravity separation systems should be evaluated. Understanding VS loading as bedding is important. Reuse of dried manure solids for bedding should be included in evaluation of benefits from manure management practices used to mitigate emissions.

Recommendations

Additional research into herd demographics and management includes updating the current list of San Joaquin Valley dairies due to attrition and to ensure smaller facilities that may not have submitted permit applications to the SJVAPCD are included. Including dairies from the North Coast, San Francisco Bay and Santa Ana Regional Water Quality Control Board areas would encompass approximately 245 additional dairies and additional manure management practices. Due to the importance of solid liquid separation on potential methane reduction, additional research to improve the understanding of mechanical separator and gravity separation system use should also be conducted. Much of these additional needs are being carried out as part of another project.

Chapter 2 Determination of animal time on concrete by facility housing design and animal class

Abstract

The project used four commercial dairy farms in the San Joaquin Valley (SJV) of California (USA) between January and July 2018. Two of the farms were freestall dairies and two were non-freestall dairies. The objective was to collect feed intake and composition data during 3 seasons (i.e., winter, spring, summer) in order to allow calculation of total organic matter output as feces by dairy cattle, and to determine where in the pen (i.e., relative to being on an open lot or flush lane surface) feces were deposited. The "Winter" period occurred during the week of January 30th - February 7th (2018). The "Spring" period occurred during late April and early May (2018), and the "Summer" period occurred during the week of July 8th through July 12th (2018). Three 24 h cattle observation and data collection periods were completed to represent winter, spring/fall and summer conditions in order to re-create annual weather and management conditions in the SJV. Each period consisted of determining the number of cows on concrete in the sentinel pens every 90 minutes of the 24 h day, as well as body condition score (BCS) measurements and TMR sampling of the diet fed to each sentinel pen. Over all seasons, lactating cows on the two freestall dairies spent about 73% of their time on concrete (TOC), whereas those on non-freestall dairy farms spent about 34% of their TOC. In contrast, non-lactating cattle on both freestall and non-freestall dairy farms spent a broadly equal amount of TOC (~26%), primarily because, regardless of dairy type, virtually all non-lactating cattle were housed in open lot pens. The TOC was modestly impacted by season on both the freestall dairy farms (most in winter, least in spring), but TOC was not impacted by season on the two non-freestall dairy farms.

Introduction

Methane is 9% of California's greenhouse gas inventory. The 2015 summary identifies the top three methane emitters as dairy manure (25%), dairy enteric (20%), and landfills (20%). Current policy incentivizes collection and anaerobic treatment of dairy manure to collect and utilize biogas thereby preventing emissions of methane to the atmosphere (CDFA, 2018b). An alternative to collecting and treating manure for biogas recovery is to divert VS from anaerobic storage and treatment conditions (CDFA, 2018c). Key in this process are inventory calculations that 59% of dairy cow VS go to anaerobic ponds and 20% of dairy cow VS go to "liquid/slurry" where 33 percent of B_0 is realized (potentially this is settling basin solids).

Recent work by Arndt et al., (2018) conducted field campaigns on two freestall dairies in summer and winter. Manure methane emissions contributed 69 to 79% and 26 to 47% of whole-facility CH_4 emissions during the summer and winter campaigns. Methane emissions normalized by VS loading were 1.7 to 3.5 times greater at one dairy than at the other during summer and winter. The authors identified that manure management practices that reduce VS stored in anaerobic conditions could reduce CH_4 emissions. They estimated on-farm practices for percent of dairy manure captured by flush and stored in the liquid manure storage system was at least 6.6 hours daily based on work of Grant (2009), Legrand et al., (2009) and Gomez and Cook (2010).

Farm managers are key in restricting animal access to open lots associated with freestall housing. This may be done when conditions are foggy or rainy and lots get muddy. Although heat abatement is provided in freestalls (soakers on feedline and fans over feedline or freestalls) cattle may also be restricted from open lots during increased temperatures in summer. Feed intake and nutritional value of feed consumed is useful to estimate manure excretion (ASAE, 2005). The objective was to quantify TOC and estimate feed intake and manure production for different categories of animals in freestall and non-freestall housing in the San Joaquin Valley.

Materials and Methods

Experimental design and animal management

This project was conducted on four commercial dairy farms in the San Joaquin Valley (SJV) of California (USA) between January and July 2018 inclusive. Two of the farms were freestall dairies and two were non-freestall dairies.

Before starting the study, a model was created in Excel to facilitate a sensitivity analysis to determine factors which would impact total fecal organic matter (OM) output by the animals, as well as where on the dairy (i.e., on concrete flush surfaces or on open lot surfaces) that the feces would be deposited. If total OM intake and its chemical composition is known, there are ample published data to develop the equations needed to predict total fecal OM output by various classes of cattle. However, there are no published data on where that feces would be deposited in pens, and how that is impacted by pen type and season of the year. Thus, the focus of the study was to collect feed intake and composition data in order to allow calculation of total OM output as feces by dairy cattle, and to determine where in the pen feces were deposited.

Prior to study initiation, site visits were completed at each farm to determine management practices and understand the layout of the pens to ensure that each site met base criteria. These criteria included electronic record keeping of diet mixing and delivery, as well as electronic herd records. During this initial visit, sentinel pens for animal observation were determined. Sentinel pens included each class (i.e., lactating cows, dry cows, replacement heifers subdivided into bred heifers, pre-bred heifers and weaned heifers) of cattle on the farm, at least if all classes were represented on the farm. None of these dairy farms housed pre-weaned heifers on-site.

Within the study timeframe, three 24 h cattle observation and data collection periods were completed to represent winter, spring/fall and summer conditions in order to re-create annual weather and management conditions in the SJV. The "Winter" period occurred during the week of January 30th - February 7th (2018). The "Spring" period occurred during late April and early May (2018), and the "Summer" period occurred during the week of July 8th through July 12th (2018). Each period consisted of determining the number of cows on concrete in the sentinel pens every 90 minutes of the 24 h day, as well as body condition (BCS) scoring and TMR sampling of the diet fed to each sentinel pen.

Data collection

Environmental Conditions

Portable weather stations (HOBO) were set up at each dairy site. The location of the weather stations were out of direct sunlight and out of reach of cattle. Weather stations that were placed in covered barns were away from fans and soakers. Ambient temperature and relative humidity were recorded every 1.5 h from January through July 2018 inclusive (i.e., the entire study period). Rain gauges were located in open locations in close proximity to the pens on each dairy farm. Rain levels were recorded as needed to determine rainfall during each season.

TMR sampling

Two samples of the total mixed ration (TMR) fed to each sentinel pen on each dairy farm were collected, unless the pen was only fed once in the 24 hour sampling period. The TMR samples were collected immediately after feeding, before the cows had access to it. One handful of TMR was collected at regular intervals along the bunk line of each target pen according to Robinson and Meyer (2010). This large sample was then mixed and quartered, with two opposite quarters used for 55ºC dry matter (DM) determination, one quarter kept for chemical analysis, and one quarter kept as a reserve.

Body condition scoring

The BCS of 20 randomly selected cattle in all sentinel pens at each site were assessed by the same trained scorer during each observation period and season. Scores were assigned in the range of 1 to 5 where a score of 1 indicates extreme emaciation, and 5 indicates extreme obesity (Swanepoel et al. 2014). These scores were then averaged to create an average BCS for each sentinel pen during each season.

Cattle behavioral (location in pen) observations

Counting occurred in all sentinel pens in time increments of 1.5 h over each 24 h observation period on each dairy farm in each season. Thus, there were a total of 17 observations in each pen (the start and end time of each day were the same) in each observation period. During each pen observation, cattle in the pen were manually counted as being either on concrete (i.e., an area where manure was routed to a manure pond) or in the open lot area (i.e., not routed to a manure pond). Cattle counting was conducted while slowly driving along the feed bunk. Results were tabulated as % of cattle found on concrete (TOC) as the average of all observations within each period.

Sample Analysis

TMR chemical analysis

Upon collection, quartered TMR samples (described above) were bagged and placed in a -20°C freezer until analysis. Samples were removed from the freezer and thawed to room temperature one day prior to oven drying. The TMR samples were dried at 55°C for 48 h and then air equilibrated for 24 h and weighed to determine DM. Samples preserved for chemical and assays were assayed for total N and neutral detergent fiber (aNDFom) at the UC Davis analytical laboratory. These samples were first ground to pass a 1 mm screen in a Model 4 Wiley Mill (Thomas Scientific, Swedesboro, NJ, USA). Ash determination was by combusting ground samples at 550°C for at least 3 h (AOAC, 2005). The N content was determined as total N in a combustion N analyzer (Elementar, Mount Laurel, NJ, USA) according to Sweeney (1989). The aNDFom content was analyzed according to methods of Goering and Van Soest (1970) using a heat stable amylase and expressed on an ash-free basis.

TMR intake

The weights of TMR delivered to each pen, and the weight of TMR refused from each pen (if it occurred), were collected for each collection period from electronic EZFeed or FeedWatch records. The TMR delivered and the TMR refused were calculated for all observation days.

The DM intake of each pen was calculated using the weights of feed delivered for each pen (corrected for refusals) during each 24 h as:

$$DM\ intake = \left(Feed\ provided_{as\ fed\frac{kg}{d}} - Feed\ refused_{as\ fed\frac{kg}{d}}\right) * \left(\frac{TMR\ DM\ percent}{100}\right)$$

Statistical Analysis

Prior to statistical analysis, all data sets were visually assessed for biologically improbable values based on any of the outputs. Any samples so identified were deemed outliers and not considered in the statistical analysis. The final number of sentinel pens considered for diet composition and intake, as well as BCS and TOC were: Dairy 1, 7 sentinel pens; Dairy 2, 8 sentinel pens, Dairy 3, 7 sentinel pens, and Dairy 4, 7 sentinel pens. Results were statistically analyzed as a factorial design using the GLM procedure of the Statistical Analysis System (SAS) within each dairy farm with model fixed factors being animal class (i.e., Cl; lactating or non-lactating animals), season (i.e., S; winter, spring/fall, summer) and the Class*Season interaction as fixed factors. Pens of the same class within each dairy farm were treated as replicates. Numerical differences among treatments were accepted as significant if $P \leq 0.05$, and tendencies to significance were accepted if $0.10 \geq P \geq 0.05$.

Results

Results are reported by dairy farm due to the unique aspects among each dairy farm in terms of management, dairy layout and pen classification. All dairy sites were located in the SJV and distances between them did not exceed 132 miles.

Weather patterns during the winter, spring and summer observations were broadly normal for the SJV during these periods. During the winter observations, within day temperatures among dairy sites ranged from ~6°C to ~20°C, with maximum humidity occurring at the minimum temperature (Tables 2.1 to 2.4). During the summer, within day temperatures ranged from a minimum of ~19°C to a maximum of ~35°C, again with maximum humidity occurring at minimum temperatures. Spring temperature and humidity levels were intermediate between the winter and summer observation values.

Dairy 1

Dairy one is a freestall dairy housing ~3,000 mature animals that are milked 3 times daily. The animal population consisted of both multiparous and primiparous lactating, and dry cows, as well as 1 pen of replacement heifers. Lactating cows were exclusively housed in freestall barns with access to an open lot. Gates separated the freestall concrete area and the open lot area. Access to the open lot was dependent on weather conditions and the resultant management decision on access to the open lot area. For example, all animals in lactation pens had no access to open lot areas during the winter observation period. All freestall areas were equipped with overhead fans as well as bunk line soakers. The sentinel pens consisted of 4 lactation pens, 2 dry cow pens, and 1 replacement heifer pen.

Diet composition and intake

Diet composition differed by class with lower (P<0.05) levels of aNDFom in lactation rations, which had a lower (P<0.05) N content (Table 2.1). In addition, the diet OM content was lower (P<0.05) in winter than in spring and summer. Diet intakes of DM and all of its components was much higher (P<0.05) in lactating *versus* non-lactating pens, but none were influenced by season.

Cattle characteristics

The BCS was lower (P<0.05) in lactating cattle, but unaffected by season (Table 2.1). Lactating cows spent much more (P<0.05) TOC than did non-lactating animals, and all cattle spent more (P<0.05) TOC in winter than in spring, with summer intermediate (Table 2.1).

Dairy 2

Dairy two is a freestall dairy. The farm housed ~5,300 cattle cows and milked twice daily. The cattle population consisted of multiparous and primiparous lactating and dry cows, as well as replacement heifers who return to the farm at ~120 days of age. All lactating cows were housed in freestall barns with potential access to an open lot. The exception was one lactating pen that did not have freestalls, but only a concrete flush lane and open lot. Gates separate the freestall concrete area and the open lot area. Access to the open lot was dependent on weather conditions. All freestall areas were equipped with overhead fans and bunk line soakers. The sentinel pens included 5 lactation pens, 1 dry cow pen and 2 replacement heifer pens.

Diet composition and intake

Diet composition differed by class with lower (P<0.05) levels of aNDFom in lactation rations (Table 2.2). Diets had higher (P<0.05) OM levels in spring than in winter, with summer intermediate. There were trends (P<0.10) to higher intake of DM, OM and N in lactating *versus* non-lactating cattle, but intake of all dietary components was not impacted by season.

Cattle characteristics
The BCS tended (P<0.10) to be lower in lactating cattle, and was higher overall in winter *versus* spring and summer (Table 2.2). Lactating cows spent much more (P<0.05) TOC than did non-lactating animals, but TOC was not impacted by season.

Dairy 3
Dairy three is a traditional California non-freestall dairy. The farm housed ~3,600 cattle and milked twice daily. The cattle population included multiparous and primiparous lactating and dry cows, as well as replacement heifers starting at ~120 days of age. All cows were housed in open lot pens with shade structures toward the back of each pen. Lactating cow pens also had shade cloth over the feed lane for added weather protection. Bunk line soakers were located only in lactation pens. The sentinel pens consisted of 3 lactation pens and 4 replacement heifer pens.

Diet Composition and intake
Diet composition differed by class with lower (P<0.05) levels of aNDFom in lactation rations, which had a lower (P<0.05) N content (Table 2.3). The composition of the diets was not impacted by season. Diet intakes of DM and its components were much higher (P<0.05) in lactating *versus* non-lactating pens, but none were influenced by season.

Cattle characteristics
The BCS was lower (P<0.05) in lactating cattle, and higher overall in winter than in summer with spring intermediate (Table 2.3). Lactating cows spent much more (P<0.05) TOC than did non-lactating animals, but TOC was not impacted by season.

Dairy 4
Dairy four is a traditional California non-freestall dairy facility. The farm housed ~2,750 cattle and milked twice daily. The cattle population consisted of multiparous and primiparous lactating and dry cows, as well as replacement heifers from ~120 days of age. All cows are housed in open lot pens with shade structures toward the back of each pen. Lactating cow pens also had shade cloths over the feed lane for added weather protection. Bunk line soakers were only in lactation pens. The sentinel pens consisted of 3 lactation pens, 1 dry cow pen and 3 replacement heifer pens. Due to communication issues with dairy management, there was no winter observation period on this dairy farm.

Diet Composition and intake
Diet composition differed by class with lower (P<0.05) levels of aNDFom in lactation rations, higher levels of OM, and a tendency to lower N levels (Table 2.4). However diet composition was not impacted by season. Diet intakes of DM and all of its components was much higher (P<0.05) in lactating *versus* non-lactating pens, but none were influenced by season.

Cattle characteristics
The BCS was lower (P<0.05) in lactating cattle, but not impacted by season (Table 2.4). Lactating cows spent more (P<0.05) TOC than did non-lactating animals, but TOC was not impacted by season.

Table 2.1. Impacts of cattle class and season of the year on diet composition, intake and cattle characteristics on a freestall dairy farm (Dairy 1).

	Class (Cl)		Season (S)				P		
	Lactating	Non-Lactating	Winter	Spring	Summer	SEM	Class	Season	Cl*S
Temperature, °C									
Maximum	-	-	17.2	27.5	34.9	-	-	-	-
Minimum	-	-	4.8	12.6	19.2	-	-	-	-
Humidity, %									
Maximum	-	-	94.1	80.1	68.3	-	-	-	-
Minimum	-	-	67.1	33.9	30.7	-	-	-	-
Pens represented	*4*	*3*[x]	*7*[y]	*7*[y]	*7*[y]	-	-	-	-
Diet Composition									
Dry matter, %	50.1	44.1	46.9	48.0	46.3	3.49	0.10	0.92	0.67
Organic matter, % DM	89.9	88.7	86.1[a]	90.8[b]	91.1[b]	0.82	0.14	<0.01	0.39
Nitrogen, % DM	2.64	2.13	2.33	2.42	2.41	0.08	<0.01	0.59	0.06
Neutral detergent fiber, % DM	30.1	37.8	33.0	32.8	35.9	1.94	<0.01	0.35	0.54
Diet Intake									
Dry matter, kg/d	26.0	15.2	21.0	21.7	19.1	2.52	<0.01	0.69	0.38
Organic matter, kg/d	23.4	13.5	18.1	19.6	17.5	2.22	<0.01	0.73	0.36
Nitrogen intake, kg/d	0.69	0.32	0.51	0.53	0.47	0.061	<0.01	0.68	0.59
Neutral detergent fiber, kg/d	7.8	5.6	6.7	7.1	6.4	0.87	0.02	0.81	0.39
Animal Characteristics									
Body Condition Score, units	2.80	3.26	3.07	3.06	2.95	0.13	<0.01	0.71	0.88
Time on Concrete, %	78.2	35.9	73.2[a]	43.2[b]	54.8	8.53	<0.01	0.03	0.58

[a, b, c] - means among season within descriptor differ (P <0.05).

[w] - all lactation pens were freestall pens, but all non-lactating pens were drylot pens.

[x] - 2 pens of non-lactating cows and 1 pen of replacement heifers.

[y] - 4 pens of lactating cows, 2 pens of non-lactating cows and 1 pen of replacement heifers.

Table 2.2. Impacts of cattle class and season of the year on diet composition, intake and cattle characteristics on a freestall dairy farm (Dairy 2).

	Class (Cl)		Season (S)				P		
	Lactating	Non-Lactating	Winter	Spring	Summer	SEM	Class	Season	Cl*S
Temperature, °C									
Maximum	-	-	21.7	19.9	34.5	-	-	-	-
Minimum	-	-	7.8	6.6	20.3	-	-	-	-
Humidity, %									
Maximum	-	-	95.1	86.4	63.4	-	-	-	-
Minimum	-	-	59.8	30.1	21.9	-	-	-	-
Pens represented	*5*	*3*[x]	*8*[y]	*8*[y]	*8*[y]	-	-	-	-
Diet Composition									
Dry matter, %	55.4	51.4	54.9	54.8	50.5	1.98	0.04	0.11	0.60
Organic matter, % DM	91.2	89.5	88.2[a]	92.2[b]	90.7	1.14	0.13	0.02	0.09
Nitrogen, % DM	2.54	2.43	2.48	2.40	2.57	0.084	0.16	0.21	0.42
Neutral detergent fiber, % DM	32.7	40.8	35.2	37.0	38.0	3.91	0.04	0.83	0.96
Diet Intake									
Dry matter, kg/d	19.9	13.9	17.5	16.5	16.7	3.34	0.07	0.96	0.95
Organic matter, kg/d	18.2	12.4	15.4	15.2	15.3	3.08	0.06	1.00	0.98
Nitrogen intake, kg/d	0.50	0.34	0.44	0.41	0.44	0.093	0.07	0.93	0.99
Neutral detergent fiber, kg/d	6.1	5.3	5.6	5.6	5.8	0.79	0.29	0.98	0.94
Animal Characteristics									
Body Condition Score, units	3.06	3.41	3.62[a]	3.00[b]	3.07[b]	0.19	0.07	0.02	0.19
Time on Concrete, %	69.8	21.0	48.1	42.7	45.5	2.53	<0.01	0.21	>0.05

[a, b, c] - means among season within descriptor differ (*P* <0.05).

[w] - all lactation pens were freestall pens, but all non-lactating pens were drylot pens.

[x] - 1 pen of non-lactating cows and 2 pens of replacement heifers.

[y] - 5 pens of lactating cows, 1 pen of non-lactating cows and 2 pens of replacement heifers.

Table 2.3. Impacts of cattle class and season of the year on diet composition, intake and cattle characteristics on a non-freestall dairy farm (Dairy 3).

	Class (Cl)		Season (S)				P		
	Lactating	Non-Lactating	Winter	Spring	Summer	SEM	Class	Season	Cl*S
Temperature, °C									
Maximum	-	-	22.9	23.8	35.9	-	-	-	-
Minimum	-	-	7.6	8.3	19.3	-	-	-	-
Humidity, %									
Maximum	-	-	97.4	86.8	68.2	-	-	-	-
Minimum	-	-	52.9	37.4	25.8	-	-	-	-
Pens represented	*3*	*4*[x]	*7*[y]	*7*[y]	*7*[y]	-	-	-	-
Diet Composition									
Dry matter, %	55.2	57.5	54.8	55.1	59.2	1.86	0.27	0.16	0.08
Organic matter, % DM	92.4	90.8	91.6	91.3	91.9	0.71	0.06	0.81	0.99
Nitrogen, % DM	2.65	2.06	2.33	2.36	2.38	0.17	<0.01	0.97	0.93
Neutral detergent fiber, % DM	29.4	44.3	37.5	36.5	36.5	4.03	<0.01	0.98	0.94
Diet Intake									
Dry matter, kg/d	26.8	10.9	19.0	18.2	19.4	1.12	<0.01	0.70	0.39
Organic matter, kg/d	24.7	9.9	17.4	16.7	18.0	1.00	<0.01	0.65	0.38
Nitrogen intake, kg/d	0.71	0.22	0.46	0.45	0.48	0.02	<0.01	0.62	0.53
Neutral detergent fiber, kg/d	7.9	5.0	6.7	6.0	6.7	0.76	<0.01	0.76	0.53
Animal Characteristics									
Body Condition Score, units	2.73	3.47	3.37[a]	3.03	2.90[b]	0.15	<0.01	0.08	0.26
Time on Concrete, %	31.0	25.1	26.8	29.2	28.2	2.31	0.03	0.74	0.49

[a, b, c] - means among season within descriptor differ (*P* <0.05).

[w] - all pens were drylot pens.

[x] - 4 pens of replacement heifers.

[y] - 3 pens of lactating cows and 4 pens of replacement heifers.

Table 2.4. Impacts of cattle class and season of the year on diet composition, intake and cattle characteristics on a non-freestall dairy farm (Dairy 4).

	Class (Cl)		Season (S)				P		
	Lactating	Non-Lactating	Winter	Spring	Summer	SEM	Class	Season	Cl*S
Temperature, °C									
Maximum	-	-	-	29.1	36.6	-	-	-	-
Minimum	-	-	-	12.6	19.1	-	-	-	-
Humidity, %									
Maximum	-	-	-	72.9	50.3	-	-	-	-
Minimum	-	-	-	31.5	20.5	-	-	-	-
Pens represented	*3*	*4*[x]	-	*7*[y]	*7*[y]	-	-	-	-
Diet Composition									
Dry matter, %	54.9	56.0	-	55.3	55.7	2.15	0.60	0.84	0.88
Organic matter, % DM	92.2	86.7	-	89.8	89.2	1.22	<0.01	0.62	0.96
Nitrogen, % DM	2.84	2.53	-	2.70	2.67	0.165	0.08	0.85	0.92
Neutral detergent fiber, % DM	25.3	37.7	-	30.8	32.2	3.79	<0.01	0.69	0.92
Diet Intake									
Dry matter, kg/d	28.9	9.6	-	19.0	19.5	2.03	<0.01	0.81	0.69
Organic matter, kg/d	26.7	8.2	-	17.3	17.6	1.69	<0.01	0.87	0.66
Nitrogen intake, kg/d	0.82	0.23	-	0.53	0.53	0.046	<0.01	0.92	0.56
Neutral detergent fiber, kg/d	7.3	3.8	-	5.4	5.8	1.01	<0.01	0.65	0.82
Animal Characteristics									
Body Condition Score, units	2.83	3.21	-	3.02	3.02	0.09	<0.01	0.99	0.45
Time on Concrete, %	37.0	23.8	-	28.8	32.0	2.52	<0.01	0.21	0.11

[w] - all pens were drylot pens.

[x] - 1 pen of non-lactating cow and 3 pens of replacement heifers.

[y] - 3 pens of lactating cows, 1 pen of non-lactating cow and 3 pens of replacement heifers.

Discussion

The two freestall dairies participating in this project paid considerable attention to animal management and open lot conditions. Access restrictions of lactating cattle to open lots modified the amount of TOC. Cattle in herds where less attention is paid to open lot restrictions will likely have lactating cattle spending more time in open lots. Almost all facilities have dry cows. This population of animals spends less TOC than lactating cows. Given the findings herein, the use of 80% recovery of VS for freestall herds in the Alternative Manure Management Program is an overestimate for the herd population. Housing type and management preferences alter how much TOC animals reside. These are important considerations to determine effectiveness of manure management strategies and technologies to reduce VS in an anaerobic state.

Conclusions

Overall, lactating cows on the two freestall dairies spent about 69.8 and 78.2% of their time on concrete, whereas those on non-freestall dairy farms spent about 31.0 and 37.0% of their time on concrete. In contrast, non-lactating cattle on both freestall and non-freestall dairy farms spent a broadly equal amount of time on concrete (~26%; range 21.0 to 35.9%), primarily because, regardless of dairy type, virtually all non-lactating cattle were housed in open lot pens.

The TOC was modestly impacted by season on both the freestall dairy farms (most in winter, least in spring), but TOC was not impacted by season on the two non-freestall dairy farms.

Recommendations

Use of a single value for TOC within housing type does not allow for site specific management practices. Selection from a range of values will provide more reliable information. Feed intake data may be input into various models to estimate organic matter (VS) digestibility. The indigestible fraction of VS has potential to form methane if sufficient time elapses and conditions are conducive for methanogens.

Chapter 3 Characterization of waste stream

Abstract

Monthly in-depth analysis of waste stream distribution occurred at four commercial dairies (July 2017 through June 2018) to understand how herd specific management decisions alter manure collected in the liquid stream. Liquid manure was reused for flushing lanes on three dairies. Volatile solids entered the liquid stream 1) in water reused from the dairy pond, 2) excreted from cattle and collected in their housing area, transfer lanes (from housing to milking parlor) and at the milking parlor, and 3) as bedding (dried manure with or without almond shells). Quarterly expeditions onto dairy ponds retrieved samples from multiple locations and depths to evaluate chemical (pH, N fractions, electrical conductivity and oxidation reduction potential) and physical (temperature) properties of pond water. Each dairy had different animal and manure management techniques. Dairy 1 housed 3,000 animals: 88.8% lactating cows, 9.7% dry cows, and 3.1% springing heifers (near parturition). Housing was freestall with open lots. Dried composted manure with or without almond shells was the bedding source. Bedding use was 1.9 kg VS per animal (one set of measurements made). Bedding was 60.5% ± 8.5% VS. Manure management included processing pit, two screen mechanical separator, and two cell gravity separation system (cleaned out infrequently). Dairy 2 consisted of 5,300 animals: 41.5% lactating cattle, 8.2% dry cows and 50.3% replacement heifers. Housing was freestall with open lots. Dried manure with or without almond shells was the bedding source. Bedding use was 5.9 kg VS per animal per day. Bedding was 57.0% ± 15.4% VS. Manure management included an alternating cell gravity separation system cleaned out frequently. Dairy 3 housed 3,600 cattle: 47.9% lactating cows, 7.6% dry cows and 44.5% replacement heifers. Housing was open lots with shade structures. Manure management included collection of lactating cow manure from concrete near feed bunks via flush, scrape with tractor, or vacuumed with tractor. Flushed manure went to a gravity separation system that is cleaned out frequently. The vacuumed material was placed into the gravity separation system or stockpiled depending on weather conditions. Vacuumed manure was 8.5 to 12.0% VS. Dairy 4 had 2,750 animals: 46.6% lactating cows, 6.7% dry cows, and 46.7% replacement heifers. Animal housing was open lots with shade structures provided for bred heifers and lactating and dry cows. Parlor water was collected and used to flush lactating cattle concrete lanes and part of the heifer concrete lanes. All heifer manure lanes were scraped manually with a small tractor. All data identify site specific animal and manure management, yield tremendous variability in VS flow through the liquid system at sampling locations. Quarterly pond analyses showed tremendous variability in pH, electrical conductivity, oxidation reduction potential and ammoniacal and organic N concentration and ratios within and between dairies.

Introduction

Modifications to dairy manure management systems are key to reduce GHG emissions, specifically CH_4, in California. The CARB identifies that dairy manure management and enteric fermentation account for 45% of CH_4 emissions in the 2015 GHG inventory (CARB, 2015). Key to the formation of CH_4 is the management of VS in anaerobic conditions. Maximizing VS collection, maintaining an anaerobic environment and capturing methane will reduce atmospheric emissions of CH_4. This is valuable when manure methane produced displaces use of other fuel sources, where CH_4 is not emitted to the atmosphere and GHG associated with use of other natural gases or petroleum based energy sources are not emitted as well. The Dairy Digester Research and Development Program (DDRDP) currently provides funding to offset costs associated with installation of dairy digesters where biogas will be used to displace natural gas or compressed for vehicle fuel. Alternatively, manure management can strive to maximize removal of VS from the waste stream to limit the amount of VS that enter anaerobic conditions. The Alternative Manure Management Practice program provides funding to aid producers to restrict VS loading of anaerobic storage systems.

Key in the analysis of VS flow through dairies is obtaining representative samples or a sufficient number of samples over time that capture the nature of the stream sampled. Also key is understanding confounding management practices that can occur with animal husbandry (bedding freestalls, feeding times, lane scraping times, use of soakers to cool animals, etc.) that affect VS concentration of a liquid stream. One peer reviewed paper was identified that evaluated total solids (and VS although not reported) of a gravity flow solid liquid separation system in California (Meyer et al., 2004). This project analyzed sequential samples during multiple flushes to determine appropriate sampling frequency protocol.

Additional research conducted in California was presented and not readily available in peer review publications. A review of previous and current emissions research conducted on dairies was presented August 14, 2017 (Fitzgibbon, 2017) to the Research subcommittee of the Dairy and Livestock Greenhouse Gas Reduction Working Group. One project in progress was detailed at the September meeting (Zhang, 2017) where scientists identified their methodology of making a composite sample for analysis of periodic samples taken during a 24 hr period. Previously, other work reported used less intensive sampling procedures. Proceedings papers from the American Society Agricultural and Biological Engineers have been reported by Chastain (2009) and Wright (2005). Chastain (2009) calculated efficiency of separation based on mass and composition of solids removed by separation and measurement of system effluents. An undisclosed number of liquid samples were collected over a 1hour period during operation and a composite was made. During the second sampling campaign an undisclosed number of effluent samples were collected throughout the day. Different methods of evaluating efficiency of solid liquid separation were defined (Wright, 2005). The approximate method is most simplistic and requires evaluation of the concentration of the influent and effluents of a separator. The exact method requires mass flow rate of solids in the influent and effluent or separator solids. The third method relies on knowing the volumetric flow rate of the liquid influent and effluent streams. Although these different methods were defined, no analysis of variability of TS concentration over time within a day were discussed.

Understanding VS flow through dairies is essential to identify potential mitigations associated with manure modifications on farms. Our objectives were to develop and deploy on-farm analyses of manure pathways on dairies with and without freestalls to quantify physical (temperature) and chemical (redox, pH, TS, VS, and N fractions (organic and ammonium)) composition of liquid streams.

Materials and methods

Results from Chapter 1 informed selection of dairies for the field campaign. A list of criteria for facility layout and feed management were identified. Aerial photos of 177 dairies in the San Joaquin Valley were used to identify potential facilities. Eighteen facilities fit the physical layout needs for potential participants. On the ground, review of facilities and determining potential interest of cooperators was conducted to further refine facility options. Holstein was the breed criteria. Site visits were conducted and four facilities were enrolled. Two facilities are non-freestall (c. 1,200 and 1,800 lactating cows) and two are freestall (2,650 and 2,250 lactating cows) facilities. An additional 50 dairies were reviewed by the research team. Three facilities fit the physical layout needs for potential participants. Operators/owners at two of these facilities were contacted to determine interest in hosting the research team. Both facilities declined. The third facility contacted remained silent. Attempts to find a fifth facility were dropped after 5 months of unsuccessfully locating an additional facility. All dairies enrolled reside in the San Joaquin Valley.

Descriptions of sites

Dairy 1 Freestall

Cattle present: Lactating and dry cows, heifers just prior to calving. Replacement heifers from 12 hours old until just before calving are reared off-site. Replacement heifers are returned to the facility near calving.

Housing: Freestalls for all lactating cattle. Manure bedded loafing barn for heifers and dry cows just prior to parturition. Corrals present for lactating cattle. Soakers are used on feedlines for all cattle and in the milk parlor holding area. Soakers are automatic and turn on when temperatures are above 20.5 °C.

Manure management (Figure 3.1): flushed freestalls, liquid manure processing pit, two mechanical separators in sequence, two settling pits and liquid manure storage/treatment structure. Freestall flush water originates from the liquid manure storage/treatment structure. Separator solids are managed to undergo active composting. Once cured and dried, these solids are used for bedding. Almond hulls are used as a bedding extender when needed. Flush water and parlor water (from cleaning milk contact surfaces, sprinkler pen water and holding pen animal soaker water) flow to a processing pit. Water is pumped (nearly 24 h/day) from the processing pit over a sequential near horizontal separator system where effluent from the first separator goes to the second separator. Effluent from the second separator gravity flows to one of two long gravity separation structures. Processing pit water is pumped through a separator by-pass line directly to the gravity separation structure when volumes accumulate. The settling pits are used for an extended duration before cleanout; one cell filling for two years prior to clean-out.

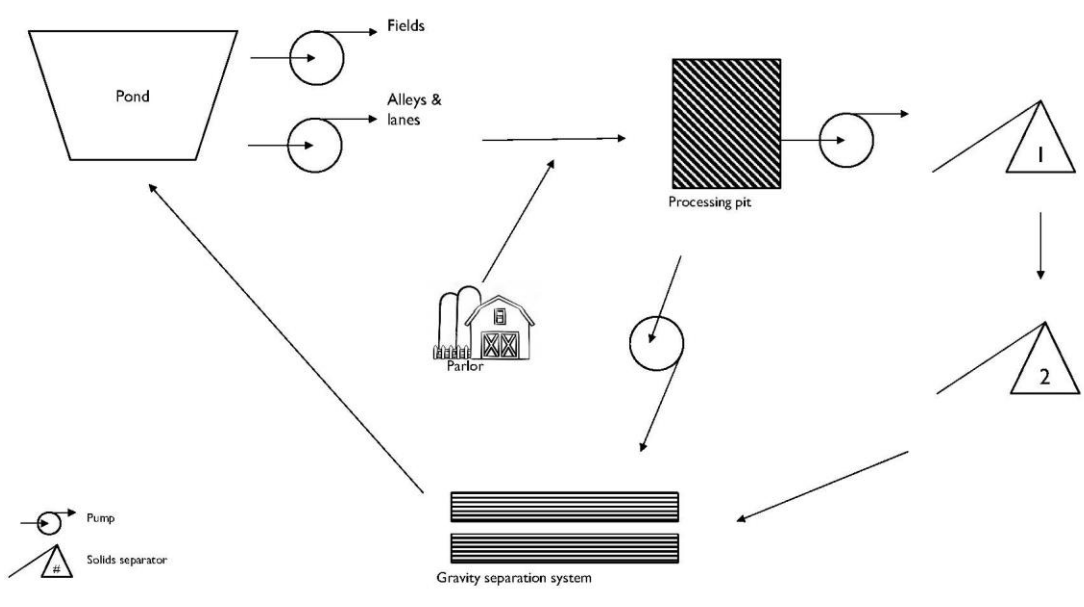

Figure 3.1 Dairy 1 liquid manure flow through facility.

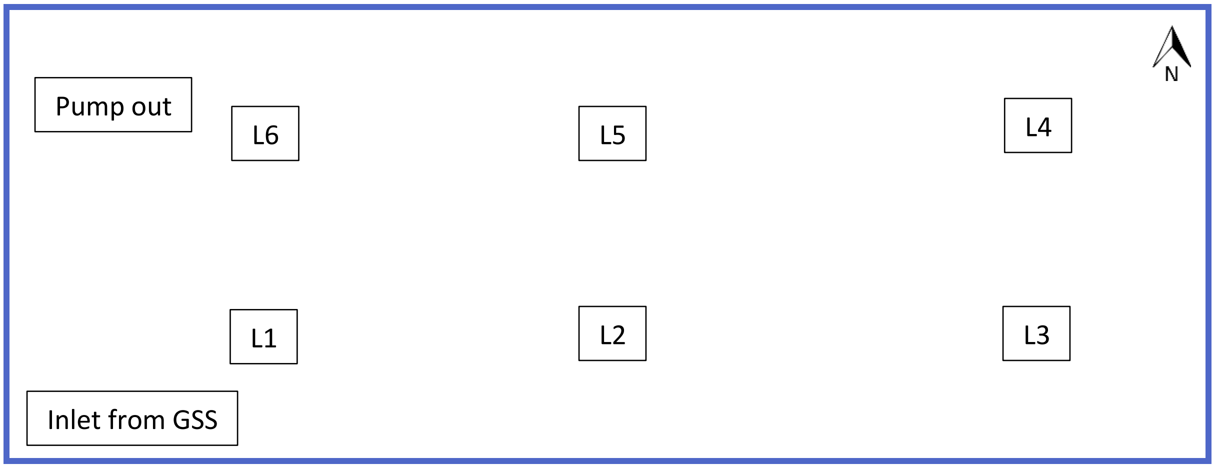

Figure 3.2 Dairy 1 pond schematic for sampling locations during quarterly sampling.

Sampling locations: influent flush water entering alleys or lanes, mechanical separator 1 influent, mechanical separator 1 effluent (mechanical separator 2 influent), mechanical separator 2 effluent (gravity separation system influent); gravity separation system effluent (pond influent). Flush water is reused from pond. Pond sampling locations are 1 through 6. Sample locations 1 through 3 represent 25, 50 and 75% of the distance from the west bank of the pond. Water flows into the pond and passes through sites 1 through 3. Water then turns (90 degrees) and flows in the reverse direction. Sample sites 4 through 6 are in line with sites 1 through 3 on the northern side of an earthen jetty in the pond. Two pumps are available to pump water from the pond downstream of site 6. These either provide pond water for irrigation or flush purposes.

Dairy 2 Freestall

Cattle present: Lactating and dry cows, most replacement heifers. Calves are reared off-site and return about 120 days of age.

Housing: freestalls for all lactating cattle. All freestall pens have corrals present. Close-up dry cows in corrals with shade structures or loafing barn bedded with dried manure and straw. Replacement heifers in corrals with shade structures. Replacement heifer feed aprons are flushed daily. Animal soakers are used on all lactating and dry cow feedlines and in the milk parlor holding area. Soakers are set to run when temperatures are above 20.5 °C. Run time is 40 seconds on with 4 or 7 minute intervals depending on ambient temperature.

Manure management (Figure 3.3): Freestall flush water originates from the liquid manure storage/treatment structure. Freestalls are bedded once weekly with one load of bedding. Bedding consists of dried solids from the gravity separation system and dried solids from corrals as needed. Almond shells are used as a bedding extender and are used most of the year. Each freestall line receives one load of bedding weekly. Flush water (all lactating cattle and one-half of replacement heifers) and parlor water (from cleaning milk contact surfaces, sprinkler pen water and holding pen animal soaker water) flow to one of two gravity separation cells. Use of cells alternates. One is filled, and as it dewaters for clean out, the other is filled. Gravity separation cells are cleaned every 4 to 6 weeks. Water flows from the gravity separation cells to the primary storage pond. This water receives a commercial product to enhance solids digestion. One-half of heifer flush water is sent directly to a separate liquid storage structure. This pond was not evaluated as the primary path for VS (>85% VS excreted) is to the gravity separation cells and primary pond. Water from one pen of dry cows enters the pond directly (by-pass of gravity separation system).

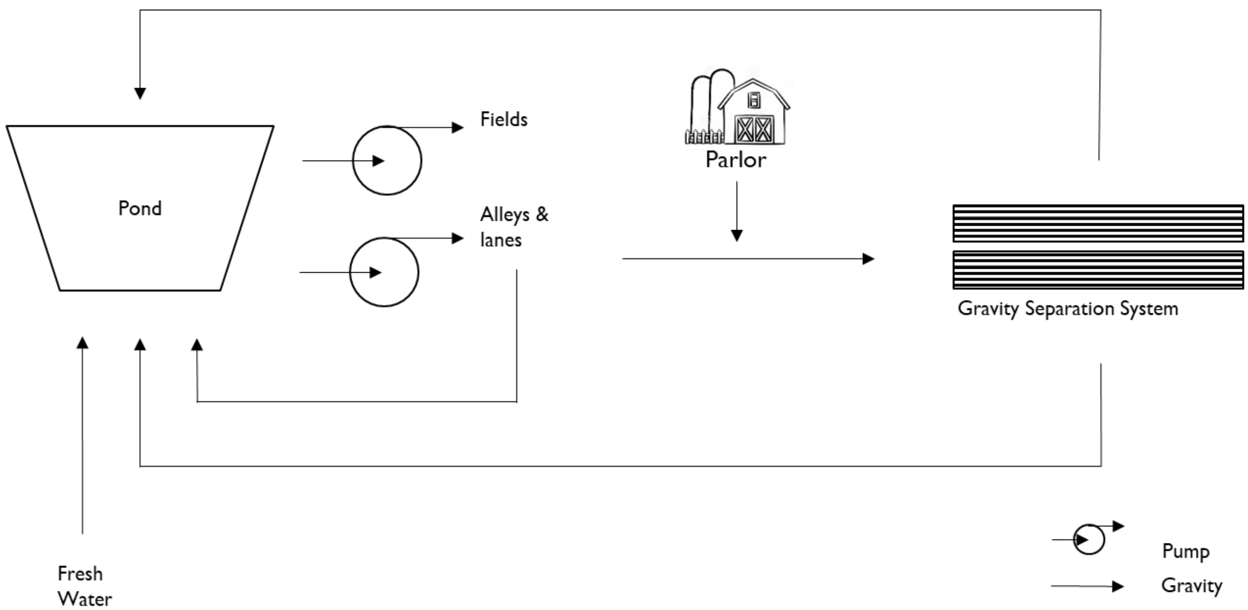

Figure 3.3 Dairy 2 liquid manure flow through facility.

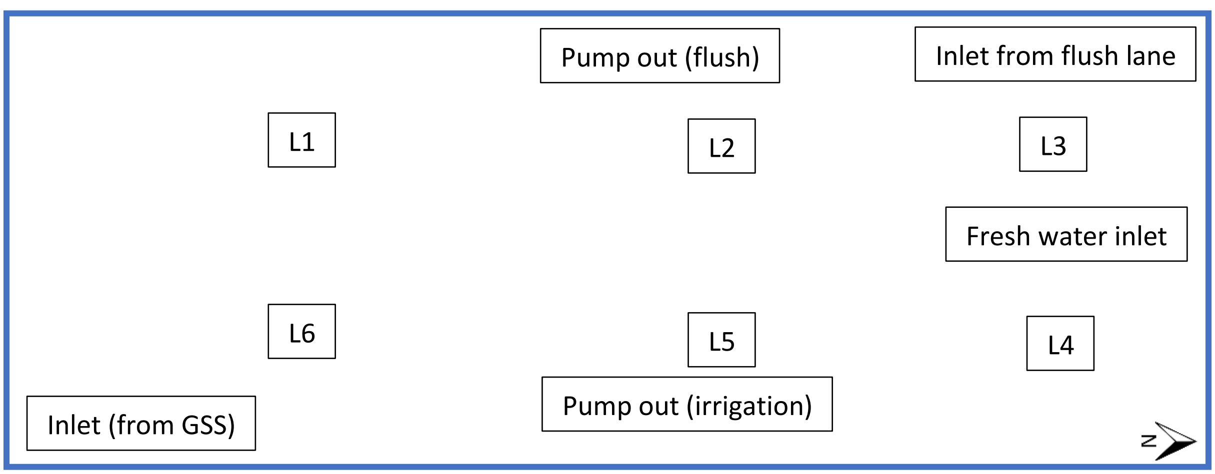

Figure 3.4 Dairy 2 pond schematic for sampling locations during quarterly sampling.

Sampling locations: influent flush water entering alleys and lanes, gravity separation system influent (sampled through standpipe over junction box where flow is directed to one of two pipes to transfer water to north or south gravity separation cell), gravity separation system effluent (primary pond influent). South separation cell is sampled through a hole in the transfer pipe; north separation cell is sampled as water enters the pond (use of body harness for safety). Pond sampling locations are 1 through 6. Sample locations 1 through 3 represent 25, 50 and 75% of the distance from the south bank of the pond and are approximately one-third the distance between the east and west banks of the pond. Sample locations 4 through 6 begin in the north and are at approximately one-third of the distance from the east bank. Water flows into the pond from the GSS in the southeast corner (near location 6). An irrigation pump is located east of location 5. The pump for flushing animal lanes is near site 2.

Dairy 3 Non-freestall

Cattle present: Lactating and dry cows, and most replacement heifers are present. Calves are reared off-site and return about 120 days of age.

Housing: Non-freestall facility for all animals. All animals housed in open corrals. In-corral shade structures present for all categories of animals. Feed lane shade present for milking and dry cows, and pregnant heifers. Soakers are used on feedlines for lactating and dry cows and pregnant heifers. Soakers are used in the milk parlor holding area. Soakers are set to run when temperatures are above 20.5 °C. Run time is 40 seconds on with 4 or 7 minute intervals depending on ambient temperature.

Manure management (Figure 3.5): Cattle feed lanes are flushed, scraped or vacuumed. Flush water originates from the large liquid storage pond to reuse on one flush lane of lactating cattle. Fresh irrigation water can be used as well (i.e., July and August). Flush occurs once or twice daily, manually. Flush water joins parlor water in a sump and is pumped to the gravity separation system. One lane of lactating cattle (including some replacement heifers) is vacuumed Monday, Wednesday and Friday with a 4,000-gallon vacuum. Two (W, F) or three (M) loads are collected with the slurry deposited into the gravity separation cell. Additionally, concrete lined water retention areas on the down slope of open lots are vacuumed as they accumulate water (2 to 4 loads/week in summer; variable in winter depending on rain frequency and intensity and soaker runoff). Runoff water contains a negligible amount of manure solids. Open lots are groomed daily to manage and dry manure. Solid manure from heifers and open lots is removed, dried and stockpiled prior to land application, offsite manifest or use as bedding. The gravity separation cell is cleaned every 4 to 8 weeks by farm staff.

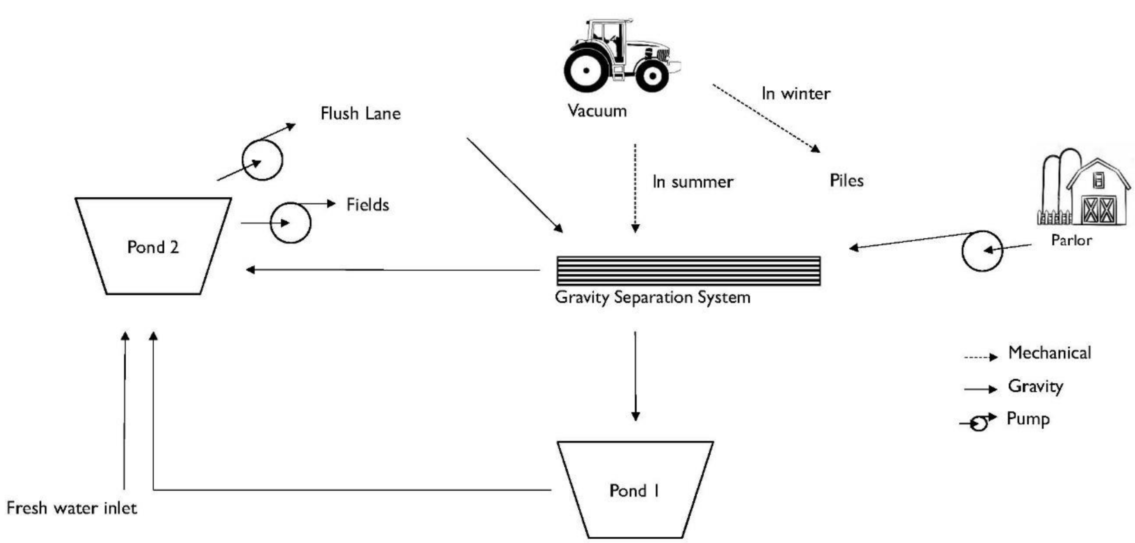

Figure 3.5 Dairy 3 liquid manure flow through facility.

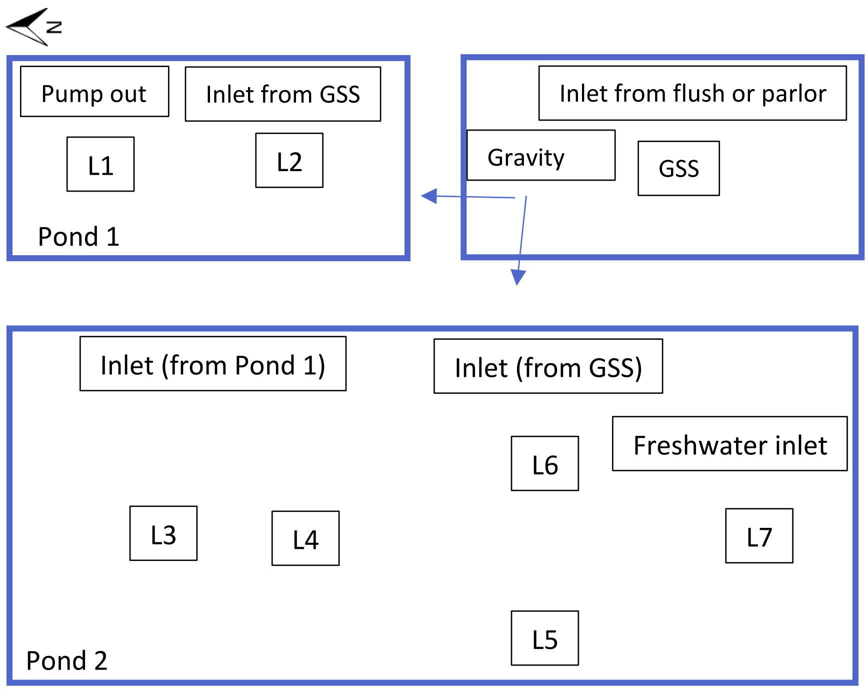

Figure 3.6 Dairy 3 pond schematic for sampling locations during quarterly sampling.

Sampling locations: influent flush water entering lane, gravity separation system influent (parlor water only or parlor water and flush), gravity separation system effluent (pond 1 or pond 2 influent), and pond 2 influent from gravity transfer from pond 1. Pond sampling locations are 1 through 7. Sample locations 1 and 2 are in pond 1 (smaller pond). Location 2 is near the inlet from the gravity separation system. Location 1 is at the opposite end. Water gravity flows to a second pond. The smaller cell of this pond has locations 3 and 4 with 3 nearer the inlet from pond 1. A small channel separates the smaller and larger parts of pond 2. Locations 5 and 6 are at the northern end one-third of the larger cell in pond 2. Location 6 is closest to the inlet from the gravity separation system. Location 7 is midway between 5 and 6 and one-third of the way from the southern bank. Outlet pump for irrigation or flushing is at the south western corner of the pond.

Dairy 4 Non-freestall

Cattle present: Lactating and dry cows and most replacement heifers are present. Calves are reared off-site and return about 120 days of age.

Housing: Non-freestall facility for all animals. All animals housed in open corrals. In-corral shade structures present for milking and dry cows and some heifers. Feed lane shade present for milking and dry cows. Soakers are used on feedlines for lactating and dry cattle and in the milk parlor holding area. Soakers are set to run when temperatures are above 20.5 °C (7 minute intervals) and above 30 °C (4 minute intervals). Run time is 40 seconds on.

Manure management (Figure 3.7): Flushes occur when sufficient water accumulates from milking parlor activities. Some milking parlor water is collected and pumped down the east cow pens. The majority of the milking parlor water is collected in a cistern and pumped into a 20,000 gallon upright tank. Once the tank is full, additional water overflows through a pipe on top. This signals staff milking cows to manually open the bottom valve to discharge water. This water bifurcates and flushes each side of lactating cow lanes and also flows to a separate lane and sump, pump for storage in a smaller structure. The secondary storage structure is used to flush one lane of replacement heifers. The other lane of replacement heifers is not flushed. Flush water flows down the east or west side cow pens (4 pens/side) and enters the liquid storage structure through 2 large and one small pipe. Flush events occur sporadically depending on water generation. One should occur at the end of each milking shift if not before. In the peak of summer, two events during the day milking may occur due to extra water use in the milking parlor. No gravity or mechanical separation system is in place. Corrals are groomed regularly to manage solid manure. Water is not reused from the pond to flush lanes.

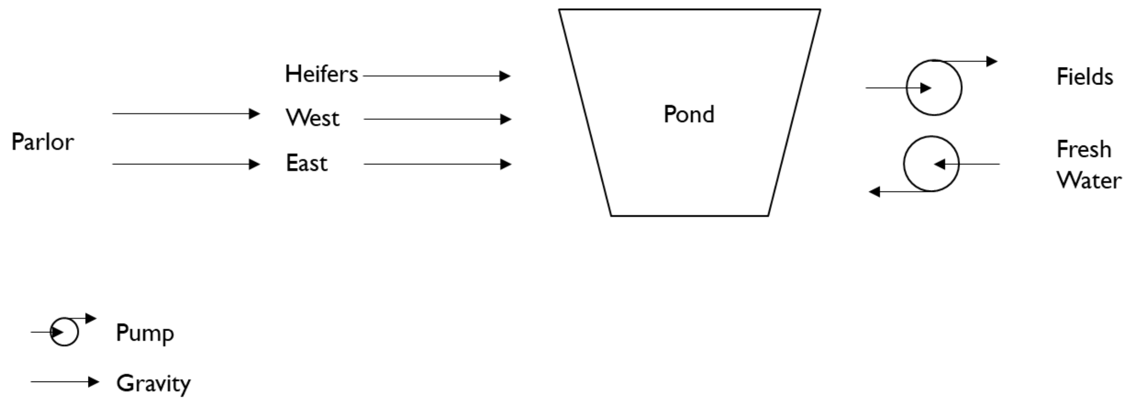

Figure 3.7 Dairy 4 liquid manure flow through facility.

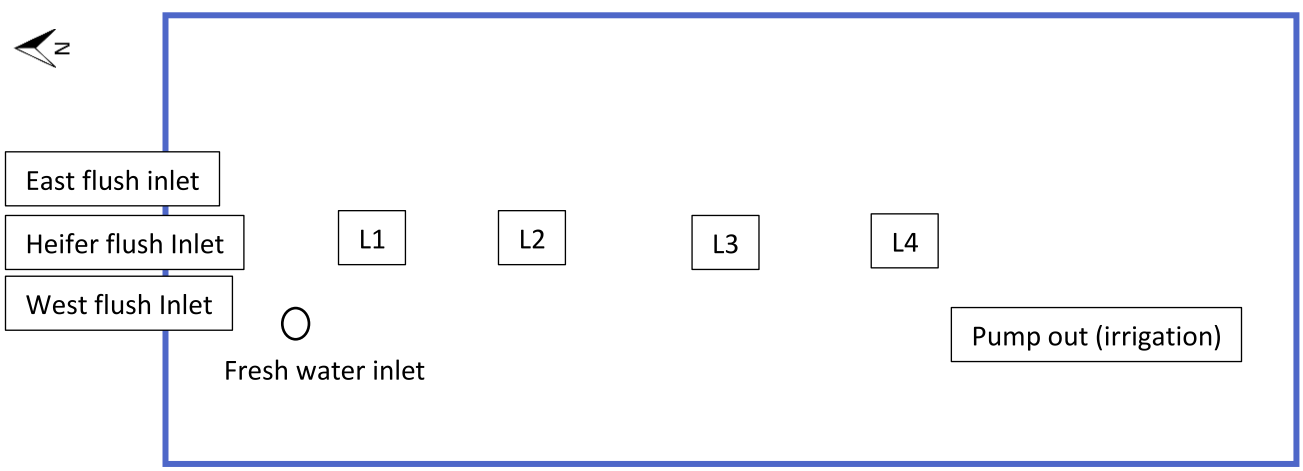

Figure 3.8 Dairy 4 pond schematic for sampling locations during quarterly sampling.

Sampling locations: Influent to pond from east or west milking cow pens or from heifers. Pond sampling locations were down the center of the pond. One irrigation pump is located at the south end of the pond.

Sampling methods

A preliminary sampling event occurred in June, 2017. Multiple samples from each sampling location were obtained and evaluated. Variability of VS concentration by sampling location was used to identify the minimum number of samples needed from each sampling source during each sampling event. The field campaign occurred monthly from July, 2017 through June, 2018. Seasons were defined as summer

(June through August), fall (September through November), winter (December through February), and spring (March through May).

Monthly samples of liquid manure streams were collected into labelled 250 ml Nalgene bottles. Samples were collected directly into bottles by inserting the open bottle into the liquid stream flow. Caution was taken so no overtopping would occur. If samples did overtop the contents of the bottle were emptied, the bottle cleaned, and then a new grab sample was taken. The same locations were sampled potentially at different flushes to allow comparisons. This is useful when lanes were flushed multiple times daily. Samples were analyzed for pH and temperature within 15 minutes of collection. Samples were stored in an ice cooled chest and transported to UC Davis. Samples remained in a 4°C refrigerator prior to analysis for EC, VS, and TS. Although fixed solids are not reported here (TS-VS), they are an important component of the waste stream.

Quarterly, a flat bottom boat was used to retrieve samples from ponds. A 250 ml stainless steel bomb sampler was used to collect samples at each location and depth. The sampler consists of a reservoir chamber and a weighted plunger fitted with an "O" ring seal. The sampler is dropped to the appropriate depth and the cable attached to the plunger is pulled thereby opening the plunger and capturing the sample. After the sample fills the chamber, the cable is released and the plunger reseals the chamber allowing removal of a sample from a specific depth. Samples were collected at each location identified in farm schematics from the top down to not disturb underlying material. At each location samples were retrieved at .3 m below and 1.5 m increments from the surface until no further sample retrieval was possible. Final depth was noted. Samples were analyzed for pH, temperature and oxidation reduction potential (redox) within 15 minutes of collection. Samples were stored in an ice cooled chest. Within each pond, samples from two locations were split. One set remained for UC laboratory analysis. One set was delivered to a commercial analytical laboratory for analysis of total Kjeldahl and ammonium nitrogen.

Field measurements

Field measurements of pH and temperature were made using an Oakton PCTS 50, PCSTestr 35 or pHTestr 30. Instruments were calibrated in the lab 24 hours prior to field work according to manufacturer's recommendations for 3-point calibration. In the field, instruments were again calibrated and validated with pH 7.00 standard solution from Fisher Scientific.

Field measurements of oxidation-reduction potential (redox) were made using an Oakton ORP Testr 10. This instrument was calibrated in the lab 24 hours prior to field work according to manufacturer's recommendations using Zobell's solution from VWR Scientific.

Laboratory analysis

Electrical conductivity was measured on each liquid sample in the laboratory using an Oakton Con 100 series meter and conductivity probe. The probe was calibrated according to manufacturer's recommendations with 1413 uS standard solution from Fisher Scientific. Samples were removed from the 4 °C cold room and each was inverted gently 2-3 times to mix contents just prior to measurement. The probe was re-calibrated after every 10-15 readings to reduce drift.

Total solids (TS) concentration (%) was determined by weighing and drying 15-25 ml aliquots of each sample in triplicate in a 120 °C oven for 4-16 hours, weighing the residual, then dividing by the wet weight. Aliquots were made using the shake and pour method (Meyer et al. 2004). Fixed solids (FS) concentration (% DM basis) was determined by further combustion of the dried samples in a muffle oven at 540 °C for 4 hours, weighing the residual, then dividing by the dry weight (Holstege et al., 2010). Volatile solids concentration (% as-is basis) is the difference between TS and FS divided by wet weight.

Statistical analysis

Statistical analyses were performed using the available statistics tools in R plus the DescTools package for summary statistics.

Quality assurance and quality control were conducted on all data. Data were visually assessed for outliers and then checked to determine if they were different or if there was an error in calculations. Prior to statistical analysis, all data were evaluated for biologically improbable values based on any of the outputs. Any samples so identified were deemed outliers and not considered in the statistical analysis. Results were statistically analyzed for each farm by Chi square analysis. Monthly liquid stream flow samples were evaluated for main effects of location of sample, season of year and interaction of location*season. For quarterly pond samples, multiple sets of analyses were conducted to determine if location, depth, month and associated interaction terms were significant. Numerical differences among treatments were accepted as significant if $P \leq 0.05$, and tendencies to significance were accepted if $0.10 \geq P \geq 0.05$.

The maximum number of samples were collected each month at each farm. This number varied by month. Uneven sample numbers were obtained each month over time. Review of monthly data are useful. Data are grouped by season for some analyses. Caution should be used to avoid calculation of an annual mean due to unequal number of samples collected at each location each month. Sample collection for some locations was only done during daylight hours.

Results

Dairy 1

Population distribution of the 3,000 head facility was 88.8% lactating cows, 9.7% dry cows, and 3.1% springing heifers (near parturition). Bedding was composted and dried manure from the separators may contain dried manure from the open lots as well as some almond shells. The VS concentration on an as-is basis was 60.5% ± 8.5%. Bedding VS per animal in pen was measured and calculated as 19.2 kg per animal. Bedding was replenished at inconsistent frequencies based on farm labor and equipment availability. At 10 day frequency this equates to 1.9 kg VS per animal. If animals are bedded more frequently, then the contribution of bedding increases.

Flush stream samples were collected monthly (except in February due to weather) and pond samples were collected quarterly throughout the project. Monthly sampling results are summarized for the entire project (Table 3.1 through 3. 4 and Figure 3.9). The interaction term sampling location*season was significant ($P<0.01$). Flush influent (Table 3.1) had the lowest VS concentration in summer months. Fall samples had the greatest variability with spring samples also variable. Winter and spring samples of flush influent (water reused from the dairy pond) were consistent within season. These were low VS concentrations. The VS concentration of Separator 1 influent (Table 3.2) followed a similar trend as the flush water with greatest variability in samples from fall and spring. Less variability of samples was present in summer and winter. The highest concentration of VS in samples was in winter. These were low VS concentrations. The VS concentration of Separator 2 effluent (Table 3.3) followed a similar trend as the flush water with greatest variability in samples from fall and spring. Less variability of samples was present in summer and winter. The highest concentration of VS in samples was in winter.

The coefficient of variation for Separator 1 influent and Separator 2 effluent was 25.3%. Gravity separation system effluent (inflow to pond) had the most variable VS concentrations with the highest values in winter and spring and a coefficient of variation at 27% ± 16.2. These results are provided (Figure 3.9).

Table 3.1 Dairy 1 summary of flush influent percent volatile solids (as-is basis) by season.

Parameter	Summer (Jun-Aug)	Fall (Sep-Nov)	Winter (Dec-Feb)	Spring (Mar-May)
Mean (%)	0.252	0.296	0.337	0.319
Standard dev.	0.020	0.153	0.006	0.050
Interquartile range (%)	0.032	0.127	0.005	0.059
n	19	15	6	14
Kruskal-Wallis chi-squared = 20.475, df = 3, p<0.001.				

Table 3.2 Dairy 1 summary of separator 1 influent percent volatile solids (as-is basis) by season.

Parameter	Summer (Jun-Aug)	Fall (Sep-Nov)	Winter (Dec-Feb)	Spring (Mar-May)
Mean (%)	0.609	0.583	0.749	0.658
Standard dev.	0.103	0.174	0.095	0.230
Interquartile range (%)	0.134	0.180	0.102	0.326
n	42	48	19	31
Kruskal-Wallis chi-squared = 18.305, df = 3, p<0.001.				

Table 3.3 Dairy 1 summary of gravity separation system influent (separator 2 effluent) percent volatile solids (as-is basis) by season.

Parameter	Summer (Jun-Aug)	Fall (Sep-Nov)	Winter (Dec-Feb)	Spring (Mar-May)
Mean (%)	0.425	0.511	0.624	0.558
Standard dev.	0.162	0.120	0.074	0.155
Interquartile range (%)	0.179	0.078	0.076	0.235
n	37	49	20	31
Kruskal-Wallis chi-squared = 21.955, df = 3, p<0.001.				

Table 3.4 Dairy 1 summary of gravity separation system effluent percent volatile solids (as-is basis) by season.				
Parameter	Summer (Jun-Aug)	Fall (Sep-Nov)	Winter (Dec-Feb)	Spring (Mar-May)
Mean (%)	0.327	0.490	0.574	0.537
Median	0.316	0.507	0.519	0.516
Standard dev.	0.163	0.101	0.144	0.066
Interquartile range (%)	0.347	0.083	0.186	0.066
n	17	9	8	7
Kruskal-Wallis chi-squared = 12.997, df = 3, p<0.005.				

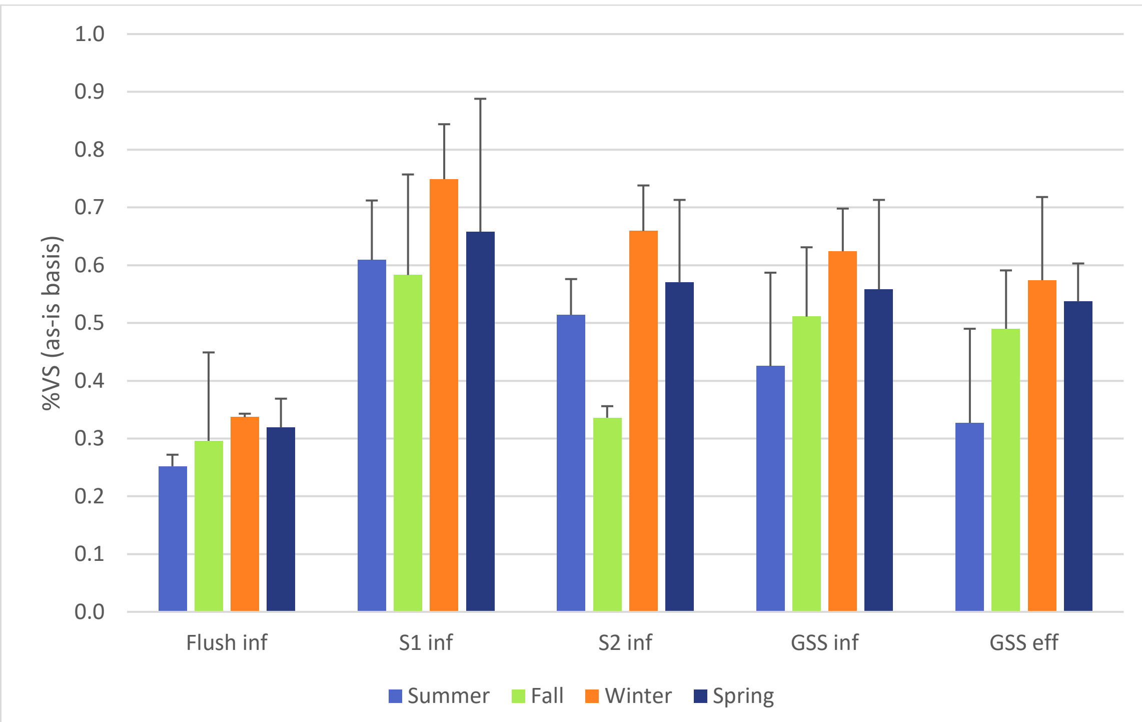

Figure 3.9 Dairy 1 Percent volatile solids (%VS) concentration (as-is basis) by sampling location and season.

The dairy pond was sampled quarterly. Five to six locations were sampled at 0.3 m below the surface and 1.5m increments from the surface of the pond. Pond pH values were between 6.8 and 7.6. Average pH values for each pond sampling outing were: July, 6.92; October, 7.18; January, 7.40; and April, 6.98. Oxidation reduction potential values varied: July, -300 ± 15; October, -269 ± 26; January, -322 ± 8; and April, -298 ± 14. Electrical conductivity results ranged from 3.78 mS to 5.38 mS. Analysis of VS data indicated sampling month*depth interaction was significant. Results are presented in Tables 3.5 through 3.8 (Figure 3.10) for percent VS by month and depth. Water just below the surface (0.3 m) had very low VS percent throughout the sampling year. The percent VS at 3 m in fall was abnormally low

0.898 (Table 3.6) compared with results from similar depths at other times during the year (3.200, summer; 3.762, spring). Insufficient water was in the pond in winter for a sample to be obtained.

Table 3.5 Dairy 1 summary of percent volatile solids (as-is basis) of July samples from all locations at a given depth in pond.					
	Surface (0.3 m)	1.5 m	3 m	4.5 m	Lowest
Mean (%)	0.252	0.252	3.200		3.490
Standard dev.	0.008	0.004	1.742		0.694
Interquartile range (%)	0.008	0.000	1.010		0.243
n	6	6	4		6
Min depth (m)					2.4
Max depth (m)					4.5
Kruskal-Wallis chi-squared = 16.566, df = 3, p<0.001.					

Table 3.6 Dairy 1 summary of percent volatile solids (as-is basis) of October samples by depth in pond.					
	Surface (0.3 m)	1.5 m	3 m	4.5 m	Lowest
Mean (%)	0.115	0.301	0.898		0.990
Standard dev.	0.008	0.272	0.354		0.321
Interquartile range (%)	0.007	0.320	0.130		0.330
n	6	7	5		6
Min depth (m)					3.8
Max depth (m)					4.5
Kruskal-Wallis chi-squared = 16.914, df = 3, p<0.001.					

Table 3.7 Dairy 1 summary of percent volatile solids (as-is basis) of January samples by depth in pond.					
	Surface (0.3 m)	1.5 m	3 m	4.5 m	Lowest
Mean (%)	0.752	2.868			3.617
Standard dev.	0.708	2.227			1.526
Interquartile range (%)	0.140	3.683			2.150
n	6	6			6
Min depth (m)					1.5
Max depth (m)					3.0
Kruskal-Wallis chi-squared = 5.3066, df = 2, p=0.07042.					

Table 3.8 Dairy 1 summary of percent volatile solids (as-is basis) of April samples by depth in pond.					
	Surface (0.3 m)	1.5 m	3 m	4.5 m	Lowest
Mean (%)	0.357	1.857	3.762	1.420	3.855
Standard dev.	0.031	1.706	1.929		0.758
Interquartile range (%)	0.040	2.930	1.130		1.614
n	6	7	5	1	6
Min depth (m)					2.7
Max depth (m)					5.2
Kruskal-Wallis chi-squared = 14.519, df = 4, p<0.01.					

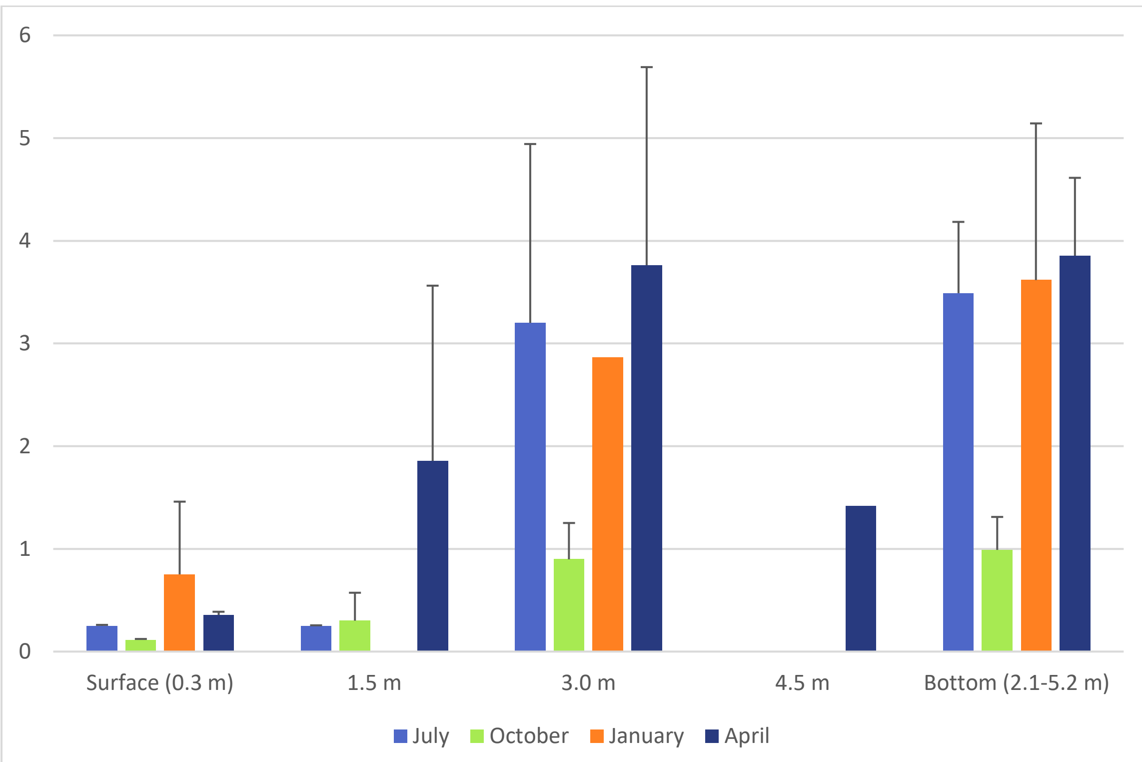

Figure 3.10 Dairy 1 Volatile solids concentration (as-is basis) by sampling depth and month.

Samples from at least two locations during quarterly pond sampling were split with one part submitted to a commercial laboratory for analyses of N constituents. Results are provided (Table 3.9). Both ammoniacal and organic fractions of N were highly variable within pond. The percent of N in the organic form varied as well. Consideration to animal management restrictions that result in greater manure collection during summer and winter may play a role in nutrient concentration. We did not observe fresh irrigation water entering the pond. Organic N is greatest in the bottom most samples. As a reminder, location 1 is taken nearest the inlet to the pond. Water flows from the gravity separation system. Sample 6 is taken nearest the outlet for either flushing or irrigation purposes. Ammoniacal N as a percent of total Kjeldahl N averaged 25.9% for bottom or near bottom samples and 65.9% for water further from the bottom.

Table 3.9 Dairy 1 ammonia (NH_3), total Kjeldahl (TKN) and organic (Org-N) nitrogen concentrations (mg/l) by month, sample site location[1] and depth. Each sample represents a single time, location, and depth (Figure 3.2).									
Month	Location	Depth (m)	NH_3 (mg/l)	TKN (mg/l)	Org-N (mg/l)	Temp (°C)	pH	EC (mS)	ORP
July	L1	0.3 (surface)	400	599	199	24.7	7.40	8.16	-291
		1.5	420	605	185	25.4	7.49	8.13	-283
		3.0	501	1200	699	26.0	7.36	8.34	-284
		4.5 m (bottom)	518	767	249	26.5	7.32	7.33	-282
	L4	2.4 m (bottom)	661	2440	1779	27.8	7.24	7.36	-307
	L6	0.3 (surface)	459	728	269	28.8	7.38	7.79	-308
		1.5	448	683	235	28.4	7.39	8.23	-310
		3.0 (bottom)	700	2760	2060	27.8	7.23	8.43	
October	L3	0.3 (surface)	235	314	79	18.8	7.38	4.64	
		1.5	319	375	56	18.5	7.36	2.84	-276
		3.0	120	1550	1430	20.6	7.10	4.18	-263
		4.1 (bottom)	465	1800	1335	19.7	7.11	4.28	-267
	L6	0.3 (surface)	160	302	142	20.7	7.36	4.36	-293
		1.5	302	353	51	19.8	7.36	4.87	-292
		3.0	344	1710	1366	20.3	7.20	4.69	-283
		4.1 (bottom)	106	4410	4304	20.3	7.21	4.75	-288
January	L3	0.3 (surface)	412	700	288	13.1	7.37	5.66	-326
		1.5	605	2460	1855	12.6	7.22	4.87	-318
		3.0 (bottom)	602	2620	2018	12.6	7.16		-316
	L6	0.3 (surface)	403	672	269	12.4	7.16	5.25	-335
		1.5	414	683	269	12.3	7.36	5.68	-330
		3.0 (bottom)	580	1760	1180	12.3	7.28	5.46	-334

Table 3.9 Dairy 1 ammonia (NH_3), total Kjeldahl (TKN) and organic (Org-N) nitrogen concentrations (mg/l) by month, sample site location[1] and depth. Each sample represents a single time, location, and depth (Figure 3.2).									
Month	Location	Depth (m)	NH_3 (mg/l)	TKN (mg/l)	Org-N (mg/l)	Temp (°C)	pH	EC (mS)	ORP
April	L2	0.3 (surface)	409	666	257	17.6	7.25	5.3	-316
		1.5	423	767	344	17.2	7.24	5.24	-319
		3.0	563	2490	1927	17.9	7.18	4.7	-312
		4.5 (bottom)	566	2120	1554	17.2	7.17	4.24	-314
	L4	0.3 (surface)	395	644	249	17.6	7.33	4.97	-332
		1.5	630	1230	600	17.9	7.14	4.64	-336
		1.5	832	2130	1298	18.4	7.15	4.74	-337
		3.0 (bottom)	624	3520	2896	17.1	7.19	4.03	-317

[1]See Figure 3.2
These samples are non-repeating, so summary statistics cannot be calculated.

Dairy 2

Population distribution of the 5,300 head was 41.5% lactating cattle, 8.2% dry cows and 50.3% replacement heifers. Manure solids removed from the gravity separation system and dry lots were dried and stockpiled (passive compost). Almond shells were regularly included in dried manure as a bedding extender. The VS concentration on an as-is basis was 57.0% ± 15.4%. Bedding was collected at alternate months. Two loads per pen were distributed weekly for each of 10 pens, one for each side of the freestall beds. Bedding VS per animal in pen was calculated as 5.9 kg VS per animal per day. Bedding was replenished weekly on Fridays unless there was an equipment malfunction.

Flush stream samples were collected monthly and pond samples were collected quarterly throughout the project. Monthly sampling results are summarized for the entire project (Tables 3.10 through 3.13 and Figure 3.11). The interaction term sampling location*season was significant ($P<0.01$). Flush lane influent (Table 3.10) had highest VS concentration in winter and spring months along with the greatest variability. The sizeable variability in these samples follows through the system. Summer and fall samples had the lowest VS concentrations.

Samples were not always accessible for gravity separation system effluent. At times when the gravity separation system had just had or was in the process of solids removal, there was insufficient water remaining in the system for water to gravity flow to the dairy pond resulting in missed samples. Sampling the northern cell of the gravity separation system required descending down the pond bank toward the outflow pipe. Safe sampling required use of a harness or rope when this cell was being filled and draining to the pond. If bank conditions were wet or pond water was too high, samples were not retrieved.

Feedline soakers and soakers in the milking parlor sprinkler pen were well utilized in summer, fall and spring. Gravity separation background influent samples represent water flowing to the gravity separation system when there is no active flush occurring (Table 3.11). Samples were not taken for this source in the first two quarters of sampling. This location was added after review of results. Unfortunately there was not always sufficient depth of water to take samples at this location when soakers were not used. The VS concentrations during flush events were greatest in winter and spring reflecting the higher VS concentration in influent water source used to flush lanes (Table 3.12).

Table 3.10 Dairy 2 summary of flush lane influent expressed as percent volatile solids (as-is basis) by season.

Parameter	Summer (Jun-Aug)	Fall (Sep-Nov)	Winter (Dec-Feb)	Spring (Mar-May)
Mean (%)	0.174	0.157	2.013	1.523
Standard dev.	0.138	0.016	1.129	1.275
Interquartile range (%)	0.068	0.013	1.657	2.192
n	18	6	6	14
Kruskal-Wallis chi-squared = 29.534, df = 3, p<0.001				

Table 3.11 Dairy 2 summary of gravity separation system background influent representing flow from milk parlor activities and feedline soakers expressed as percent volatile solids (as-is basis) by season.

Parameter	Summer (Jun-Aug)	Fall (Sep-Nov)	Winter (Dec-Feb)	Spring (Mar-May)
Mean (%)	0.481		0.461	1.143
Standard dev.	0.241		0.274	1.107
Interquartile range (%)	0.217		0.394	1.077
n	3	0	9	6
Kruskal-Wallis chi-squared = 1.7349, df = 2, p = 0.42				

Table 3.12 Dairy 2 summary of gravity separation system influent during flush events percent volatile solids (as-is basis) by season.				
Parameter	Summer (Jun-Aug)	Fall (Sep-Nov)	Winter (Dec-Feb)	Spring (Mar-May)
Mean (%)	0.762	0.872	1.471	1.887
Standard dev.	0.620	0.856	0.888	1.223
Interquartile range (%)	0.604	0.520	1.236	2.286
n	42	63	53	40
Kruskal-Wallis chi-squared = 35.198, df = 3, p<0.001				

Table 3.13 Dairy 2 summary of gravity separation system effluent percent volatile solids (as-is basis) by season.				
Parameter	Summer (Jun-Aug)	Fall (Sep-Nov)	Winter (Dec-Feb)	Spring (Mar-May)
Mean (%)	0.234	0.343	0.431	1.763
Standard dev.	0.024	0.059	0.155	1.623
Interquartile range (%)	0.023	0.046	0.234	2.241
n	3	7	12	10
Kruskal-Wallis chi-squared = 17.076, df = 3, p<0.001				

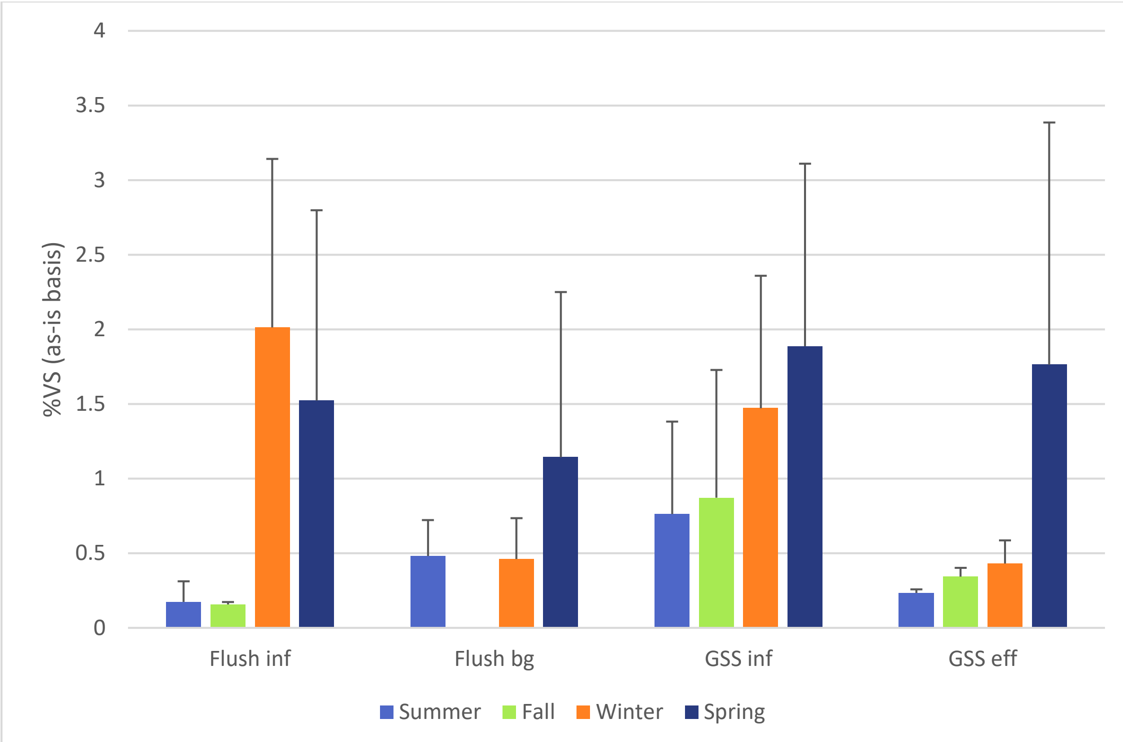

Figure 3.11 Dairy 2 percent volatile solids (%VS) as-is basis by sampling source and season. Flush influent (inf), flush background (bg), gravity separation system influent (GSS inf), and gravity separation system effluent (GSS eff).

Quarterly pond sampling occurred. Irrigation water is pumped into the pond at different intervals from late spring through early fall. This water enters closest to quarterly pond location 4. Pond pH values were between 7.1 and 7.6. Oxidation reduction potential values varied: July, -246 ± 57; October, -274 ± 15 January, -324 ± 25; April, -331 ± 13). Electrical conductivity results were: July, 5.0 ± 0.3 mS; October, 4.3 ± 0.4 mS; January, 5.2 ± 0.4 mS; and April, 4.7± 0.4 mS. Sampling month*depth interaction was significant. Results are presented for percent VS by month and depth (Tables 3.14 through 3.17). Water just below the surface (0.3 m) had very low VS percent throughout the sampling year. Surface samples taken at 0.3 m deep had lower VS than samples taken from deeper within pond.

Table 3.14 Dairy 2 summary of percent volatile solids (as-is basis) of July samples by depth in pond.

Parameter	Surface (0.3 m)	1.5 m	3 m	4.5 m	Lowest
Mean (%)	0.142	2.155	2.941	4.046	1.877
Standard dev.	0.014	1.520	1.247		1.352
Interquartile range (%)	0.018	2.223	1.876		1.352
N	4	5	4	1	4
Min depth (m)					3.8
Max depth (m)					6.7
Kruskal-Wallis chi-squared = 9.7175, df = 4, p<0.05					

Table 3.15 Dairy 2 summary of percent volatile solids (as-is basis) of October samples by depth in pond.					
Parameter	Surface (0.3 m)	1.5 m	3 m	4.5 m	Lowest
Mean (%)	0.156	4.002	2.385	1.260	5.352
Standard dev.	0.005	0.951	1.520		0.862
Interquartile range (%)	0.010	0.990	1.075		0.960
n	5	5	2	1	5
Min depth (m)					2.3
Max depth (m)					5.2
Kruskal-Wallis chi-squared = 14.549, df = 4, p<0.01					

Table 3.16 Dairy 2 summary of percent volatile solids (as-is basis) of January samples by depth in pond.					
Parameter	Surface (0.3 m)	1.5 m	3 m	4.5 m	Lowest
Mean	0.392	3.020	5.285	4.580	5.666
Standard dev.	0.088	0.416	0.686		3.125
Interquartile range	0.060	0.415	0.485		1.470
n	5	3	2	1	5
Min depth (m)					1.5
Max depth (m)					5.8
Kruskal-Wallis chi-squared = 7.7956, df = 4, p=0.09936					

Table 3.17 Dairy 2 summary of percent volatile solids (as-is basis) of April samples by depth in pond.					
Parameter	Surface (0.3 m)	1.5 m	3 m	4.5 m	Lowest
Mean	0.925	2.430	3.018	4.923	4.094
Standard dev.	0.534	0.183	0.405	1.532	1.805
Interquartile range	0.800	0.070	0.070	1.365	1.680
n	6	5	5	3	5
Min depth (m)					1.1
Max depth (m)					6.1
Kruskal-Wallis chi-squared = 18.389, df = 4, p<0.005					

Select pond samples from each sampling day were split with one-half of the sample analyzed at a commercial laboratory for ammonia N, total Kjeldahl N (Table 3.18). Organic N was calculated by difference. Small numbers of samples and herd variations yield no definitive trends in these samples. Each sample location analyzed had at least one sample that was much higher or much lower than the remainder of the samples. Ammoniacal N ranged from 11% of TKN (a location at 1.5 m below surface) to 70.1% (0.30 m below the surface).

Table 3.18 Dairy 2 ammonia (NH_3), total Kjeldahl (TKN) and organic (Org-N) nitrogen concentrations (mg/l) by month, sample site location[1] and depth. Each sample represents a single time, location, and depth (Figure 3.4).									
Month	Location	Depth (m)	NH_3	TKN	Org-N	Temp (°C)	pH	EC (uS)	ORP
July	L1	0.3 (surface)	160	336	176	25.9	6.90	5.35	-259
		1.5	185	1140	955	25.8	6.87	5.14	-288
		3.0	384	2340	1956	26.2	6.93	4.91	-285
		4.6	322	1010	688	25.5	6.90	4.94	-270
	L4	0.3 (surface)	246	347	101	26.2	6.92	4.63	-187
		1.5	302	739	434	26.1	6.95	4.74	-244
		3.0	146	224	78	27.0	6.81	5.13	-300
		4.6 (bottom)	132	218	86	26.4	6.86	4.87	-306
October	L2	0.3 (surface)	216	347	131	18.5	7.28	3.84	-276
		1.5	213	1340	1127	19.4	7.17	4.55	-283
		3.0	204	1340	1136	20.2	7.11	3.92	-284
		4.0 (bottom)	230	1620	1390	20.5	7.13	3.02	-278
January	L2	0.3 (surface)	428	655	227	12.3	7.40	5.58	-322
		1.5	510	1960	1450	12.4	7.40	4.56	-345
	L3	0.3 (surface)	437	689	252	13.0	7.49	5.32	-342
		1.5	487	1410	923	12.5	7.35	4.66	-273
	L5	1.5	384	3430	3046	14.3	7.39		-366
April	L1	0.3 (surface)	414	1230	816	18.5	6.91	4.49	-313
		1.5	454	1660	1206	18.5	6.97	4.57	-321

Table 3.18 Dairy 2 ammonia (NH_3), total Kjeldahl (TKN) and organic (Org-N) nitrogen concentrations (mg/l) by month, sample site location[1] and depth. Each sample represents a single time, location, and depth (Figure 3.4).									
Month	Location	Depth (m)	NH_3	TKN	Org-N	Temp (°C)	pH	EC (uS)	ORP
		3.0	456	1620	1164	18.5	6.91	4.88	-331
		4.6 (bottom)	440	1470	1030	18.5	6.93	4.45	-328
	L5	0.3 (surface)	426	1510	1084	19.8	6.93	4.81	-346
		1.5	448	1800	1352			5.53	-302
		3.0	454	2320	1866	19.1	6.94	5.04	-313

[1] See Figure 3.4

The samples are non-repeating, so summary statistics cannot be calculated.

Dairy 3

The dairy herd population of 3,600 cattle consists of 47.9% lactating cows, 7.6% dry cows and 44.5% replacement heifers. Manure on concrete adjacent to lactating cow feed bunks is collected via flush, scrape with tractor, or vacuumed with tractor. The flushed lane is flushed manually and requires an individual to open a valve and turn on the pump in the dairy pond. During summer irrigation season, fresh irrigation water may be used to flush lane. Flushing may occur at any time during the day. Flushed water accumulated in a sump that also collects water from the milking parlor. This combined water is pumped to the gravity separation system.

Two pens of lactating cows and one pen of heifers make a line of cattle where the concrete adjacent to the feed bunk is vacuumed Monday and Wednesday around 8 am and Friday around 4:30 am. This material is either deposited in the gravity separation system or is stockpiled. All other concrete surfaces adjacent to feed bunks are scraped as needed. Open lots are groomed daily. Manure is mounded for cattle resting. When manure becomes too wet, it is removed from open lots for drying. Fresh dried manure (from a large stockpiled source) is brought into pens for mounds. Solids are removed from the gravity separation system as needed (5 to 8 week intervals) by farm labor and equipment. These solids are dried in a large drying area in summer and stockpiled in winter until drying is appropriate. Once manure is dried, solids are pushed up into windrows. Windrows may or may not be turned with a tractor depending on staff and equipment availability. Some solid manure is manifested offsite. Other solid manure is retained for open lot bedding. These areas are a distance from the concrete area. Negligible amounts of bedding (if any) would enter the liquid stream. After rain events occur, care is taken to vacuum concrete adjacent to feed bunks. Manure solids removed from the gravity separation system and open lots are dried and stockpiled (passive compost). Bedding was not analyzed on this facility as it was not entering the liquid stream.

Liquid stream samples were collected monthly and pond samples were collected quarterly throughout the project. Monthly sampling results are summarized for the entire project (Table 3.19 through 3.21

and Figure 3.12). The interaction term sampling location*season was not significant (P=.173). Flush lane influent samples were challenging to collect (Table 3.19) due to irregularity of flushing. Prior to flushing, a small tractor was used to scrape manure from the curb between the feed area and the open lot into the flush lane. The high variability in summer samples is a function of fresh irrigation water being used for flushing on one day and dairy pond water used at another event.

Water collected in the sump near the milking parlor (milking parlor water as well as flush water when it occurs) is pumped to the gravity separation system. Sampling of water entering the gravity separation system was done by inserting a sample bottle onto an adapted pole and lowering it in front of the liquid stream flow. Duration of pumping may be less than 10 minutes or more than 25 minutes. Longer inflow times are associated with sprinkler pen run times in conjunction with lane flush times. At the beginning of sampling it is not known which type of flush occurs. Multiple inflow events are sampled. The goal is to obtain three to five samples per event. Results are in Table 3.20. It is unclear why there is such high variability in gravity separation system influent VS concentration. No differences in TOC were observed (Table 2.3). Increased use of soakers in the milking parlor sprinkler pen during spring, summer and fall would decrease VS concentration. Increased evaporation may offset the additional use of water. It is likely that lower VS samples (fewer samples) did not include scraping of lactating cow feed apron during sampling events. These results show the wide shifts in VS concentrations in influent to the gravity separation system as well as the high variability in sample results.

Outflow from the gravity separation system enters either the small pond or the large pond depending on how flow pipes are turned. At either location, the sample bottle and pole are used again to retrieve three to five samples. At times when the gravity separation system had just had or was in the process of solids removal, there was insufficient water remaining in the system for water to gravity flow to either pond, resulting in missed samples. Effluent from the gravity separation system had the lowest and most consistent VS concentration in summer (Table 3.21). Note, vacuumed material is also deposited in the gravity separation system during part of the year (including summer). This is not manure included in the gravity separation influent as that water is from the milking parlor or flushing the one lane that is flushed. Also, there are concrete sumps that collect runoff from animal housing and concrete lanes. During summer these areas can accumulate runoff water from cow soakers associated with the pens of lactating cattle, dry cows, and bred heifers. A summary of these tables is provided graphically (Figure 3.12).

Transfer of water from pond 1 to pond 2 could only occur when pond 1 had sufficient water to gravity flow through the transfer pipe and the gravity separation system was flowing to pond 1. Data are summarized (Table 3.22). The VS concentrations are very low (less than 0.3%). There was minimal variability in these results within a sampling day. Vacuumed manure (Monday, Wednesday and Friday) was sampled by load. Reported in Tables 3.23 and 3.24 are results for load 1 and load 2 collected each day. On Mondays a third load may be collected. Full loads held 15,141 l (4,000 gallons). An indicator on the tanker showed tanker fullness. Loads 1 and 2 were full loads. Manure with VS concentration between 8.5 and 12.0% is wet and looks similar to a lava flow. Removal of solids from the gravity separation system was sampled. The percent VS was 11.3 ± .4 (as-is basis).

Table 3.19 Dairy 3 summary of flush influent percent volatile solids (as-is basis) by season.				
Parameter	Summer Jul-Sep	Fall Oct-Dec	Winter Jan-Mar	Spring Apr-Jun
Mean (%)	0.183	0.124		0.203
Standard dev.	0.107			0.011
Interquartile range (%)	0.148			0.021
N	7	1	0	5
Kruskal-Wallis chi-squared = 1.394, df = 2, p = 0.4981				

Table 3.20 Dairy 3 summary of gravity separation system influent percent volatile solids (as-is basis) by season.				
Parameter	Summer Jul-Sep	Fall Oct-Dec	Winter Jan-Mar	Spring Apr-Jun
Mean (%)	1.242	0.486	0.455	1.189
Standard dev.	0.686	0.176	0.284	1.049
Interquartile range (%)	0.918	0.231	0.193	1.091
N	30	12	9	33
Kruskal-Wallis chi-squared = 17.435, df = 3, p<0.001				

Table 3.21 Dairy 3 summary of gravity separation system effluent percent volatile solids (as-is basis) by season.				
Parameter	Summer Jul-Sep	Fall Oct-Dec	Winter Jan-Mar	Spring Apr-Jun
Mean (%)	0.199	0.276	0.280	0.282
Standard dev.	0.014	0.033	0.041	0.111
Interquartile range (%)	0.014	0.053	0.056	0.027
N	14	5	7	11
Kruskal-Wallis chi-squared = 26.094, df = 3, p<0.001				

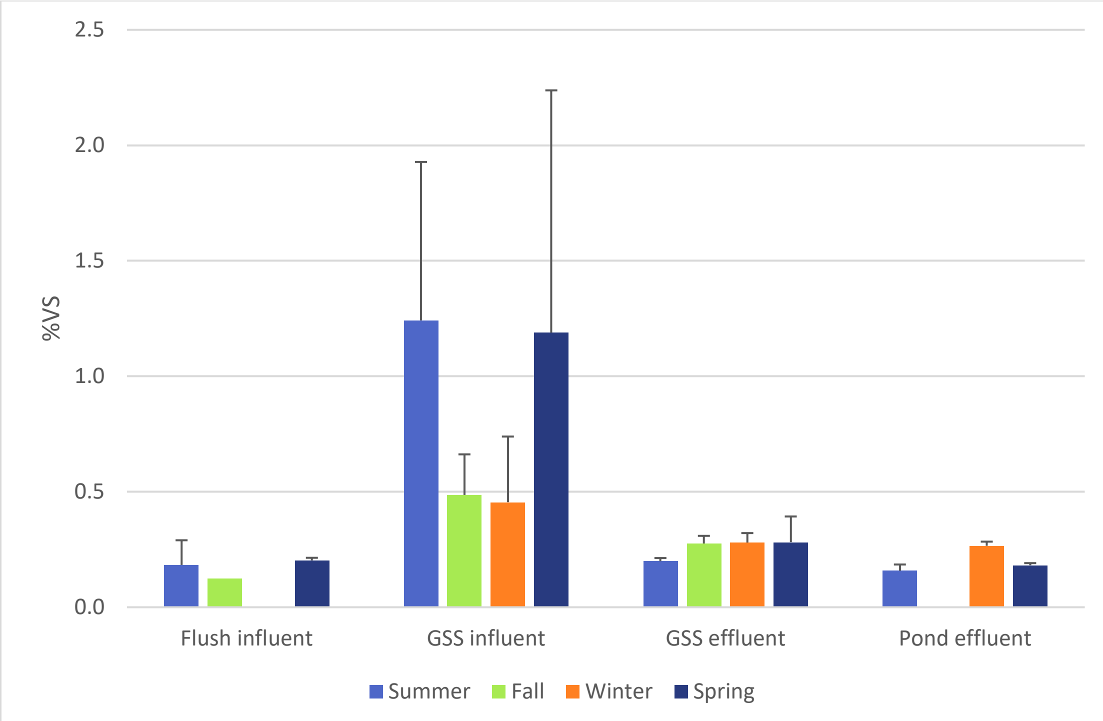

Figure 3.12 Dairy 3 percent volatile solids (%VS) as-is basis by sampling source and season. Seasons are: summer (June through August); fall (September through November), winter (December through February), spring (March through May).

Table 3.22 Dairy 3 summary of pond effluent transfer from pond 1 to pond 2 percent volatile solids (as-is basis) by season.				
	Summer Jul-Sep	Fall Oct-Dec	Winter Jan-Mar	Spring Apr-Jun
Mean (%)	0.158		0.266	0.182
Standard dev.	0.027		0.018	0.009
Interquartile range (%)	0.015		0.016	0.008
n	4	0	3	3
Kruskal-Wallis chi-squared = 6.3, df = 2, p<0.05				

Table 3.23 Dairy 3 vacuum slurry percent volatile solids (as-is basis) for load 1 sampled at each event.				
Parameter	Summer Jul-Sep	Fall Oct-Dec	Winter Jan-Mar	Spring Apr-Jun
Mean (%)	8.889	10.466	11.102	10.544
Standard dev.	0.235	1.542	0.848	2.348
Interquartile range (%)	0.357	2.556	1.282	4.737
n	8	20	15	21
Kruskal-Wallis chi-squared = 13.37, df = 3, p<0.005				

Table 3.24 Dairy 3 vacuum slurry percent volatile solids (as-is basis) for load 2 sampled at each event.				
	Summer Jul-Sep	Fall Oct-Dec	Winter Jan-Mar	Spring Apr-Jun
Mean (%)	8.409	8.993	11.581	7.992
Standard dev.	1.215	1.311	0.774	0.467
Interquartile range (%)	1.000	1.274	0.898	0.499
n	10	29	26	15
Kruskal-Wallis chi-squared = 53.903, df = 3, p<0.001				

Quarterly pond sampling occurred (Tables 3.25 through 3.28). Pond pH values were between 6.8 and 7.6. Oxidation reduction potential values varied: July, -262 ± 30; October, -200 ± 12 January, -295 ± 34; April, -321 ± 12). Electrical conductivity results were: July, 3.5 ± 0.2 mS; October, 1.7 ± 0.5 mS; January, 6.7 ± 0.5 mS; and April, 2.9 ± 0.1 mS. No interaction terms were significant. The %VS by depth was 0.415 ± .162, 0.355 ± .163, 2.510 ± 2.631 and 2.913 ± 3.296 for the 0.3, 1.5, 3.0 m sample depth and the bottom.

Table 3.25 Dairy 3 summary of percent volatile solids (as-is basis) of July samples by depth in pond.				
Parameter	Surface (0.3 m)	1.5 m	3 m	Lowest
Mean (%)	0.128	0.131	1.959	2.813
Standard dev.	0.011	0.013	1.997	1.583
Interquartile range (%)	0.013	0.018	2.880	2.142
n	7	7	4	7
Min depth (m)				2.7
Max depth (m)				4.5
Kruskal-Wallis chi-squared = 12.081, df = 3, p<0.01				

Table 3.26 Dairy 3 summary of percent volatile solids (as-is basis) of October samples by depth in pond.				
Parameter	Surface (0.3 m)	1.5 m	3 m	Lowest
Mean (%)	1.183			4.213
Standard dev.	1.851			0.477
Interquartile range (%)	1.775			0.409
n	7			7
Min depth (m)				1.5
Max depth (m)				1.5
Kruskal-Wallis chi-squared = 6.8612, df = 1, p<0.01				

Table 3.27 Dairy 3 summary of percent volatile solids (as-is basis) of January samples by depth in pond.				
Parameter	Surface (0.3 m)	1.5 m	3 m	Lowest
Mean (%)	0.180	0.430	2.840	2.247
Standard dev.	0.012	0.453	0.664	0.894
Interquartile range (%)	0.008	0.408	0.639	1.12
n	7	7	3	7
Min depth (m)				2.9
Max depth (m)				4.0
Kruskal-Wallis chi-squared = 16.85, df = 3, $p<0.001$				

Table 3.28 Dairy 3 summary of percent volatile solids (as-is basis) of April samples by depth in pond.				
Parameter	Surface (0.3 m)	1.5 m	3 m	Lowest
Mean (%)	0.169	0.502	3.117	2.380
Standard dev.	0.010	0.867	0.771	0.816
Interquartile range (%)	0.011	0.029	0.545	1.194
n	7	7	2	7
Min depth (m)				1.9
Max depth (m)				3.5
Kruskal-Wallis chi-squared = 14.648, df = 3, $p<0.01$				

Select pond samples from each sampling day were split with one-half of the sample analyzed at a commercial laboratory for ammonia N and total Kjeldahl N (Table 3.29). Organic N was calculated by difference. No definitive trends occur in these samples. Results for two samples had higher ammoniacal N than total Kjeldahl N. Samples are not always easy to aliquot during lab analysis. Each sample location analyzed had at least one sample that was much higher or much lower than the remainder of the samples. Few samples had ammoniacal N concentrations greater than 300 mg/l. No pattern was present for percent of total Kjeldahl N in the ammoniacal form.

Table 3.29 Dairy 3 ammonia (NH_3), total Kjeldahl (TKN) and organic (Org-N) nitrogen concentrations (mg/l) by month, sample site location[1] and depth. Each sample represents a single time, location, and depth (Figure 3.6).									
Month	Location	Depth (m)	NH_3	TKN	Org-N	Temp (°C)	pH	EC (uS)	ORP
July	L2	0.3 (surface)	582	1420	838	29.1	7.30	3.40	-276
		1.5	428	1850	1422	27.9	7.19	3.52	-279
		3.0 (bottom)	314	1010	696	28.6	7.17	3.27	-267
	L5	0.3 (surface)	157	196	39	27.3	7.59	3.55	-271
		1.5	160	162	2	28.2	7.72	3.42	-257
		3.0	280	414	134	27.2	7.45	3.61	-268
		3.0 (bottom)	504	806	302	26.9	7.49	3.54	-291
October	L1	0.3 (surface)	263	2310	2047	21.7	7.07	2.59	-205
		1.5 (bottom)	216	2450	2234	20.4	7.01	2.01	-204
	L3	0.3 (surface)	53.2	112	58.8	22.8	7.09	0.76	-189
		1.5 (bottom)	137	2590	2453	22.0	6.90		-182
	L6	0.3 (surface)	56	140	84	22.2	7.08	1.45	-206
		1.5 (bottom)	182	2140	1958	21.1	6.98		-211
January	L2	0.3 (surface)	154	280	126	14.4	7.21	3.80	-329
		1.5	185	767	582	14.3	7.16	3.80	-291
		3.5 (bottom)	224	1970	1746	14.9	7.02	3.59	-328
	L7	0.3 (surface)	154	258	104	12.8	7.48	2.94	-316
		1.5	160	252	92	12.4	7.51	3.03	-292
		3.0	227	157	?	12.2	7.31	3.01	-323

Table 3.29 Dairy 3 ammonia (NH_3), total Kjeldahl (TKN) and organic (Org-N) nitrogen concentrations (mg/l) by month, sample site location[1] and depth. Each sample represents a single time, location, and depth (Figure 3.6).									
Month	Location	Depth (m)	NH_3	TKN	Org-N	Temp (°C)	pH	EC (uS)	ORP
April	L2	0.3 (surface)	160	246	86	20.9	6.90	2.73	-324
		1.5	207	1670	1463	21.5	6.80	2.80	-331
		3.0	216	1690	1474	21.8	6.80	2.87	-331
		3.5 (bottom)	227	2080	1853	21.7	6.80	2.93	-337
	L5	0.3 (surface)	288	241	?	22.2	7.10	2.76	-313
		1.5	146	235	89	20.8	7.10	2.92	-331
		2.3 (bottom)	204	2250	2046	20.9	6.80	2.78	-329

[1] See Figure 3.6

The samples are non-repeating, so summary statistics cannot be calculated.

Dairy 4

The dairy herd population of 2,750 consists of 46.6% lactating cows, 6.7% dry cows, and 46.7% replacement heifers. Parlor water is the water source for flushing. There is no scheduled time for flushing to occur. When the pond is filled to the bottom of the pond inlet pipes sampling did not occur. There was no significant interaction for source by season percent VS. Main effects were significant and are presented in Tables 3.30 and 3.31. Large deviations in the results are a function of how the system is managed. During warmer weather, soakers are used in the parlor sprinkler pen and at the feedline. Feedline water and water from the parlor floor wash keep a constant flow of water on the east lane removing some amount of VS. The west feed lane also has feedline soakers with no parlor water added unless a flush is occurring. Samples were taken sequentially across the flush inlet pipes while water flowed. More samples were taken from east and west lactating cow lanes than the heifer lane due to the flow of water and how long it took to reach the pond. Flush occurrences on this facility do not fully clean flush lanes. The heifer lane is scraped at unknown intervals and solids are deposited into the open lot. Visual evaluation of solids on the heifer lane before and after a flush indicate that most solids remain on concrete and are ultimately scraped into open lot pens.

Table 3.30 Dairy 4 pond influent by season from all sources percent volatile solids (as-is basis).				
Parameter	Summer (Jun-Aug)	Fall (Sep-Nov)	Winter (Dec-Feb)	Spring (Mar-May)
Mean (%)	0.824	1.386	1.478	1.705
Standard dev.	0.924	1.234	1.022	1.208
Interquartile range (%)	0.530	1.095	1.210	2.007
n	63	84	41	44
Kruskal-Wallis chi-squared = 32.751, df = 3, p<0.001				

Table 3.31 Dairy 4 pond influent by location from all seasons percent volatile solids (as-is basis).			
	East Cow Pen	West cow Pen	Heifer Pen
Mean (%)	1.160	1.870	1.163
Standard dev.	1.005	1.225	1.141
Interquartile range (%)	0.078	1.020	2.005
n	78	60	84
Kruskal-Wallis chi-squared = 38.338, df = 3, p<0.001			

Quarterly pond sampling occurred. During summer irrigation season, the dairy pond served as temporary storage for irrigation water. The July sampling event was an excellent example of how this affects sampling. The pond surface rose more than 2.25 m overnight. This pond was unusual as it had duckweed present at all sampling events. Sampling at location 4 did not always occur due to heavy solids on the surface of the pond. The irrigation pump was located near sampling location 4. No water is used from this pond for flushing. Water entering the pond only exits when the irrigation pump is turned on or if a portable pump is brought in.

Pond pH values were between 6.4 and 7.1 (July, 6.6 ± .1; October, 6.7 ± .1; January, 7.1 ± .1 and April, 6.6 ± .2). Oxidation reduction potential values varied: July, -85 ± 89; October, -195 ± 15, January; -306 ± 22; April, -315 ± 9). Positive values were measured for some samples in July (after irrigation water was added to the pond). Electrical conductivity results were: July, 1.2 ± 0.2 mS; October, 2.3 ± 0.2 mS; January, 5.2 ± 0.4 mS; and April, 3.4 ± 0.2 mS. The large differences in conductivity are believed to be a function of dilution of pond with irrigation water.

Solids in the pond settled at the far end of the pond (sites 3 and 4). Fresh irrigation water entered the pond from under the pond surface near site 1. Higher %VS in samples were present in sites 3 (1.389 ± .842) and 4 (1.596 ± 1.302) (p=.065) than sites 1 (0.384 ± .205) and 2 (0.473 ± .279). Distinct differences existed by depth (Table 3.32) with surface and 0.3 m having less %VS than samples taken at greater depths.

Table 3.32 Dairy 4 summary of pond samples by depth expressed as percent volatile solids (as-is basis).						
	Surface (0.3 m)	1.5 m	3.0 m	4.5 m	6.1 m	7.6 m
Mean	0.484	0.451	0.837	1.671	1.747	3.048
Standard dev.	1.018	0.852	1.053	1.583	1.404	0.615
Interquartile range	0.196	0.214	1.115	2.203	2.165	0.435
n	14	14	12	6	5	2
Kruskal-Wallis chi-squared = 15.714, df = 6, p-value = 0.01538						

Select pond samples from each sampling day were split with one-half of the sample analyzed at a commercial laboratory for ammonia N and total Kjeldahl N (Table 3.33). Organic N was calculated by difference. No definitive trends occur in these samples. July and October samples had the lowest ammoniacal N (< 155 mg/l). January and April samples were similar (244 mg/l ± 19). The ammoniacal N as a percent of total Kjeldahl N was relatively low. This likely was a result of irrigation water infusion serving to dilute soluble ions during summer.

Table 3.33 Dairy 4 ammonia (NH_3), total Kjeldahl (TKN) and organic (Org-N) nitrogen concentrations (mg/l) by month, sample site location[1] and depth. Each sample represents a single time, location, and depth (Figure 3.8).									
Month	Location	Depth (m)	NH_3	TKN	Org-N	Temp (°C)	pH	EC (uS)	ORP
July	L1	0.3 (surface)	25.2	33.6	8.4	24.4	6.59	0.89	48
		1.5	22.4	39.2	16.8	24.4	6.67	0.89	28
		3.0	19.6	33.6	14	24.5	6.58	0.89	53
		4.3 (bottom)	39.2	378	338.8	24.4	6.45	0.85	18
	L4	0.3 (surface)	42	112	70	26.6	6.48	1.39	-161
		1.5	39.2	78.4	39.2	26.2	6.44	1.37	-169
		3.0	42	84	42	26.5		1.38	-171
		4.6	86.8	706	619.2	26.7	6.41	1.60	-199
October	L1	0.3 (surface)	146	246	100	17.9	6.74	2.40	-168
		1.5	146	174	28	17.4	6.75	2.41	-180
	L3	1.5	129	140	11	18.2	6.75	2.27	-204
		3.0	151	1020	869	18.8	6.67	1.90	-205
		4.6 (bottom)	151	342	191	18.3	6.69	1.96	
January	L1	0.3 (surface)	244	386	142	14.7	7.01	5.29	-265
		1.5	241	370	129	13.3	7.04	5.33	-289
		3.0	252	454	202	12.5	7.07	5.29	-275
		3.8 (bottom)	291	756	465	12.4	7.08	5.44	-311
	L2	0.3 (surface)	252	1620	1368	12.6	7.09	5.41	-266
		1.5	246	1990	1744	12.3	7.06	5.47	-310
April	L1	0.3 (surface)	230	504	274	20.9	6.86	3.67	-320
		1.5	232	302	70	20.5	6.81	3.61	-311
		3.0	252	1360	1108	18.2	6.82	3.59	-327
		4.6	230	498	268	19.7	6.60	3.70	-320
		6.1 (bottom)	249	437	188	18.7	6.60	3.15	-313
	L3	3.0	246	420	174	18.8	6.50	3.58	-318
		4.6	207	2880	2673	18.3	6.50	3.20	-325

[1] See Figure 3.8

The samples are non-repeating, so summary statistics cannot be calculated.

Discussion

The hours of time spent at each facility monthly were critical to more fully appreciate animal and manure management impacts on manure flow. During this project, many new challenges were realized. Although most were worked through there were two that remained unresolved. One related to determining the effectiveness of the mechanical separation system at Dairy 1. Although not a goal of this project, it would have been nice to accomplish this task. Struvite formation in the pipe leading from the processing pit to the mechanical separator altered the flow of water. Sufficient struvite existed to prevent use of a Doppler meter to measure flow rate of water entering the separator. This reinforced the need to actually measure flow and not rely on a pump manufacturer's estimate of flow rate. Such an estimate assumes good operating conditions. An assumption that may be in error. In this situation, the vertical distance between where the pump inlet was and the top of the separator was well over 13 m. Use of a flow meter to measure water would allow one to differentiate flow differences in the processing pit when it is full and when it is near empty. In addition it would be important to measure and sample solids removed over a given time period. Given the variability associated with bedding animals (from composition of bedding to frequency of bedding) analyses of separator efficacy should be done with full knowledge of when and how much bedding was delivered to freestall beds.

The use of dairy pond water to flush lanes likely helps to neutralize the alkaline pH of freshly excreted manure. As pH is lowered, less NH_3 is likely emitted and conditions are more favorable to methanogens.

The end fate of inclusion of organic matter (almond shells) as bedding material is uncertain. The extent that almond shells are used at dairies is unknown. Given the increasing scale of the almond industry this is likely a sizeable volume of organic matter.

Analysis of quarterly pond sampling data requires considerable thought. The pond depth is not consistent year round and for some ponds there are inconsistencies either due to how the pond was designed or sludge accumulation. Bomb sampling equipment is quite useful for fluids and not reliable when large particles exist (interferes with top of plunger closing) or too many solids are present (does not adequately fill chamber). Evaluation of data requires that a 1.5 m sample collected in one month may be the upper 25% of water and at a different sampling may be near the bottom. These results are informative to provide a better understanding of the chemical and physical composition of ponds at different depths and locations. Ideal conditions for methanogenesis is for oxidation reduction potential values to be <-350 and pH near 7.

Detailed analyses of pond VS concentration reinforced the need to do due diligence when evaluating effectiveness of alternative manure management practices. The VS in ponds prior to implementing new practices are stored carbon. Any direct measurements of CH_4 emissions will need to account for this carbon source and its variability.

One of the key challenges in working with liquid manure streams is having sufficient quality assurance and quality control. Although care was taken to send split samples to the commercial laboratory for analysis it is not always apparent that the results are from the same sample. Two sample analyses returned ammoniacal N values greater than total Kjeldahl N. This is not biologically possible. This may be a function of the difficulty associated with analyzing small volumes of non-homogeneous samples. Replicated samples did not always return with similar results. This may be a function of not adequately splitting the sample or may be error associated with the difficulties of handling the sample in the laboratory. This variability requires greater sampling detail and analysis of individual samples. Analysis of composite samples instead of individual samples masks actual system complexity.

Large variations existed in flush stream VS concentration. This makes both taking just a few samples futile for analytical purposes and makes one ponder about modelling efforts that do not use an upper and lower range when modelling VS flow on dairies. Exact values do not occur. Tremendous variation in herd management and facility design are responsible for variation between facilities. Facility design and manure collection methods are key players in exacerbating VS flow.

Specific lessons learned at individual dairies that may be useful across the California dairy sector.

Dairy 1

Bedding use at Dairy 1 was within the range reported by Arndt et al., (2018). Flush stream VS concentrations were low. Variabilities in fall and spring samples were attributed to a reduced volume of water in the pond during late fall sampling due to irrigation of the winter crop. Spring variability was likely associated with increased pond activity and decreased volume after irrigations occurred for summer crop. Use of pond water to partially meet crop nutrient needs results in increased VS concentration in flush water. These values are very minor changes in VS concentrations. The water flowing over Separator 1 contains flush water, parlor water, and manure and bedding from animal lanes. During spring, summer and fall, feedline soakers automatically turn on and soakers are used in the milking parlor holding area for cow cooling. Animals had restricted or no access to open lots during wet or foggy weather conditions while open lots were damp. Animals had restricted or no access to open lots during hot temperatures. If temperatures dropped at night on hot days, animals were given access to open lots. As reported above, a key lesson learned related to any assumptions in sampling that require fully open pipes.

Since the flush water originated from the dairy pond, it added fine solids to the waste stream. A processing pit that serves to return flush water collected to flush additional lanes before the water goes to the pond should have higher VS concentration and likely higher pH. The pH of reused water is less than the pH of fresh manure.

Dairy 2

Bedding used was much greater than that reported by Arndt et al., (2018) and greater than 2.9 kg VS (11.0 kg total solids) per animal per day reported previously from California work (Meyer et al., 2004). This is likely a result of fastidious attention to freestall bed conditions. The pond had areas of higher solids making it difficult to maneuver across. Sampling in relatively thick sludge like material is challenging. Fresh irrigation water contribution during July and August and water from animal soakers are in part responsible for lower VS concentration and greater variability in VS concentration in July samples. The pond was biologically very active in April with eruptions occurring while samples were collected. This mixing of pond contents may be responsible for the low variability associated with depth samples collected in April.

Dairy 3

Vacuumed material does not stack. Also, it would not be feasible to vacuum concrete without the added benefit of animal soakers in summer to keep material sufficiently wet to be moved and collected with the vacuum. Manure must have sufficient moisture for the vacuum to function appropriately. Vacuuming only occurred on lanes associated with feed bunks. Manure in cattle transfer lanes (to get to and from the milking barn) and manure deposited at the milking barn would not be collected with the vacuum. This is an important consideration when evaluating efficacy of vacuum systems as an alternative manure management practice. Having sufficient land area devoted to drying vacuumed manure in summer is advantageous. Also it is critical to have a winter management plan for this stream.

Dairy 4

Inclusion of irrigation water visibly modified pond composition. This practice is used on dairies. The frequency of use is unknown. Diluting water will likely impact methanogenisis. It is unknown how many dairies collect and use generated parlor water to flush animal lanes and not water from the dairy pond.

Conclusions

Animal and manure management choices at dairies impact liquid stream VS flow and removal of solids from this stream. Gravity separation systems may be managed with frequent solids removal (4 to 6 week residence time) or infrequent solids removal (greater than 6 months residence time). It is important to differentiate frequency of removal prior to assigning a methane formation potential value. Considerable variability exists in VS flow through liquid streams within dairies. Any modelling of VS flow must consider this variability and use a range of values, not a single value. Detailed analysis of liquid streams on dairies indicated variability within herd sampling events and over time. Housing design and animal management are responsible for large differences in manure potentially collected in a liquid stream (percent of time on concrete). For permitted lactating cattle in the San Joaquin Valley c. 54% of manure would enter the liquid stream (anaerobic lagoon or liquid/slurry storage). The remaining c. 46% would be deposited in open lots and remain in solid storage. This does not account for solids removed from liquid streams. Modelling efforts to estimate VS reduction due to implementation of different (alternative) manure management practices need to consider the variability associated with these systems. Determining efficacy of manure management practices needs to fully measure actual VS removed under field conditions. This requires complete understanding of the operation of the facility and how management of animals may modify results.

Recommendations

Analysis of frequency of clean out of gravity separation systems with respect to reducing methane formation is needed. This should include an evaluation of the end fate of the solids. The true net benefit of reducing methane forming potential by separating manure solids and then reinserting these solids into the liquid stream as bedding should be evaluated. A detailed analysis of end fate of almond shell use as bedding is important. Resolving these unknown gaps in knowledge will inform staff responsible for inventory estimates and refinement of calculators used for AMMP and DDRDP. Manure collected via vacuum is likely restricted to housing area concrete (not transfer lanes or milk parlor area). The AMMP calculator should be modified to reflect this practice.

Project Summary and Conclusions

This project evaluated existing San Joaquin Air Pollution Control dairy permit data to identify dairy demographics in the San Joaquin Valley: facilities and animals housed in non-freestall versus freestall facilities. Mechanical or gravity solid liquid separation may occur prior to entering the liquid storage system. Results provide dairy herd demographic information useful to CARB staff responsible for refining GHG emissions inventory.

A comprehensive survey and analysis of freestall and non-freestall (open lot) facilities to quantify TS, VS and nitrogen N flows from excretion through storage used existing information on dietary composition and digestibility, dairy housing design, and facility manure flow. A two-pronged field campaign occurred on four cooperating San Joaquin Valley dairy farms: 2 freestall; 2 non-freestall (open lot) facilities. Evaluation of animal residence time on concrete occurred in months representing winter, spring/fall, and summer seasons. Animal residence time on concrete was monitored by counting animals in sentinel pens at 1.5 hour increments for 24 hours. Feed information was obtained and digestibilities were determined.

Monthly in-depth analysis of waste stream distribution at these same four dairies (July 2017 through June 2018) occurred to understand how herd specific management decisions alter manure collected in the liquid stream. Liquid manure was reused for flushing lanes on three dairies. Volatile solids entered the liquid stream 1) in water reused from the dairy pond, 2) excreted from cattle and collected in their housing area, transfer lanes (from housing to milking parlor) and at the milking parlor, and 3) as bedding (dried manure with or without almond shells). Frequency of cleanout of gravity separation system varies. The methane emissions impact of cleaning out gravity separation systems more or less frequently is not currently considered in emissions inventory and it is not known if it should be considered. Modelling efforts to estimate VS reduction due to implementation of different (alternative) manure management practices need to consider the variability associated with these systems. Determining efficacy of manure management practices need to fully measure actual VS removed under field conditions requires complete understanding of the operation of the facility and how management of animals may modify results.

Recommendations

Additional research into herd demographics and management includes updating the current list of San Joaquin Valley dairies due to attrition and to ensure smaller facilities that may not have submitted permit applications to the SJVAPCD are included. Including dairies from the North Coast, San Francisco Bay and Santa Ana Regional Water Quality Control Board areas would encompass approximately 245 additional dairies and additional manure management practices. Due to the importance of solid liquid separation on potential methane reduction, additional research to improve the understanding of mechanical separator and gravity separation system use should also be conducted. Much of these additional needs may be answered as part of another project.

Use of a single value for time on concrete within housing type does not allow for site specific management practices. Selection from a range of values will provide more reliable information. Detailed analysis of liquid streams on dairies indicated variability within herd sampling events and over time. Housing design and animal management are responsible for large differences in manure potentially collected in a liquid stream (percent of time on concrete). For permitted lactating cattle in the San Joaquin Valley c. 54% of manure would enter the liquid stream (anaerobic lagoon or liquid/slurry storage). The remaining c. 46% would be deposited in open lots and remain in solid storage. This does not account for solids removed from liquid streams. Feed intake data may be input into various models to estimate organic matter (volatile solids) digestibility. The indigestible fraction of volatile solids has potential to form methane if sufficient time elapses and conditions are conducive for methanogens.

Analysis of frequency of clean out of gravity separation systems with respect to reducing methane formation is needed. This should include an evaluation of the end fate of the solids. The true net benefit of reducing methane forming potential by separating manure solids and then reinserting these solids into the liquid stream as bedding should be evaluated. A detailed analysis of end fate of almond shell use as bedding is important. Resolving these unknown gaps in knowledge will inform staff responsible for inventory estimates and refinement of calculators used for the Alternative Manure Management Program and the Dairy Digester Research Development Program. Manure collected via vacuum is likely restricted to housing area concrete (not transfer lanes or milk parlor area). The AMMP calculator should be modified to reflect this practice. Detailed analyses of pond VS concentration reinforced the need to do due diligence when evaluating effectiveness of alternative manure management practices. The VS in ponds prior to implementing new practices are stored carbon. Any direct measurements of CH_4 emissions will need to account for this carbon source and its variability.

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Abbreviations

AMMP	Alternative Manure Management Program
aNDFom	neutral detergent fiber assayed with a heat stable amylase and expressed exclusive of ash
B_0	Maximum methane producing capacity
BCS	Body condition score
CARB	California Air Resources Board
CDFA	California Department of Food and Agriculture
CH_4	Methane
Cl	Class of cattle
DDRDP	Dairy digesters research and development program
DM	Dry matter
Freestall housing	Barn (open sided in California) with two or more rows of cubicles for animals to stand or lie. These cubicles are elevated above the concrete floor. Feces, urine, and freestall bedding (reused dried manure with or without almond shells) drop onto the concrete floor and are collected via flush (reused water from the dairy storage or treatment pond), vacuum, tractor, or shovel and conveyed to liquid or

	slurry storage system. Animals have free access to feed bunks, waterers, and beds.
EC	Electrical conductivity
FS	Fixed solids
GHG	Greenhouse gas
HOBO	Portable temperature/humidity weather stations
Mature cattle	Lactating and dry cattle
N	Nitrogen
OM	Organic matter (i.e., not ash)
ORP	Oxidation-reduction potential
Region 1	North Coast Regional Water Quality Control Board
Region 5	Central Valley Regional Water Quality Control Board
S	Season of the year
SAS	Statistical analysis system
SJV	San Joaquin Valley
SJVAPCD	San Joaquin Valley Air Pollution Control District
TKN	Total Kjeldahl nitrogen
TMR	Total mixed ration (for cattle)
TOC	Time on concrete
VS	Volatile solids