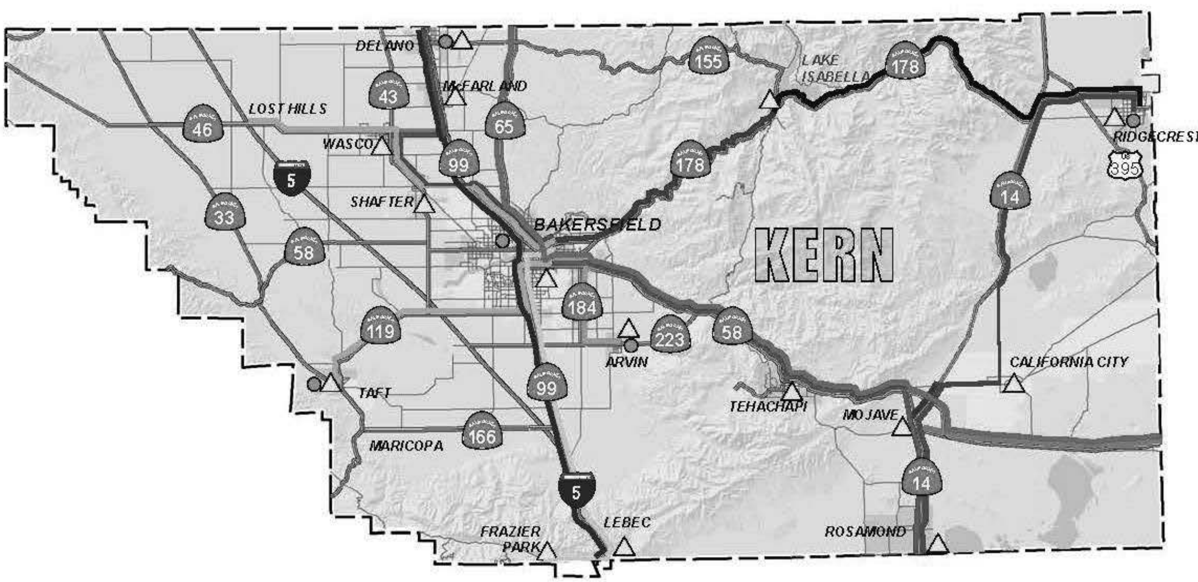
Lakeside-02

Appendix A Supporting the Prepared Direct Testimony of Daryl Maas

(Pilot Project)

[PUBLIC VERSION VOLUME 5]

Transit Services on State Routes
Kern County



Transit Service & Trips

Kern County Transit

- **Bakersfield to Lost Hills**
  Weekdays: 5 trips per day
  Saturday: 3 trips
- **Bakersfield to Frazier Park**
  Weekdays: 4 trips per day
  Saturday: 4 trips per day
- **Bakersfield to Lancaster**
  Weekdays: 8 trips per day
  Weekends: 2-3 trips per day
- **Bakersfield to Lake Isabella**
  Weekdays: 4 trips per day
  Weekends: 4 trips per day
- **Bakersfield to Taft**
  Weekdays: 5 trips per day
  Saturday: 3 trips per day
- **Bakersfield to Arvin**
  Weekdays: 11 trips per day
  Weekends: 9-11 trips per day
- **Bakersfield to Delano**
  Weekdays: 7 trips per day
  Weekends: 3 trips per day
- **Lancaster to California City**
  Weekdays: 7 trips per day
  Saturdays: 3 trips
- **Mojave to Ridgecrest**
  Monday, Wednesday, Friday: 2 trips per day
- **Mojave to Boron**
  Wednesdays: 3 trips per day
- **Lake Isabella to Ridgecrest**
  Monday, Wednesday, Friday: 3 trips per day

- **Greyhound Bus Service**
  Daily: 6 trips
- **Orange Belt Stages**
  Daily: 1 trips

- △ **Demand Response Service**
  (Various Locations)
- ● **Fixed Transit Routes Within Cities**
  Bakersfield, Delano, Taft, *Arvin and *Ridgecrest
  Service: Weekdays & Weekends
  *No service on weekends

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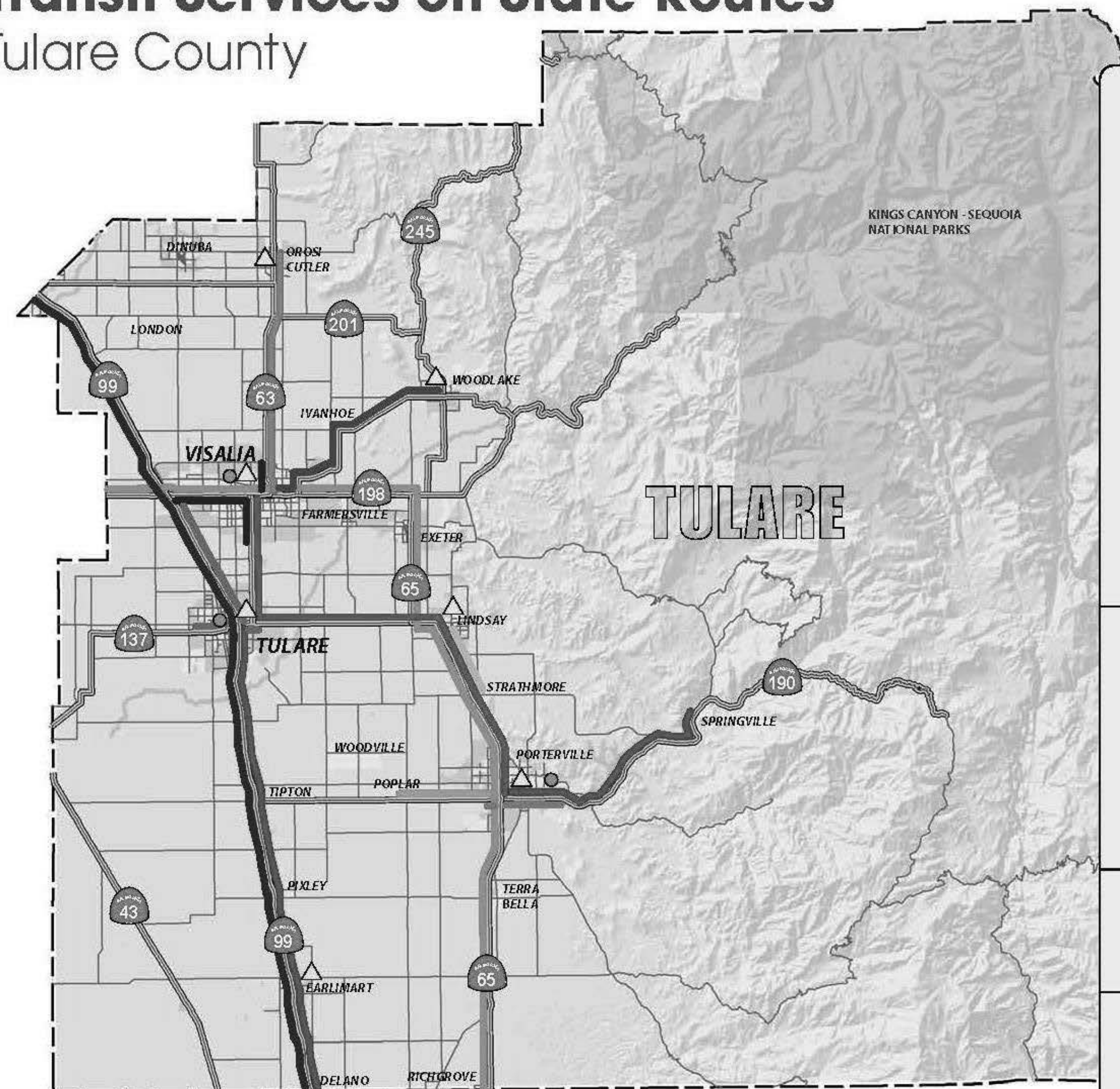
Transit Services on State Routes

Tulare County



Transit Service & Trips

Tulare County Area Transit

Visalia to Orosi
Weekdays: 12 trips per day
Weekends: 4 trips per day

Visalia to Woodlake/Three Rivers
Weekdays: 18 trips per day
Weekends: 6 trips per day

Visalia to Porterville
Weekdays: 12 trips per day
Weekends: 4 trips per day

Tulare to Delano
Weekdays: 10 trips per day
Weekends: 3 trips per day

Lindsay to Strathmore
Weekdays: 5 trips per day

Porterville to Poplar
Weekdays: 5 trips per day

Porterville to Springville
Weekdays: 2 trips per day

Fixed Routes Within Cities

Visalia Transit
Weekdays: 6am-9pm service
Weekends: 8am-6pm service

Tulare Transit
Weekdays: 6:30am-6pm service
Weekends: 9:30am-6pm service

Porterville Transit
Weekdays: 6am-9pm service
Weekends: 8am-4pm service

Greyhound Bus Service
Daily: 6 trips

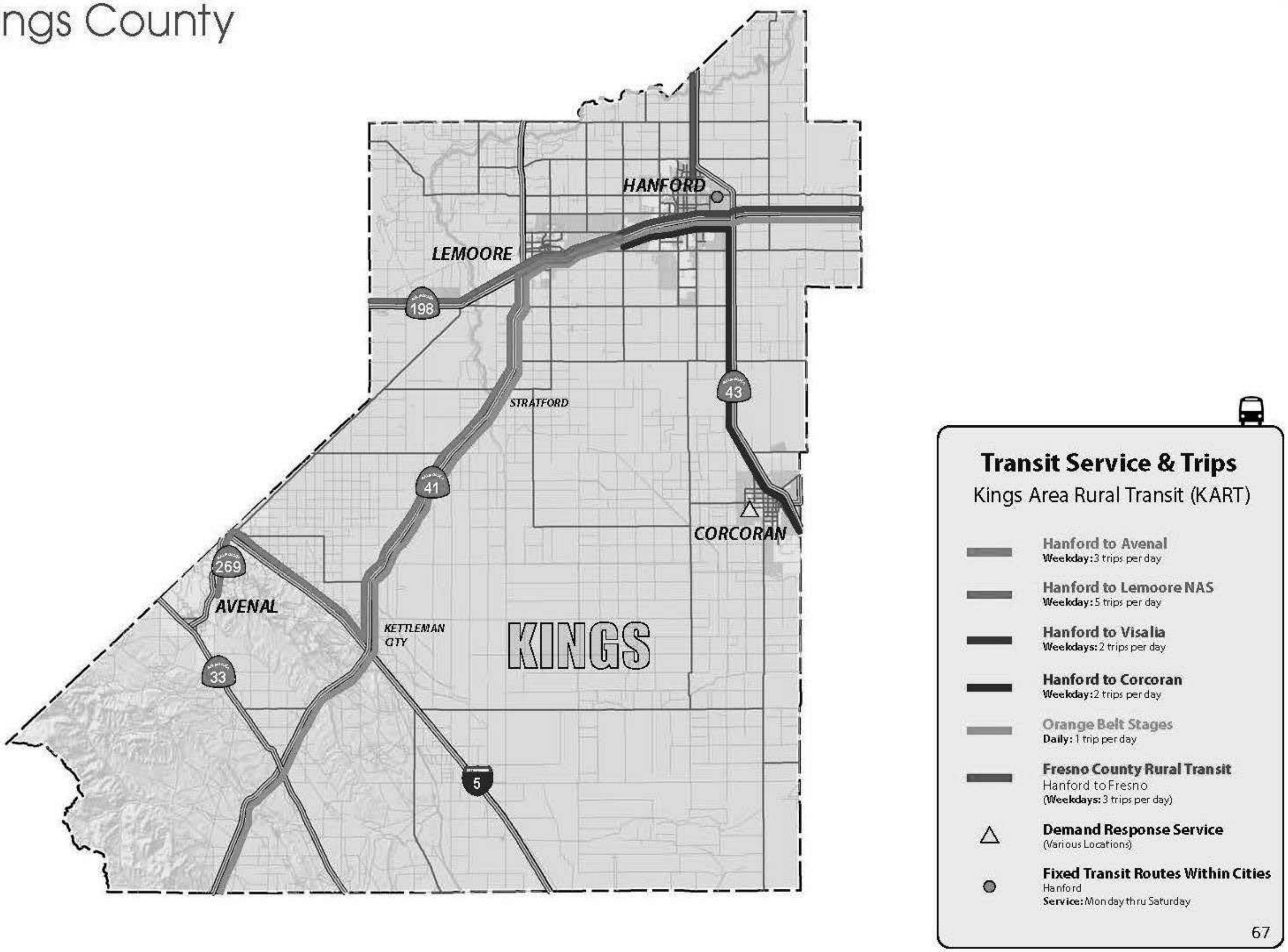
Orange Belt Stages
Daily: 1 trips

Demand Response Service
(Various Locations)

Fixed Transit Routes Within Cities
Service: Monday thru Saturday

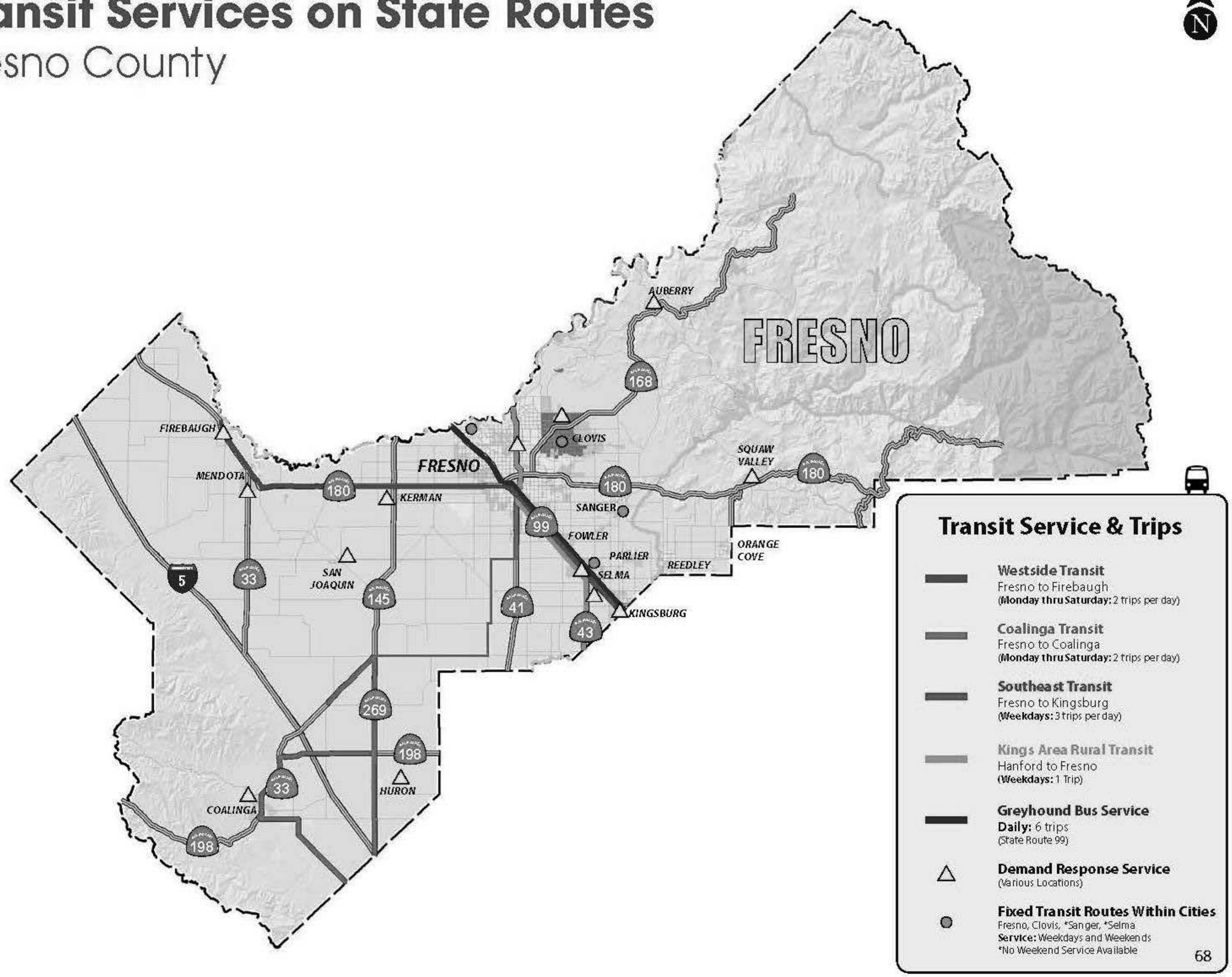
Transit Services on State Routes

Kings County



Transit Services on State Routes

Fresno County



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Evaluation of Earthen Liquid Dairy Manure Lagoons in the Central Valley of California: Seepage, Mass Emissions, and Effects on Groundwater Quality

Central Valley Dairy Representative Monitoring Program

LUHDORFF & SCALMANINI
CONSULTING ENGINEERS

April 6, 2017

Prepared by:

PROFESSIONAL GEOLOGIST
TILL ERIC ANGERMANN
No. 7789
4-6-2017
STATE OF CALIFORNIA

PROFESSIONAL GEOLOGIST
TILL ERIC ANGERMANN
No. 853
CERTIFIED HYDROGEOLOGIST
STATE OF CALIFORNIA

Till Angermann, P.G., C.Hg.
Principal Hydrogeologist

Vicki Kretsinger Grabert
Senior Principal Hydrologist

Suggested Citation: Luhdorff and Scalmanini Consulting Engineers. **2017**. Evaluation of Earthen Liquid Dairy Manure Lagoons in the Central Valley of California: Seepage, Mass Emissions, and Effects on Groundwater Quality. April 6, 2017.

LSCE File Number: 16-7-129

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Figures, Tables, Map Series, and Attachments

EXECUTIVE SUMMARY

As recently as in 2012, critical questions pertaining to Central Valley earthen liquid manure lagoons' seepage rates, their subsurface nitrogen (N) mass emissions as compared to N-emissions from manured cropland, and the spatial extent of salinity effects on lagoons' surroundings (i.e., vadose zone and shallow groundwater) could only be answered speculatively due to a fundamental lack of data. In addition, groundwater monitoring was the primary, if not the only, means of assessment for regulatory compliance despite unequivocal technical limitations.

In response to these data gaps, the Central Valley Dairy Representative Monitoring Program (CVDRMP) devised and implemented systematic investigative efforts, and this report comprehensively evaluates the results of these efforts, including:

1. Groundwater quality data from dedicated monitoring wells adjacent to lagoons collected quarterly since 2012;
2. Seepage rates and subsurface N emissions from whole-lagoon seepage tests conducted in winters 2013/14 and 2014/15;
3. Lagoon liquor quality;
4. Lagoon perimeter soil borings and groundwater sampling at the water table conducted in fall 2014; and
5. Geophysical surveys carried out in fall 2014 (reconnaissance testing) and spring/summer 2015 (expanded testing).

Results from Items 1 through 4 have previously been made available in stand-alone reports as data were developed and analyzed to keep Central Valley Regional Water Quality Control Board (Regional Board) staff abreast of CVDRMP's progress. This report compiles and synthesizes pertinent information and findings from these previous reports and adds the results from the most recent investigative effort, the geophysical testing. Conclusions comprise three main categories:

- Seepage rates and N-mass emissions from lagoons and manured cropland
- Spatial extent of salinity effects on subsurface soils and groundwater
- Utility of concentration-based assessment of lagoon performance

Seepage Rates and N-Mass Emissions

A total of 50 seepage tests were carried out on 17 lagoons. Mean seepage rates ranged from zero to 2.2 mm d^{-1} with the exception of one outlier lagoon where exposed gravel strata may be present and a maximum seepage rate of 3.9 mm d^{-1} was determined. The mean and median seepage rates of all 17 lagoons were 1.1 and 0.7 mm d^{-1}, respectively. Ten of the 17 tested lagoons had seepage rates $\leq$0.8 mm d^{-1}, which is smaller than the most recent and stringent NRCS design seepage rate of 0.86 mm d^{-1}.

These results are consistent with the pertinent academic literature. Specifically, small seepage rates and a narrow range of seepage rates across the soil textures ranging from clay to coarse sand have been documented in other studies, which have been attributed to the moderating effect of a sludge layer of very low hydraulic conductivity. CVDRMP's results and the academic literature are not congruent with seepage rates suggested by *Review of Animal Waste*

Management Regulations, Task 2 Report: Evaluate Title 27 Effectiveness to Protect Groundwater Quality by Brown, Vence & Associates (BVA 2003). That report implied seepage rates ranging from centimeters to meters per day that were based on theoretical hydraulic conductivities associated with soil textures in accordance with Title 27 regulations.

Despite the inherent uncertainty in the data-supported estimation of subsurface N-mass emissions from liquid manure lagoons and from manured cropland, the data developed as part of CVDRMP's initiatives strongly indicate that the great majority of subsurface N-emissions originate from dairies' cropland, not from their lagoons. CVDRMP found that the proportion of cropland emissions to lagoon emissions on a dairy farm scale may be as asymmetrical as 20:1 even assuming optimistic future improvements in field-scale nitrogen use efficiencies. When including N-contributions from corrals and non-manured dairy cropland, the proportional N-contribution from lagoons would be expected to be even less. This compares well to *Addressing Nitrate in California's Drinking Water* (Harter, Lund et al. 2012). On the scale of the Tulare Lake basin and the Salinas Valley, that report suggests a proportional relationship of 1000:1 between subsurface N-emissions from cropland and from lagoons.

Salinity Effects on Subsurface Soils and Groundwater

The lateral extent of measurable salinity effects on subsurface soils and groundwater, as investigated with three different geophysical methods, was found to remain in the immediate vicinity of the lagoons' footprint in most cases. Specifically, effects are most developed in the center of lagoon systems (i.e., between basins), they are typically significantly reduced along lagoons' perimeters, and little or no impact was generally seen at a distance of 50 to 150 feet from the lagoon berms. Along the lagoon perimeter and beyond, salinity effects were mostly seen above a depth of approximately 40 feet below the water table. In the center of lagoon systems, effects on groundwater salinity extended below the maximum investigation depth of 60 feet below ground surface (bgs) in some cases (120 feet, bgs in one case). At other sites, most of the salinity-effects remained limited to the unsaturated zone (~20 feet thick) or were not apparent at all.

Concentration-based Assessment

Several technical limitations of concentration-based assessment (e.g., via monitoring wells) were initially identified by CVDRMP's Groundwater Technical Advisory Committee (GTAC) during the development of the Phase 2 Well Installation Workplan (July 16, 2012 GTAC meeting). Since then, insight gained through CVDRMP's representative groundwater monitoring program, focused investigative efforts in addition to requirements for data collection set forth in the General Order, and sustained collaboration with professionals on the GTAC, the Multidisciplinary Advisory Committee (MAC), and beyond, has supported expanded discussion of this issue in CVDRMP's Annual Reports. Specifically:

- The empirical data developed by CVDRMP illustrate that monitoring wells are an unreliable tool for detecting impacts of lagoon seepage on groundwater even under relatively favorable hydrogeologic conditions. In most cases, seepage remains either not evident or inconclusive based on groundwater testing. In contrast, follow-up data collection efforts involving multiple boreholes around lagoon perimeters to investigate sites with such unsatisfactory results demonstrated that seepage in fact had affected groundwater quality in more than 8 out of 10 cases.

- More fundamentally, groundwater constituent concentrations do not yield information on the concentration of the lagoon seepage, the seepage rate, overall subsurface mass loading rate, or the duration of the loading. Although groundwater monitoring generates quantitative information, this information can only be used qualitatively with respect to lagoon seepage, i.e., supporting a statement such as, "groundwater chemistry is (or is not) indicative of lagoon seepage". Since guidelines, standards, and laws for the construction of existing earthen lagoons were intended to control seepage but not to stop it, seepage is to be expected and a data collection effort (e.g., groundwater sampling via monitoring wells or other means) that supports a qualitative statement of whether a lagoon seeps or not has limited utility for devising a path to subsurface N-emission reductions on a dairy-farm scale.

Toward Recommendations

Due to fairly consistent performance across the range of lagoons evaluated (i.e., wide range of ambient soil types, ages of lagoons, lagoon construction details and operational characteristics), CVDRMP was not able to identify variables (other than exposed gravel strata) that could be used to predict performance in existing earthen-lined lagoons. This suggests that rather than devoting further technical effort to evaluating performance of individual lagoons as a means for prioritizing those lagoons most in need of additional or standardized management practices, a more appropriate strategy may be to develop practicable management measures that may be deployed on all existing earthen-lined ponds. CVDRMP explored this issue in depth with a review of pertinent literature that was reported on in the *Literature Review and Workplan – Controlling Seepage from Liquid Dairy Manure Lagoons in the Central Valley of California (Draft)* (LSCE 2016b). In summary, the literature review did not find quantitative information indicating the effectiveness of specific management measures in reducing seepage below existing levels. Many management measures appear to be based on what is considered common sense. However, whether such measures reduce seepage is largely unknown.

The development of evidence that demonstrates further seepage reductions for existing earthen lagoons will be exceedingly difficult and probably not practical because seepage rates are already very small without the implementation of management measures. Documenting incremental improvements would require essentially the level of control associated with laboratory experiments. However, laboratory tests are not a viable option because results have been amply shown to not be scalable to whole lagoon performance. A difficulty related to the small seepage rates and even smaller incremental improvements is the imprecision (i.e., uncertainty) inherent in whole-lagoon seepage rate estimates. It is expected that, in most cases, the uncertainty interval would be prohibitively large to support comparative analysis.

As a consequence of the above conditions, it is expected that the development of management measures will largely need to rely on qualitative reasoning rather than quantitative evidence. This highlights the importance of weighing the (quantitative) cost of management measures against the perceived (qualitative) benefits.

The *Literature Review and Workplan* identified several outstanding work efforts and these work efforts are well underway. For example, CVDRMP is presently evaluating the utility and feasibility of the following items:

- Further limiting N-subsurface emissions after lagoon decommissioning,
- Different soil treatments of lagoon banks, and
- Partial synthetic liners for lagoon banks.

In addition, CVDRMP devised and sent a producer survey to dairies that have lagoons with synthetic membranes. This effort aims to collect information on practical experiences with these facilities. Also, in winter 2016/17, several electrical leak location surveys paired with whole-lagoon seepage testing were carried out and are being evaluated. This effort addresses the following questions:

- What is the magnitude and range of whole-lagoon seepage rates from operational lagoons with synthetic membranes, and can it be measured with the water balance method?
- How does the seepage rate relate to the size of identified leaks?

The results from these efforts are expected to help devise recommendations guiding the role of synthetic-lined lagoons on dairies, particularly the role of single-membrane synthetic liners.

1 INTRODUCTION

1.1 Purpose and Motivation

The purpose of the Central Valley Dairy Representative Monitoring Program's (CVDRMP) lagoon investigations is to support an evidence-informed solution regarding the fate of existing earthen liquid dairy manure lagoons.

Prior to the adoption of *Waste Discharge Requirements General Order No. R5-2007-0035 for Existing Milk Cow Dairies* (General Order) adopted by the Central Valley Regional Water Quality Control Board (CVRWQCB) in May 2007 (CVRWQCB 2007), it was implied that seepage rates from lagoons, even when constructed in accordance with California Code of Regulations Title 27, may be substantial and exhibit a wide range from centimeters to meters per day (BVA 2003). In contrast, LSCE compiled evidence from the pertinent academic literature documenting the opposite, namely, small seepage rates exhibiting a narrow range from near-zero seepage to a few millimeters per day (LSCE 2008).

In spring 2015, CVDRMP completed seepage testing on 17 earthen lagoons with minimal or no construction records; the lagoons ranged in age from less than 10 years to approximately 50 years at the time of testing (LSCE 2015c). The lagoons were built in native materials ranging from clay loam to sand. The field investigation found mostly small seepage rates (i.e., there was one outlier with a higher seepage rate at a location where exposed gravel strata are suspected) and a narrow range of seepage rates between lagoons across a wide range of mapped soil textures. These results are consistent with the pertinent academic literature (LSCE 2008).

This report comprehensively evaluates different types of data that CVDRMP collected from 2012-2015 to investigate the performance of earthen lagoons with respect to their ability to contain liquid dairy manure, their subsurface nitrogen (N) mass emissions, and effects on groundwater. This includes:

1. Groundwater quality data from dedicated monitoring wells adjacent to lagoons collected quarterly since 2012;
2. Seepage rates and subsurface N emissions from whole-lagoon seepage tests conducted in winters 2013/14 and 2014/15;
3. Lagoon liquor quality;
4. Lagoon perimeter soil borings and groundwater sampling at the water table conducted in fall 2014; and
5. Geophysical surveys carried out in fall 2014 (reconnaissance testing) and spring/summer 2015 (expanded testing).

Items 1 through 4 have already been independently reported on (LSCE 2013; LSCE 2014b; LSCE 2015b; LSCE 2015c; LSCE 2015a). This report compiles and synthesizes pertinent information and findings from these previous reports and adds the results from the most recent investigative effort, the geophysical testing.

1.2 Background

1.2.1 Title 27 Regulations and Theoretical Seepage Rates

In the early 2000s, the State Water Resources Control Board commissioned Brown, Vence and Associates (BVA) to review existing animal waste management regulations and to evaluate California Code of Regulations Title 27 effectiveness to protect groundwater quality. Title 27 § 22562 – Wastewater Management was signed into law in 1984[1]. It contains the law applicable to retention pond design at confined animal facilities. Specifically, it states:

> (d) Retention Pond Design — Retention ponds shall be lined with, or underlain by, soils which contain at least 10 percent clay and not more than 10 percent gravel or artificial materials of equivalent impermeability.

BVA (2003) notes that the hydraulic conductivity of materials that meet these criteria conceivably ranges from 10^{-6} to 10^{-3} cm s^{-1} and implies that seepage rates among liquid dairy manure lagoons may vary over three orders of magnitude (1,000-fold) even if they are constructed in compliance with Title 27.

This hydraulic conductivity range was set forth without support of any actual seepage testing or reference to (at the time) current and relevant research efforts. Rather, it was based on a speculative 1:1 proportional relationship between saturated hydraulic conductivity of subsurface materials and the seepage rate. It implicitly dismissed the seepage-reducing effect of the sludge layer that commonly develops in manure lagoons due to settling of very fine solids that are not retained by mechanical solids separators nor in settling basins. It also implicitly dismissed already existing evidence of the sludge layer's moderating effect on the seepage rate of lagoons of widely differing construction and subsurface materials.

BVA's approach led to relatively high hypothetical seepage estimates. Under a unit gradient (i.e., 1), seepage rates would conservatively range from a millimeter to a meter per day (1 meter ≈ 3.28 feet). Seepage estimates that are based on the assumption of 9 feet liquid lagoon depth and a 1-foot liner thickness (i.e., a gradient of 10), as typically done for lagoon liner design (NRCS 1997; NRCS 2009), yield a range from a centimeter to several meters per day (i.e., dozens of feet per day), not accounting for a sludge layer. Such high hypothetical seepage estimates are not supported by field observations as lagoons maintain liquid levels under moderate additions of "new" water (e.g., milk parlor wash water, etc.). Also, such high losses would render lagoons unusable as part of a water/nutrient recycling system because manure water would infiltrate faster than it could be added to the lagoon.

1.2.2 Dairy General Order

The General Order supersedes Title 27 regulations with respect to the construction of new dairy manure lagoons and the reconstruction of existing dairy manure lagoons[2]. Specifically, the General Order provides a tiered lagoon design approach, as follows:

---

[1] When signed into law, it was Title 23, Chapter 15, Section 2561 (it became effective November 27, 1984)

[2] *General Order No. R5-2007-0035* was rescinded and replaced by CVRWQCB, 2013: Reissued Waste Discharge Requirements General Order No. R5-2013-0122 for Existing Milk Cow Dairies. Central Valley Regional Water

> Tier 1: A pond designed to consist of a double liner constructed with 60- mil high density polyethylene or material of equivalent durability with a leachate collection and removal system (constructed in accordance with Section 20340 of title 27) between the two liners will be considered to be consistent with Resolution 68-16. Review for ponds designed to this standard will be conducted in less than 30 days of receipt of a complete design plan package submitted to the Board.
>
> Tier 2: A pond designed in accordance with California Natural Resource Conservation Service (NRCS) Conservation Practice Standard 313 (as described in the Information Sheet) or equivalent and which the Discharger must demonstrate through submittal of technical reports that the alternative design is protective of groundwater quality as required in Pond Specification 5. C. below.

The General Order provides requirements that are specific to the Tier 2 lagoon design:

> For Tier 2 pond design, the design report shall also include a technical report and groundwater model that demonstrates the proposed pond is in compliance with the groundwater limitations in this Order, including calculations that demonstrate the amount and quality of seepage from the proposed pond and its effect on groundwater quality, and include proposed groundwater monitoring to evaluate the impact of pond seepage on groundwater quality.

1.2.3 CVDRMP Efforts

The chronology of CVDRMP's lagoon investigations and associated reports is presented in **Table 1**. Prior to the inception of CVDRMP in 2010, the Dairy Cares coalition commissioned Luhdorff and Scalmanini Consulting Engineers (LSCE) and the University of California at Davis (UC Davis) to conduct a comprehensive literature review regarding liquid manure lagoon seepage rates, subsurface mass loading, lagoon water chemistry, and impacts to soils and groundwater. The resulting Technical Memorandum (LSCE 2008) was submitted to the CVRWQCB in 2008 in conjunction with a briefing of the Executive Officer and other management staff. The Technical Memorandum reported on a data-supported water balance method used to quantify actual lagoon seepage rates with specified statistical confidence. The water balance method and other findings with respect to seepage were derived from the academic literature, much of it predating BVA (2003), and included:

- Seepage rates are moderated by the sealing effect of manure, especially dairy manure (as opposed to hog manure)
- Seepage variance is small between sites
- A study in Kansas reported seepage rates from hog, cattle, and dairy lagoons ranging from 0.2 – 2.4 mm d^{-1} (n=20).

Following these findings, Western United Dairymen partnered with the California Department of Food and Agriculture, the Dairy Cares coalition, East Stanislaus Resource Conservation District, LSCE, and UC Davis to verify the utility of the above mentioned water balance method under Central Valley conditions. A secondary objective was to make the method accessible to a broader audience. This was a field-work intensive effort that was conducted in winter 2010/11 and resulted in a comprehensive Technical Field Guide.

Quality Control Board. October 3, 2013. In this document, the term 'General Order' is used in collective reference to both the 2007 and 2013 General Orders, their respective Monitoring and Reporting Programs (MRPs), and all other attachments. Specificity is added, where needed, by identifying the years of adoption.

CVDRMP commenced systematic seepage measurements in winter 2013/14 and briefed CVRWQCB staff on its initial findings in May 2014. Seepage measurements were expanded and concluded in winter 2014/15. The results of this two-year investigation were comprehensively reported in *Seepage Rates of Liquid Dairy Manure Lagoons in the Central Valley of California and Associated Subsurface Nitrogen Mass Emissions* (LSCE 2015c). To CVPRMP's knowledge, this effort is the first of its kind in California and it includes rigorous estimation of Central Valley dairy lagoons' subsurface nitrogen mass loading (i.e., emissions).

As stated in *Section 1.1*, that report presents results from 17 completed seepage tests on earthen lagoons with minimal or no construction records built in areas with soil textures ranging from clay loam to sand and lagoon ages that range from less than 10 years to approximately 50 years. Key results of the report are summarized below:

- Mean seepage rates ranged from zero to 2.2 mm d^{-1} with the exception of one outlier lagoon where exposed gravel strata may be present and a maximum seepage rate of 3.9 mm d^{-1} was determined.
- The mean and median seepage rates of all 17 lagoons were 1.1 and 0.7 mm d^{-1}, respectively.
- Ten of the 17 tested lagoons had seepage rates $\leq$0.8 mm d^{-1}, which is smaller than the most recent and stringent NRCS design seepage rate of 0.86 mm d^{-1}.

Due to fairly consistent performance across the range of lagoons that were evaluated, it was not possible to identify variables (other than possibly exposed gravel strata) that could be used to predict performance in existing earthen-lined lagoons. This suggests that rather than devoting further technical effort to evaluating performance of individual lagoons as a means for prioritizing those lagoons most in need of additional or standardized management practices, a more appropriate strategy may be to develop practicable management measures that may be deployed on all existing earthen-lined ponds. This was further examined in a literature review and workplan (LSCE 2016b) that focused on existing lagoon construction standards and guidance on lagoon operation and maintenance, specifically developed for seepage control. This report delineates additional data collection efforts to generate supporting evidence toward CVDRMP's development of recommendations for management practices on dairies.

CVDRMP's activities have not been limited to direct whole-lagoon seepage testing. In fall 2014, CVDRMP completed a lagoon perimeter subsurface hydrogeologic investigation. This investigation was carried out on lagoons at twelve Phase 1 dairies[3] where lagoon seepage was either not evident or inconclusive based on groundwater testing conducted in 2012 and 2013. A final report was submitted to the CVRWQCB in March 2015 (LSCE 2015a). The 2014 investigation was complemented with a pilot geophysical testing program in fall 2014 to test an alternative or complementary approach to investigating lateral impacts of lagoon seepage on shallow groundwater quality. Based on the initial findings, the program was subsequently expanded and field testing was completed in August 2015.

[3] Phase 1 RMP dairies are those where groundwater data collection efforts commenced in January 2012.

Table 1: Summary of CVDRMP's Lagoon Investigations and Associated Reports

Chronology	Activity/Deliverable
September 2008 [Report]	"Technical Memorandum – Liquid Animal Waste Lagoons, Input Loading to Subsurface Soils and Groundwater, A Research Review"
Winter 2010/11	Field testing under favorable and adverse conditions of the water balance method for quantification of lagoon seepage rates and associated uncertainty
January 2012	CVDRMP groundwater monitoring begins; monthly groundwater level measurements; quarterly groundwater quality sampling
March 2012 [Report]	"Protocols for Measuring Dairy Lagoon Seepage Using the Water Balance Method – Technical Field Guide"
April 2013 [Report]	"Central Valley Dairy Representative Monitoring Program Year 1 Annual Report (2012)"
Winter 2013/14	Lagoon seepage testing in CVDRMP's Central Area
April 2014 [Report]	"Central Valley Dairy Representative Monitoring Program Year 2 Annual Report (2013)"
May 2014	RWQCB briefing on preliminary seepage testing results
Fall 2014	Lagoon perimeter subsurface hydrogeologic investigation; soil borings and sampling of uppermost first encountered groundwater
Fall 2014	Pilot geophysical testing (electrical resistivity tomography, ERT)
Winter 2014/15	Lagoon seepage testing in CVDRMP's Central, North, and South Areas
March 2015 [Report]	"Lagoon Perimeter Subsurface Hydrogeologic Investigation Report"
April 2015 [Report]	"Central Valley Dairy Representative Monitoring Program Year 3 Annual Report (2014)"
Summer 2015	Expanded geophysical testing (ERT, Ohm-Mapper, electromagnetic tomography (EMT))
November 2015 [Report]	"Seepage Rates of Liquid Dairy Manure Lagoons in the Central Valley of California and Associated Subsurface Nitrogen Mass Emissions"
February 2016 [Draft Report]	"Literature Review and Workplan, Controlling Seepage from Liquid Dairy Manure Lagoons in the Central Valley of California" (revised June 2016)
April 2016 [Report]	"Central Valley Dairy Representative Monitoring Program Year 4 Annual Report (2015)"

1.3 Role of Lagoons on Dairies

Lagoons play an integral part in receiving, storing, and recycling water and nutrients at nearly all existing dairies in the Central Valley. The great majority of Central Valley dairies are constructed as freestall dairies. Freestall barns are roofed structures without walls where cows spend much of their time feeding and loafing. Freestall barns provide a well-ventilated environment while also providing protection from rain and the sun. To increase summertime comfort, they are often equipped with fans and misters. Manure is excreted onto curbed concrete lanes (i.e., flush lanes), which are regularly cleaned by flushing. Flush water typically undergoes some form of solids separation process, e.g., via mechanical separators, settling basins, or weeping walls.

Lagoons also receive inputs from other sources depending on the specific dairy configuration. Freestall barns are typically surrounded by earthen exercise pens and corrals where manure is deposited on bare ground. At dairies where these pens and corrals are equipped with feed aprons, these also may be equipped with flush lanes linked to a lagoon. Other lagoon inputs may be wash water from the milk parlor and cow wash water, all of which may contain some manure. Additional water may be derived from equipment sanitation and cooling. Lagoons typically also function as storm water retention basins and may be configured to receive tailwater runoff from cropland. Generally, this water is stored in the lagoon and recycled for cleaning the flush lanes. Storm water runoff, water from the milking parlor, equipment sanitation, and cooling contains much less or no manure residue and provides needed dilution of lagoon water to maintain effective cleaning of the flush lanes.

Ultimately, lagoon water is injected into the irrigation water stream and used to fertilize crops that are grown on dairies for feed. This practice recycles nutrients locally, supporting farmers' ability to grow feed crops for cows while reducing dependence on synthetic fertilizers. The storage of nutrients in liquid form bears an enormous advantage over solid manure. Liquid manure can be applied to the crop throughout the growing season, thus, matching crop demand with supply. In contrast, solid manure can only be applied pre-planting or shortly thereafter, i.e., when crop uptake is low. This makes nutrients vulnerable to leaching. In the context of nutrient management, the lagoon enables farmers to store nutrients during times of low nutrient demand (i.e., between harvest and planting, and during winter months) and to apply nutrients to crops when needed.

2 METHODS

CVDRMP systematically conducted seepage testing on all of the lagoons that met operational conditions for such testing on its monitored member dairies and three additional dairies for a total of 17 lagoons. Fieldwork was carried out in winter 2013/14 (Central Area) and winter 2014/15 (North and South Areas) (**Figure 1**).

The lagoon perimeter investigation focused on 12 lagoons, where lagoon seepage was either not evident or inconclusive based on groundwater testing in 2012 and 2013. Fieldwork was carried out in October 2014.

Twenty-two of the investigated lagoons have one to four associated dedicated monitoring wells in first encountered groundwater. Groundwater quality information collected on a quarterly schedule from the first quarter of 2012 through the last quarter of 2014 is included in this report.

Geophysical surveys were coordinated, to the extent possible, with seepage testing and the lagoon perimeter investigations. All 12 lagoons where geophysical surveys were carried out also have groundwater quality information available. Eight of these lagoons were correlated with the lagoon perimeter investigation, and five lagoons also have quantified seepage rates (**Table 2**).

2.1 Seepage Testing

Surveys were sent to 41 of the 42 monitored CVDRMP dairies[4] to delineate viable candidate lagoons based on operational characteristics. Surveys were followed up via email, phone and/or field visits to address producers' questions, as needed, and to further delineate the site-specific merits of seepage testing. In four cases, instrumentation was deployed but producers were ultimately not able to hydraulically isolate their lagoon, and testing did not yield usable results in these cases. Successful seepage testing was completed at 14 of the monitored CVDRMP dairies. Three additional non-monitored CVDRMP dairies volunteered for testing, which resulted in a total of 17 dairies where successful seepage tests were conducted.

The testing protocol used in this effort is the product of approximately 10 years of research and development between 1999 and 2009, including hog, cattle, and dairy farms in Kansas and other Midwestern states (Ham 1999; Ham and DeSutter 1999; Ham and DeSutter 2000; Ham 2002a; Ham 2002b; Ham and DeSutter 2003; Ham 2007; Ham and Baum 2009). The method was further tested under Central Valley conditions in winter 2010/11 and is comprehensively described in *Protocols for Measuring Dairy Lagoon Seepage Using the Water Balance Method – Technical Field Guide* (LSCE 2012). Following is a brief overview.

The water balance accounts for inflow to and outflow from the lagoon and accounts for changes in storage over a period of time. Inflows may be wash water carrying manure from the flush lanes of freestall barns where livestock are housed, discharge from other lagoons or settling

[4] ADO was closed and dismantled before lagoons could be tested.

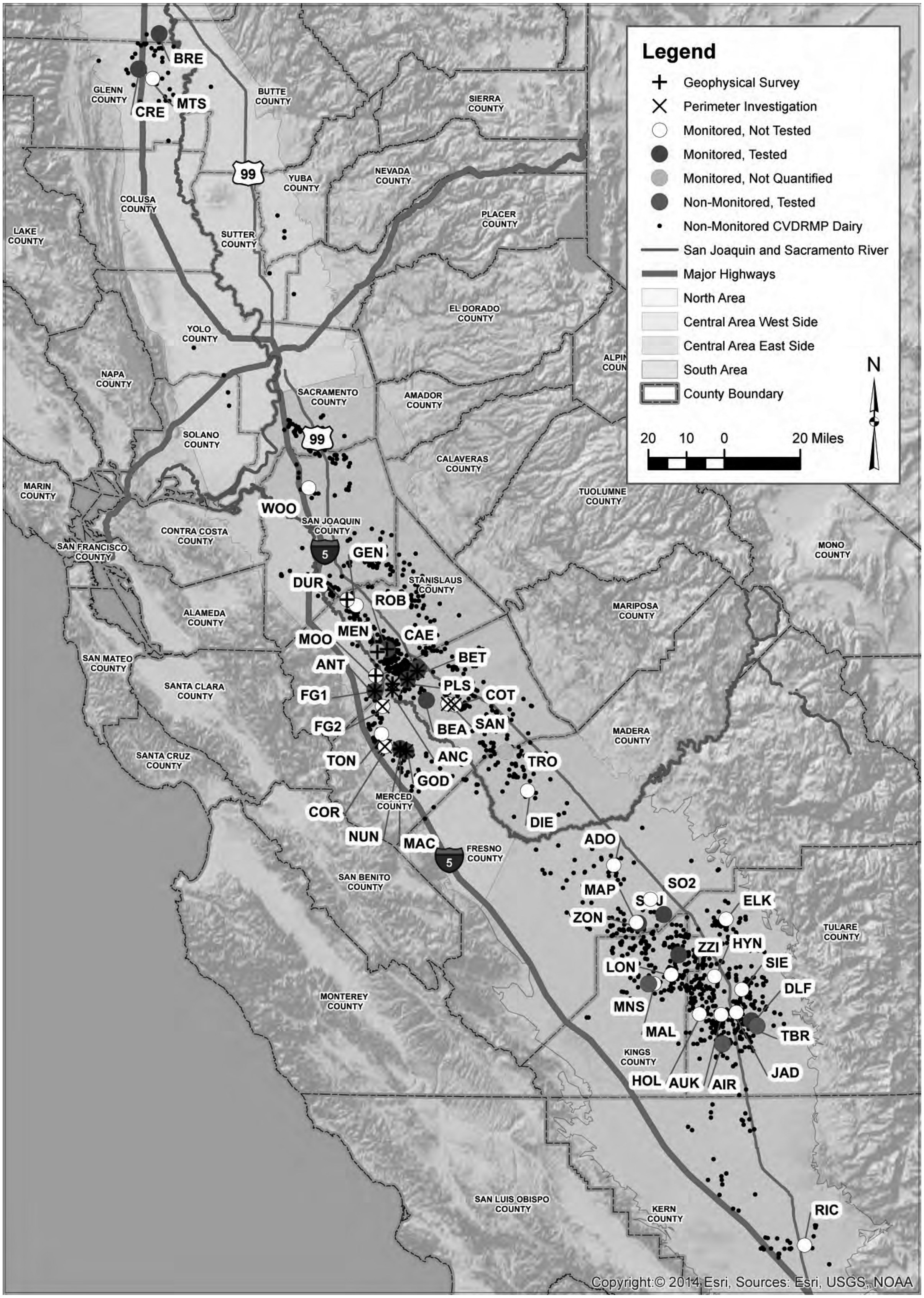

Figure 1: Dairy and Testing Location Map

Table 2: Fieldwork Matrix

Dairy	Water Balance Test	Lagoon Perimeter Investigation	Dedicated Monitoring Wells	Geophysical Survey
Central Area - East				
MEN			✓	✓
ANC		✓	✓	✓
BET	✓	✓	✓	✓
DUR			✓	✓
FG1		✓	✓	✓
BEA	✓		✓	
COT		✓	✓	
SAN		✓	✓	
PLS	✓	✓	✓	✓
CAE	✓		✓	
ROB	✓		✓	✓
Central Area - West				
ANT	✓	✓	✓	✓
COR		✓	✓	
FG2		✓	✓	
GOD	✓	✓	✓	✓
MAC		✓	✓	✓
NUN †	✓	✓	✓	✓
MOO			✓	✓
North Area				
BRE	✓			
CRE	✓			
South Area				
DLF	✓		✓	
ZZI	✓		✓	
MAP	✓			
SO2	✓		✓	
AIR	✓			
MNS	✓			
TBR	✓			

† Two lagoons were investigated at this site. One of the lagoons has a dedicated monitoring well, and the lagoon perimeter investigation and the geophysical survey were carried out on that lagoon. However, it was not suitable for water balance testing, which was completed on a different lagoon.

basins, irrigation tail water from adjacent crop fields, wash water from the milk barn and other facilities, direct precipitation, and precipitation runoff from the lagoon's banks, and any other surfaces at the facility from where storm water is routed to the lagoon. Outflows may include intentional removal to irrigate crop fields or to flush freestall barns, transfer to other lagoons operated in series, evaporation, and seepage.

By avoiding times of precipitation, discharge to the lagoon, and the removal of water from the lagoon (all of which introduce uncertainties to the water balance that can far exceed the magnitude of the lagoon's seepage rate), the seepage rate can be computed as the difference between only two terms: the decline of the water level (i.e., change in storage) and evaporative losses from the water surface. The uncertainty introduced by rain stems from its geographic heterogeneity. Specifically, a measurement obtained with a rain gauge may not be reflective of the actual amount of rain that fell on a lagoon. In some cases, seepage rates were computed from water balance tests during which minor precipitation occurred. In these cases, seepage rates were computed in two ways: (i) not accounting for precipitation inputs, thus, yielding a result that tends to underestimate the actual seepage rate, and (ii) making an adjustment for precipitation inputs using two times the precipitation depth registered by the rain gauge, thus, yielding a result that very likely does not underestimate the actual seepage rate. The effects of precipitation inputs were too small or too widely distributed over the duration of the tests such that they are not perceptible on the depth change graphs. The associated seepage rate plots show results without correction for precipitation (i.e., as described in above item (i)).

Hydraulic isolation from inflows and outflows is important for successful seepage testing. To most accurately quantify evaporative losses, lagoons need to also be relatively free of floating materials (e.g., manure solids). The effect of floating manure solids on evaporative losses is not well understood and could conceivably reduce evaporation due to a cover effect (i.e., seepage would be overestimated), or enhance it due to capillary forces and increased solar heating of the thin film of water on the solids particles.

CVDRMP used research-grade instrumentation for the measurement of water level elevation changes in the lagoon, ambient air temperature, relative humidity, wind speed, and water surface temperature. The latter four variables support a bulk-aerodynamic transfer model estimating evaporative losses. Best results are obtained when evaporative demand is low and small relative to seepage losses. Application of the water balance method in the Central Valley outside the months of November – February/March has shown to produce data that are unusable to quantify seepage losses.

Lagoons were visited frequently for data downloads and field observations to ensure continued hydraulic isolation and uncompromised data collection. In some cases, floating particulate matter (i.e., saturated manure solids) was observed.

2.1.1 Multi-Day Testing

Best results are obtained when inflows to and outflows from the lagoon can be halted for several days. In that case, the seepage rate estimate can be augmented with an uncertainty interval, where a range around the seepage rate estimate is specified within which the true seepage rate is expected to reside. The uncertainty analysis accounts for uncertainty in the measured variables and random error introduced by environmental conditions. Therefore, uncertainty is unique for each water balance test. In this document, uncertainty is expressed as a 95% confidence interval on the computed seepage rate (Coleman and Steele 2009). For example, a seepage rate of 1.0 ± 0.1 mm d^{-1} (i.e., millimeters per day) suggests that, with 95% confidence, the true seepage rate resides within 0.9 and 1.1 mm d^{-1} (where the uncertainty is ± 0.1 mm d^{-1}).

2.1.2 Overnight or Short-Term Testing

If uninterrupted multi-day testing is not possible, shorter-term testing provides a viable alternative. Very short tests (i.e., approximately 12 hours) were carried out at night. Overnight testing benefits from generally more favorable meteorological conditions resulting in reduced evaporative losses. However, a short test duration significantly increases the uncertainty in the results because both the absolute and relative uncertainty contribution from depth measurements increases. As a result, uncertainty analysis loses its utility in conjunction with overnight testing. Confidence in results can be gained, although less quantitatively, by carrying out the water balance during several successive or near successive nights. In these cases, the uncertainty estimate was expressed with two standard deviations around the mean seepage rate (i.e., containing 95% of the statistical sample of the normal distribution).

2.2 Lagoon Water Sampling

Lagoon water was retrieved at three locations in each lagoon and ammoniacal-N concentrations were averaged for mass emissions calculations. One sample was retrieved near the center and two samples were retrieved toward the sides of the lagoon under consideration of the discharge point to the lagoon. This sampling scheme was employed to avoid potential sample bias toward fresh manure sources (i.e., near the inflow of flush water) or older, well-digested manure (i.e., distal to the discharge point). To quantify constituent concentrations most likely to represent concentrations in the seepage itself, samples were retrieved near the lagoon floor. Specifically, samples were retrieved with a heavy, stainless steel sampling bomb equipped with remote opening/closing mechanism. This bomb was lowered to the bottom of the lagoon and a depth reading was obtained. The bomb was then raised to approximately 1-2 feet above the floor and filled. This was done to avoid sampling of the sludge layer itself or otherwise increased solids content due to turbulence caused by resting the bomb on the lagoon floor. Upon retrieval of the bomb, the sample fluid was decanted in its entirety into an unpreserved 1-liter bottle supplied by the laboratory and immediately placed on ice in a dark ice chest. Field measurements of temperature, pH, dissolved oxygen, oxygen reduction potential, and electrical conductivity were recorded at the time of sample retrieval.

2.3 Estimation of Lagoon Subsurface Mass Emissions

The mass flux of the sum of all dissolved constituents transported from the lagoon liquid into the underlying soil (i.e., subsurface mass emissions) was calculated as the product of the seepage rate and the total dissolved solids (TDS) concentration in the lagoon liquid, and expressed on a unit area basis (i.e., one acre) to facilitate comparison between lagoons and field emissions. For the computation of nitrogen emissions, the concentration of ammoniacal-N (i.e., the sum of NH_4^+ and NH_3) in the lagoon liquid was invoked. Ammoniacal-N was chosen for the mass calculations because it constitutes the majority of the soluble and mobile fraction of total nitrogen in the lagoon. Following the approach of Ham and DeSutter (1999), organic nitrogen, mostly occurring as particulate matter, was not fully included in the calculations due to its immobility and pore-clogging attributes.

Organic nitrogen exists in many different forms in lagoon water and is broadly categorized as dissolved organic nitrogen (DON) and particulate organic nitrogen (PON). To investigate the relationship between DON and PON, total Kjeldahl nitrogen (TKN) analyses were conducted on unfiltered and filtered lagoon samples. TKN is the sum of nitrogen from ammoniacal-N and organic nitrogen. Due to the strongly anaerobic conditions in lagoon water, TKN is an accepted estimator of total nitrogen, since nitrite and nitrate are not stable under strongly anaerobic conditions. Filtered TKN was used as an estimate of the sum of ammoniacal-N and DON, and this quantity was used for N-mass emission computations unless it was smaller than the results of laboratory analysis of ammoniacal-N (i.e., EPA method 350.1), in which case ammoniacal-N concentrations were used. Mechanisms for loss of ammoniacal-N during filtration, which could lead to filtered TKN concentrations that are smaller than the results from EPA method 350.1, are not entirely clear (e.g., both volatilization and sorption to filtrate should be minimal). The computational approach used herein was selected to avoid incidental underestimation of N-mass emissions.

2.4 Lagoon Perimeter Soil Borings and Sampling

Two to six boreholes were advanced along the perimeter of twelve lagoons for a total of 53 boreholes. Drilling services were provided by EnProbe (C-57 license 777007; Oroville, CA - http://enprobedirectpush.com/) using 5410, 6600, and 7822DT rigs and GeoProbe™ direct push dual-tube technology with a borehole diameter of 2.25 inches. Continuous soil cores (1.25-inch diameter) were retrieved in plastic (butyrate) single-use tubes. Tubes were double-cut lengthwise to expose the soil core for examination. Earthen materials were described and logged in the field by California licensed professional geologists experienced in water well and environmental drilling, testing, and construction. The description of the samples followed the American Society for Testing and Materials (ASTM) Unified Soil Classification System (USCS). Representative material samples were collected and archived.

The boreholes were abandoned in accordance with County requirements and in the presence, or under the direction of, a County inspector. The boreholes were backfilled using Portland cement based grout. PVC tremie pipe was installed in the borehole with its opening near the bottom of the borehole. Cement grout was then mixed and poured into the tremie until the cement grout approached ground surface. The lower end of the tremie remained immersed in fresh grout so that the rising grout from the bottom displaced groundwater in the borehole without washing out or diluting the grout. The tremie was then removed and additional grout was poured from the surface to bring it to ground surface.

Groundwater samples were retrieved from the uppermost few inches or feet of first-encountered groundwater. This is the saturated zone nearest to the bottom of the ponds; therefore, groundwater chemical characteristics in the test holes are expected to more closely resemble chemical characteristics of the lagoon liquor than groundwater samples retrieved from monitoring wells.

Samples were retrieved with the inertial pumping technique using HDPE tubing and foot valves. New materials were used for each sample. Field measurements of specific conductance (SC), pH, and temperature were obtained.

2.5 Groundwater Data Collection

CVDRMP collects monthly depth to water measurements in all 443 network wells and quarterly groundwater samples for chemical analyses. Groundwater samples for chemical analyses are retrieved from all network well sites. Specifically, at a given well site composed of either a single well, nested wells, a well cluster, or a combination thereof, a groundwater sample is retrieved from the well that intersects the uppermost portion of first encountered groundwater. When groundwater levels decline below the shallow well screen, a sample is retrieved from the next deeper well.

2.5.1 Groundwater Level Measurements

An electrical sounder is used to measure the depth to groundwater from a specified reference point (usually the top, north side of the well casing). Measurements are recorded to the nearest 0.01 foot. Measurements on any one dairy are collected near in time to obtain a data set resembling a “snapshot in time”.

During groundwater quality sampling campaigns, a depth to water measurement is obtained prior to sampling a monitoring well. The static water level in conjunction with well construction information is used to calculate the volume of water in the well. This information is used to determine the minimum volume of water to be purged prior to sample collection.

2.5.2 Purging Protocol

Monitoring wells are purged and sampled using dedicated HDPE tubing equipped with stainless steel foot valves. Where groundwater is sufficiently shallow, this assembly is used in combination with a centrifugal pump on the surface. Prior to sample collection, the dedicated tubing is disconnected from the pump, and sample bottles are filled with groundwater using the inertial pump process. Using this equipment and process eliminates the need for decontamination because the groundwater sample does not come into contact with equipment shared between wells.

Monitoring wells are purged of three or more wet casing volumes and until indicator parameters (temperature, pH, and specific conductance) have stabilized prior to sample retrieval. Stabilization is defined as consecutive readings at approximately 5-minute intervals (or at intervals of casing volumes) where parameters do not vary by more than 5 percent. Purged groundwater is disposed of by spreading it on the ground at a reasonable distance from the sampled well to avoid the potential for purge water to enter the well casing again during the purging process.

The following parameters are monitored during the well purging:

- Temperature (°C)
- pH (standard pH-units)
- Specific Conductance (µS/cm)
- Dissolved oxygen (mg/L)
- Dissolved oxygen (percent saturation) (added in February 2013)
- Oxygen reduction potential (mV)
- Turbidity (NTU)

Visual (color, occurrence of solids), olfactory (odor) and other observations (e.g., wellhead conditions, well access, ground conditions, weather) are noted as appropriate.

2.5.3 Instrumentation and Maintenance

The following equipment is used during purging and sampling activities:

- Purging: dedicated tubing with foot valve, centrifugal/inertial pumping
- Sample retrieval: dedicated tubing with foot valve
- Depth to water: electrical sounder
- Temperature, pH, electrical conductivity: *YSI* multi probe instrumentation (or similar)
- Dissolved oxygen: *YSI* instrumentation (or similar)
- Oxygen reduction potential: *Oakton ORPTestr* (or similar)
- Turbidity: *Orbeco-Hellige* Model 966 turbidity meter (or similar)

Shop and field calibration of instrumentation is conducted following the manufacturer's instructions and guidelines using appropriate standard solutions and procedures and at manufacturer recommended intervals. The electrical sounder and thermometer are factory calibrated and are not field calibrated.

Due to the use of dedicated equipment, there are no decontamination procedures needed.

2.5.4 Sample Handling and Recordation

Upon completion of purging activities, groundwater quality samples were collected in laboratory-supplied bottles with or without preservative (depending on analyses to be conducted and recommendation from the analyzing laboratory) according to laboratory instructions. Bottles were labeled with laboratory-supplied labels, immediately placed on ice, and kept in a dark ice chest (at 4 °C) until received by the laboratory. Sample pick-up was coordinated between the field technicians and the laboratory's own courier service under observance of applicable holding times. All samples were analyzed by an ELAP (Environmental Laboratory Accreditation Program) certified laboratory.

A chain-of-custody (COC) form is used to record sample identification numbers, type of samples (matrix), date and time of collection, and analytical tests requested, and blind duplicate samples. In addition, times, dates, and individuals who had possession of the samples are documented to record sample custody. A field sheet is used to document field activities and measurements. Constituents, analytical methods, and their reporting limits are shown on **Table 3**.

2.5.4.1 Quality Assurance Procedures

Quality assurance (QA) is an overall management plan used to guarantee the integrity of data collected by the monitoring program. This includes the above guidelines for groundwater level measurements, purging protocol, and sample handling and recordation. Quality control (QC) is a component of QA that includes analytical measurements used to evaluate the quality of the data. A brief discussion of field QC is followed by a discussion of laboratory QC requirements.

2.5.4.1.1 Field Quality Control

"Blind" duplicate field samples (duplicate samples) are collected to assess the precision (i.e., repeatability) of sampling results as influenced by natural variability of constituent concentrations in the sample and laboratory performance. Therefore, concentration differences between sample pairs, even large differences, do not necessarily indicate poor laboratory performance. Laboratory performance is addressed via laboratory quality control measures (see next section) and the cation/anion balance. This field quality control program is not used to adjust individual sample results.

The identified sample and its duplicate sample are retrieved immediately following each other to limit natural variability. The true identity of duplicate samples is not noted on the COC form, rather a unique identifier is provided. The identities of the duplicate samples are recorded on the field sheet, but the sampling locations of the duplicate samples are not revealed to the laboratory. Duplicate samples are collected from at least 5 percent (1 in 20) of the total number of sample locations (i.e., in these cases two samples are collected from the same sample location).

2.5.4.1.2 Laboratory Quality Control

Quality assurance and quality control samples (e.g., spiked samples, blank samples, duplicates) are employed by the laboratory to document the laboratory performance. Results of this testing are provided with each laboratory report.

2.5.4.1.3 Review of Laboratory Data Reports

Data validation includes a data completeness check of each laboratory analytical report. Specifically, this review includes:

- Review of data package completeness (ensuring that required QC and analytical results are provided);
- Review of the required reporting summary forms to determine if the QC requirements were met and to determine the effect of exceeded QC requirements on the precision, accuracy, and sensitivity of the data;
- Review of the overall data package to determine if contractual requirements were met; and
- Review of additional QA/QC parameters to determine technical usability of the data.

In addition, the data validation includes a comprehensive review of the following QA/QC parameters:

- Holding times (to assess potential for degradation that may affect accuracy)
- Blanks (to assess potential laboratory contamination)
- Matrix spikes/matrix spike duplicates and laboratory control samples (to assess accuracy of the methods and precision of the method relative to the specific sample matrix)
- Internal standards (to assess method accuracy and sensitivity)
- Compound reporting limits and method detection limits
- Field duplicate relative percent differences

Table 3: Analytical Methods and Reporting Limits for Groundwater and Lagoon Water Analysis

Constituent	Analytical Method	Reporting Limit (mg/L)
Sodium	EPA 200.7	1.0
Potassium	EPA 200.7	1.0
Magnesium	EPA 200.7	1.0
Calcium	EPA 200.7	1.0
Chloride	EPA 300.0	0.5
Sulfate	EPA 300.0	1.0
Bicarbonate (as CaCO3)	SM2310B	5.0
Carbonate (as CaCO3)	SM2310B	5.0
Hydroxide (as CaCO3)	SM2310B	5.0
Phosphorous	EPA 365.4	0.15
Total Dissolved Solids	SM2540C	10
Ammoniacal-N	EPA 350.1	0.1
Total Kjeldahl Nitrogen-N	EPA 351.2	0.2

2.6 Geophysical Investigations

NORCAL Geophysical Consultants conducted reconnaissance electrical resistivity (ER) testing on two dairy lagoons in fall 2014 (BET and MAC). In 2015, additional geophysical work was carried out on the MAC lagoon plus ten more lagoons, including ER, the OhmMapper method, and electromagnetic (EM) testing. An overview of these methods is provided in the following sections. Detailed mathematical method descriptions, limitations, and discussions of the instrumentation and data processing are provided in the appendices of each of NORCAL Geophysical Consultants' reports provided in **Attachment 7**.

2.6.1 Electrical Resistivity Profiling

Electrical resistivity is a measure of the resistance of a volume of material to the flow of electrical current. The electrical resistivity of earth materials is affected by factors such as mineralogy, porosity, permeability, and water content. In saturated unconsolidated materials, electrical resistivity is typically directly proportional to permeability. The more permeable a material is, the more resistive it becomes. For example, coarse-grained materials such as sand and gravel typically exhibit higher electrical resistivities than fine-grained materials such as silt and clay. However, the resistivity of saturated earth materials is also greatly affected by the concentration of dissolved salts or free ions in the saturating fluid. The introduction of highly conductive fluids, such as lagoon water, can significantly decrease the electrical resistivity of both coarse-grained and fine-grained materials. Therefore, earth materials that have been invaded by lagoon water are expected to have anomalously low electrical resistivity. Generally, saturation does not seem to have as much of an effect on resistivity as permeability unless the saturating fluid is very conductive. In that case, saturation significantly lowers the resistivity of the permeable zone.

The ER survey employed the most commonly used electrode configuration, the dipole-dipole array. In practice, data were collected using multiple electrodes distributed at uniform intervals along a line. Each electrode was a stainless steel stake, about twelve inches long and with a diameter of approximately 3/8-inch. Each electrode was driven into the ground to a depth of approximately ten inches. Once the electrodes were in place, they were connected to an electrical resistivity meter through multi-connector (take-out) cables. Prior to data collection, the electrical contact resistance was measured between each electrode and the ground. If any of the contact resistance values were determined to be too high to acquire accurate data, the contact resistance was lowered by (i) improving the contact between the electrode and the cable, (ii) re-seating the electrode, (iii) wetting the ground around the electrode with salt water, and/or (iv) adding more electrodes connected in parallel. Once all of the contact resistances were within a satisfactory range, electrical resistivity data were automatically collected according to a set of instructions (command file) programmed into the electrical resistivity meter. Upon completion of the readings, the resulting electrical resistivity data were transferred to a computer for subsequent processing.

Following completion of the ER survey, a Trimble global positioning system (GPS) with sub-foot accuracy was used to measure the geographical coordinates of select electrodes along each ER line. These positions were exported for mapping and data analysis. The results of ER surveys are shown on color contoured cross-sections (i.e., profiles) that depict the variation in electrical resistivity beneath each ER line. The dashed horizontal lines on the profiles indicate the approximate location of the water table at the time of the survey. <u>Of primary importance for the interpretation of these profiles are the changes of electrical resistivity, not their absolute values.</u> In fact, ER values are not absolute values. Instead, they are relative to a starting model that is used in the inversion process of the raw data. This model accounts for all of the measured apparent ER values in any given survey. The profiling models for the ER surveys tended to yield lower electrical resistivities than the OhmMapper method. This is due to the deeper penetration depth of the ER surveys (typically 60 feet) and a larger proportion of the investigated depth being situated below the water table (i.e., lower electrical resistivities in the saturated zone), whereas OhmMapper results are proportionally more influenced by high electrical resistivities in the unsaturated zone (depth of investigation approximately 15-20 feet). There are other reasons why results from the two methods differ:

- The ER method uses galvanic coupling (metal stakes driven in the ground) whereas the OhmMapper method uses capacitive (a type of electromagnetic) coupling.
- The ER method operates at direct current levels whereas the OhmMapper method operates at a frequency of approximately 18 kHz. Since electrical resistivity is affected by frequency, the two methods generate different values.

- ER and OhmMapper data sets require different software for post-acquisition data processing.

Consequently, ER and OhmMapper results cannot be directly compared. Results between sites also cannot be directly compared.

The color scheme for the ER profiles (and also for the OhmMapper profiles) uses cold colors to indicate high electrical resistivities and increasingly warmer colors to indicate lower resistivities. Increasingly warmer colors are interpreted as an increasing effect of high-salinity water emanating from the lagoon and invading the underlying groundwater.

2.6.2 OhmMapper

The Ohmmapper consists of a transmitter, a number of receivers and an instrument console. Each transmitter/receiver unit consists of a cylindrical pod with cables extending from both ends. Each pod contains a gel-cell battery and the appropriate electronic circuitry that enables the unit to transmit or receive electromagnetic signals of specified frequency. Together, the pod and its cables act as one plate of a capacitor whereas the earth represents the other plate. In addition, each pod and its extending cables are considered to be analogous to a dipole in an electrical resistivity survey.

In operation, electromagnetic signals produced by the transmitting dipole are injected into the ground through capacitive coupling and are detected by the receiving dipoles, also through capacitive coupling. The receiver dipoles are connected daisy-chain style to the control console via umbilical cable. The transmitter dipole is independent and is attached by a rope to the end of the receiver dipole farthest from the console. The longer the rope, the farther the receivers are from the transmitter and the greater the depth of penetration. However, if the rope is too long, the signal-to-noise ratio at the receivers farthest from the transmitter may obstruct collection of usable data. Therefore, the rope length has to be adjusted (at 2.5 meter intervals) to provide the maximum depth of investigation while maintaining an acceptable signal-to-noise ratio at each receiver. Once a proper rope length is established, the entire assembly is towed along a traverse at a slow walking speed. As the array is in motion, the signals produced by the transmitting dipole are detected by each receiver dipole in the array and are transmitted to the instrument console.

The results of Ohmmapper surveys are shown on color contoured cross-sections (i.e., profiles) that depict the variation in electrical resistivity beneath each transverse. This is similar to the results of the ER surveys. The dashed horizontal lines on the profiles indicate the approximate location of the water table at the time of the survey. Of primary importance for the interpretation of these profiles are the changes of electrical resistivity, not their absolute values (see discussion in the last paragraphs of *Section 2.6.1*). The advantage of the OhmMapper over standard resistivity methods is that it does not require driving electrodes into the ground, thus, making data collection more rapid. It also tends to provide higher resolution profiles (i.e., it can differentiate smaller-scale resistivity changes than the ER survey). The disadvantage is its smaller depth of penetration. The depth of investigation was approximately 15-20 feet.

2.6.3 Electromagnetic Profiling

EM profiling is a method whereby electrical current is injected into the subsurface through electromagnetic induction. EMP instruments contain two sets of coils mounted at fixed locations on opposite ends of a boom with an instrument package mounted in the middle. One set of coils transmits the primary electromagnetic field and the other set of coils detects the resulting secondary magnetic field. In operation, the instrument is carried at hip level in the horizontal position at a moderate walking pace. Survey marks were referenced every 50 feet using GPS as the instrument was carried. Measurements were taken approximately every 2.2 feet along the walked transects.

The results of the EMP are depicted as terrain conductivity maps. The terrain conductivity is representative of the electrical bulk properties of a roughly cube-sized volume of subsurface materials. The penetration depth cannot be increased without proportionally increasing the length and width of the investigated volume. Larger investigated volumes involve a greater degree of volume averaging, including both the unsaturated and saturated zones) while local detail (resolution) diminishes. Of primary importance for the interpretation of the terrain conductivity maps are the changes of electrical resistivity, not their absolute values. Results cannot be compared between sites because instrumentation output is calibrated separately for each site based on site-specific conditions.

This technology was used at the two sites with the shallowest groundwater (<5 feet) and the penetration depth was approximately 15 feet.

3 RESULTS AND DISCUSSION

Map Series 1 provides site maps of the 27 dairies discussed herein. These maps show the dairies' production areas with the associated infrastructure (lagoons, animal housing, and adjacent fields) and wells (e.g., domestic, irrigation, and dedicated monitoring wells), and soils. **Attachment 1** provides a comprehensive tabulation of key properties of the soils that are mapped within the footprint of the lagoons and **Attachment 2** summarizes lagoon construction and operational information. **Map Series 2** shows maps of the 24 dairies where water balance tests and/or lagoon perimeter investigations were carried out, including the locations of the lagoon perimeter boreholes and select borehole water quality results, water level hydrographs from monitoring wells adjacent to the lagoons, the predominant directions of groundwater flow beneath the lagoons, and select lagoon properties. Lagoon water quality obtained for those lagoons where water balance tests were done is summarized in **Attachment 3**. For those lagoons where water balance tests were not carried out, lagoon water quality information was extracted from the dairies' most recent annual reports (covering calendar year 2014) and summarized in the narrative of the site-specific discussions. Depth-to-water readings (2012-2015) and groundwater level elevations are tabulated in **Attachment 4**. Groundwater quality data (2012-2015) from the monitoring wells are tabulated in **Attachment 5**, including data from other on-site monitoring wells that are part of CVDRMP's well network (some wells are far removed from the lagoons such that they are not shown on the maps). Test hole groundwater quality from the 2014 lagoon perimeter subsurface hydrogeologic investigation is provided in **Attachment 6**. **Map Series 3** depicts geophysical lines together with the soil boring locations, lithological profiles, resistivity profiles from the ER and OhmMapper surveys, contours of ground conductivity from the EM surveys. NorCal Geophysical Consultants' geophysical investigation reports are provided in their entirety in **Attachment 7**.

Field sheets from groundwater sampling campaigns and the associated laboratory analytical reports were provided in CVDRMP's annual reports (LSCE 2013; LSCE 2014b; LSCE 2015b; LSCE 2016a). The annual reports also include extensive and cumulative discussion of groundwater levels, groundwater flow directions, and gradients. This effort is not reproduced in this report. Lithologic logs and laboratory analytical reports for soil boring groundwater results were provided in LSCE (2015a). Laboratory analytical reports for lagoon sampling results were provided in LSCE (2015c).

3.1 Description of Ambient Soils and Lagoons

3.1.1 Ambient Soil Characteristics

Lagoons are most cost effectively constructed below the surrounding grade. In areas of relatively shallow groundwater occurrence, lagoons are constructed as above-ground basins. These are shallow excavations where the excavated material is used to build the side berms. This reduces the excavation depth and total excavation volume over that of a similarly sized below-ground lagoon. The earthen depth of above-ground lagoons is the vertical distance between the crest of the berm and the floor of the lagoon. While an above-ground lagoon is still partially below ground, a below-ground lagoon is entirely below ground.

USDA NRSC SSURGO soil maps can provide an indication of the texture and associated permeability of earthen materials that were used or penetrated during construction, but they cannot provide evidence for the actual material composition. These NRCS soil surveys are completed most typically to a depth of five to six feet and lagoon excavation may exceed this depth. Also, soil properties can be highly variable over the surveyed depth. In the case of above-ground lagoons, it is unknown how the undocumented excavation depth is related to the documented earthen depth[5], especially in cases where borrowed material was incorporated in construction. Depending on lagoon geometry, an above-ground lagoon with an earthen depth of 12-15 feet may or may not have been excavated more than 6 feet below the existing grade. In cases where this depth was moderately exceeded (e.g., by 2 feet), the majority of the side wall area would still fall within the depth of the soil survey. Another limitation of soil survey information is that it represents averages and ranges that may or may not be reflective of site conditions. For example, clay content may range from 10-45% in a particular loam but how that relates to the on-site clay content is unknown.

3.1.2 Lagoon Construction Records and Operational Characteristics

In all but two cases (SO2 and DLF), construction documentation was not available for the lagoons where water balance testing was completed (**Attachment 2**). The absence of engineering drawings, specifications, as-built construction documentation, quality assurance protocols and quality control documentation (QA/QC), or any supporting data, such as soil texture analysis, compaction tests, construction notes, or information from percolation tests, is reflective of broader industry conditions before the adoption of the Dairy General Order.

For the SO2 lagoon (constructed in the late 1980s), documentation of the installation of an earthen liner with imported material exists. Earthen-liner thickness is given as a minimum of 2 feet on the lagoon floor and a minimum thickness of 1 foot on the sides. The liner was compacted with the wheels of a loaded scraper. The degree of compaction was not specified. The imported material is reported to have a clay content ranging from 20 to 26%. At the DLF lagoon (constructed in 2001), several 3-hour percolation tests (after three days of presoaking) were performed before lagoon construction. These tests were done with both fresh water and waste water, and yielded infiltration rates ranging from 73 to 1,996 mm d^{-1} (fresh water) and from 81 to 687 mm d^{-1} (waste water). Soil textural testing results documented clay content ranging from 8.5 to 32.1%. Areas of insufficient clay content were covered with a partial clay liner, including repair work after berm failure.

In both of these cases, testing and construction documentation is minimal, pertinent information and QA/QC are missing; as a result, it is impossible to ascertain with confidence whether these lagoons conform to Title 27 regulations.

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[5] The earthen depth of a lagoon is the vertical elevation difference between the deepest point of excavation and the lowest crest elevation.

3.1.3 Lagoon Operational Characteristics

Attachment 2 provides information on operational and management decisions, such as the presence of a mechanical solids separator, minimum waste depth, and the method of cleaning manure solids out of the lagoon to maintain storage capacity. While these are essentially categorical variables, the following discussion highlights the great variability within each category.

All but the NUN and TBR lagoons are operated together with settling basins. NUN operates a mechanical separator. Several of the other dairies use a mechanical separator in addition to settling basins. Excessive solids build-up and storage loss in the lagoon are managed in different ways. Most operators use a combination of agitation/dilution during pump-out for irrigation to control solids build-up. The frequency varies from several times per year to every few years. CAE reports to never have deliberately removed solids from the lagoon. BRE and MAP dry their lagoons periodically and remove solids via excavation.

The ability of manure solids to clog soil pores and reduce seepage has been amply documented and is summarized in LSCE (2008). At the time of the 2008 literature review, no information was found on the effect of particle size distribution of lagoon inflow on seepage rates. Mechanical separators typically remove only the coarsest solids that would otherwise float and not significantly contribute to a sealing effect. Similarly, settling basins do not remove the finest of particles and unless properly maintained, even larger particles can easily bypass the settling basin into the lagoon. The presence of a mechanical separator or settling basins does not provide information on actual efficacy of solids reductions and particle size distribution. Further, it is unknown how seepage rates would react to differing lagoon inputs once a sludge layer has developed.

The efficacy of solids removal can vary widely between individual lagoons, spatially within individual lagoons, and over the years. The degree to which an established sludge layer is left intact may also vary significantly. The frequency of deliberate solids removal ranges widely from many times per year to every few years or never.

A different mode of solids removal is that of emptying the lagoon and drying it before solids are excavated. This practice is also reflected in the minimum waste depth along with other operational considerations. The degree to which an established sludge layer is left intact when scooped out with loaders or scrapers may vary significantly. Scraping ‘to dirt’ is a common practice. While this practice removes the sludge layer, it maximizes lagoon storage and the intervals between lagoon cleanout.

Beyond the physical clogging of soil pores, two other modes of manure sealing are recognized: (i) biological sealing by microbial communities and their byproducts and (ii) chemical sealing caused by salt-induced dispersion of clays. While the proportional contribution to the overall manure sealing effect may vary, it is well documented that it is a process that acts within a few weeks and months of initial filling of the lagoon (LSCE 2008).

3.2 Seepage Rates and Subsurface Mass Loading

3.2.1 Seepage Rates

At seven sites, repeat tests were carried out resulting in two to four seepage rates per lagoon with individual uncertainty intervals (**Table 4**). At five sites, single tests were carried out. At the remaining five sites, multiple short-term tests were completed (up to 10 tests per site). Start times, end times, and durations of each test are shown, and lagoon level trends between tests due to pump-outs or pump-ins. For tests where precipitation was registered with the on-site rain gauge, an adjusted seepage rate (S_{adj}) accounting for twice the logged precipitation was computed along with the unadjusted seepage rate.

In sum, 50 water balance tests were carried out at 17 lagoons. Seepage rates ranged from 0.0-3.9 mm d^{-1}. This accounts for all repeat testing, including short-term without individual uncertainty intervals and longer-term with individual uncertainty intervals, seepage rates obtained immediately after lagoon filling, and seepage rates that were adjusted for precipitation uncertainty. Mean and median values are not discussed for all 50 tests because these statistics would be heavily biased toward the lagoons with the most repeat testing (i.e., ANT and NUN), which would introduce bias toward small seepage rates.

To facilitate unbiased description of the data set, seepage rates were aggregated for each lagoon. Five lagoons have single test results available with uncertainty intervals (BEA, ROB, GOD, ZZI, and TBR). For lagoons where repeat short-term test results are available without individual uncertainty intervals, mean seepage rates were calculated (BET, CAE, PLS, ANT, and NUN) and uncertainty intervals were computed as two times the standard deviation of the individual rates (i.e., containing 95% of the sample population). Seven lagoons have multiple test results available, each with individual uncertainty intervals (BRE, CRE, DLF, MAP, SO2, AIR, and MNS). All of these mean values include seepage rates obtained immediately after lagoon filling, and seepage rates that were adjusted for precipitation uncertainty. The mean of these 17 seepage rates is 1.1 mm d^{-1}, the median is 0.7 mm d^{-1}, and the range is 0.0-2.9 mm d^{-1}.

BRE is of particular interest because the high seepage rates (S=2.8 mm d^{-1} and S_{adj}=3.9 mm d^{-1}) are clear outliers. This is the only location where soil maps indicate significant gravel content (up to 35%). Anecdotal evidence indicates that water quality impacts at a nearby well that occurred shortly after the lagoon was first put into service were remedied with a partial clay liner. This is also one of the few tested lagoons that is dried out in preparation for solids removal via excavation, a process that can facilitate damage to the protective sludge layer and the earthen liner, both of which could expose high porosity strata at this location. Despite these circumstances, these high seepage rates do not appear to reflect long-term conditions at this location. Seepage rate values increased from an initial 2.3 to 2.5 mm d^{-1} as the lagoon was filled between tests and, according to the owner, the lagoon was already filled beyond normal operating levels in preparation for the water balance test. These rates are similar to the next largest seepage rates that were observed at CRE, DLF, and TBR.

The seepage rates determined by this study are consistent with the pertinent academic literature as reviewed in LSCE (2008). For example, Meyer and Baier (1971) and Meyer, Olson et al.

(1972) studied the performance of 17 established dairy and poultry waste lagoons (age of lagoons not disclosed) located in the San Joaquin Valley and constructed on soils of various textures ranging from sands to clay loams. They found that the infiltration rate was on the order of 1 mm d^{-1} (ca. 10^{-6} cm s^{-1}) regardless of the underlying soil type.

Korom and Jeppson (1994) report a seepage rate of 13 to 91 mm d^{-1} after 5 years of operation of an unlined dairy manure lagoon constructed on very gravelly loamy coarse sand in Heber Valley of north central Utah. Among the literature reviewed, this study reported the largest infiltration rates from dairy manure lagoons.

Parker, Schulte et al. (1999) provide a review of research on seepage from earthen animal waste lagoons, ranging from laboratory and small-scale investigations to full-scale investigations, subsurface soil and groundwater investigations. Based on their comparison of published seepage data for different soil types, they conclude that there may be problems with accurately predicting infiltration rates based on soil texture or grain size distribution alone.

3.2.1.1 Effects of Rapid Lagoon Level Fluctuations on Seepage Rates

The saturation of previously dry berm material due to rising liquid levels provides a conceptual explanation for temporarily increased seepage rates. Side walls are also subject to desiccation which can cause secondary porosity causing increased seepage losses. Lastly, the thickness of the protective sludge layer typically decreases toward the top of the side walls as the opportunity for it to develop decreases in the same direction.

On the other hand, the drainage of previously saturated berm material due to falling liquid levels provides a conceptual explanation for temporarily decreased seepage rates.

At BET, BRE, CRE, and DLF, water balance tests that were carried out immediately after lagoons received liquid manure inputs yielded higher seepage rates than water balance tests carried out before liquid levels were raised. At ANT, effects of lagoon level rises on seepage rates were less apparent, which may be explained by relatively high clay content of natural soils at this site (i.e., loam with 18-30% clay content) and associated low hydraulic conductivities. ANT is the only site where a water balance test was carried out immediately after lagoon levels were lowered and the results indicated a clearly decreased seepage rate. At NUN, also a site with high clay content in natural soils (i.e., silty clay with 30-65% clay content), the effects of the pump-ins on seepage rates, if any, were masked by the noisy results.

3.2.1.2 Correlation of Mapped Soil Types and Seepage Rates

The seepage investigation did not find a strong correlation between mapped soil type and seepage rates. This is not surprising given the limitations of mapped soil characteristics predicting actual on-site soil conditions. However, some overall trends can be observed:

Three lagoons with relatively high mapped soil clay content were among the ones with the smallest seepage rates:

- ANT (18-30% clay) S=0.2 mm d^{-1}

- GOD (18-35% clay) S=0.2 mm d^{-1}
- NUN (30-65% clay) S=0.0 mm d^{-1}

Four of the highest seepage rates were associated with potentially gravely soil, sand, and sandy loam:

- BRE (up to 35% gravel and 10-60% clay) S=2.4 mm d^{-1} and up to S_{adj}=3.9 mm d^{-1} after filling
- BEA (sand, 0-15% clay) S=1.7 mm d^{-1} after filling
- ROB (sandy loam, 0-15% clay) S=2.0 mm d^{-1}
- ZZI (sandy loam, 6-18% clay) S_{adj}=2.0 mm d^{-1}

Despite TBR's substantial clay content (20-25% clay), its seepage rate of S_{adj}=2.2 mm d^{-1} was similar to those on sand and sandy loam. In contrast, the other four lagoons constructed in sand and sandy loam had much smaller seepage rates:

- BET (sand, 0-15% clay) S=0.2 mm d^{-1} and up to 1.0 mm d^{-1} after filling
- CAE (sand, 0-1% clay) 0.8 mm d^{-1}
- PLS (sandy loam, 7-18% clay) 0.6 mm d^{-1}
- MAP (sandy loam, 0-18% clay) 0.3 mm d^{-1}

Two lagoons were built in areas where the mapped clay content ranges from small to substantial proportions:

- CRE (10-45% clay) S=1.4 mm d^{-1} before filling to 2.3 mm d^{-1} after filling
- MNS (6-35% clay) 0.0 mm d^{-1}

Three lagoons were constructed with engineered clay liners. However, only two have documentation available (*Section 3.1.2*):

- AIR (18-33% clay native material) S=0.7 mm d^{-1}
- SO2 (1-2 foot thick clay liner with imported material; 20-26% clay content) S_{adj}=0.1 mm d^{-1}
- DLF (native sandy loam with 8.5-32.1% clay; areas with <10% clay were patched with clay liner) S=1.9 mm d^{-1} (initial test after essentially dry lagoon was filled to approximately one third of capacity) to S_{adj}=2.4 mm d^{-1} after additional filling)

Table 4: Lagoon Seepage Rates

Location	Start [Julian Day]	End [Julian Day]	Duration [d]	Lagoon Conditions †	Seepage Rate [mm d-1] Unadjusted	Seepage Rate [mm d-1] Adjusted for Rain	Mean Seepage Rate ¶ [mm d-1]
BET	339.65	340.92	1.27	15%	0.2	n/a	0.7 ± 0.8
	347.54	348.33	0.79	15% | ↑	1.0	n/a	
	354.78	356.63	1.85	15% | ↑	0.8	n/a	
BEA	330.71	335.27	4.56	↑	1.7 ± 0.5	n/a	n/a
PLS	6.40	7.42	1.02	-	0.6	n/a	0.6 ± 0.2
	8.34	9.32	0.98	-	0.5	n/a	
	10.42	11.36	0.94	-	0.7	n/a	
CAE	344.90	345.39	0.49	10%	0.7	n/a	0.8 ± 1.1
	345.95	346.34	0.39	10%	1.2	n/a	
	346.92	347.40	0.48	10%	0.1	n/a	
	347.90	348.32	0.42	10%	1.3	n/a	
ROB	325.71	331.27	5.56	-	2.0 ± 0.6	n/a	n/a
ANT	345.64	347.36	1.72	-	-0.1	n/a	0.2 ± 0.6
	347.72	350.46	2.74	↑	-0.1	n/a	
	350.54	351.66	1.12	↑	0.4	n/a	
	351.71	353.35	1.64	↑	-0.2	n/a	
	353.71	355.45	1.74	↑	0.6	n/a	
	355.50	357.46	1.96	↑	0.4	n/a	
	357.73	359.45	1.72	↑	0.4	n/a	
	359.49	360.33	0.84	↑	0.5	n/a	
	360.66	361.66	1.00	↓	-0.1	n/a	
	361.72	364.46	2.74	↑	-0.2	n/a	
GOD	73.36	74.76	1.4	-	0.2 ± 2.1	n/a	n/a
NUN	357.69	359.39	1.70	20% | ↑	-1.2	n/a	0.0 ± 1.3
	359.52	361.44	1.92	10% | ↑	0.3	n/a	
	361.56	364.42	2.86	5% | ↑	-0.2	n/a	
	364.50	366.39	1.89	↑	-0.1	n/a	
	1.58	3.34	1.76	↑	1.1	n/a	
	4.54	5.42	0.88	↑	0.4	n/a	
	5.53	7.5	1.97	↑	-0.2	n/a	
	7.56	8.29	0.73	↑	0.0	n/a	
BRE	13.36	16.21	2.85	↑	2.4 ± 0.9	n/a	2.9
	16.38	20.27	3.89	↑	2.3 ± 0.4 ‡	2.5 ± 0.4	
	20.39	23.25	2.86	↑	2.8 ± 0.8	n/a	
	23.40	26.24	2.84	↑	3.7 ± 1.2 ‡	3.9 ± 1.2	
CRE	8.58	16.21	7.63	-	1.4 ± 0.4	n/a	1.9
	58.66	69.78	11.12	↑	2.3 ± 1.1	n/a	
DLF	316.58	322.70	6.12	↑	1.9 ± 0.6 ‡	1.9 ± 0.6	2.2
	353.54	358.84	5.30	↑	2.3 ± 0.4 ‡	2.4 ± 0.4	
	358.97	363.33	4.36	-	2.2 ± 0.7	n/a	
ZZI	315.51	334.26	18.75	-	1.9 ± 0.6 ‡	2.0 ± 0.6	n/a
MAP	323.54	328.41	4.87	-	0.0 ± 0.7	n/a	0.3
	340.52	344.54	4.02	-	0.5 ± 0.5	n/a	
SO2	353.60	354.46	0.86	-	0.0 ± 1.2	n/a	0.1
	355.00	355.93	0.93	-	0.0 ± 1.1 ‡	0.1 ± 1.1	
AIR	50.57	53.51	2.94	10%	0.4 ± 0.7 ‡	0.6 ± 0.7	0.7
	62.86	66.33	3.47	10%	0.6 ± 1.1 ‡	0.7 ± 1.1	
MNS	35.31	37.52	2.21	-	-0.2 ± 0.9 ‡	-0.1 ± 0.9	0.0
	39.89	43.42	3.53	-	0.1 ± 0.8	n/a	
TBR	40.69	43.28	2.59	20%	2.0 ± 0.7 ‡	2.2 ± 0.7	n/a

† Percent lagoon coverage with floating manure solids. ↑ and ↓ indicate lagoon water level rises and drops, respectively, due to pump-in/pump-out prior to testing. ‡ Seepage rate potentially represents an underestimate due to a small amount of rain registered by the on-site rain gauge that was not accounted for in the computation.
¶ Uncertainty at the 95% confidence interval was approximated as two times the standard deviation. n/a=not applicable.

3.2.2 Nitrogen and Mineral Subsurface Mass Loading

Estimates of subsurface nitrogen (N) mass loading rates ranged from zero to 3,503 lbs ac^{-1} y^{-1} with a mean of 1,045 lbs ac^{-1} y^{-1} (**Table 5**). Lagoon water at MAP (south lagoon) and SO2 was inadvertently not sampled. However, due to their small seepage rates, mass loading rates are expected to be relatively small. Discounting the two lagoons with zero-seepage (and associated zero subsurface mass loading), the second smallest N loading rate was 241 lbs ac^{-1} y^{-1}, indicating a 15-fold range (i.e., the same range as the mean seepage rates, excluding zero-seepage rates). Ammoniacal-N concentrations used for N-mass loading computations exhibited a 19-fold range from the minimum value to the maximum value (i.e., from 44 to 853 mg L^{-1}).

Measurements of total dissolved solids (TDS) were used to estimate subsurface mineral mass loading rates, and they ranged from zero to 27,330 lbs ac^{-1} y^{-1} with a mean of 10,886 lbs ac^{-1} y^{-1} (**Table 6**). Discounting the two lagoons with zero-seepage (and associated zero subsurface mass loading), the second smallest mineral loading rate was 3,250 lbs ac^{-1} y^{-1}, indicating an 8-fold range. TDS concentrations used for the mineral mass loading computations exhibited a 7-fold range from the minimum value to the maximum value (i.e., from 1,133 to 7,850 mg L^{-1}).

Given the range of lagoons that were tested, including the range of soil textural characteristics and geographic distribution, these mass loading ranges may be reasonable approximations of the actually occurring N-loading rates across Central Valley dairy lagoons.

Table 5: Lagoon Subsurface Nitrogen Mass Loading

Dairy	Sample	Ammonia as N	TKN filtered	Highest Mean †	Seepage Rate ¶	Subsurface Mass Loading Rate
		- - - - - - - - - - - - - mg L^{-1}	- - - - - - - - - - - - -		mm d^{-1}	lbs $ac^{-1}y^{-1}$
BET	1	360	310	357	0.7	811
BET	2	420	390			
BET	3	290	270			
BEA	1	41	35	44	1.7	241
BEA	2	45	46			
BEA	3	45	47			
PLS	1	150	150	147	0.6	286
PLS	2	170	160			
PLS	3	23	130			
CAE	1	440	370	430	0.8	1,118
CAE	2	430	370			
CAE	3	420	380			
ROB	1	210	190	152	2.0	988
ROB	2	46	49			
ROB	3	200	180			
ANT	1	800	480	473	0.2	308
ANT	2	550	460			
ANT	3	62	480			
GOD	1	770	850	853	0.2	555
GOD	2	790	850			
GOD	3	810	860			
NUN	1	100	520	527	0.0	0
NUN	2	540	500			
NUN	3	61	560			
BRE	1	260	250	253	2.9	2,387
BRE	2	240	230			
BRE	3	260	260			
CRE	1	130	130	137	1.9	844
CRE	2	130	96			
CRE	3	150	140			
DLF	1	470	350	490	2.2	3,503
DLF	2	490	360			
DLF	3	510	380			
ZZI	1	230	250	223	2.0	1,452
ZZI	2	220	210			
ZZI	3	200	210			
AIR	1	490	420	485	0.7	1,103
AIR	2	460	400			
AIR	3	500	440			
AIR	4	490	480			
MNS	1	290	320	293	0.0	0
MNS	2	260	280			
MNS	3	290	280			
TBR	1	270	260	290	2.2	2,073
TBR	2	240	230			
TBR	3	360	250			

† Mean of ammoniacal N or filtered TKN, whichever is higher for calculation of subsurface mass loading rates.
¶ Mean seepage rates from Table 4.

Table 6: Lagoon Subsurface Mineral Mass Loading †

Dairy	Sample	Total Dissolved Solids (TDS)	TDS Mean	Seepage Rate ¶	Subsurface Mass Loading Rate
		- - - - - - - - - - - - - mg L^{-1}	- - - - - - - - - - - - -	mm d^{-1}	lbs $ac^{-1}y^{-1}$
BET	1	4,400			
BET	2	3,600	3,900	0.7	8,872
BET	3	3,700			
BEA	1	1,200			
BEA	2	1,100	1,133	1.7	6,261
BEA	3	1,100			
PLS	1	1,700			
PLS	2	1,700	1,667	0.6	3,250
PLS	3	1,600			
CAE	1	4,200			
CAE	2	4,000	4,100	0.8	10,659
CAE	3	4,100			
ROB	1	1,600			
ROB	2	1,200	1,567	2.0	10,183
ROB	3	1,900			
ANT	1	6,200			
ANT	2	6,800	6,500	0.2	4,225
ANT	3	6,500			
GOD	1	5,800			
GOD	2	7,200	6,733	0.2	4,376
GOD	3	7,200			
NUN	1	6,300			
NUN	2	6,600	6,500	0.0	0
NUN	3	6,600			
BRE	1	2,900			
BRE	2	2,900	2,900	2.9	27,330
BRE	3	2,900			
CRE	1	2,400			
CRE	2	2,400	2,433	1.9	15,025
CRE	3	2,500			
DLF	1	3,200			
DLF	2	3,000	3,067	2.2	21,925
DLF	3	3,000			
ZZI	1	2,200			
ZZI	2	2,400	2,267	2.0	14,732
ZZI	3	2,200			
AIR	1	4,000			
AIR	2	4,000	7,850	0.7	17,857
AIR	3	19,000			
AIR	4	4,400			
MNS	1	7,000			
MNS	2	5,800	6,233	0.0	0
MNS	3	5,900			
TBR	1	2,600			
TBR	2	2,500	2,600	2.2	18,589
TBR	3	2,700			

† Total dissolved solids concentrations used as estimate of mineral concentrations.
¶ Mean seepage rates from Table 4.

3.3 Groundwater Concentrations and Geophysical Imaging

This section discusses site-specific groundwater quality (21 sites) from dedicated monitoring wells and temporary soil borings that were advanced in fall 2014 in the context of hydrogeologic conditions, lagoon water characteristics, and the results from the geophysical testing that was started in fall 2014, expanded in spring 2015, and concluded in summer 2015 (LSCE 2013; LSCE 2014b; LSCE 2014a; LSCE 2015a; LSCE 2015b; LSCE 2016a).

3.3.1 MEN

Lagoon liquor was sampled three times in 2014 and concentrations were as follows:

1. TKN concentrations ranged from 302 to 510 mg/L.
2. Ammoniacal N concentrations ranged from 188 to 389 mg/L.
3. Organic N accounted for 5 to 38% of total nitrogen (TN).
4. Phosphorous (P) concentrations ranged from 23.60 to 34.70 mg/L.
5. Potassium (K) concentrations ranged from 385 to 820 mg/L.
6. Electrical conductivity (EC) measurements ranged from 3,704 to 5,197 µS/cm.

Monthly groundwater level measurements indicate that first encountered groundwater occurred at depths ranging from less than 5 to 14 ft (bgs) beneath the dairy between 2012 and 2015. Contours of equipotential water level elevations indicate mainly northwesterly groundwater flow near the lagoons, with occasional northerly to northeasterly flow components. As a result, MW1 and MW2 were generally down- to crossgradient of the lagoons and settling basins. During the time of geophysical testing in April and August 2015, groundwater in the monitoring wells adjacent to the lagoon system (i.e., MEN-MW1 and 2) was approximately 8 feet (bgs).

Key 2012-2015 groundwater chemistry is summarized below:

MEN-MW1

1. Ammoniacal N concentrations ranged from 0.29 to 140 mg/L.
2. TKN concentrations ranged from 1.6 to 140 mg/L.
3. Comparison of TKN and ammoniacal N indicates organic N concentrations of approximately 1-5 mg/L.
4. Nitrite-N concentrations were near or below the reporting limit.
5. Nitrate-N concentrations ranged from 9.2 to 60 mg/L.
6. K concentrations were distinctively elevated (16-240 mg/L).
7. SO_4 concentrations were distinctively elevated (150-280 mg/L).
8. TDS concentrations were significantly higher than in non-lagoon wells (3,000-4,100 mg/L). Na, Cl, and HCO_3 were the main contributors to the elevated salinity.

Groundwater chemistry at this location is indicative of lagoon seepage.

MEN-MW2

1. Ammoniacal N concentrations ranged from nondetect to 3.6 mg/L.
2. TKN concentrations ranged from 1.5 to 4.8 mg/L.
3. Comparison of TKN and ammoniacal N indicates organic N concentrations of approximately 1-2 mg/L.
4. Nitrite-N concentrations ranged from nondetect to 0.24 mg/L.
5. Nitrate-N concentrations ranged from nondetect to 48 mg/L.
6. K concentrations were distinctively elevated (21-90 mg/L).
7. SO_4 concentrations were distinctively elevated (190-290 mg/L)
8. TDS concentrations were significantly higher than in non-lagoon wells (2,100-3,100 mg/L). Na, Cl, and HCO_3 were the main contributors to the elevated salinity.

Groundwater chemistry at this location is indicative of lagoon seepage.

3.3.1.1 Geophysical Imaging

Line 5, located on the berm of the main lagoon and between the main lagoon and the adjacent in-ground settling basin, indicates the most apparent effects of lagoon seepage on underlying groundwater and in some areas, the water table coincides with a distinct decrease in electrical resistivity. The unsaturated zone is largely imaged yellow on this line. This is important because Line 6, located along the main lagoon's southern berm, does not show distinct resistivity changes at the water table and is imaged predominantly in yellow. This suggests that saline lagoon seepage has essentially no effect on groundwater immediately south of the lagoon. This is consistent with the predominantly northwestern groundwater flow directions beneath the lagoon and settling basins.

Line 9, located along the west side of the lagoon and settling basins, depicts very resistive zones in some areas of the lagoon's unsaturated berm material and also a distinct resistivity decrease at the water table in the northern corner of the lagoon. Low resistivity zones are also shown farther north along the water table suggesting effects of settling basin seepage. These effects appear to dissipate over the distance of 75 feet to the west, where Line 8 shows largely yellow and green colors north of the intersect with Line 5. Between the intersects of Lines 5 and 6, the effects of main lagoon seepage have also diminished. The occurrence of decreased resistivity at increased depth at the intersection of Lines 8 and 6, may indicate downward migration of saline water.

Line 1, located approximately 120 feet north of the northernmost settling basin, shows significantly higher resistivities than the other ER profiles, with the exception of a small area between 280-350 feet along the profile, indicating localized impact.

This area of localized impact was also identified by the OhmMapper on Line 1. OhmMapper Lines 2, 3, and 4 (all located between settling basins) show increasingly distinct resistivity changes below the water table from north to south (i.e., more orange and red colors toward the center of the settling basin/lagoon system). OhmMapper Lines 7, 8, and 10 show moderate resistivity decreases below the water table. These are largely imaged with green and yellow colors, which likely reflect the change from an unsaturated to a saturated soil matrix, rather than impact of lagoon or settling basing seepage.

3.3.1.2 Summary

Groundwater quality in two dedicated monitoring wells is indicative of lagoon seepage. However, groundwater quality is very different between the two wells and highly variable in time. The spatial and temporal variability illustrates the non-uniqueness of groundwater concentrations with respect to lagoon performance.

Geophysical imaging suggests that salinity effects on groundwater are the most developed in the center of the lagoon system where they extend below the maximum investigation depth of ~50 feet below the water table. Lateral movement of seepage-affected shallow groundwater is very limited and impacts are apparent only in the immediate vicinity of the lagoon footprint.

3.3.2 ANC

Lagoon liquor was sampled one time in 2014 and concentrations were as follows.

1. TKN: 806 mg/L.
2. Ammoniacal N: 538 mg/L.
3. P: 39.5 mg/L.
4. K: 820 mg/L.
5. EC: 9,330 µS/cm.

Monthly groundwater level measurements indicate that first encountered groundwater occurred at depths ranging from approximately 10 to 22 ft (bgs) beneath the dairy between 2012 and 2015. MW2 and MW4 are located on top of the lagoon's berm and, as a result, the depth to water is deeper in these wells. Contours of equipotential water level elevations indicate rather consistent westerly to northwesterly groundwater flow beneath the dairy. MW1 was downgradient of the lagoon, and MW2 and MW4 were crossgradient to downgradient of the lagoons. MW3 was downgradient of the animal housing (and also immediately upgradient of the lagoons). During the time of geophysical testing in April 2015, groundwater in the monitoring wells located at the foot of the lagoon berms (i.e., ANC-MW1 and 3) was approximately 13-15 feet (bgs).

Key 2012-2015 groundwater chemistry is summarized below:

ANC-MW1

1. Ammoniacal N concentrations were near or below the reporting limit.
2. TKN concentrations ranged from 0.36 to 0.54 mg/L.
3. Comparison of TKN and ammoniacal N indicates that TKN essentially reflected organic N concentrations.
4. Nitrite-N concentrations ranged from 0.15 to 0.43 mg/L.
5. Nitrate-N concentrations ranged from 4.2 to 14 mg/L.
6. TDS concentrations and individual general mineral concentrations were similar to non-lagoon wells.

Groundwater chemistry at this location is not indicative of lagoon seepage.

ANC-MW2

1. Ammoniacal N concentrations were near or below the reporting limit.
2. TKN concentrations ranged from 0.92 to 1.6 mg/L.
3. Comparison of TKN and ammoniacal N indicates that TKN essentially reflected organic N concentrations.
4. Nitrite-N concentrations ranged from below the reporting limit to 0.64 mg/L.
5. Nitrate-N concentrations ranged from 15 to 28 mg/L.
6. TDS concentrations and individual general mineral concentrations were similar to non-lagoon wells.

Groundwater chemistry at this location is not indicative of lagoon seepage.

ANC-MW3
Groundwater chemistry at this location is substantially attributed to recharge occurring in a source area within the animal housing. This includes nitrate-N concentrations ranging from 25 to 59 mg/L. Based solely on the proximity of this well to the lagoon, effects of lagoon seepage on its water chemistry are conceivable. However, presently, groundwater chemistry at this location is not indicative of lagoon seepage.

ANC-MW4

1. Ammoniacal N concentrations were below the reporting limit.
2. TKN concentrations were below the reporting limit.
3. Nitrite-N concentrations were below the reporting limit.
4. Nitrate-N concentrations ranged from 8.0 to 54 mg/L.
5. TDS concentrations and individual general mineral concentrations were similar to non-lagoon wells.

Groundwater chemistry at this location is not indicative of lagoon seepage.

3.3.2.1 Soil Boring Water Quality

At this facility, six soil borings were advanced and six groundwater samples were retrieved. All soil borings were advanced on the downgradient edge of the lagoon or between the lagoons.

1. Ammoniacal N concentrations ranged from 1.0 to 160 mg/L.
2. TKN concentrations ranged from 4.6 to 190 mg/L.
3. Nitrite-N concentrations were nondetect or near the reporting limit.
4. Nitrate-N concentrations ranged from 0.57 to 17 mg/L.
5. K concentrations ranged from 9.4 to 200 mg/L.
6. HCO_3 concentrations ranged from 560 to 2,200 mg/L.
7. PO_4 concentrations ranged from 51 to 87 mg/L.

Groundwater chemistry at all six soil borings is indicative of lagoon seepage. Soil boring SB5, which is centrally located and near MW1, exhibits the least indication of seepage. Its water chemistry is very similar to that at MW1, but with slightly higher salinity and slightly elevated levels of TKN (and organic N), K, HCO_3, and significantly higher PO_4. For comparison, groundwater chemistry at MW1 and the other lagoon wells (i.e., MW2 and MW4) is not indicative of lagoon seepage.

Nitrogen in the groundwater samples retrieved from the soil borings exists predominantly in the form of ammoniacal N and organic nitrogen. In contrast, these constituents have been found below or near their detection limits in groundwater samples retrieved from the lagoon monitoring wells. This indicates essentially complete oxidation of the reduced nitrogen forms within a few feet from the bottom of the ponds. Furthermore, TKN concentrations from the soil boring samples are more than twice as high compared to the lagoon monitoring well samples. TDS and several individual constituents show similar concentration decreases. For example, K concentrations are less than 10 mg/L in the monitoring wells, while they are up to 200 mg/L in the groundwater samples from the boreholes.

3.3.2.2 Geophysical Imaging

Line 4, located on the berm separating the two lagoons, indicates the most apparent effects of lagoon seepage on underlying groundwater. The water table coincides with a distinct decrease in electrical resistivity along the length of the lagoon, with predominantly orange and red colors to the maximum depth of investigation of ~40 feet below the water table. Lines 3 and 5, located on the outer berms of the lagoons parallel to Line 4, do not show this effect on groundwater salinity, suggesting very limited lateral movement of seepage-affected shallow groundwater. These two lines show moderate resistivity decreases below the water table. The resistivity decrease is imaged as a transition from blue/green colors to yellow, which likely reflects the change from an unsaturated to a saturated soil matrix.

3.3.2.3 Summary

Groundwater quality in four dedicated monitoring wells is not indicative of lagoon seepage. In contrast, groundwater quality obtained from six temporary boreholes is clearly indicative of lagoon seepage. This demonstrates monitoring wells' unreliability in detecting lagoon seepage.

Stark concentration decreases and changing redox conditions between the temporary boreholes and monitoring wells indicate substantial moderation of impacts to groundwater within the immediate proximity of the lagoons. The extreme constituent variability among soil boring water quality demonstrates the randomness of a small sample size and illustrates the non-uniqueness of groundwater concentrations with respect to lagoon performance.

Geophysical imaging suggests that salinity effects on groundwater are the most developed in the center of the lagoon system where they extend below the maximum investigation depth of ~40 feet below the water table. Lateral movement of salinity-affected shallow groundwater is very limited and impacts are apparent only in the immediate vicinity of the lagoon footprint.

3.3.3 BET

Lagoon liquor was sampled quarterly in 2014 and concentrations were as follows (see **Attachment 3** for additional lagoon water quality from CVDRMP's testing associated with the water balance testing):

1. TKN concentrations ranged from 106 to 739 mg/L.
2. Ammoniacal N ranged from 61.60 to 344 mg/L.
3. Organic N accounted for 42 to 70% of TN.
4. P concentrations ranged from 13.50 to 107 mg/L.
5. K concentrations ranged from 164 to 1390 mg/L.
6. EC measurements ranged from 2,300 to 8,020 μS/cm.

Monthly groundwater level measurements indicate that first encountered groundwater occurred at depths ranging from approximately 5 to 23 ft (bgs) beneath the dairy between 2012 and 2015. During the time of geophysical testing in November 2014, groundwater in the monitoring well adjacent to the lagoon (i.e., BET-MW1) was approximately 17 feet (bgs). Contours of equipotential water level elevations indicate consistent west-northwesterly to northwesterly groundwater flow beneath most of the dairy. However, in the vicinity of the lagoon, intermittent groundwater flow in northeasterly directions has also been documented such that BET-MW1 is not always clearly downgradient of the lagoon system.

Key 2012-2015 groundwater chemistry is summarized below:

BET-MW1

1. Ammoniacal N concentrations ranged from nondetect to 0.12 mg/L.
2. TKN concentrations ranged from 0.29 to 0.71 mg/L.
3. Comparison of TKN and ammoniacal N indicates that TKN essentially reflected organic N concentrations.
4. Nitrite-N concentrations were below the reporting limit.
5. Nitrate-N concentrations ranged from 21 to 57 mg/L.
6. TDS concentrations were relatively low (350-690 mg/L, Med=410 mg/L, n=12).
7. K concentrations were slightly elevated (6.5-22 mg/L) but not higher than at several non-lagoon wells.
8. HCO_3 concentrations were low (52-78 mg/L).

Groundwater chemistry at this location does not exhibit typical indications of lagoon seepage. However, it is possible that ammoniacal N is rapidly oxidized to nitrate-N in the coarse-textured subsurface.

3.3.3.1 Soil Boring Water Quality

At this facility, six soil borings were advanced and six groundwater samples were retrieved. Groundwater flow directions have been nonsteady in the vicinity of the lagoon since monitoring started in January 2012 such that none of the soil borings can be considered to be in a solely downgradient location. However, two of the soil borings (i.e., SB5 and SB6) were advanced between the lagoon and the settling basin.

1. Ammoniacal N concentrations ranged from 0.12 to 5.4 mg/L.
2. TKN concentrations ranged from 0.59 to 8.4 mg/L.
3. Nitrite-N concentrations ranged from 0.057 to 0.37 mg/L.
4. Nitrate-N concentrations ranged from 12 to 38 mg/L.

5. K concentrations ranged from 3.5 to 15 mg/L.
6. HCO_3 concentrations ranged from 93 to 1,200 mg/L.
7. TDS concentrations ranged from 390 to 1,600 mg/L.

Groundwater chemistry at SB1, 3, 4, and 5 does not exhibit typical characteristics of lagoon seepage. However, the occurrence of low but persistent nitrite-N concentrations in comparison to those at the eight monitoring wells at this dairy (i.e., generally below the reporting limit) may provide an indication of lagoon seepage. Nitrate-N concentrations from the Geoprobe investigation are within the range of observed values from monitoring wells across the dairy. It is possible that ammoniacal N is rapidly oxidized to nitrate-N in the coarse-textured subsurface.

Groundwater chemistry at SB2 (i.e., mainly the moderately elevated ammoniacal N and TKN concentrations) is indicative of lagoon seepage. SB2 also exhibits moderately elevated K and HCO_3 concentrations (i.e., 15 and 780 mg/L, respectively). However, K concentrations of equal or greater magnitude (up to 270 mg/L at MW4) have also been observed at all but one of the eight monitoring wells at this dairy. At SB6, indications for lagoon seepage are limited to an elevated HCO_3 concentration (1,200 mg/L) and slightly elevated TKN (4.6 mg/L).

Groundwater chemistry at the soil borings nearest to MW1 (i.e., SB3 and SB4) is very similar to MW1. For comparison, groundwater chemistry at MW1 does not exhibit typical indications of lagoon seepage. However, it is possible that ammoniacal N is rapidly oxidized to nitrate-N in the coarse-textured subsurface.

3.3.3.2 Geophysical Imaging

Line 1, located between the lagoon and the settling basin, exhibits a zone of low resistivity below the water table. This is indicative of lagoon seepage in the center of the lagoon system. These impacts appear substantially moderated between the two settling basins along Line 2. To the west, lagoon seepage appears to have little or no effect on groundwater salinity although this is the primary direction of groundwater flow. East of the settling basins, three zones of low resistivity are depicted on Line 5. These zones are merged in one elongated feature on Line 6, which is approximately 75 feet farther east.

Line 7, located on the northern side of the lagoon system, indicates a distinct zone of low electrical resistivity with orange and red colors extending over approximately 200 feet in the center of the line. This zone occurs deeper than the low resistivity zone along Line 1, indicating apparent downward movement of salt-affected groundwater over the distance between the lagoon and Line 7. This zone of salt-affected groundwater is also depicted 75 feet north on Line 8, indicating lateral movement of salt-affected groundwater.

3.3.3.3 Summary

Groundwater chemistry in the dedicated monitoring well and four of the six temporary boreholes does not exhibit typical indications of lagoon seepage. The samples from the other two temporary boreholes exhibited slight or moderately elevated concentrations of some indicator parameters. This demonstrates monitoring wells' unreliability in detecting lagoon seepage and illustrates the non-uniqueness of groundwater concentrations with respect to lagoon performance.

Geophysical imaging suggests that lateral movement of seepage-affected shallow groundwater mainly occurred to the north along a path limited to the center portion of the lagoon. Effects are minimal to the west and east of the lagoon, while some effects are more apparent just east of the settling basins. Vertical downward movement of salt-affected groundwater was detected to a depth of approximately 70 feet below the water table in the center of the lagoon system and exceeded the maximum depth of investigation of ~120 feet below the water table approximately 120 feet north of the lagoon.

3.3.4 DUR

Lagoon liquor was sampled quarterly during 2014 and concentrations were as follows:

1. TKN concentrations ranged from 286 to 476 mg/L.
2. Ammoniacal N ranged from 235 to 336 mg/L.
3. Organic N accounted for 18 to 43% of TN.
4. P concentrations ranged from 31.30 to 53 mg/L.
5. K concentrations ranged from 555 to 880 mg/L.
6. EC measurements ranged from 5,170 to 8,010 μS/cm.

Monthly groundwater level measurements indicate that first encountered groundwater occurred at depths ranging from 8 to 16 ft (bgs) beneath the dairy between 2013 and 2015. DUR-MW2 is located on the side of the lagoon's berm and, as a result, the depth to water is approximately 4 ft deeper in this well. During the time of geophysical testing in April and August 2015, groundwater in the monitoring wells adjacent to the lagoon (excluding DUR-MW2) was approximately 12-15 feet (bgs). Contours of equipotential groundwater level elevations indicate overall westerly groundwater flow beneath the contoured area with flow frequently converging toward MW2. Groundwater flow conditions in the vicinity of the lagoon were variable. It appears that MW1 was mainly downgradient of the lagoon; MWs 2 and 4 were cross- to downgradient, and potentially also upgradient of the lagoon; and MW3 was upgradient of the lagoon and downgradient of animal housing.

Key 2013-2015 groundwater chemistry is summarized below:

DUR-MW1

1. Ammoniacal N concentrations were near or below the reporting limit.
2. TKN concentrations ranged from 0.22 to 1.1 mg/L.
3. Comparison of TKN and ammoniacal N indicates that TKN essentially reflected organic N concentrations.
4. Nitrite-N concentrations were below the reporting limit.
5. Nitrate-N concentrations ranged from 71 to 120 mg/L.
6. TDS concentrations ranged from 1,300 to 2,000 mg/L.
7. K was low (2.7-2.8 mg/L).
8. HCO_3 concentrations ranged from 490 to 560 mg/L.

Groundwater chemistry at this location does not exhibit typical indications of lagoon seepage. However, it is possible that ammoniacal N is rapidly oxidized to nitrate-N in the coarse-textured subsurface.

DUR-MW2

1. Ammoniacal N concentrations ranged from 130 to 350 mg/L.
2. TKN concentrations ranged from 140 to 250 mg/L.
3. Comparison of TKN and ammoniacal N indicates approximately 10 mg/L organic N in the February 2015 sample.
4. Nitrite-N concentrations were below the reporting limit.
5. Nitrate-N concentrations ranged from nondetect to 23 mg/L.
6. TDS concentrations ranged from 1,700 to 3,000 mg/L.
7. K was high (290-330 mg/L).
8. HCO_3 was high (2,200-2,300 mg/L).

Groundwater chemistry at this location is indicative of lagoon seepage.

DUR-MW3

1. Groundwater chemistry at this location is substantially attributed to recharge occurring in a source area within upgradient animal housing and the lagoon. Ammoniacal N concentrations ranged from below the reporting limit to 2.9 mg/L.
2. TKN concentrations ranged from below the reporting limit to 2.7 mg/L.
3. Comparison of TKN and ammoniacal N indicates that TKN essentially reflected organic N concentrations in February 2015.
4. Nitrite-N concentrations ranged from below the reporting limit to 0.60 mg/L.
5. Nitrate-N concentrations ranged from 74 to 100 mg/L.
6. TDS concentrations ranged from 1,600 to 2,500 mg/L.
7. K was relatively low (5.6-20 mg/L).
8. HCO_3 concentrations ranged from 790 to 900 mg/L.

Groundwater chemistry at this location does not exhibit typical indications of lagoon seepage. However, it is possible that ammoniacal N is rapidly oxidized to nitrate-N in the coarse-textured subsurface.

DUR-MW4

1. Ammoniacal N concentrations ranged from 5.2 to 150 mg/L.
2. TKN concentrations ranged from 62 to 83 mg/L.
3. Comparison of TKN and ammoniacal N indicates organic N ranges from 3 to 56.8 mg/L.
4. Nitrite-N concentrations were below the reporting limit.
5. Nitrate-N concentrations ranged from 13 to 250 mg/L.
6. TDS concentrations ranged from 2,000 to 3,700 mg/L.
7. K was high, concentrations ranged from 240 to 270 mg/L).
8. HCO_3 was high (1,500-2,100 mg/L).

Groundwater chemistry at this location is indicative of lagoon seepage.

3.3.4.1 Geophysical Imaging

Line 3 (ERP), located on the eastern berm of the lagoon, exhibits a zone of low resistivity (yellow and orange colors) extending over the southern two thirds of the line. In the center portion of Line 3 (ERP), the transition from higher resistivity zone (depicted in green) to the lower resistivity zone appears closely correlated with the water table. Farther to the east (farther upgradient and in closer proximity to the corrals), a high resistivity zone (depicted in blue and purple colors) extends parallel to the water table over much of the length of Line 4 (ERP). From there, a steep resistivity gradient extends vertically down to distinct zones of low resistivities depicted by orange and red colors. This is particularly apparent along the northern segment of Line 4 (ERP). However, this condition may not be due to lagoon seepage as groundwater chemistry at MW3 is not indicative of lagoon seepage although it is located nearer the lagoon and between Line 3 (ERP) and Line 4 (ERP). Also, the northern segment of Line 4 (ERP) is farther from Line 3 (ERP) than its southern segment.

A similar condition exists on the downgradient west side of the lagoon. Specifically, Line 1 (ERP) exhibits lower resistivities and a more extensive zone thereof than Line 2 (ERP) although it is farther away from the lagoon. This may suggest non-lagoon sources of subsurface loading such as deep percolation from the adjacent field. Along all of the north-south oriented lines, salinity effects on groundwater extend below the maximum depth of investigation of ~40 feet below the water table.

The OhmMapper lines provide additional detail of the resistivity distribution but mainly in the unsaturated zone due to the limited depth of exploration.

3.3.4.2 Summary

Groundwater chemistry at MW1 does not exhibit typical indications of lagoon seepage although it is the well most consistently situated downgradient of the lagoon. Two of the four wells located around the lagoon have groundwater quality indicative of lagoon seepage. This demonstrates monitoring wells' unreliability in detecting lagoon seepage and illustrates the non-uniqueness of groundwater concentrations with respect to lagoon performance.

Geophysical imaging indicates seepage-affected shallow groundwater under the berms of the lagoon extending below the maximum investigation depth of ~40 feet below the water table. However, at greater distance from the lagoon (i.e., 30-80 feet), higher-salinity groundwater appears to be more ubiquitous than under the berms, indicating other contributing sources (e.g., fields and corrals).

3.3.5 FG1

Lagoon liquor was sampled quarterly in 2014 and concentrations were as follows:

1. TKN concentrations ranged from 274 to 409 mg/L.
2. Ammoniacal N concentrations ranged from 210 to 344 mg/L.
3. Organic N accounted for 9 to 41% of TN.
4. P concentrations ranged from 48.10 to 104 mg/L.
5. K concentrations ranged from 505 to 865 mg/L.

6. EC measurements ranged from 5,690 to 8,730 µS/cm.

Monthly groundwater level measurements indicate that first encountered groundwater occurred at depths ranging from 10 to 21 ft (bgs) beneath the dairy between 2012 and 2015. During the time of geophysical testing in April 2015, groundwater in the monitoring well adjacent to the lagoon (i.e., FG1-MW1) was approximately 15 feet (bgs). Contours of equipotential groundwater level elevations indicate groundwater flow ranging from westerly to southwesterly directions in the vicinity of the lagoon. Therefore, MW1 was downgradient to crossgradient of the lagoon.

Key 2012-2015 groundwater chemistry is summarized below:

FG1-MW1

1. Ammoniacal N concentrations ranged from below the reporting limit to 0.52 mg/L.
2. TKN concentrations ranged from below the reporting limit to 0.62 mg/L.
3. Comparison of TKN and ammoniacal N indicates very low organic nitrogen concentrations (i.e., <0.4 mg/L).
4. Nitrite-N concentrations were below the reporting limit.
5. Nitrate-N concentrations ranged from nondetect to 23 mg/L. Two of 12 quarterly samples were retrieved from the shallow well (14 and 23 mg/L). Concentrations in the deep well ranged from nondetect to 8.6 mg/L (median = 1.2 mg/L).
6. TDS concentrations and several individual general mineral concentrations were higher than at the field wells.

Groundwater chemistry at this location does not exhibit typical indications of lagoon seepage. However, this well may not be favorably located for purposes of lagoon seepage detection.

3.3.5.1 Soil Boring Water Quality

At this facility, five soil borings were advanced and five groundwater samples were retrieved.

1. Ammoniacal N concentrations ranged from near the reporting limit to 70 mg/L.
2. TKN concentrations ranged from near the reporting limit to 73 mg/L.
3. Nitrite-N concentrations were below or near the reporting limit.
4. Nitrate-N concentrations ranged from nondetect to 43 mg/L.
5. K concentrations ranged from 5.3 to 330 mg/L.
6. HCO_3 concentrations ranged from 470 to 1,200 mg/L.

The groundwater chemistry at SB4 and SB5 is indicative of lagoon seepage. Groundwater chemistry at the other three soil borings does not exhibit typical indications of lagoon seepage (except possibly PO_4 concentration of 33 mg/L at SB1).

3.3.5.2 Geophysical Imaging

The lagoon at this site is constructed as an in-ground basin, i.e, without berms. Lines 1 and 7 were surveyed within a few feet of the wetted lagoon perimeter. Although these lines are not directly downgradient of the lagoon, they exhibit lower resistivity zones from ground surface to below the water table. Line 1 shows the lateral extent of this zone in predominantly yellow colors along the northern side of the lagoon. This zone extends east of the lagoon and ends just west of the lagoon. In the center of the line, there is a small zone of lower resistivity (red colors) extending below the maximum depth of investigation of 45 feet below the water table.

Line 7, shows a low resistivity zone with orange and red colors limited to the width of the lagoon. Line 8, located approximately 110 feet east of Line 7, indicates that this zone is petering out.

Effects of lagoon seepage on underlying groundwater salinity are significantly reduced within a distance of 50 feet to the south and west, as shown on Lines 2 and 6. At greater distances (approximately 130 feet and beyond), effects are no longer visible.

3.3.5.3 Summary

Groundwater chemistry at MW1 and most of the temporary soil borings does not exhibit typical indications of lagoon seepage. In contrast, groundwater chemistry at the two northern soil borings are indicative of lagoon seepage. This demonstrates monitoring wells' unreliability in detecting lagoon seepage. Also, the spatial variability illustrates the non-uniqueness of groundwater concentrations with respect to lagoon performance.

Geophysical imaging suggests that lateral movement of seepage-affected shallow groundwater is very limited and that impacts are apparent only in the immediate vicinity of the lagoon footprint. Even directly next to the lagoon, effects on groundwater salinity are generally limited to a depth of 25-35 feet below the water table.

3.3.6 BEA

CVDRMP sampled lagoon water in January 2014 and concentrations were as follows (see **Attachment 3** for additional lagoon water quality):

1. TKN concentrations ranged from 55 to 240 mg/L.
2. Ammoniacal N concentrations ranged from 41 to 45 mg/L.
3. Organic N accounted for 25 to 81% of TN.
4. P concentrations ranged from 15 to 48 mg/L.
5. K concentrations ranged from 94 to 150 mg/L.
6. EC measurements were approximately 1,960 µS/cm.

Monthly groundwater level measurements indicate that first encountered groundwater occurs at depths ranging from approximately 15 to 50 ft (bgs) beneath the dairy between 2012 and 2015. Contours of equipotential groundwater level elevations indicate predominantly southerly to southeasterly groundwater flow beneath the facility such that MW1 was downgradient of the lagoon and settling basins.

Key 2012-2015 groundwater chemistry is summarized below:

BEA-MW1

1. Ammoniacal N concentrations and TKN were high (7.4-85 and 12-83 mg/L, respectively).

2. Comparison of TKN and ammoniacal N indicates absence of organic N in August 2012 and February 2015 and concentrations of approximately 4 mg/L in May 2012.
3. Nitrite-N concentrations ranged from 0.083 to 2.0 mg/L.
4. Nitrate-N concentrations ranged from below the reporting limit to 140 mg/L.
5. TDS concentrations ranged from 900 to 3,300 mg/L (Med=1,500, n=11)
6. K concentrations were the highest of all monitoring wells (51-120 mg/L).
7. HCO_3 concentrations were by far the highest of all monitoring wells (900-1,500 mg/L).

Groundwater chemistry at this location is indicative of lagoon seepage. However, the temporal constituent variability illustrates the non-uniqueness of groundwater concentrations with respect to lagoon performance.

3.3.7 COT

Lagoon liquor was sampled monthly in 2014, and concentrations were as follows:

1. TKN ranged from 16 to 356 mg/L.
2. Ammoniacal N concentrations ranged from 5.0 to 236 mg/L.
3. Nitrate concentrations ranged from nondetect to 20 mg/L.
4. P concentrations ranged from 4.7 to 193 mg/L.
5. K concentrations ranged from 13 to 458 mg/L.
6. TDS ranged from 252 to 2,608 mg/L.

Monthly groundwater level measurements indicate that first encountered groundwater occurred at depths between less than 5 ft (bgs) and nearly 47 ft (bgs) between 2012 and 2015. Contours of equipotential groundwater level elevations indicate persistent groundwater flow to the north such that MW11 is downgradient of the lagoon.

Key 2012-2015 groundwater chemistry is summarized below:

COT-MW11

1. Ammoniacal N concentrations were near or below the reporting limit.
2. TKN concentrations ranged from 0.68 to 1.8 mg/L.
3. Comparison of TKN and ammoniacal N indicates that TKN essentially reflected organic N concentrations.
4. Nitrite-N concentrations ranged from below the reporting limit to 0.61 mg/L.
5. Nitrate-N concentrations ranged from 25 to 120 mg/L.
6. K concentrations were high (29-79 mg/L).

Groundwater chemistry at this location does not exhibit typical indications of lagoon seepage with the exception of elevated potassium concentrations. It is possible that ammoniacal N is rapidly oxidized to nitrate-N in the coarse-textured subsurface. Also, it is conceivable that the source area of this well extended beyond the footprint of the lagoon.

3.3.7.1 Soil Boring Water Quality

At this facility, four soil borings were advanced and four groundwater samples were retrieved.

1. Ammoniacal N concentrations ranged from near the reporting limit to 58 mg/L.
2. TKN concentrations ranged from near the reporting limit to 59 mg/L.
3. Nitrite-N concentrations ranged from nondetect to 0.38 mg/L.
4. Nitrate-N concentrations ranged from below the reporting limit to 87 mg/L.
5. K concentrations ranged from 30 to 74 mg/L.
6. HCO_3 concentrations ranged from 380 to 840 mg/L.

Groundwater chemistry at SB3 and SB4 is indicative of lagoon seepage although they are located on the upgradient edge of the lagoon. Groundwater chemistry at the downgradient soil borings SB1 and SB2 does not exhibit typical indications of lagoon seepage, with the exception of elevated K concentrations (38 and 30 mg/L, respectively) and a slightly elevated PO_4 concentration at SB1 (9.0 mg/L). SB1 was advanced next to MW11, and the water quality was very similar.

3.3.7.2 Summary

Groundwater chemistry in the dedicated monitoring well and two of the four temporary boreholes does not exhibit typical indications of lagoon seepage. This demonstrates monitoring wells' unreliability in detecting lagoon seepage and illustrates the non-uniqueness of groundwater concentrations with respect to lagoon performance.

3.3.8 SAN

Lagoon liquor was sampled ten times in 2014, and concentrations were as follows:

1. TKN ranged from 150 to 356 mg/L.
2. Ammoniacal N concentrations ranged from 85.4 to 221 mg/L.
3. Nitrate concentrations were below 1 mg/L.
4. P concentrations ranged from 22.7 to 99.2 mg/L.
5. K concentrations ranged from 187.5 to 458 mg/L.
6. TDS ranged from 1,672 to 3,136 mg/L.

Monthly groundwater level measurements indicate that first encountered groundwater occurred at depths ranging from approximately 10 to 50 ft (bgs) beneath the dairy between 2012 and 2015. Contours of equipotential groundwater level elevations indicate easterly to northerly groundwater flow beneath the lagoon such that MW1 is typically upgradient of the lagoon. Groundwater chemistry at this location is substantially attributed to recharge occurring in a source area within the fields. This includes nitrate-N concentrations ranging from 35 to 53 mg/L (Med=46 mg/L, n=12) and TDS concentrations ranging from 1,200 to 2,000 mg/L (Med=1,650 mg/L, n=12). Based solely on the proximity of this well to the lagoon, effects of lagoon seepage on its water chemistry are conceivable. However, presently, groundwater chemistry at this location is not indicative of lagoon seepage.

3.3.8.1 Soil Boring Water Quality

At this facility, three soil borings were advanced and three groundwater samples were retrieved, all downgradient of the lagoon, and two of them between the lagoon and adjacent settling basins.

1. Ammoniacal N concentrations ranged from below the reporting limit to 0.63 mg/L.
2. TKN concentrations ranged from 1.3 to 1.4 mg/L.
3. Nitrite-N concentrations were near the reporting limit.
4. Nitrate-N concentrations ranged from 17 to 25 mg/L.
5. K concentrations ranged from 7.4 to 12 mg/L.
6. HCO_3 concentrations ranged from 890 to 1,300 mg/L.
7. TDS concentrations ranged from 1,100 to 1,600 mg/L.

Overall, these results do not exhibit typical indications of lagoon seepage, except possibly very slightly elevated TKN concentrations and moderately elevated HCO_3 concentrations.

3.3.8.2 Summary

Groundwater quality results from the adjacent but upgradient monitoring well are not indicative of lagoon seepage. The temporary soil borings are also not indicative of lagoon seepage despite the fact that they were advanced directly downgradient of the lagoon; two of the borings were also located between the lagoon and the settling basins. While these results may be due to near-zero mass loading, the absence of detectable impacts to groundwater quality does not indicate that a lagoon has zero-seepage or no impacts to groundwater. The results may also be attributed to the substantial thickness of the unsaturated zone at this location (i.e., approximately 38 feet in fall 2014) and associated long travel times of percolating seepage, which would indicate another limitation to relying on groundwater quality for purposes of detecting lagoon seepage.

3.3.9 PLS

Lagoon liquor was sampled four times in 2014 and concentrations were as follows (see **Attachment 3** for additional lagoon water quality from CVDRMP's testing associated with the water balance testing):

1. TKN concentrations ranged from 291 to 342 mg/L.
2. Ammoniacal N concentrations ranged from 146 to 196 mg/L.
3. Organic N accounted for 43 to 50% of TN.
4. P concentrations ranged from 17.8 to 68.5 mg/L.
5. K concentrations ranged from 110 to 570 mg/L.
6. EC measurements ranged from 1,940 to 4,780 µS/cm.

Monthly groundwater level measurements indicate that first encountered groundwater occurred at depths ranging from less than 5 to approximately 16 ft (bgs) beneath the dairy between 2012 and 2015. During the time of geophysical testing in August 2015, groundwater in the monitoring wells adjacent to the lagoon (i.e., PLS-MW1 and 2) was approximately 12-14 feet (bgs). Contours of equipotential groundwater level elevations indicate predominantly southeasterly to southerly groundwater flow beneath lagoon. MW1 and MW2 were mainly up- to crossgradient of the lagoon.

Key 2012-2015 groundwater chemistry is summarized below:

PLS-MW1

1. Ammoniacal N concentrations were near or below the reporting limit.
2. TKN concentrations ranged from 1.0 to 1.2 mg/L.
3. Comparison of TKN and ammoniacal N indicates that TKN essentially reflected organic N concentrations.
4. Nitrite-N concentrations ranged from below the reporting limit to 0.27 mg/L.
5. Nitrate-N concentrations ranged from 47 to 120 mg/L.
6. TDS concentrations and individual general mineral concentrations were similar to non-lagoon wells.

Groundwater chemistry at this location does not exhibit typical indications of lagoon seepage. However, it is possible that ammoniacal N is rapidly oxidized to nitrate-N in the coarse-textured subsurface. Also, this well may not be favorably located for purposes of lagoon seepage detection.

PLS-MW2

1. Ammoniacal N concentrations were at or below the reporting limit.
2. TKN concentrations ranged from 1.1 to 1.6 mg/L.
3. Comparison of TKN and ammoniacal N indicates that TKN essentially reflected organic N concentrations.
4. Nitrite-N concentrations ranged from below the reporting limit to 0.27 mg/L.
5. Nitrate-N concentrations ranged from 39 to 75 mg/L.
6. TDS concentrations and individual general mineral concentrations were similar to non-lagoon wells.

Groundwater chemistry at this location does not exhibit typical indications of lagoon seepage. However, it is possible that ammoniacal N is rapidly oxidized to nitrate-N in the coarse-textured subsurface. Also, this well may not be favorably located for purposes of lagoon seepage detection.

3.3.9.1 Soil Boring Water Quality

At this facility, two soil borings were advanced and two groundwater samples were retrieved. Soil borings were also planned on the south side of the lagoon but could not be advanced due to subsurface infrastructure.

1. Ammoniacal N concentrations ranged from 0.16 to 0.59 mg/L.
2. TKN concentrations ranged from 2.5 to 2.8 mg/L.
3. Nitrite-N concentrations ranged from 0.42 to 1.1 mg/L.
4. Nitrate-N concentrations ranged from 69 to 98 mg/L.
5. K concentrations ranged from 4.0 to 15 mg/L.
6. HCO_3 concentrations ranged from 600 to 660 mg/L.
7. TDS concentrations ranged from 1,700 to 1,800 mg/L.

Overall, these results do not exhibit typical indications of lagoon seepage, except possibly slightly elevated TKN concentrations. It is possible that ammoniacal N is rapidly oxidized to nitrate-N in the coarse-textured subsurface.

3.3.9.2 Geophysical Imaging

The four lines nearest to the edge of the lagoon (Lines 2, 3, 5, and 6) exhibit a transition to a lower resistivity zone at the water table with a moderate color change from green to yellow. In most places, this zone extends to a depth of approximately 30 to 40 feet below the water table. Line 4, which is located approximately 80 feet downgradient of the lagoon, shows the top of this lower resistivity zone approximately 10 feet below the water table, indicating apparent downward movement of salt-affected groundwater over the short distance between the lagoon and Line 4. Overall, the effects on groundwater salinity appear moderate as indicated by predominantly yellow colors (i.e., almost no orange and red colors).

Line 2 shows very high resistivity zone above the water table east of the lagoon along the facility road. In contrast, Line 3 shows lower resistivities above the water table beneath the calf hutches. Line 7, shows a fairly continuous low resistivity zone above the water table beneath the calf hutches. The salt-affected zone below the water table appears to be petering out.

3.3.9.3 Summary

Groundwater quality in groundwater monitoring wells and in the temporary soil borings is not indicative of lagoon seepage, except possibly slightly elevated TKN concentrations in the two soil borings. The wells and the soil borings may not be favorably located for purposes of lagoon seepage detection. However, soil borings could not be advanced along the lagoon's south side that is most consistently downgradient.

Geophysical imaging suggests that lagoon seepage has moderate salinity impacts on groundwater and that lateral movement is limited. Salt-affected groundwater generally extended to a depth of only 30 to 40 feet below the water table.

3.3.10 CAE

Lagoon liquor was sampled four times in 2014 and concentrations were as follows (see **Attachment 3** for additional lagoon water quality from CVDRMP's testing associated with the water balance testing):

1. TKN concentrations ranged from 269 to 405 mg/L.
2. Ammoniacal N concentrations ranged from 135 to 272 mg/L.
3. Organic N accounted for 33 to 50% of TN.
4. P concentrations ranged from 69.80 to 469 mg/L.
5. K concentrations ranged from 355 to 2,690 mg/L.
6. EC measurements ranged from 3,680 to 8,440 µS/cm.

Monthly groundwater level measurements indicate that first encountered groundwater occurred at depths ranging from approximately 5 to 25 ft (bgs) beneath the dairy between 2012 and 2015.

Contours of equipotential groundwater level elevations indicate consistent southwesterly groundwater flow beneath the dairy. MW1 was downgradient of the lagoon

Key 2012-2015 groundwater chemistry is summarized below:

CAE-MW1

1. Ammoniacal N concentrations were high (84-170 mg/L).
2. TKN concentrations were high (85-130 mg/L).
3. Comparison of TKN and ammoniacal N indicates absence of organic N (May 2012, August 2013, August 2014 and February 2015) and concentrations of approximately 3 mg/L in August 2012).
4. Nitrite-N concentrations ranged from below the reporting limit to 6.5 mg/L.
5. Nitrate-N concentrations ranged from nondetect to 38 mg/L.
6. K concentrations were high (230-340 mg/L).
7. HCO_3 concentrations were high (1,100-1,600 mg/L).
8. ORP measurements were positive except in February and May 2012. The May 2012 sample also had the highest nitrite concentration.

Groundwater chemistry at this location is indicative of lagoon seepage. However, the temporal constituent variability illustrates the non-uniqueness of groundwater concentrations with respect to lagoon performance.

3.3.11 ROB

Lagoon liquor was sampled seven times in 2014 and concentrations were as follows (see **Attachment 3** for additional lagoon water quality from CVDRMP's testing associated with the water balance testing):

1. TKN concentrations ranged from 157 to 762 mg/L.
2. Ammoniacal N concentrations ranged from 30.8 to 470 mg/L.
3. Organic N accounted for 5 to 80 % of TN.
4. P concentrations ranged from 7.35 to 74 mg/L.
5. K concentrations ranged from 46.1 to 785 mg/L.
6. EC measurements ranged from 1,650 to 8,690 µS/cm.

Monthly groundwater level measurements indicate that first encountered groundwater typically occurred at depths ranging from approximately 8 to 30 ft (bgs) beneath the dairy between 2012 and 2015. During the time of geophysical testing in August 2015, groundwater in the monitoring wells adjacent to the lagoon (i.e., ROB-MW1 and 2) had just declined below the well bottoms situated at 28 ft (bgs). Despite the non-steady groundwater flow conditions at this dairy, MW1 and MW2 were downgradient or at least crossgradient to the lagoon during the period of record (a possible exception was March 2012).

Key 2012-2015 groundwater chemistry is summarized below:

ROB-MW1

1. Ammoniacal N concentrations ranged from below the reporting limit to 1.5 mg/L.
2. TKN concentrations ranged from 0.46 to 2.6 mg/L.
3. Comparison of TKN and ammoniacal N indicates that TKN essentially reflected organic N concentrations.
4. Nitrite-N concentrations ranged from below the reporting limit to 4.3 mg/L.
5. Nitrate-N concentrations ranged from 26 to 110 mg/L (Med=50 mg/L, n=13).
6. K concentrations varied from 5.7 to 60 mg/L.
7. HCO_3 concentrations ranged from 190 to 1,300 mg/L.

Although ammoniacal N and TKN concentrations were relatively low, the occurrence of high K and HCO_3 concentrations suggest lagoon seepage. It is possible that ammoniacal N is rapidly oxidized to nitrate-N in the coarse-textured subsurface.

ROB-MW2

1. Ammoniacal N concentrations ranged from below the reporting limit to 0.78 mg/L.
2. TKN concentrations ranged from 1.3 to 1.6 mg/L.
3. Comparison of TKN and ammoniacal N indicates organic N concentrations of approximately 0.8-1.3 mg/L.
4. Nitrite-N concentrations were below the reporting limit.
5. Nitrate-N concentrations ranged from 37 to 160 mg/L (Med=59 mg/L, n=13).
6. K concentrations varied widely from 9.5 to 160 mg/L.
7. HCO_3 concentrations ranged from 580 to 1,000 mg/L.

Although ammoniacal N and TKN concentrations were relatively low, the occurrence of high K and HCO_3 concentrations suggest lagoon seepage. It is possible that ammoniacal N is rapidly oxidized to nitrate-N in the coarse-textured subsurface.

3.3.11.1 Geophysical Imaging

Anomalously low resistivities that could be interpreted as the effect of lagoon seepage on groundwater salinity are essentially non-existent at this site. Line 4 is located between two settling basins. However, no seepage impact on groundwater salinity is apparent except possibly in a small location at the north end of the line. The mere transition from unsaturated to saturated soil matrix causes a decrease in resistivity and this is depicted by the transition from green to yellow colors in some portions of Line 6 (just downgradient of the lagoon). Line 5 (farther downgradient from the lagoon along the edge of the almond orchard) shows the same pattern but more distinctly.

3.3.11.2 Summary

Groundwater quality in two downgradient monitoring wells is indicative of lagoon seepage and relatively similar between the well locations. In contrast, geophysical imaging was not able to identify effects of lagoon seepage on groundwater salinity.

3.3.12 ANT

Lagoon liquor was sampled quarterly in 2014 and concentrations were as follows (see **Attachment 3** for additional lagoon water quality from CVDRMP's testing associated with the water balance testing):

1. TKN concentrations ranged from 532 to 1,848 mg/L.
2. Ammoniacal N concentrations ranged from 279 to 890 mg/L.
3. Organic N accounted for 35 to 48 % of TN.
4. P concentrations ranged from 48.5 to 74.4 mg/L.
5. K concentrations ranged from 810 to 2,370 mg/L.
6. EC measurements ranged from 1,230 to 16,500 µS/cm.

Monthly groundwater level measurements indicate that first encountered groundwater occurred at depths ranging from approximately 5 to 40 ft (bgs) beneath the dairy between 2012 and 2015. During the time of geophysical testing in April 2015, groundwater in the monitoring well adjacent to the lagoon (i.e., ANT-MW1) had declined below the well bottom situated at 33 ft (bgs). Contours of equipotential groundwater level elevations indicate predominantly southerly flow directions near the lagoon system. Thus, MW1 was predominantly crossgradient or even upgradient of the lagoon.

Key 2012-2015 groundwater chemistry is summarized below:

ANT-MW1

1. Ammoniacal N concentrations were below the reporting limit.
2. TKN concentrations ranged from 0.66 to 1.2 mg/L.
3. Comparison of TKN and ammoniacal N indicates that TKN essentially reflected organic N concentrations.
4. Nitrite-N concentrations were below the reporting limit.
5. Nitrate-N concentrations ranged from 17 to 54 mg/L.
6. TDS concentrations and individual general mineral concentrations were similar to those observed at non-lagoon wells.

Groundwater chemistry at this location is not indicative of lagoon seepage. However, due to its up- to crossgradient position to the lagoon, this well may not be favorably located for purposes of lagoon seepage detection.

3.3.12.1 Soil Boring Water Quality

At this facility, three soil borings were advanced and two groundwater samples were retrieved.

1. Ammoniacal N concentrations ranged from 2.2 to 3.2 mg/L.
2. TKN concentrations ranged from 3.3 to 5.2 mg/L.
3. Nitrite-N concentrations were below the reporting limit.
4. Nitrate-N concentrations ranged from 17 to 25 mg/L.
5. K concentrations ranged from 13 to 21 mg/L.
6. HCO_3 concentrations ranged from 480 to 670 mg/L.

Although soil borings were advanced between the lagoons, the groundwater chemistry does not exhibit strong indications of lagoon seepage; TKN and ammoniacal N concentrations were only slightly elevated over those encountered at the monitoring wells at this site.

3.3.12.2 Geophysical Imaging

The effects of lagoon seepage on subsurface salinity are most apparent along Line 4 (between two settling basins) and Line 5 (south of settling basin D). Line 5 exhibits a very low resistivity zone above the water table. This may indicate the effects of saline lagoon seepage causing relatively high degree of saturation in the clay-rich subsurface soils. A similar pattern is displayed on Line 8. Approximately 180 feet south (and downgradient) of the lagoon system, Line 6 shows no signs of lagoon seepage affecting groundwater salinity.

Effects of lagoon seepage are less wide spread along Line 3. Line 7, just west of the lagoon system, exhibits only localized effects adjacent to settling basin B. Impacts appear minimal immediately north of the lagoon system at Line 2 and are absent farther north at Line 1.

3.3.12.3 Summary

Groundwater chemistry at MW1 is not indicative of lagoon seepage. While this well may not be favorably located for purposes of lagoon seepage detection, soil borings that were advanced between the lagoon and settling basin also did not show strong indications of lagoon seepage.

Geophysical imaging suggests that lateral movement of seepage-affected shallow groundwater is very limited and that impacts are apparent only in the immediate vicinity of the lagoon footprint. In fact, it appears that most of the impacts are limited to the unsaturated zone at this site. This is consistent with the groundwater quality results.

3.3.13 COR

Lagoon liquor was sampled quarterly in 2014 and concentrations were as follows:

1. TKN concentrations ranged from 146 to 644 mg/L.
2. Ammoniacal N concentrations ranged from 123 to 370 mg/L.
3. Organic N accounted for 33 to 68 % of TN.
4. P concentrations ranged from 24.6 to 71 mg/L.
5. K concentrations ranged from 326 to 1,110 mg/L.
6. TDS concentrations ranged from 2,528 to 6,701 mg/L.

Monthly groundwater level measurements indicate that first encountered groundwater occurred at depths ranging from less than 5 to approximately 12 ft (bgs) beneath the dairy between 2012 and 2015. Contours of equipotential groundwater level elevations indicate consistent east-northeasterly to northeasterly groundwater flow. MW1 was consistently downgradient of the lagoon.

Key 2012-2015 groundwater chemistry is summarized below:

COR-MW1

1. Ammoniacal N concentrations were below the reporting limit.
2. TKN concentrations ranged from 0.60 to 0.84 mg/L.
3. Comparison of TKN and ammoniacal N indicates that TKN essentially reflected organic N concentrations.
4. Nitrite-N concentrations were below the reporting limit.
5. Nitrate-N concentrations were low (0.78-13 mg/L).
6. TDS concentrations were higher than in non-lagoon wells (ranging from 1,600 to 2,300 mg/L, Med=2,150 mg/L, n=16). Na, Cl, and HCO_3 were the main contributors to the elevated salinity (i.e., 2 to 3 times higher than in other non-lagoon wells).

Although ammoniacal N was essentially absent and TKN concentrations were low, the presence of organic N in conjunction with clearly elevated salinity, including Na, Cl, and HCO_3, suggests that groundwater at this location is impacted by lagoon seepage.

3.3.13.1 Soil Boring Water Quality

At this facility, four soil borings were advanced and four groundwater samples were retrieved.

1. Ammoniacal N concentrations ranged from below the reporting limit to 0.47 mg/L.
2. TKN concentrations ranged from 1.3 to 5.5 mg/L.
3. Nitrite-N concentrations ranged from nondetect to 0.24 mg/L.
4. Nitrate-N concentrations ranged from 0.82 to 97 mg/L.
5. K concentrations ranged from 5.0 to 65 mg/L.
6. HCO_3 concentrations ranged from 490 to 1,600 mg/L.

Overall, these results are indicative of lagoon seepage. This includes slightly elevated TKN and organic nitrogen concentrations in all soil borings, high K concentrations at SB3 and SB4 (60 and 65 mg/L, respectively), and high salinity (TDS=4,200 mg/L) and HCO_3 concentrations (1,600 mg/L) at SB3, compared to monitoring well data.

SB4 was advanced next to MW1, yet, groundwater quality was significantly different. For example, nitrate-N concentrations were 97 mg/L at SB4 whereas they never exceeded 2.7 mg/L at MW1. Similarly, TKN and K concentrations were 5.5 and 65 mg/L at SB4 compared to 0.60-0.82 and 2.7-3.0 mg/L at MW1, respectively.

The groundwater chemistry at SB1 and SB2 does not exhibit strong indications of lagoon seepage. At SB1, the only indication is an elevated HCO_3 concentration (1,100 mg/L), and SB2 exhibits a somewhat elevated K concentration (16 mg/L).

3.3.13.2 Summary

Lagoon seepage was previously inferred based on elevated Na, Cl, and HCO_3 concentrations in the downgradient monitoring well. Two of four downgradient soil borings do not exhibit strong indications of lagoon seepage and the groundwater quality in the soil boring right next to the monitoring well was significantly different from the monitoring well data. The spatial variability illustrates the non-uniqueness of groundwater concentrations with respect to lagoon performance and the unreliability of concentration-based assessment.

3.3.14 FG2

Lagoon liquor was sampled five times in 2014 and concentrations were as follows:

1. TKN concentrations ranged from 89.6 to 302 mg/L.
2. Ammoniacal N concentrations ranged from 118 to 168 mg/L.
3. Organic N accounted for 27 to 52% of TN.
4. P concentrations ranged from 22.1 to 45.3 mg/L.
5. K concentrations ranged from 150 to 441 mg/L.
6. EC measurements ranged from 2,810 to 5,050 µS/cm.

Monthly groundwater level measurements indicate that first encountered groundwater occurred at depths ranging from less than 5 to 12 ft (bgs) beneath the dairy between 2012 and 2015. MW1 is located directly adjacent to the main liquid manure storage lagoon and Settling Basin No. 2 at the base of its southern berm. However, despite its adjacency to the lagoon, this MW was mainly crossgradient to upgradient of the lagoon. Groundwater chemistry at MW1 is substantially attributed to recharge occurring in a source area within Field 6. This includes nitrate-N concentrations ranging from below the reporting limit to 10 mg/L and high sulfate concentrations (1,200-2,100 mg/L). Based solely on the proximity of this well to the lagoon, effects of lagoon seepage on its water chemistry are conceivable. However, presently, groundwater chemistry at this location is not indicative of lagoon seepage.

3.3.14.1 Soil Boring Water Quality

At this facility, five soil borings were advanced and five groundwater samples were retrieved.

1. Ammoniacal N concentrations ranged from near the reporting limit to 4.5 mg/L.
2. TKN concentrations ranged from near the reporting limit to 7.9 mg/L.
3. Nitrite-N concentrations were below the reporting limit.
4. Nitrate-N concentrations ranged from 1.1 to 95 mg/L.
5. K concentrations ranged from 3.1 to 11 mg/L.
6. HCO_3 concentrations ranged from 290 to 1,300 mg/L.
7. TDS concentrations ranged from 1,700 to 8,000 mg/L.

Groundwater chemistry at three of the locations (SB3-SB5) does not exhibit typical indications of lagoon seepage although they were advanced along the downgradient edge of the lagoon. Indication for lagoon seepage at SB1 and SB2 is mainly limited to moderately elevated TKN and a high HCO_3 concentration (1,300 mg/L).

3.3.14.2 Summary

Three of five downgradient soil borings do not exhibit typical indications of lagoon seepage. The spatial variability illustrates the non-uniqueness of groundwater concentrations with respect to lagoon performance and the unreliability of concentration-based assessment.

3.3.15 GOD

Lagoon liquor was sampled quarterly in 2014 and concentrations were as follows (see **Attachment 2** for additional lagoon water quality from CVDRMP's testing associated with the water balance testing):

1. TKN concentrations ranged from 123 to 1,030 mg/L.
2. Ammoniacal N concentrations ranged from 72.8 to 781 mg/L.
3. Organic N accounted for 24 to 41% of TN.
4. P concentrations ranged from 24 to 60.5 mg/L.
5. K concentrations ranged from 180 to 1,200 mg/L.
6. EC measurements ranged from 3,170 to 12,300 μS/cm.

Monthly groundwater level measurements indicate that first encountered groundwater occurred at depths ranging from less than 5 to 18 ft (bgs) beneath the dairy between 2012 and 2015. During the time of geophysical testing in April 2015, groundwater in the monitoring well adjacent to the lagoon (i.e., GOD-MW1) was approximately 7 ft (bgs). Based on the groundwater elevation data, it cannot be unambiguously inferred whether MW1 is up- or downgradient of the lagoon system.

Key 2012-2015 groundwater chemistry is summarized below:

GOD-MW1

1. Ammoniacal N concentrations were near or below the reporting limit.
2. TKN concentrations ranged from 0.35 to 0.63 mg/L and were similar to non-lagoon wells.
3. Comparison of TKN and ammoniacal N indicates that TKN essentially reflected organic N concentrations.
4. Nitrite-N concentrations were below the reporting limit.
5. Nitrate-N concentrations were among the lowest (0.54-3.8 mg/L) on this dairy.
6. TDS concentrations and individual general mineral concentrations were similar to non-lagoon wells, with the exception of somewhat higher HCO_3.

Groundwater chemistry at this location is not indicative of lagoon seepage. However, this well may not be favorably located for purposes of lagoon seepage detection.

3.3.15.1 Soil Boring Water Quality

At this facility, six soil borings were advanced and five groundwater samples were retrieved (not at SB6).

1. Ammoniacal N concentrations ranged from near the reporting limit to 2.8 mg/L.
2. TKN concentrations ranged from 1.4 to 8.1 mg/L.
3. Nitrite-N concentrations were near the reporting limit.
4. Nitrate-N concentrations ranged from 57 to 110 mg/L.
5. K concentrations ranged from 2.9 to 47 mg/L.
6. HCO_3 concentrations ranged from 700 to 1,800 mg/L.
7. TDS concentrations ranged from 2,000 to 3,700 mg/L.

Overall, these results are indicative of lagoon seepage, although mainly at SB4 and SB5, which were advanced in between the lagoon and the settling basins.

3.3.15.2 Geophysical Imaging

The effects of lagoon seepage on subsurface salinity are most apparent along Line 4 (between two settling basins), Line 3 (north of lagoon), and Line 5 (south of settling basins). Along these lines, the effects on groundwater salinity extend below the maximum investigation depth of ~30 feet below the water table.

Line 9 (east of the lagoon system) shows weaker signs of lagoon seepage. Overall, the distribution of subsurface salinity around the lagoon system may suggest radial flow patterns or variable flow directions. This is consistent with the inability to infer a predominant flow direction from groundwater elevation data.

Stepping out to Lines 2 and 1 (located in a forage field north of the lagoon system), resistivities are much higher at the water table and below. However, low resistivities are still shown at depth. This may indicate that saline water emanating from the lagoon is being displaced by percolating irrigation water.

Line 8, located on the western berm of the lagoon system shows moderate resistivities and high resistivities a few feet farther to the west, indicating minimal seepage effects. Rapid resistivity increases are also seen to the east.

3.3.15.3 Summary

Overall, groundwater chemistry in the temporary soil borings is indicative of lagoon seepage, although mainly at two of the six borings located in the center of the lagoon system. The spatial variability illustrates the non-uniqueness of groundwater concentrations with respect to lagoon performance and the unreliability of concentration-based assessment. For comparison, groundwater chemistry at MW1 does not exhibit typical indications of lagoon seepage. However, this well may not be favorably located for purposes of lagoon seepage detection.

Geophysical imaging suggests that salinity effects on groundwater are the most developed in the center of the lagoon system where they extend below the maximum investigation depth of ~30 feet below the water table. Lateral movement of seepage-affected shallow groundwater is very limited and impacts are apparent only in the immediate vicinity of the lagoon footprint.

3.3.16 MAC

Lagoon liquor was sampled quarterly in 2014 and concentrations were as follows:

1. TKN concentrations ranged from 325 to 521 mg/L.
2. Ammoniacal N concentrations ranged from 210 to 406 mg/L.
3. Organic N accounted for 11 to 37% of TN.
4. P concentrations ranged from 51 to 78 mg/L.
5. K concentrations ranged from 545 to 1,010 mg/L.

6. EC measurements ranged from 5,520 to 9,450 µS/cm.

Monthly groundwater level measurements indicate that first encountered groundwater occurred at depths ranging from less than 5 to 10 ft (bgs) beneath the dairy between 2012 and 2015. During the time of geophysical testing at in November 2014 and April 2015, groundwater in the monitoring wells adjacent to the lagoon (i.e., MW1 and 2) was approximately 4 to 6 ft (bgs). Contours of equipotential groundwater level elevations indicate northerly to north-northeasterly groundwater flow. MW1 and MW2 were downgradient of the lagoon.

Key 2012-2015 groundwater chemistry is summarized below:

MAC-MW1

1. Ammoniacal N concentrations were near or below the reporting limit.
2. TKN concentrations ranged from 0.41 to 0.73 mg/L and were similar or lower than at non-lagoon wells.
3. Comparison of TKN and ammoniacal N indicates that TKN essentially reflected organic N concentrations.
4. Nitrite-N concentrations were very low (nondetect to 0.13 mg/L) and similar to concentrations at non-lagoon wells.
5. Nitrate-N concentrations ranged from 13 to 23 mg/L (Med=16 mg/L, n=16) and were similar to concentrations at non-lagoon wells.
6. Overall salinity and individual general mineral concentrations were similar or lower than in non-lagoon wells.

Groundwater chemistry at this location is not indicative of lagoon seepage.

MAC-MW2

1. Ammoniacal N concentrations were near or below the reporting limit.
2. TKN concentrations ranged from below the reporting limit to 0.45 mg/L and were lower than at non-lagoon wells.
3. Comparison of TKN and ammoniacal N indicates that TKN essentially reflected organic N concentrations.
4. Nitrite-N concentrations were below the reporting limit.
5. Nitrate-N concentrations ranged from 14 to 67 mg/L (Med=22 mg/L, n=16) and were similar to concentrations at non-lagoon wells.
6. TDS concentrations and individual general mineral concentrations were similar or lower than at non-lagoon wells.

Groundwater chemistry at this location is not indicative of lagoon seepage.

3.3.16.1 Soil Boring Water Quality

At this facility, five soil borings were advanced and five groundwater samples were retrieved.

1. Ammoniacal N concentrations ranged from below the reporting limit to 0.74 mg/L.
2. TKN concentrations ranged from 1.1 to 7.6 mg/L.

3. Nitrite-N concentrations were near the reporting limit.
4. Nitrate-N concentrations ranged from 2.4 to 21 mg/L.
5. K concentrations ranged from 3.1 to 160 mg/L.
6. HCO_3 concentrations ranged from 600 to 1,200 mg/L.
7. TDS concentrations ranged from 1,400 to 2,500 mg/L.

Groundwater chemistry at SB2 exhibits some characteristics that are typical of lagoon seepage (i.e., the highest TKN, K, and PO_4 concentrations). However, this soil boring was advanced at the most remote location to the lagoon, namely within the corrals (due to overhead wires, concrete slab, and other difficulties along the berm of the lagoon), and groundwater quality at SB2 is likely not merely attributable to lagoon seepage but possibly more so to corral activities.

At SB3, the K concentration was much smaller (13 mg/L) and only its slightly elevated HCO_3 concentration (1,200 mg/L) may provide an indication for lagoon seepage (for comparison, concentrations at monitoring wells across this dairy were as high as 940 mg/L). Groundwater chemistry at the other three soil boring locations was not indicative of lagoon seepage.

3.3.16.2 Geophysical Imaging

ER Profiling (Fall 2014)
ER profiling indicates salt-affected groundwater extending to the maximum depth of investigation of ~120 feet below the water table in some areas along Lines 1 and 3 (southwest corner of the lagoon) and Line 7 (northeast corner of the lagoon). East of the lagoon, salinity effects are exhibited along Line 5. However, less than 100 feet farther east, along Line 6, impacts are no longer apparent. While there is also substantial attenuation south and west of the lagoon, low-resistivity zones exhibited on the lines nearest to the lagoon (Lines 1 and 3) Line 3 extend farther beyond the outer Lines 2 and 4.

OhmMapper Profiling (Spring 2015)
OhmMapper profiles completed south of the lagoon indicate agreement with the fall 2014 ER results (Line 2 – 2014) and OhmMapper Lines 2 and 3 show essentially the same results. However, the shallower depth penetration of the OhmMapper method presents a limitation for the comparison to the ER results and it is too shallow to sufficiently depict the salinity effects on groundwater. As a result, this effort's results do not appreciably contribute to the site characterization. In addition, the OhmMapper results west of the lagoon along Line 6 (Line 4 – 2014) and also east of the lagoon are not in agreement with results from 2014. The discrepancies could not be reconciled.

EM Terrain Survey (Spring 2015)
The EM Terrain Survey is in agreement with the ERP as it indicates lagoon seepage effects to the west and south. To the west, the salinity effected zone extends beyond the area of investigation. To the south, effects are limited to a distance of approximately 200 feet before background values are reached. EM testing could not be performed north of the lagoon due to highly conductive infrastructure such as iron fencing.

3.3.16.3 Summary

Groundwater chemistry in downgradient wells and in most of the temporary soil borings is not indicative of lagoon seepage. Only one soil boring exhibits slight indications of lagoon seepage. In contrast, geophysical imaging suggests lateral movement of salt-affected shallow groundwater to the west and, more limited, to the south. Salt-affected groundwater extends to the maximum depth of investigation of ~120 feet below the water table in some areas adjacent to the lagoon.

3.3.17 NUN

Lagoon liquor was sampled quarterly in 2014 and concentrations were as follows:

1. TKN concentrations ranged from 448 to 980 mg/L.
2. Ammoniacal N concentrations ranged from 386 to 529 mg/L.
3. Organic N accounted for 14 to 47% of TN.
4. P concentrations ranged from 24.4 to 74 mg/L.
5. K concentrations ranged from 220 to 1,080 mg/L.
6. EC measurements ranged from 3,990 to 11,100 μS/cm.

Monthly groundwater level measurements indicate that first encountered groundwater occurred at depths ranging from less than 5 to 10 ft (bgs) beneath the dairy between 2012 and 2015. During the time of geophysical testing in April 2015, groundwater in the monitoring well adjacent to the lagoon (i.e., NUN-MW1) was approximately 4 ft (bgs). Contours of equipotential groundwater level elevations indicate northerly to north-northeasterly groundwater flow. MW1 was mainly crossgradient of the lagoon.

Key 2012-2015 groundwater chemistry is summarized below:

NUN-MW1

1. Ammoniacal N concentrations were below the reporting limit.
2. TKN concentrations ranged from 0.50 to 0.83 mg/L and were similar or lower than at non-lagoon wells.
3. Comparison of TKN and ammoniacal N indicates that TKN essentially reflected organic N concentrations.
4. Nitrite-N concentrations were below the reporting limit.
5. Nitrate-N concentrations were very low (0.88-4.4 mg/L) and similar or lower than at non-lagoon wells.
6. TDS concentrations and individual general mineral concentrations were similar or lower than at non-lagoon wells, with the exception of slightly higher HCO_3 concentrations.

Groundwater chemistry at this location is not indicative of lagoon seepage. However, due to its crossgradient position to the lagoon, this well may not be favorably located for purposes of lagoon seepage detection.

3.3.17.1 Soil Boring Water Quality

At this facility, four soil borings were advanced and four groundwater samples were retrieved.

1. Ammoniacal N concentrations ranged from 1.2 to 19 mg/L.
2. TKN concentrations ranged from 2.9 to 20 mg/L.
3. Nitrite-N concentrations were below or near the reporting limit.
4. Nitrate-N concentrations ranged from 12 to 550 mg/L.
5. K concentrations ranged from 8.6 to 40 mg/L.
6. HCO_3 concentrations ranged from 380 to 930 mg/L.
7. TDS concentrations ranged from 5,400 to 16,000 mg/L.

Overall, these results are indicative of lagoon seepage, although mainly at SB3 and SB4, which were advanced on the upgradient side of the lagoon. Local groundwater mounding provides a mechanism for affecting groundwater quality at these locations. Groundwater mounding is plausible at this location, even if lagoon seepage is minimal, due to shallow groundwater conditions and clay-rich subsurface materials (i.e., small hydraulic conductivity).

3.3.17.2 Geophysical Imaging

Line 3, located just south of the lagoon, shows anomalously low resistivities just below the water table along the entire length of the line, extending approximately 200 feet west of the lagoon (paralleling the silage storage) and 200 feet east of the lagoon onto the field. The high salinity found at SB3 and SB4 are consistent with the geophysical results south of the lagoon and could be associated with lagoon seepage. However, Line 3 is upgradient of the lagoon and while low hydraulic conductivity materials (i.e., clay-rich) may facilitate groundwater mounding at this site, it may be more plausible that infiltration from the corrals is the primary source for the low resistivity zone around SB4. Further, lagoon seepage is an unlikely explanation for the low-resistivity zones to the west and east. Various sources such as infiltration of fluids from the silage storage area, manure handling activities south of the lagoon, and crop growing activities may all contribute to these low resistivity zones. Along all other sides of the lagoon, including the downgradient side, the geophysical results do not indicate lagoon seepage impacts on the salinity of underlying groundwater. It is unclear, why the low resistivities exhibited along Line 3 are not shown on Lines 5, 7, and 8, where these lines intersect Line 3.

The EM survey shows two main areas of high terrain conductivity; one is in the area of SB4 and the other one is centered about the silage storage area.

3.3.17.3 Summary

Groundwater chemistry at MW1 is not indicative of lagoon seepage. However, due to its crossgradient position to the lagoon, this well may not be favorably located for purposes of lagoon seepage detection. Impacts to groundwater quality were mostly seen in soil borings just upgradient of the lagoon in an area which may be affected by slight groundwater mounding.

Geophysical imaging suggests that lateral movement of seepage-affected shallow groundwater is minimal, and occurs only on its upgradient side, if at all, as there are other more plausible sources in this area. Effects on groundwater salinity extend below the maximum depth of investigation of ~20 feet below the water table.

3.3.18 MOO

Lagoon liquor was sampled three times in 2014 and concentrations were as follows:

1. TKN concentrations ranged from 56 to 353 mg/L.
2. Ammoniacal N concentrations ranged from 30.8 to 235 mg/L.
3. Organic N accounted for 33 to 45% of TN.
4. P concentrations ranged from 11.4 to 51.5 mg/L.
5. K concentrations ranged from 92.5 to 520 mg/L.
6. EC measurements ranged from 2,390 to 5,290 µS/cm.

Monthly groundwater level measurements indicate that first encountered groundwater occurred at depths ranging from less than 10 to 30 ft (bgs) between 2012 and 2015. During the time of geophysical testing at in April 2015, groundwater in the monitoring wells adjacent to the lagoon (i.e., MOO-MW1 and 2) was approximately 14 to 18 ft (bgs). Contours of equipotential groundwater level elevations indicate consistent northeasterly to east-northeasterly groundwater flow toward the San Joaquin River. MW1 and MW2 were downgradient of the lagoon and settling basins.

Key 2012-2015 groundwater chemistry is summarized below:

MOO-MW1

1. Ammoniacal N concentrations ranged from 0.16 to 1.4 mg/L and were consistently found in quarterly samples. These concentrations are relatively low. However, non-lagoon wells did not show detectable levels of ammoniacal N with the exception of sporadic detections in MW6 (up to 0.12 mg/L).
2. TKN concentrations ranged from 0.45 to 1.8 mg/L.
3. Comparison of TKN and ammoniacal N indicates low organic N concentrations (i.e., <0.6 mg/L).
4. Nitrite-N concentrations ranged from below the reporting limit to 0.37 mg/L.
5. Nitrate-N concentrations were relatively low (1.5-15 mg/L).
6. K concentrations were relatively low (3.1-4.0 mg/L) and comparable to concentrations at non-lagoon wells.
7. Na concentrations were elevated (360-440 mg/L) over those observed in non-lagoon wells.
8. HCO_3 concentrations were higher than at any of the other wells (880-940 mg/L).

Although TKN concentrations were relatively low, the presence of ammoniacal and organic N in conjunction with elevated concentrations of Na and HCO_3 suggests that groundwater at this location is impacted by lagoon seepage.

MOO-MW2

1. Concentrations of ammoniacal N ranged from below the reporting limit to 0.45 mg/L.
2. TKN concentrations ranged from below the reporting limit to 0.60 mg/L.
3. Comparison of TKN and ammoniacal N indicates low organic N concentrations (i.e., <0.6 mg/L).
4. Nitrite-N concentrations were below the reporting limit.

5. Nitrate-N concentrations ranged from 20 to 43 mg/L (Med=33, n=16) and were higher than at the other wells with the exception of MOO-MW7.
6. K concentrations were relatively low (2.6-3.5 mg/L) and comparable to concentrations in other wells.
7. Na concentrations were substantially higher than in any of the other wells (360-570 mg/L).
8. Bicarbonate concentrations were higher than at the non-lagoon wells (850-880 mg/L) with the exception of one sample from MW4.

Although ammoniacal N and TKN concentrations were rather low, the presence of ammoniacal N in conjunction with elevated concentrations of nitrate-N, Na, and HCO_3 suggests that groundwater at this location is impacted by lagoon seepage.

3.3.18.1 Geophysical Imaging

Line 3, located on the berm separating the lagoon from the settling basins, indicates the most apparent effects of lagoon seepage on underlying groundwater. Anomalously low resistivity zones are shown in orange and red colors and extend along much of the line. In some areas, the effects on groundwater salinity extend below the maximum investigation depth of ~45 feet below the water table. However, in the southeastern area, most of the affected groundwater appears to reside above this depth.

Line 4, located between the settling basins, also indicates effects of lagoon seepage on underlying groundwater. However, the affected zone only extends to ~20 feet below the water table. There appears to be no or virtually no impact to the northwest and northeast of the lagoon and only minimal lateral movement to the southeast.

3.3.18.2 Summary

Groundwater constituent concentrations in the downgradient monitoring wells provide slight evidence for lagoon seepage.

Geophysical imaging suggests that salinity effects on groundwater are the most developed in the center of the lagoon system where they extend below the maximum investigation depth of ~45 feet below the water table. Lateral movement of seepage-affected shallow groundwater is very limited and impacts are apparent only in the immediate vicinity of the lagoon footprint.

3.3.19 DLF

Lagoon liquor was sampled quarterly in 2014 and concentrations were as follows (see **Attachment 3** for additional lagoon water quality from CVDRMP's testing associated with the water balance testing):

1. TKN concentration ranged from 246 to 534 mg/L.
2. Ammoniacal N concentrations ranged from 147 to 310 mg/L.
3. Organic N accounted for 28 to 45% of TN.
4. P concentrations ranged from 29.7 to 82.5 mg/L.
5. K concentrations ranged from 330 to 650 mg/L.
6. EC measurements ranged from 4,540 to 6,200 µS/cm.

Monthly groundwater level measurements indicate that first encountered groundwater in the monitoring well cluster adjacent to the lagoon (i.e., DLF-MW4) occurred at depth greater than 140 ft (bgs) since 2013. Groundwater chemistry at this location is substantially attributed to recharge occurring in a source area within the fields and the lagoons. Nitrate-N and TDS concentrations were low (8.1-9.5 mg/L and 380-440 mg/L, respectively). Nitrite-N, ammoniacal N, TKN, and K concentrations were near of below the respective reporting limits. Groundwater chemistry at this location is not indicative of lagoon seepage despite its construction immediately adjacent to the lagoon.

3.3.20 ZZI

Lagoon liquor was sampled quarterly in 2014 and concentrations were as follows (see **Attachment 3** for additional lagoon water quality from CVDRMP's testing associated with the water balance testing):

1. TKN concentration ranged from 234 to 613 mg/L.
2. Ammoniacal N concentrations ranged from 79 to 295 mg/L.
3. Organic N accounted for 31 to 78% of TN.
4. P concentrations ranged from 18.58 to 71.85 mg/L.
5. K concentrations ranged from 121.21 to 340.17 mg/L.
6. EC measurements ranged from 1,500 to 4,200 µS/cm.

Monthly groundwater level measurements indicate that first encountered groundwater in the monitoring well clusters adjacent to the lagoons occurred at depths as shallow as 23 ft (bgs) and greater than 100 ft (bgs) at ZZI-MW3 and 7, respectively, since 2013. Contours of equipotential groundwater level elevations (2012-2015) indicate consistent westerly to west-northwesterly groundwater flow. MW3 was downgradient of the big lagoon and MW7 down- to crossgradient of the small lagoon.

Key 2013-2014 groundwater chemistry is summarized below:

ZZI-MW3

Groundwater in the shallow wells (MW3A and 3AA) exhibits high ammoniacal N (210-300 mg/L) and TKN (290 mg/L) concentrations, high K, HCO_3, and PO_4 (460, 2,100, and 170 mg/L, respectively). Nitrite-N and nitrate-N were below their respective reporting limits. Groundwater chemistry in the shallow wells is indicative of lagoon seepage.

Groundwater in the deeper zone (MW3B) exhibits ammoniacal N, K, and PO_4 concentrations near or below their respective reporting limits. Nitrate-N, nitrite-N and TKN concentrations ranged from 6.6 to 17 mg/L (n=7), 0.37 to 0.48 mg/L and 0.35 to 0.41 mg/L respectively. Groundwater chemistry in the deeper zone is not indicative of lagoon seepage.

ZZI-MW7

Groundwater chemistry at this location is substantially attributed to recharge occurring in a source area that includes animal housing and the lagoon. This includes nitrate-N concentrations ranging from 12 to 16 mg/L. Ammoniacal N was near or below its reporting limit. TKN and nitrite-N concentrations were also low (0.36-0.57 and 0.21-034 mg/L, respectively). K concentrations were below the reporting limit. Groundwater chemistry at this location is not indicative of lagoon seepage.

3.3.21 SO2

Lagoon liquor was sampled quarterly in 2014 and concentrations were as follows:

1. TKN concentration ranged from 217 to 368 mg/L.
2. Ammoniacal N concentrations ranged from 14.1 to 140.3 mg/L.
3. Organic N accounted for 59 to 94% of TN.
4. P concentrations ranged from 5.1 to 29.7 mg/L.
5. K concentrations ranged from 73 to 294 mg/L.
6. EC measurements ranged from 1,800 to 3,040 μS/cm.

Monthly groundwater level measurements indicate that first encountered groundwater occurred at depths ranging from approximately 60 to 90 ft (bgs) beneath the dairy since 2013. Contours of equipotential water level elevations (2013-2015) indicate mainly westerly to northwesterly groundwater flow. MW-2 and MW-8 were downgradient of the lagoon.

Key 2013-2014 groundwater chemistry is summarized below:

SO2-MW2

This well could only be sampled once since 2013 due to declining water levels. TDS and nitrate-N concentrations were significantly higher than in any of the non-lagoon wells (1,900 and 110 mg/L, respectively). Ammoniacal N was below its reporting limit.

SO2-MW8

TDS and nitrate-N concentrations were significantly higher than in any of the non-lagoon wells (1,400-2,200 mg/L, Med=1,850 mg/L, n=6; and 94-160 mg/L, Med=115 mg/L, n=6, respectively). Nitrite-N and ammoniacal N were near or below the reporting limits. TKN was relatively low but approximately twice as high as in non-lagoon wells. K concentration (12 mg/L) was elevated over those observed at non-lagoon wells. Although TKN and ammoniacal N concentrations were low at this location, concentrations of TDS, nitrate-N, and K that are significantly higher than those observed in non-lagoon wells indicate that groundwater chemistry at this location is impacted by lagoon seepage.

4 DISCUSSION

4.1 Seepage Rates and N-Loading Rates

In sum, CVDRMP carried out 50 water balance tests on 17 lagoons located in areas of different native soils (i.e., ranging from clay to sand). The lagoons were of varying age, apparent construction and management, and included lagoons that were constructed before pertinent Title 27 regulations became effective. Seepage rates were generally small (i.e., no larger than 2.4 mm d^{-1}) with one exception. At one location, where exposed gravel strata possibly affected results, the maximum seepage rate was S_{adj}=3.9 mm d^{-1}. Seepage rates available for the three lagoons that were constructed to Title 27 regulations exhibited the same range as the other lagoons in this study.

The investigation did not find a strong correlation between mapped soil type and seepage rates. This is not surprising given the limitations of mapped soil characteristics predicting actual berm conditions. Three lagoons with relatively high mapped soil clay content were among the ones with the smallest seepage rates, while four of the highest seepage rates were associated with gravelly soil, sand, and sandy loam. However, four additional lagoons with equally low mapped clay content as those with the higher seepage rates exhibited very low seepage rates and at least one lagoon with substantially higher mapped clay content exhibited a seepage rate near the top of the range.

Formal categorical bi- and/or multivariate statistical analyses were not performed on this data set due to the combined variability and uncertainty associated with seepage rates, actual on-site soil characteristics, and lagoon operational characteristics.

Ten of the 17 tested lagoons had seepage rates ≤0.8 mm d^{-1}, which is smaller than the most recent and stringent NRCS design seepage rate of 0.86 mm d^{-1} for locations where credit for manure sealing is prohibited. Five of these lagoons were built in areas of sand or sandy loams with no records available to support evidence of construction to Title 27 regulations.

The results of the water balance tests provide strong evidence against the notion of seepage rate differences in the centimeter to meter range, as implied by BVA (2003). The magnitude and range of seepage rates measured here are consistent with the pertinent literature (LSCE 2008). The similarity of seepage rates across soil types (clay to sand) is attributed to the moderating effect of a sludge layer of very low hydraulic conductivity that typically develops on the lagoon's liner surface.

Estimates of subsurface nitrogen (N) mass loading rates ranged from zero to 3,503 lbs ac^{-1} y^{-1} with a mean of 1,045 lbs ac^{-1} y^{-1} (*Section 3.2.2*). The total area occupied by lagoons and settling basins on the 41 monitored CVDRMP dairies is 380 ac. This is 1.3% of the manured field area (approximately 29,000 ac) or less if compared to the total area taken up by these dairies. Using the mean N-loading rate of 1,045 lbs ac^{-1} y^{-1} yields a total N-loading rate of 400,000 lbs y^{-1}.

4.1.1 Context to Other's Estimates of N-Loading Rates – Lagoons and Fields

The context to the lagoon loading rates estimated herein (previously provided in LSCE (2015c)) is provided by three non-CVDRMP efforts specific to California and Central Valley dairy. These efforts are briefly described in the following *Sections 4.1.1.1* to *4.1.1.3*.

4.1.1.1 Addressing Nitrate in California's Groundwater

Harter, Lund et al. (2012) identified sources of nitrate pollution in a study area comprised of the four-county Tulare Lake Basin in the Central Valley and the Monterey County portion of the Salinas Valley for 2005. The study area includes four of the nation's five counties with the largest agricultural production. It represents about 40% of California's irrigated cropland (including 80 different crops) and over half of California's dairy herd. Within the study area, human/animal-generated nitrate sources (as N) to groundwater include (**Figure 2**, reproduced with permission from Harter, Lund et al. (2012), ES-1):

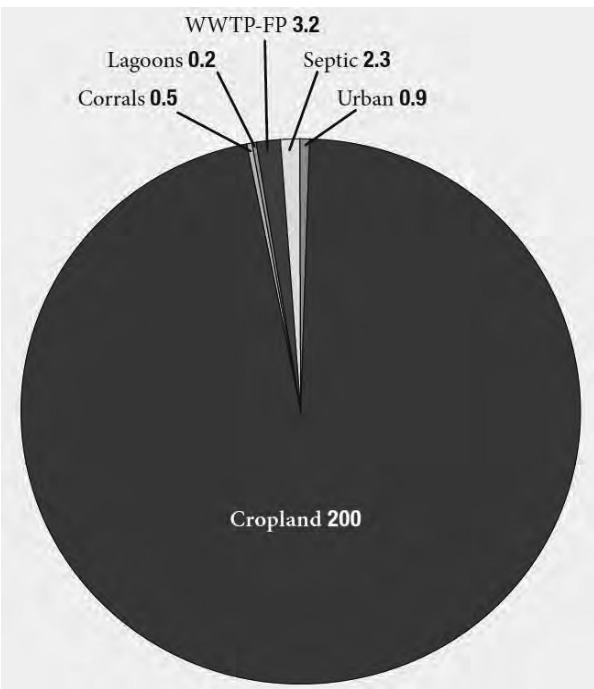

Figure ES-1. Estimated groundwater nitrate loading from major sources within the Tulare Lake Basin and Salinas Valley, in Gg nitrogen per year (1 Gg = 1,100 t).

- ❑ Cropland (96% of total), where nitrogen applied to crops, but not removed by harvest, air emission, or runoff, is leached from the root zone to groundwater. Nitrogen intentionally or incidentally applied to cropland includes synthetic fertilizer (54%), animal manure (33%), irrigation source water (8%), atmospheric deposition (3%), and wastewater treatment and food processing facility effluent and associated solids (2%);
- ❑ Percolation of wastewater treatment plant (WWTP) and food processing (FP) wastes (1.5% of total);
- ❑ Leachate from septic system drainfields (1% of total);
- ❑ Urban parks, lawns, golf courses, and leaky sewer systems (less than 1% of total); and
- ❑ Recharge from animal corrals and manure storage lagoons (less than 1% of total);
- ❑ Downward migration of nitrate-contaminated water via wells (less than 1% of total).

Figure 2: Estimated groundwater nitrate loading (excerpted from Harter, Lund et al., 2012)

Based on this assessment, nitrogen mass loading from manure storage lagoons is 1,000 times less than from cropland. However, the study area includes data from the Salinas Valley which has a comparatively small cow herd. Harter, Lund et al. (2012) reviewed a range of previous work on lagoon seepage rates and considered N-mass loading rates ranging from 714 to 1,628 lbs ac^{-1} y^{-1} to develop upper limits on total lagoon N-mass loading in the study area. This range includes the mean mass loading estimate developed herein (i.e., 1,045 lbs ac^{-1} y^{-1}).

4.1.1.2 Managing Dairy Manure in the Central Valley of California

Chang, Harter et al. (2005a) developed nitrogen application rate guidelines for agricultural cropping systems that rely on large inputs from dairy manure based on review of existing research and computer simulations. They state:

> The results presented here undoubtedly are subject to a great number of uncertainties. It nevertheless demonstrates that the upper end of computer-simulated optimal N loading rates of 1.4 to 1.65 times the crop N harvest removal are practical and, based on field observations, achievable if the production field is properly managed.

and,

> Investigations of the crop N recovery in several field experiments showed that the appropriate N loading rate that minimizes N leaching and maximizes N harvest is between 140 to 150% of the N harvested. Computer models indicated a somewhat larger range of 140% to 165%. While field studies provided important feedback on loss pathways and loss rates as well as mineralization rates, model simulations were well suited to study the dynamic behavior of the soil nitrogen pool and its interaction with the crop N uptake. Simulations are particularly valuable to understand the role of various loss pathways.

They also indicate uncertainty associated with the relationship between their results and the practical realities of full-scale production systems:

> The combined evidence from laboratory, field, and modeling studies indicates that precise nutrient management, while plausible in principle, may be problematic when implemented in full-scale production systems, as it requires careful timing of the N applications, close monitoring of the amount of N and water inputs, and best management of crop production. More importantly, the growers must show flexibility to make necessary adjustments on N inputs during the course of a growing season to achieve satisfactory results.

4.1.1.3 A Field-Scale Mass Balance

Groundwater N loading from fields is illustrated with a simplified field N balance developed by Harter and Menke (2005). The estimate developed during this study preceded the Dairy General Order. This example was developed with values typical of management practices prior to targeted nutrient management with a double cropping system of summer corn and winter grain, irrigation efficiencies of 50-70%, and recharge rates (i.e., seepage below the crop root zone) of 1-2 ft y^{-1}. Their example, based on a research project, includes four to six diluted liquid manure applications per year, pre-irrigation in the fall, commercial fertilizer applications, and lagoon releases in the winter in order to maintain storage capacity for storm water. The field nitrogen balance assumes no accumulation or depletion of soil nitrogen over the course of the year (i.e., quasi-steady state conditions). Total N-inputs were estimated at 1,070 lbs ac^{-1} y^{-1}, and total crop removal was estimated at 500 lbs ac^{-1} y^{-1}.

Input – Output – Losses = 0

		$lbs\ ac^{-1}\ y^{-1}$		$lbs\ ac^{-1}\ y^{-1}$
Input	commercial fertilizer N	250		
	liquid manure, organic N	450		
	liquid manure, ammoniacal N	350		
	atmospheric deposition	10		
	irrigation water N	10	SUM	1,070
Output	crop removal – summer corn	300		
	crop removal – winter grain	200	SUM	500
Losses	volatilization (less than 10% of applied N)	0-100		
	denitrification (less than 10% of applied N)	0-100		
	groundwater N loading	***370-570***	SUM	570

The above example yields an application/removal (AR) ratio of 2.14 regardless of the magnitude of losses to volatilization and denitrification. However, under the assumption of zero volatilization and denitrification losses, 570 lbs ac^{-1} y^{-1} of N would leach below the crop root zone. Applying this loading rate to 29,000 ac of manured cropland on 41 monitored CVDRMP dairies yields an N-loading rate of $1.7x10^{7}$ lbs y^{-1} or 2.3% of the total N-mass (i.e., fields and lagoons combined) (**Table 7**).

In comparison, the Dairy General Order mandates an AR ratio of 1.4. Using AR ratios of 1.4 and 1.65 (see *Section 4.1.1.2*) while holding N-inputs from Harter and Menke (2005) steady at 1,070 lbs ac^{-1} y^{-1} results in 306 and 422 lbs ac^{-1} y^{-1} of N leaching below the crop root zone, respectively (i.e., assuming no volatilization and no denitrification). These examples are hypothetical because it is uncertain that increased crop uptake alone can achieve these kinds of improvements. It is more likely that yield increases will be accompanied with N-input reductions for an improved AR ratio. On the other hand, it is unknown whether the ambitious AR ratio of 1.4 can be achieved in full-scale production systems that rely heavily on the input of organic fertilizer products. Therefore, the mean loading rate of 364 lbs ac^{-1} y^{-1} is applied to 29,000 ac of manured cropland yielding a preliminary N-loading rate of $1.1x10^{7}$ lbs y^{-1} or 3.5% of the total N-mass (i.e., fields and lagoons combined), which may be reflective of substantially improved nitrogen management (see **Table 7**).

Table 7: Comparison of N-Loading Rates and N-Mass Contributions from Lagoons and Cropland

N-Loading Source	N-Loading Rate [lbs ac^{-1} y^{-1}]	N-Mass Contribution [lbs y^{-1}]	Proportional N-Mass Contribution
Prior to Targeted N-Management (Harter and Menke, 2005)			
Lagoon	1,045	400,000	2.3%
Cropland	570	17,000,000	97.7%
Improved N-Management on Cropland			
Lagoon	1,045	400,000	3.5%
Cropland	364	11,000,000	96.5%

The difference between lagoons' and cropland's per-acre N-loading rates may be surprisingly small to non-agronomists because the mere sight of a dairy manure lagoon, which contains nutrient-rich water year round, may erroneously evoke the perception that it constitutes the major source of nitrogen emissions. In contrast, observing a field of corn does not appear to evoke such a perception. However, while lagoons benefit from the manure sealing effect, farmers deliberately irrigate and or manage with the intent to cause at least a fraction of the water to infiltrate through the permeable soil profile and past the root zone so as to prevent salt buildup in the root zone. In soils that are not sufficiently permeable due to natural soil characteristics or compaction from tractor traffic, the soil's infiltration capacity is routinely enhanced with mechanical means and/or chemical soil amendments.

Many factors create uncertainty with respect to current and future N-loading rates, including:

- It is unknown whether the ambitious AR ratio of 1.4 can be achieved in full-scale production systems that rely heavily on the input of organic fertilizer products (Chang, Harter et al. 2005b).
- Irrigation management is key to nutrient management. Irrigation system technologies continue to develop rapidly, providing options to farmers today that were not available just a few years ago. In this context, California's uncertain water supply situation is expected to be a major consideration for farmers in years to come.
- New crop varieties continue to be developed and, while it is likely that yield increases will be part of California's future, it is unknown how improved, targeted N-management will ultimately affect farm-scale nutrient use efficiency.
- Improving nitrogen use efficiency will require complex, custom solutions for individual dairies, and this will require long-term access to and collaboration with highly skilled agronomists and irrigation specialists with local expertise.
- As with any on-farm improvements, improvements on dairies will necessarily be implemented incrementally and on a trial-and-error basis.

4.2 Groundwater Quality from Monitoring Wells and Temporary Boreholes

The Year 2 Annual Report (LSCE 2014b) noted that seepage was either not evident or inconclusive based on groundwater testing conducted in 2012 and 2013 around lagoons on 12 of 18 Phase 1 dairies. All of these monitoring wells were constructed as very shallow dedicated monitoring wells intersecting first encountered groundwater, and all of these wells were installed directly adjacent to the lagoons. However, despite careful, site-specific monitoring well network design, unexpected and/or nonsteady groundwater flow conditions rendered some of these wells in suboptimal positions (i.e., not consistently downgradient of the lagoon). Others showed no signs of groundwater impacts although they are consistently downgradient of the lagoon. This condition illustrates that monitoring wells are an unreliable tool to detect impacts of lagoon seepage on groundwater even under relatively favorable hydrogeologic conditions. A further limitation of monitoring wells is that the absence of detectable impacts to groundwater quality does not indicate that a lagoon has zero-seepage or no impacts to groundwater.

Therefore, CVDRMP conducted lagoon perimeter subsurface hydrogeologic investigations at 12 lagoons in 2014. Groundwater quality obtained from water samples retrieved from the lagoon perimeter soil borings produced strong evidence of lagoon seepage as indicated by high ammoniacal N and/or TKN concentrations at four of the 12 dairies where temporary soil borings were advanced. These were ANC, COT, FG1, and NUN. However, even at ANC, where the highest ammoniacal N and TKN concentrations were observed, concentrations ranged over several orders of magnitude, including a measurement of only 1.0 mg/L of ammoniacal N in a downgradient soil boring. None of the dedicated monitoring wells at ANC exhibits groundwater chemical characteristics that are indicative of lagoon seepage. This evidences substantial moderation of impacts to groundwater within the immediate proximity of the lagoon. At COT and NUN, chemical characteristics strongly indicative of lagoon seepage were only observed on one side of the investigated lagoons and, interestingly, on their upgradient side. Similarly, impacts to groundwater quality at FG1 appeared limited to one side of the lagoon.

The results from six dairy lagoons indicate lesser effects to groundwater quality both in terms of magnitude of concentrations and spatial distribution (BET, ANT, COR, FG2, GOD, MAC). In these cases, indicator constituents were only slightly or moderately elevated. Sometimes only one or two constituents were elevated (such as K, PO_4, or HCO_3) and/or only one or two of the soil borings produced groundwater samples indicative of lagoon seepage. In some cases, non-lagoon monitoring wells exhibit higher concentrations than the samples retrieved from the soil borings.

At two dairies, groundwater chemical characteristics were not typical of lagoon seepage. At SAN, this was despite the fact that all soil borings were advanced directly downgradient of the lagoon; two of the borings were also located between the lagoon and the settling basins. At PLS, soil borings could not be advanced along the side of the lagoon that is most consistently downgradient. However, testing at the other downgradient side (possibly crossgradient at times) yielded essentially no indication of seepage impacts.

The discussion below presents several reasons why the lagoon perimeter subsurface hydrogeologic investigation effort was more successful in detecting whether lagoon seepage has had an effect on groundwater quality than observations from monitoring wells.

Temporary boreholes provide data redundancy, i.e., data can be collected from multiple locations around a lagoon in a relatively short time frame. This tends to address the heterogeneous subsurface distribution of impacts to groundwater. This is not only affected by the heterogeneity of subsurface materials, but also by nonsteady groundwater flow directions and spatially nonuniform seepage. Temporary boreholes can also be advanced in locations where permanent structures are not desirable (e.g., unstable ground, high traffic areas, areas used for storage during part of the year, etc.). As a result, they can sometimes be drilled closer to the wetted perimeter of the lagoon than a monitoring well.

Temporary boreholes enable groundwater sample collection from the uppermost few inches or feet of the water table at any moment in time. This type of measurement approaches that of a point measurement in proximity to the source. Therefore, constituents percolating from the bottom of the lagoon are more likely to be detected in higher concentrations than in a monitoring well. The technical limitations of monitoring wells, particularly with respect to the assessment of lagoon seepage, were first discussed in the Year 2 Annual Report (LSCE 2014b). Specifically, lagoons are often the smallest management unit on a dairy (i.e., compared to animal housing and fields); and if lagoon seepage approaches zero, the source area of a downgradient monitoring well will extend beyond the lagoon's footprint. In that case, groundwater chemical characteristics cannot be isolated to the lagoon as the sole contributing source, and the identification of seepage impacts on groundwater relies on unique identifiers such as elevated ammoniacal nitrogen.

4.3 Comparison of Seepage Rates, Mass Loading, and Groundwater Quality

Under ideal conditions, a groundwater constituent concentration may yield information on the effect of one source on groundwater quality at a specific point in the aquifer. However, it yields no information on the concentration of the seepage, the seepage rate, overall subsurface mass loading rate, or the duration of the loading. This means that the presence of a high concentration of an indicator parameter does not necessarily equate to "lots of seepage" or "lots of mass loading". A high concentration may be associated with a small seepage rate and an overall small subsurface mass loading rate. Similarly, a low concentration of an indicator parameter does not necessarily equate to "little seepage" or "little mass loading". A low concentration may be associated with a high seepage rate and an overall high subsurface mass loading rate.

The empirical results of this investigation, particularly the large spatial and temporal variability of groundwater constituent concentrations found in temporary boreholes and monitoring wells around individual lagoons, illustrate the non-uniqueness of groundwater concentrations with respect to lagoon performance and the limitations of concentration-based assessment (**Figures 3** to **5**). Although groundwater monitoring generates quantitative information, this information can only be used qualitatively with respect to lagoon seepage, i.e., supporting a statement such as, "groundwater chemistry is (or is not) indicative of lagoon seepage".

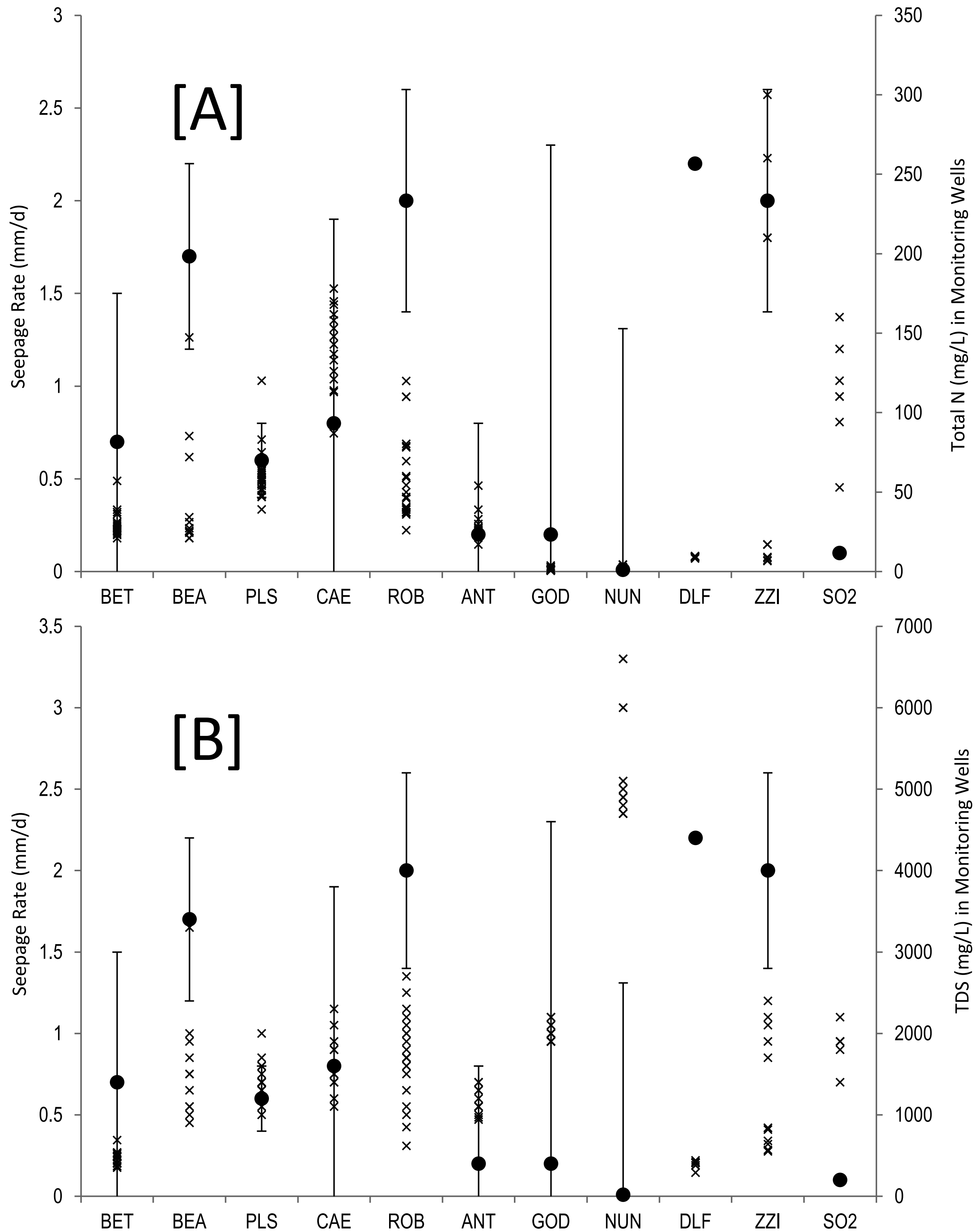

Figure 3: Seepage rates with uncertainty intervals (solid dots with whiskers) and groundwater quality from monitoring wells adjacent to lagoons. Water quality record from 2012 (2013 for DLF, ZZI, and SO2) to 2015. [A] Total N = nitrate + ammoniacal N [B] TDS = Total Dissolved Solids

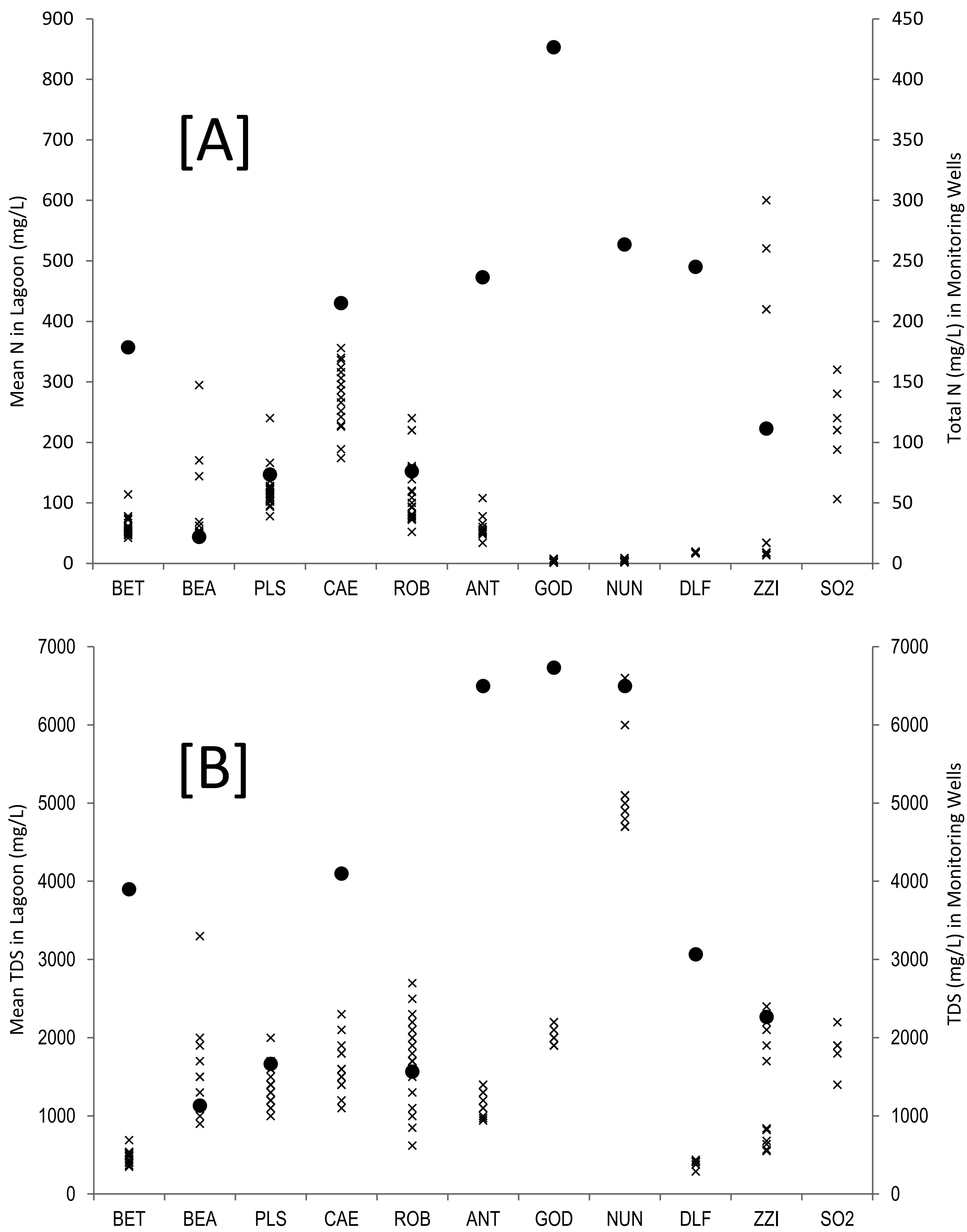

Figure 4: Lagoon water concentrations used for mass loading computations in *Section 3.2.2* (solid dots) and groundwater quality from monitoring wells adjacent to lagoons. Water quality record from 2012 (2013 for DLF, ZZI, and SO2) to 2015. [A] Total N = nitrate + ammoniacal N [B] TDS = Total Dissolved Solids

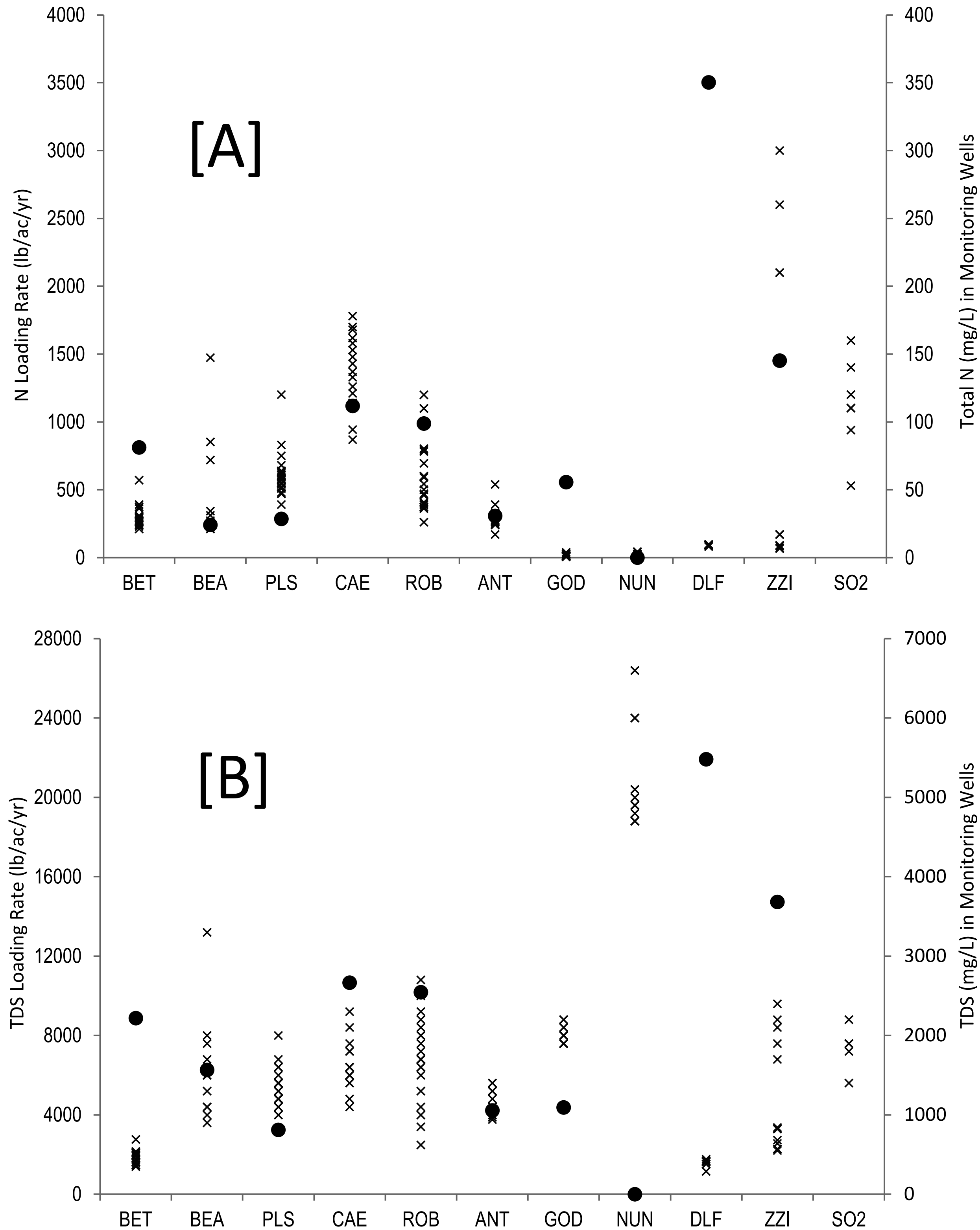

Figure 5: Lagoon mass loading rates (solid dots) and groundwater quality from monitoring wells adjacent to lagoons. Water quality record from 2012 (2013 for DLF, ZZI, and SO2) to 2015.
[A] Total N = nitrate + ammoniacal N [B] TDS = Total Dissolved Solids

4.4 Geophysical Imaging

4.4.1 Methods Review

Geophysical resistivity surveys were completed to generate profiles of subsurface resistivity along the perimeter of 12 lagoons. Two different methods were used, the traditional ER method and the more rapid OhmMapper method. The depth of investigation using traditional ER was approximately 60 feet (bgs) and reached 120 feet (bgs) in two locations (BET and MAC). The depth of investigation using OhmMapper was 15 to 20 feet.

Intrusion of saline lagoon water into the subsurface is indicated by resistivity anomalies (i.e., zones of low resistivity). Typically, an inner set of four geophysical lines (i.e., the surface trace of the profiles) was completed on the lagoons' berms and an outer set of four lines was competed by stepping out approximately 50 to 75 feet to support assessment of the lateral movement of saline lagoon water. In several cases, additional lines were completed.

Geophysical lines cannot be completed under water. However, in seven cases, lagoon systems of multiple lagoons and/or settling basins were investigated. This provided the opportunity to complete lines between basins and investigate conditions in the center of lagoon systems where effects on subsurface soils and groundwater may be expected to be most prevalent.

At two locations (MAC and NUN) with particularly shallow groundwater (i.e., 4-6 feet, bgs) electromagnetic (EM) conductivity surveys were completed in addition to the ER profiles to generate surface maps of terrain conductivity. The terrain conductivity maps show contours of subsurface bulk electrical conductivity to a depth of approximately 15 feet (bgs). The terrain conductivity represents a composite of unsaturated zone and saturated zone conductivities. Intrusion of saline lagoon water into the subsurface is indicated by conductivity anomalies (i.e., zones of high conductivity). Geophysical data are collected along lines, similar to ER lines. The lateral movement of saline lagoon water away from lagoons is indicated by anomalously high terrain conductivities. This method does not yield depth-specific information.

4.4.2 Results

At five of the seven sites where lagoon systems of multiple lagoons and/or settling basins were investigated (i.e., MEN, ANC, BET, GOD, and MOO), salinity effects on groundwater are most developed in the center of the lagoon system where they typically extend below the maximum investigation depth (i.e., typically 60 feet, bgs). Lateral movement of seepage-affected shallow groundwater is very limited and impacts are apparent only in the immediate vicinity of the lagoon footprint. While effects may be seen along the perimeter (i.e., below the berms) of a lagoon, effects are greatly attenuated or not apparent anymore at a distances of 50-150 feet from the lagoons, and typically not on all sides of the lagoon system. BET appears to present an exception due to highly permeable subsurface materials. At this location, salt-affected groundwater extends beyond the lateral area of geophysical investigation of ~140 feet on one side of the lagoon. In contrast, at ROB, also a fairly sandy site, anomalously low resistivities that could be interpreted as the effect of lagoon seepage on groundwater salinity are essentially non-existent. At ANT, a site characterized by clay-rich soils, most of the salinity effects are limited to the unsaturated zone. This is remarkable as the first basins at this site were installed around 1980 and have been in operation continuously for over 30 years.

At DUR, FG1, PLS, MAC, and NUN, single lagoons were investigated. At these sites too, lateral movement of salt-affected shallow groundwater is very limited and impacts are apparent only in the immediate vicinity of the lagoon footprint. Vertical movement of salt-affected groundwater was captured at most of these locations as impacts were mostly seen above a depth of 40 feet below the water table. The MAC lagoon (in service since 1979) appears to present an exception as lateral effects on subsurface salinity extend beyond the zone of geophysical investigation and below the maximum investigation depth of ~120 feet below the water table although this site is characterized by clay-rich subsurface materials. At DUR and NUN, other sources of salt such as manured fields, corrals, and silage storage were identified to contribute to increased subsurface salinity near the lagoons.

4.4.3 Summary

Geophysical imaging, particularly traditional ER profiling, can provide useful information to supplement point measurements of groundwater quality to investigate the effects of lagoon liquor seepage on the salinity of subsurface soils and groundwater. In most cases, these effects were found to remain in the immediate vicinity of the lagoons' footprint. Specifically, effects are most developed in the center of lagoon systems (i.e., between basins), are typically significantly reduced along lagoons' perimeters, and little or no impact was seen at a distance of 50-150 feet from the lagoon berms in 10 out of 12 cases. In the center of the lagoon systems, effects on groundwater salinity extend below the maximum investigation depth (i.e., typically 60 feet, bgs), whereas along the lagoon perimeter and beyond, high salinity zones remain shallower.

The geophysical imaging shows that the effects of lagoon liquor seepage on the salinity of subsurface soils and groundwater is highly heterogeneous. This is one reason why groundwater quality data are highly variable around lagoons and cannot serve as an estimator for lagoon performance with respect to seepage and mass emissions. Effects on groundwater salinity may not always manifest downgradient of a lagoon system depending on the distribution of relatively higher-permeability subsurface materials and preferential groundwater flow paths.

This effort investigated seven lagoons constructed in areas of permeable, sandy soils, and five lagoons constructed in areas of low-permeability, clay-rich soils. The investigation did not find categorically different results associated with these different areas.

5 SUMMARY AND KEY FINDINGS

This report comprehensively evaluates different types of data that CVDRMP collected from 2012-2015 to investigate the performance of earthen lagoons with respect to their ability to contain liquid dairy manure, their subsurface nitrogen (N) mass emissions, and effects on groundwater. This includes:

1. Groundwater quality data from dedicated monitoring wells adjacent to lagoons collected quarterly since 2012;
2. Seepage rates and subsurface N emissions from whole-lagoon seepage tests conducted in winters 2013/14 and 2014/15;
3. Lagoon liquor quality;
4. Lagoon perimeter soil borings and groundwater sampling at the water table conducted in fall 2014; and
5. Geophysical surveys carried out in fall 2014 (reconnaissance testing) and spring/summer 2015 (expanded testing).

Items 1 through 4 have already been independently reported on (LSCE 2013; LSCE 2014b; LSCE 2015b; LSCE 2015c; LSCE 2015a). This report compiles and synthesizes pertinent information and findings from these previous reports and adds the results from the most recent investigative effort, the geophysical testing.

Key Findings:

1) **Geophysical Imaging:** Traditional electrical resistivity (ER) profiling was found to be useful in visualizing the spatial extent of the effects of seepage from earthen liquid dairy manure lagoons on the salinity of subsurface soils and groundwater.
   a) This effort investigated 12 lagoons without construction records[6] ranging in age from 10 to over 50 years. Seven lagoons are situated in areas of permeable, sandy soils, and five are situated in areas of lower-permeability, clay-rich soils.
   b) *Lateral Extent:* Effects were found to remain in the immediate vicinity of the lagoons' footprint in most cases. Specifically, effects are most developed in the center of lagoon systems (i.e., between basins), they are typically significantly reduced along lagoons' perimeters, and little or no impact was seen at a distance of 50-150 feet from the lagoon berms in 10 out of 12 cases. With increasing distance from the lagoons, influences from other sources such as corrals and fields become more apparent.
   c) *Vertical Extent:* At seven sites, lagoon systems were investigated and ER profiles were completed between adjacent basins. At four of these sites, effects on groundwater salinity in the center of the lagoon systems extend below the maximum investigation depth of 60 feet, bgs (120 feet, bgs in one case). At one site, most of the salinity-effects remained limited to the unsaturated zone (~20 feet thick). At the last site, effects of lagoon seepage on the subsurface were not apparent.
      i) At all of the sites, salinity impacts were mostly seen above a depth of 40 feet below the water table along the lagoon perimeters and beyond.

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[6] Soil test results from the lagoon at MOO indicate clay content ranging from 11.7-38.6%.

d) The results do not suggest a relationship between variables such as ambient soil type, age of the lagoon, lagoon liquor strength, seepage rate, or mass loading rate and the extent of subsurface impacts.

2) **Groundwater Concentrations:** The empirical data developed by CVDRMP illustrate:

a) Monitoring wells are an unreliable tool for detecting impacts of lagoon seepage on groundwater even under relatively favorable hydrogeologic conditions.

i) Seepage was either not evident or inconclusive based on groundwater testing conducted in 2012 and 2013 around lagoons on 12 of 18 Phase 1 dairies (LSCE 2014a; LSCE 2014b). The absence of detectable impacts to groundwater quality does not indicate that a lagoon has zero-seepage or no impacts to groundwater.

b) Groundwater constituent concentrations do not yield information on the concentration of the lagoon seepage, the seepage rate, overall subsurface mass loading rate, or the duration of the loading. Although groundwater monitoring generates quantitative information, this information can only be used qualitatively with respect to lagoon seepage, i.e., supporting a statement such as, "groundwater chemistry is (or is not) indicative of lagoon seepage."

i) As a corollary, the presence of a high concentration of an indicator parameter does not necessarily equate to "lots of seepage" or "lots of mass loading." A high concentration may be associated with a small seepage rate and an overall small subsurface mass loading rate. Similarly, a low concentration of an indicator parameter does not necessarily equate to "little seepage" or "little mass loading." A low concentration may be associated with a high seepage rate and an overall high subsurface mass loading rate.

3) **Seepage Rates:** Mean seepage rates from 16 liquid manure lagoons exhibited a range from zero to 2.2 mm d^{-1}.

a) Two of the tested lagoons have documentation indicating that they may have been constructed to Title 27 regulations. Four lagoons were constructed before pertinent Title 27 legislation was enacted. The remaining 11 lagoons have no construction documentation; it is unknown whether they were constructed to Title 27 regulations.

b) One lagoon exhibited seepage rates as high as 3.9 mm d^{-1}. This is the only location where the NRCS Soil Survey indicates significant gravel content (up to 35%).

c) The two lagoons that have documentation indicating that they may have been constructed to Title 27 regulations performed the same as the remaining 14 lagoons (not the outlier lagoon, see above Item 3b).

d) This investigation found a narrow range of seepage rates for 17 lagoons, including one where exposed gravel strata may exist.

i) The field test results contradict seepage rates suggested by BVA (2003) ranging from centimeters to many meters per day that were based on theoretical hydraulic conductivities associated with soil textures in accordance with Title 27 regulations.

e) Ten of the 17 tested lagoons had seepage rates ≤0.8 mm d^{-1}.

i) This is smaller than the most recent and stringent NRCS design seepage rate of 0.86 mm d^{-1} for locations where credit for manure sealing is prohibited.

ii) Five of these lagoons were built in areas of sand or sandy loams with no records supporting construction to Title 27 regulations.

f) This investigation did not find a strong correlation between mapped soil type and seepage rates.

        i) Mapped soil types are likely not consistently representative of the characteristics of the earthen lagoon floor and side walls.
    g) The results of this investigation are consistent with the pertinent academic literature as reviewed in LSCE (2008).
        i) Similarly small seepage rates and a narrow range of seepage rates across the soil textures ranging from clay to coarse sand have been documented in other studies, and are attributed to the moderating effect of a sludge layer of very low hydraulic conductivity.

4) **Subsurface N-Loading:** Estimates of subsurface N-mass loading rates ranged from zero to 3,503 lbs ac^{-1} y^{-1} with a mean of 1,045 lbs ac^{-1} y^{-1}.
    a) Harter, Lund et al. (2012) reviewed a range of previous work on lagoon seepage rates and considered N-mass loading rates ranging from 714 to 1,628 lbs ac^{-1} y^{-1} to develop upper limits on total lagoon N-mass loading in the study area. This range compares favorably to CVDRMP's findings. Remarkably, CVDRMP's mean N-loading rate closely approximates the mean loading rate from Harter, Lund et al. (2012).
    b) The subsurface N-loading rate emanating from cropland in association with N-management reflective of pre-General Order conditions was estimated by Harter and Menke (2005) to be as high as 570 lbs ac^{-1} y^{-1}. It is uncertain how much N-loading rates can be reduced in the future due to improved, targeted N-management. However, it was reasoned herein, that an ambitious 36% reduction to 364 lbs ac^{-1} y^{-1} may be a realistic target (see *Section 4.1.1.3*).
        i) Application of the above loading rates to the summed areas on the 41 monitored CVDRMP dairies that are occupied by lagoons/settling basins and manured cropland suggests that lagoon N-loading contributes only 2.3% (pre-General Order) to 3.5% (targeted N-management) of the total N-mass on a dairy farm scale. These estimates are considered overestimates because they do not account for N-contributions from corrals and non-manured cropland on dairies.

6 TOWARD RECOMMENDATIONS

Due to fairly consistent performance across the range of lagoons evaluated (i.e., wide range of ambient soil types, ages of lagoons, lagoon construction details and operational characteristics), CVDRMP was not able to identify variables (other than exposed gravel strata) that could be used to predict performance in existing earthen-lined lagoons. This suggests that rather than devoting further technical effort to evaluating performance of individual lagoons as a means for prioritizing those lagoons most in need of additional or standardized management practices, a more appropriate strategy may be to develop practicable management measures that may be deployed on all existing earthen-lined ponds. CVDRMP explored this issue in depth with a review of pertinent literature that was reported on in the *Literature Review and Workplan – Controlling Seepage from Liquid Dairy Manure Lagoons in the Central Valley of California (Draft)* (LSCE 2016b). In summary, the literature review did not find quantitative information indicating the effectiveness of specific management measures in reducing seepage below existing levels. Many management measures appear to be based on what is considered common sense. However, whether such measures actually reduce seepage is largely unknown.

The development of evidence that demonstrates further seepage reductions for existing earthen lagoons will be exceedingly difficult and probably not practical because seepage rates are already very small without the implementation of management measures. Documenting incremental improvements would require essentially the level of control associated with laboratory experiments. However, laboratory tests are not a viable option because results have been amply shown to not be scalable to whole lagoon performance. A difficulty related to the small seepage rates and even smaller incremental improvements is the imprecision (i.e., uncertainty) inherent in whole-lagoon seepage rate estimates. It is expected that, in most cases, the uncertainty interval would be prohibitively large to support comparative analysis.

As a consequence of the above conditions, it is expected that the development of management measures will largely need to rely on qualitative reasoning rather than quantitative evidence. This highlights the importance of weighing the (quantitative) cost of management measures against the perceived (qualitative) benefits.

The *Literature Review and Workplan* identified several outstanding work efforts and a schedule toward the formulation of recommendations. These work efforts are well underway and on track with the schedule. For example, CVDRMP is presently evaluating the utility and feasibility of the following items:

- Further limiting N-subsurface emissions after lagoon decommissioning,
- Different soil treatments of lagoon banks, and
- Partial synthetic liners for lagoon banks.

In addition, CVDRMP devised and sent a producer survey to dairies that have lagoons with synthetic membranes. This effort aims to collect information on practical experiences with these facilities. Also, in winter 2016/17, several electrical leak location surveys paired with whole-lagoon seepage testing were carried out and are being evaluated. This effort addresses the following questions:

- What is the magnitude and range of whole-lagoon seepage rates from operational lagoons with synthetic membranes, and can it be measured with the water balance method?
- How does the seepage rate relate to the size of identified leaks?

The results from these efforts are expected to help devise recommendations guiding the role of synthetic-lined lagoons on dairies, particularly the role of single-membrane synthetic liners.

A Comparison of Dairy Cattle Manure Management with and without Anaerobic Digestion and Biogas Utilization

Submitted To:
Kurt Roos
AgSTAR Program
U.S. Environmental Protection Agency
Ariel Rios Building
1200 Pennsylvania Ave. NW (6202J)
Washington, DC 20460

Submitted By:
Eastern Research Group, Inc.
35 India Street, 4th Floor
Boston, MA 02110

Prepared By:
John H. Martin, Jr. Ph.D.

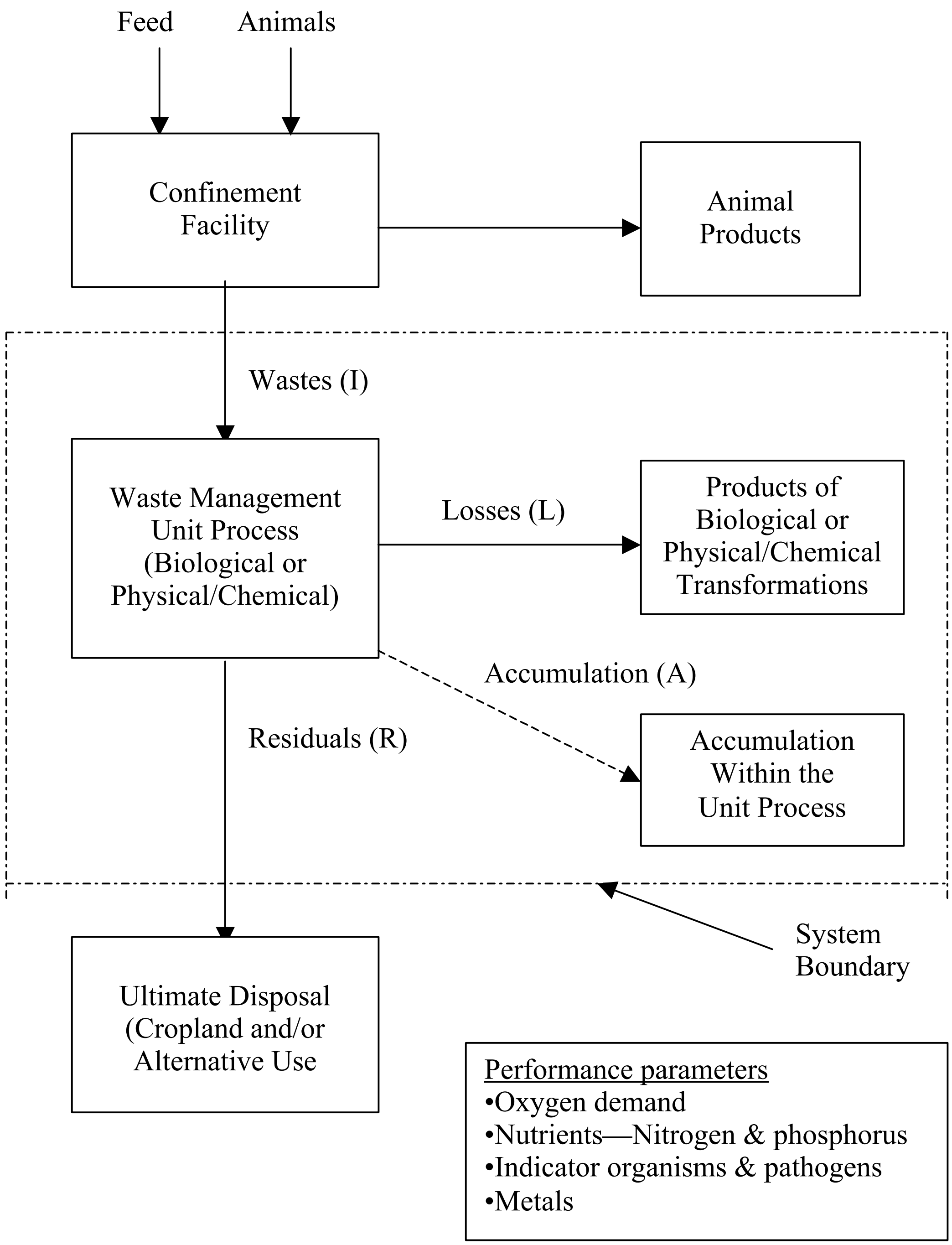
17 March 2003

EPA Contract #68-W7-0068
Task Order 400

PREFACE

This report summarizes the results from one of a series of studies designed to: 1) more fully characterize and quantify the protection of air and water quality provided by waste management systems currently used in the swine and dairy industries and 2) delineate associated costs. The overall objective of this effort is to develop a better understanding of: 1) the potential of individual system components and combinations of these components to ameliorate the impacts of swine and dairy cattle manures on environmental quality and 2) the relationships between design and operating parameters and the performance of the biological and physical/chemical processes involved. A clear understanding of both is essential for the rational planning and design of these waste management systems. With this information, swine and dairy producers and their engineers as well as the regulatory community will have the ability to identify specific processes or combinations of processes that will effectively address air and water quality problems of concern.

The following schematic illustrates the comprehensive mass balance approach that is being used for each unit process in these performance evaluations. When a system is comprised of more than one unit process, the performance of each process is characterized separately. Then the results are aggregated to characterize overall system performance. This is the same approach commonly used to characterize the performance of domestic and industrial wastewater treatment and chemical manufacturing unit processes. Past characterizations of individual process and systems performance frequently have been narrowly focused and have ignored the generation of side streams of residuals of significance and associated cross media environmental quality impacts. A standardized approach for cost analysis using uniform boundary conditions also is a key component of this comparative effort.



Where: L = I - (R + A)
(I and R are measured and
L and A are estimated)

Figure 1. Illustration of a standardized mass balance approach to characterize the performance of animal waste management unit processes.

Section 1

Summary and Conclusions

The objectives of this study were to compare: 1) the reductions in the potential air and water quality impacts of scraped dairy manure by preceding liquid-solids separation and storage with mesophilic anaerobic digestion in a plug-flow reactor with a flexible geotextile membrane, and 2) the associated cost differential. These reductions and the associated cost differential were determined from characterizations of performance and associated costs for these two dairy manure management strategies on two typical upstate New York dairy farms, AA Dairy and Patterson Farms, Inc. The characterizations of performance were based on materials balances developed for both systems and the cost differential was based on the differential between the cost of anaerobic digestion and the income generated through biogas utilization.

AA Dairy, with an average milking herd of 550 cows, uses anaerobic digestion with biogas utilization to generate electricity, followed by separation of solids, using a screw press separator, in their system of manure management. Patterson Farms also employs solids separation, using a drum type separator, in their manure management system but not anaerobic digestion. Both farms compost separated solids and store the liquid manure remaining after solids separation in earthen storage ponds.

The results of this study provide further confirmation of the environmental quality benefits realized by the anaerobic digestion of dairy cattle manure with biogas collection and utilization for the generation of electricity. These results also confirm that these environmental quality benefits can be realized while concurrently generating revenue adequate to recover capital invested and increase farm net income through the on-site use and sale of electricity generated. In Table 1-1, the impacts of anaerobic digestion on semisolid dairy cattle manure management with solids separation and storage, which are discussed below, are summarized.

Odors

The most readily apparent difference between the AA Dairy and Patterson Farms manure management systems is the effectiveness of anaerobic digestion at AA Dairy in reducing odors. This is the direct result of the degree of waste stabilization provided by anaerobic digestion under controlled conditions. As shown in Table 4-2, average reductions in total volatile solids, chemical oxygen demand, and volatile acids during anaerobic digestion were 29.7, 41.9, and 86.1 percent, respectively. With these reductions, additional degradation during storage under uncontrolled anaerobic conditions and the associated odors are minimized.

Table 1-1. Impacts of anaerobic digestion on a semisolid dairy cattle manure management systems with solids separation and storage.

Parameter	With anaerobic digestion (AA Dairy vs. Patterson Farms)
Odor	Substantial reduction
Greenhouse gas emissions	Methane—substantial reduction (8.16 tons per cow-yr) Nitrous oxide—No evidence of emissions with or without anaerobic digestion
Ammonia emissions	No significant reduction
Potential water quality impacts	Oxygen demand—substantial reduction (8.4 lb per cow-day) Pathogens—substantial reduction (Fecal coliforms: ~99.9%) (*M. avium paratuberculosis*: ~99%) Nutrient enrichment—no reduction
Economic impact	Significant increase in net farm income ($82 per cow-yr)

Greenhouse Gas Emissions

Methane—Perhaps the most significant impact of the anaerobic digestion of dairy cattle manure with biogas capture and utilization is the reduction of the emission of methane, a greenhouse gas with 21 times the heat-trapping capacity of carbon dioxide, to the atmosphere. The reduction in methane emissions, on a carbon dioxide equivalent basis, was determined to be 7.13 tons per cow-year, or 3,924 tons per year for the 550-cow AA Dairy milking herd. If this herd were expanded to the anaerobic digestion-biogas utilization system design value of 1,034 cows, this reduction would increase to 6,076 tons per year. In addition, the electricity generated using biogas has the potential of reducing carbon dioxide emissions from the use of fossil fuels for generating electricity. Under current operating conditions, this reduction is estimated to be 1.03 tons per cow-year and would increase to 1.29 tons per cow-year with herd expansion.

Nitrous Oxide—Analyses of samples of the stored liquid phase of dairy cattle manure after separation at both AA Dairy and Patterson Farms showed that no oxidized forms of nitrogen (nitrite or nitrate nitrogen) were present. Given that conditions required for nitrification, residual concentrations of dissolved oxygen and the absence of inhibitory concentrations of unionized or free ammonia (NH_3), the absence of evidence of nitrification was not surprising. Thus, the expectation of nitrous oxide emissions, as an end product of denitrification, from dairy cattle manure storage structures seemingly has no theoretical basis given the absence of the necessary prerequisite of nitrification.

Other Gaseous Emissions

Analysis of the biogas produced at AA Dairy indicated the presence of only a nominal concentration, 15±5 ppm, of NH_3. The results of this analysis in combination with the total Kjeldahl nitrogen balance results (Table 4-2) indicate the loss of nitrogen via ammonia volatilization during anaerobic digestion of dairy cattle manure is negligible. Thus, it appears reasonable to conclude that ammonia is insignificant as a source of emissions of oxides of nitrogen during biogas combustion. However, the concentration of hydrogen sulfide found in the AA Dairy biogas, 1,930 ppm, indicates that emissions of oxides of sulfur during biogas combustion potentially are significant.

Although anaerobic lagoons used for animal waste stabilization are generally considered significant sources of NH_3, emissions to the atmosphere, the results of this study suggest that at least structures used for the storage of dairy cattle manure are not. For both anaerobically digested and unstabilized manure, nitrogen losses were minimal but somewhat greater (30.2 lbs per cow-year) for the unstabilized manure. However, estimating nitrogen losses from both the AA Dairy and Patterson Farms manure storage structures was confounded by significant spatial variation in total Kjeldahl nitrogen concentrations in both storage structures. Thus, the losses reported in here may be underestimates.

Water Quality Impacts

Oxygen Demand—As mentioned above, the results of data collected at AA Dairy show (Table 4-2) that anaerobic digestion can substantially reduce dairy cattle manure total volatile solids and chemical oxygen demand. These reductions translate directly into a lower potential for depletion of dissolved oxygen in natural waters. Although anaerobically digested dairy cattle manure clearly is not suitable for direct discharge to surface or ground waters, these reductions still are significant due to the potential for these wastes to enter surface waters by nonpoint source transport mechanisms.

Pathogens—As shown in Table 4-4, mesophilic anaerobic digestion at a hydraulic retention time of 34 days was found to provide a mean reduction in the density of members of the fecal coliforms group of enteric bacteria that approached 99.9 percent. For the pathogen, *Mycobacterium avium paratuberculosis*, reduction slightly exceeded 99 percent. *M. avium paratuberculosis* is responsible for paratuberculosis (Johne's disease) in cattle and other ruminants and is suspected to be the causative agent in Crohn's disease, a chronic enteritis in humans. No regrowth of either organism during storage was observed. Thus, it appears that anaerobic digestion of dairy cattle manure also can reduce the potential for the contamination of natural waters by both non-pathogenic and pathogenic microorganisms. . No reductions were observed in the Patterson Farm manure management system.

Nutrient Enrichment—Both nitrogen and phosphorus mass balance results (Table 4-2) demonstrate that anaerobic digestion in a plug flow reactor without the accumulation of settleable solids provides no reduction of the potential impact of these nutrients on water quality.

In addition, results of this study indicate that separation of coarse solids with or without anaerobic digestion only reduces the masses of nitrogen and phosphorus in the remaining liquid fraction by about five percent (Tables 4-9 and 4-14) even though a 17 percent reduction in volume is realized.

Economic Impact

As noted above, the results of this study also confirm that anaerobic digestion with biogas utilization can produce revenue adequate to recover the required capital investment and increase farm net income through the on-site use and sale of electricity generated. Because the AA Dairy anaerobic digester-biogas utilization system was designed for a milking herd of 1,054 cows but currently is being operated with a herd of only 550 cows, the maximum potential of the system to produce biogas and generate electricity currently is not being realized. One of the more significant ramifications of the current operation of this system at less than design capacity is the reduction in the efficiency of the conversion of biogas energy to electrical energy from 30 to 20 percent. Even under these sub-optimal operating conditions, the net income produced by the on-site use and sale of electricity generated is such that the required capital investment can be recovered or repaid in approximately 11 years and then add $32,785 annually to net farm income over the remaining useful life of the system, a period of at least nine years. At the design herd size of 1,034 cows, the capital invested would be recovered in approximately three years and would then add $86,587 annually to net farm income over the remaining useful life of system. Recovery or repayment of the required capital investment over the useful life of the system, estimated conservatively to be 20 years, would somewhat reduce total additions to net farm income but still provide a satisfactory rate of return management and labor. Thus, it can be concluded that there is a significant economic incentive to realize the environmental quality benefits that the anaerobic digestion of dairy cattle manure can provide.

In this study, it was found that anaerobic digestion prior to the separation of course solids does not enhance the separation process or alter the characteristics of the separated solids or the remaining liquid fraction with one notable exception. With anaerobic digestion, the densities of fecal coliforms and *M. avium paratuberculosis* in both fractions were substantially lower.

Therefore, dependence on composting for effective pathogen reduction in the separated solids is lessened.

SECTION 2
INTRODUCTION

Anaerobic digestion is a controlled biological process that can substantially reduce the impact of liquid livestock and poultry manures and manure slurries on air and water quality. Unlike comparable aerobic waste stabilization processes, energy requirements are minimal. In addition, a relatively small fraction of the energy in the biogas produced and captured is adequate to satisfy process needs with the remaining biogas energy available for use as a boiler fuel or to generate electricity. Thus, anaerobic digestion with biogas utilization produces a source of revenue that will at least partially offset process costs and may increase farm net income.

Past interest in anaerobic digestion of livestock and poultry manures was driven primarily by the need for conventional fuel substitutes. For example, interest intensified in France and Germany during and immediately after World War II in response to disruptions in conventional fuel supplies (Tietjen, 1975). This was followed by a renewal of interest in anaerobic digestion of livestock and poultry manures in the mid-1970s stimulated primarily by the OPEC oil embargo of 1973 and the subsequent price increases for crude oil and other fuels. In both instances, this interest dissipated rapidly, however, as supplies of conventional fuels increased and prices declined.

A substantial majority of the anaerobic digesters constructed for biogas production from livestock and poultry manures in the 1970s failed for a variety of reasons. However, the experience gained during this period allowed the refinement of both system design and operating parameters and the demonstration of technical viability.

In the early to mid-1990s, a renewal of interest in anaerobic digestion by livestock and poultry producers occurred. Three primary factors contributed to this renewal of interest. One factor was the need for a cost-effective strategy for reducing manure-related odors from storage facilities, including anaerobic lagoons and land application sites. Another factor was the re-emerging concern about the impacts of livestock and poultry manures on water quality. Finally, the level of concern about global climate change was intensifying and the significance of methane emissions to the atmosphere was receiving increased attention. Recognition of the magnitude of methane emissions resulting from the uncontrolled anaerobic decomposition of livestock and poultry manures led to the creation of the U.S. Environmental Protection Agency's AgSTAR Program. The primary mission of this program is to encourage the use of anaerobic digestion with biogas collection and utilization in the management of livestock and poultry manures.

Although aerobic digestion also was demonstrated in the 1960s and 1970s to be an effective strategy for controlling odors from and water quality impacts of livestock and poultry manures (Martin and Loehr, 1976 and Martin *et al*., 1981), the cost is prohibitively high due primarily to the electrical energy required for aeration and mixing. In addition, the reduction in methane emissions is at least partially negated by the greenhouse gas emissions associated generation of the electricity required.

Objectives

The objectives of this study were to compare: 1) the reductions in the potential air and water quality impacts of scraped dairy manure by preceding liquid-solids separation and storage with mesophilic anaerobic digestion in a plug-flow reactor, and 2) the associated cost differential. These reductions and the associated cost differential were determined from characterizations of performance and associated costs for these two dairy manure management strategies on two typical upstate New York dairy farms. The characterizations of performance were based on materials balances developed for both systems and the cost differential was based on the differential between the cost of anaerobic digestion and the income generated through biogas utilization.

SECTION 3
METHODS AND MATERIALS

Study Sites

As indicated above, two typical upstate New York dairy farms served as sites for this study. Below is a brief description of each farm and its manure management system.

AA Dairy—AA Dairy is a 2,200-acre dairy farm located in Candor, New York. Candor is in Tioga County, a southern tier county in upstate New York. The AA Dairy milking herd consists, on average, of 550 Holstein-Friesian cows. Average yearly milk production is 23,000 lb per cow. The milking herd is housed in a naturally ventilated free-stall barn, which is connected to a milking parlor.

Manure is removed from the alleys in the free-stall barn daily by scraping into a cross-alley with step dams. In this cross-alley, the manure then moves by gravity to a mixing tank/lift station containing a chopper-type pump for mixing. After mixing, manure is then transferred daily to a mesophilic plug-flow anaerobic digester using a piston pump. After digestion, the coarse solids in the digester effluent are removed mechanically using a FAN screw press separator with the remaining liquid discharged to a 2.4 million-gallon lined earthen storage pond. Both tank wagons and a traveling gun irrigation system are used for application to cropland of manure from the storage lagoon.

The separated solids, consisting primarily of fibrous materials, are transported to a site adjacent to the free-stall barn-milking parlor complex for further stabilization and drying by windrow composting. The finished compost is sold in bulk and bags for use as a soil amendment and mulch material. Approximately 1,825 yd^3 are sold annually at an average of $16 per yd^3.

The plug-flow anaerobic digester was designed and constructed by RCM Digesters, Inc., of Berkley, California, with the expectation of a future herd expansion to 1,054 cows. The digester dimensions are 112 ft long by 28 ft wide by 14 ft deep, and it has an operating volume of 39,568 ft^3. The design hydraulic retention time (HRT) for the digester, based on an expected herd expansion to 1,054 cows, is 24 days with a predicted rate of biogas production of 64,720 ft^3 per day. The digester channel is covered with an impermeable flexible geotextile membrane, which is inflated to a nominal positive pressure by the biogas collected to maintain a semi-rigid surface. The digester has been in operation since mid-1998 and has addressed the odor problems that were the catalyst for considering anaerobic digestion.

Captured biogas is used to fuel a 130 kW engine generator set. The engine, a Caterpillar 3306, is a diesel engine modified by the addition of spark ignition system to use low pressure/low energy biogas as a fuel. The generator is an induction type unit with the following specifications: three phase, 208 volts, and 430 amps at 1,835 rpm. The electricity generated is used to satisfy on-farm demand with any excess energy sold at wholesale rates to the local electric utility, the New York State Electric and Gas (NYSEG) Corporation. Waste heat from the engine cooling system is recovered through a heat exchanger and used to maintain digester temperature at approximately 95 to 98°F. A fuel oil fired hot water boiler is available to maintain digester temperature if the engine-generator set is out of service for maintenance or repairs for an extended period. Biogas produced during such periods is flared to prevent an excessive increase in digester pressure.

<u>Patterson Farms, Inc.</u>—Patterson Farms, Inc. is 1,500-acre dairy farm located in Union Springs, New York. Union Springs is in Cayuga County, a central Finger Lakes county in upstate New York. During this study, the average size of the milking herd increased from 600 to 800 cows. Average yearly milk production is 24,000 lbs per cow. The milking herd is housed in two naturally ventilated free-stall barns, which are connected to a milking parlor.

Manure is removed from the alleys in two free-stall barns daily using alley scrapers, which deposit the scraped manure into a cross alley for transport by gravity into a piston pump reception pit. The manure is then transferred to a holding tank that provides temporary storage before separation of coarse solids. A Houle drum-type separator is used for solids separation with the remaining liquid discharged to a 5.4 million-gallon unlined earthen storage pond. All of the manure from the storage pond is applied to cropland by tank wagon type spreaders. Due to odor problems and the cost of electricity, Patterson Farms is currently is considering the construction of a plug-flow anaerobic digester.

The separated solids, consisting primarily of fibrous materials, are transported by conveyor to a mechanical distribution system in a covered static pile composting facility with forced-air aeration. The finished compost is used as bedding and reduces bedding costs by approximately $60 per cow-year.

Data Collection

The basis for comparing the performance of the two dairy cattle waste management systems evaluated in this study was materials balances developed from measured concentrations of selected parameters in combination with mass flow estimates. At AA Dairy, the following four waste streams; anaerobic digester influent, effluent, and liquid and solid phase effluents from the liquid-solids separation unit; were sampled semi-monthly from late May 2001 through early June 2002. At Patterson Farms, the influent to and the liquid and solid phase effluents from the liquid-solids separation unit also were sampled semi-monthly during the same period. Each sample collected for analysis was a composite of several sub-samples collected over a 15 to 20 minute period of flow to insure that the samples analyzed were representative.

In addition, the storage pond at each farm were sampled at the end of months four, eight, and twelve of the study. For each sampling event, samples were collected at three locations along the axis of the pond perpendicular to the location of the influent discharge. At each location, samples were collected at three depths: the top, middle, and bottom of the liquid column. Each sample was analyzed separately.

As noted earlier, a piston pump is used to initially transfer manure at each farm. This enabled estimation of the volume of manure produced daily by determining the average number of piston strokes per day using a mechanical counter and the manufacturers specification for volume displaced per stroke. The liquid and solid fraction volumes after separation were estimated based the partitioning of total solids between the two fractions assuming conservation of mass through the separation process.

Additional data collection at AA Dairy included volume of biogas utilized and kilowatt-hours (kWh) of electricity generated between days of collection of manure samples. The kWh of biogas-generated electricity used on-site and sold to the local public utility, the NYSEG Corporation, were determined from farm records.

Sample Analyses

Physical and Chemical Parameters—All manure samples collected were analyzed to determine concentrations of the following: total solids (TS), total volatile solids (TVS), chemical oxygen demand (COD), soluble chemical oxygen demand (SCOD), total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH_4-N), total phosphorus (TP), orthophosphate phosphorus (PO_4-P), and pH. U.S. Environmental Protection Agency (1983) methods were used for TS, TVS, TKN, TP, PO_4-P, and pH determinations. American Public Health Association (1995) methods were used to determine COD, SCOD, and NH_4-N concentrations. All analyses were performed by an analytical laboratory certified by the New York State Department of Environmental Conservation.

Biodegradability—A 55-day batch study was conducted to estimate the biodegradable and refractory fractions of TVS in a random sample of as excreted manure from AA Dairy. The study was a laboratory scale study in which two liters of AA Dairy manure was maintained at 95 °F (35 °C) in a glass reactor. A water trap was used to vent the biogas produced and maintain anaerobic conditions in the reactor. The contents of the reactor were sampled and analyzed to determine TVS on days 0, 7, 10, 15, 30, and 55 of the batch study.

Microbial Parameters—Two parameters were used to characterize the fate and transport of indicator and pathogenic microorganisms in the AA Dairy and the Patterson Farms waste management systems. One parameter was the fecal coliform group of bacteria (fecal coliforms), a group of bacteria that includes *Escherichia coli*, *Klebsiella pneumoniae*, and other species, which are common inhabitants of the gastro-intestinal tract of all warm-blooded animals. The presence of fecal coliforms is commonly used as an indicator of fecal contamination and the possible presence of pathogenic microorganisms. In addition, a reduction in fecal coliform density serves as an indicator of reductions in the densities of pathogenic microorganisms. Densities of fecal coliforms were estimated using the multiple tube fermentation technique (American Public Health Association, 1995) by the same laboratory that performed determinations of physical and chemical characteristics.

The second microbial parameter was the pathogen *Mycobacterium avium paratuberculosis*, which is the microorganism responsible for paratuberculosis (Johne's disease) in cattle and other ruminants. Paratuberculosis is a chronic, contagious enteritis characterized eventually by death. *M. avium paratuberculosis*, formerly known as *M. paratuberculosis* or *M. johnei*, is also suspected to possibly be the causative agent in Crohn's disease, a chronic enteritis in humans (Merck and Company, Inc., 1998). Thus, *M. avium paratuberculosis* is considered a possible zoonotic risk. Determinations of densities of *M. avium paratuberculosis* were performed by the New York Animal Health Diagnostic Laboratory, Cornell University College of Veterinary Medicine using the "Cornell Method," which has been described by Stabel (1997). Although Stabel reported the Cornell Method to be less sensitive than other methods, it satisfies the requirements of the U.S. Department of Agriculture (USDA) National Veterinary Services Laboratory proficiency-testing program.

Biogas Composition—A random sample of AA Dairy biogas was analyzed by gas chromatography using ASTM Method D1946 (ASTM International, 1990) to determine methane and carbon dioxide content. The same sample was analyzed using EPA Method 16 to determine hydrogen sulfide content and using Sensidyne ammonia detection tubes to determine ammonia (NH_3) content.

Data Analysis

Each data set generated in this study was analyzed statistically for the possible presence of extreme observations or outliers using Dixon's criteria for testing extreme observations in a single sample (Snedecor and Cochran, 1980). If the probability of the occurrence of a suspect observation based on order statistics was less than five percent ($P<0.05$), the suspect observation was considered an outlier and not included in subsequent statistical analyses.

With the exception of bacterial densities, all data sets were found to be approximately normally distributed and the null hypothesis that two means do not differ significantly ($P<0.01$) was tested using the Student's *t* test. For multiple comparisons, one-way analysis of variance (ANOVA) was used. If the null hypothesis that the means do not differ significantly ($P<0.01$) was rejected, Tukey's Honest Significance Test for pairwise comparisons of means (Steel and Torrie, 1980) was used. To equalize variances, densities of fecal coliform bacteria and *Mycobacterium avium* *paratuberculosis* were transformed logarithmically before calculation of means and standard deviations and comparisons of means to determine the statistical significance of differences. A $\log_{10}$ (Y+1) transformation was used because the presence of *M. avium paratuberculosis* was not always detected.

The procedure used to estimate the biodegradable and refractory fractions of TVS in as excreted AA Dairy manure from the results of the batch biodegradability study is based on the assumption that the biodegradable fraction of TVS approaches zero as the solids retention time (SRT) approaches infinity. Therefore, the refractory fraction of TVS can be determined graphically by plotting a time series of ratios of TVS concentrations to the initial TVS concentration versus the inverse products of the initial TVS concentration and the corresponding unit of time. The resulting relationship should be linear with the ordinate axis intercept representing the refractory fraction of TVS.

SECTION 4
RESULTS

AA Dairy

Manure Production and Characteristics—As shown in Table 4-1, the volume of manure produced per cow-day at the AA Dairy is somewhat higher than the standard reference values proposed by the American Society of Agricultural Engineers (2001) and the U.S. Department of Agriculture (1992). However, both the American Society of Agricultural Engineers (ASAE) and the USDA estimates are as excreted values. Thus, they do not include any water used for cleaning or accidental spillage from drinkers, which are included in the AA Dairy value.

Generally, the AA Dairy manure characteristics, on a kg per cow-day basis, are within the ranges of the ASAE and USDA values suggesting any dilution is minimal. COD is, however, the one notable exception. The reason or reasons for the substantially higher AA Dairy value are unclear but may reflect differences in feeding practices or differences in analytical precision and accuracy. Because of the presence of particulate matter in a variety of sizes (undigested fiber) in dairy cow manure and the degree of sample dilution necessary prior to COD determination, obtaining a representative subsample, even after sample homogenization, is a difficult process. Finally, the absence of significant differences in rates of excretion of TKN and total TP between the AA Dairy and the standard reference values is noteworthy.

Digester Operating Conditions—Based on manure production rate of 2.1 ft^3 per cow-day and the herd size of 550 cows, the HRT of the AA Dairy anaerobic digester as operated during this study was 34 days. This is 10 days longer than the design HRT of 24 days, which was based on planned expansion of the herd size of 1,054 cows. If future herd expansion to 1,054 cows does occur, the digester HRT will be reduced to approximately 18 days, which is 75 percent of the design HRT.

Waste Stabilization—An assessment of the AA Dairy plug-flow anaerobic digester performance, based on comparisons of mean influent and effluent concentrations, is presented in Table 4-2. As shown, there were substantial and statistically significant ($P<0.01$) reductions in TS, TVS, COD, SCOD, and TVA. Conversely, concentrations of NH_4-N and PO_4-P increased while there were no statistically significant differences between influent and effluent concentrations of fixed solids (FS), TKN, organic nitrogen (ON), and TP. The lack of significant differences between influent and effluent concentrations of FS and TP indicate that this digester is operating in an ideal plug-flow mode with no accumulation of total solids and related parameters occurring. The one anomaly in these data is the absence of a statistically significant reduction in ON concentration comparable to the increase in the concentration of NH_4-N. The reason for this anomaly is not clear, but the lack of a statistically significant difference between influent and effluent TKN concentrations indicates that nitrogen loss through desorption of NH_4-N in the digester is at most minimal. The differences between influent and effluent concentrations of TVS and COD (Table 4-2) translate into the mass reductions presented in Table 4-3. It should be noted that the mass reductions in TS and TVS essentially are the same providing further evidence of the validity of the data set.

Biodegradability—The results of the batch study to estimate AA Dairy manure TVS biodegradability indicate that 30 percent of the TVS are readily biodegradable and 70 percent are refractory.

Indicator Organism and Pathogen Reduction—As shown in Table 4-4, the $\log_{10}$ densities of both the fecal coliform group of bacteria and *M. avium paratuberculosis* were reduced substantially in the AA Dairy anaerobic digester. On a colony-forming unit (CFU) per g of manure basis, the reduction in the density of fecal coliforms was almost 99.9 percent while the reduction in *M. avium paratuberculosis* density was slightly greater than 99 percent.

Biogas Production—As described earlier, AA Dairy uses the biogas produced to generate electricity with waste heat from the engine-generator set used to heat the digester. When the engine-generator set is out of service, biogas is flared and a fuel oil-fired hot water boiler is used to maintain digester temperature. Only the biogas utilized to fuel the engine-generator set is metered. During this study, this meter failed in late November 2001 and was not replaced until early January 2002. This failure resulted in the loss of a little over two months of biogas production data. This failure was followed by an engine-generator set controller problem resulting in the unit being shut down from January through March 2002. However, resolution of this problem by installing a new controller with a cumulative kWh meter also resolved the problem of accurately determining cumulative engine-generator set electrical output. Originally, it was planned to acquire and install a commercial type kilowatt-hour meter at the beginning of the study to obtain this information. It was found, however, purchases of these meters from manufacturers now are limited to public utilities, and the local public utility, the NYSEG Corporation, was unable to locate a suitable reconditioned meter.

Because of the gas meter failure followed by the failure of the engine-generator set failure, determination of biogas production from late November 2001 through early April 2002 was not possible. Thus, there were two separate periods for which biogas production was determined. For the period of the study prior to the gas meter and engine-generator set controller problems (21 May through 26 November 2001), biogas production averaged 38,907 ± 13,386 ft^3 per day. For the period of the study after the resolution of the gas meter and engine-generator set controller problems discussed earlier (2 April through 17 June 2002), biogas production was 42,868 ± 3,144 ft^3 per day. Although the difference between these two periods in average daily biogas production is relatively small, the accuracy of the biogas production estimate for the 21 May through 26 November time is suspect because of a high degree of daily variability. The coefficient of variation for this period was approximately 34 percent, probably reflecting the gradual failure of the gas meter that eventually was replaced. In contrast, variability in daily biogas production for the period after gas meter replacement was only approximately seven percent. Therefore, it seems reasonable to conclude that the estimate of average daily biogas production of 42,868 ft^3 based on data collected from 2 April through 17 June 2002 is the more accurate estimate of biogas production at AA Dairy. This translates into a rate of biogas production of 78 ft^3 per cow-day, which is 28 percent higher than the originally anticipated rate of biogas production of 61 ft^3 per cow-day based on a herd size of 1,054 cows.

Previously, the methane content of the biogas produced by the AA Dairy anaerobic digester has been reported to vary between 50 to 55 percent with a variation in hydrogen sulfide content from 0.1 to 0.36 percent (Peranginangin and Scott, 2002). Results (Table 4-5) of the analysis of a random sample of the AA Dairy biogas indicated a slightly higher methane content of 59.1 percent. The concentration of hydrogen sulfide in that sample was 1,930 ppm. The NH_3. concentration, based on five replicate determinations, was found to be 15±5 parts per million, confirming the conclusion, based on mass balance results, that NH_3 desorption during anaerobic digestion is nominal.

Based on a methane content of 59.1 percent (Table 4-5) and the previously discussed rate of biogas production of 42,868 ft^3 per day, the rate of methane production by the AA Dairy anaerobic digester is 25,335 ft^3 per day. Theoretically, the destruction of one lb of ultimate biochemical oxygen demand (BOD_u) under anaerobic conditions should result in the generation of 5.62 ft^3 of methane (Metcalf and Eddy, 1991). Although not all COD is biodegradable, it can be assumed that a microbially mediated reduction of COD is equal to a reduction of the same magnitude in BOD_u. Thus, the 41.9 percent reduction in COD in the AA Dairy anaerobic digester (Table 4-2) is equivalent to a 4,641 lb per day (Table 4-3) reduction in BOD_u. As shown in Table 4-6, this translates into a rate of methane production of 5.46 ft^3 per lb of COD destroyed, which is slightly more than 97 percent of the theoretical value. Based on the ratio COD to TVS destroyed of 2.25 (Table 4-3), 12.64 ft^3 of methane should have been produced per lb of TVS destroyed. Thus, observed value of 12.30 ft^3 of methane produced per lb of TVS destroyed also compares favorably with the theoretical value. Anaerobic digestion of municipal wastewater treatment sludges (biosolids) typically yields between 12 and 18 ft^3 of methane per lb TVS destroyed (Metcalf and Eddy, Inc., 1991).

<u>Biogas Utilization</u>—For the period 2 April through 17 June 2002, 1,433±133 kWh of electricity was generated daily. The on-line efficiency of the engine-generator set during this time period was 96.8 percent and 33.29 ± 1.13 kWh were generated per 1,000 ft^3 of biogas utilized. The validity of this estimate of electricity was confirmed by the subsequent determination that the rate of electricity generation for the 180-day period from 2 April though 30 September 2002 was 1,429 kWh per day with an on-line efficiency of 98.8 percent. Thus, only about 20 percent of biogas energy is being recovered as electrical energy. This low conversion efficiency is probably is the result of the utilization of somewhat less than 50 percent of the engine-generator set's rated capacity of 130 kW. At full load, conversion of biogas energy to electrical energy should approach 30 percent with the added potential of recovering up to 60 percent of biogas energy as heat energy (Koelsch and Walker, 1981).

Solids Separation—As mentioned earlier, AA Dairy uses a screw press separator to recover coarse solids from the digester effluent for sale after composting as a mulch material or soil amendment. On a volume basis, 196 ft^3 of separated solids are generated daily, which reduces the digester effluent flow to the storage pond by approximately 17 percent. In Table 4-7, the characteristics of the digester effluent and the separated liquid and solid fractions are compared.

As indicated in Table 4-7, the digester effluent, separated liquid, and separated solid concentrations of TS, TVS, FS, and COD differ significantly ($P<0.01$) from each other, whereas there are no statistically significant differences in SCOD, TKN, NH_4-N, and PO_4-P concentrations. For ON, there is no statistically significant difference between the digester effluent (separator influent) and the separated liquid and separated solids concentrations. However, the difference between the separated liquid and separated solids concentrations is significant statistically indicating the concentration of ON in the separated solids. For TP, the digester effluent and separated liquid concentrations are not significantly different statistically but the differences between these concentrations and the concentration in the separated solids fraction is significant statistically. This is probably a reflection of the concentration of the organic fraction of TP in the separated solids.

As shown in Table 4-8, the digester effluent and separated liquid densities of fecal coliforms and *M. avium paratuberculosis* are not significantly different statistically ($P<0.01$), but the digester effluent and separated solids densities do differ significantly. However, there are no statistically significant differences in separated liquid and separated solids densities. Therefore, it only can be concluded that separation provides no statistically significant reductions in fecal coliform and *M. avium paratuberculosis* densities as would be expected.

As indicated earlier, the solids separated from the AA Dairy digester effluent represent about 17 percent of the digester effluent volume with the liquid fraction remaining after separation constituting the remaining 83 percent. As shown in Table 4-9, the separated solids, on a mass basis, also contain 17 percent of the TS and TVS present before separation with the remaining 83 percent in the liquid fraction. The partitioning of COD is similar to that of TS and TVS. However, the separated solids contain only about five percent of the nitrogen and phosphorus present before separation.

As previously mentioned, the separated solids at the AA Dairy are composted for further stabilization prior to sale as a mulch material or soil amendment. Assuming that the organic carbon content of the separated solids can be estimated with a reasonable degree of accuracy as approximately 55.5 percent of TVS (Haug, 1980 and Rynk *et al*., 1992), the carbon to nitrogen (C:N) ratio of the AA Dairy separated solids is approximately 23:1. At this C:N ratio, nitrogen availability will not limit the rate of stabilization but some nitrogen loss through NH_3-N volatilization should occur. A C:N ratio of 30 to 35:1 generally is considered optimal for minimizing nitrogen loss without limiting the rate of stabilization.

Storage Pond Transformations—As mentioned earlier, the AA Dairy earthen structure used to store the liquid fraction of the digester effluent after separation was sampled at the end of months four, eight, and twelve of this study. The results of the analyses of these samples showed significant variation in concentrations of both physical and chemical parameters with depth and to a lesser degree with location relative to the point of influent discharge to the storage structure. To provide a general characterization of the contents of the storage structure, a mean value was calculated for each parameter that was calculated for each sampling event. Then, mean values were calculated from the mean values for each sampling event. The results of these calculations are compared to the characteristics of the storage pond influent (separator liquid phase effluent) in Table 4-10. As shown, there are substantial differences in the concentrations of all of the parameters listed between storage pond influent and the pond contents. Because there is no microbial or physical/chemical process that could cause the loss of TP, it is apparent that significant dilution is occurring in this storage pond. To adjust for the effect of dilution, each storage pond influent concentration was multiplied by the ratio of storage pond influent TP concentration to the storage pond TP concentration. Based on these transformations, it appears that only minimal reductions in TS and TVS and no reduction in COD are occurring. Nitrogen loss also appears to be minimal and translates into a loss of about 5.5 lbs per cow-year.

Patterson Farms, Inc.

Manure Production and Characteristics—As shown in Table 4-11, the volume of manure produced per cow-day at Patterson Farms also is somewhat higher than the standard reference values proposed by the ASAE (2001) and the USDA (1992). However, the Patterson Farms manure characteristics, on a kg per cow-day basis, also are within the ranges of the ASAE and USDA values with COD again being the one notable exception. The reason or reasons for the substantially higher Patterson Farm value are unclear but again may reflect differences in feeding practices or differences in analytical precision and accuracy for the reasons discussed earlier. The somewhat lower PO_4-P value is noteworthy but does not appear to be significant.

Solids Separation— As noted earlier, Patterson Farms uses a drum-type separator to remove the coarse solids fraction from their manure for use as a bedding material after composting. On a volume basis, about 38 ft^3 of separated solids per 100 cows are generated daily, which reduces manure storage requirements by approximately 16 percent. In Table 4-12, the characteristics of the digester effluent and the separated liquid and solid fractions are compared. As indicated, the separator influent, separated liquid, and separated solid concentrations of TS, TVS, and COD differ significantly ($P<0.01$) from each other, whereas there are no statistically significant differences in, TKN, ON, TP, and PO_4-P concentrations. For SCOD and NH_4-N, separator influent and separated liquid concentrations did not differ significantly, but separated solids concentrations were significantly but not substantially lower.

As shown in Table 4-13, fecal coliform densities in separator influent and separated liquid and solids do not differ significantly ($P<0.01$). However, separation appears to significantly reduce the density of *M. avium paratuberculosis* with mean separated liquid and solids densities approximately one $\log_{10}$ (90 percent) lower than the mean influent density. Given that there was no observed reduction in fecal coliform density, it is not clear what mechanism or mechanisms could be responsible for the reduction in *M. avium paratuberculosis* density. However, it may be some function the higher influent density, 4.00 ± 0.48 $\log_{10}$ CFU per gram, versus 1.94 ± 0.62 CFU $\log_{10}$ per gram in the separator influent at AA Dairy.

As indicated earlier, the solids separated from Patterson Farms manure represent about 16 percent of the volume of manure produced daily. As shown in Table 4-14, the separated solids, on a mass basis, also contain 16 percent of the TS and TVS present before separation with the remaining 84 percent in the liquid fraction. The partitioning of COD is similar to that of TS and TVS. However, the separated solids contain only about six percent of the nitrogen and four percent of the phosphorus present before separation, which is similar to the AA Dairy partitioning values (Table 4-9).

As discussed earlier, the separated solids at Patterson Farms are used after stabilization by composting. The C:N ratio of the separated solids of 32:1 suggests that nitrogen availability should not limit the rate of stabilization and nitrogen loss via NH_3 volatilization should be minimal.

Storage Pond Transformations—The earthen structure used to store the liquid fraction of the separator effluent also was sampled at the end of months four, eight, and twelve of this study. The results of the analyses of these samples also showed significant variation in concentrations of both physical and chemical parameters with depth, and to a lesser degree, with location relative to the point of influent discharge to the storage structure. Using the same approach described above for the AA Dairy storage pond, mean values to characterize the storage pond contents were calculated. The results of these calculations are compared to the characteristics of the storage pond influent (separator liquid phase effluent) in Table 4-15. As shown, there are some differences in the concentrations of all of the parameters listed between storage pond influent and the pond contents. However, the difference between the TP concentrations in the storage pond influent and contents is significantly less than that for the AA Dairy storage pond, indicating much less dilution for reasons that are not clear. However, the storage pond influent concentrations also were adjusted using the previously described approach to provide for direct comparisons.

Based on these transformations, it appears again that only minimal reductions in TS and TVS and no reduction in COD are occurring. However, nitrogen loss is greater than that from the AA Dairy storage pond and translates into a loss of about 29.5 lbs per cow-year but is only approximately six percent of the nitrogen excreted. It should be noted that the densities of fecal coliforms and *M. avium paratuberculosis* in the storage pond influent adjusted for dilution and the storage pond contents are essentially the same. This suggests that storage provides no reduction in pathogen densities.

SECTION 5

DISCUSSION

Manure Production and Characteristics

As shown in Table 5-1, there is little difference between AA Dairy and Patterson Farms rates of production of manure and its various constituents. In addition, there is little difference, as previously discussed, between these rates and the standard reference values published by the ASAE (2001) USDA (1992). This suggests that the two farms involved in this study are representative of typical U.S. dairy operations with respect to rates of production of manure and its various constituents. In addition, there is little difference between the AA Dairy and Patterson Farms in raw manure concentrations of solids, COD, nitrogen, and phosphorus (Table 5-2).

AA Dairy Anaerobic Digester Performance and Biogas Utilization

Waste Stabilization—As indicted earlier, the AA Dairy plug-flow anaerobic digester was designed to operate at a HRT of 24 days but operated at a HRT of 34 days during this study because the anticipated herd expansion from 550 to 1,054 cows has not yet occurred. At this HRT, TVS and COD reductions averaged 29.7 and 41.9 percent, respectively (Table 4-2). The 29.7 percent reduction in TVS observed in this study is significantly lower than the reduction reported by Morris (1976) of 37.6 percent at a HRT of 30 days in a bench-scale anaerobic digester. However, the 41.9 percent reduction in COD is essentially the same as the 40.6 percent reduction reported by Morris. The 29.7 percent reduction in TVS observed in this study also is significantly lower than the reduction reported by Jewell *et al*. (1991) for a 65-cow plug-flow digester of 40.6 percent at a HRT of 30 days. However, Jewell *et al*. also reported a TVS reduction of 31.7 percent in a 65-cow completely mixed digester operated at the same HRT. A possible explanation for this difference between the plug-flow and the completely mixed digester in TVS reduction is that the plug-flow digester was not operating in an ideal plug-flow mode and accumulation of settleable solids in the digester was occurring. The approximately 10 percent higher rates of biogas and methane production per unit of TVS destroyed in the completely mixed digester provide some support for the validity of this hypothesis. Thus, the 29.7 percent reduction of TVS observed in this study does seems reasonable and may simply reflect differences in dairy cattle feeding programs. The lack of statistically significant differences in influent and effluent concentrations of FS and TP (Table 4-2) suggests that such accumulation was not occurring in the AA Dairy digester during this study.

The results of the batch biodegradability study indicate that 30 percent of AA Dairy manure TVS are readily biodegradable with the remaining 70 percent being refractory. Thus, it appears that essentially all (99.0 percent) of the biodegradable volatile solids (BVS) in AA Dairy manure are being degraded at the digester HRT of 34 days. The linear regression relationship developed from the batch biodegradability data (Equation 1) also suggests that reducing digester HRT to the design value of 24 days would reduce TVS reduction from 29.7 to 26.0 percent and BVS reduction to 86.7 percent. Therefore, increasing herd size to the design value of 1,054 cows would only marginally reduce the degree of waste stabilization.

$$TVS_t/TVS_0 = 0.12\ (1/TVS_0 * t) + 0.70 \qquad (1)$$

where: TVS_t = total volatile solids concentration at time t,

TVS_0 = total volatile solids concentration at time 0,

t = time (SRT).

Pathogen Reduction—Given that paratuberculosis is a major problem in the dairy industry with transmission by fecal-oral contact and the possibility that *M. avium paratuberculosis* is the pathogen responsible for the development of Crohn's disease in humans, the 99 percent reduction in the density of this pathogen during anaerobic digestion is highly significant. In addition, the 99.9 percent reduction in the density of fecal coliforms suggests that significant reductions in other pathogens also are possible. The impact of a reduction in digester HRT from 34 to 18 days on fecal coliforms and *M. avium paratuberculosis* reductions is less clear. However, it is probable that some decrease in the reductions of the densities of these microorganisms could occur.

Biogas Production—As noted earlier, the mean rate of biogas production observed in this study was 78 ft^3 per cow-day, which is 28 percent higher than the design value of 61 ft^3 per cow-day for the anticipated herd size of 1,054 cows and a digester HRT of 24 days. However, the rate of manure production for AA Dairy of 2.10 ft^3 per cow-day determined in this study would result in an HRT of only 18 days if herd expansion to the design value of 1,054 cows occurs in the future. While it is probable that some reduction in TVS and COD reduction and biogas production per cow-day would occur, the work of Morris (1976) and Jewell *et al*. (1991) suggests that any reductions should be minimal. Morris reported a slight decrease in TVS reduction from 37.6 to 35.1 percent when HRT was reduced from 30 to 20 days. He also reported that COD reduction increased, which probably was an anomaly, from 40.6 to 42.9 percent. If these TVS and COD reductions at 20 and 30 day HRTs could be compared statistically, it is probable that there would be no significant differences. In addition, Jewell *et al*. reported only nominal decreases in TVS reductions in both a plug-flow and completely mixed digester as HRTs were reduced from 30 to 15 days. The reductions for the plug-flow and completely mixed digester were respectively from 40.6 to 34.1 percent and from 31.7 to 27.8 percent.

Based on the linear regression relationship derived from the batch biodegradability study (Equation 1), a reduction in the HRT of the AA Dairy plug-flow digester from 34 to 18 days would reduce TVS reduction from 29.7 to 24.0 percent. This translates into a reduction in biogas production from 78 ft^3 to approximately 63 ft^3 per cow-day, which is close to the original design value of 61 ft^3 per cow-day noted above. However, it also would result in an increase in the daily rate of biogas production from 42,868 ft^3 per day for 550 cows to 63,840 ft^3 per day for the design herd size of 1,054 cows.

Biogas Utilization—As previously discussed, less than 50 percent of the AA Dairy engine-generator set capacity for the conversion of biogas energy to electrical energy currently is being utilized. Thus, the efficiency of conversion of biogas energy to electrical energy is only about 20 percent as opposed to a potential conversion efficiency approaching 30 percent if the 130 kW engine-generator set was being operated at or near full load. An increase in conversion efficiency from 20 to 30 percent would increase the kWh of electricity generated per 1,000 ft^3 of biogas from 33.29 to 49.94 kWh. Therefore, the anaerobic digestion-biogas utilization infrastructure currently in place at AA Dairy has the capacity with the design herd size of 1,054 cow of generating 3,315 kWh of electricity per day. This estimate is conditioned on the validity of the previously stated assumption that biogas production per cow-day only would decrease from 78 to 63 ft^3 per cow-day with a reduction of digester HRT from 34 to 18 days.

Methane Emissions—At the observed rate of methane production by the AA Dairy digester of 25,335 ft^3 per day, 9,247,275 ft^3 of methane per year is being captured and utilized to generate electricity. Because methane has 21 times the heat trapping capacity of carbon dioxide (U.S. Environmental Protection Agency, 2002), the reduction in methane emission being realized is equal to a reduction in the emission of an equivalent of 4,120 tons of carbon dioxide per year or 7.49 tons per cow-year. Although carbon dioxide emissions do occur with methane combustion, this only decreases the impact of the reduction in methane emissions by roughly five percent or 206 tons per year. Therefore, the net reduction in methane emission on a carbon dioxide equivalent basis is 3,924 tons per year or 7.13 tons per cow-year. At the design herd size of 1,054 cows, the net reduction in methane emission on a carbon dioxide equivalent basis would be 6,076 tons per year.

However, the reduction in greenhouse gas emissions due to biogas production and utilization at AA Dairy is not limited to the reduction in methane emissions. The use of the biogas produced and captured to generate electricity reduces the demand for electricity generated using fossil fuels. Thus, carbon dioxide emissions resulting from the use of fossil fuels to generate electricity also are reduced. Assuming 2,249 lbs of carbon dioxide are emitted per megawatt-hour (MWh) of electricity generated from coal (Spath *et al*., 1999), the estimated 501,510 kWh of electricity generated annually by AA Dairy using biogas potentially reduces fossil fuel derived carbon dioxide emissions by an additional 564 tons per year or 1.03 tons per cow-year. At the design herd size of 1,054 cows, the reduction in fossil fuel derived carbon dioxide emissions would be an additional 1,361 tons per year or 1.29 tons per cow-year.

Therefore, the current total reduction in greenhouse gas emissions, on a carbon dioxide equivalent basis, is 4,488 tons per year or 8.16 tons per cow-year. The potential reduction at the design herd size of 1,054 cows would be 7,437 tons per year or 7.06 tons per cow-year. In this analysis, the emission during combustion of the carbon dioxide component of biogas is not considered since it is not a carbon dioxide emission derived from a sequestered carbon source. Rather, it is an emission that is part of the natural short-term carbon cycle where carbon dioxide is fixed by photosynthesis and then is regenerated as the plant matter produced is degraded microbially and by higher animals.

Nitrous Oxide Emissions—The results of analyses of samples of the stored liquid phase of dairy cattle manure after separation at both AA Dairy and Patterson Farms showed that no oxidized forms of nitrogen (nitrite or nitrate nitrogen) were present. This finding was not surprising given the absence of residual dissolved oxygen concentrations required for nitrification and the high unionized ammonia (NH_3.)concentrations, which inhibits nitrification, in both storage structures. Thus, the expectation of nitrous oxide emissions, as an end product of denitrification, from dairy cattle manure storage structures seemingly has no theoretical basis given the absence of the necessary prerequisite of nitrification. In addition, any nitrite or nitrate nitrogen, which is rarely present in dairy cattle manure when excreted, would be denitrified before storage due the high level of carbonaceous oxygen demand in these wastes.

Separator Performance

As discussed earlier, AA Dairy uses a screw press separator to separate coarse solids from the effluent from the anaerobic digester while Patterson Farms uses a drum-type unit to remove coarse solids from raw manure before storage of the separated liquid fraction. Due to the anaerobic digestion prior to solids separation, the influent to the AA Dairy separator has substantially lower concentrations of solids and COD than the influent to the Patterson Farm's separator. Thus, an expectation that the efficiency of separation would differ would be reasonable. However, the distribution of influent constituents between liquid and solid phases after separation was remarkably similar as shown previously in Tables 9 and 13. In addition, there was little difference between the two farms in the characteristics of the separated solids with the exception of concentrations of nitrogen and phosphorus and densities of fecal coliforms and *M. avium paratuberculosis* (Table 5-3). In contrast, there were significant differences in the characteristics of the separated liquids (Table 5-4). Generally, these differences were reflections of the differences in separator influent characteristics (Tables 7 and 11). The similarities in the characteristics of the AA Dairy and Patterson Farms separated solids (Table 5-3) as well the distributions of the influent constituents between liquid and solid phases (Tables 9 and 13) suggest that anaerobic digestion of dairy manure prior to separation neither enhances nor negatively impacts the efficiency of separation. However, qualification of this conclusion is necessary because it is based on the assumption that the efficiencies of screw press and drum-type separators are equal.

Storage Pond Transformations

Based on comparisons of the physical, chemical, and microbiological characteristics of the influents to and the contents of the AA Dairy and Patterson Farms storage ponds (Tables 10 and 15), there is no evidence of any significant transformations occurring in either structure. With respect to reductions in TS, TVS, and COD, this finding is not entirely surprising given that these structures are designed for solely for storage. If designed as an anaerobic lagoon with the objective of waste stabilization following the USDA (1992) suggested TVS loading rate for central New York State, a structure with approximately six times the volume of the AA dairy storage pond would be required. The Patterson Farms structure would have to be approximately four times larger. Therefore, it seems reasonable to conclude, with the following caveat, that the lack of significant reductions in TS, TVS, and COD are reflections of the absence of conditions suitable for anaerobic waste stabilization processes. The comparisons of characteristics of the influents to and the contents of both storage ponds may have been unintentionally biased, however, by the schedule for storage pond sampling. The first sampling events where in October following reductions in stored manure volume to provide adequate storage capacity through early spring. Therefore, the characteristics of these sets samples did not necessarily reflect transformations that occurred during warm weather when microbial activity would have been highest. In addition, the second set of samples from each storage structure was collected in January and the third set was collected in early April. Thus, the results obtained may have been unintentionally biased by not proportionally reflecting the effect of low temperature on microbial activity.

It was expected that there would be a significant loss of nitrogen as the result of NH_3. volatilization from both storage structures given the influent NH_4-N concentrations (Tables 10 and 15). However, there appear to be at least two factors contributing to the lack of any significant NH_3. volatilization from either storage pond. In the contents of both storage ponds, NH_4-N concentrations increased as TS concentrations increased with depth. This indicates sorption of NH_4-N to particulate matter was significant and thereby limited the potential for nitrogen loss by NH_3. volatilization. In addition, mean pH values for both storage ponds (Tables 10 and 15) were near neutral, which also limited the potential for NH_3. volatilization. The sampling schedule discussed above also may have unintentionally biased the estimations of nitrogen losses because NH_3. volatilization potential also decreases with temperature.

The results from this phase of the study do demonstrate, however, that storage does not provide significant reductions in fecal coliform or *M. avium paratuberculosis* densities. This finding is further evidence of the merit of anaerobic digestion as a component of dairy cattle manure management systems.

Economic Analysis

Introduction—One of the objectives of this study was to quantify the impact of anaerobic digestion with biogas capture and utilization to generate electricity on the cost of dairy cattle manure management. In previous cost analyses of anaerobic digestion with biogas utilization at AA Dairy, the costs associated with liquid solids separation and the revenue generated from the sale of the composted solids have been included (Moser and Mattocks, 2000 and Peranginangin and Scott, 2002). However, the results of this study indicate that anaerobic digestion prior to liquid solids separation neither enhances nor adversely impacts separation of solids. In addition, the volume of the liquid fraction is not reduced by anaerobic digestion prior to separation. Thus, the required storage capacity for the separated liquid fraction and the associated cost is not reduced. This reduces the assessment of the attractiveness of the investment in anaerobic digestion with biogas utilization at AA Dairy simply to a comparison of costs of biogas production and utilization and income derived from biogas utilization.

Capital Cost—Moser and Mattocks (2000) reported the total capital cost of the AA Dairy anaerobic digester, including the engine-generator set and electrical intertie, to be $295,700. As shown in Table 5-5, this sum includes the cost of a lift station pump including electrical work. However, this pump would be required without anaerobic digestion to transfer manure scraped from the free-stall barn alleys to the storage lagoon. It also includes the cost of the facilities required for liquid solids separation, which is not dependent on anaerobic digestion as discussed above. Therefore, the capital cost of anaerobic digestion and biogas utilization actually is $245,200 or $446 per cow as the system currently is being operated. However, the system was designed for 1,054 cows, which reduces the capital cost per cow to $233. This difference becomes highly significant because revenue from the generation of electricity will more than double if herd expansion to 1,054 cows occurs. It should be noted, however, that the engine-generator set used at AA Dairy is a used, reconditioned unit. The cost of a new unit is approximately $120,000. With a new engine-generator set the cost of the AA Dairy system would have been $300,000 or $285 per cow based on the design herd size of 1,054 cows.

Value of Electricity Generated—As previously discussed, AA Dairy currently generates an average of 1,429 kWh of electricity per day at the conversion efficiency of biogas energy to electrical energy of about 20 percent and an on-line efficiency of 98.8 percent. However, the conversion efficiency of 20 percent is a reflection of the less than maximum utilization of the engine-generator set capacity, which would approach 30 percent if fully utilized. Thus, AA Dairy would be able to generate one-third more electricity (2,144 kWh per day) with an engine-generator set sized for the current rate of biogas production of 42,868 ft^3 per day and 4,211 kWh per day with the engine-generator set currently in use at the system design herd size of 1,054 cows.

AA Dairy purchases electricity from the NYSEG Corporation under Service Classification No. 7 at a on-peak rate (7:00 AM to 11:30 PM) of $0.06868 per kWh and at a off-peak rate (11:30 PM to 7:00 AM) of $0.04060 per kWh with a on-peak demand charge of $11.68 per kW and a reactive charge of $0.00095 per billing reactive kilovolt-ampere hour. Based on pre-digester electricity use (i.e., prior to mid-1998) and current rates, the cost per kWh of electricity without on-site generation would range between $0.09 and $0.12 due to variation in time of use and demand charges. This range of cost per kWh reflects the increased consumption of electricity from May through October for free-stall barn ventilation for cow cooling and from September through May for increased free-stall barn lighting (Minott and Scott, 2001). For this analysis, it seems reasonable to consider $0.105 per kWh to be the fair value of the biogas-derived electricity used on site at AA Dairy.

Prior to mid-2001, AA Dairy received an average $0.025 per kWh for the electricity sold to the NYSEG Corporation. As of mid-2001, this rate was increased to $0.0525 per kWh, which is the value that will be assumed in this analysis. Because of the previously discussed problem with the engine-generator set during from January through March 2002, a continuous record of typical monthly sales of electricity to the NYSEG Corporation reflecting seasonal variation in total on-farm electricity use was not available. However, such records for 2000 and 2001 were available. During 2000 and 2001, AA Dairy respectively sold 178,970 and 191,380 kWh of electricity to the NYSEG Corporation or an average of 185,175 kWh per year. Thus, the average revenue being generated by sale of electricity at $0.0525 per kWh is estimated to be $9,722 per year.

Although electricity purchases from and sales to the NYSEG Corporation are metered, there is no metering to determine the amount of biogas-generated electricity consumed by AA Dairy. However, this value is simply the difference between the estimate biogas derived electricity generated, 521,585 kWh, and sold, 185,175 kWh, annually, which is 336,410 kWh per year. At the assumed price of $0.105 per kWh, the additional revenue generated from on-site biogas generated electricity use is estimated to be $35,323 per year. Thus, the total income produced by the AA Dairy anaerobic digester-biogas utilization system is $45,045 per year.

The current capacity for generating electricity at AA Dairy, 521,585 kWh per year, substantially exceeds the farm's estimated annual demand of 413,869 kWh per year (Minott and Scott, 2001). However, only about 64 percent of the electricity generated is consumed on site due to the inability to always satisfy demand. Yet periods when generation capacity exceeds demand also occur. Thus, an opportunity to increase revenue through load management appears to exist.

As noted earlier, AA Dairy has the potential to generate 3,315 kWh of biogas-derived electricity per day or 1,209,975 kWh per year if herd expansion to 1,054 cows occurs. Assuming on-site electrical use would double, the value of biogas-derived electricity used on site would double, increasing to $70,646 per year. The revenue generated by sale of excess electricity, 537,155 kWh per year, to the NYSEG Corporation also would increase to $28,201 per year. Thus, total income produced by the AA Dairy anaerobic digester-biogas utilization system would be $98,847 per year.

Annual Operation and Maintenance Costs—Because the AA Dairy anaerobic digester and engine-generator set have only been in operation since mid-1998, there is no long-term record on which to base an estimate of annual operating and maintenance costs. Previously, Wright and Perschke (1998) and Nelson and Lamb (2002) have estimated operation and maintenance costs for the anaerobic digestion of dairy cattle manure with biogas utilization to generate electricity to be $0.015 per kWh of electricity generated. With this approach, the operating and maintenance cost for the AA Dairy system under current operating conditions would be $7,824 per year, which is approximately three percent of the capital cost of the system. However, the operating and maintenance cost would increase to $23,055 per year or 9.4 percent of the capital cost of the system with a herd expansion to 1,054 cows. The magnitude of this increase seems unreasonable since the only significant change in operation would be an increase in the volume of manure pumped. The hours of engine-generator set operation would not change since this unit currently is being operated 24 hours per day at a partial load.

Based on the work of Moser and Langerwerf (2000), estimating annual operating and maintenance cost at five percent of the system capital cost seems like a more accurate approach. The value of five percent reported by Moser and Langerwerf was based on 16 years of operation of an anaerobic digester and engine-generator set for a herd of 400 dairy cattle and includes periodic rebuilding of the engine-generator set and renovation of the digester after 16 years of operation. For the AA Dairy system, an operating and maintenance cost rate of five percent of the system capital cost per year translates into a cost of $12,260 per year.

Economic Viability—The attractiveness of any investment generally depends on the ability of the capital investment required to generate income adequate to recover the capital invested with a rate of return on the capital invested and for management and labor that is competitive with other investment opportunities. If there is no other reason for considering anaerobic digestion, such as the need for odor control, this should be the basis for evaluating the option of adding anaerobic digestion with biogas utilization to any animal waste management system. If, however, odor control or some other benefit provided by anaerobic digestion is a necessity to continue the general farm operation, acceptance of a rate of return that is somewhat less than competitive than other investment alternatives may be acceptable if the general farm operation remains profitable.

As currently operated, the gross revenue produced by the AA Dairy anaerobic digestion-biogas utilization system from on-site use and sale of the electricity generated, as discussed above, is estimated to be $45,045 at a cost for operation and maintenance of $12,260 per year. Thus, net revenue generated is $32,785 per year. However, the AA Dairy system has the potential of producing gross revenue of $98,847 and net revenue of $86,587 per year if expansion of herd size of 1,054 cows occurs. Thus, current net revenue is adequate to recover the capital invested,

$245,200, in approximately 7.5 years if the time value of money is not considered. If the system were being operated at design capacity, the payback period would be reduced to approximately 2.8 years. At an interest rate of seven percent, these payback periods increase to approximately 11 and 4 years, respectively. Beyond these payback periods, all net revenue from biogas utilization represents net income. Assuming a system life of 20 years, the income generated by the AA Dairy system as currently operated would be approximately $295,000 or an average of $14,750 per year. With herd expansion, income would increase to approximately $1,385,250 or $69,260 per year.

If the AA Dairy system was financed over a 20-year period at the same interest rate of seven percent, the net income generated would be somewhat less, but there would be a steady stream of net income over the life of the system. Under current operating conditions, the net income would be $9,641 per year or a total of $192,820 over the life of the system. With herd expansion to the design value of 1,054 cows income would increase to $63,443 per year or a total of $1,268,860 over the life of the system.

The results of these cost analyses clearly demonstrate that anaerobic digestion of dairy cattle manure with biogas collection and utilization can provide significant environmental quality benefits as previously described while concurrently producing a significant source of income. Although the alternative of aerobic digestion can provide some of the same environmental quality benefits, no income is produced to offset capital and operating costs. Thus, total farm income is decreased rather than enhanced, as is the case with anaerobic digestion.

Under both the short-term and long-term financing scenarios described above, it appears that there would be considerable merit in replacing the current engine-generator set with unit sized for the current rate of biogas production if the plan for herd expansion is being abandoned. This system modification would increase electricity generated by 33 percent with a somewhat lower but still significant increase in net income. It probably would be most logical to make this change when the current engine-generator set requires rebuilding.

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Table 4-1. Comparison of AA Dairy manure production and characteristics with standard reference values assuming a live-weight of 1,400 lb per cow.

Parameter	AA Dairy	ASAE (2001)	USDA (1992)
Volume, ft^3/cow-day	2.10	1.94	1.82
Total solids, kg/cow-day	6.7	7.6	6.4
Total volatile solids, kg/cow-day	5.7	6.4	5.4
Fixed solids, kg/cow-day	1.0	1.2	1.0
Chemical oxygen demand, kg/cow-day	9.1	7.0	5.7
Total Kjeldahl nitrogen, kg/cow-day	0.28	0.29	0.29
Total phosphorus, kg/cow-day	0.048	0.060	0.044
Orthophosphate phosphorus, kg/cow-day	0.027	0.039	—
pH	7.4	7.0	—

Table 4-2. AA Dairy anaerobic digester performance summary, mg/L[*].

Parameter	Influent	Effluent	Reduction, %
Total solids	113,186[a]±10,097	84,739[b]±5,993	25.1
Total volatile solids	96,080[a]±9,477	67,518[b]±4,446	29.7
Fixed solids	17,106[a]±1,495	17,221[a]±2,461	—
Chemical oxygen demand	153,496[a]±77,178	89,144[b]±23,185	41.9
Soluble chemical oxygen demand	24,239[a]±6,568	16,961[b]±7,073	30.0
Total volatile acids	3,687 [a] ±806	513 [b]±227	86.1
Total Kjeldahl nitrogen	4,631[a]±513	5,111[a]±894	—
Organic nitrogen	2,500[a]±491	2,268[a]±891	—
Ammonia nitrogen	2,159[a]±387	2,881[b]±322	+33.4[†]
Total phosphorus	813[a]±124	838[a]±124	—
Orthophosphate phosphorus	457[a]±104	562[b]±90	+23.0[†]
pH	7.4[a]±0.3	7.9[b]±0.1	—

[*]Means in a row with a common superscript are not significantly different ($P<0.01$).
[†]Increase in concentration.

Table 4-3. AA Dairy anaerobic digester reductions of total solids, total volatile solids, chemical oxygen demand, and soluble chemical oxygen demand.

Parameter	Reduction, lb/day
Total solids	2,052
Total volatile solids	2,060
Chemical oxygen demand	4,641
Soluble chemical oxygen demand	525

Table 4-4. Comparison of AA Dairy anaerobic digester $\log_{10}$ influent and effluent densities of fecal coliform bacteria and *M. avium paratuberculosis*.

	Influent	Effluent	Reduction
Fecal coliforms			
CFU/g*	6.08±0.59	3.30±0.73	2.78
M. avium paratuberculosis			
CFU/g	3.94±0.72	1.86±0.72	2.08

*Log_{10} colony-forming units per g of manure

Table 4-5. AA Dairy Biogas Composition.

Parameter	% by volume
Methane	59.1
Carbon dioxide	39.2
Hydrogen sulfide	0.193
Ammonia	0.0015
Other gases	1.5055

Table 4-6. Methane and total biogas production as functions of chemical oxygen demand and total volatile solids destruction.

Parameter	Biogas	Methane
$ft^3/lb\ COD_D$	9.24	5.46
$ft^3/lb\ TVS_D$	20.81	12.30

Table 4-7. Comparison of the characteristics of the AA Dairy anaerobic digester effluent (separator influent) with the separated liquid and solid fractions, mg/L*.

Parameter	Digester effluent	Separated liquid	Separated solids
Total solids	$84{,}739^{a}\pm5{,}993$	$51{,}088^{b}\pm1{,}357$	$247{,}444^{c}\pm18{,}153$
Total volatile solids	$67{,}518^{a}\pm4{,}446$	$35{,}763^{b}\pm1{,}280$	$220{,}982^{c}\pm18{,}235$
Fixed solids	$17{,}221^{a}\pm2{,}461$	$15{,}325^{b}\pm988$	$26{,}463^{c}\pm2{,}906$
Chemical oxygen demand	$89{,}144^{a}\pm23{,}185$	$54{,}744^{b}\pm6{,}068$	$224{,}040^{c}\pm78{,}277$
Soluble chemical oxygen demand	$16{,}961^{a}\pm7{,}073$	$15{,}185^{a}\pm4{,}474$	$16{,}350^{a}\pm5{,}160$
Total Kjeldahl nitrogen	$5{,}111^{a}\pm894$	$4{,}723^{a}\pm601$	$5{,}374^{a}\pm1{,}076$
Ammonia nitrogen	$2{,}881^{a}\pm322$	$2{,}964^{a}\pm305$	$2{,}656^{a}\pm502$
Organic nitrogen	$2{,}268^{a}\pm891$	$1{,}837^{ab}\pm570$	$2{,}625^{ac}\pm755$
Total phosphorus	$838^{a}\pm124$	$802^{a}\pm90$	$1{,}106^{b}\pm308$
Orthophosphate phosphorus	$526^{a}\pm90$	$538^{a}\pm96$	$620^{a}\pm156$
pH	$7.9^{a}\pm0.1$	$7.9^{a}\pm0.2$	$8.5^{b}\pm0.2$

*Means in a row with a common superscript are not significantly different ($P<0.01$).

Table 4-8. Comparison of AA Dairy $\log_{10}$ densities of fecal coliform bacteria and *M. avium paratuberculosis* in the anaerobic digester effluent with separated liquid and solid fraction densities[•].

	Digester effluent	Separated liquid	Separated solids
Fecal coliforms			
CFU/g[†]	3.30[a]±0.73	2.66[ab]±0.88	2.55[b]±0.88
M. avium paratuberculosis			
CFU/g	1.94[a]±0.62	1.26[ab]±0.95	0.56[b]±0.88

[*]Means in a row with a common superscript are not significantly different (P<0.01).

[†]$\log_{10}$ colony-forming units per g of manure.

Table 4-9. Distributions of constituents of AA Dairy anaerobic digester effluent following separation.

Parameter	Liquid fraction, %	Solid fraction, %
Total solids	83	17
Total volatile solids	83	17
Fixed solids	93	7
Chemical oxygen demand	85	15
Total Kjeldahl nitrogen	95	5
Ammonia nitrogen	96	4
Organic nitrogen	94	6
Total phosphorus	95	5
Orthophosphate phosphorus	96	4

Table 4-10. Comparison of the characteristics of the AA Dairy storage pond influent with the pond contents.

Parameter	Storage pond influent	Storage pond influent (adjusted for dilution)	Storage pond
Total solids, mg/L	51,088±1,357	29,239	28,407±2,892
Total volatile solids, mg/L	35,763±1,280	20,468	18,634±2,268
Fixed solids, mg/L	17,221±2,461	9,856	9,774±794
Chemical oxygen demand, mg/L	54,744±6,068	31,331	31,399±1,396
Soluble chemical oxygen demand, mg/L	15,185±4,474	8,691	12,233±2,837
Total Kjeldahl nitrogen, mg/L	4,723±601	2,702	2,564±126
Ammonia nitrogen, mg/L	2,964±305	1,696	1,553±690
Organic nitrogen, mg/L	1,837±570	1,051	1,012±566
Total phosphorus, mg/L	802±90	459	459±42
Orthophosphate phosphorus, mg/L	538±96	308	356±47

Table 4-10. Continued.

pH	7.9±0.2	—	7.6±01
Fecal coliforms, CFU/g*	2.66±0.88	1.52	2.75±0.36
M. avium paratuberculosis, CFU/g	1.26±0.95	—	No data

*Log_{10} colony-forming units per g of manure.

Table 4-11. Comparison of Patterson Farms manure production and characteristics with standard reference values assuming a live-weight of 1,400 lb per cow.

Parameter	Patterson Farms	ASAE (2001)	USDA (1992)
Volume, ft^3/cow-day	2.35	1.94	1.82
Total solids, kg/cow-day	7.1	7.6	6.4
Total volatile solids, kg/cow-day	5.8	6.4	5.4
Fixed solids, kg/cow-day	1.3	1.2	1.0
Chemical oxygen demand, kg/cow-day	9.4	7.0	5.7
Total Kjeldahl nitrogen, kg/cow-day	0.28	0.29	0.29
Total phosphorus, kg/cow-day	0.045	0.060	0.044
Orthophosphate phosphorus, kg/cow-day	0.020	0.039	—
pH	7.4	7.0	—

Table 4-12. Comparison of the characteristics of Patterson Farms separator influent with the separated liquid and solid fractions, mg/L*.

Parameter	Separator influent	Separated liquid	Separated solids
Total solids	107,063^{a}±5,972	79,463^{b}±8,961	248,600^{c}±11,716
Total volatile solids	87,490^{a}±5,333	61,389^{b}±7,374	227,622^{c}±11,071
Fixed solids	19,572^{ab}±1,564	18,074^{a}±1,697	20,978^{b}±2,401
Chemical oxygen demand	141,871^{a}±21,057	96,513^{b}±24,649	280,842^{c}±65,196
Soluble chemical oxygen demand	22,668^{a}±9,821	22,290^{a}±5,057	18,701^{b}±6,926
Total Kjeldahl nitrogen	4,237^{a}±609	4,015^{a}±522	3,942^{a}±785
Ammonia nitrogen	1,999^{a}±310	1,938^{a}±297	1,496^{b}±301
Organic nitrogen	2,239^{a}±597	2,078^{a}±409	2,444^{a}±594
Total phosphorus	677^{a}±109	608^{a}±96	510^{b}±129
Orthophosphate phosphorus	306^{a}±98	280^{a}±84	214^{a}±107
pH	7.5^{a}±0.2	7.5^{a}±0.2	8.2^{b}±0.2

*Means in a row with a common superscript are not significantly different (P<0.01).

Table 4-13. Comparison of Patterson Farms $\log_{10}$ densities of fecal coliform bacteria and *M. avium paratuberculosis* in the anaerobic digester effluent with separated liquid and solid fraction densities*.

	Separator influent	Separated liquid	Separated solids
Fecal coliforms			
CFU/g†	5.68^{a}±0.47	5.86^{a}±0.53	5.28^{a}±0.64
M. avium paratuberculosis			
CFU/g	4.00^{a}±0.48	3.05^{b}±0.50	2.71^{b}±1.13

*Means in a row with a common superscript are not significantly different (P<0.01).
†$\log_{10}$ colony-forming units per g of manure.

Table 4-14. Distributions of constituents of Patterson Farms separator influent following separation.

Parameter	Liquid fraction, %	Solid fraction, %
Total solids	84	16
Total volatile solids	84	16
Fixed solids	48	52
Chemical oxygen demand	85	15
Total Kjeldahl nitrogen	94	6
Ammonia nitrogen	96	4
Organic nitrogen	93	7
Total phosphorus	96	4
Orthophosphate phosphorus	97	3

Table 4-15. Comparison of the characteristics of the AA Dairy storage pond influent with the pond contents.

Parameter	Storage pond influent	Storage pond influent (adjusted for dilution)	Storage pond
Total solids, mg/L	79,463±8,961	71,752	71,630±7,250
Total volatile solids, mg/L	61,389±7,374	55,432	54,493±4,992
Fixed solids, mg/L	18,074±1,697	16,320	17,134±2,265
Chemical oxygen demand, mg/L	96,513±24,649	87,147	84,819±7,291
Soluble chemical oxygen demand, mg/L	22,290±5,057	20,127	20,032±4,078
Total Kjeldahl nitrogen, mg/L	4,015±522	3,625	3,315±504
Ammonia nitrogen, mg/L	1,938±297	1,750	1,531±798
Organic nitrogen, mg/L	2,078±409	1,875	1,784±301
Total phosphorus, mg/L	608±96	549	549±53
Orthophosphate phosphorus, mg/L	280±84	252	301±51

Table 4-15. Continued.

pH	7.5±0.2	—	7.2±0.2
Fecal coliforms, CFU/g*	5.86±0.53	5.29	4.63±0.25
M. avium paratuberculosis, CFU/g	3.05±0.50	2.75	2.85±0.06

*Log_{10} colony-forming units per g of manure.

Table 5-1. Comparison of AA Dairy and Patterson Farms rates of production of manure and its various constituents.

	AA Dairy	Patterson Farms
Volume, ft^3/cow-day	2.10	2.35
Total solids, kg/cow-day	6.7	7.1
Total volatile solids, kg/cow-day	5.7	5.8
Fixed solids, kg/cow-day	1.0	1.3
Chemical oxygen demand, kg/cow-day	9.1	9.4
Total Kjeldahl nitrogen, kg/cow-day	0.28	0.28
Total phosphorus, kg/cow-day	0.048	0.045
Orthophosphate phosphorus, kg/cow-day	0.027	0.020
pH	7.4	7.4

Table 5-2. Comparison of AA Dairy anaerobic digester and Patterson Farms separator influent characteristics, mg/L.

Parameter	AA Dairy	Patterson Farms
Total solids	113,186±10,097	107,063±5,972
Total volatile solids	96,080±9,477	87,490±5,333
Fixed solids	17,106±1,495	19,572±1,564
Chemical oxygen demand	153,496±77,178	141,871±21,057
Soluble chemical oxygen demand	24,239±6,568	22,668±9,871
Total Kjeldahl nitrogen	4,631±513	4,237±609
Ammonia nitrogen	2,159±387	1,999±310
Organic nitrogen	2,500±491	2,239±597
Total phosphorus	813±124	677±109
Orthophosphate phosphorus	457±104	306±98
pH	7.4±0.3	7.5±0.2

Table 5-3. Comparison of the characteristics of the AA Dairy and Patterson Farms separated solids, mg/L.

Parameter	AA Dairy	Patterson Farms
Total solids, mg/L	247,444±18,153	248,600±11,716
Total volatile solids, mg/L	220,982±18,235	227,622±11,071
Fixed solids, mg/L	26,463±2,906	20,978±2,401
Chemical oxygen demand, mg/L	224,040±78,277	280,842±65,196
Soluble chemical oxygen demand, mg/L	16,350±5,160	18,701±6,926
Total Kjeldahl nitrogen, mg/L	5,374±1,076	3,942±785
Ammonia nitrogen, mg/L	2,656±502	1,496±301
Organic nitrogen, mg/L	2,625±755	2,444±594
Total phosphorus, mg/L	1,106±308	510±129
Orthophosphate phosphorus, mg/L	620±156	214±107
pH	8.5±0.2	8.2±0.2
Fecal coliforms, CFU/g*	2.55±0.88	5.28±0.64
M. avium paratuberculosis, CFU/g	0.56±0.88	2.71±1.13

*Log_{10} colony-forming units per g of manure.

Table 5-4. Comparison of the characteristics of the AA Dairy and Patterson Farms separated liquid, mg/L.

Parameter	AA Dairy	Patterson Farms
Total solids, mg/L	51,088±1,357	79,463±8,961
Total volatile solids, mg/L	35,763±1,280	61,389±7,374
Fixed solids, mg/L	15,325±988	18,074±1,697
Chemical oxygen demand, mg/L	54,744±6,068	96,513±24,649
Soluble chemical oxygen demand, mg/L	15,185±4,474	22,290±5,057
Total Kjeldahl nitrogen, mg/L	4,723±601	4,015±522
Ammonia nitrogen, mg/L	2,964±305	1,938±297
Organic nitrogen, mg/L	1,837±570	2,078±409
Total phosphorus, mg/L	802±90	608±96
Orthophosphate phosphorus, mg/L	538±96	280±84
pH	7.9±0.2	7.5±0.2
Fecal coliforms, CFU/g*	2.66±0.88	5.86±0.53
M. avium paratuberculosis, CFU/g	1.26±0.95	3.05±0.50

*Log_{10} colony-forming units per g of manure.

Table 5-5. Cost of the AA Dairy anaerobic digestion with biogas utilization and liquid solids separation system (Moser and Mattocks, 2000).

Item	Cost
Lift station/Mix tank*	$12,500
Digester	$121,000
Engine-generator set†	$32,000
Electrical and intertie	$33,200
Structure for engine-generator set, piping, etc.	30,500
Liquid solids separation	$38,000
Engineering	$24,000
Start-up	$4,500
Total	$295,700

*Only pump and electrical work.

†Used, reconditioned unit.

Manure Digester Systems and Odor Control

Properly designed and operated digester systems reduce odors associated with the collection, storage and land application of livestock manure. The odors traditionally associated with livestock facilities, if not properly managed, can impair local air quality and may be a nuisance to nearby communities. Digester systems reduce the generation and migration of these odors because the volatile organic acids, the primary odor causing compounds associated with manure, are consumed by methane-producing bacteria. The odor associated with digester systems is significantly less than that from conventional manure management systems.

Manure is partially digested feed. The remaining partially degraded and unused feed (manure) continues to decompose upon leaving the animal. Bacterial decomposition begins in any manure containment structure (lagoon, pond, tank, etc.) and continues until the manure is removed or is stabilized. In a very simplified form: Step 1 - anaerobic bacteria degrade manure into the odiferous compounds often associated with livestock facilities; Step 2 – methane-producing bacteria consume the Step 1 compounds, substantially eliminating the odors.

In more detail, the digestion process begins with bacterial hydrolysis of the input materials in order to break down insoluble organic polymers such as proteins, carbohydrates and fats and make them available for other bacteria. Acidogenic bacteria then convert the resulting sugars and amino acids into carbon dioxide, hydrogen, ammonia, and organic acids (where most of the odor associated with animal manure arises from). Acetogenic bacteria then convert these resulting organic acids into acetic acid, along with additional ammonia, hydrogen, and carbon dioxide. Finally, methanogens convert these products to methane and carbon dioxide.

Digester systems help to reduce odors primarily by (1) containing the manure during decomposition in an engineered, impervious structure, and (2) optimizing the manure decomposition process by controlling the temperature, volume, pH, and retention time. Manure is traditionally stored in open lagoons, ponds and tanks with little or no attention to process control. Therefore, there are significant odors associated with manure storage. Most stored livestock manure is then applied to cropland for growing animal feed. When partially digested manure is land applied, significant odors can be associated with this practice as decomposition is incomplete. Manure that has been adequately digested can be considered "biologically stabilized" and is no longer manure but treated effluent, with much reduced odors when stored and land applied.

AgSTAR commissioned a series of studies to characterize the environmental improvements provided by anaerobic digester systems. The sections from these reports that briefly discuss the results related to odors are below. The full Performance Evaluations can be found at: http://www.epa.gov/agstar/anaerobic/evaluation.html

An Evaluation of a Covered Anaerobic Lagoon for Flushed Dairy Cattle Manure Stabilization and Biogas Production - Castelanelli Brothers Dairy (2008)

> *"Odors - The most readily apparent benefit of the use of anaerobic digestion at Castelanelli Brothers Dairy is the low level of the noxious odors commonly associated with dairy cattle manure management systems. This is the direct result of the degree of waste stabilization provided by anaerobic digestion under controlled conditions. Total volatile solids were reduced by 62 percent, chemical oxygen demand*

by 60 percent, and volatile acids during by ~100 percent. With these reductions and additional degradation during storage of lagoon effluent, odors are minimized."

A Comparison of Dairy Cattle Manure Management With and Without Anaerobic Digestion and Biogas Utilization - AA Dairy and Patterson Farms, Inc. (2004)

"Odors - The most readily apparent difference between the AA Dairy and Patterson Farms manure management systems is the effectiveness of anaerobic digestion at AA Dairy in reducing odors. This is the direct result of the degree of waste stabilization provided by anaerobic digestion under controlled conditions. As shown in Table 4-2, average reductions in total volatile solids, chemical oxygen demand, and volatile acids during anaerobic digestion were 29.7, 41.9, and 86.1 percent, respectively. With these reductions, additional degradation during storage under uncontrolled anaerobic conditions and the associated odors are minimized."

An Evaluation of a Mesophilic, Modified Plug Flow Anaerobic Digester for Dairy Cattle Manure - Gordondale Farms, WI (2005)

"Odors - The most readily apparent benefit of the use of anaerobic digestion at Gordondale Farms is the low level of the noxious odors commonly associated with dairy cattle manure management systems. This is the direct result of the degree of waste stabilization provided by anaerobic digestion under controlled conditions. As shown in Table 4-2, average reductions in total volatile solids, chemical oxygen demand, and volatile acids during anaerobic digestion were 39.6, 38.5, and 87.8 percent, respectively. With these reductions, additional degradation during storage under uncontrolled anaerobic conditions and the associated odors are minimized."

An Assessment of the Performance of the Colorado Pork, LLC Anaerobic Digestion and Biogas Utilization System (2003)

"Odor Reduction - Although odor threshold levels prior to anaerobic digester operation were not available, the average of seven determinations of odor threshold level adjacent to the digester during the 12 months of data collection was 2,842. Adjacent to the storage and evaporation pond, the average of eight determinations was 5,589. Both averages were below the maximum compliance level of 6,000. Thus, it can be concluded that the objective of odor reduction was achieved."

Additional references related to digester systems and odors.

Anaerobic Digestion: Holistic Bioprocessing of Animal Manures
http://molecol.ifas.ufl.edu/images/wilkie1.pdf

Cornell University Dairy Environmental Systems Anaerobic Digestion Case Studies
http://www.manuremanagement.cornell.edu/Pages/Resources/Resources-Case_Studies.htm

Benefits, Costs and Operating Experience at Seven New Agricultural Anaerobic Digesters
http://www.epa.gov/agstar/documents/lib-ben.pdf

Anaerobic Digesters Control Odors, Reduce Pathogens, Improve Nutrient Manageability, Can be Cost Competitive with Lagoons, and Provide Energy Too!
http://www.epa.gov/agstar/documents/lib-man_man.pdf

U.S. Environmental Protection Agency's AgSTAR Program is a voluntary outreach and educational program that promotes the recovery and use of methane from animal manure.
- www.epa.gov/agstar -

Evaluation of Commercial Digester

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Vander Haak Dairy

Parameter (g/L)	Before AD	After AD	% change
Total solids	60-100	30-60	- 35-40
Volatile solids	40-75	25-50	- 40-45
COD	50-90	35-50	- 40-50
Total N	3-5	3-5	n.c.
Avail. N	2-3	3-4	+ 25-28
Total P	0.4-1.0	0.4-0.9	n.c.
Fecal coliform (cfu/g)	200-500K	2-9K	- 98

Competition from Energy Uses of Manure

There is growing interest in using manure as a feedstock for energy production, driven by rising energy prices and growing concerns over the environmental risks associated with excess applications of manure nutrients and with fossil fuel energy production. Two types of manure-based energy production are in current commercial use in the United States.[21]

Anaerobic digesters are in use on dairy and hog farms, and a few community digesters also serve multiple operations in a local area. Digesters capture biogas, which contains methane, carbon dioxide, and trace amounts of other gases, from manure. The gas can be used as a fuel for boilers, heaters, chillers, and generators, but it can also be cleaned and conditioned for insertion into a natural gas (97 percent methane) pipeline. Most current applications burn the gas for on-farm electricity generation.

Manure can also be treated and burned as a feedstock in electricity generating plants. Manure must be transported from farms to centralized generating plants to realize scale economies in combustion. Several such plants are in operation in England and Scotland. A plant using fed cattle manure first operated in California in 1987; that plant is currently idled, but a plant relying on turkey litter recently opened in Minnesota, and others are under construction in Connecticut (using litter from an egg-laying operation) and Texas (using cattle manure).

Manure to Energy Systems in Current Commercial Use

In the manure storage systems that are typically used on large dairy and hog operations, little oxygen can dissolve into the mix, which creates anaerobic (without air) conditions. Certain microbes that are naturally found in manure feed on organic materials in the manure. The bacteria function best in anaerobic conditions, and they give off biogases, primarily methane and carbon dioxide. Methane is the primary component of natural gas and is a clean-burning fuel.

If methane can be captured from manure, it can be used as a feedstock for electricity generation. Farmers could then reduce their purchases of electricity and fuels, and might be able to sell excess electricity or methane. Society can gain because an existing product, manure-based methane gas, would replace some fossil fuels used for the same purpose. In addition, the manure effluent that is left after anaerobic digestion has few remaining decomposable compounds. Decomposition is what creates odor, so digestion also provides a solution to odor problems.[22]

Anaerobic digestion presents several important technical challenges in on-farm applications. An anaerobic digester is a sealed air-tight container that more effectively excludes oxygen from the manure and encourages a higher level of biogas production. Manure is added daily to the digester, and spends about 20 days flowing through the digester to the effluent storage and handling system. Growth of methane bacteria can be encouraged by maintaining higher temperatures, so heat must usually be added to a

[21]In this section, we rely on media reports, academic journal articles, and EPA databases for source data on manure-to-energy projects, and we use ARMS data to generate estimates of the potential avoided costs of on-farm electricity generation.

[22]The gas that digesters capture is 60-70 percent methane and 30-40 percent carbon dioxide, another greenhouse gas. Carbon dioxide could be separated, refined, and cooled for industrial uses, but that would require additional capital investment.

digester—typically via pipes running through the digester—and regulated for maximum gas production. The bacteria are quite pH-sensitive, so high alkalinity must be maintained in digesters, through added ingredients (lime) and by carefully regulating the flow of organic material to the digester. A variety of materials, such as salts, heavy metals, ammonia, and antibiotics, are toxic to methane bacteria, and must be carefully controlled.

The potential for generating methane is greatest when manure is collected and stored as a liquid, slurry, or semi-solid. Biogas potential is greatest at large dairy and swine operations because they use liquid or slurry manure management systems, and they have attracted the most attention. Manure managed in solid form, as in the fed cattle and poultry sectors, offers little opportunity for current digester designs.[23]

While there are a few centralized community digesters, most are on-farm systems. Manure can also be used as a feedstock for power plants, where the manure is incinerated and the heat from combustion creates steam for turning electricity-generating turbines. The manure produced on dairy and hog farms is costly to transport, and combustion is difficult to maintain with such high-moisture fuels, so combustion plants focus on poultry litter and fed cattle manure, which have high energy content and lower moisture content and transportation costs. The latter consideration is important because a power plant may draw in a large volume of manure from a significant catchment area.

But the moisture content of dry manure remains higher and more variable than non-manure feedstocks, making it harder to sustain combustion. Manure can create significant nitrous oxide emissions when burned, and it creates large volumes of ash residue. Some compounds added to feeds may present air pollution concerns when the litter is burned; on the other hand, manure is low in sulphur content compared to other fuels. These technical barriers stand in the way of widespread adoption of manure for energy production.

Extent of Current Adoption

Manure-to-energy systems are in limited commercial use in the U.S. By the summer of 2008, 91 commercial dairy farms were using digesters and another 64 had projects in the construction, design, or planning (CDP) phase. Farms in the two categories accounted for 0.2 percent of all dairy farms and 2.9 percent of all dairy cows in the U.S. (Table 10). In addition, the Environmental Protection Agency reports that 17 hog farms had operating digesters by the summer of 2008, with the manure supplied by 355,000 hogs. But that amounts to just 0.5 percent of the inventory of hogs and pigs on U.S. farms (0.6 percent when the 6 farms in the CDP phase were added).

Larger dairy and hog farms are more likely to adopt digesters, but adoption is not widespread even among them (Table 11). About 4.5 percent of dairy farms with at least 2,000 cows have digesters, and another 3.4 percent are in the CDP phase, but they account for just 8 percent of the cows on dairy farms with at least 2,000 head.[24]

Combustion plants are still in their commercial infancy in the U.S. An 18.5-megawatt plant in El Centro, California, was opened in 1987 and utilized the

[23]A large digester under construction in Alberta, Canada, will use cattle feedlot manure and a newly developed separation technology to remove sand and dirt from the manure before digestion (Kryzanowski, 2009). The biogas will be used to generate electricity to power an onsite ethanol plant, with excess electricity to be sold into the power grid.

[24]Most of the hog operations with digesters had at least 5,000 hogs in inventory, which is a relatively large hog feeding operation, and two large complexes had over 100,000.

manure produced by 100,000 cattle, just under 1 percent of all feedlot cattle. The plant was idled but acquired by GreenHunter Energy in 2007, which expects to reopen the plant by 2009. The plant has a 30-year supply contract with a California utility.

A large combustion plant was opened in Benson, Minnesota, in May of 2007. The plant, called Fibrominn, sells the electricity it generates to Xcel Energy, a Minnesota-based public utility, under a 21-year contract. The plant's 55-megawatt generating capacity helps Xcel meet a mandate set by the Minnesota legislature for each of the State's utilities to realize 125 megawatts from biomass or wind power.

The Benson plant utilizes turkey litter from about 300 farms within a radius of 100 miles. The farms currently supplying the plant account for about 40 percent of Minnesota turkey production, or about 6.6 percent of U.S. turkey production, although they do not provide all of their litter to Fibrominn (some is used on-farm as fertilizer). Fibrominn was financed by Fibrowatt, a company whose management developed four poultry-litter plants in the

Table 10

Anaerobic digesters on dairy farms, by region

States	Total milk cows	Farms and cows, by status of digester projects			
		Steady state/start-up		Construction/ Design/Planned	
		Farms	*Cows*	*Farms*	*Cows*
CA	1,780,000	15	28,162	4	10,795
Other West*	1,345,000	11	27,275	3	6,650
IN/MI/OH	759,000	4	12,400	10	44,870
NY/PA/VT	1,333,000	29	26,943	23	28,370
WI	1,243,000	19	28,000	13	15,750
IA/IL/MN	758,000	6	7,350	11	15,900
All	9,112,000	91	139,505	64	122,335

*ID/OR/TX/UT/SD/WA

Source: U.S. Environmental Protection Agency, Agstar Program, Anaerobic Digester Database.

Table 11

Farm size and adoption of anaerobic digesters

Herd size of farm	All U.S. dairy farms		Farms with digesters, by status			
			Steady state/startup		Construction/ Design/Planned	
	Farms	*Cows*	*Farms*	*Cows*	*Farms*	*Cows*
<500	68,295	4,656,000	18	4,973	8	1,575
500-999	1,700	1,139,000	22	16,424	16	11,450
1000-1999	920	1,212,000	24	31,107	20	27,010
>1999	595	2,106,000	27	87,001	20	82,300
All farms	71,510	9,112,000	91	139,505	64	122,325

Source: U.S. Environmental Protection Agency, Agstar Program, Anaerobic Digester Database.

United Kingdom. Fibrowatt is pursuing projects for similar plants in major broiler producing regions in North Carolina, Maryland, Arkansas, and Mississippi. Although the company has announced a site in North Carolina, construction has not commenced there or at the other locations.[25]

Another combustion plant has been proposed in Bozrah, Connecticut, by Clearview Renewable Energy. The 30-megawatt plant would utilize litter from a large egg-laying operation (340 tons a day) and waste wood from pallets and tree trimmings. It has received approval from the State's utility board and a site on the egg farm has been selected, but construction has not begun.

Panda Ethanol has a plant under construction in Hereford, Texas, which would use manure from feedlots to generate the steam needed to operate an ethanol refinery. The plant would gasify about 500,000 tons of manure a year; feedlots within 50 miles of the plant generate 2.1 million tons annually. Panda has announced plans to build three other plants, although the Hereford plant is the only one currently under construction.

Drivers of Adoption

Few manure-to-energy projects are now in commercial operation, but there is widespread interest in such projects and considerable potential for future growth. In order to understand the prospects for future growth, and the limits to current adoption, it is important to understand the incentives faced by individual decision makers.

Centralized combustion facilities require a substantial capital investment. Even though Fibrominn secured an agreement to sell its electricity to Xcel in August of 2000, it was unable to secure the $202 million in financing for the plant from a consortium of insurance companies until late 2004.

Moreover, Fibrominn's costs of electricity generation exceed those at conventional coal-fired plants, even though the plant's size allows it to realize lower costs than smaller biomass facilities. A Minnesota legislative mandate, requiring Xcel to generate 125 MW of power from biomass and wind sources, played an important role in securing the electricity supply contract for Fibrominn. Public support, either indirectly through mandates or directly through payments, may be critical for widespread adoption of manure-to-energy systems.[26]

Specific location also plays an important role. A viable combustion plant needs large local supplies of excess litter to minimize its costs of purchasing and transporting fuel, as well as easy transmission connections to limit its cost of transporting electricity.

The Fibrominn plant burns about 2,000 tons of litter a day. Half is acquired under long-term contracts from farmers in the immediate area, and the rest is trucked in from farms within a 100-mile radius. The plant pays farmers a price, 3-5 dollars per ton of litter, that matches what they can earn from selling the litter for fertilizer. The plant is also located near a new 115-kilovolt transmission line, and a co-located plant produces and sells phosphate fertilizer from the ash residue of the combustion process.

[25]Broilers are an attractive potential feedstock because broiler production generates about 6 times as much litter as turkey production, based on ASAE standards for per animal manure production by broilers, male turkeys and female turkeys, ASAE estimates of the fraction of males in turkey production, and USDA estimates of annual broiler and turkey slaughter.

[26] The proposed Clearview plant in Connecticut is expected to cost $140 million. The project was spurred by a legislative mandate imposed on Connecticut utilities, and financing was secured through the offer of long-term supply contracts offered to renewable energy providers by a State agency.

The California plant is located in California's Imperial Valley, with 400,000 head of feedlot cattle within a 20-mile radius. When operating, the plant took about one-quarter of the area's manure. The proposed Connecticut plant would be located on an egg farm; with limited crop production in the area, the farm faces a problem of excess nutrients. The Texas ethanol plant, now under construction, is located in a dense region of cattle feedlots, and has contracted to acquire manure for no cost, save for the expense of trucking it to the site.

Most anaerobic digesters are on-farm systems, so the costs and benefits facing the individual farmer are crucial in adoption.

The costs include:

- Capital costs, for digester and generation equipment;
- Operation and maintenance (O&M) expenses;
- Costs of adapting existing manure handling and storage to biogas systems; and
- The farmer's time costs in learning about and maintaining the system, which could amount to an hour a day.

The financial benefits include:

- Avoided costs of electricity, if the biogas is used onsite for generation that replaces electricity purchased from the electric utility;
- Avoided propane, fuel oil, or natural gas purchases, if waste heat is recovered from generation and used for space and water heating;
- Revenues from the sale of excess electricity to the local utility, or from the sale of methane gas (each requires additional costs);
- Avoided costs—or revenues from sales—of bedding made from digested solids;
- Avoided costs of commercial fertilizer and herbicides deriving from an improved fertilizer value of digester effluent over raw manure; and
- Revenues from the sale of carbon credits in greenhouse gas markets.

We used ARMS Phase III data to analyze the avoided costs of electricity and fuel purchases on dairy and hog operations. Farm size matters. A typical Northeastern dairy farm with 200 cows spent nearly $29,000 on electricity, propane, and natural gas expenses in 2005, and that expense rose to $63,000 on farms with 500 cows, and $114,000 on farms with 1,000 cows. Larger farms have a much stronger incentive to seek out investments that will allow them to replace purchased electricity, while small farms with digesters would need a market outlet for their electricity. But among farms of a given size, expenses can vary widely, and so can the incentives for digester adoption, with differences in farm production practices and location.

Location matters because prices for electricity vary across the country and variations in climate affect heating and cooling demand. In 2006, the average nationwide retail electricity price paid by firms in the commercial sector was 9.46 cents a kilowatt hour, but State-level averages ranged from 5.16 cents in Idaho, the 4th largest dairy State, to 16.3 cents in New York, the 3rd largest.[27] Propane and natural gas prices varied much less across States. Electricity and fuel usage can also vary because of differences in farm organization and technology.

Farms that milk three times a day use more electricity and fuel than those that milk twice a day, as do those with older milking systems. Farms that grow more crops, either for feed or for sale, use more electricity and fuel, holding herd size constant. Farms that use pasture for some of their forage, that raise heifers off-site, or that dry cows off seasonally, use considerably less, as do farms that keep cows in dry lots.

The impact of these differences can be quite large. Farms in the Northeast and Western Corn Belt have substantially higher electricity, propane, and natural gas expenses than similarly sized farms in the West, South, and Eastern Corn Belt. If a typical 500-cow Northeastern dairy spent about $63,000 on those expenses in 2007, a dairy with 500 cows but with production practices more common for Western operations would spend about $28,000. Moreover, a Western operation with 1,000 cows would spend about $51,000, still well below expenses at a 500-cow Northeastern dairy.

Hog production has also shifted to much larger operations, but the way hog production is organized has also changed. Traditional farrow-to-finish operations, covering all stages of production, are being replaced with farms specializing in specific stages of production. As a result, the volume of manure per animal varies considerably, depending on the farm's specialty. In addition, production is usually coordinated by an integrator that provides feed and feeder pigs to contract farmers, who grow the pigs to market weight. The farmer provides labor and capital services while the integrator retains ownership of the pigs and handles their disposition when they reach market weight. Integrators can have an important impact on adoption, both directly through their own actions and indirectly through the design of contracts with growers.

Electricity and fuel expenses increase with the volume of hog production, so larger operations are likely to see greater gains from investment in digesters. The EPA estimates that digesters are economical for operations with at least 2,000 hogs, but conditions vary considerably, even among large operations. Some have deep-pit manure storage systems that would require costly retrofitting for digester adoption. Avoided costs also vary widely across apparently similar operations. For a given number of market hogs produced, drylot operations have substantially lower electric and fuel expenses; farrow-to-finish operations have substantially higher expenses than feeder-to-finish operations; and hog farms with significant crop production have substantially higher electric and fuel expenses. Few finishing operations remove more than 10,000 hogs/year, and electricity and fuel expenses for those with no crop production are unlikely to exceed $10,000. By contrast, those with substantial cropping operations may have expenses reaching $40,000-$50,000. As in dairy, location matters, with electric and fuel expenses substantially higher in eastern hog production States than in Corn Belt and Plains States.

There have been several other recent analyses of digester adoption. Leuer, Hyde, and Richard (2008) analyzed incentives for adoption on Pennsylvania dairy farms, and included the potential for additional revenues from sales of

[27]According to data from the Energy Information Administration, at http://eia.doe.gov.

1.2 - Lakeside Pipeline LLC - Application - 2018 Solicitation SB 1383 Dairy Pilot Projects

electricity or carbon credits. Their analysis showed that larger operations were more likely to profit from a digester, but their findings suggested that farms would have to be quite large, on the order of 1,000 to 2,000 head. Profits from adoption were quite sensitive to the digester's initial capital cost.[28] Changes of 10 percent from a base case cost had large impacts on the profitability of adoption, an important finding when estimates of capital costs still vary widely.

Profits were also quite sensitive to the availability of revenues from the sale of electricity or carbon credits. Few large dairies would find a digester investment to be profitable without significant support for capital costs, carbon credit revenues, or revenues from electricity sales. To realize revenues from electricity sales, farms must connect their biogas-fired generators to the electrical power grid, an action that raises safety, power quality, technical, legal, and procedural issues. Farms must often make additional capital investments to support connection, and they will often need to hire technical experts for information and guidance in negotiating contracts. Utilities are often reluctant to purchase excess electricity from farmers, and when they do are likely to offer rates reflective of their avoided generation costs, which are generally well below retail rates. Opportunities to sell electricity are dependent on regulatory or legislative support in the State, so public policy will play a major role at the margin in driving adoption.

Farmers may qualify for carbon credits if they can capture methane and prevent it from emitting into the atmosphere. If farmers can provide credible claims of reduction in methane emissions, they may be able to sell the carbon credits in private transactions or in organized exchanges, thereby gaining further revenues from an investment in a digester. Credits traded on the Chicago Climate Exchange (CCX) varied over 2008 from $1.90 per metric ton to $7.40, with a mean price of $4.98 (Liebrand and Ling, 2008). If a lactating dairy cow produces five metric tons of methane in a year (five credits), then the farm could realize $25 per cow per year from the sale of carbon credits at a credit price of $5, and a farm with 1,000 cows could realize $25,000 in additional revenues. The farmer who had already invested in an anaerobic digester would bear some additional costs of qualifying for credits, for metering equipment and for fees paid to intermediaries, but the additional net revenues could make the project as a whole profitable.

The costs to be borne by farmers for digester adoption, as well as the benefits accruing to them, are subject to considerable uncertainty. Stokes, Rajagopalan, and Stefanou (2008) examined the impacts of uncertainty on digester adoption among Pennsylvania dairy operations. They conclude that uncertainty can play a major role in deterring adoption, and that grant funding might be necessary to induce farmers who are uncertain about the value of the completed project to invest in digester adoption.

Impacts on Fertilizer Uses for Manure

Only a small fraction of dairy manure is currently used for energy production through anaerobic digesters, with another small fraction in the CDP phase. If all current projects stayed in use, and all those in CDP phase were added, they would still account for less than 3 percent of the manure from dairy cows in the U.S. An even smaller share of hog manure is directed to energy

[28]USDA Rural Development has supported investments in anaerobic digesters through grants and loans. In the six years covering 2003-2008, USDA provided grants of $40.6 million, and loans of $19.1 million, in support of 121 digester projects.

use through digesters. Less than 1 percent of fed cattle manure, and less than 10 percent of turkey litter, is used in combustion energy processes, and we know of no current energy operations using broiler litter.

However, more large dairy and hog farms, and more contract poultry farms, could find energy operations to be profitable options if energy prices were to rise, or if producers could realize additional revenue from the sale of electricity, gas, or carbon credits. Production is continuing to consolidate among larger hog and dairy operations for whom digester use is potentially feasible, and there could be a movement into digester use if the economics of the investment were to improve. Would a major shift toward energy production divert manure away from use as fertilizer?

Anaerobic digestion has one important feature that matters here: the N, P, and K fertilizer nutrients present in raw manure are retained in the effluent from the digestion process. Digestion reduces pathogen counts and denatures weed seeds in raw manure, and the odors of raw manure are greatly reduced in the effluent, thereby easing the storage, movement, and application of manure nutrients. As a result, anaerobic digestion may increase the fertilizer value of raw manure.

Since the volume of liquid digester effluent is unchanged from the amount of liquid in the raw manure entering the digester, the effluent will still be costly to ship.

Digesters are often used in combination with solids separators, although separators may also be used on farms without digesters. The liquid effluent from separation is usually stored in lagoons and sprayed on crops as fertilizer. The solids may be used as bedding for cows, or they may be sold as compost to commercial and residential buyers. The nutrients that are retained in the solids are therefore lost to farming operations. However, it seems likely that if the solids had real value as crop nutrients, farmers would have used them as such instead of bearing the additional expense of turning them into compost.

Most nitrogen nutrients are burned during combustion processes. But the ash residues from combustion retain phosphorus and potash nutrients, in concentrated form because the process leaves about one pound of ash for every five pounds of turkey litter. Combustion plants market the ash residue as fertilizer to farmers, and indeed Fibrominn located a fertilizer processing plant on site next to its generating facility. The transportation costs of the resulting fertilizer product are substantially reduced because of its lower weight and volume, which creates a larger market area for sales.

The fertilizers derived from combustion processes might not be sold to farmers, and the nitrogen nutrients in the manure will be lost to crop fertilization, but local market forces play an important role here as well. Operators of combustion facilities purchase their manure feedstock, and operation will be most profitable in those areas with low prices for manure. Those are likely to be locations with excess manure nutrients and, therefore, a very low value for manure used locally.

Weed Seed Survival in Anaerobic Digesters

By Elizabeth J. Katovich and Roger L. Becker
Agronomy and Plant Genetics, University of Minnesota

Jerry Doll, University of Wisconsin

For more information, please contact:

Amanda Bilek
The Minnesota Project
651.645.6159, ext. 5
abilek@mnproject.org
www.mnproject.org

Elizabeth J. Katovich
University of Minnesota
612.625.5230
katov002@umn.edu

Roger L. Becker
University of Minnesota
612.625.5753
becke003@umn.edu

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MANURE IS AN IMPORTANT SOIL AMENDMENT PROVIDING valuable nutrients. However, many assume manure is always rich in weed seeds. The opposite is probably the case as most of our harvested forage is relatively free of weed seeds. Exceptions obviously exist. There is no simple method to extract weed seeds from feed or manure and to then test them for viability. So the best advice is to understand current knowledge about weed seeds in manure and how they may impact your operation. Key factors that determine the potential for weed seed problems from livestock systems are feed sources, type of animals, and type of feed and manure handling systems.

Feed Sources

Weed seeds enter livestock systems from forages, grain, and palletized feed products. Cash *et al.* (1998) estimated that for palletized products, less that 1% of weed seed survive feed grinding and palletizing. Though small in number, feed pellets can be a source of introduction of new weed species to a farm, and if one considers the volume of palletized feed fed, can be a significant source of weed seed. The biggest contribution of weed seed can come from contaminated hay and grain, however. A portion of weed seed present in feed can remain viable after passing through an animal's digestive tract. Weed seed present in bedding or in spilt-feed bypasses the animal directly entering the manure stream. Both of these weed seed sources may result in manure containing viable weed seeds. A study conducted in New York State (Mt.Pleasant and Schlather 1994) showed that farms with low amounts of weed seed in dairy manure used feed with low numbers of weed seeds. Farms with high manure weed seed counts either harvested feed from weedy fields or imported feed containing weed seeds. A California study (Cudney *et al.* 1992) showed that dairy manure from producing cows had fewer weed seeds than manure from dry cows, presumably because the dry cows received lower quality (weedier) feed.

Type of Animals, Ensiling, Digestion, and Manure Handling

The animal source of manure can be important. Two studies in Nebraska characterized the effects of the digestive tract and manure on weed seeds (Harmon and Keim 1934). Weed seeds were fed to calves, horses, sheep, hogs, or chickens. Nearly 25% of the seeds fed to hogs and cattle were recovered in the manure, while only 10 to 12% were recovered from horses and sheep. Chickens were the most effective in destroying weed seeds with only 2% of the velvetleaf seeds fed recovered, while none of the bindweed, sweet clover, smooth dock, smartweed, wild rose and pepperweed seeds fed were recovered.

Of the seeds recovered from calves, horses, sheep or hogs, an average of 25% germinated. Although few in number, 62% of the velvetleaf seeds that survived the trip through a chicken germinated, suggesting that the gizzard may have actually scarified the seed and stimulated germination. Combining seed recovered and germination of weed seeds fed, sheep, horses, pigs, and calves passed 6, 9, 9, and 10% viable seeds, respectively, while poultry passed only 1%

Table 1. Average weed seed viability after ensiling in a silo, fermentation in a rumen, or both. Lethbridge, Alberta. 1986-1989.

Species	Control	Ensiling in asilo	Rumen	Silo and rumen
	Viable seed (%)			
Green foxtail	96	0	17	0
Downy brome	98	0	0	0
Foxtail barley	87	0	0	0
Barnyardgrass	97	0	0	0
Flixweed	92	5	7	5
Kochia	94	10	15	10
Redroot pigweed	93	6	45	4
Lambsquarters	87	3	52	2
Wild buckwheat	96	30	56	16
Round-leaf mallow	93	23	57	17
Pennycress	98	10	68	10

Adapted from Blackshaw and Rode. Weed Sci. 39:104-108. 1991.

viable seed owing to the grinding action of sand in the gizzard. Olson and Wallander (2002) found that only 4% of mature leafy spurge seed was recovered when fed to sheep, and for grazing, recommended feeding livestock uninfested feed for 4 to 5 days before transfer to grazing land not infested with leafy spurge.

The fermentation process that is part of ensiling corn or forages can reduce the viability of weed seed, as can digestion in the rumen of cattle. In general, grass weed seeds are more likely to be killed by ensiling or rumen digestion than broadleaf weeds. In a study by Blackshaw and Rode (1991), seeds of downy brome, foxtail barley and barnyardgrass died if ensiled for 8 weeks or by rumen digestion for 24 hours (Table 1). Some green foxtail seed survived rumen digestion but were killed by ensiling. Broadleaf weeds are more likely to be killed by ensiling than by rumen digestion, but both processes are needed to kill the greatest number of seed. This study showed that ensiling redroot pigweed, common lambsquarters or wild buckwheat seed for 8 weeks reduced weed seed survival more than rumen digestion.

Both ensiling and rumen digestion reduced but did not eliminate the viability of flixweed, pennycress, kochia, pigweed, lambsquarters, wild buckwheat and round-leaved mallow. A few seeds remained viable in all treatments and could germinate in the field. Hard-seeded broadleaf weed seeds such as velvetleaf, field bindweed and common lambsquarters, were less likely to be killed by rumen digestion than other broadleaf seeds (Harmon and Keim 1934).

Recent research on the effects of manure handling on weed seed is limited, but earlier works add valuable insight. An early 1900 Maryland Extension Bulletin was one of the first to report the effects of animal digestion and manure handling on the vitality of weed seeds (Oswald 1908). Two sources of weed seeds in manure were studied: one was contaminated feed that passed through the animal, while the other source was seeds in the bedding which bypassed the animal. These seeds from 52 weed species were placed in piles of horse, cow, or a mixture of horse and cow manure. The temperature in the piles reached 201°F for horse manure, 168°F for cow manure, and 188°F for the mixture. After 60 days, the temperature of the manure pile cooled to the ambient temperature so the seeds were recovered and germination tests conducted. All seeds of all 52 weed species died at these temperatures in manure piles.

Oswald (1908) also reported on seeds of 21 species that were fed to 1-year-old dairy animals, with the manure managed in ways common at the time. When manure was hauled daily to fields and shallowly mixed with soil, 13% of the fed seeds germinated. The species that survived feeding were roundleaf mallow, jimsonweed, common ragweed, wild mustard, pepperweed, smart-weed, horse nettle, cockle and dock. If fresh manure was plowed into the soil, only 3% of fed seeds germinated. In modern containment systems, sediments from either solid separators or sedimentation ponds, may concentrate the weed seed in liquid manure, creating manure with very high numbers of viable weed seeds (Cudney *et al.* 1992) compared to that observed by Oswald.

In Idaho, Atkeson and colleagues (1934) assessed the impact of cattle digestion and subsequent manure storage on the viability of weed seeds. Milk cows were fed 2 quarts of weed seeds in a single day and the manure collected, mixed with straw to simulate barn manure, and stored for 3 months. Seeds passed through the animals for 4 days. Weeds with soft seed coats were more affected than those with hard seed coats. Digestion alone reduced the viability of wild oats, yellow sweet clover, broadleaf plantain and alfalfa by more than 80%, but had considerably less impact on green foxtail, common lambsquarters, curled dock, redroot pigweed and cow cockle. Add 3 months storage in manure, and very few viable weed seeds were found. Only pigweed, curled dock, lambsquarters, and cow cockle seed survived both digestion and manure storage. All seeds of the following species died: yellow sweet clover, buckthorn plantain, green foxtail, pennycress, dodder, wild oats, tumble mustard, and Russian thistle.

More recently, Mt.Pleasant and Schlather, (1994) collected manure from fresh droppings in the barn or from piles of manure just prior to application in the field on 20 dairy farms in upstate New York. They found apparently viable seed from 13 grass and 35 broadleaf weed species. Lambs-quarters seed was in the manure of more than half the farms, yellow foxtail in 35%, common chickweed and dandelion in 30%, and wild mustard, redroot pigweed, and barnyardgrass in 25%. One farm had 400,000 seeds per ton of manure, most of which were common lambsquarters seeds. Four farms had no weed seed in the manure and the rest averaged more than 75,000 seeds per ton of manure.

Applying 30 tons per acre of manure with 75,000 seeds per ton would increase the seedbank by 2.25 million seeds per acre. Is this a serious situation? This depends on the current number of weed seeds in the seed bank. Estimates of weed seed in trials in Wisconsin showed 15 million weed seed per acre, in which case, adding the typical manure in the New York study would increase the weed seed bank by 15%, a noticeable amount. In fields with high seed populations in the seedbank, this addition would be less noticeable. Conversely, this addition would result in dramatic increases in weed populations in relatively clean fields.

This New York study seems to contradict earlier reports leaving us with less assurance that ensiling, digestion and manure storage will greatly reduce or eliminate weed seed viability. Given that the New York work was conducted with current farming practices, one cannot discount the seriousness of weed seed contamination in manure in today's livestock systems. Earlier studies do, however, indicate that ensiling or passage through poultry does destroy many weed seeds.

An equally serious consideration is the introduction of new weed species. Velvetleaf became widely distributed in New York from feed grains purchased from the Mid-west in the 1970s. We believe the migration of velvetleaf northward in Wisconsin and Minnesota has primarily been the result of contaminated feeds.

Composting Manure

Composting is a biological process where the mechanical mixing of manure incorporates air into the manure pile, which in turn, stimulates the decomposition of manure to organic materials, such as humus. The effectiveness of composting manure as a means to kill weed seed depends on the temperature generated by the heating process, available moisture, and the species of weed seed present. Texas A&M scientists found that if composted manure with 35% moisture reached 120°F for three days, barnyard-grass, pigweeds and kochia seeds were killed (Wiese *et al.* 1998). Additionally, Johnsongrass seed was killed with three or more days of exposure at

Haubenschild digester barn and electrical generation building is shown above. Dennis Haubenschild (right) visits with field day tour participants.

Table 2. **Average cumulative weed seed germination for two seasons in a field assay when planted following 20 days storage in manure with or without anaerobic digestion. 2002 - 2004. St. Paul, MN.** (Katovich and Becker 2004).

Manure/Fertilizer Treatment	Germination by Weed Species (%)					
	Vele[a]	Colq	Rrpw	Lath	Gift	Wipm
Manure with anaerobic digestion	16	12	1	0	0	0
Manure without digestion	12	18	5	0	0	0
Untreated inorganic fertilizer control	14	11	4	0	0	0
LSD (P=0.05%)	NS[b]	NS	NS	NS	NS	NS

[a] Vele = velvetleaf, Colq = common lambsquarters, Rrpw = redroot pigweed, Lath = ladysthumb smartweed, Gift = giant foxtail, Wipm = wild proso millet. Mean of 4 reps of 100 seeds for each species. All seed were pretreated with rumen fermentation.
[b] NS = no significant difference.

160°F, but 7 days at 180°F was needed to kill field bindweed seeds. In contrast, they showed the importance of moist manure in seed death in that seeds of all species survived a 140°F temperature for 30 days if not mixed with manure but heated in dry air. Raising the dry air temperature to 160°F for three days killed all seeds except field bindweed. They concluded that composting will kill all weed seeds if the temperature is at least 180°F for longer than three days and that such compost would be safe to use on lawns, nurseries and agricultural land without fear of spreading weed seeds.

Work in Nebraska showed that moist compost killed cocklebur, morning-glory, pigweed, sunflower, velvetleaf, foxtail, smooth brome and shattercane faster and more completely than dry compost, in part due to increased compost temperatures when moist (Eghball and Lesoing 2000). In contrast to the Texas A&M study, the methods used in the Nebraska study were essentially those of on-farm composting comparing water added to dry composting. One week after weed seed placement, compost piles were turned. All seed in moist cattle manure were dead, while most seed in the dry dairy and dry beef manure were still alive.

Adding water to beef manure greatly enhanced the destruction of weed seeds. All weed seeds in the dry dairy manure eventually did die after 4- to 5-months of composting, with the exception that 14% of velvetleaf seed were still viable.

Some seed death occurred even though the temperature of dry compost windrows never exceeded 140°F, the temperature assumed necessary to kill weed seed. The authors concluded that composting that generates high temperatures (above 140°F) can destroy seed viability after only one turning and that keeping compost moist for most of the composting period reduces weed seed viability even though the critical temperature may not be reached. To put the benefits of composting into perspective, Chudney *et al.* (1992) noted the number of viable weed seed in California dairies was reduced from approximately 11,000 per ton to 300 to 4000 viable seed per ton through composting. They recommended that dairies compost longer than the typical 6 to 8 weeks, in deeper piles, and to add supplemental water to increase temperatures.

Based on these studies, we conclude that moist compost with temperatures above 140°F for two weeks should kill most weed seed. Some hard-seeded weeds such as velvetleaf and field bindweed would require temperatures in the range of 160 to 180°F and longer composting times to kill all seed.

Anaerobic Digesters

Confined animal operations are coming under increased regulatory pressure to manage animal manure in ways that minimize environmental problems and reduce odors. This has increased interest in anaerobic manure digestion. This process biologically converts manure under anaerobic conditions into an effluent with properties that differ from raw manure, produces methane, which can be converted into electricity, and greatly reduces manure odor.

A University of Minnesota study assessed the effect of anaerobic manure digestion on weed seed survival (Katovich and Becker 2004). In the fall of 2001 and 2002, seed of 6 weed species were subjected to rumen fermentation and a subset of seed placed in a plug-flow anaerobic digester for 20 days (the length of time for one batch of manure to pass through the digester), and another subset stored for the same time period in the manure collection pit before entering the digester. A field germination assay was conducted by removing sod from a long-term bluegrass area to expose bare ground. The retrieved seed and digested or non-digested manure were fall-applied to the bare ground at 6000 gallons/acre. A subset of weed seed not stored in manure was applied with inorganic N fertilizer as a control. Weed emergence was monitored for next two growing seasons.

Viability of weed seed used in this study ranged from 82% for wild proso millet to 99% for velvetleaf and germination ranged from 1 to 14% in preliminary tests. The rumen treatment appeared to have killed all the

Table 3. First- compared to second-season cumulative velvetleaf seed germination for two growing seasons after planting following 20 days of fall storage in manure with or without anaerobic digestion. 2002 - 2004. St. Paul, MN. (Katovich and Becker 2004).

	Cumulative velvetleaf germination (%)	
Manure / Fertilizer treatment	**First season**	**Second season**
Manure with anaerobic digestion	14	2
Manure without digestion	6	6
Untreated inorganic fertilizer control	9	6
LSD (0.05)	3	3

giant foxtail, wild proso millet, and ladysthumb smartweed seed, since none germinated in the inorganic fertilizer control (Table 2).

Some velvetleaf, common lambsquarters, and redroot pigweed survived the rumen treatment, but manure management did not alter germination of surviving seed compared to that of the inorganic fertilizer control. Temperatures in the anaerobic digester where the seed were placed ranged from 95 to 100°F, well below the 140°F required to kill weed seeds.

Although velvetleaf seed germination was not altered by digestion when averaged over the entire sampling period (Table 2), the rate of germination was accelerated with a higher percentage of digested velvetleaf germinating the first season compared to conventional manure or inorganic fertilizer treatments (Table 3). This may reduce velvetleaf problems in the future if emerged seedlings are effectively managed the first season since seed dormancy perpetuates annual weed problems. Velvetleaf seed appeared to be "primed" for germination as a result of anaerobic digestion.

Anaerobic manure digestion did not kill or reduce germination of weed seeds in this study, however, this process clearly reduced odor and generated sufficient electricity through methane conversion to not only run the operation, but also with excess electricity to sell. The possibility that anaerobic digestion might kill seed in spilt-feed was not tested, since all seed were exposed to rumen digestion.

Contrast this with results of research in the Czech Republic (Sarapatka *et al.* 1993) where weed seeds of eight species were placed at two depths in simulated anaerobic digester tanks for approximately 30 days (Table 4). Passage through dairy cows did not kill all weed seeds of any species but effectively reduced viability of lambsquarters and barnyardgrass. Some weed seeds at the16-inch depth survived digestion but no viable seeds were found at the 70-inch depth near the bottom of the tank. These differences were attributed in part to higher initial temperatures at the 70-inch depth.

Jeyanayagam and Collins (1984) compared weed seed survival in batch and daily-fed 3-liter jar simulated digesters maintained at 95°F. After simulated rumen treatment followed by 15 to 20 days in a digester, weed seed viability of Johnsongrass dropped 18 and 82% and fall panicum dropped 24 and 76% for dormant and non-dormant seed, respectively. Anaerobic digestion killed roughly 3- to 5-times more non-dormant seed than dormant seed.

The three anaerobic digester studies differed significantly in design: the first used an operational flow through digester but placed seed artificially at a mid-depth at the end of flow; the second used a batch digester with initial higher temperatures in the bottom layers which all weed seed may not be exposed to; and the third study, simulated digestion and used only grass species, which often have seeds

Table 4. Weed seed viability when seeds were fresh, after passage through milking cows, and after one-month fermentation at two depths in a methane generator (Sarapatka et al. 1993).

			After digester[a]	
Plant species	**Fresh**	**After passage**	**16" deep**	**70" deep**
	Germination[b] (%)			
Barnyardgrass	94	5	36	0
Quackgrass	96	13	0	0
Wild oat	88	N/A	0	0
Lambsquarter	90	3	9	0
Pigweed	74	13	4	0
Pennycress	98	35	0	0
Smartweed	91	50	0	0
Curly dock	96	91	19	0

[a] Temperatures of 86° F at 16" and 113 to 122° F gradually declining to 86°F at 70".
[b] Though authors labeled as germination, appears to be viability, the sum of germination following repeated stratification and seeds that did not germinate but remained firm to the touch.

that are easier-to-kill compared to broadleaf species. Regardless, in all three anaerobic digestion studies significant numbers of weed seed survived which, when scaled up to field-scale operations, would pose a risk of increased weed problems in the field.

Summary

Avoid feed high in weed content. Livestock vary on the effect their digestion has on weed seeds, but all decrease weed seed viability. Well executed composting destroys most weed seeds. Weed species with hard seed coats like field bindweed and velvetleaf present the greatest risk of surviving composting. However, if the compost is moist, reaches the desired temperature, and completes its full cycle of decomposition, even seeds of these species are killed. Anaerobic digesters offer significant benefits in odor reduction and power generation, but will not offer the complete kill of weed seed afforded by well executed composting. Still, if the weed content of feedstock is known, particularly if produced on the same land where manure will be utilized, the benefits of anaerobic digesters in odor reduction and power generation likely outweigh the risks of potential survival of weed seed and resultant potential for increased weed pressure in the field.

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Acknowledgments

Thanks to the USDA NRCS EQIP program for partial funding of this anaerobic digester weed seed research. Thanks to Haubenschild Farms for their kind assistance and use of their facilities. Thanks to Dr. Jerry Doll, University of Wisconsin, for laying the groundwork for this publication and graciously sharing his knowledge.

San Joaquin Valley Air Pollution Control District
Authority to Construct
Application Review
New Dairy

Facility Name:	Brothers Farms, LLC	Date:	January 22, 2008
Mailing Address:	4070 Ave 256	Engineer:	Juscelino Siongco
	Tulare, CA 93274	Lead Engineer:	Martin Keast
Contact Person:	Eric Westra		
Telephone:	(559) 688-7688		
Application #s:	S-6918-1-0, -2-0, -3-0, -4-0, and -5-0		
Project #:	S-1063789		
Deemed Complete:	July 27, 2007		

I. Proposal

Brothers Farms, LLC has requested Authority to Construct (ATC) permits to expand their existing 2,850 milking cow (5,135 total head) dairy operation to 5,410 milk cows (11,995 total head). The dairy expansion is located on 122 acres of a 1,028-acre site SW of Ave 256 & Rd 36 in Tulare County.

The Westra Family owns and operates two existing dairies that are contiguous or adjacent to the proposed dairy expansion. Westhill Dairy (S-5346) is a 900 milking cow (1,200 total head) dairy operation and Richard Westra Dairy (S-5348) is a 1,950 milking cow (3,935 total head) dairy operation. Per section 3.37 of District Rule 2201, the District considers Westhill Dairy and Richard Westra Dairy, and the proposed expansion, Brothers Farms dairy, as one stationary source.

Brothers Farms proposes to add an additional 6,860 head consisting of 2,560 milk cows, 512 dry cows, 1,690 large heifers (15-24 months), 1,014 medium heifers (7-14 months), 853 small heifers (4-6 months), and 231 calves (under 3 months) (4,913 animal units, AU). The expansion dairy will construct a milk barn equipped with one 80 stall double parallel milking center; flushed freestall barns to house milk cows and dry cows, construct shaded open corrals with flush system to house heifers. Calves will be housed in individual calf hutches. The liquid manure handling system will consist of a processing pit, six weeping walls solid separation system, and a two-stage anaerobic treatment lagoon system designed in accordance with the NRCS Conservation Practice Standard Code 359–Waste Treatment Lagoon. The dairy will construct hay barns, commodity barns, and silage stacking slabs for the storage of animal feed. Additionally, the mitigation measures that the applicant has selected to comply with District Rule 4570 will be incorporated into the ATCs for the expansion dairy.

The proposed herd composition is equal to approximately 4,913 Animal Units (1,400 lb AU), which is below the limit of 4,989 AU allowed at this site by the Tulare County Special Use Permit No PSP-99-121 (see Appendix A for AU calculations).

The expansion dairy of 6,860 head will result in PM_{10}, VOC, and NH_3, emissions at the site.

The project triggers the public notice requirements of District Rule 2201. Therefore, the preliminary decision for the project will be submitted to the California Air Resources Board (CARB), a public notice will be published in a local newspaper of general circulation in the county of the project, and a 30-day public comment period will be completed prior to issuance of the ATCs.

The expansion dairy is a discretionary project subject to the requirements of the California Environmental Quality Act (CEQA). As a responsible agency, the District must decide on the adequacy of the environmental documents prepared by the Lead Agency, Tulare County, make appropriate findings, and file the required notices. The District has determined that the Environmental Impact Report (EIR) (State Clearinghouse (SCH) No. 2000-011046) prepared by Tulare County adequately addresses environmental concerns resulting from the project. The District has also made appropriate findings regarding the project, which are attached as Appendix F of this evaluation. The District will file a Notice of Determination with Tulare County upon issuance of the Authority to Construct (ATC) permits.

II. Applicable Rules

Rule 1070	Inspections (12/17/92)
Rule 2010	Permits Required (12/17/92)
Rule 2201	New and Modified Stationary Source Review Rule (9/21/06)
Rule 2520	Federally Mandated Operating Permits (6/21/01)
Rule 2550	Federally Mandated Preconstruction Review for Major Sources of Air Toxics (6/18/98)
Rule 4101	Visible Emissions (2/17/05)
Rule 4102	Nuisance (12/17/92)
Rule 4550	Conservation Management Practices (CMP) (8/19/04)
Rule 4570	Confined Animal Facilities (CAF) (6/15/06)
CH&SC 41700	Health Risk Assessment
CH&SC 42301.6	School Notice

Senate Bill 700 (SB 700)
California Environmental Quality ACT (CEQA)

III. Project Location

The facility is located at SW of Ave 256 & Rd 36, (Section 29, Township 19S, Range 23E), CA in Tulare County.

This dairy is not located within 1,000 feet of the outer boundary of a K-12 school. Therefore, the public notification requirement of California Health and Safety Code 42301.6 is not applicable to this project.

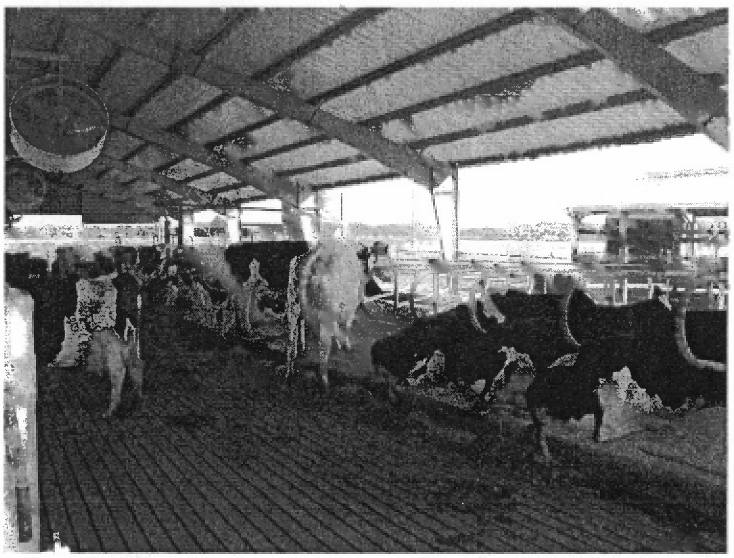
IV. Process Description

The primary function of Brothers Farms, LLC dairy is the production of milk, which is used to make dairy products for human consumption. Production of milk requires a herd of mature dairy cows that are lactating. In order to produce milk, the cows must be bred and give birth. The gestation period for a cow is 9 months, and dairy cows are bred again 4 months after calving. Thus, a mature dairy cow produces a calf every 12 to 14 months, which is why there will be different ages and types of cows at the dairy, including calves, heifers, dry cows, and lactating cows. This dairy does not have mature bulls.

The milk cows at a dairy usually generate anywhere from 130 to 150 pounds of manure per day. Manure accumulates in confinement areas such as barns, open corrals (dry lots), and the milking center. Manure is primarily deposited in areas where the herd is fed and given water. How the manure is collected, stored, and treated depends directly on the manure management techniques used at a particular dairy. Dairy manure is collected and managed as a liquid, a semi-solid or slurry, and a solid. Manure with a total solids or dry matter content of 20% or higher usually can be handled as a solid while manure with a total solids content of 10% or less can be handled as a liquid.

Cow Housing

Milk cows and dry cows at this dairy are housed in freestall barns with flushed lanes. In a freestall barn, the cows are grouped in large pens with free access to feed bunks, water, and stalls for resting. A standard freestall barn design has a feed alley in the center of the barn separating two feed bunks on each side. The dry cows and heifers are housed in open corrals with flushed lanes. An open corral is a large open area where cows are confined with unlimited access to feed and water. Open corrals at this dairy include structures that provide shade for the animals. The open corrals for the heifers will include sprinklers for dust control. Calves will be housed in individual calf hutches at the dairy.



Freestalls and Concrete Feed lane

Special Needs Housing

The special needs area serves the gestating cows at the dairy or any cows that are in need of medical condition. This area acts as a veterinary area. It is also the area in which cows are given special attention as they progress from dry cow, a mature cow that is gestating and not lactating, to maternity, to milking status or until their health improves.

Milking Parlor

The milking parlor is a separate building, apart from the lactating cow confinement. The milking parlor is designed to facilitate changing the groups of cows milked and to allow workers access to the cows during milking. A holding area confines the cows that are ready for milking. The holding area is covered with open sides and is part of the milking parlor, which in turn, is located in the immediate vicinity of the cow housing. The cows at this dairy are milked in one double 40 parallel 80-stall milking parlor. The lactating cows will be milked two to three times per day in the milking parlor. The milking parlor will have concrete floors sloped to a drain. Manure that is deposited in the milking parlor will be sprayed or flushed into the drain using fresh water after each milking. The effluent from the milking parlor will be carried through pipes to the lagoon system.

Processing Pit (Lift Station)

The dairy will have one processing pit. A processing pit is a small basin that temporarily stores the flush water from the milking parlor and the corral flush system. The processing pit allows this water to be reused to flush the concrete feed lanes in the corrals. After each flush, the flush water, including the waste from the feed lanes, is returned to the processing pit to be recycled in the next flush. As the volume of flush water in the processing pit increases, pumps and agitators are turned on. The agitators mix the contents in the processing pit so that the solids in the processing pit do not settle. The stored flush water is then pumped to the mechanical separators to remove the fibrous and heavy solids prior to the treatment lagoon. This is done daily or several times a day to prevent excessive solids buildup and to ensure that the water used for flushing the corral feed lanes is relatively clean. The processing pit decreases the amount of piping and energy required by recycling the flush water and pumping water from a central location.

Solids Separation (Weeping Walls)

The liquid manure handling system at this facility will include six weeping walls for solids separation. The flushed liquid manure will be pumped to the weeping walls for solids separation. Weeping walls are structures designed to separate solids from liquid manure by retaining the fibrous solids in a basin that is designed so that a screen or boards with slots in between serve as a perforated wall. The inflow of liquid manure is restricted as fibrous solids accumulate at the screen or slots and other solids settle out. The liquid manure entering a weeping wall slowly drains through the retained solids until the liquid reaches the screen or slots, which act as a dewatering face. The liquid then slowly drains ("weeps") through the screen or the slots between the boards while the solids are retained in the basin. The liquids from the weeping walls will gradually drain to the treatment lagoons. Solids remaining in the weeping walls are removed after they have become sufficiently dry. The separated solids from the weeping walls will either be immediately incorporated into cropland or dried and stored for use as fertilizer or as bedding in the freestalls.

Solids separation removes material from the waste stream that would prematurely fill a lagoon or storage pond. A weeping wall may achieve a solids removal rate of 40-70%. The efficiency of treatment would decrease without separation, resulting in more odors and potentially more VOC emissions from the liquid manure handling system. Most of the separated solids are fibrous material that leads to excessive sludge buildup or the formation of crusts on the surface of the storage ponds, both of which interfere with pumping operations. Separation reduces the land area required when designing a liquid manure treatment system since the volume to be treated is less. As a final benefit, the separated solids may be recycled and used for composting, soil amendments, re-feeding, bedding, etc.

Manure Stock Piles (Storage)

Separated solids from the mechanical separator are the only solid manure that will be stockpiled at this dairy. The solid waste removed from the pens or corrals will be removed from the facility within 72 hours. Once the separated solids are dry, the applicant will remove the separated solids weekly from the facility.

Anaerobic Treatment Lagoon

An anaerobic treatment lagoon is a waste treatment lagoon that is designed to facilitate the decomposition of manure by microbes in the absence of oxygen. This process of anaerobic decomposition results in the preferential conversion of organic compounds in the manure into methane, carbon dioxide, and water rather than intermediate metabolites (VOCs). The National Resource Conservation Service (NRCS) California Field Office Technical Guide Code 359–Waste Treatment Lagoon specifies the following criteria for anaerobic treatment lagoons:

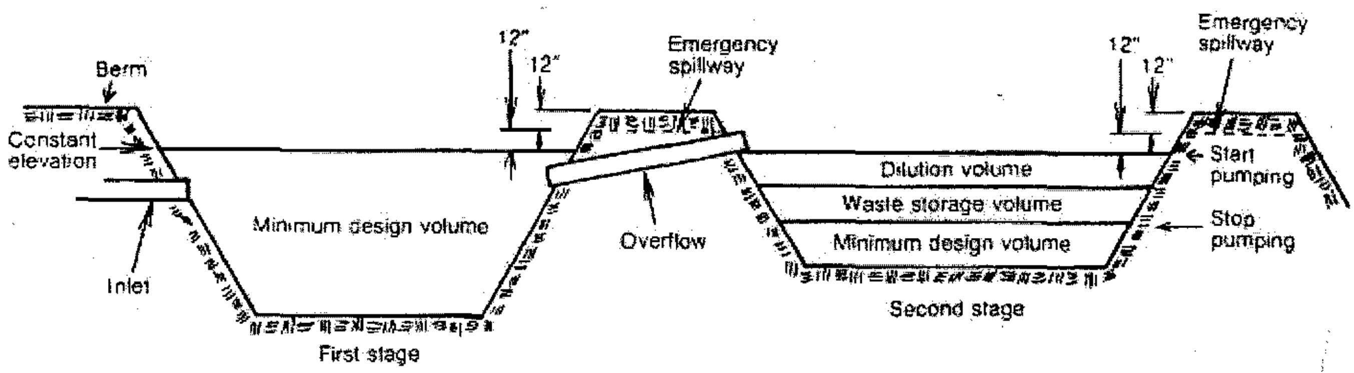
1) Minimum treatment volume – The minimum design volume must account for all potential sludge, treatment, precipitation, and runoff volumes;

2) Minimum hydraulic retention time – The retention time of the material in the lagoon must be adequate to provide environmentally safe utilization of waste;

3) Maximum Volatile Solids (VS) loading rate – The VS loading rate shall be based on maximum daily loading considering all waste sources that will be treated by the lagoon. The suggested loading rate for the San Joaquin Valley is 6.5-11 lb-VS/1000 ft^3/day depending on the type of system and solids separation; and

4) Minimum operating depth of at least 12 feet – Maximizing the depth of the lagoon has the following advantages: 1) The surface area in contact with the atmosphere is minimized, which will reduce volatilization of air pollutants; 2) The smaller surface area reduces the effects of the environment on the lagoon, which provides a more stable and favorable environment for anaerobic bacteria; 3) There is better mixing of lagoon due to rising gas bubbles; 4) and A deeper lagoon requires less land for the required treatment volume.

The liquid manure handling system for the proposed dairy will have one storage anaerobic treatment lagoon system designed in accordance with the specifications set forth in NRCS practice standard 359. The anaerobic treatment lagoon system consists of two stages, a treatment lagoon (primary lagoon) and a storage pond (secondary lagoon). The effluent from the treatment lagoon (480 ft x 300 ft x 18 ft) overflows into the storage pond/secondary lagoon (560 ft x 485 ft x 20 ft), which is designed for liquid storage. The liquid level of the storage pond/secondary lagoon fluctuates and can be emptied when necessary. Effluent from the storage pond is used for the irrigation of cropland. All the liquid manure at the dairy is pumped to the anaerobic treatment lagoon system.



Storage Pond/Secondary Lagoon

The dairy will have one 560' X 485' X 20' storage pond designed for temporary collection and storage of organic waste. Storage ponds are designed to have a storage period of about 90 to 180 days and may be completely emptied when pumped. As stated above, the storage ponds/secondary lagoon sat this dairy will be part of a two-stage anaerobic treatment lagoon system. Storage ponds are designed to have sufficient volume to hold all of the following: all manure and wastewater accumulated at the dairy for a period of 120 days; normal precipitation and any drainage to the lagoon system minus evaporation from the surface of lagoons; and precipitation during a 25 year, 24 hour storm event.

Covered Lagoon Anaerobic Digester

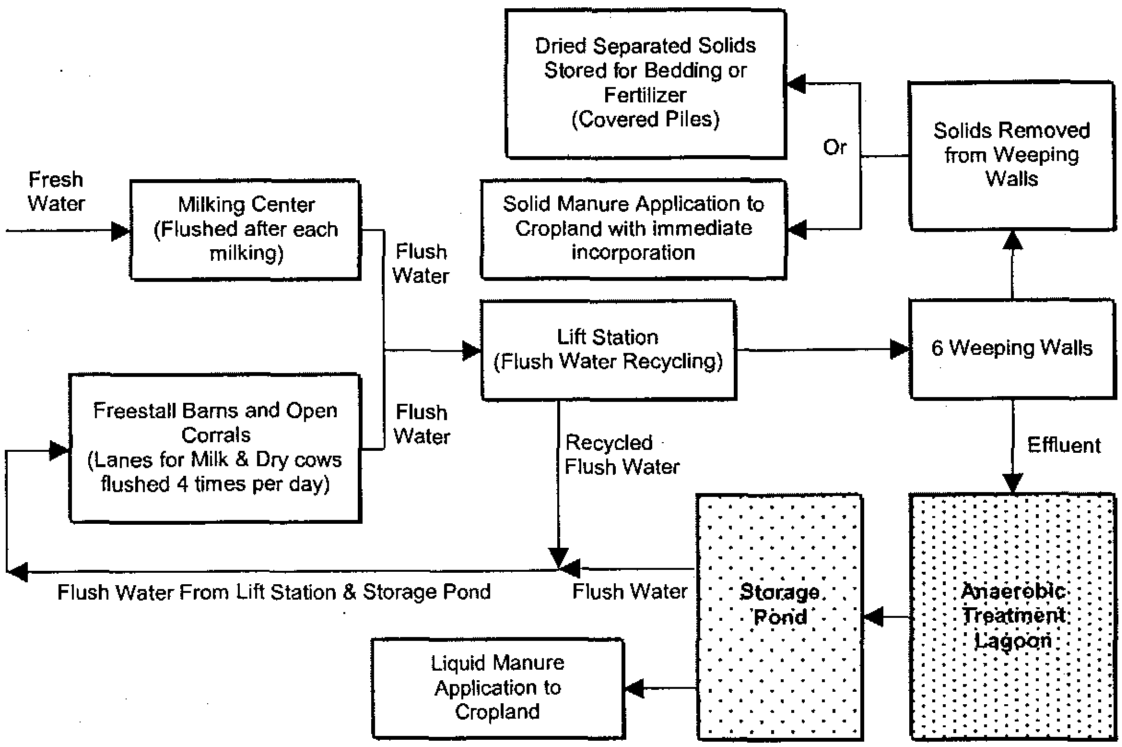
Pursuant to Section 5.3 of the Settlement Agreement (9/20/2004) between the District and the Western United Dairyman and the Alliance of Western Milk Producers Inc, installation of an anaerobic digester will only be required if this technology is proven effective in reducing emissions and is required by the final Dairy BACT Guideline[1]. The applicant has agreed to install a lagoon cover over the treatment lagoon or storage pond if it is required. The applicant will redesign the lagoon system, if required, so that it can be retrofit with a cover and converted to a covered lagoon digester meeting the specifications set forth in NRCS practice standard 365 - Anaerobic Digester - Ambient Temperature. The biogas generated by the lagoon will be captured by a relatively airtight lagoon cover. The captured biogas could then be cleaned to remove H_2S and other impurities, upgraded, and routed into a natural gas pipeline. If it is not feasible for the facility to route the biogas into a natural gas pipeline, the biogas can be used to

[1] Settlement Agreement. Western United Dairymen, Alliance of Western Milk Producers v. San Joaquin Valley Air Pollution Control District, settled in the Fresno Superior Court September 2004 (http://www.valleyair.org/busind/pto/dpag/settlement.pdf)

generate useful heat or electrical energy by sending the gas to a boiler or internal combustion engine that is equipped with emission controls to minimize combustion contaminants. If an anaerobic digester is required by the final Dairy BACT Guideline, the applicant shall submit the details of the proposed covered lagoon anaerobic digester system and combustion device to the District and shall install the system in accordance with the timeframes and procedures established by the APCO in the Dairy BACT Guideline.

<u>Schematic of Manure and Wastewater Flow</u>

The following schematic shows how the manure and flushed wastewater will travel throughout the proposed dairy:



V. Equipment Listing

S-6918-1-0: 2,560 COW MILKING OPERATION WITH ONE DOUBLE 40 STALL (80 STALLS) PARALLEL MILKING PARLOR

S-6918-2-0: COW HOUSING – 2,560 MILK COWS HOUSED IN 5 FREESTALL BARNS (2,160 HOUSED IN 4 FREESTALLS AND 400 IN 1 FREESTALL) WITH FLUSH SYSTEM, AND 512 DRY COWS HOUSED IN 2 FREESTALL BARNS (270 IN 1 FREESTALL AND 242 IN 1 FREESTALL) WITH FLUSH SYSTEM; 1,690 LARGE HEIFERS (15-24 MONTHS), 1,014 MEDIUM HEIFERS (7-14 MONTHS), AND 853 SMALL HEIFERS (4-6 MONTHS) HOUSED IN OPEN CORRALS WITH SHADE STRUCTURES AND FLUSH SYSTEM; 231 CALVES (UNDER 3 MONTHS) HOUSED IN INDIVIDUAL ABOVE GROUND CALF HUTCHES WITH

FLUSH SYSTEM; INCLUDING SPECIAL NEEDS HOUSING. ALL OPEN CORRALS SCRAPED

S-6918-3-0: LIQUID MANURE HANDLING SYSTEM CONSISTING OF 6 WEEPING WALLS (80X76X7 EACH), 1 ANAEROBIC TREATMENT LAGOON (480X300X20) AND 1 STORAGE POND (560X485X20). MANURE IS LAND APPLIED THROUGH FLOOD IRRIGATION AND FURROW IRRIGATION

S-6918-4-0: SOLID MANURE HANDLING CONSISTING OF COVERED MANURE STOCK PILES WITH MANURE HAULED OFFSITE.

S-6918-5-0: FEED STORAGE AND HANDLING CONSISTING OF COMMODITY BARNS AND SILAGE PILES

VI. Emission Control Technology Evaluation

PM_{10}, VOC, and NH_3 are the major pollutants of concern from dairy operations.

Gaseous pollutant emissions at a dairy result from the ruminant digestive processes (enteric emissions), from the decomposition and fermentation of feed, and also from decomposition of organic material in dairy manure. Volatile Organic Compounds (VOCs) are formed as intermediate metabolites when organic matter in manure degrades. Ammonia volatilization is the result of the microbial decomposition of nitrogenous compounds in manure. The quantity of enteric emissions depends directly on the number and types of cows. The quantity of emissions from manure decomposition depends on the amount of manure generated, which also depends on the number and types of cows. Therefore, the total herd size and composition is the critical factor in quantifying emissions from a dairy.

Various management practices are used to control emissions at this dairy. Some of these practices include frequent flushing, frequent scraping of open corrals, and removal of manure from paved areas such as the milk parlor, feed lanes, and walkways.

Milking Parlor (S-6918-1)

This dairy uses a flush/spray system to wash out the manure from the milking parlor after each group of cows is milked. Since the milking parlor is constantly flushed, there will be no particulate matter emissions from the milking parlor. Manure, which is a source of VOC emissions, is removed from the milking parlor many times a day by flushing after each milking. Because of ammonia's high affinity for and solubility in water, volatilization of ammonia from the milking parlor will also be reduced by flushing after each milking.

Cow Housing and Feed (S-6918-2 and S-6918-5)

The milk and dry cows at this dairy will be housed in freestall barns with concrete lanes. Particulate matter emissions from freestall barns are greatly reduced because the cows will be on a paved surface rather than on dry dirt. Additionally, flushing of the freestall lanes creates a moist environment, which further decrease particulate matter emissions.

All of the heifers will be housed in open corrals with concrete lanes and shade structures. Providing shade for the animals reduces movement and unnecessary activity during hot weather, which reduces PM_{10} emissions. The surfaces of the exercise corrals will be scraped in the morning hours on a weekly basis except during wet conditions. Frequent scraping of the corrals will reduce the amount of dry manure on the corral surfaces that may be pulverized by the cow's hooves and emitted as PM_{10}. This practice will also reduce the chance of anaerobic conditions developing in the manure pack of the corral surface, potentially reducing VOC emissions.

The freestall lanes and walkways for milk and dry cows will be flushed four times per day, and the open corral lanes and walkways for all the heifers will be flushed twice per day to remove manure, which is a source of emissions. Because of ammonia's high affinity for and solubility in water, flushing the freestall and open corral lanes and walkways will also reduce volatilization of ammonia from the manure deposited in the lanes.

All animals housed at this dairy will be fed in accordance with National Research Council (NRC) guidelines using routine nutritional analysis for rations. Feeding the cows in accordance with NRC guidelines minimizes undigested protein and other undigested nutrients in the manure, which would emit NH_3 and VOCs upon decomposition. Refused feed will be removed from the feed lanes on a daily basis to minimize gaseous emissions from decomposition. The surface area of silage exposed to the atmosphere will be minimized by enclosing silage or covering it with tarps, except for the face of the pile where feed is being removed.

Windbreaks/shelterbelts are single or multiple rows of trees in linear configurations planted on the windward or downwind side of a given site. The windbreaks are proposed in accordance with the National Research Conservation Service (NRCS) standard #380. Guidelines from this standard in conjunction with guidelines discussed with the local NRCS office are summarized as follows:

- Windbreak density on the leeward side of the source and windward of the area to be protected should be at least 65%. This density will provide the optimum PM interception. "Density", when viewing through the windbreak from 60 feet to 100 feet away upwind of the rows, is the percentage of the background view that is obscured or hidden.
- In order to reach a density of 65%, three rows are required consisting of the following:

Row	Type of tree/shrub	Spacing[2]	Height
First Row	Low shrubs Tall shrubs	3' to 6' apart 8' to 12' apart	5' +
Second Row	Tall shrubs or medium size trees	8' to 12' apart	8'-25'
Third Row	Large Evergreens	Varies	35' +

- Spacing between rows should be sufficient to accommodate cultivation equipment.
- Windbreaks should be irrigated to provide the greatest survivability and the most rapid growth of the trees and shrubs.
- Weed control in the windbreak must be completed as well as rapid replacement of any dead tress or shrubs.

[2] These are general spacing requirements and vary depending on type of tree.

- Each row should plant trees that are offset of one another.

A downwind windbreak/shelterbelt will be established as follows:

The applicant has proposed to plant one row of tall shrubs (Xylosma), one row of a medium size trees (Arizona Cypress) and one row of an evergreen (Chinese Pistache). The applicant will maintain an irrigation system for greater survivability and rapid growth of the trees and shrubs. The following conditions will be placed on the permit:

Permittee shall establish windbreaks along 2,267 ft of the East boundary and 2,688 ft of the South boundary of the dairy. Windbreaks shall consist of the following rows with the first row closest to the dairy: first row shall consist of Xylosma shrubs, planted 6 feet apart; the second row shall consist of Arizona Cypress tree, planted 10 feet apart, and the final row shall consist of Chinese Pistache tree, planted 14 feet apart. Each row should be offset from the adjacent row. Spacing between rows shall be sufficient to accommodate cultivation equipment. This spacing shall not exceed 20 feet. Any alternative windbreak proposal must be approved by the District. [District Rule 2201]

Trees and shrubs that are initially planted as part of the windbreak shall have a minimum container size of five gallons. [District Rule 2201]

Windbreaks shall be irrigated and maintained for survivability and rapid growth. Dead trees and shrubs shall be replaced as necessary to maintain a windbreak density of 65%. [District Rule 2201]

Density is the percentage of the background view that is obscured or hidden when viewing through the windbreak from 60 ft to 100 ft upwind of the rows. [District Rule 2201]

In addition, the applicant has proposed to sprinkle water over 49% of area of the heifer corrals to match the evaporation rate. By applying water at appropriate rates, a significant amount of PM_{10} emissions reductions can be achieved. Water application has to be strictly controlled since excess water has the potential of forming VOC and ammonia emissions. In addition, application of water in corrals may pose a health risk for the animals. The following conditions will be placed on the permit:

Permittee shall sprinkle water over 49% of area of the heifer corrals. Sprinkling rate shall match the wet soil evaporation rate (70-80% of the local pan evaporation rate) to keep sufficient moisture content in the surface of the corrals. [District Rule 2201]

Sprinkling shall be performed as such so that there is no standing water on the corrals. [District Rule 2201]

Sprinklers shall be designed to spray the corrals uniformly to prevent inconsistent distribution of water. [District Rule 2201]

Permittee shall determine the moisture content of at least one of the corrals on a monthly basis from April to October and once every two months from November to March. Two samples should be taken from the corral, one at the midpoint of the sprinkler spray arc or if multiple sprinklers then at the driest mid point of any of the arcs, and the second farthest from the sprinklers. Successive moisture sampling shall be performed on alternate corrals (e.g., first month - sample corral 1, second month - sample corral 2, etc.). Samples shall be performed by an independent party. [District Rule 2201]

Moisture content shall be determined by an independent lab using the Test Method for the Examination of Compost and Composting (TMECC) Method 3.09, ASTM Test Method for moisture content, D-4643, or any other alternative test method approved by the APCO. [District Rule 2201]

Permittee shall maintain records of 1) daily local evaporation rate/soil evaporation rate, 2) the amount of water (inches or cm) applied to the corral surface, and 3) records of the required moisture content samples including the date the samples were taken. Records of sprinkler run time and flow rate may be used to satisfy item 2. [District Rule 2201]

Liquid Manure Handling System (S-6918-3)

All emissions from the liquid manure handling system are the result of manure decomposition. Because of the amount of liquid manure being flushed to the liquid manure handling system, there will be emissions from the liquid manure handling system.

The liquid manure handling system will consist of a two-stage anaerobic lagoon treatment system designed in accordance with the specifications set forth in NRCS practice standard 359. A properly designed and operated anaerobic treatment lagoon system will reduce VOC emissions because the organic compounds in the manure will be mostly converted into methane, carbon dioxide, and water rather than a significant amount of VOCs. A two-stage anaerobic treatment lagoon system also has an air pollution benefit over single lagoon systems. Odorous emissions are reduced with a two-stage system since the primary lagoon has a constant treatment volume, which promotes more efficient anaerobic digestion. The proposed anaerobic treatment lagoon meets the design requirements (see design check in Appendix B).

Solids Separation

The liquid manure handling system is equipped with six weeping walls for solids separation. Solids separation prevents excessive loading of volatile solids in lagoon treatment systems. Excessive loading of volatile solids in lagoons inhibits the activity of the methanogenic bacteria and leads to increased rates of volatile solids production. When the activity of the methanogenic bacteria is not inhibited, most of the VOCs are metabolized to simpler compounds, and the potential for VOC emissions is reduced. The separated solids piles from the mechanical separators will be removed from the stacking pad at least once a week.

Liquid Manure Land Application

Liquid manure from the storage pond will be applied through flood and furrow irrigation. The dairy will apply liquid manure to cropland at agronomic rates. Liquid manure will be applied in thin layers and will be blended with irrigation water in compliance with the dairy's comprehensive nutrient management plan and the requirements of the Regional Water Quality Control Board. These practices will reduce odors and result in faster uptake of nutrients, including organic nitrogen, which can emit VOCs and ammonia during decomposition, and ammonium nitrogen, which is readily lost to the atmosphere as gaseous ammonia.

VII. General Calculations

A. Assumptions

- Potential to Emit for the dairy will be based on the maximum design capacity of the number and types of cows at the dairy.
- Only emissions from the lagoons/storage ponds (Permit # S-6918-3) at the dairy will be used to determine if the facility is a major source since these units are considered to be the only sources of non-fugitive emissions at dairies.
- 2,560 milk cows, 512 dry cows are housed in freestall barns with flushed lanes. 1,690 heifers (15-24 months), 1,014 heifers (7-14 months), 853 heifers (4-6 months) are housed in open corrals with flushed lanes. 231 calves will be housed in above ground flushed calf hutches.
- The weeping walls will remove at least 50% of the volatile solids prior to the manure entering the anaerobic treatment lagoon.
- All PM_{10} emissions from the dairy will be allocated to the cow housing permit unit (S-6918-2).
- The following PM_{10} control efficiencies will be applied: downwind shelterbelts = 12.5%, Shade Structures for heifers = 8.3%, weekly scraping of manure using a pull-type manure harvesting = 15%, and feeding stock (heifers) near dusk = 10%, water sprinklers in open corrals = 25%[3].
- Because of the moisture content of the separated solids, PM_{10} emissions from solid manure handling are considered negligible.
- The PM_{10} emission factors for the dairy animals are based on a District document entitled "Dairy and Feedlot PM_{10} Emissions Factors", which compiled data from studies performed by Texas A & M ASAE and a USDA/UC Davis report quantifying dairy and feedlot emissions.
- The VOC and NH_3 emission factors for milk cows are based on an internal document entitled "*Breakdown of Dairy VOC Emission Factor into Permit Units*". The VOC and NH_3 emission factors for the other cows were developed by taking the ratio of manure generated by the different types of cows to the milk cow and multiplying it by the milk cow emission factor.
- For BACT analysis purposes, each permit unit at a dairy will also be treated as an emissions unit, except for the liquid manure handling permit unit. For BACT analysis purposes, the liquid manure handling permit unit will contain two emissions units: lagoons/storage ponds and liquid manure land application.

[3] The District is currently applying a 50% PM_{10} control efficiency for sprinkling of the corrals as long as the amount of water applied meets the evaporation rates and 100% of the corral area is being covered by the sprinklers. The applicant has proposed to sprinkle water over 49% of the corral area, which matches the evaporation rate. Therefore, a control efficiency of 25% will be applied (CE of 50% x 49% = 25%).

- Feeding animals in accordance with the National Research Council (NRC) guidelines is a feed formulation practice used to improve animal health and productivity. This typically limits the overfeeding of certain feed that have the potential of increasing emissions. This mitigation measure has the potential of reducing a significant amount of emissions, however, since there is not much data available, a conservative control efficiency of 5% will be applied to the overall dairy EF.

- Flushing or hosing down the milking parlor immediately after each milking has the potential of reducing a significant amount of emissions since many of the compounds emitted from the fresh manure, such as alcohols (ethanol and methanol) and many Volatile Fatty Acids (VFAs), are highly soluble in water and the fresh excreted manure is almost immediately flushed out of the milk barn. However, a conservative control efficiency estimate of 75% will be applied at this time. This control efficiency does not apply to the enteric emissions generated from the cows themselves. Taking that into account, the overall control efficiency for the milk barn is approximately 16.7%. (EF from milk barn is = 0.9 lbs/hd-yr. EF from fresh waste is equal to 0.2 lbs/hd-yr. 75% of 0.2 lbs/hd-yr = .15 lbs/hd-yr. 0.15 lbs/hd-yr/0.9 lbs/hd-yr = 16.7% control).

- Flushing the feed lanes for milk cows and dry cows four times per day is expected to reduce emissions since manure degradation and decomposition in the feed lanes is reduced. Increasing the frequency of the flush will remove manure, which is a source of VOC emissions. Many of the compounds emitted from the fresh manure, such as alcohols (ethanol and methanol) and many Volatile Fatty Acids (VFAs), are highly soluble in water. Based on calculations in the Final Dairy Permitting Advisory Group's (DPAG) Report - "Recommendations to the San Joaquin Valley Air Pollution Control Officer Regarding Best Available Control Technology for Dairies in the San Joaquin Valley" dated January 31, 2006 (http://www.valleyair.org/busind/pto/dpag/dpag_idx.htm), a 47% control will be applied to flushing the corral lanes four times per day, until better data becomes available. This control efficiency only applies to the manure and does not apply to the enteric emissions generated from the cows themselves. Taking that into account, the overall control efficiency for the cow housing is approximately 18.2%. (Milk Cow EF from cow housing is = 12.4 lbs/hd-yr. EF from fresh waste is equal to 4.8 lbs/hd-yr. 47% x 4.8/12.4 lbs/hd-yr = 18.2% control)

- An anaerobic treatment lagoon designed in accordance with the NRCS Guideline (359) has the potential of reducing significant amount of emissions, since the system is designed to promote the conversion of Volatile Solids (VS) into methane by methanogenic bacteria. Although VOC emission reductions are expected to be high, to be conservative, a control efficiency of 40% will be applied to this mitigation measure for both the lagoon(s) and land application until better data becomes available.

- All other mitigation measures required are expected to result in VOC emission reductions, however, lacking emissions reductions data, the emissions reductions will not be quantified in this evaluation.

- Many of the mitigation measures required will also have a reduction in ammonia emissions, however, due to limited data, these reductions will not be quantified in this evaluation.

B. Emission Factors

DAIRY PERMITS (S-6918-1, -2, -3, AND -4)

The following emission factors PM_{10}, VOC, and NH_3 will be used to calculate the emissions from the dairy from the following permit units: the milking parlor (permit S-6918-1); the cow housing (permit S-6918-2); the liquid manure handling system (permit S-6918-3); and the solid manure handling system (permit S-6918-4).

PM_{10} Emission Factors for the Dairy

The following tables list the PM_{10} emission factors for the animals at the dairy. The control efficiencies for the different management practices proposed for this dairy will be applied to the uncontrolled emission factors to arrive at the controlled emission factors that will be used to calculate post-project PM_{10} emissions from the dairy.

Uncontrolled PM_{10} Emission Factors for Animals at the Dairy		
Type of Cow	Uncontrolled Emission Factor (lb-PM_{10}/head-yr)	Source
Mature Cows (Milk and Dry Cows) in Freestalls	**1.37**	Based on a Summer 2003 study by Texas A&M ASAE at a West Texas Dairy
Mature Cows (Milk Cows, Dry Cows and Bulls) in Open Corrals	**5.46**	Based on a Summer 2003 study by Texas A&M ASAE at a West Texas Dairy
Heifers in Open Corrals	**10.55**	Based on a USDA/UC Davis report quantifying dairy and feedlot emissions in Tulare and Kern Counties (April 2001)
Calves	**1.37**	SJVAPCD (Assumptions based on a Summer 2003 study by Texas A&M ASAE at a West Texas Dairy)

Post-Project PM_{10} Emission Factors

PE_2 PM_{10} Emission Factors (EF) (S-6918-2-0)				
Type of Cow	Uncontrolled EF ($lb\text{-}PM_{10}/hd\text{-}yr$)	Control(s)	Controlled EF Calculation	Controlled EF ($lb\text{-}PM_{10}/hd\text{-}yr$)
Milk Cows in Freestalls	1.37	Weekly Scraping using Pull-Type Equipment in morning (15%) Downwind Shelterbelts (12.5%)	1.37 x (1-0.15)(1-0.125) =	**1.02**
Dry Cows in Freestalls	1.37	Weekly Scraping using Pull-Type Equipment in morning (15%) Downwind Shelterbelts (12.5%)	1.37 x (1-0.15)(1-0.125) =	**1.02**
Heifers in Open Corrals (15-24 months)	10.55	Shade Structures (8.3%) Weekly Scraping using Pull-Type Equipment in morning (15%) Feeding Heifers Near Dusk (10%) Sprinkling of Heifer Corrals (25%)[4] Downwind Shelterbelts (12.5%)	10.55 x (1-0.083)(1-0.15)(1-0.10)(1-0.25)(1-0.125) =	**4.86**
Heifers in Open Corrals (7-14 months)	10.55	Shade Structures (8.3%) Weekly Scraping using Pull-Type Equipment in morning (15%) Feeding Heifers Near Dusk (10%) Sprinkling of Heifer Corrals (25%) Downwind Shelterbelts (12.5%)	10.55 x (1-0.083)(1-0.15)(1-0.10)(1-0.25)(1-0.125) =	**4.86**
Heifers in Open Corrals (4-6 months)	10.55	Shade Structures (8.3%) Weekly Scraping using Pull-Type Equipment in morning (15%) Feeding Heifers Near Dusk (10%) Sprinkling of Heifer Corrals (25%) Downwind Shelterbelts (12.5%)	10.55 x (1-0.083)(1-0.15)(1-0.10)(1-0.25)(1-0.125) =	**4.86**
Calves	1.37	Above-Ground calf Hutches (95%) Downwind Shelterbelts (12.5%)	1.37 x (1-0.95)(1-0.125) =	**0.06**

VOC and NH_3 Emission Factors for the Dairy

The following tables list the VOC and NH_3 emission factors for the animals at the dairy. These emission factors and the control efficiencies given in the assumptions above will be used to calculate the post-project VOC and NH_3 emissions from the dairy.

[4] 49% coverage area x 50% control = 25% overall control

Consolidated Emission Factors for Dairy Cows[5]		
Type of Cow and Housing	(lb-VOC/cow-yr)	(lb-NH_3/cow-yr)
Milk Cow (freestalls)	21.0	74.0
Dry Cow (freestalls)	13	45.4
Heifer (15-24 mo) (corral)	8.3	31.8
Heifer (7-14 mo) (corral)	7.2	27.8
Heifer (4-6 mo) (corral)	6.6	25.1
Calf (< 3 mo) (Above-ground calf hutches)	6.8	23.6
Mature Bull (corral)	11.1	42.5

Post Project Emissions

Milk Parlor Emission Factors[5]		
Permit Units	VOC Emissions (lb/cow-yr)	NH_3 Emissions (lb/cow-yr)
Milking Center (Freestall)	0.9	1.2

Cow Housing Emission Factors for Dairy Cows[5]		
Type of Cow	(lb-VOC/cow-yr)	(lb-NH_3/cow-yr)
Milk Cow (Freestalls)	12.4	28.0
Dry Cow (Freestall)	8.2	17.9
Heifer (15–24 months)(Corral)	5.7	14.4
Heifer (7–14 months)(Corral)	5.0	12.6
Heifer (4–6 months)(Corral)	4.5	11.4
Calf (under 3 months) (Above-ground Hutches)	4.3	9.3

Lagoon/Storage Pond Emission Factors for Dairy Cows[5]		
Type of Cow and Housing	(lb-VOC/cow-yr)	(lb-NH_3/cow-yr)
Milk Cow (Freestall)	2.7	15.7
Dry Cow (Freestall)	1.7	9.6
Heifer (15–24 months) (Corral)	1.0	6.7
Heifer (7–14 months)(Corral)	0.9	5.8
Heifer (4–6 months)(Corral)	0.8	5.3
Calf (under 3 months) (Above-ground Hutches)	0.9	5.0

[5] The emission factor for the milk cow is based on an internal document entitled "*Breakdown of Dairy VOC Emission Factor into Permit Units*". The emission factor for the other cows were developed by taking the ratio of manure generated by the different types of cows to the milk cow and multiplying it by the milk cow VOC EF.

New York State Energy Research and Development Authority

Assessment of Biochemical Process Controls for Reduction of Hydrogen Sulfide Concentrations in Biogas from Farm Digesters

Final Report

February 2012

No. 12-20

nyserda
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Assessment of Biochemical Process Controls for Reduction of Hydrogen Sulfide Concentrations in Biogas From Farm Digesters

Final Report

Prepared for the

New York State Energy Research and Development Authority

Albany, NY
nyserda.ny.gov

Kathleen O'Connor
Senior Project Manager

Prepared by:
Environmental Management Group International, Inc.
Media, PA

Manaf H. Farhan, Ph.D., P.E., Project Director
Yassar Farhan, Ph.D., P.E., Project Manager

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1.0 INTRODUCTION

Use of anaerobic digestion for animal manure treatment at dairy farms in New York State (NYS) has considerably increased over the past decade. In addition to reduction in odors, anaerobic digestion generates biogas and provides a viable option for nutrient management at farms. It is estimated that up to 280 Gega Watt-Hours can be generated from manure digestion at dairy farms in NYS (Zicari, 2003). Typically, biogas produced by farm digesters is used to generate energy for farm use and sale to the power grid. One of the main difficulties associated with biogas utilization at dairy farms is the presence of relatively high hydrogen sulfide (H_2S) concentrations in the biogas stream. Hydrogen sulfide present in biogas corrodes engine parts in the combustion chamber, exhaust system, and in various bearings throughout an engine. The presence of water vapor in the biogas stream along with hydrogen sulfide exasperates this problem by producing pure hydrogen, which accelerates cracking and blistering of steel parts. Furthermore, combustion of biogas with hydrogen sulfide generates sulfur dioxide which, upon reaction with water droplets, forms sulfuric acid. Like hydrogen sulfide, sulfuric acid is also highly corrosive to biogas handling equipment. In general, the operational hydrogen sulfide concentration limit for most biogas utilization systems is below 800 parts per million on a volumetric basis (ppmv) in the gas stream. The typical composition of biogas generated from a dairy farm digester is provided in Table 1 below. The primary two components of biogas are Methane (CH_4) (at approximately 60%) and Carbon Dioxide (CO_2) (at approximately 40%). Although H_2S constitutes only a small fraction of the biogas (0.2% to 0.45% or 2,000 to 4,500 ppmv), it is the compound of most concern when using digester biogas. Development of a reliable, cost-effective technology for control of H_2S concentrations in farm digesters is vital for wide-spread application of manure digesters in NYS. This project assessed the use of simple, low maintenance biochemical process controls to reduce biogas H_2S concentrations in manure digesters.

Table 1: Typical Composition of Anaerobic Digester Biogas at Dairy Farms

Parameter	Concentration
Methane	55% - 60%
Carbon dioxide	40% - 45%
Hydrogen sulfide	2,000 - 4,500 ppmv*

* ppmv is part per million on a volumetric basis

The goal of this project was to assess the effects of dissolved iron addition to dairy manure digesters on H_2S concentrations in the biogas stream. This was achieved by completing the following investigation steps:

1. Measure baseline bulk liquid and biogas hydrogen sulfide concentrations in an operational manure digester in NYS;
2. Complete a laboratory experimental investigation designed to estimate the dissolved iron dosage necessary to reduce dissolved hydrogen sulfide concentrations to desired levels; and

3. Complete a field-scale assessment of H_2S reduction in the biogas stream due to the addition of dissolved iron compounds to an operational dairy farm digester in NYS.

2.0 BACKGROUND

2.1 DESCRIPTION OF ANAEROBIC DIGESTION AND SULFIDE PRODUCTION

Anaerobic digestion is a complex, multi-step biological process during which the organic portion of the waste is converted into bacterial cells, carbon dioxide, and methane gas while sulfates are converted into H_2S. The conversion of the organic portion of the waste is often described as having the following three basic stages: (i) hydrolysis, liquefaction and fermentation; (ii) hydrogen and acetic acid (or acetate-CH_3COOH) formation; and (iii) methane formation. This three-stage process involves possibly five groups of bacteria: *fermentation bacteria*; *hydrogen-producing bacteria*; *hydrogen-consuming bacteria*; *carbon dioxide (CO_2) -reducing methanogens*; and *aceticlastic methanogens*. Methane (CH_4) is generated by the latter two groups of bacteria (CO_2-reducing and acid-utilizing methanogens). Acetate cleavage by aceticlastic methanogens is responsible for the majority of methane production, and takes place according to the following reaction:

$$CH_3COOH \rightarrow CH_4 + CO_2$$

Methanogenic bacteria can only use a specific group of substrates as an energy source. This group includes formic acid, acetic acid, methanol, hydrogen, and carbon dioxide (Parkin and Owen, 1986; and Zeikus *et al.*, 1985). Jeris and McCarty (1975) employed tracer studies to evaluate the direct contribution of acetate to methane production for anaerobic digestion of various substrates. They estimated that 67-100% of the methane production from fatty substrates is directly due to acetate cleavage. Carbohydrates, which are easier to digest than fats, showed 67% methane production from acetate. Proteins and sewage sludge had approximately 70% of their methane production directly attributable to acetic acid. The remainder of produced methane is a result of carbon dioxide reduction using hydrogen as an energy source, according to the following reaction:

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

Conversion of sulfates (SO_4^{-2}) and sulfur-containing compounds into H_2S in anaerobic digesters is carried out by sulfate-reducing bacteria (SRB). SRB use the same sources of energy (acetic acid and hydrogen) as methane producing bacteria (MPB) (Karhadkar *et al.*, 1987). SRB can usually out-compete MPB for the carbon source (Thiele, 1991). Yoda et al., (1987) observed that, in the presence of sulfate, SRB out-compete MPB at low acetate concentrations but MPB out-compete SRB at high acetate concentrations. The reactions involved in H_2S production are as follows (Speece, 1996):

$$4H_2 + SO_4^{2-} + H^+ \rightarrow HS^- + 4H_2O$$

$$CH_3COO^- + SO_4^{2-} \rightarrow HS^- + 2HCO_3^-$$

$$4\ CH_3CH_2COO^- + 3\ SO_4^{2-} \rightarrow 4[CH_3COO^-] + 4HCO_3^- + 3HS^-$$

$$2\ CH_3CH_2CH_2COO^- + SO_4^{2-} \rightarrow 4[CH_3COO^-] + HS^- + H^+$$

Where: CH_3COO^- is Acetate, $CH_3CH_2COO^-$ is Propionate, and $CH_3CH_2CH_2COO^-$ is Butyrate.

In general, sulfur-containing compounds are reduced in anaerobic environments to sulfide compounds as follow:

$$SO_4^{2-} + \text{Organic Matter} \text{ —— Anaerobic Bacteria} \rightarrow S^{2-} + H_2O + CO_2$$

$$HS^- \leftrightarrow S^{2-} + H^+$$

$$H_2S \leftrightarrow HS^- + H^+$$

Thus, the production of H_2S in farm digesters is inevitable given the abundance of sulfur-containing compounds in manure and the ability of SRB to compete with MPB for acetate and hydrogen in anaerobic environments.

2.2 CURRENTLY AVAILABLE TECHNOLOGIES FOR BIOGAS HYDROGEN SULFIDE CONTROL

The majority of currently available biogas H_2S control technologies focus on the removal of H_2S from the biogas stream prior to or after combustion. Control technologies are generally based on physical, chemical, or biological treatment of the biogas stream.

Physical control technologies of H_2S include sorption onto solid media, dissolution into water or other solvents, or membrane or micro-filtration processes. Adsorption of H_2S onto solid surfaces from the gas stream often uses granular activated carbon (GAC) combined with alkalines; oxides; zeolits; or specially-designed resins that have an affinity to absorb H_2S. Dissolution of H_2S in water or other solvents capitalizes on the higher gas-liquid partition coefficient for H_2S than the other biogas constituents. The Henry's law partition coefficient for H_2S is 1.0×10^{-1} Mole/L/atm, as compared to 1.0×10^{-3} Mole/L/atm for CH_4 and 3.4×10^{-2} Mole/L/atm for CO_2. Although physical control technologies can be effective in reducing H_2S, they frequently generate a waste stream of "spent" material that requires special management and disposal.

Chemical control technologies are generally based on promotion of chemical reactions between metal oxides (or less commonly; caustic) and H_2S to remove the latter from the biogas stream. Hydrogen sulfide reaction with metal oxides forms a metal sulfide precipitate that coats the metal oxide surface. One of the most commonly used metal oxides is iron oxide (e.g. iron sponge). Zinc and nickel oxides have also been used for these systems. Although effective in removing H_2S, the efficiency of these systems decreases over time due to the build-up of metal-sulfide precipitates on the reactive oxide surfaces. This necessitates regular replacement of the metal oxide and disposal of the spent material (which may be classified as hazardous). Regeneration of the spent material can also be employed to minimize costs, but such a process generally requires specific training and handling due to the presence of high sulfur concentrations in the spent material.

Biological H_2S control technologies include aerobic conversion of sulfur into its oxidized forms using bioreactors, biofilters, or similar systems, or the addition of chemicals to selectively deactivate SRB in the digester. These technologies can be effective in removing H_2S from the biogas stream but often have high capital and/or chemical usage costs and, in the case of aerobic treatment, require control of sulfuric acid buildup in the reactors.

2.3 PROJECT TECHNOLOGY DESCRIPTION

This investigation evaluated a sulfide removal technology based on control of H_2S in the digester (i.e., at the source) to reduce its concentrations in the biogas stream. More specifically, this project evaluated the addition of dissolved iron compounds to the digester to precipitate sulfur as insoluble iron sulfides. This method is used successfully to control H_2S levels in sludge digesters at municipal wastewater treatment plants. The basic chemical reaction for two commonly used dissolved iron compounds and H_2S are as follows:

$$FeCl_2 + H_2S \rightarrow FeS \downarrow + 2\ HCl$$

$$2\ FeCl_3 + 3\ H_2S \rightarrow Fe_2S_3 \downarrow + 6\ HCl$$

McFarland and Jewell (1989) evaluated the addition of iron phosphate to anaerobic digesters and concluded that this approach could be an effective method for H_2S control. In their laboratory study, the addition of iron phosphate to an anaerobic digester reduced hydrogen sulfide concentrations in the biogas from approximately 2,500 ppmv to 100 ppmv. This decrease was accompanied with a rise in the pH from 6.7 to 8.2 and an increase in soluble sulfide concentrations from 18 to 61 mg/L. The formation of stable, insoluble metal sulfides in anaerobic environments is favored at pH levels of 6.0 and above (Ehrlich, 1996).

The addition of iron compounds to anaerobic manure digesters for H_2S control has been attempted over the past decade but has yielded mixed results (Zicari, 2003). This is likely due to the complex relationship between iron and sulfur in anaerobic digestion. While sulfur and iron are needed as trace nutrients to maintain a healthy digestion process, accumulation of dissolved hydrogen sulfide in the digester to levels between 150-200 mg/L can adversely affect the anaerobia digestion process (Speece, 1996). Also, dissolved hydrogen sulfide readily binds with iron (and other trace metals) to form highly insoluble metal sulfides. Under such conditions, trace metals needed for the digestion process (such as iron, nickel, and cobalt) become unavailable to the digestion process. Thus, a balance must be established in the addition of iron whereby sufficient iron is added to the digester to: (i) bind with dissolved hydrogen sulfide; and (ii) supply the digestion process with iron as a micronutrient, without wastage or overdosing. In addition to causing hydrogen sulfide to decrease in the biogas, addition of iron may improve process efficiency by making needed trace metals (e.g. iron, cobalt, and nickel) more “bioavailable” for utilization by anaerobic bacteria.

The potential benefits of direct addition of dissolved iron to dairy digesters stems from the relatively low cost of these compounds (e.g., 30% $FeCl_2$ solution costs approximately $0.08/lb) and the significant impact of removing dissolved H_2S from the digester liquid matrix on the biogas H_2S concentrations. Based on the partition coefficient for H_2S, approximately 26 mg/L in the dissolved phase correspond to 10,000 ppmv in the gas phase (Speece, 1996). Thus, reducing the dissolved-phase H_2S concentration by 1 mg/L would result in a reduction of 380 ppmv of the H_2S concentration in the biogas stream. Therefore, dissolved H_2S concentrations in dairy digesters only need to be reduced by 5 to 7 mg/L to obtain a significant reduction in H_2S concentrations in the biogas stream. While this approach is not expected to reduce H_2S concentrations to single-digit ppmv levels, it has the potential to reduce H_2S in the biogas by 50%. Such a reduction would greatly mitigate the adverse effects of H_2S on biogas utilization equipment and improve their efficiency in utilizing biogas from dairy digesters.

3.0 DESCRIPTION OF FARM OPERATIONS AND DIGESTER SYSTEM

EMG selected AA Dairy, LLC, in Candor NY (the Farm) as the site for completing this investigation. The Farm has an operational anaerobic digester for manure treatment and electricity generation. EMG performed an onsite assessment and a review of available records and reports relating to the Farm’s digester and its operation. AA Dairy is a 600-cow dairy farm located in the town of Candor in Tioga County, NY. In 1998, AA Dairy decided to build and operate and anaerobic digester to: 1) address odor complaints from the surrounding community; 2) benefit from the electricity and heat generated from the biogas; 3) compost the post-digested separated solids; and 4) potentially use liquid from the separated digested effluent for irrigation. The electricity produced from powering the generator set is used for on-farm needs. Excess electricity produced is sold to New York State Electric and Gas (NYSEG) under provisions of the New York State Net Metering laws. The post-digestion separated solids are cured and marketed as compost to local buyers. The separated liquid effluent is mixed with milk house wastewater and allowed to flow by gravity to a lined long-term storage pond, and is eventually land applied by tanker truck or used for irrigation by way of underground piping.

The AA Digester system is a plug-flow digester designed to handle manure from a 1,000-cow dairy farm. The digester is a below-grade cast-in-place concrete digester structure that is 130 feet long, 30 feet wide and 14 feet deep. The digester is equipped with an airtight, flexible dome to trap biogas (made from Hypalon 45). The manure is kept at approximately 100^{o}F in the digester for optimal biogas production. A 7.5-Hp piston pump sends raw manure mixed with bedding (sawdust) to the digester, and operates for a period of four to six hours per day. Wastewater from the milking parlor or liquid effluent from the solid-liquid separator is used to dilute the manure stream as needed. Approximately 11,000 gallons of influent manure are fed to the digester each day. Based on the dimensions of the digester, the current hydraulic retention time (HRT) for the AA Dairy digester is approximately 37 to 40 days. The anaerobic digester produces between 13,200 and 48,500 Standard Cubic Feet per Day (SCFD) of biogas with an average daily biogas production of 34,700 SCFD. The produced biogas contains 34% to 40% CO_2, with an average CO_2 content of 34.7%. Methane gas (CH_4) accounts for the balance of the biogas content. Therefore, the produced biogas stream contains roughly 60% to 66% CH_4, with an average CH_4 concentration of 65.3%. The biogas stream also contains approximately 4,000 ppmv (or 0.4%) H_2S (based on Sensidyne Tube testing). The produced biogas stream is converted into electricity using a Caterpillar engine generator (Gooch and Pronto, 2008). Photographs of the AA Dairy Digester system are provided below (see Photos 3-1 through 3-4).

Photo 3-1—AA Dairy Digester in Operation

Photo 3-2—Houle Piston Pump Used to Deliver Raw Manure into the Digester

Photo 3-3— EMG Sampling of the Raw Manure Stream Fed into the AA Dairy Digester

Photo 3-4—EMG Sampling of the Treated Manure Stream from the AA Dairy Digester

4.0 RAW MANURE AND DIGESTER EFFLUENT CHARACTERIZATION

EMG collected eight five-gallon buckets (four raw manure, and four digester effluent) from the AA Dairy farm digester. Individually collected samples from each location were mixed into a large container to create a homogenous sample. Smaller sub-samples were then collected from the large container and refrigerated at 32 to 34^{o}C for use in the laboratory analysis and experimentation. Samples were analyzed for physical characteristics (total solids (TS), volatile solids (VS)) and chemical characteristics (e.g., Chemical Oxygen Demand-COD, sulfate, H_2S, iron, ammonia-N, nitrate, phosphorus). In addition, digester biogas CH_4, CO_2, and H_2S concentrations were measured. This data was evaluated in combination with existing historical data available for the Farm digester to develop a baseline for conducting the laboratory-scale dosing studies, and subsequently the field dosing system. A summary of results from these analyses are provided in Tables 4-1, 4-2, and 4-3 below. For the raw manure samples, the average measured COD was 70,800 mg/L, TS was 74,137 (or 7.4%), VS was 21,128 mg/L (or 2.1%), phosphorus was 2,408 mg/L, ammonia-N was 1,494 mg/L, and total iron was 133 mg/L. By comparison, the US Environmental Protection Agency (EPA) published data for manure characteristics from dairy farms with paved surfaces and a scrape collection system are as follows: COD 100,000 mg/L, VS 11.6% (or 11,600 mg/l), phosphorus 1,550 mg/L, and ammonia-N 1,250 mg/L (EPA, 2002). For the digester effluent samples, the average measured COD was 28,985 mg/L, TS 18,674 (or 1.8%), VS was 10,882 mg/L (i.e., 1.1%), phosphorus was 1,198 mg/L, ammonia-N was 1,272 mg/L, and total iron was 5.1 mg/L.

Table 4-1—Summary of Analyses (Total Solids and Volatile Solids) Performed on Raw Manure and Digester Effluent Samples Collected from AA Dairy Farm.

Sample Number	Raw Manure		Digester Effluent	
	Total Solids (mg/L)	Volatile Solids (mg/L)	Total Solids (mg/L)	Volatile Solids (mg/L)
1	78,875	21,988	17,013	13,480
2	73,425	15,413	20,500	11,225
3	73,675	20,225	19,075	10,813
4	79,844	19,356	18,891	11,127
5	68,067	25,533	18,345	11,909
6	64,222	20,067	18,836	11,582
7	72,867	21,600	18,509	9,036
8	76,711	22,044	18,327	11,782
9	72,778	19,178	18,636	9,418
10	74,822	23,222	18,800	10,182
11	82,933	21,689	19,964	12,709
12	65,289	25,089	18,400	11,236
13	80,156	20,467	18,455	9,073
14	70,311	4,622	17,891	10,564
15	76,578	23,822	17,873	11,200
16	75,800	24,578	19,364	9,618
17	80,778	25,000	18,018	10,545
18	72,289	21,178	19,200	10,473
19	69,178	26,356	18,709	10,782
Average Value	**74,137**	**21,128**	**18,674**	**10,882**
Std. Dev.	**5,211**	**4,816**	**775.5**	**1,158**

Table 4-2—Summary of Chemical Characteristics Measured in Raw Manure Samples Collected from AA Dairy Farm.

Sample Number	COD (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	Phosphorous (mg/L)	Sulfate (mg/L)	Sulfide (mg/L)	Total Iron (mg/L)
1	54,700	1,630	1,520	2,470	800	51.2	145
2	74,550	1,610	1,780	2,365	600	52.2	135
3	77,350	1,480	920	2,630	540	49.7	139.5
4	73,300	1,320	1,490	2,480	3,400	53	95
5	71,800	1,440	1,260	2,570	3,700	51.1	144
6	72,650	1,490	1,140	2,210	3,900	48.2	134
7	72,400	1,530	1,010	2,680	4,000	49.1	142.5
8	61,800	1,400	1,010	2,395	4,300	46.2	143
9	77,800	1,390	1,620	2,315	3,600	50.1	138.5
10	71,650	1,650	1,220	1,965	3,900	49.1	110
Avg. Value	**70,800**	**1,494**	**1,297**	**2,408**	**2,874**	**50.0**	**132.7**
Std. Dev.	**7,150.2**	**110.9**	**291.2**	**212**	**1,557**	**2.0**	**16.7**

Table Notes:

- COD denotes Chemical Oxygen Demand
- Nitrate analysis is based on NO_3-N concentration measurement
- Phosphorous analysis is based on PO_4 concentration measurement
- Sulfate analysis is based on SO_4 concentration measurement
- Ammonia is based on NH_3-N concentration measurement
- Total iron is mg Fe per L

Table 4-3—Summary of Chemical Characteristics Measured in Digester Effluent Samples Collected from AA Dairy Farm.

Sample Number	COD (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	Phosphorous (mg/L)	Sulfate (mg/L)	Sulfide (mg/L)	Total Iron (mg/L)
1	25,400	940	410	1,372	4,200	29.9	7
2	30,150	1,407	210	1,142	4,400	29.3	6
3	29,700	1,600	200	1,000	4,300	31.9	1
4	30,550	1,110	230	1,335	3,900	30.2	8
5	30,200	1,040	220	1,129	4,400	--	9.5
6	31,050	1,110	210	1,132	3,900	--	3
7	30,350	2,010	240	1,156	4,800	--	7.5
8	27,700	1,630	220	1,422	5,300	--	4.5
9	28,100	1,040	260	1,100	4,700	--	2.5
10	26,650	830	540	1,197	4,000	--	2
Avg. Value	**28,985**	**1,271.7**	**274**	**1,198.5**	**4,390**	**30.3**	**5.1**
Std. Dev.	**1,905**	**374.8**	**111.6**	**134.2**	**443.4**	**1.1**	**2.9**

Table Notes:

- COD denotes Chemical Oxygen Demand
- Nitrate analysis is based on NO_3-N concentration measurement
- Phosphorous analysis is based on PO_4 concentration measurement
- Sulfate analysis is based on SO_4 concentration measurement
- Ammonia is based on NH_3-N concentration measurement
- Total iron is mg Fe per L

5.0 LABORATORY DOSING EXPERIMENTATION

An experimental investigation designed to evaluate the dose of dissolved iron needed to reduce dissolved hydrogen sulfide (H_2S) levels in the digester effluent was completed at EMG's laboratory facility in Aston, PA. Based on H_2S and sulfate levels measured in samples collected from the Farm, the theoretical dosing amounts of iron solution needed to reduce H_2S levels in the digester bulk liquid were calculated. The chemical reaction used to estimate the theoretical iron amount needed is as follows:

$$FeCl_2 + H_2S \rightarrow FeS\downarrow + 2\ HCl$$

$$FeCl_2 + SO_4^{2-} \rightarrow FeSO_4\downarrow + 2Cl^-$$

Based on this reaction, 1.63 mg/L of iron (Fe) is needed to react with 1 mg/L of hydrogen sulfide. Using the average measured liquid hydrogen sulfide concentration of 50 mg/L in the raw manure (Table 4-2), the calculated required iron dose is 81.5 mg Fe/L. This value was used as a reference point for dissolved iron addition given that other sinks for iron are likely present in the digester bulk liquid matrix.

Dosing experiments were performed using triplicate batch experiments. For each experiment, a 250 milliliters bottle was filled with a raw (unfiltered) manure sample collected from the Farm. Each bottle contained a magnetic stirrer to maintain well-mixed conditions in the batch. Using an iron chloride stock solution, 13 dosing amounts that would result in the following iron concentrations were evaluated: 1.0, 2.5, 7.0, 13, 25, 50, 130, 250, 480, 700, 1,000, 2,100, and 4,200 mg Fe/L. These concentrations represent approximately 1.5%, 3%, 8%, 15%, 30%, 65%, 160%, 300%, 600%, 850%, 1,300%, 2,600%, and 5,200%, respectively, of the stoichiometrically-calculated iron dose needed to react with the measured hydrogen sulfide amount in the raw manure. Sulfate and total sulfides concentrations in each experiment were analyzed before and after iron addition. Each sample was mixed for a minimum of one hour after iron addition and prior to analysis.

Results obtained from these iron dosing experiments are shown in Figures 5-1, 5-2, and 5-3 below. The measured iron concentration in the batch bottles, as compared to the calculated iron concentration, is shown in Figure 5-1. As Figure 5-1 shows, the iron concentrations in the experiments initially increased proportionally with the amount of iron chloride added then reached a plateau of approximately 300 mg/L regardless of the amount of iron chloride added. The data shown in Figure 5-1 was expected to have a 1:1 correlation. However, the observed correlation as measured by analytical data was clearly different from a 1:1 correlation. This discrepancy is likely due to the presence of high concentrations of suspended solids and organic material in the bulk liquid matrix, as well as the highly-reductive/reactive anaerobic environment in the liquid matrix in the batches. Low Oxidation-Reduction Potential (ORP) combined with high suspended and organic solids in the bulk liquid matrix can result in significant uptake and loss of available iron ions due to chemical binding and absorption to solid surfaces. The results in Figure 5-1 show that, after the initial increase in the measured iron concentration in the bulk liquid, there is significant uptake/sorption of any additional iron added to the raw manure sample. Data for Figure 5-1 is provided in Table A-1 in Appendix A herein.

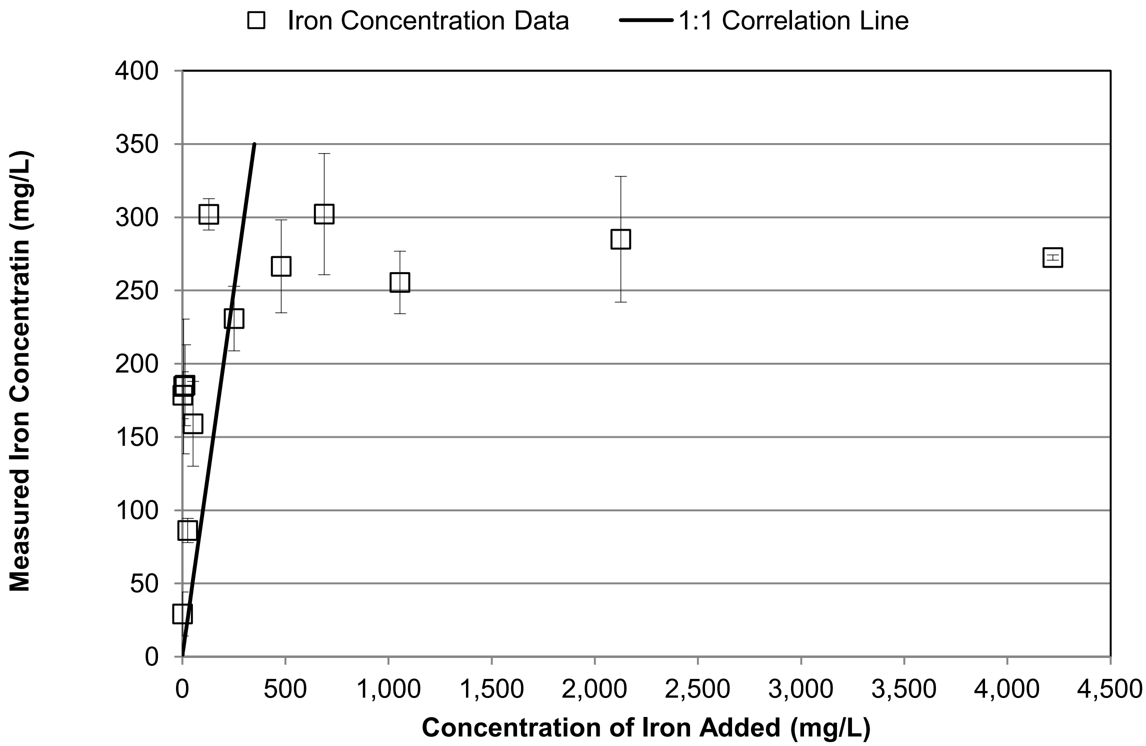

Figure 5-1—Measured vs. Added Iron Concentrations in the Batch Experiments after Iron Addition to Raw Manure Samples in Batch Experiments
(Note: Error bars shown represent one Standard Deviation)

Measured hydrogen sulfide (H_2S) and sulfate (SO_4^{2-}) concentrations in these dosing experiments are shown in Figure 5-2, and 5-3 respectively. As Figure 5-2 shows, when the calculated iron concentration increased beyond 2,000 mg/L, no significant removal of H_2S was observed in the experiments. On the other hand, Figure 5-3 shows that as the iron concentration increased beyond 500 mg/L, no significant removal of $SO_4^{2-}$was observed in the experiments. As discussed above, the calculated concentration of iron needed to react with 100% of the measured hydrogen sulfide concentration in the raw manure sample is 81.4 mg/L of iron. Figures 5-2 and 5-3 show that approximately 50% removal of both hydrogen sulfide and sulfate was observed at an iron concentration of approximately 250 mg/L (or 300% of the stoichiometric concentration calculated).

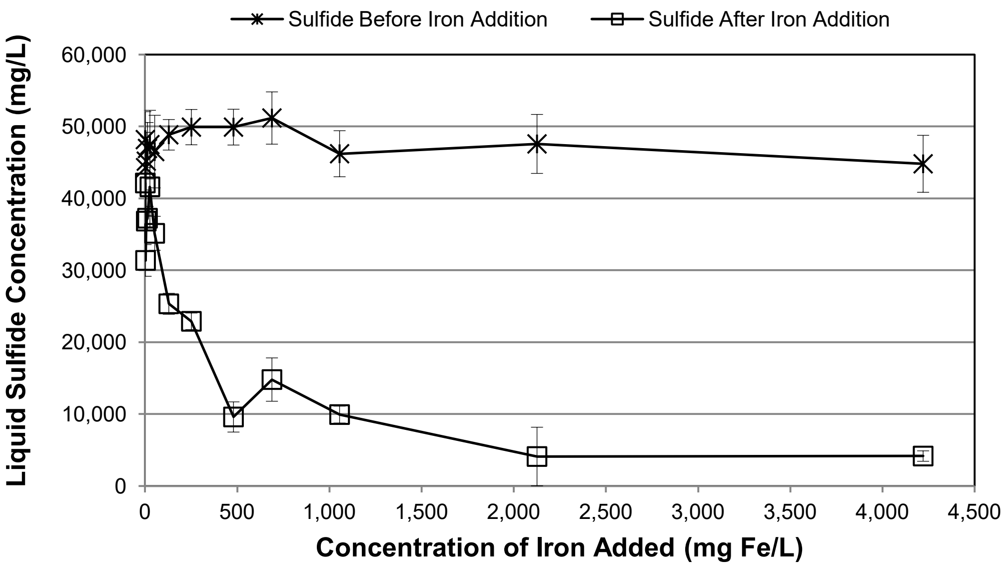

Figure 5-2—Measured Liquid Sulfide (H_2S) Concentration Before and After Iron Addition to Raw Manure Samples in Batch Experiments
(Note: Error bars shown represent one Standard Deviation)

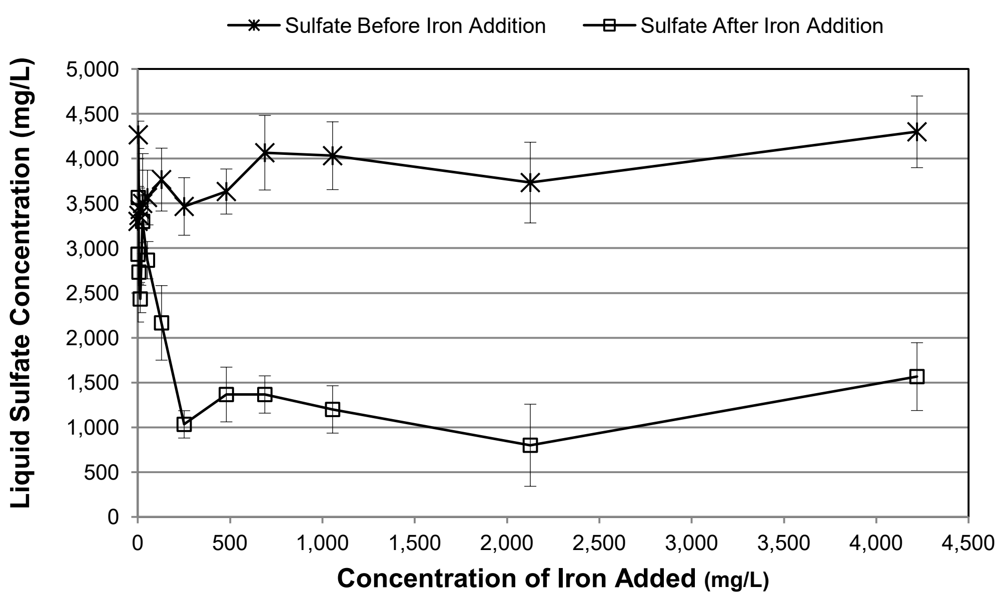

Figure 5-3—Measured Sulfate (SO_4^{2-}) Concentration Before and After Iron Addition to Raw Manure Samples in Batch Experiments
(Note: Error bars shown represent one Standard Deviation)

Measured hydrogen sulfide (H_2S) and sulfate (SO_4^{2-}) concentrations versus measured iron concentration are shown in Figure 5-4, and 5-5, respectively. As both figures show, significant sulfide and sulfate reduction is observed when the measured iron concentration increased beyond 150 mg/L. Sulfide and sulfate reduction leveled-off at measured iron concentrations beyond 275 mg/L.

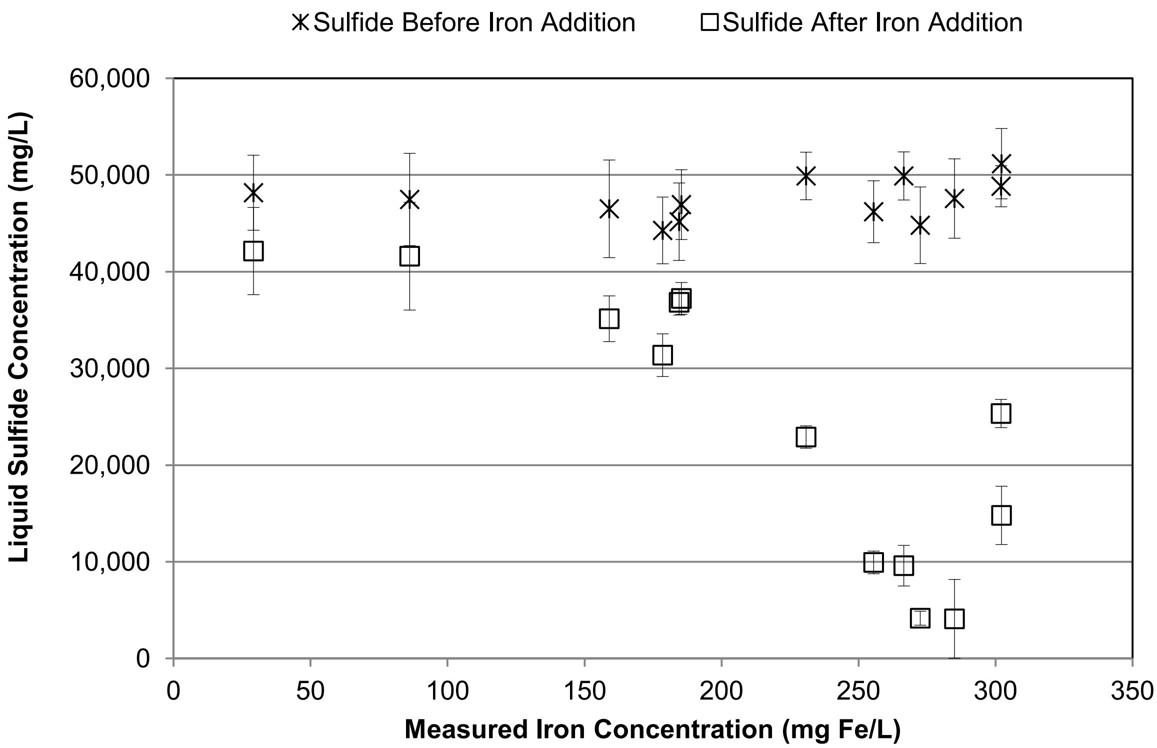

Figure 5-4—Measured Sulfate (SO_4^{2-}) Concentration Before and After Iron Addition to Raw Manure Samples in Batch Experiments
(Note: Error bars shown represent one Standard Deviation)

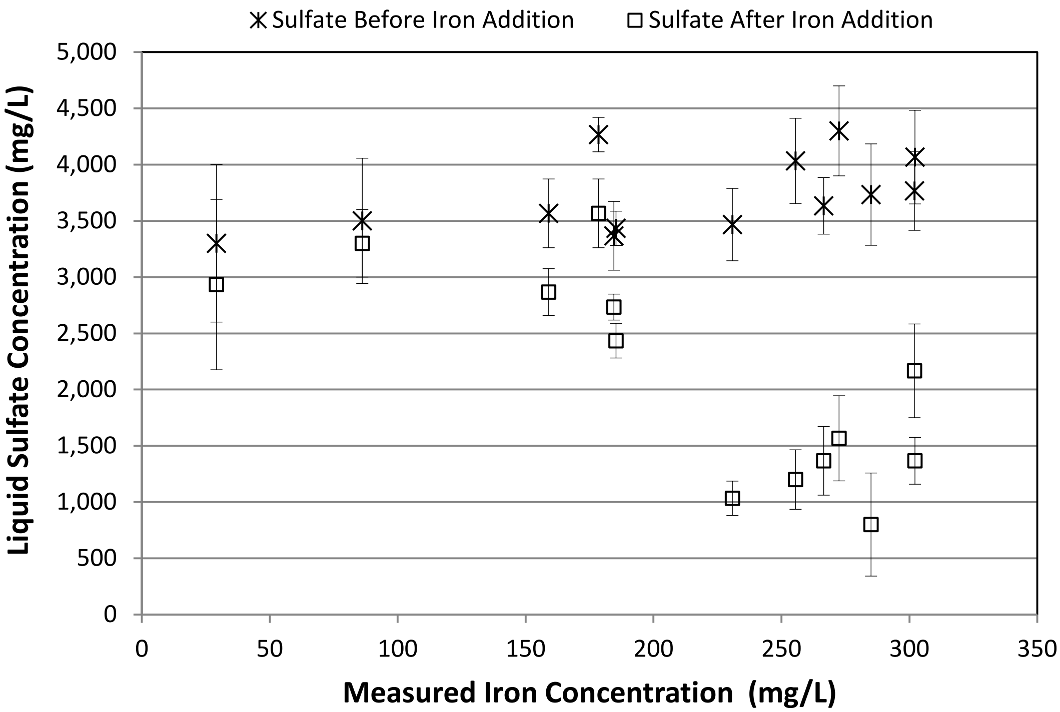

Figure 5-5—Measured Sulfate (SO_4^{2-}) Concentration Before and After Iron Addition to Raw Manure Samples in Batch Experiments
(Note: Error bars shown represent one Standard Deviation)

Based on the data observed in Figures 5-2 and 5-3, the percent reduction in sulfide and sulfate concentrations were calculated as follows:

$$\% \text{ reduction} = \frac{\text{(starting concentration - ending concentration)}}{\text{starting concentration}} \times 100$$

The calculated reductions in sulfide and sulfate are shown in Figure 5-6. As the figure shows, as the added iron concentration increased to 500 mg/L, the percent reduction in both sulfides and sulfates increased to approximately 80%. These results were used to design the field dosing system for the AA Dairy digester.

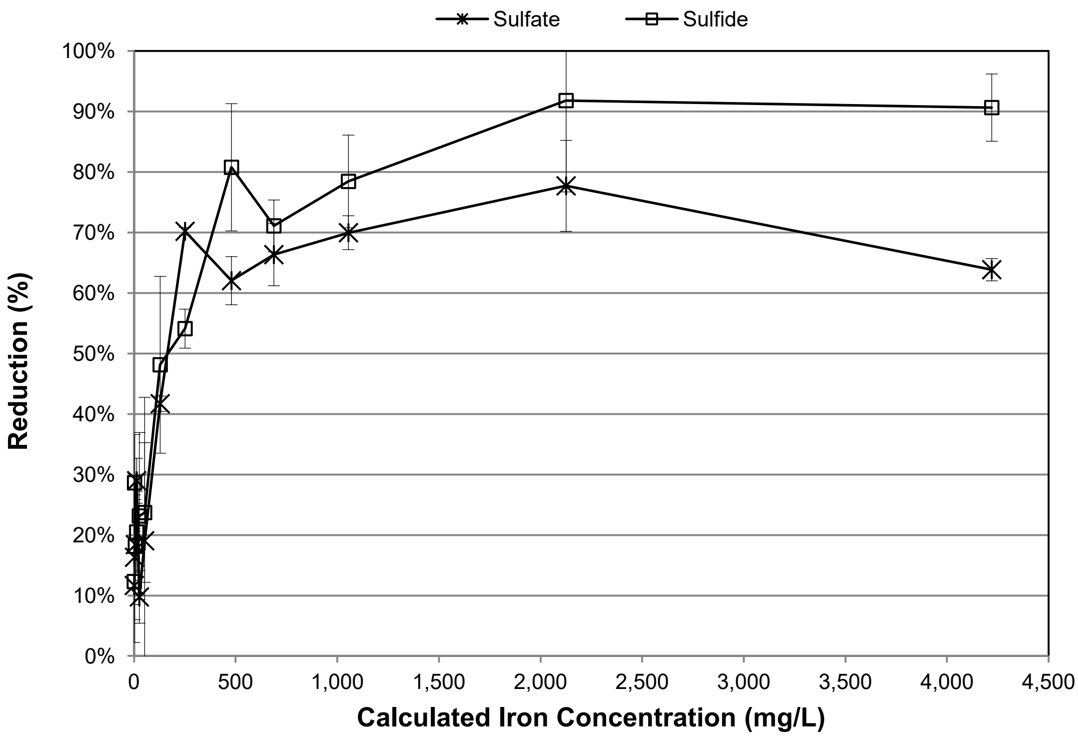

Figure 5-6— Reduction in Sulfate and Sulfide Concentrations at the Different Iron Concentrations in the Dosing Batch Samples in Batch Experiments
(Note: Error bars shown represent one Standard Deviation)

6.0 FIELD DOSING SYSTEM DESIGN AND FABRICATION

6.1 SYSTEM DESIGN

A dosing system for dissolved iron addition to the digester at AA Dairy was designed and fabricated based on results from the laboratory dosing experiments. The dosing system was designed to treat the entire volume of the manure stream fed to the digester. A schematic diagram of the dosing system is shown in Figure 6-1 below. The dosing system consists of a feed tank, mixing pump, iron feed pump, isolation valves, and a timer for control of the dosing rate.

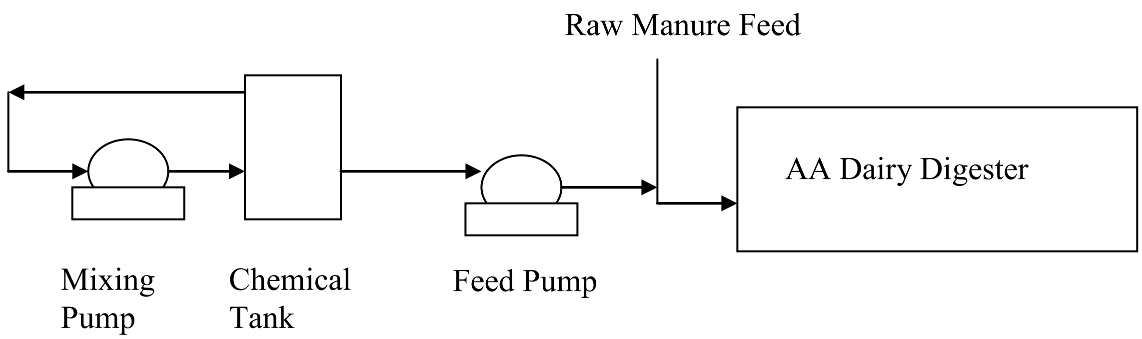

Figure 6-1: Schematic Diagram of the Proposed Chemical Dosing System Used

Based on the data obtained from the dosing experiments above (Figures 5-2, 5-3, and 5-4), and using the average raw manure feed rate to the digester of 11,000 gallons per day (41,640 liters/day) the following estimates are made for the experimental dosage required for the AA Dairy digester:

(Note: the molecular weight of Fe is 55.5 g/mole and Cl is 35.5 g/mol)

<u>For 40% Total Sulfides Concentration Reduction:</u>

$$\frac{150 \text{ mg Fe/L} \times 41{,}640 \text{ liters/day}}{1{,}000{,}000 \text{ mg/kg}} = 6.2 \text{ kg Fe per day needed}$$

$$= 13.7 \text{ lbs Fe per day}$$

The first phase of this investigation was performed using $FeCl_2$ solution with a target of 40% total sulfides removal. Using the fact that one mole of Fe is present in one mole of $FeCl_2$, and that 44.0% of $FeCl_2$ is Fe by weight, 14.1 kg of $FeCl_2$ per day (or 31.1 lbs of $FeCl_2$ per day) need to be added to the digester for 40% total sulfides reduction. Using a solution with a concentration of 0.23 lbs $FeCl_2$ per gallon, this translates to 135 gal of $FeCl_2$ solution per day

<u>For 60% Total Sulfides Concentration Reduction:</u>

$$\frac{250 \text{ mg Fe/L} \times 41{,}640 \text{ liters/day}}{1{,}000{,}000 \text{ mg/kg}} = 10.4 \text{ kg Fe per day needed}$$

$$= 22.9 \text{ lbs Fe per day}$$

The second phase of this investigation was performed using $FeCl_3$ solution since it would provide a less costly alternative for farm digester applications (calculated on a pound for pound basis), with a target of 60% total sulfides removal. Using the fact that one mole of Fe is present in one mole of $FeCl_3$, and that 34.4% of $FeCl_3$ is Fe by weight, 30.3 kg of $FeCl_3$ per day (or 66.6 lbs of $FeCl_3$ per day) need to be added to the digester for 60% total sulfides reduction. Using a solution with a concentration of 0.48 lbs $FeCl_3$ per gallon, this translates to 139 gal of $FeCl_3$ solution per day.

Therefore, the field chemical dosing system was designed to deliver a maximum of 180 Gallons per Day (GPD) of iron solution. A diaphragm pump (Pulsafeeder E series) was used to deliver the required dose to the digester. The dosing pump was operated on a timer to deliver the desired amounts of $FeCl_2$ or $FeCl_3$ to the digester over a 24-hour period. Data obtained from field operation of the demonstration dosing system was evaluated to determine the effects of iron dosing on sulfides reduction in the produced biogas stream from the anaerobic digester at AA Dairy.

6.2 FIELD DOSING EXPERIMENTATION RESULTS

The field dosing system was installed and operated at AA Dairy for approximately 80 days. Prior to starting the chemical feed system, samples were collected from the digester for a period of one week to establish base line H_2S concentrations in the biogas and digester effluent streams. Iron solution was fed to the digester over a time period that represented approximately two hydraulic retention times (HRTs). Samples were collected from the raw manure feed line, the digester effluent, and the biogas stream to determine the effects of the dosing system on H_2S concentrations in the biogas stream. Analytical results of the field samples are shown in Tables 6-1, and 6-2.

Table 6-1. Summary of Measured Parameters for the Influent Raw Manure Stream at AA Dairy.

Table Notes:

Day	COD (mg/L)	Total Suspended Solids (mg/L)	Percent Solids (%)	Total Sulfides (mg/kg)	Dissolved Sulfides (mg/kg)	Total Iron (mg/kg)	Dissolved Iron (mg/kg)	pH	Total Alkalinity (as CaCO3) (mg/L)
0	36,000	38,500	8.65%	208	< 100	63	3.9	7.31	8,830
9	232,000	25,500	10.3%	176	112	61	6.1	7.48	15,520
19	168,000	49,400	14.1%	256	128	52	3.6	7.06	12,120
29	116,352	30,000	15.8%	128	< 100	61	7.4	7.2	12,560
39	160,000	23,000	13.0%	176	< 100	45	< 2.0	7.42	11,920
49	152,000	89,000	20.3%	288	< 100	63	3.5	7.74	11,840
59	79,992	35,000	13.0%	192	< 100	55	3.6	7.50	1,184
69	53,328	30,000	12.0%	208	< 100	20	4.5	7.72	1,092
79	44,440	29,000	12.0%	160	< 100	31	2.0	7.65	960

- Experimental investigation started on Day 0
- COD denotes Chemical Oxygen Demand
- pH measured in water (at 25^{o}C)
- < denotes "Below Analytical Detection Limit"
- Total Sulfides measured as S^{2-}
- Dissolved Sulfides measured as S^{2-}
- Alkalinity measured as $CaCO_3$
- Total Sulfate and Dissolved Sulfate were analyzed but they were both below the detection limits of 2,500mg/Kg and 500 mg/Kg, respectively, for the duration of the study.

Table 6-2. Summary of Measured Parameters for the Digester Effluent at AA Dairy.

Table Notes:

Day	COD (mg/L)	Total Suspended Solids (mg/L)	Percent Solids (%)	Total Sulfides (mg/kg)	Total Iron (mg/kg)	Dissolved Iron (mg/kg)	pH	Total Alkalinity (as $CaCO_3$) (mg/L)
0	20,000	36,500	7.7%	232	65	12.0	8.01	17,200
9	72,000	23,500	7.2%	112	74	15.0	7.97	18,160
19	48,000	28,200	8.4%	176	89	35.0	7.99	16,560
29	50,904	20,666	7.7%	100	111	30.0	8.08	18,020
39	48,000	19,333	9.0%	160	115	30.0	8.20	17,400
49	64,000	21,333	7.5%	176	148	35.0	8.22	17,440
59	35,600	25,300	10.0%	176	171	37.0	8.10	1,656
69	35,552	25,333	8.0%	144	166	37.0	8.31	1,688
79	35,552	21,333	9.0%	144	142	14.0	8.24	780

- Experimental investigation started on Day 0
- COD denotes Chemical Oxygen Demand
- pH measured in water (at 25°C)
- < denotes "Below Analytical Detection Limit"
- Total Sulfides measured as S^{2-}
- Dissolved Sulfides measured as S^{2-}
- Alkalinity measured as $CaCO_3$
- Total Sulfate, Dissolved Sulfate, and Dissolved Sulfides were analyzed, but they were all below the detection limits of 2,500 mg/Kg for Total Sulfates, 500 mg/Kg for Dissolved Sulfate, and 100 mg/Kg for Dissolved Sulfides for the duration of the study.

Hydrogen sulfide concentrations measured in the biogas stream during the study period are shown in Figure 6-2. Figure 6-2 also shows the amount of iron added to the digester. During the first 30 days of this project, approximately 14 lbs/day of iron were added to the digester to achieve 40% reduction of hydrogen sulfide concentrations. For this period, a decrease in hydrogen sulfide concentration was observed from 4,000 ppmv to approximately 2,500 ppmv. This represents approximately a 38% reduction in H_2S concentrations in the biogas phase. Between day 30 and day 79, the iron feed to the digester was increased to approximately 23 lbs/day (fed as $FeCl_3$). This amount was expected to achieve a 60% reduction in H_2S concentrations in the biogas phase. As can be seen in Figure 6-2, increasing the iron feed did not result in a consistent decrease in hydrogen sulfide concentrations in the biogas. In general, hydrogen sulfide concentrations during the second phase of this project remained near 3,000 ppmv. This result is consistent with observed iron patterns in the laboratory where iron concentrations initially increased in the bulk liquid, but then reached a plateau and became unavailable for further reaction with, and reduction of, H_2S. In addition, based on Figure 6-2, the use of $FeCl_3$ during the second phase of this project as compared with $FeCl_2$ during the first phase, did not seem to change the effectiveness of the iron at reducing hydrogen sulfide concentrations in the biogas. Finally, Figure 6-2 also shows that brief interruption in the iron feed generally resulted in a fast rebound of the hydrogen sulfide concentrations measured in the biogas. This observation suggests that there is no “excess” iron in the digester, and that the amounts supplied are readily used within the digester for reaction with H_2S, as well as other binding biochemical reactions. Data for Figure 6-2 is provided in Table A-2 in Appendix A herein.

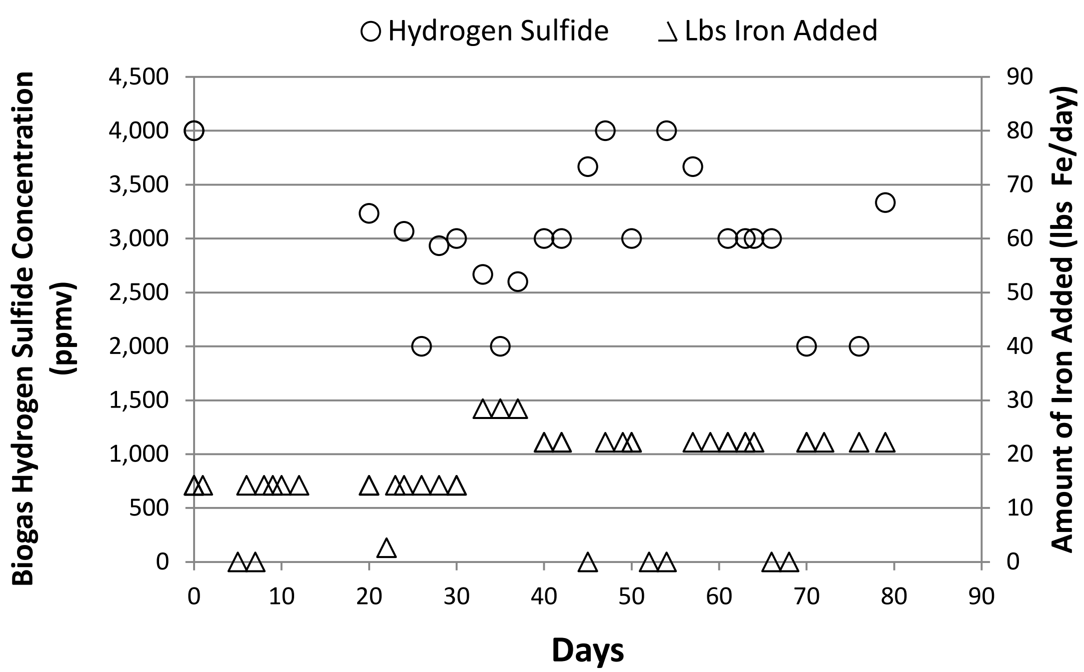

Figure 6-2. Measured H_2S in Biogas and Amount of Iron Added to the Digester

Figure 6-3 below shows the iron and total sulfide concentrations measured in the digester effluent (as per the data provided in Table 6-2). As the Figure shows, the dissolved total sulfide concentration in the digester effluent decreased from approximately 230 mg/L to approximately 150 mg/L during this study. This decrease coincided with an increase in the measured iron concentration in the digester effluent from approximately 60 mg/L to approximately 160 mg/L. Based on the reaction ratio presented in Section 5.0 herein (i.e., 1.63 mg/L iron reacts with 1 mg/L of H_2S), the measured increase in iron concentration in the digester of 100 mg/L should have resulted in a 61.3 mg/L decreased in H_2S concentration in the liquid phase. This calculated amount is comparable to the observed 80 mg/L decrease in the liquid H_2S concentration in the digester effluent. Note again that the actual measured iron concentration in the digester effluent was lower than the expected (or calculated) increase in iron concentration. This is attributable to the highly reductive anaerobic environment and the high total solids concentration in the bulk liquid matrix. These two factors create sinks that bind/absorb some of the added iron ions from the bulk liquid matrix before they react with available sulfide compounds.

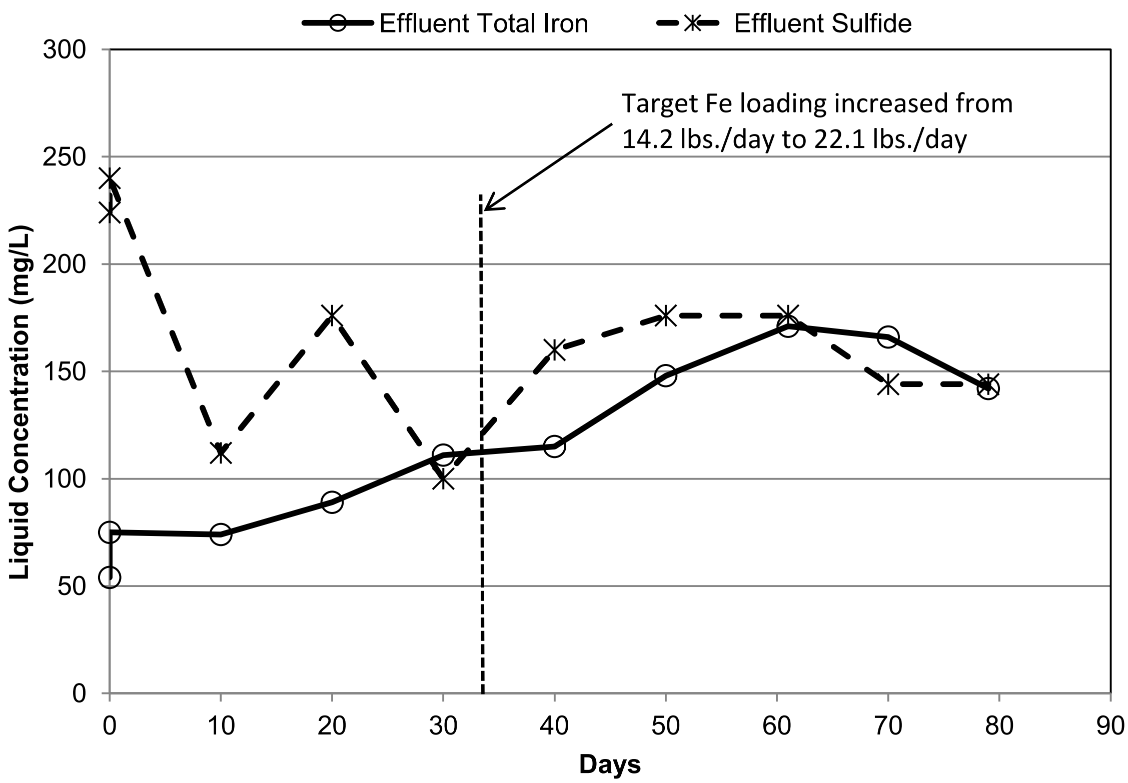

Figure 6-3. Measured Iron & Total Sulfide Concentrations in the Digester Effluent

Methane (CH_4) and Carbon Dioxide (CO_2) composition in the biogas stream produced by the AA Dairy digester was measured during this investigation. Results of these analyses are presented in Figure 6-4 below. As the figure shows, the biogas CH_4 and CO_2 levels remained relatively steady around 58% and 42%, respectively, with no clear trend of concentration increase or decrease. In general, when iron is a limited nutrient in a digester, iron addition can enhance methanogenic activity and result in an increase in the methane content of the biogas. Given that iron addition did not change the composition of the biogas (Figure 6-4), iron does not seem to be a limiting nutrient in the digester. This result is consistent with the fact that the digester system at AA Dairy is currently being operated significantly under design capacity. The AA dairy digester was designed to handle manure from a 1,000-cow dairy farm while AA Dairy maintains approximately 600 cows. If the digester is operated near or above its design load capacity, iron limitation of the anaerobic process could become more important for this digester.

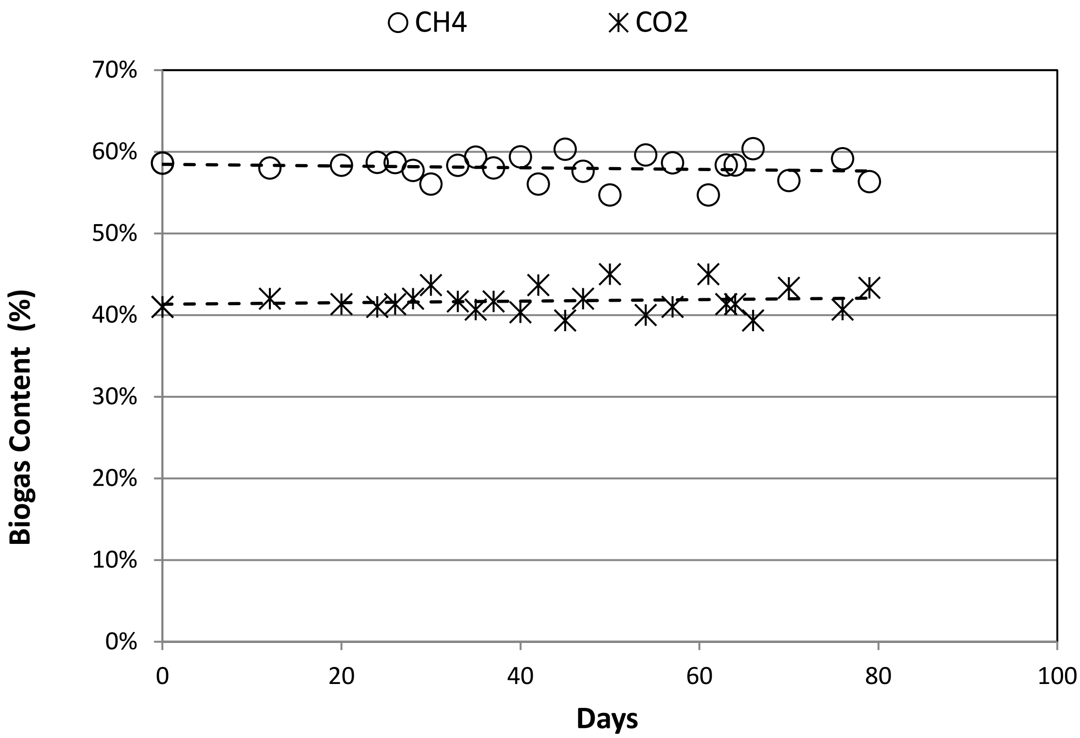

Figure 6-4. Measured CO_2 and Calculated CH_4 Fraction in Biogas
(Note: These analyses were completed by J. Pronto - Cornell University**)**

The potential for digester plugging due to iron sulfide precipitation was evaluated using stoichiometric calculations and field data. Based on the chemical reaction for removal of H_2S using $FeCl_2$ (as stated in Section 2.3 herein), 1 mole of $FeCl_2$ produces 1 mole of FeS, which is expected to precipitate out of solution as solids. Using molecular weights, 126.5 grams of $FeCl_2$ is expected to produce 87.5 grams of FeS, or 1 lb of $FeCl_2$ added to the digester bulk liquid is expected to produce 0.692 lbs. of FeS as solids. For the first phase of this investigation, 31.1 lbs/day of $FeCl_2$ were added to the digester. Therefore, 21.5 lbs/day of FeS precipitate is expected to be produced as solids in the digester bulk liquid.

Similarly, for the second phase of this investigation, based on the chemical reaction for removal of H_2S using $FeCl_3$ (as stated in Section 2.3 herein), 2 moles of $FeCl_3$ produce 1 mole of Fe_2S_3, which is expected to precipitate out of the solution as solids. Using molecular weights, 324 grams of $FeCl_3$ is expected to produce 207 grams of Fe_2S_3, or 1 lb of $FeCl_3$ added to the digester bulk liquid is expected to produce 0.639 lbs of Fe_2S_3 as solids. For the second phase of this investigation, 66.6 lbs/day of $FeCl_3$ were added to the digester. Therefore, 42.6 lbs/day of Fe_2S_3 precipitate is expected to be produced as solids in the digester bulk liquid.

By comparison, using the average total solids concentration of 74,137 mg/L (see 4-1 herein), and a flow rate of 11,000 gallons per day, the incoming raw manure stream introduces 6,805 lbs of solids per day into the AA Dairy digester. Thus, the expected additional solids loading from the H_2S removal technology under investigation, is a negligible 0.32% and 0.63% for phase 1 and phase 2 respectively.

The potential for digester plugging due to iron sulfide precipitation was also evaluated using field data (total suspended solids analyses shown in Table 6-2). As noted in Section 3.0 herein, the AA Dairy digester is a plug flow reactor with a 37 to 40 day Hydraulic Retention Time. Thus, for the digester bulk liquid, the effects of iron addition at the inlet point would be seen approximately 40 days later at the effluent point. Based on this understanding, an evaluation of the effect of iron addition on the bulk liquid total suspended solids content is presented in Table 6-3 below.

Table 6-3. Affect of Iron Addition on Digester Effluent Total Suspended Solids

HRT PERIOD	TSS at T_0 (mg/L)	TSS at T_F (mg/L)	REDUCTION IN TSS (%)
Day 0 — Day 39	36,500	19,333	47.0%
Day 9 — Day 49	23,500	21,333	9.2%
Day 19 — Day 59	28,200	25,300	10.3%
Day 29 — Day 69	20,666	25,333	-22.6%
Day 39 — Day 79	19,333	21,333	-10.4%
AVERAGE			6.7%

Table Notes:

- TSS Denotes Total Suspended Solids
- T_0 denotes beginning day in HRT Period
- T_f denotes ending day in HRT Period

As shown in Table 6-3, the average reduction in effluent total suspended solids for the duration of this study was 6.7%. Since the calculated reduction in effluent TSS for the period from day 0 to day 39 is significantly higher than the remaining periods observed, this measurement appears to have been skewed by sampling irregularity/error. If the values for the period from day 0 to day 39 are not included in the calculations, the change in the effluent total suspended solids content over the duration of this study is negligible. Based on stoichiometric calculations and the results shown in Table 6-3, iron addition and precipitation are not expected to affect digester plugging.

6.3 ECONOMIC EVALUATION OF PROPOSED TECHNOLOGY

Based on results obtained under this investigation, an economic analysis comparing iron chloride addition to the digester for hydrogen sulfide removal with conventional hydrogen sulfide removal from the biogas stream is presented below. This analysis was conducted for a digester system sized to handle 1,000 cows (i.e., similar to the digester at AA Dairy). The target H_2S removal chosen for this comparison is 50%. Three technologies were evaluated: Iron Sponge, Granular Activated Carbon, and a Caustic Scrubber.

Iron sponge use for hydrogen sulfide removal relies on media, typically steel wool or impregnated wood-chips (such as pine), which forms a reaction bed that selectively interacts with, and removes, hydrogen sulfide. Due to the fact that wood chips have a greater surface area and thus higher binding capacity than steel wool, they are generally preferred for the reaction bed material. The primary active ingredients are hydrated iron oxides (Fe_2O_3) of alpha and gamma crystalline structures. This process is highly effective, resulting in insoluble iron sulfides that can be rinsed off the media, and then easily filtered out of the aqueous solution. A typical iron sponge system handling a biogas flow rate of 30 SCFM is capable of reducing the hydrogen sulfide concentration to less than 300 ppm and costs typically range between $40,000 and $50,000. The media typically requires replacement every four to six months.

Granular activated carbon (GAC) particles have a highly porous adsorptive surface, which is the reason they are utilized in the removal of hydrogen sulfide. The GAC particles are typically impregnated with alkaline or oxide coatings to specifically enhance the efficiency of the removal of hydrogen sulfide. The coatings enhance the physical adsorptive characteristics of the carbon. Sodium hydroxide, sodium carbonate, potassium hydroxide, potassium iodide, and metal oxides are the most common coatings employed in such industrial applications. Activated carbon has a very high surface area (4,400 to 5,300 square inches per ounce), a wide variety of pore sizes, and a slightly charged nature, which attracts both inorganic and organic compounds. Typically, the carbon is loaded into two or more sequential pressure vessels and the biogas is pumped through the packed beds. As the surface area of the carbon becomes saturated with sulfur, the H_2S begins to appear in the gaseous effluent, which indicates that one of the vessels needs to be recharged or regenerated. For a 30-SCFM GAC system, equipment costs are approximately $12,000 to $14,000. Replacement GAC, expected to be needed twice per year, is sold in 35-pound bags at $1.50 - $2.00 per pound.

A Caustic Scrubber process uses reactions between sodium hydroxide and hydrogen sulfide gas to remove hydrogen sulfide from biogas streams by forming sodium hydrosulfide and water. The general chemical reaction of this process is as follows:

$$NaOH + H_2S \longrightarrow NaSH + H_2O$$

Typically, a caustic scrubber system can reduce hydrogen sulfide concentrations from 4,000 ppmv to approximately 500 ppmv. For a 30-SCFM caustic scrubber system, equipment costs are approximately $12,000 to $14,000. Caustic usage for such a unit is expected to range between 600 to 900 gallons per year, at a cost of approximately $4.25 per gallon.

Table 6-4. Cost Comparison of Different Hydrogen Sulfide Removal Technologies

Technology	Capital Investment Costs	Annual O&M Costs	Total Cost NPV[*1] 5 Yrs	10 Yrs
Iron Chloride Addition	$1,500 - $2,000	$8,000 - $10,000	($45,815)	($91,012)
Iron Sponge System	$40,000 - $50,000	$1,500 - $2,000	($52,268)	($61,056)
Carbon Filter System	$12,000 - $14,000	$3,500 - $4,500	($32,229)	($52,316)
Caustic Scrubber System	$12,000 - $15,000	$2,500 - $3,800	($28,548)	($44,366)

Table Notes:
*1 "Total Cost NPV" denotes the net present value of the capital investment and annual O&M costs for each technology, calculated as an average for the range of values shown.

As shown in Table 6-4, iron chloride addition has the lowest capital costs, but also has the highest operational/chemical costs. Based on the five and ten-year Net Present Value (NPV), carbon filter and caustic scrubber systems are less costly than iron chloride addition and iron sponge systems.

7.0 SUMMARY AND CONCLUSIONS

One of the main difficulties associated with digester biogas use at dairy farms is the presence of relatively high hydrogen sulfide (H_2S) concentrations. Hydrogen sulfide present in biogas streams corrodes engine parts in the combustion chamber, exhaust system, and in various bearings within the engine. The primary goal of this project was to assess the affect of dissolved iron addition to dairy farm digesters on H_2S concentrations in the biogas stream. A farm in NYS with an operational anaerobic plug-flow digester was selected for this project. Laboratory dosing experiments were completed to determine the relationship between the amount of iron added and the decrease in dissolved sulfide concentrations in the bulk liquid matrix. These experiments were used to design and construct a field chemical-dosing system at the selected farm. The dosing system was operated for approximately two digester hydraulic retention periods. Hydrogen sulfide levels in the liquid and biogas were monitored during the experimental period. Based on results observed from this investigation, the following observations and conclusions are noted:

1. The raw feed manure stream to the Farm digester and the treated effluent stream from the digester had the following physical and chemical properties prior to commencing this investigation:

	Raw Feed Manure Stream		**Digester Treated Effluent Stream**	
Parameter	**Average Value**	**Standard Deviation**	**Average Value**	**Standard Deviation**
TS	74,137 mg/L	5,211	18,674 mg/L	775
VS	21,128 mg/L	4,816	10,882 mg/L	1,158
COD	70,800 mg/L	7,150	28,985 mg/L	1,905
NH_3-N	1,494 mg/L	111	1,272 mg/L	375
NO_3-N	1,297 mg/L	291	274 mg/L	112
PO_4	2,408 mg/L	212	1,198 mg/L	134
SO_4	2,874 mg/L	1,557	4,390 mg/L	443
Sulfides	50 mg/L	2	30 mg/L	1.1
Total Iron	133 mg/L	16.7	5.1 mg/L	2.9

2. Addition of ferric chloride to manure samples in laboratory experiments resulted in significant reduction in H_2S and sulfate concentrations in the liquid phase.

3. In the laboratory-scale experiments, a Fe concentration of 150 mg/L in the raw manure bulk liquid resulted in approximately 40% reduction in total sulfide concentration in the liquid matrix.

4. In the on-farm demonstration, an iron chloride concentration of 150 mg/L resulted in a reduction of approximately 40% of the sulfide concentration in the biogas stream.

5. Further reduction in sulfide biogas concentration (60% or above) was not readily achievable, likely due to significant sinks/binding of iron ions in the digester bulk liquid matrix. For example, in order to achieve a 70% reduction in the total sulfides concentration in the liquid matrix a Fe concentration of 250 mg/L in the raw manure bulk liquid was required.

6. The low Oxidation-Reduction Potential (ORP) created by the anaerobic environment combined with the presence of high suspended solids in the bulk liquid matrix is suspected to cause the "loss" of available iron ions through chemical precipitation and absorption mechanisms.

7. Lack of mixing and high suspended solids in the bulk liquid matrix appear to be inherent disadvantages for using iron dosing systems to remove biogas H_2S content in plug-flow digesters specifically.

8. The use of ferrous chloride as compared with ferric chloride did not seem to change the effectiveness of the iron salts at reducing hydrogen sulfide concentrations in the field (when compared on a similar weight basis).

9. No measurable changes in the CH_4 and CO_2 content in the biogas stream were observed due to iron addition, suggesting that iron was not a limiting nutrient under the digester operational parameters prevailing during this investigation.

10. Formation and precipitation of iron sulfides did not result in a measurable increase in the total solids concentration in the digester, thus there is minimal potential for digester plugging due to this process.

11. Direct addition of ferric chloride and ferrous chloride to dairy farm digesters is an effective method for reducing the hydrogen sulfide concentration in the biogas produced from the digesters. Further investigation into minimizing the effects of iron sinks/binding in the digester bulk liquid matrix, such as enhanced delivery and digester mixing, offer the potential to further improve performance.

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Assessment of Biochemical Process Controls for Reduction of Hydrogen Sulfide Concentrations in Biogas from Farm Digesters

Final Report
February 2012

State of New York
Andrew M. Cuomo, Governor

New York State Energy Research and Development Authority
Francis J. Murray, Jr., President and CEO

APPENDIX D:

TABLES FOR EMISSION REDUCTION AND COST-EFFECTIVENESS CALCULATIONS

This appendix presents tables summarizing the data needed to calculate the emission reductions and cost-effectiveness of potential projects. Included are data such as engine emission factors, load factors, and other conversion factors used in the calculations discussed in Appendix C: Cost-Effectiveness Calculation Methodology.

Table D-1
Heavy-Duty Vehicles
14,001-33,000 pounds (lbs) Gross Vehicle Weight Rating (GVWR)
Emission Factors (g/mile)[(a)] (EF) and Deterioration Rates (g/mile-10k miles) (DR)

Engine Model Year	NOx[(b)]		ROG[(b),(c)]		PM[(b),(i)]	
	EF[(d)]	DR[(e)]	EF[(d)]	DR[(e)]	EF[(d)]	DR[(e)]
Pre-1987	14.52	0.031	0.89	0.051	0.713	0.0283
1987-90	14.31	0.041	0.70	0.060	0.774	0.0252
1991-93	10.70	0.054	0.37	0.031	0.425	0.0193
1994-97	10.51	0.063	0.27	0.036	0.241	0.0129
1998-02	10.33	0.072	0.28	0.036	0.266	0.0116
2003-06	6.84	0.071	0.23	0.021	0.175	0.0067
2007-09	3.99	0.090	0.18	0.007	0.014	0.0008
2007+[(f)] (0.21-0.50 g/bhp-hr NOx FEL)	1.27	0.079	0.06	0.002	0.002	0.0001
2010-12 (0.20 g/bhp-hr NOx std)	1.03	0.079	0.06	0.002	0.002	0.0001
2013+[(g)] (0.20 g/bhp-hr NOx std)	1.03	0.045	0.06	0.001	0.002	0.0001
2016+[(h)] (0.10 g/bhp-hr NOx std)	0.52	0.023	0.06	0.001	0.002	0.0001
2016+[(h)] (0.05 g/bhp-hr NOx std)	0.26	0.011	0.06	0.001	0.002	0.0001
2016+[(h)] (0.02 g/bhp-hr NOx std)	0.10	0.005	0.06	0.001	0.002	0.0001

(a) EMFAC 2014 Zero-Mile Based Emission Factors. Factors are based on diesel engines. Same factors used for alternative fuel engines due to limited alternative fuel data in EMFAC.

(b) Emission factors incorporate the ultra low-sulfur diesel fuel correction factors listed in Table D-22. NOx – Oxides of nitrogen, ROG – Reactive Organic Gases, PM – Particulate Matter.

(c) EMFAC provides HC emission factors which are converted into ROG. ROG = HC * 1.26639.

(d) Emission Factors are based on zero-mile rates contained in EMFAC 2014.

(e) Deterioration Rate per 10,000 miles.

(f) All model year 2007 and newer engines with Family Emission Limits (FEL) from 0.21 g/bhp-hr to 0.50 g/bhp-hr NOx must use different emission factors from those listed for model years 2010 and newer engines certified to 0.20 g/bhp-hr NOx standards. FEL emission factors are based on EMFAC factors for model year 2010-2012 engines that include weighted averaging of 0.5, 0.35, and 0.20 g/bhp-hr NOx standards based on sales.

(g) Deterioration rates for 2013+ engines incorporate use of on-board diagnostic system.

(h) Factors for 2016+ engines are reduced values of 2013 factors by 50 percent, 75 percent, and 90 percent to correspond with 0.10 g/bhp-hr NOx, 0.05 g/bhp-hr NOx, and 0.02 g/bhp-hr NOx optional low NOx standards.

(i) Factors for 2006 or older engines are for unfiltered trucks.

Table D-2
Heavy-Duty Vehicles
Over 33,000 pounds (lbs) GVWR
Emission Factors (g/mile)[a] (EF) and Deterioration Rates (g/mile-10k miles) (DR)

Engine Model Year	NOx[b]		ROG[b],[c]		PM[b],[i]	
	EF[d]	DR[e]	EF[d]	DR[e]	EF[d]	DR[e]
Pre-1987	21.37	0.018	1.38	0.031	1.260	0.0200
1987-90	21.07	0.024	1.08	0.037	1.369	0.0178
1991-93	18.24	0.037	0.78	0.027	0.574	0.0104
1994-97	17.92	0.043	0.58	0.031	0.377	0.0080
1998-02	17.61	0.049	0.60	0.031	0.415	0.0073
2003-06	11.66	0.049	0.49	0.018	0.267	0.0041
2007-09	6.80	0.077	0.39	0.007	0.022	0.0006
2007+[f] (0.21-0.50 g/bhp-hr NOx FEL)	2.17	0.068	0.13	0.002	0.004	0.0001
2010-12 (0. 2 g/bhp-hr NOx std)	1.76	0.068	0.13	0.002	0.004	0.0001
2013+[g] (0. 2 g/bhp-hr NOx std)	1.76	0.039	0.13	0.001	0.004	0.0001
2016+[h] (0.10 g/bhp-hr NOx std)	0.88	0.019	0.13	0.001	0.004	0.0001
2016+[h] (0.05 g/bhp-hr NOx std)	0.44	0.010	0.13	0.001	0.004	0.0001
2016+[h] (0.02 g/bhp-hr NOx std)	0.18	0.004	0.13	0.001	0.004	0.0001

[a] EMFAC 2014 Zero-Mile Based Emission Factors. Factors are based on diesel engines. Same factors used for alternative fuel engines due to limited alternative fuel data in EMFAC.
[b] Emission factors incorporate the ultra low-sulfur diesel fuel correction factors listed in Table D-22.
[c] EMFAC provides HC emission factors which are converted into ROG. ROG = HC * 1.26639.
[d] Emission Factors are based on zero-mile rates contained in EMFAC 2014.
[e] Deterioration Rate are per 10,000 miles.
[f] All model year 2007 and newer engines with Family Emission Limits (FEL) from 0.21 g/bhp-hr to 0.50 g/bhp-hr NOx must use different emission factors from those listed for model years 2010 and newer engines certified to 0.20 g/bhp-hr NOx standards. FEL emission factors are based on EMFAC factors for model year 2010-2012 engines that include weighted averaging of 0.5, 0.35, and 0.20 g/bhp-hr NOx standards based on sales.
[g] Deterioration rates for 2013+ engines incorporate use of on-board diagnostic system.
[h] Factors for 2016+ engines are reduced values of 2013 factors by 50 percent, 75 percent, and 90 percent to correspond with 0.10 g/bhp-hr NOx, 0.05 g/bhp-hr NOx, and 0.02 g/bhp-hr NOx optional low NOx standards, respectively.
[i] Factors for 2006 or older engines are for unfiltered trucks.

Table D-3
Diesel Urban Buses
Emission Factors (g/mile)[a]

Engine Model Year	NOx[b]	ROG[b],[c]	PM[b],[e]
Pre-1987	42.97	1.88	0.929
1987-1990	37.39	1.87	0.878
1991-1993	23.72	1.84	0.835
1994-1995	27.71	1.81	1.015
1996-1998	36.46	1.81	1.217
1999-2002	18.97	1.81	0.417
2003	13.02	0.77	0.084
2004-2006	3.56	0.08	0.084
2007+ (0.20 g/bhp-hr NOx std)	1.90	0.03	0.011
2016+[d] (0.10 g/bhp-hr NOx std)	0.95	0.03	0.011
2016+[d] (0.05 g/bhp-hr NOx std)	0.47	0.03	0.011
2016+[d] (0.02 g/bhp-hr NOx std)	0.19	0.03	0.011

[a] EMFAC 2014 Zero-Mile Based Emission Factors.
[b] Emission factors incorporate the ultra low-sulfur diesel fuel correction factors listed in Table D-22.
[c] EMFAC provides HC emission factors which are converted into ROG. ROG = HC * 1.26639.
[d] Factors for 2016+ engines are reduced values of 2007 factors by 50 percent, 75 percent, and 90 percent to correspond with 0.10 g/bhp-hr NOx, 0.05 g/bhp-hr NOx, and 0.02 g/bhp-hr NOx optional low NOx standards, respectively.
[e] Factors for 2006 or older engines are for unfiltered trucks.

Table D-4
Alternative Fuel Urban Buses
Emission Factors (g/mile)[a]

Engine Model Year	NOx	ROG[b]	PM[d]
Pre-2003	21.60	2.68	0.043
2003-06	15.40	3.87	0.023
2007+ (0.20 g/bhp-hr NOx std)	0.65	0.04	0.001
2016+[c] (0.10 g/bhp-hr NOx std)	0.33	0.04	0.001
2016+[c] (0.05 g/bhp-hr NOx std)	0.16	0.04	0.001
2016+[c] (0.02 g/bhp-hr NOx std)	0.07	0.04	0.001

[a] EMFAC 2014 Zero-Mile Based Emission Factors.
[b] EMFAC provides HC emission factors which are converted into ROG.
ROG (Pre-2007 engines) = HC * 0.16137.
ROG (2007+ engines) = HC * 0.013972.
[c] Factors for 2016+ engines are reduced values of 2007 factors by 50 percent, 75 percent, and 90 percent to correspond with 0.10 g/bhp-hr NOx, 0.05 g/bhp-hr NOx, and 0.02 g/bhp-hr NOx optional low NOx standards, respectively.
[d] Factors for 2006 or older engines are for unfiltered trucks.

Table D-5
Diesel Refuse Trucks
Emission Factors (g/mile)[a]

Engine Model Year	NOx[b]	ROG[b],[c]	PM[b],[g]
pre-1994	34.69	0.01	0.346
1994-97	31.53	0.01	0.137
1998-02	31.25	0.01	0.144
2003-06	21.39	0.01	0.086
2007-09	11.25	0.14	0.008
2007+[d] (0.21-0.50 g/bhp-hr NOx FEL)	1.23	0.26	0.008
2010+[e] (0.20 g/bhp-hr NOx std)	1.09	0.04	0.008
2016+[f] (0.10 g/bhp-hr NOx)	0.54	0.04	0.008
2016+[f] (0.05 g/bhp-hr NOx)	0.27	0.04	0.008
2016+[f] (0.02 g/bhp-hr NOx)	0.11	0.04	0.008

Note: These emission factors are not applicable to transfer trucks. Transfer trucks must use the emission factors from Table D-1 or D-2. Per EMFAC 2014, solid waste collection vehicles are considered to be well-maintained and have negligible deterioration which is why only zero-mile emission factors are to be used in calculations for solid waste collection vehicle projects.

(a) EMFAC 2014 Zero-Mile Based Emission Factors.
(b) Emission factors incorporate the ultra low-sulfur diesel fuel correction factors listed in Table D-22.
(c) EMFAC provides HC emission factors which are converted into ROG. ROG = HC * 1.26639.
(d) All model year 2007 and newer engines with Family Emission Limits (FEL) from 0.21 g/bhp-hr to 0.50 g/bhp-hr NOx must use different emission factors from those listed for model years 2010 and newer engines certified to 0.20 g/bhp-hr NOx standards. FEL emission factors are based on EMFAC factors for model year 2010-2012 engines that include weighted averaging of 0.5, 0.35, and 0.20 g/bhp-hr NOx standards based on sales.
(e) These 2010+ emission factors are based only on engines certified to the 0.20 g/bhp-hr NOx standard.
(f) Factors for 2016+ engines are reduced values of 2013 factors by 50 percent, 75 percent, and 90 percent to correspond with 0.10 g/bhp-hr NOx, 0.05 g/bhp-hr NOx, and 0.02 g/bhp-hr NOx optional low NOx standards, respectively.
(g) Factors for 2006 or older engines are for unfiltered trucks.

Table D-6
Alternative Fuel Refuse Trucks
Emission Factors (g/mile)[a]

Engine Model Year	NOx	ROG[b]	PM[d]
Pre-2007	53.20	9.86	0.091
2007-09	18.80	3.68	0.004
2010+ (0.20 g/bhp-hr NOx std)	0.88	0.14	0.004
2016+[c] (0.10 g/bhp-hr NOx)	0.44	0.14	0.004
2016+[c] (0.05 g/bhp-hr NOx)	0.22	0.14	0.004
2016+[c] (0.02 g/bhp-hr NOx)	0.09	0.14	0.004

Note: These emission factors are not applicable to transfer trucks. Transfer trucks must use the emission factors from Table D-1 or D-2. Per EMFAC 2014, solid waste collection vehicles are considered to be well-maintained and have negligible deterioration which is why only zero-mile emission factors are to be used in calculations for solid waste collection vehicle projects.

[a] EMFAC 2014 Zero-Mile Based Emission Factors.
[b] EMFAC provides HC emission factors which are converted into ROG.
ROG (Pre-2007 engines) = HC * 0.16137.
ROG (2007+ engines) = HC * 0.013972.
[c] Factors for 2016+ engines are reduced values of 2010 factors by 50 percent, 75 percent, and 90 percent to correspond with 0.10 g/bhp-hr NOx, 0.05 g/bhp-hr NOx, and 0.02 g/bhp-hr NOx optional low NOx standards, respectively.
[d] Factors for 2006 or older engines are for unfiltered trucks.

OFF-ROAD PROJECTS AND
NON-MOBILE AGRICULTURAL PROJECTS

Table D-7
Off-Road Diesel Engines Default Load Factors

Category	Equipment Type	Load Factor
Airport Ground Support	Aircraft Tug	0.54
	Air Conditioner	0.75
	Air Start Unit	0.90
	Baggage Tug	0.37
	Belt Loader	0.34
	Bobtail	0.37
	Cargo Loader	0.34
	Cargo Tractor	0.36
	Forklift	0.20
	Ground Power Unit	0.75
	Lift	0.34
	Passenger Stand	0.40
	Service Truck	0.20
	Other Ground Support Equipment	0.34
Agricultural (Mobile, Portable or Stationary)	Agricultural Mowers	0.43
	Agricultural Tractors	0.70
	Balers	0.58
	Combines/Choppers	0.70
	Chippers/Stump Grinders	0.73
	Generator Sets	0.74
	Hydro Power Units	0.48
	Irrigation Pump	0.65
	Shredders	0.40
	Sprayers	0.50
	Swathers	0.55
	Tillers	0.78
	Other Agricultural	0.51
Construction	Air Compressors	0.48
	Bore/Drill Rigs	0.50
	Cement & Mortar Mixers	0.56
	Concrete/Industrial Saws	0.73
	Concrete/Trash Pump	0.74
	Cranes	0.29
	Crawler Tractors	0.43
	Crushing/Process Equipment	0.78
	Excavators	0.38
	Graders	0.41

Table D-7
Off-Road Diesel Engines Default Load Factors
(Continued)

Category	Equipment Type	Load Factor
Construction	Off-Highway Tractors	0.44
	Off-Highway Trucks	0.38
	Pavers	0.42
	Other Paving	0.36
	Pressure Washer	0.30
	Rollers	0.38
	Rough Terrain Forklifts	0.40
	Rubber Tired Dozers	0.40
	Rubber Tired Loaders	0.36
	Scrapers	0.48
	Signal Boards	0.78
	Skid Steer Loaders	0.37
	Surfacing Equipment	0.30
	Tractors/Loaders/Backhoes	0.37
	Trenchers	0.50
	Welders	0.45
	Other Construction Equipment	0.42
Industrial	Aerial Lifts	0.31
	Forklifts	0.20
	Sweepers/Scrubbers	0.46
	Other General Industrial	0.34
	Other Material Handling	0.40
Logging	Fellers/Bunchers	0.71
	Skidders	0.74
Oil Drilling	Drill Rig	0.50
	Lift (Drilling)	0.60
	Swivel	0.60
	Workover Rig (Mobile)	0.50
	Other Workover Equipment	0.60
Cargo Handling	Container Handling Equipment	0.59
	Cranes	0.20
	Excavators	0.55
	Forklifts	0.30
	Other Cargo Handling Equipment	0.51
	Sweeper/Scrubber	0.68
	Tractors/Loaders/Backhoes	0.55
	Yard Trucks	0.39
Other	All	0.43

Table D-8
Uncontrolled Off-Road Diesel Engines
Emission Factors (g/bhp-hr) (EF) and Deterioration Rates (g/bhp-hr-hr) (DR)

Horsepower	Model Year	NOx		ROG		PM10	
		EF	DR	EF	DR	EF	DR
25-49	Pre-1988	6.51	0.000098	1.68	0.000210	0.547	0.0000424
	1988+	6.42	0.000097	1.64	0.000210	0.547	0.0000424
20-119	Pre-1988	12.09	0.00028	1.31	0.000061	0.605	0.0000440
	1988+	8.14	0.00019	0.90	0.000042	0.497	0.0000361
120+	Pre-1970	13.02	0.00030	1.20	0.000056	0.554	0.0000403
	1970-1979	11.16	0.00026	0.91	0.000042	0.396	0.0000288
	1980-1987	10.23	0.00024	0.80	0.000037	0.396	0.0000288
	1988+	7.60	0.00018	0.62	0.000029	0.274	0.0000199

Table D-9
Controlled Off-Road Diesel Engines
Emission Factors (g/bhp-hr) (EF) and Deterioration Rates (g/bhp-hr-hr) (DR) [(a)]

Horsepower	Tier	NOx		ROG		PM10	
		EF	DR	EF	DR	EF	DR
25-49	1	5.26	0.0000980	1.32	0.000170	0.480	0.0000372
	2	4.63	0.0000930	0.22	0.000050	0.280	0.0000218
	4 (Interim)	4.55	0.0000950	0.09	0.000036	0.128	0.0000096
	4 (Final)	2.75	0.0000570	0.09	0.000036	0.009	0.0000010
50-74	1	6.54	0.0001500	0.90	0.000042	0.552	0.0000402
	2	4.75	0.0000710	0.17	0.000025	0.192	0.0000141
	3[(b)]	2.74	0.0000360	0.09	0.000023	0.192	0.0000141
	4 (Interim)	2.74	0.0000360	0.09	0.000023	0.112	0.0000080
	4 (Final)	2.74	0.0000360	0.09	0.000023	0.009	0.0000009
75-99	1	6.54	0.0001500	0.90	0.000042	0.552	0.0000402
	2	4.75	0.0000710	0.17	0.000025	0.192	0.0000141
	3	2.74	0.0000360	0.09	0.000023	0.112	0.0000080
	4 (Phase-Out)	2.74	0.0000360	0.09	0.000030	0.009	0.0000009
	4 (Phase-In or Alt. NOx)	2.15	0.0000270	0.08	0.000021	0.009	0.0000009
	4 (Final)	0.26	0.0000035	0.05	0.000015	0.009	0.0000009
100-174	1	6.54	0.0001500	0.62	0.000029	0.304	0.0000221
	2	4.15	0.0000600	0.15	0.000023	0.128	0.0000094
	3	2.32	0.0000300	0.09	0.000030	0.112	0.0000080
	4 (Phase-Out)	2.32	0.0000300	0.09	0.000030	0.009	0.0000004
	4 (Phase-In or Alt. NOx)	2.15	0.0000270	0.08	0.000020	0.009	0.0000004
	4 (Final)	0.26	0.0000040	0.05	0.000011	0.009	0.0000004

Table D-9
Controlled Off-Road Diesel Engines
Emission Factors (g/bhp-hr) (EF) and Deterioration Rates (g/bhp-hr-hr) (DR) [(a)]
(Continued)

Horsepower	Tier	NOx		ROG		PM10	
		EF	DR	EF	DR	EF	DR
175-299	1	5.93	0.0001400	0.29	0.000013	0.120	0.0000064
	2	4.15	0.0000600	0.11	0.000022	0.088	0.0000046
	3	2.32	0.0000300	0.09	0.000023	0.088	0.0000046
	4 (Phase-Out)	2.32	0.0000300	0.09	0.000023	0.009	0.0000003
	4 (Phase-In or Alt. NOx)	1.29	0.0000170	0.06	0.000017	0.009	0.0000003
	4 (Final)	0.26	0.0000036	0.05	0.000011	0.009	0.0000003
300-750	1	5.93	0.0000990	0.29	0.000010	0.120	0.0000064
	2	3.79	0.0000500	0.09	0.000023	0.088	0.0000044
	3	2.32	0.0000300	0.09	0.000023	0.088	0.0000044
	4 (Phase-Out)	2.32	0.0000300	0.09	0.000023	0.009	0.0000003
	4 (Phase-In or Alt. NOx)	1.29	0.0000170	0.06	0.000017	0.009	0.0000003
	4 (Final)	0.26	0.0000036	0.05	0.000011	0.009	0.0000003
751+	1	5.93	0.0000990	0.29	0.000010	0.120	0.0000064
	2	3.79	0.0000500	0.09	0.000023	0.088	0.0000044
	4 (Interim)	2.24	0.0000280	0.06	0.000017	0.051	0.0000021
	4 (Final)	2.24	0.0000280	0.05	0.000011	0.017	0.0000009

Note: Engines participating in the "Tier 4 Early Introduction Incentive for Engine Manufacturers" program per California Code of Regulations, Title 13, section 2423(b)(6) are eligible for funding provided the engines are certified to the final Tier 4 emission standards. The Air Resources Board (ARB) Executive Order indicates engines certified under this provision. The emission rates for these engines shall be equivalent to the emission factors associated with Tier 3 engines.

Note: For equipment with baseline engines certified under the flexibility provisions per California Code of Regulations, Titles 13, section 2423(d), baseline emission rates shall be determined by using the previous applicable emission standard or Tier for that engine model year and horsepower rating. The ARB Executive Order indicates engines certified under this provision.

[(a)] Emission factors were converted using the ultra low-sulfur diesel fuel correction factors listed in Table D-23.
[(b)] Alternate compliance option.

LARGE SPARK IGNITION ENGINES

Table D-10
Off-Road LSI Equipment Default Load Factors

Category	Equipment Type	Load Factor
Agriculture (Mobile, Portable or Stationary)	Agricultural Tractors	0.62
	Balers	0.55
	Combines/Choppers	0.74
	Chipper/Stump Grinder	0.78
	Generator Sets	0.68
	Sprayers	0.50
	Swathers	0.52
	Pumps	0.65
	Other Agricultural Equipment	0.55
Airport Ground Support	A/C Tug	0.80
	Baggage Tug	0.55
	Belt Loader	0.50
	Bobtail	0.55
	Cargo Loader	0.50
	Forklift	0.30
	Ground Power Unit	0.75
	Lift	0.50
	Passenger Stand	0.59
	Other Ground Support Equipment	0.50
Construction	Air Compressors	0.56
	Asphalt Pavers	0.66
	Bore/Drill Rigs	0.79
	Concrete/Industrial Saws	0.78
	Concrete/Trash Pump	0.69
	Cranes	0.47
	Gas Compressor	0.85
	Paving Equipment	0.59
	Pressure Washer	0.85
	Rollers	0.62
	Rough Terrain Forklifts	0.63
	Rubber Tired Loaders	0.54
	Skid Steer Loaders	0.58
	Tractors/Loaders/Backhoes	0.48

Table D-10
Off-Road LSI Equipment Default Load Factors
(Continued)

Category	Equipment Type	Load Factor
Construction	Trenchers	0.66
	Welders	0.51
	Other Construction	0.48
Industrial	Aerial Lifts	0.46
	Forklifts	0.30
	Sweepers/Scrubbers	0.71
	Other Industrial	0.54

Table D-11a
Off-Road LSI Engines
Emission Factors (g/bhp-hr) (EF) and Deterioration Rates (g/bhp-hr-hr) (DR)
Gasoline

Horsepower	Model Year	NOx		ROG		PM10	
		EF	DR	EF	DR	EF	DR
25-50	Uncontrolled pre-2004	8.01	0.0000406	3.760	0.000412	0.060	0.000
	Controlled 2001 - 2006	1.33	0.0004710	0.710	0.000169	0.060	0.000
	Controlled 2007 - 2009	0.89	0.0001192	0.473	0.000064	0.060	0.000
	Controlled 2010+	0.27	0.0000250	0.142	0.000013	0.060	0.000
51-120	Uncontrolled Pre-2004	11.84	0.0000601	2.630	0.000287	0.060	0.000
	Controlled 2001 – 2006	1.78	0.0002070	0.260	0.000081	0.060	0.000
	Controlled 2007 - 2009	1.17	0.0000660	0.130	0.000074	0.060	0.000
	Controlled 2010+	0.35	0.0000300	0.030	0.000014	0.060	0.000
121+	Uncontrolled pre-2004	12.94	0.0001270	1.610	0.000042	0.060	0.000
	Controlled 2001 – 2006	1.94	0.0002780	0.160	0.000102	0.060	0.000
	Controlled 2007 - 2009	1.17	0.0000660	0.130	0.000074	0.060	0.000
	Controlled 2010+	0.35	0.0000300	0.030	0.000014	0.060	0.000

Table D-11b
Off-Road LSI Engines
Emission Factors (g/bhp-hr) (EF) and Deterioration Rates (g/bhp-hr-hr) (DR)
Alternative Fuels

Horsepower	Model Year	NOx		ROG		PM10	
		EF	DR	EF	DR	EF	DR
25-50	Uncontrolled pre-2004	13.00	0.0000662	1.380	0.000151	0.060	0.000
	Controlled 2001 - 2006	1.95	0.0002760	0.140	0.000106	0.060	0.000
	Controlled 2007 - 2009	1.30	0.0000011	0.093	0.000172	0.060	0.000
	Controlled 2010+	0.39	0.0000002	0.028	0.000036	0.060	0.000
51-120	Uncontrolled pre-2004	10.53	0.0000533	1.550	0.000169	0.060	0.000
	Controlled 2001 – 2006	1.58	0.0003500	0.160	0.000103	0.060	0.000
	Controlled 2007 - 2009	1.04	0.0000125	0.100	0.000047	0.060	0.000
	Controlled 2010+	0.31	0.0000380	0.030	0.000014	0.060	0.000
121+	Uncontrolled pre-2004	10.51	0.0001040	1.380	0.000035	0.060	0.000
	Controlled 2001 – 2006	1.58	0.0002640	0.140	0.000106	0.060	0.000
	Controlled 2007 - 2009	1.04	0.0000125	0.100	0.000047	0.060	0.000
	Controlled 2010+	0.31	0.0000380	0.030	0.000014	0.060	0.000

Table D-12
Emission Factors for Off-Road LSI Engine Retrofits
Verified to Absolute Emission Number (g/bhp-hr)

Manufacturers of LSI retrofit systems may verify to a percentage emission reduction or absolute emissions. If a retrofit system is verified to a percentage reduction, the emission factors will be that verified percentage of the appropriate emissions factors in Table D-11a or D-11b. If a retrofit system is verified to an absolute emission number, when calculating emission reductions use the following table for the emission factors and the deterioration rate for the baseline engine.

Fuel	Verified Value	NOx	ROG	PM10
Gasoline	3.0	1.78	0.26	0.060
	2.5	1.48	0.22	0.060
	2.0	1.19	0.17	0.060
	1.5	0.89	0.13	0.060
	1.0	0.59	0.09	0.060
	0.6	0.35	0.03	0.060
	0.5	0.29	0.03	0.060
Alt Fuel	3.0	1.58	0.16	0.060
	2.5	1.32	0.13	0.060
	2.0	1.05	0.11	0.060
	1.5	0.79	0.08	0.060
	1.0	0.53	0.05	0.060
	0.6	0.31	0.03	0.060
	0.5	0.26	0.03	0.060

Table D-13a
Off-Road LSI Engines Certified to Optional Standards
Emission Factors (g/bhp-hr) (EF) and Deterioration Rates (g/bhp-hr-hr) (DR)
Gasoline

Horsepower	Optional Standard	NOx		ROG		PM10	
		EF	DR	EF	DR	EF	DR
25-50	0.4	0.18	0.000017	0.09	0.0000087	0.060	0.000
	0.2	0.09	0.000008	0.05	0.0000043	0.060	0.000
	0.1	0.04	0.000005	0.02	0.0000027	0.060	0.000
51-120	0.4	0.24	0.000021	0.04	0.0000034	0.060	0.000
	0.2	0.12	0.000010	0.02	0.0000017	0.060	0.000
	0.1	0.06	0.000005	0.01	0.0000009	0.060	0.000
121+	0.4	0.26	0.000022	0.02	0.0000017	0.060	0.000
	0.2	0.13	0.000011	0.01	0.0000009	0.060	0.000
	0.1	0.06	0.000005	0.01	0.0000009	0.060	0.000

Table D-13b
Off-Road LSI Engines Certified to Optional Standards
Emission Factors (g/bhp-hr) (EF) and Deterioration Rates (g/bhp-hr-hr) (DR)
Alternative Fuels

Horsepower	Optional Standard	NOx		ROG		PM10	
		EF	DR	EF	DR	EF	DR
25-50	0.4	0.26	0.000022	0.02	0.0000017	0.060	0.000
	0.2	0.13	0.000011	0.01	0.0000009	0.060	0.000
	0.1	0.07	0.000006	0.00	0.0000000	0.060	0.000
51-120	0.4	0.21	0.000031	0.02	0.0000030	0.060	0.000
	0.2	0.11	0.000015	0.01	0.0000013	0.060	0.000
	0.1	0.05	0.000007	0.01	0.0000013	0.060	0.000
121+	0.4	0.21	0.000034	0.01	0.0000016	0.060	0.000
	0.2	0.11	0.000015	0.01	0.0000013	0.060	0.000
	0.1	0.05	0.000010	0.00	0.0000000	0.060	0.000

LOCOMOTIVES

Table D-14a
Locomotive Emission Factors (g/bhp-hr)
Based on 1998 Federal Standards

Engine Model Year	Type	NOx[(a)]	ROG[(b)]	PM10[(a)]
Pre-1973	Line-haul and Passenger	12.22	0.51	0.275
	Switcher	16.36	1.06	0.378
1973-2001 Tier 0	Line-haul and Passenger	8.93	1.05	0.516
	Switcher	13.16	2.21	0.619
2002-2004 Tier 1	Line-haul and Passenger	6.96	0.58	0.387
	Switcher	10.34	1.26	0.464
2005-2011 Tier 2	Line-haul and Passenger	5.17	0.32	0.172
	Switcher	7.61	0.63	0.206

Note: These factors are to be used for the project baseline emissions if the baseline locomotive is certified or required to be certified to the 1998 federal locomotive remanufacture standards, and for the reduced emission locomotive if the project locomotive is remanufactured to these 1998 standards. Factors are based upon Regulatory Impact Analysis: Final United States Environmental Protection Agency (U.S. EPA) Locomotive Regulation (2008).

(a) NOx and PM10 emission factors have been adjusted by a factor of 0.94 and 0.86, respectively, to account for use of California ultra-low sulfur diesel fuel.
(b) ROG = HC * 1.053

Table D-14b
Locomotive Emission Factors (g/bhp-hr)
Based on 2008 Federal Standards

Engine Model Year	Type	NOx(a)	ROG(b)	PM10(a)
1973-2001 Tier 0+	Line-haul and Passenger	6.96	0.58	0.189
	Switcher	11.09	2.21	0.224
2002-2004 Tier 1+	Line-haul and Passenger	6.96	0.58	0.189
	Switcher	10.34	1.26	0.224
2005-2011 Tier 2+	Line-haul and Passenger	5.17	0.32	0.086
	Switcher	7.61	0.63	0.112
2011-2014 Tier 3	Line-haul and Passenger	5.17	0.32	0.086
	Switcher	4.70	0.63	0.086
2015 Tier 4	Line-haul and Passenger	1.22	0.15	0.026
	Switcher	1.22	0.15	0.026

Note: These factors are to be used for the project baseline emissions if the baseline locomotive is certified or required to be certified to the new (2008) federal locomotive remanufacture standards, and for the reduced emission locomotive if the project locomotive is remanufactured to the new standards or meets Tier 3 standards. Factors are based upon Regulatory Impact Analysis: Final U.S. EPA Locomotive Regulation (2008).

(a) NOx and PM10 emission factors have been adjusted by a factor of 0.94 and 0.86, respectively, to account for use of California ultra-low sulfur diesel fuel.
(b) ROG = HC * 1.053

MARINE VESSELS

Table D-15a
Uncontrolled Harbor Craft Propulsion Engine
Emission Factors (g/bhp-hr)

Horsepower	Model Year	NOx	ROG	PM10
25-50	All	7.57	1.32	0.520
51-120	pre-1997	14.27	1.04	0.575
	1997+	9.70	0.71	0.524
121-250	pre-1971	15.36	0.95	0.527
	1971-1978	14.27	0.79	0.451
	1979-1983	13.17	0.72	0.376
	1984+	12.07	0.68	0.376
251+	pre-1971	15.36	0.91	0.506
	1971-1978	14.27	0.76	0.431
	1979-1983	13.17	0.68	0.363
	1984-1994	12.07	0.65	0.363
251-750	1995+	8.97	0.49	0.260
751+	1995+	12.07	0.60	0.363

Table D-15b
Controlled Harbor Craft Propulsion Engine
Emission Factors (g/bhp-hr)

Horsepower	Tier	NOx	ROG	PM10
25-50	1	6.93	1.30	0.580
	2	5.04	1.30	0.240
	3	5.04	1.30	0.176
51-120	1	6.93	0.71	0.524
	2	5.04	0.71	0.240
	3	5.04	0.71	0.176
121-175	1	8.97	0.49	0.290
	2	4.84	0.49	0.176
	3	3.60	0.49	0.077
176-750	1	8.97	0.49	0.290
	2	4.84	0.49	0.120
	3	3.87	0.49	0.068
751-1900	1	8.97	0.49	0.290
	2	5.24	0.49	0.160
	3	3.87	0.49	0.068
1901+	1	8.97	0.49	0.290
	2	5.24	0.49	0.160
	3	4.14	0.49	0.085

Table D-16
Tier 4 Harbor Craft Propulsion Engine
Emission Standards (g/bhp-hr)
(Not applicable for engines using FEL or ABT for compliance)

Model Year	Horsepower	Tier	NOx	ROG	PM10
2016+	805-4960	4	1.34	0.142	0.030

Table D-17a
Uncontrolled Harbor Craft Auxiliary Engine
Emission Factors (g/bhp-hr)

Horsepower	Model Year	NOx	ROG	PM10
25-50	all	6.42	1.58	0.460
51-120	pre-1997	12.09	1.23	0.508
	1997+	8.14	0.85	0.417
121-250	pre-1971	13.02	1.13	0.466
	1971-1978	12.09	0.94	0.399
	1979-1983	11.16	0.86	0.333
	1984-1995	10.23	0.82	0.333
	1996+	7.75	0.59	0.255
251-750	pre-1971	13.02	1.08	0.448
	1971-1978	12.09	0.90	0.381
	1979-1983	11.16	0.81	0.321
	1984-1994	10.23	0.77	0.321
	1995+	7.60	0.58	0.230
751+	pre-1971	13.02	1.08	0.448
	1971-1978	12.09	0.90	0.381
	1979-1986	11.16	0.81	0.321
	1987-1998	10.23	0.72	0.321
	1999+	7.75	0.58	0.255

Table D-17b
Controlled Harbor Craft Auxiliary Engine
Emission Factors (g/bhp-hr)

Horsepower	Tier	NOx	ROG	PM10
25-50	1	6.54	1.54	0.511
	2	5.04	1.54	0.240
	3	5.04	1.54	0.176
51-120	1	6.93	0.85	0.464
	2	5.04	0.85	0.240
	3	5.04	0.85	0.176
121-175	1	6.93	0.58	0.255
	2	4.84	0.58	0.176
	3	3.60	0.58	0.077
176-750	1	6.93	0.58	0.255
	2	4.84	0.58	0.120
	3	3.78	0.58	0.068
751-1900	1	6.93	0.58	0.255
	2	5.24	0.58	0.160
	3	3.87	0.58	0.068
1901+	1	6.93	0.58	0.255
	2	5.24	0.58	0.160
	3	4.14	0.58	0.085

Table D-18
Harbor Craft Load Factors

Vessel Type	Propulsion Engine	Auxiliary Engine
Charter Fishing	0.52	0.43
Commercial Fishing	0.27	
Ferry/Excursion	0.42	
Pilot	0.51	
Tow	0.68	
Work	0.45	
Other	0.52	
Barge/Dredge	0.45	0.65
Crew & Supply	0.38	0.32
Tug	0.50	0.31

Table D-19
Shore Power
Default Emission Rates (Grams per kilowatt-hour (g/kW-hr))

Pollutant	Emission Rate
NOx	13.09
ROG	0.49
PM10 (marine gas oil fuel with 0.11- 0.5 % sulfur content)	0.38
PM10 (marine gas oil fuel with <= 0.10 % sulfur content)	0.25

Table D-20
Shore Power
Default Power Requirements

Ship Category	Ship Size / Type Default (Twenty-foot Equivalent Unit (TEU))	Power Requirement (kW)
Container Vessel	<1,000	1,000
	1,000 – 1,999	1,300
	2,000 – 2,999	1,600
	3,000 – 3,999	1,900
	4,000 – 4,999	2,200
	5,000 – 5,999	2,300
	6,000 – 6,999	2,500
	7,000 – 7,999	2,900
	8,000 – 9,999	3,300
	10,000 – 12,000	3,700
Passenger Vessel	No Default Value – Use Actual Power Requirement[(a)]	
Reefer	Break Bulk	1,300
	Fully containerized	3,300

[(a)] The average power requirement for passenger vessels is 7,400 kW (ARB Oceangoing Vessel Survey, 2005).

ALL ENGINES

Table D-21
Fuel Consumption Rate Factors (bhp-hr/gal)

Category	Horsepower/Application	Fuel Consumption Rate
Non-Mobile Agricultural Engines	ALL	17.5
Locomotive	Line Haul and Passenger (Class I/II)	20.8
	Line Haul and Passenger (Class III)	18.2
	Switcher	15.2
Other	< 750 hp	18.5
	≥ 750 hp	20.8

REFERENCES

The information in these tables has already been incorporated into the preceding emission factor tables. These tables are included for informational purposes.

Table D-22
Fuel Correction Factors
On-Road Diesel Engines

Model Year	NOx	PM10	HC
Pre- 2007	0.93	0.72	0.72
2007+	0.93	0.80	0.72

Table D-23
Fuel Correction Factors
Off-Road Diesel Engines

Model Year	NOx	PM10	HC
Pre-Tier 1	0.930	0.720	0.720
Tier 1 – Tier 3	0.948	0.800	0.720
Tier 4	0.948	0.852	0.720

Table D-24
Capital Recovery Factor (CRF) for Various Project Lives
At a 1% Discount Rate

Project Life	CRF
1	1.010
2	0.508
3	0.340
4	0.256
5	0.206
6	0.173
7	0.149
8	0.131
9	0.117
10	0.106
11	0.096
12	0.089
13	0.082
14	0.077
15	0.072
16	0.068
17	0.064
18	0.061
19	0.058
20	0.055

Table D-25
Capital Recovery Factor (CRF) for Various Project Lives
At a 2% Discount Rate[(a)(b)]

Project Life	CRF
1	1.020
2	0.515
3	0.347
4	0.263
5	0.212
6	0.179
7	0.155
8	0.137
9	0.123
10	0.111
11	0.102
12	0.095
13	0.088
14	0.083
15	0.078
16	0.074
17	0.070
18	0.067
19	0.064
20	0.061

(a) Upon ARB approval of the 2017 Moyer Program Guidelines, the discount rate is one percent. Per statute ARB reviews and may update discount rates annually, using the average rates of return for U.S. Treasury securities and the California Consumer Price Index data available at the time of publication.
(b) The Discount Rate varies from year to year, and may increase beyond 2 percent. The formula used to calculate the CRF based on the Discount Rate can be found in Appendix C, Formula C-2.

USEPA Emission Standards for Tier 1 - 3 engines

Engine Power (hp)	Model Years	Regulation	Emission Standards (g/hp-hr) HC [a, d]	VHC [b]	NOx [a, d]	NMHC+NOx [a]	CO [a]	PM [a]	Year the Std Takes Effect
50 to <75	1998-2003	Tier 1			6.90				1998
	2004-2007	Tier 2	0.40	0.3996	5.20	5.60	3.70	0.30	2004
	2008-2012	Tier 3	0.20	0.1998	3.3	3.50	3.70	c	2008
>75 to <100	1998-2003	Tier 1			6.90				1997
	2004-2007	Tier 2	0.40	0.3996	5.20	5.60	3.70	0.30	2004
	2008-2011	Tier 3	0.20	0.1998	3.3	3.50	3.70	c	2007
>100 to <175	1997-2002	Tier 1			6.90				1997
	2003-2006	Tier 2	0.40	0.3996	4.5	4.90	3.70	0.22	2003
	2007-2011	Tier 3	0.20	0.1998	2.8	3.00	3.70	c	2007
>175 to <300	1996-2002	Tier 1	1.00	0.9990	6.90		8.50	0.40	1996
	2003-2005	Tier 2	0.40	0.3996	4.5	4.90	2.60	0.15	2003
	2006-2010	Tier 3	0.20	0.1998	2.8	3.00	2.60	c	2006
>300 to <600	1996-2000	Tier 1	1.00	0.9990	6.90		8.50	0.40	1996
	2001-2005	Tier 2	0.30	0.2997	4.5	4.80	2.60	0.15	2001
	2006-2010	Tier 3	0.20	0.1998	2.8	3.00	2.60	c	2006
>600 to 750	1996-2001	Tier 1	1.00	0.9990	6.90		8.50	0.40	1996
	2002-2005	Tier 2	0.30	0.2997	4.5	4.80	2.60	0.15	2002
	2006-2010	Tier 3	0.20	0.1998	2.8	3.00	2.60	c	2006
>750 except generator sets	2000-2005	Tier 1	1.00	0.9990	6.90		8.50	0.40	2000
	2006-2010	Tier 2	0.30	0.2997	4.5	4.80	2.60	0.15	2006
Generator sets >750 to 1200	2000-2005	Tier 1	1.00	0.9990	6.90		8.50	0.40	2000
	2006-2010	Tier 2	0.30	0.2997	4.5	4.80	2.60	0.15	2006
Generator sets >1200	2000-2005	Tier 1	1.00	0.9990	6.90		8.50	0.40	2000
	2006-2010	Tier 2	0.30	0.2997	4.5	4.80	2.60	0.15	2006

Notes:

[a] Nonroad CI Engine Emission Standards from Title 13, California Code of Regulations, Section 2423 (ARB Executive Order "Std").
[b] VHC = Total Hydrocarbons (THC) minus methane and ethane fractions. Equivalent APCD standard. (**Highlighted in Orange**) See *Conversion Factors to Hydrocarbon Emission Components*, Report No. NR-002a, US EPA, 5/2003. {VHC = ROC}
[c] Tier 3 PM standards have not yet been adopted. Tier 3 engines must meet the Tier 2 PM standard until the Tier 3 PM standard has been adopted.
[d] Tier 2 and Tier 3 HC and NOx equivalent standards used to determine the NMHC + NOx standard. (**Highlighted in blue**)

\\sbcapcd.org\shares\groups\engr\library\permitting\icengines\diesel-ice\usepa emission standards for tier 1-3.doc

AVERAGE MONTHLY EVAPORATION FROM CLASS
'A' PAN IN IRRIGATED PASTURE ENVIRONMENTS NEAR
BAKERSFIELD, CALIFORNIA FROM 1958-2010 /1

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MAR - OCT TOTAL	JAN - DEC TOTAL
	****EVAPORATION IN INCHES****													
AVERAGE	1.44	2.25	4.13	5.95	8.35	9.58	9.94	8.85	6.62	4.47	2.24	1.35	57.89	65.17
STD DEV	0.34	0.45	0.71	0.86	0.82	0.79	0.82	0.71	0.64	0.43	0.36	0.36	0.72	0.61
STD ERROR	0.05	0.06	0.10	0.12	0.11	0.11	0.11	0.10	0.09	0.06	0.05	0.05	0.10	0.08

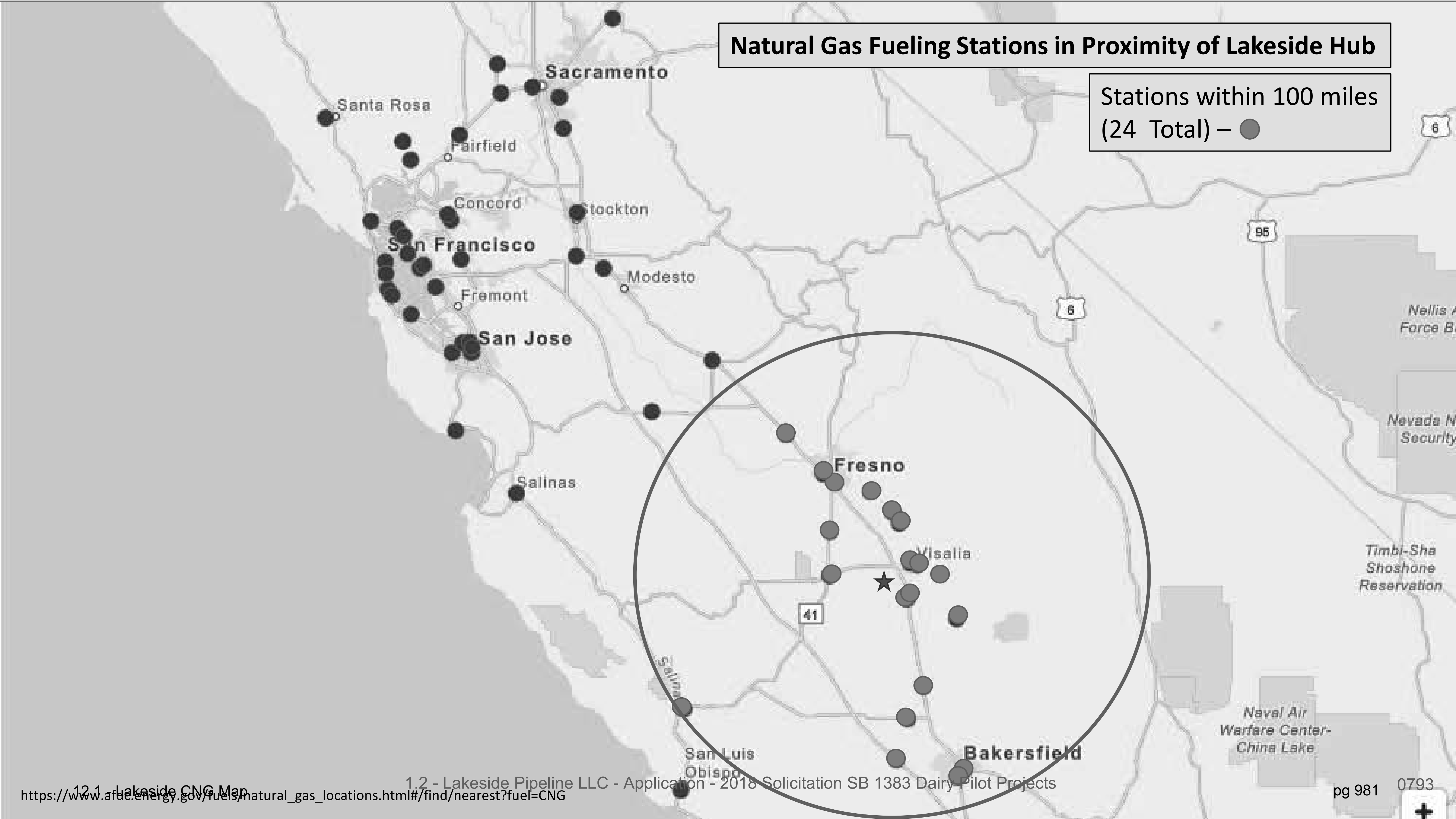
AVERAGE MONTHLY EVAPORATION FROM CLASS
'A' PAN IN IRRIGATED PASTURE ENVIRONMENTS AT
CALIFORNIA STATE UNIVERSTIY AT FRESNO
FROM 1968-2010 /1

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MAR - OCT TOTAL	JAN - DEC TOTAL
	****EVAPORATION IN INCHES****													
AVERAGE	1.26	2.08	3.94	6.03	8.75	10.43	11.02	9.67	6.99	4.42	2.25	1.21	61.26	68.07
STD DEV	0.28	0.41	0.77	0.86	1.03	0.92	0.73	0.68	0.57	0.49	0.40	0.30	0.76	0.62
STD ERROR	0.04	0.06	0.12	0.13	0.16	0.14	0.11	0.11	0.09	0.07	0.06	0.05	0.12	0.10

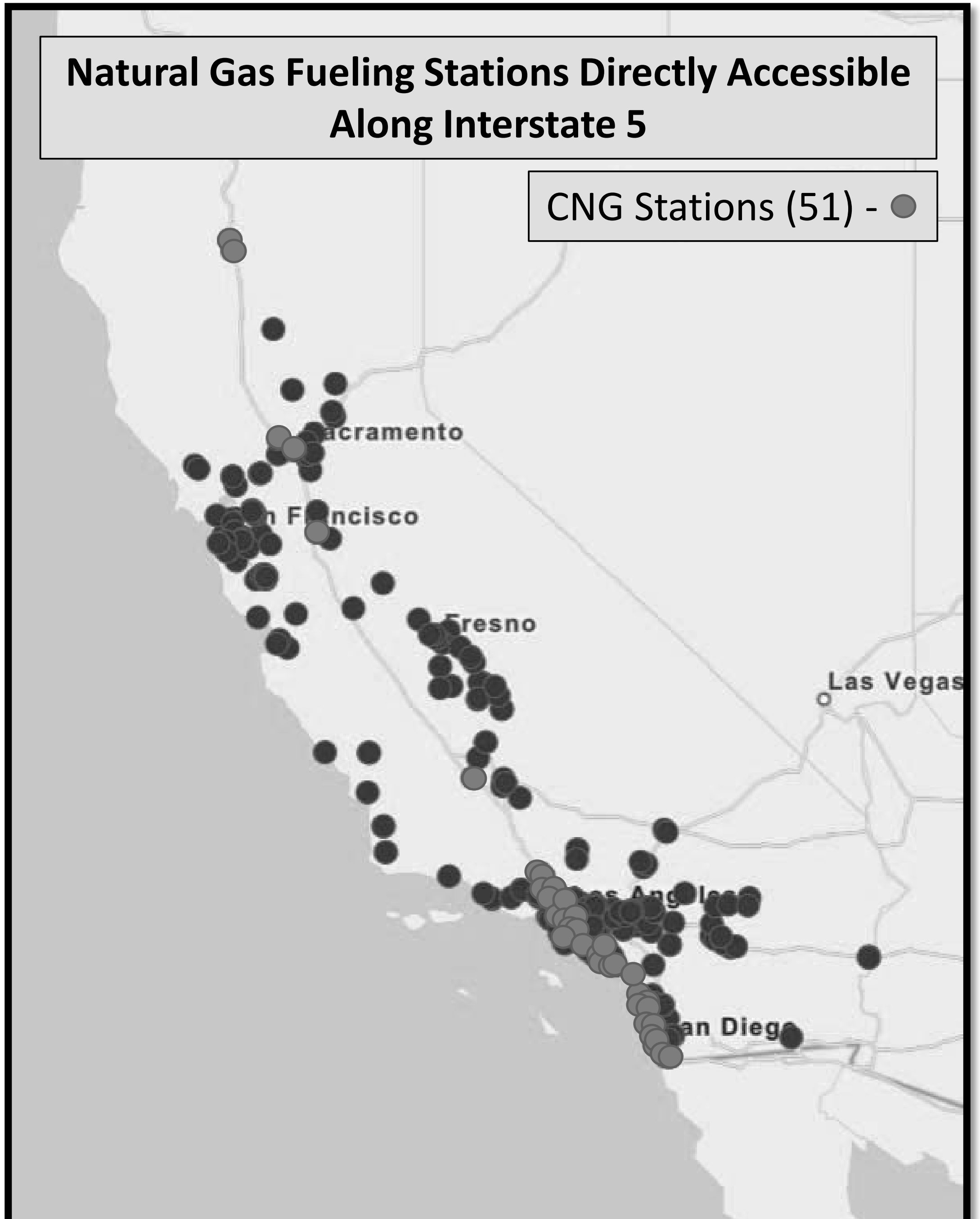
1/ Evaporation measurements are taken from evaporation pans located at standardized sites (irrigated pastures) with static water levels maintained in the pans by supply tanks. The sites are visited at least weekly to measure evaporation from a U.S. Weather Bureau Class 'A' Pan. Other agrometeorological equipment, (i.e.raingauge, anemometer, ambient air thermometers) is installed at onsite DWR agroclimatic stations, and this data is collected weekly along with pan evaporation. The evaporation may be adjusted during times of high wind or dry periods, which represent non-standard conditions.

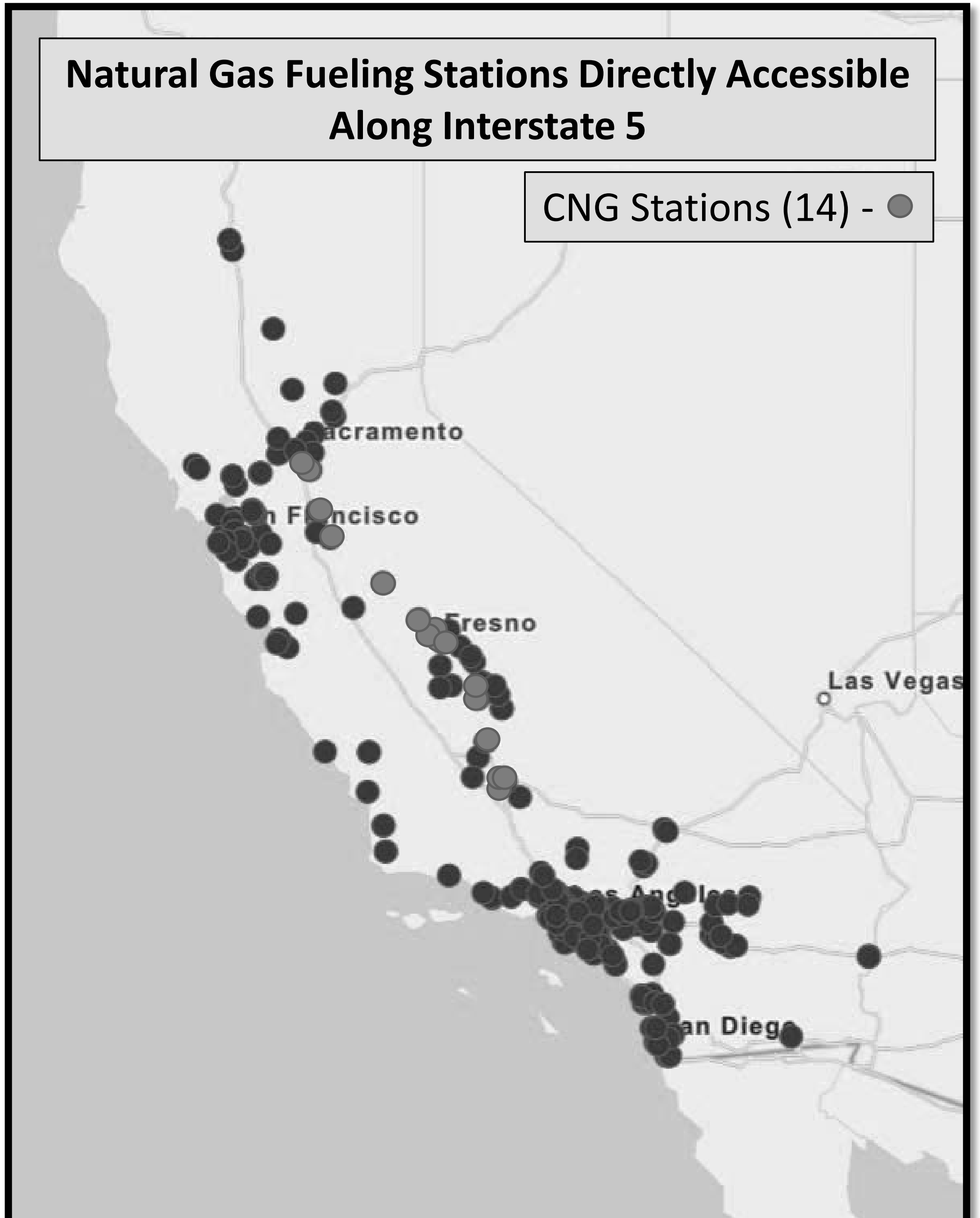
Natural Gas Fueling Stations in Proximity of Lakeside Hub

Stations within 100 miles (24 Total) – ●



https://www.afdc.energy.gov/fuels/natural_gas_locations.html#/find/nearest?fuel=CNG


Natural Gas Fueling Stations Directly Accessible Along Interstate 5
CNG Stations (51) -
Sacramento
San Francisco
Fresno
Las Vegas
Los Angeles
San Diego


Natural Gas Fueling Stations Directly Accessible Along Interstate 5
CNG Stations (14) -
Sacramento
San Francisco
Fresno
Las Vegas
Los Angeles
San Diego

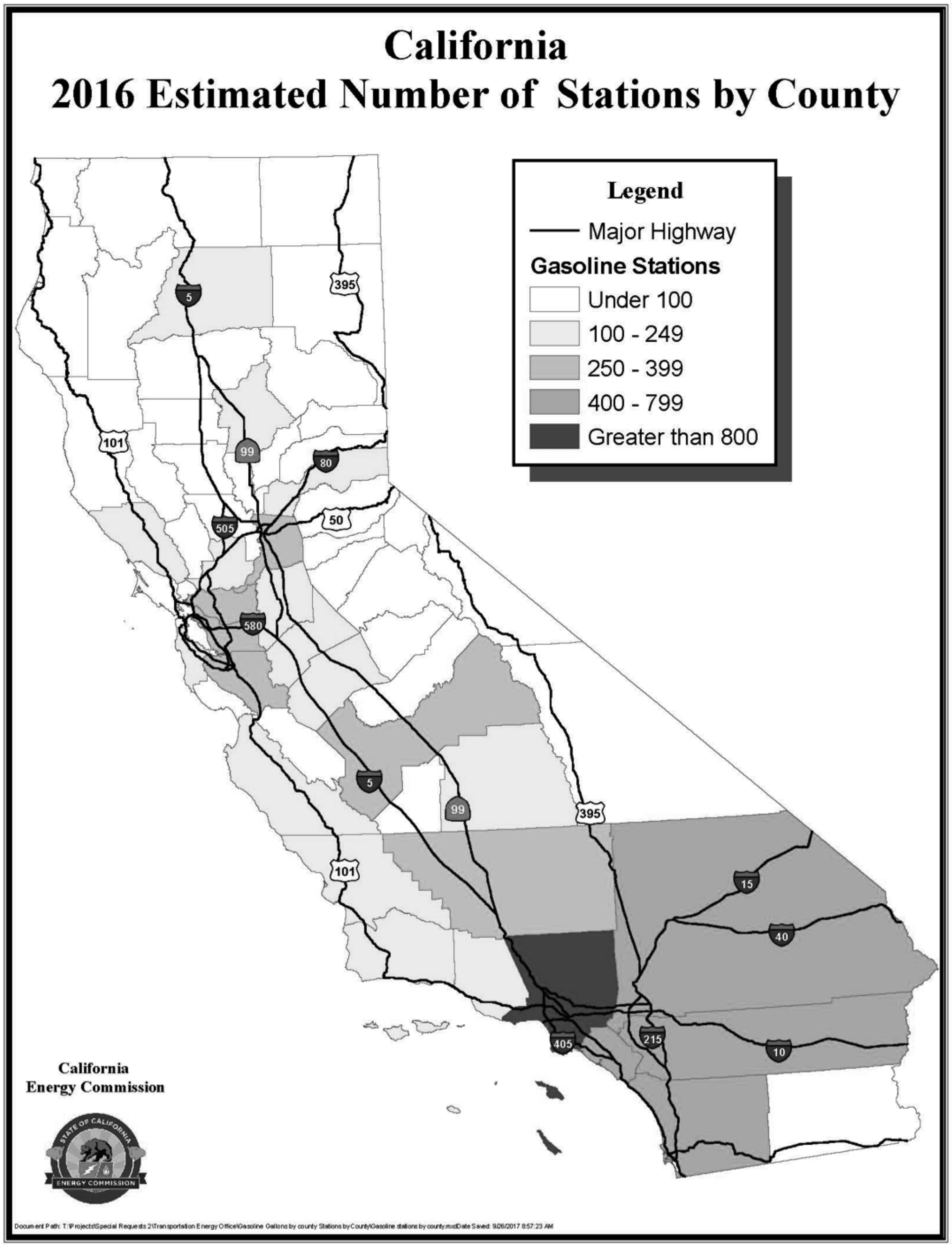
California Retail Fuel Outlet Annual Reporting (CEC-A15) Results

The Petroleum Industry Information Reporting Act (PIIRA) requires all retail transportation fueling stations in California to file a Retail Fuel Outlet Annual Report (CEC-A15). These stations report retail sales of gasoline, diesel, and other transportation fuels. Sales data reported does not include commercial fleets, government entities, or rental facilities/equipment yards.

Number of Retail Fuel Stations by Fuel – Survey Responses

Reporting Year	Gasoline	Diesel	E85[1]	Propane	Natural Gas[3]	Total Stations Survey Responses	Total Stations Estimated
2009	8,138	3,826	30	726	52	8,369	9,790
2010	7,707	3,715	36	679	42	7,965	9,800
2011	8,036	3,942	42	809	48	8,343	9,710
2012	7,748	3,847	51	805	32	8,038	10,000
2013	7,044	3,579	59	699	46	7,293	9,579
2014	6,369	3,416	56	714	29	6,594	10,040
2015	7,240	4,095	81	573	139	7,516	9,718
2016	8,456	4,790	111	651	164	8,824	10,202

Source: California Energy Commission
*Stations by fuel type will not equal total respondents due to stations often dispensing multiple fuel types.



Retail Sales Volumes – Survey Responses (Million Gallons)

Reporting Year	Gasoline	Diesel	E85[1]	Propane	Natural Gas[2]
2009	12,764	1,393	1.38	40.87	3.84
2010	12,238	1,285	2	32.64	4.09
2011	12,644	1,346	3.89	19.82	7.26
2012	12,241	1,325	5.12	25.44	6.6
2013	11,418	1,262	7.31	13.99	6.17
2014	10,220	1,227	4.99	18.23	3.94
2015	12,044	1,592	11.99	13.83	41.19
2016	13,787	1,743	16.85	9.09	45.16

Source: California Energy Commission

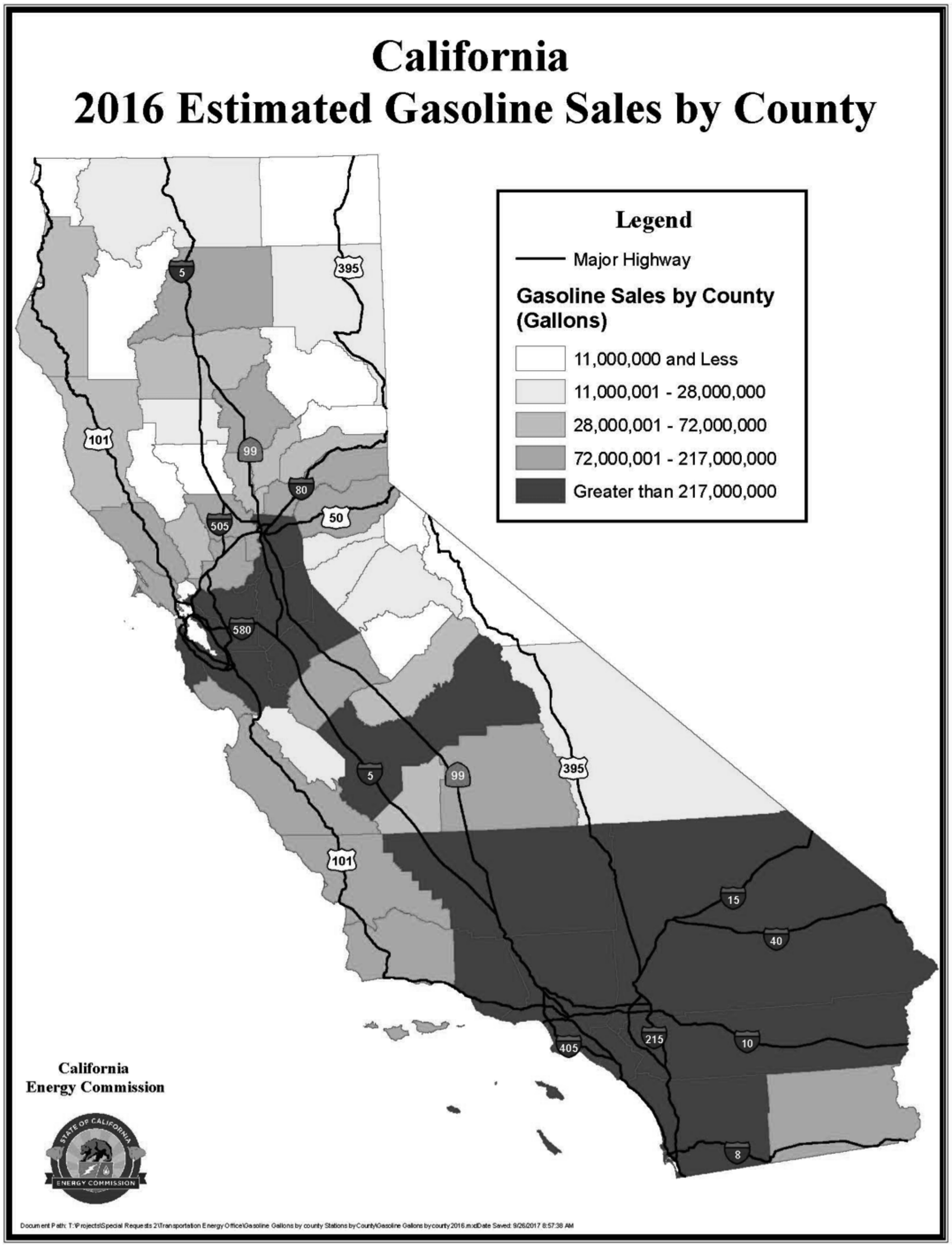
A15 Report Responses vs. Board of Equalization (BOE) (Million Gallons)

	Gasoline			Diesel	
Reporting Year	Survey Responses	% Differences	BOE[3] Taxable	Survey Responses	BOE[4] Taxable
2009	12,764	13.80%	14,814	1,393	2,580
2010	12,238	17.60%	14,861	1,285	2,590
2011	12,644	13.40%	14,606	1,346	2,622
2012	12,241	12.70%	14,486	1,325	2,603
2013	11,394	21.60%	14,540	1,262	2,740
2014	10,220	30.40%	14,701	1,227	2,776
2015	12,044	20.30%	15,108	1,592	2,825
2016	13,787	11.0%	15,492	1,743	3,005

Gasoline Diesel
Reporting Year Survey Responses % Differences BOE3 Taxable Survey Responses BOE4 Taxable

Source: California Energy Commission

Note: BOE tracks all gasoline and diesel sales in California for taxation purposes, but accounts for those sales at the finished fuel terminal level where taxation first occurs. Because of this, BOE gasoline and diesel sales have no regional dimension available. The CEC-A15 tracks fuel sales at the retail level, station by station, but since the current number of stations is constantly changing and the full station population is unknown, staff uses the total known BOE gasoline and diesel sales figures as a benchmark to achieve in data collection efforts. Differences in these two figures estimate the amount of sales underreported in CEC-A15 results.



California Annual Retail Fuel Outlet Report Results (CEC-A15) Spreadsheets

The following Excel files contain annual CEC-A15 results and analysis summarized in county level tables for station counts, gasoline sales, and diesel sales. Figures in the workbooks graphically display the gasoline sales and diesel sales tables.

- 2016 CEC-A15 Results and Analysis (XLSX File)
- 2015 CEC-A15 Results and Analysis (XLSX File)
- 2014 CEC-A15 Results and Analysis (XLSX File)
- 2013 CEC-A15 Results and Analysis (XLSX File)
- 2012 CEC-A15 Results and Analysis (XLSX File)
- 2011 CEC-A15 Results and Analysis (XLSX File)
- 2010 CEC-A15 Results and Analysis (XLSX File)

Methodology for Estimating Stations and Sales

Using a statistical resampling methodology, staff estimates the total gasoline station population by matching gasoline sales reported by the California Board of Equalization (BOE). This is done by using a subset of the CEC-A15 reporting stations to estimate the characteristics of the missing fueling station population. Since large fueling retailer chains are easier to survey due to their visibility, the resampling is weighted toward smaller retailers as it is assumed they are the primary non-responders to this report.

[1] According to the Air Resources Board (ARB), E-85 dispensed, in California, averages 83 percent ethanol and 17 percent gasoline.

[2] Natural Gas survey responses are measured in Gasoline Gallon Equivalent (GGE).

[3]Source: California Energy Commission (CEC) analysis of Board of Equalization (BOE) taxable gasoline figures.

[4] Source: BOE taxable diesel figures which include taxable retail sales and taxable non-retail sales.

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J.D. Heiskell & Company

June 20, 2017

Mr. Lyle Schlyer, President
Calgren Renewable Fuels
11704 Road 120
P.O. Box E
Pixley, CA 93256

RE: RNCG vehicle fueling

Dear Mr. Schlyer,

This letter confirms our desire to consider implementing Renewable Compressed Natural Gas vehicle fueling for our fleet of feed delivery trucks. J.D. Heiskell Holdings, LLC (JDH) is a leading supplier of animal feed throughout the California Central Valley as well as other regions in the US. We employ over 400 full time workers and deliver over 1 million tons of feed per year to dairies and other consumers. Our Pixley, California mill has 19 Class A trucks for delivery of livestock feed to the greater Tulare area. Our overall enterprise operates approximately 30 total trucks.

Pursuant to our conversations to date, the anticipated implementation schedule for our CNG conversion is as follows.

> 2017-2018: Calgren installs 10x dairy digesters to supply biogas to refinery.
>
> 2018: Calgren installs RCNG fueling station. JDH considers replacing up to 4x Class A Trucks to CNG and if implemented begins receiving fuel at the Calgren Dairy Fuels CNG station.
>
> 2019: Pursuant to successful trial of initial trucks, JDH may consider converting its entire fleet to CNG. Parties investigate RCNG expansion to other JDH facilities.

We look forward to working with you to make renewable fueling of agricultural freight a reality in the Central Valley. This letter establishes mutual intent but is not a binding contract and does not require either party to perform any of the terms contemplated herein.

Regards,

Rick Bowen
Chief Operating Officer – J.D. Heiskell Holdings, LLC

June 27, 2017

Dear Mr. Schlyer,

This letter confirms our project to implement Renewable Compressed Natural Gas vehicle fueling for our fleet of fuel delivery trucks. Flyers Energy is a leading supplier of fuels throughout the California Central Valley. Our transportation division employs 240 full time workers and delivers 500 million gallons of fuel annually to our customers. We currently have 7 trucks in service hauling fuel for Calgren's Pixley, California ethanol plant. Our overall enterprise operates approximately 195 total trucks.

Pursuant to our conversations to date, the anticipated implementation schedule for our CNG conversion is as follows.

2017-2018: Calgren installs 10x dairy digesters to supply biogas to refinery.

2018: Calgren installs RCNG fueling station. Flyers converts a portion of its Pixley Class A Trucks to CNG and begins receiving fuel at the Calgren Dairy Fuels CNG station.

2019: Pursuant to a successful initial trial, Flyers converts entire Pixley fleet to CNG. Parties investigate RCNG expansion to other Flyers locations.

We look forward to working with you to make renewable fueling of freight haulers a reality in the Central Valley. This document establishes mutual intent but is not a binding contract.

Ken Dwelle
Chief Operating Officer

Flyers Energy, LLC
2360 Lindbergh Street
Auburn, CA 95602
(530) 885-0401 Ext. 2226
(530) 885-5851 Fax
www.flyersenergy.com

MAAS
ENERGY WORKS

3711 Meadow View Dr.
Suite 100
Redding, CA 96002
www.maasenergy.com

June 25, 2018

California Public Utilities Commission (CPUC)
300 Capitol Mall
Sacramento, CA 95814

RE: Attachment 14 – Verification of contracts for the use of pipeline- injected renewable natural gas in electricity generation.

To Whom it May Concern,

The purpose of this letter is to inform the selection committee of the California Public Utilities Commission (CPUC) that all digester sites contracted in the Lakeside Pipeline cluster will be 100% pipeline injection only and not used for pipeline injected renewable natural gas in electrical generation. Attachment 14 is therefore not applicable to this application.

Sincerely,

Daryl Maas, CEO
Maas Energy Works

STATE CAPITOL
P.O. BOX 942849
SACRAMENTO, CA 94249-0032
(916) 319-2032
FAX (916) 319-2132

Assembly California Legislature

RUDY SALAS, JR.
ASSEMBLYMEMBER, THIRTY-SECOND DISTRICT

COMMITTEES
AGRICULTURE
GOVERNMENTAL ORGANIZATION
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VETERANS AFFAIRS
WATER, PARKS AND WILDLIFE

SELECT COMMITTEES
CALIFORNIA-MÉXICO BI-NATIONAL AFFAIRS
LOCAL PUBLIC SAFETY AND EMERGENCY PREPAREDNESS
PORTS AND GOODS MOVEMENT

JOINT COMMITTEE ON RULES

January 25, 2018

Karen Ross, Secretary
California Department of Food and Agriculture
1120 N Street
Sacramento, CA 95814

RE: 2018 DDRDP – Letter of Support for Hanford Lakeside Cluster Project: Lakeside Dairy, Lone Oak Farms #1, River Ranch Dairy, High Roller Dairy, Lakeshore Dairy

Dear Secretary Ross,

I write in support of the Hanford Lakeside Cluster Project grant applications to the California Department of Food and Agriculture (CDFA) for the Dairy Digester Research and Development Program (DDRDP). Dairy is an important industry in the Central Valley, providing more than 189,000 jobs and $65 billion in dairy related economic activity. Kern and Kings Counties are home to over 150 Family owned dairies that collectively milk approximately 300,000 cows.

Through CDFA's DDRDP grant assistance, the projects in the Hanford Lakeside Cluster Project will have over 20,000 cows powering the digesters and will produce renewable energy that will not only help achieve the state's goal of a 40% reduction in dairy manure methane emissions by 2030, but will also create jobs and support regional economic development.

For these reasons, I fully support the Hanford Lakeside Cluster Project's DDRDP grant application. The collaboration between these dairies and Maas Energy Works to produce biogas and utilize it as CNG to fuel vehicles will help the state meet its target goals for greenhouse gas emissions. If you have any questions or concerns, please do not hesitate to contact me or Janea Benton, my District Director, at (661) 335-0302.

Sincerely,

Rudy Salas

RUDY SALAS
Member of the Assembly
32nd District

RS: jb

DISTRICT OFFICE: KERN COUNTY DISTRICT 1430 TRUXTUN AVENUE, SUITE 803 • BAKERSFIELD, CA 93301 • (661) 335-0302 • FAX (661) 335-0361
KINGS COUNTY DISTRICT 113 COURT STREET, SUITE 201 • HANFORD, CA 93230 • (559) 585-7170 • FAX (559) 585-7175

KINGS edc california

KINGS COUNTY ECONOMIC DEVELOPMENT CORPORATION

120 North Irwin Street • Hanford, California 93230
www.kingsedc.org • info@kingsedc.org
Phone (559) 585-3576 • Fax (559) 585-7398

June 25, 2018

California Public Utilities Commission (CPUC)
300 Capital Mall
Sacramento, CA 95814

RE: 2018 CPUC - Letter of Support; Lakeside Pipeline Cluster Project

Dear Selection Committee,

The Kings County Economic Development Corporation is a nonprofit organization that seeks to establish Kings County as a location for business prosperity. We facilitate site selection for new businesses within Kings County and assist in the growth and expansion of existing businesses in the area.

As the County's Economic Development Agency, we are well positioned to speak to the community benefits of proposed developments in the county. We see the potential economic, social and community impact of the proposed projects for Lakeside Pipeline Cluster Project. I had the opportunity to speak with Maas Energy Works and review detailed information regarding the proposed projects. I very much appreciated their effort to extend the outreach well in advance of project implementation, which is unusual.

We are pleased to hear that the projects will be locating their digesters on the dairy farm, where the manure already exists and does not need to be transported. I was also pleased to learn about the implementation of technical mitigation procedures to reduce environmental impact.

I also understand these projects will implement further mitigations by converting irrigation wells to electric motors, by reducing the need for field preparation and other diesel work for manure spreading, and by replacing diesel powered manure solids handling with electric solids separation and stacking. It seems like the project has a highly proactive mitigation plan that goes beyond that required by normal permitting on dairies, and I believe it will have a positive impact on the community and the environment.

I understand that all the dairies will be installing new, double-lined digester ponds, which reduces manure seepage into ground water from the existing dirt ponds that will be replaced. Also, the digesters will capture significant air emissions that are already escaping from manure on nearby dairies.

We see the economic and social value of the proposed investment in these nearby dairies and the pipeline. The projects will include policies that every contractor on the job will have a minimum local hiring requirement. Additionally, Maas Energy Works informed that the projects will result in increased profits for the local dairies hosting the projects. These dairies are major employers in rural Kings County and these projects would provide a form of stability to the dairies and would provide them with revenue independent of milk prices--which cause significant volatility to the local economy.

In conclusion, I am writing to voice the support of the Kings EDC for the development of the Lakeside Pipeline Cluster Project, proposed by Maas Energy Works. We support these projects that generate jobs, create new income opportunities for the farms, and help California reduce the methane emissions and mitigate greenhouse effects. Should you have further questions you may contact me at 559.852.4949 or john.lehn@co.kings.ca.us.

Sincerely,

John S. Lehn
President

PROTEUS INC.

. . . *for Education, Employment and Community Services*

Administration

February 12, 2018

California Department of Food and Agriculture
Dairy Digester Research and Development Program
1120 N Street, Sacramento, CA 95814

RE: 2018 DDRDP – Letter of Support
LAKESIDE PIPELINE CLUSTER: Decade Centralized Dairy Digester Pipeline, Lone Oak #1 Dairy Digester Pipeline, River Ranch Dairy, Digester Pipeline, Poplar Lane Dairy Biogas LLC, High Roller Dairy Digester Pipeline, Double L Dairy Digester Pipeline, Dixie Creek Dairy Digester Pipeline, Lakeshore Dairy Digester. Valley View Dairy.

Dear Secretary Ross,

Proteus, Inc., is a non-profit organization with over 50 years of community service. The organization provides services throughout the Central Valley. We work with local communities to improve the quality of life of low income population and minorities within the Central San Joaquin Valley by providing education, job training, job placement, and other support services.

We have been in touch with Mass Energy since early 2017. We are collaborating to facilitate various meetings with the community, including low income and minority groups. Community members had the opportunity to learn more about the projects, ask questions, share their ideas and make suggestions to improve the potential benefits to the community.

We believe the projects will have a positive impact in low income population and minorities, especially for those living on the surrounding areas. During the construction phase the projects will require contractors to have a percentage of local workers as well as meeting with Proteus Inc. to help them connect with local workforce. This has the potential to create working opportunities and training for low income populations and minorities around the projects and would mean that at least 10% of each project's work hours will be performed by residents of a low income AB-1550 community. We also support the proposed projects because they will help reduce odors from pollutants that are now scaping into the atmosphere, improving the quality of air in the valley.

In conclusion, I am writing to voice my support on behalf of Proteus, Inc. for the development of these projects that will become part of the LAKESIDE PIPELINE CLUSTER proposed by Maas Energy Work. I understand these projects are seeking California Department of Food and Agriculture grants. We support these projects that generate jobs, create new income opportunities for the dairy industry, help reduce methane emission into the environment and help California reduce overall emissions and mitigate greenhouse effects. Should you have further questions you may contact me by phone (559) 733-5423 or by email at Robertoa@proteusinc.org.

Robert Alcazar
Chief Executive Officer
Proteus, Inc.

A Proud Member of these Fine Organizations

February 13, 2018

California Department of Food and Agriculture
Dairy Digester Research and Development Program
1120 N Street
Sacramento, CA 95814

Dear Secretary Ross,

My name is Catarino Ramirez and I live in Kings County. We are very excited to hear that Maas Energy Works is proposing to build several Dairy Digester projects in the county. We drive by the dairies everyday and have become used to the odors that come and go with the wind, however we are very happy to hear that the projects will be capturing a good portion of the methane, which will not only help reduce methane emission into the environment but will also significantly improve the quality of the air we, our children and families bread every day.

Perhaps the most important thing for us has been that these projects have the potential to generate jobs for different people in the community. During the construction phase, there would be many opportunities for work providing services such as excavation, welding, electrical, concrete, pipe fitting and others.

Mrs. Ross, we want to thank you for these initiatives. Me and my family fully support these projects and we would like to see more and more of these initiatives taking places through the state.

Sincerely,

All the best Catarino Ramirez,

Name: Catarino Ramirez

Telephone (559) 380-8124

February 13, 2018

California Department of Food and Agriculture
Dairy Digester Research and Development Program
1120 N Street
Sacramento, CA 95814

Dear Secretary Ross,

My name is Jose Cruz and I live in Tulare County. We are very excited to hear that Maas Energy Works is proposing to build several Dairy Digester projects in the county. We drive by the dairies everyday and have become used to the odors that come and go with the wind, however we are very happy to hear that the projects will be capturing a good portion of the methane, which will not only help reduce methane emission into the environment but will also significantly improve the quality of the air we, our children and families bread every day.

Perhaps the most important thing for us has been that these projects have the potential to generate jobs for different people in the community. During the construction phase, there would be many opportunities for work providing services such as excavation, welding, electrical, concrete, pipe fitting and others.

Mrs. Ross, we want to thank you for these initiatives. Me and my family fully support these projects and we would like to see more and more of these initiatives taking places through the state.

Sincerely,

All the best Jose Cruz,

Jose Cruz

Name Jose Cruz

Telephone (559) 654-5213

February 13, 2018

California Department of Food and Agriculture
Dairy Digester Research and Development Program
1120 N Street
Sacramento, CA 95814

Dear Secretary Ross,

My name is Jose Martinez and I live in Tulare County. We are very excited to hear that Maas Energy Works is proposing to build several Dairy Digester projects in the county. We drive by the dairies everyday and have become used to the odors that come and go with the wind, however we are very happy to hear that the projects will be capturing a good portion of the methane, which will not only help reduce methane emission into the environment but will also significantly improve the quality of the air we, our children and families bread every day.

Perhaps the most important thing for us has been that these projects have the potential to generate jobs for different people in the community. During the construction phase, there would be many opportunities for work providing services such as excavation, welding, electrical, concrete, pipe fitting and others.

Mrs. Ross, we want to thank you for these initiatives. Me and my family fully support these projects and we would like to see more and more of these initiatives taking places through the state.

Sincerely,

All the best Jose Martinez,

Name: Jose Martinez

Telephone (559) 631-7168

February 13, 2018

California Department of Food and Agriculture
Dairy Digester Research and Development Program
1120 N Street
Sacramento, CA 95814

Dear Secretary Ross,

My name is Luis Lopez and I live in Kings County. We are very excited to hear that Maas Energy Works is proposing to build several Dairy Digester projects in the county. We drive by the dairies everyday and have become used to the odors that come and go with the wind, however we are very happy to hear that the projects will be capturing a good portion of the methane, which will not only help reduce methane emission into the environment but will also significantly improve the quality of the air we, our children and families bread every day.

Perhaps the most important thing for us has been that these projects have the potential to generate jobs for different people in the community. During the construction phase, there would be many opportunities for work providing services such as excavation, welding, electrical, concrete, pipe fitting and others.

Mrs. Ross, we want to thank you for these initiatives. Me and my family fully support these projects and we would like to see more and more of these initiatives taking places through the state.

Sincerely,

All the best Luis Lopez,

Name: Luis Lopez

Telephone (559) 633-6299

February 13, 2018

California Department of Food and Agriculture
Dairy Digester Research and Development Program
1120 N Street
Sacramento, CA 95814

Dear Secretary Ross,

My name is Vera Sanchez Ramirez and I live in Kings County. We are very excited to hear that Maas Energy Works is proposing to build several Dairy Digester projects in the county. We drive by the dairies everyday and have become used to the odors that come and go with the wind, however we are very happy to hear that the projects will be capturing a good portion of the methane, which will not only help reduce methane emission into the environment but will also significantly improve the quality of the air we, our children and families bread every day.

Perhaps the most important thing for us has been that these projects have the potential to generate jobs for different people in the community. During the construction phase, there would be many opportunities for work providing services such as excavation, welding, electrical, concrete, pipe fitting and others.

Mrs. Ross, we want to thank you for these initiatives. Me and my family fully support these projects and we would like to see more and more of these initiatives taking places through the state.

Sincerely,

All the best Vera Sanchez Ramirez,

Name: Vera Sanchez Ramirez

Telephone (559) 380-7886

GRANT OF OPTION TO LEASE LAND

THIS GRANT OF OPTION TO LEASE LAND ("Agreement" or "Option") is made this 19th day of April 2016, by and between JACOB DE JONG and NICOLE DE JONG, and NIC INVESTMENTS LLC, a California Limited Liability Corporation.

1. **Grant of Option**. JACOB DE JONG and NICOLE DE JONG hereby grant to NIC INVESTMENTS LLC the right to lease the property described herein as set forth in Exhibit 1 hereto, at its option.

2. **Property**. The property subject to this Agreement is located in Kings County, California, and is depicted in Exhibit 1 (hereinafter referred to as the "Property").

3. **Consideration**. The initial consideration "Consideration" for this Agreement is the payment by NIC INVESTMENTS LLC to JACOB DE JONG and NICOLE DE JONG in the amount of One Hundred and No/100ths Dollars ($100.00), the receipt and adequacy of which is hereby acknowledged by JACOB DE JONG and NICOLE DE JONG. "Additional Consideration," as defined in Section 4, "Exercise of Option," may be paid by NIC INVESTMENTS LLC pursuant to said Section 4. The Consideration and any Additional Consideration is/are not refundable, absent a breach of this Agreement by JACOB DE JONG and NICOLE DE JONG.

4. **Exercise of Option**. NIC INVESTMENTS LLC shall, if it so elects, exercise this Option by giving written notice thereof to JACOB DE JONG and NICOLE DE JONG at any time prior to December 31, 2018 (the "Option Period").

5. **Terms of Lease**. The leasehold interest which JACOB DE JONG and NICOLE DE JONG will grant and which NIC INVESTMENTS LLC shall accept upon any exercise of this Option shall be upon terms that generally reflect the following structure:

   A. A term of 30 years
   B. Use of property for construction of an anaerobic manure digester facility to be created by covering the indicated existing manure ponds, plus installation of a generator
   C. Annual lease payments to be determined at or before the Exercise of the option, but not to exceed $3,000 per month.
   D. NIC INVESTMENTS LLC pays all property taxes arising from its construction, and all other permits, fees, and utilities attributable to its presence.
   E. Other such terms as shall be reasonably necessary to protect JACOB DE JONG and NICOLE DE JONG interests in the property

6. **Closing Date**. Closing shall be held within thirty (30) days of NIC INVESTMENTS LLC's exercise of this Option pursuant to Section 4, "Exercise of Option," or as soon thereafter as NIC INVESTMENTS LLC may request.

9. **Closing Costs & Proration**. Recording costs for any memorandum of lease shall be paid by NIC INVESTMENTS LLC. Any other closing costs shall be borne equally by the parties.

10. **Taxes**. All taxes and assessments shall be prorated to the date of Closing.

11. **Preservation of Property**. JACOB DE JONG and NICOLE DE JONG acknowledge that NIC INVESTMENTS LLC intends to use the Property for development and operation of the Facility. JACOB DE JONG and NICOLE DE JONG agree that the Property shall remain as it now is until closing, and that JACOB DE JONG and NICOLE DE JONG shall refrain from and shall not actively permit any use of the Property for any purpose or in any manner which would adversely affect NIC INVESTMENTS LLC's intended use of the Property.

12. **Assignment**. NIC INVESTMENTS LLC may not assign its interest in this Agreement to any party, without JACOB DE JONG AND NICOLE DE JONG's consent, which shall be granted in the sole discretion of JACOB DE JONG AND NICOLE DE JONG.

13. **Notices**. Any notices, demands or other communications required or permitted to be given hereunder shall be given in writing and shall be delivered: (A) in person; (B) by certified mail, postage prepaid, return receipt requested; (C) by U.S. Express Mail or a commercial overnight courier that guarantees delivery within the next two business days; or (D) by telephone facsimile. All notices shall be deemed received on the date actually received or two business days after being posted, whichever is sooner. Such notices shall be addressed as follows:

JACOB DE JONG
NICOLE DE JONG
6127 Jackson Ave
Hanford, CA 93230

NIC INVESTMENTS LLC
ATTN: Jacob de Jong
6127 Jackson Ave
Hanford, CA 93230

Each party shall be deemed to have received notices when delivered to the foregoing address/facsimile numbers unless addressee has notified addressor of an address change prior to transmittal.

Persons authorized by JACOB DE JONG and NICOLE DE JONG to sign notices hereunder are:

JACOB DE JONG
NICOLE DE JONG

Persons authorized by NIC INVESTMENTS LLC to give notices hereunder are:

JACOB DE JONG

15. **Miscellaneous**.

A. This Agreement may be executed in several counterparts and signatures may be delivered via telephone facsimile, which shall constitute one agreement that is binding on all of the parties, notwithstanding that the parties may have signed different counterparts.

B. If any provision of this Agreement is held invalid, the other provisions shall not be affected thereby.

C. This Agreement and its exhibits represent the entire agreement of the parties and may not be amended except by a writing signed by each party hereto.

D. Each party warrants to the other that it is duly organized and existing and each party warrants that it and the respective signatories have full right and authority to enter into and consummate this Agreement and all related documents.

E. The obligations, covenants, representations, warranties and remedies set forth in this Agreement shall not merge with transfer of title but shall remain in effect.

F. Each party shall execute and deliver or cause to be executed and delivered all instruments reasonably required to lease the Property to NIC INVESTMENTS LLC and to vest in each party all rights, interests and benefits intended to be conferred by this Agreement.

G. This Agreement shall be governed by the laws of the state of California.

16. **Computation of Time**. Unless otherwise expressly specified herein, any period of time specified in this Agreement shall expire at 5:00 p.m. of the last calendar day of the specified period of time, unless the last day is Saturday, Sunday, or legal holiday, as prescribed in RCW 1.16.050, in which event the specified period of time shall expire at 5:00 p.m. of the next business day. Any specified period of five (5) days or less shall include business days only.

17. **Termination**. In the event of termination of this Agreement, any costs authorized under this Agreement shall be paid by the party responsible therefor.

18. **General Provisions/Termination of Option**. Time is of the essence. There are no verbal agreements which modify this Agreement. This Agreement constitutes the full understanding between JACOB DE JONG and NICOLE DE JONG and NIC INVESTMENTS LLC.

19. **Litigation, Costs**. If any legal action or any other proceeding, including an arbitration or action for declaratory relief, is brought for the enforcement of this Agreement or because of a dispute, breach, default, or misrepresentation in connection with any of the provisions of this Agreement, the prevailing party shall be entitled to recover reasonable attorney fees and other costs incurred in that action or proceeding, including appeals, in addition to any other relief to which the prevailing party may be entitled. "Prevailing party" shall include without limitation:

A. a party dismissing an action in exchange for sums allegedly due;

B. a party receiving performance from the other party of an alleged breach of covenant or a desired remedy where the performance is substantially equal to the relief sought in an action; or

C. the prevailing party as determined by a court of law. Venue for any suit shall be solely in Kings County; this Agreement shall be interpreted pursuant to California law.

20. **Successors and Assigns**. This Agreement shall, in whole or in part, inure to the benefit of and be binding on the parties and their respective successors, heirs, assigns, mortgagees and/or beneficiaries, subject to Section 13, "Assignment," hereof. All references to "JACOB DE JONG and NICOLE DE JONG" and "NIC INVESTMENTS LLC" include respective successors, heirs, assigns, mortgagees and/or beneficiaries of each.

21. **Recordation**. This Agreement may be recorded at NIC INVESTMENTS LLC's option and expense.

22. **Exhibits**. All exhibits and any others referred to in this Agreement are incorporated into this Agreement by reference.

23. **Captions**. Captions and headings in this Agreement, including the title of this Agreement, are for convenience only and are not to be considered in construing this Agreement.

24. **Modification and Amendment**. This Agreement may not be modified or amended except in writing signed by JACOB DE JONG and NICOLE DE JONG and NIC INVESTMENTS LLC.

[Balance of page left blank intentionally. Signatures follow.]

IN WITNESS WHEREOF, JACOB DE JONG and NICOLE DE JONG has caused this instrument to be signed on the date and year first above written.

JACOB DE JONG and NICOLE DE JONG:

Signature: ______________________
Jacob de Jong

Signature: ______________________
Nicole de Jong

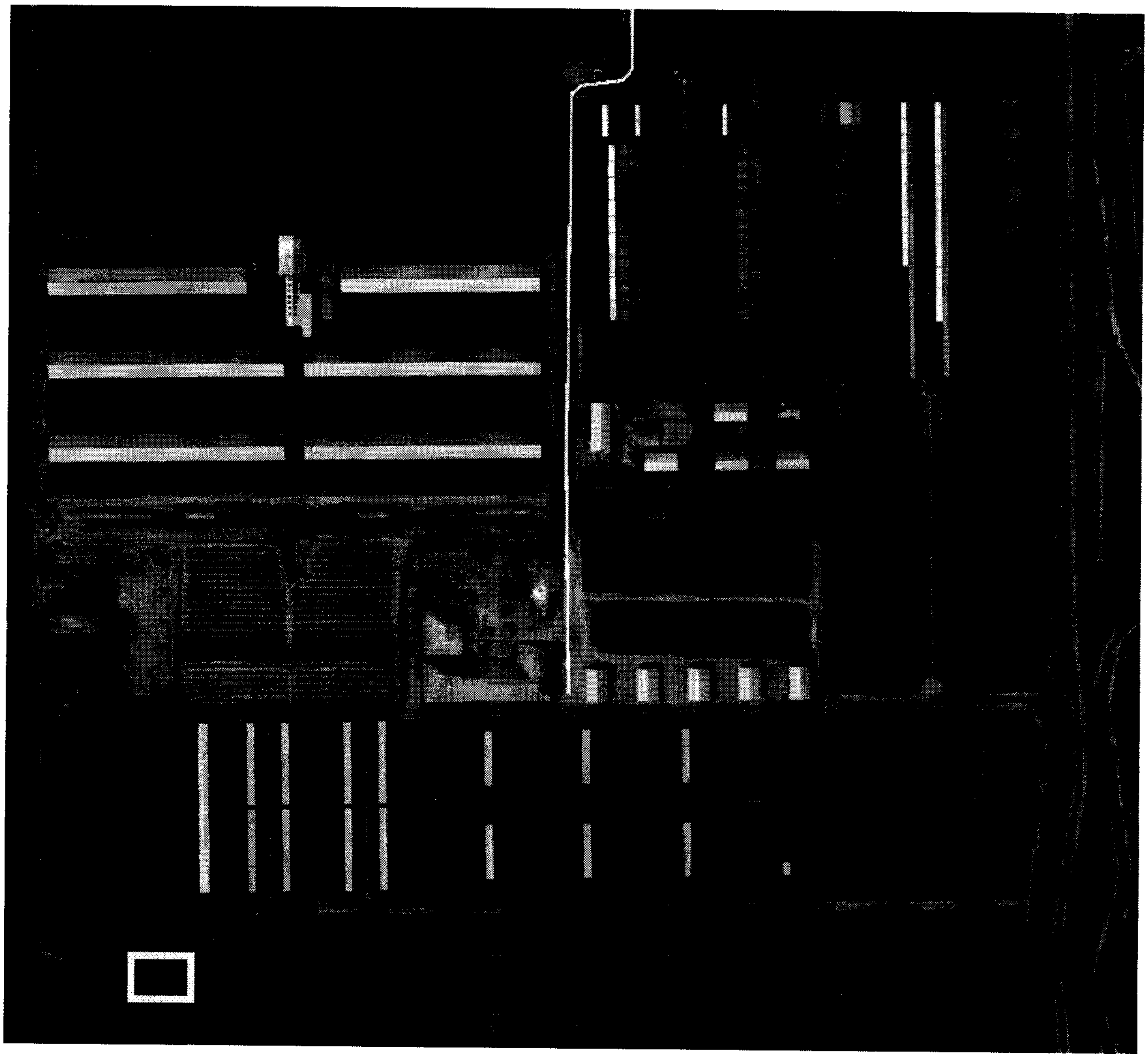
IN WITNESS WHEREOF, NIC INVESTMENTS LLC has caused this instrument to be signed by its member on the date and year first above written.

NIC INVESTMENTS LLC:

Signature: ______________________
Jacob de Jong, Manager

Exhibit 1

Depiction of Lease Property:



Explanation of GHG Inputs and Assumptions

2018 GHG Reduction Calculator

Decade Centralized Digester – Digester #1

For the purposes of calculating GHG reductions using the CARB Calculator Tool for the SB1383 Pilot Project Solicitation, the following assumptions have been made:

The primary end-use for this project is pipeline injection, with plans to build a CNG vehicle fueling station in the near future. Since the estimated fuel use at this planned future station is not large enough to handle 100% of the fuel from all digesters proposed for this cluster, a large portion of biogas will continue to be injected into the Natural Gas pipeline even after the fueling station has been completed. For simplicity, we modeled 100% of the biogas as being injected into a Natural Gas pipeline.

ARB's default values were used for all types of manure collection and separation systems. Actual GHG reductions may be higher if site specific values were used, but we have deferred to CPUC's preference for common defaults. Because this project uses one centralized digester with feedstock from two neighboring dairies with different separation methods, a manure separation ratio was calculated as follows for each livestock category and used with default separation values to determine the total amount of separation before entering the BCS.

$$\frac{Dairy\ Head}{Total\ Head} \times Default\ Separation\ Rate = Model\ Separation\ Rate$$

The net result is a weighted average of separation values between the two technologies employed on category head basis. As such, the model shows "No separation" in either the baseline or project case, and instead uses the calculated separation rates. While, Decade Dairy has and will have a weeping wall in both the baseline and project scenario, Richard Westra Dairy has no separation in the baseline but will be incorporating a vibrating screen separator for the project. This is summarized in the following table.

Baseline Separation (weighted average calcs)							
Dairy	**Herd Type**	**Herd Qty**	**% Manure Collected**	**Separation Type**	**ARB's Separator Efficiency**	**% of Manure Separated (% Manure Collected * Separator Efficiency)**	**Weighted Average Manure Separation (Attachment 5 - 9c)**
Decade Dairy	Dairy Cow (freestall)	3,000	80%	Weeping Wall	45%	36.0%	24.0%
Richard Westra Dairy	Dairy Cow (freestall)	1,500	80%	None	0%	0.0%	
Decade Dairy	Dairy Cow (Open Lot)	-	30%	Weeping Wall	45%	13.5%	0.0%
Richard Westra Dairy	Dairy Cow (Open Lot)	250	30%	None	0%	0.0%	
Decade Dairy	Dry Cow (Open Lot)	300	30%	Weeping Wall	45%	13.5%	7.4%
Richard Westra Dairy	Dry Cow (Open Lot)	250	30%	None	0%	0.0%	
Decade Dairy	Heifer (Open Lot)	1,400	30%	Weeping Wall	45%	13.5%	6.5%
Richard Westra Dairy	Heifer (Open Lot)	1,500	30%	None	0%	0.0%	

Project Separation (weighted average calcs)							
Dairy	**Herd Type**	**Herd Qty**	**% Manure Collected**	**Separation Type**	**ARB's Separator Efficiency**	**% of Manure Separated (% Manure Collected * Separator Efficiency)**	**Weighted Average Manure Separation (Attachment 5 - 12c)**
Decade Dairy	Dairy Cow (freestall)	3,000	80%	Weeping Wall	45%	36.0%	28.0%
Richard Westra Dairy	Dairy Cow (freestall)	1,500	80%	Vibrating	15%	12.0%	
Decade Dairy	Dairy Cow (Open Lot)	-	30%	Weeping Wall	45%	13.5%	4.5%
Richard Westra Dairy	Dairy Cow (Open Lot)	250	30%	Vibrating	15%	4.5%	
Decade Dairy	Dry Cow (Open Lot)	300	30%	Weeping Wall	45%	13.5%	9.4%
Richard Westra Dairy	Dry Cow (Open Lot)	250	30%	Vibrating	15%	4.5%	
Decade Dairy	Heifer (Open Lot)	1,400	30%	Weeping Wall	45%	13.5%	8.8%
Richard Westra Dairy	Heifer (Open Lot)	1,500	30%	Vibrating	15%	4.5%	

Milk content for fat and protein as well as daily production is taken from milk reports provided by Decade Dairy and Richard Westra Dairy. Fat and Protein content was averaged between the two on a gallons basis as that was the basis in which they were provided. Furthermore, a milk density of 8.6 lbs/gallon was used to calculate the daily per-cow production. The lactose content was unavailable, however, and the default number from the ARB Methodology has been used instead. Daily production is calculated as follows

$$\frac{ADaily\ MIlk\ Volume\ \ (Gal/day)\times 8.6\ (lbs/gal)}{Number\ of\ Milking\ Cows\ (cow)} = Avg.Milk\ Production\ (lbs/cow/day)$$

Electricity consumption, both in the baseline and project scenario, are estimated based on typical energy consumption of the existing and proposed waste management equipment including pumps, agitators, and separation equipment.

Diesel use reductions are calculated based on data of a 6,500-cow dairy that, by installing a digester, was able to reduce its diesel hours by 1,500 annually from tractor use for farming and lagoon cleanup. This project's diesel use was calculated assuming a direct relationship between cow head and hours reduced, an average tractor power of 150 bhp, and a fuel consumption rate of 18.5 bhp-hr/gal per the Carl Moyer program guidelines. These diesel use reductions are outlined in more detail in the supporting materials for environmental benefits.

Explanation of GHG Inputs and Assumptions

2018 GHG Reduction Calculator

Clear Lake Dairy – Digester #2

For the purposes of calculating GHG reductions using the CARB Calculator Tool for the SB1383 Pilot Project Solicitation, the following assumptions have been made:

The primary end-use for this project is pipeline injection, with plans to build a CNG vehicle fueling station in the near future. Since the estimated fuel use at this planned future station is not large enough to handle 100% of the fuel from all digesters proposed for this cluster, a large portion of biogas will continue to be injected into the Natural Gas pipeline even after the fueling station has been completed. For simplicity, we modeled 100% of the biogas as being injected into a Natural Gas pipeline.

ARB's default values were used for all types of manure collection and separation systems. Actual GHG reductions may be higher if site specific values were used, but we have deferred to CPUC's preference for common defaults.

Cow numbers are entered into the tool based on the actual numbers of animals currently on site and documented by the host dairyman. No anticipated herd growth numbers or dairy expansion numbers have been added to the actual cow numbers shown in the tool.

Default mink fat, protein, and lactose numbers have been used based on those provided in the methodology. Milk production was unavailable, and as such an average was calculated using data available from dairies in the area.

Electricity consumption, both in the baseline and project scenario, are estimated based on typical energy consumption of the existing and proposed waste management equipment including pumps, agitators, and separation equipment—as adjusted for the specific equipment already employed or to be employed at this facility.

Diesel use reductions are calculated based on data of a 6,500-cow dairy that, by installing a digester, was able to reduce its diesel hours by 1,500 annually from tractor use for farming and lagoon cleanup. This study was previously referenced in multiple 2017 CDFA DDRDP applications by other applicants and subsequently accepted by CDFA. So we have used the same ratios of diesel savings per cow to ensure equitable comparisons between projects instead of claiming superior estimates for our own. This project's diesel use was calculated assuming a direct relationship between cow head and hours reduced, an average tractor power of 150 bhp, and a fuel consumption rate of 18.5 bhp-hr/gal per the Carl Moyer program guidelines. These diesel use reductions are outlined in more detail in the supporting materials for environmental benefits.

Explanation of GHG Inputs and Assumptions

2018 GHG Reduction Calculator

Dixie Creek Dairy – Digester #3

For the purposes of calculating GHG reductions using the CARB Calculator Tool for the SB1383 Pilot Project Solicitation, the following assumptions have been made:

The primary end-use for this project is pipeline injection, with plans to build a CNG vehicle fueling station in the near future. Since the estimated fuel use at this planned future station is not large enough to handle 100% of the fuel from all digesters proposed for this cluster, a large portion of biogas will continue to be injected into the Natural Gas pipeline even after the fueling station has been completed. For simplicity, we modeled 100% of the biogas as being injected into a Natural Gas pipeline.

ARB's default values were used for all types of manure collection and separation systems. Actual GHG reductions may be higher if site specific values were used, but we have deferred to CPUC's preference for common defaults.

Cow numbers are entered into the tool based on the actual numbers of animals currently on site and documented by the host dairyman. No anticipated herd growth numbers or dairy expansion numbers have been added to the actual cow numbers shown in the tool.

Milk content figures for fat, lactose, and protein are taken from milk reports provided by the dairy. Daily production is calculated as follows

$$\frac{Average\ Daily\ MIlk\ Weight\ for\ Statement\ Period\ (lbs/day)}{Number\ of\ Milking\ Cows\ (cow)} = Avg.\ Milk\ Production\ (lbs/cow/day)$$

Electricity consumption, both in the baseline and project scenario, are estimated based on typical energy consumption of the existing and proposed waste management equipment including pumps, agitators, and separation equipment—as adjusted for the specific equipment already employed or to be employed at this facility.

Diesel use reductions are calculated based on data of a 6,500-cow dairy that, by installing a digester, was able to reduce its diesel hours by 1,500 annually from tractor use for farming and lagoon cleanup. This study was previously referenced in multiple 2017 CDFA DDRDP applications by other applicants and subsequently accepted by CDFA. So we have used the same ratios of diesel savings per cow to ensure equitable comparisons between projects instead of claiming superior estimates for our own. This project's diesel use was calculated assuming a direct relationship between cow head and hours reduced, an average tractor power of 150 bhp, and a fuel consumption rate of 18.5 bhp-hr/gal per the Carl Moyer program guidelines. These diesel use reductions are outlined in more detail in the supporting materials for environmental benefits.

Explanation of GHG Inputs and Assumptions

2018 GHG Reduction Calculator

Double L Cattle – Digester #4

For the purposes of calculating GHG reductions using the CARB Calculator Tool for the SB1383 Pilot Project Solicitation, the following assumptions have been made:

The primary end-use for this project is pipeline injection, with plans to build a CNG vehicle fueling station in the near future. Since the estimated fuel use at this planned future station is not large enough to handle 100% of the fuel from all digesters proposed for this cluster, a large portion of biogas will continue to be injected into the Natural Gas pipeline even after the fueling station has been completed. For simplicity, we modeled 100% of the biogas as being injected into a Natural Gas pipeline.

ARB's default values were used for all types of manure collection and separation systems. Actual GHG reductions may be higher if site specific values were used, but we have deferred to CPUC's preference for common defaults.

Cow numbers are entered into the tool based on the actual numbers of animals currently on site and documented by the host dairyman. No anticipated herd growth numbers or dairy expansion numbers have been added to the actual cow numbers shown in the tool.

Milk content figures for fat, lactose, and protein are taken from milk reports provided by the dairy. Daily production is calculated as follows

$$\frac{Average\ Daily\ MIlk\ Weight\ for\ Statement\ Period\ (lbs/day)}{Number\ of\ Milking\ Cows\ (cow)} = Avg.Milk\ Production\ (lbs/cow/day)$$

Electricity consumption, both in the baseline and project scenario, are estimated based on typical energy consumption of the existing and proposed waste management equipment including pumps, agitators, and separation equipment—as adjusted for the specific equipment already employed or to be employed at this facility.

Diesel use reductions are calculated based on data of a 6,500-cow dairy that, by installing a digester, was able to reduce its diesel hours by 1,500 annually from tractor use for farming and lagoon cleanup. This study was previously referenced in multiple 2017 CDFA DDRDP applications by other applicants and subsequently accepted by CDFA. So we have used the same ratios of diesel savings per cow to ensure equitable comparisons between projects instead of claiming superior estimates for our own. This project's diesel use was calculated assuming a direct relationship between cow head and hours reduced, an average tractor power of 150 bhp, and a fuel consumption rate of 18.5 bhp-hr/gal per the Carl Moyer program guidelines. These diesel use reductions are outlined in more detail in the supporting materials for environmental benefits.

Explanation of GHG Inputs and Assumptions

2018 GHG Reduction Calculator

High Roller Dairy – Digester #5

For the purposes of calculating GHG reductions using the CARB Calculator Tool for the SB1383 Pilot Project Solicitation, the following assumptions have been made:

The primary end-use for this project is pipeline injection, with plans to build a CNG vehicle fueling station in the near future. Since the estimated fuel use at this planned future station is not large enough to handle 100% of the fuel from all digesters proposed for this cluster, a large portion of biogas will continue to be injected into the Natural Gas pipeline even after the fueling station has been completed. For simplicity, we modeled 100% of the biogas as being injected into a Natural Gas pipeline.

ARB's default values were used for all types of manure collection and separation systems. Actual GHG reductions may be higher if site specific values were used, but we have deferred to CPUC's preference for common defaults.

Cow numbers are entered into the tool based on the actual numbers of animals currently on site and documented by the host dairyman. No anticipated herd growth numbers or dairy expansion numbers have been added to the actual cow numbers shown in the tool.

Milk content for fat and protein is taken from milk reports provided by the dairy, whereas the lactose content was unavailable and the default number from the ARB Methodology has been used instead. Daily production is calculated as follows

$$\frac{Total\ MIlk\ Weight\ for\ Statement\ Period\ (lbs)}{Days\ in\ Statement\ Period\ (day) \times Number\ of\ Milking\ Cows\ (cow)} = Avg. Milk\ Production\ (lbs/cow/day)$$

Electricity consumption, both in the baseline and project scenario, are estimated based on typical energy consumption of the existing and proposed waste management equipment including pumps, agitators, and separation equipment—as adjusted for the specific equipment already employed or to be employed at this facility.

Diesel use reductions are calculated based on data of a 6,500-cow dairy that, by installing a digester, was able to reduce its diesel hours by 1,500 annually from tractor use for farming and lagoon cleanup. This study was previously referenced in multiple 2017 CDFA DDRDP applications by other applicants and subsequently accepted by CDFA. So we have used the same ratios of diesel savings per cow to ensure equitable comparisons between projects instead of claiming superior estimates for our own. This project's diesel use was calculated assuming a direct relationship between cow head and hours reduced, an average tractor power of 150 bhp, and a fuel consumption rate of 18.5 bhp-hr/gal per the Carl Moyer program guidelines. These diesel use reductions are outlined in more detail in the supporting materials for environmental benefits.

Explanation of GHG Inputs and Assumptions

2018 GHG Reduction Calculator

Lakeside Dairy – Digester #6

For the purposes of calculating GHG reductions using the CARB Calculator Tool for the SB1383 Pilot Project Solicitation, the following assumptions have been made:

The primary end-use for this project is pipeline injection, with plans to build a CNG vehicle fueling station in the near future. Since the estimated fuel use at this planned future station is not large enough to handle 100% of the fuel from all digesters proposed for this cluster, a large portion of biogas will continue to be injected into the Natural Gas pipeline even after the fueling station has been completed. For simplicity, we modeled 100% of the biogas as being injected into a Natural Gas pipeline.

ARB's default values were used for all types of manure collection and separation systems. Actual GHG reductions may be higher if site specific values were used, but we have deferred to CPUC's preference for common defaults.

Cow numbers are entered into the tool based on the actual numbers of animals currently on site and documented by the host dairyman. No anticipated herd growth numbers or dairy expansion numbers have been added to the actual cow numbers shown in the tool.

Default mink fat, protein, and lactose numbers have been used based on those provided in the methodology. Milk production was unavailable, and as such an average was calculated using data available from dairies in the area.

Electricity consumption, both in the baseline and project scenario, are estimated based on typical energy consumption of the existing and proposed waste management equipment including pumps, agitators, and separation equipment—as adjusted for the specific equipment already employed or to be employed at this facility.

Diesel use reductions are calculated based on data of a 6,500-cow dairy that, by installing a digester, was able to reduce its diesel hours by 1,500 annually from tractor use for farming and lagoon cleanup. This study was previously referenced in multiple 2017 CDFA DDRDP applications by other applicants and subsequently accepted by CDFA. We have used the same ratios of diesel savings per cow to ensure equitable comparisons between projects instead of claiming superior estimates for our own. This project's diesel use was calculated assuming a direct relationship between cow head and hours reduced, an average tractor power of 150 bhp, and a fuel consumption rate of 18.5 bhp-hr/gal per the Carl Moyer program guidelines. These diesel use reductions are outlined in more detail in the supporting materials for environmental benefits.

Explanation of GHG Inputs and Assumptions

2018 GHG Reduction Calculator

Lone Oak Farms #1 – Digester #7

For the purposes of calculating GHG reductions using the CARB Calculator Tool for the SB1383 Pilot Project Solicitation, the following assumptions have been made:

The primary end-use for this project is pipeline injection, with plans to build a CNG vehicle fueling station in the near future. Since the estimated fuel use at this planned future station is not large enough to handle 100% of the fuel from all digesters proposed for this cluster, a large portion of biogas will continue to be injected into the Natural Gas pipeline even after the fueling station has been completed. For simplicity, we modeled 100% of the biogas as being injected into a Natural Gas pipeline.

ARB's default values were used for all types of manure collection and separation systems. Actual GHG reductions may be higher if site specific values were used, but we have deferred to CPUC's preference for common defaults.

Cow numbers are entered into the tool based on the actual numbers of animals currently on site and documented by the host dairyman. No anticipated herd growth numbers or dairy expansion numbers have been added to the actual cow numbers shown in the tool.

Milk content for fat is taken from milk reports provided by the dairy, whereas the lactose and protein content was unavailable and the default numbers from the ARB Methodology have been used instead. Daily production is calculated as follows

$$\frac{Total\ MIlk\ Weight\ for\ Statement\ Period\ (lbs)}{Days\ in\ Statement\ Period\ (day) \times Number\ of\ Milking\ Cows\ (cow)} = Avg.\ Milk\ Production\ (lbs/cow/day)$$

Electricity consumption, both in the baseline and project scenario, are estimated based on typical energy consumption of the existing and proposed waste management equipment including pumps, agitators, and separation equipment—as adjusted for the specific equipment already employed or to be employed at this facility.

Diesel use reductions are calculated based on data of a 6,500-cow dairy that, by installing a digester, was able to reduce its diesel hours by 1,500 annually from tractor use for farming and lagoon cleanup. This study was previously referenced in multiple 2017 CDFA DDRDP applications by other applicants and subsequently accepted by CDFA. So, we have used the same ratios of diesel savings per cow to ensure equitable comparisons between projects instead of claiming superior estimates for our own. This project's diesel use was calculated assuming a direct relationship between cow head and hours reduced, an average tractor power of 150 bhp, and a fuel consumption rate of 18.5 bhp-hr/gal per the Carl Moyer program guidelines. These diesel use reductions are outlined in more detail in the supporting materials for environmental benefits.

Explanation of GHG Inputs and Assumptions

2018 GHG Reduction Calculator

Poplar Lane Dairy – Digester #8

For the purposes of calculating GHG reductions using the CARB Calculator Tool for the SB1383 Pilot Project Solicitation, the following assumptions have been made:

The primary end-use for this project is pipeline injection, with plans to build a CNG vehicle fueling station in the near future. Since the estimated fuel use at this planned future station is not large enough to handle 100% of the fuel from all digesters proposed for this cluster, a large portion of biogas will continue to be injected into the Natural Gas pipeline even after the fueling station has been completed. For simplicity, we modeled 100% of the biogas as being injected into a Natural Gas pipeline.

Based on an average daily input of 135 gallons per day, this digester will operate with a hydraulic retention time of 76 days. This size greatly exceeds the necessary retention time, and for that reason the digester can also be used to meet the dairy's wintertime 120-day storage requirements while still acting as a "flex" digester. Consequently, the manure remains in the covered pond until it is used for irrigation, and there are no uncovered effluent storage ponds.

ARB's default values were used for all types of manure collection and separation systems. Actual GHG reductions may be higher if site specific values were used, but we have deferred to CPUC's preference for common defaults.

Cow numbers are entered into the tool based on the actual numbers of animals currently on site and documented by the host dairyman. No anticipated herd growth numbers or dairy expansion numbers have been added to the actual cow numbers shown in the tool.

Milk content data for fat, lactose, and protein are taken from milk reports provided by the dairy. Fat and protein figures are averaged over historical data for the 2017 calendar year whereas the lactose content was only available for the statement period. Daily production is calculated as follows

$$\frac{Daily\ Average\ MIlk\ Weight\ for\ Statement\ Period\ (lbs/day)}{Number\ of\ Milking\ Cows\ (cow)} = Avg.\ Milk\ Production\ (lbs/cow/day)$$

Electricity consumption, both in the baseline and project scenario, are estimated based on typical energy consumption of the existing and proposed waste management equipment including pumps, agitators, and separation equipment—as adjusted for the specific equipment already employed or to be employed at this facility.

Diesel use reductions are calculated based on data of a 6,500-cow dairy that, by installing a digester, was able to reduce its diesel hours by 1,500 annually from tractor use for farming and lagoon cleanup. This study was previously referenced in multiple 2017 CDFA DDRDP applications by other applicants and subsequently accepted by CDFA. So we have used the same ratios of diesel savings per cow to ensure equitable comparisons between projects instead of claiming superior estimates for our own. This project's diesel use was calculated assuming a direct relationship between cow head and hours reduced, an average tractor power of 150 bhp, and a fuel consumption rate of 18.5 bhp-hr/gal per the Carl Moyer program guidelines. These diesel use reductions are outlined in more detail in the supporting materials for environmental benefits.

Explanation of GHG Inputs and Assumptions

2018 GHG Reduction Calculator

River Ranch Dairy – Digester #9

For the purposes of calculating GHG reductions using the CARB Calculator Tool for the SB1383 Pilot Project Solicitation, the following assumptions have been made:

The primary end-use for this project is pipeline injection, with plans to build a CNG vehicle fueling station in the near future. Since the estimated fuel use at this planned future station is not large enough to handle 100% of the fuel from all digesters proposed for this cluster, a large portion of biogas will continue to be injected into the Natural Gas pipeline even after the fueling station has been completed. For simplicity, we modeled 100% of the biogas as being injected into a Natural Gas pipeline.

ARB's default values were used for all types of manure collection and separation systems. Actual GHG reductions may be higher if site specific values were used, but we have deferred to CPUC's preference for common defaults.

Cow numbers are entered into the tool based on the actual numbers of animals currently on site and documented by the host dairyman. No anticipated herd growth numbers or dairy expansion numbers have been added to the actual cow numbers shown in the tool.

Milk content for fat and protein is taken from milk reports provided by the dairy. The two contents from each parlor was combined as a weighted average on a mass basis. Lactose content, however, was unavailable and the default number from the ARB Methodology has been used instead. Daily production is calculated as follows

$$\frac{Total\ Daily\ MIlk\ Weight\ for\ Statement\ Period\ (lbs/day)}{Number\ of\ Milking\ Cows\ (cow)} = Avg.Milk\ Production\ (lbs/cow/day)$$

Electricity consumption, both in the baseline and project scenario, are estimated based on typical energy consumption of the existing and proposed waste management equipment including pumps, agitators, and separation equipment—as adjusted for the specific equipment already employed or to be employed at this facility.

Diesel use reductions are calculated based on data of a 6,500-cow dairy that, by installing a digester, was able to reduce its diesel hours by 1,500 annually from tractor use for farming and lagoon cleanup. This study was previously referenced in multiple 2017 CDFA DDRDP applications by other applicants and subsequently accepted by CDFA. We have used the same ratios of diesel savings per cow to ensure equitable comparisons between projects instead of claiming superior estimates for our own. This project's diesel use was calculated assuming a direct relationship between cow head and hours reduced, an average tractor power of 150 bhp, and a fuel consumption rate of 18.5 bhp-hr/gal per the Carl Moyer program guidelines. These diesel use reductions are outlined in more detail in the supporting materials for environmental benefits.

Explanation of GHG Inputs and Assumptions

2018 GHG Reduction Calculator

Lakeside Pipeline LLC – Entire Cluster

For the purposes of calculating GHG reductions using the CARB Calculator Tool for the SB1383 Pilot Project Solicitation, the following assumptions have been made:

The primary end-use for this project is pipeline injection, with plans to build a CNG vehicle fueling station in the near future. Since the estimated fuel use at this planned future station is not large enough to handle 100% of the fuel from all digesters proposed for this cluster, a large portion of biogas will continue to be injected into the Natural Gas pipeline even after the fueling station has been completed. For simplicity, we modeled 100% of the biogas as being injected into a Natural Gas pipeline.

In the CDFA GHG Reduction Calculator Tool, all ten farms have been consolidated into one calculator tool, with the ten farm totals for all four livestock categories entered. ARB's default values were used for all types of manure collection and separation systems. Actual GHG reductions may be higher if site specific values were used, but we have deferred to CPUC's preference for common defaults. Because this reduction tool consolidates nine digesters from ten dairy farms, all with slightly different separation methods, a manure separation ratio was calculated as follows for each livestock category and used with default separation values to determine the total amount of separation before entering the BCS.

$$\frac{Dairy\ Head}{Total\ Head} \times Default\ Separation\ Rate = Model\ Separation\ Rate$$

The net result is a weighted average of separation values between the technologies employed on category head basis. While, for instance, Decade Dairy has and will have a weeping wall in both the baseline and project scenario, Richard Westra Dairy has no separation in the baseline but will be incorporating a vibrating screen separator for the project. These baseline and project separation practices and calculations are summarized in the following two tables:

Baseline Separation (weighted average calcs)							
Dairy	**Herd Type**	**Herd Qty**	**% Manure Collected**	**Separation Type**	**ARB's Separator Efficiency**	**% of Manure Separated (% Manure Collected * Separator Efficiency)**	**Weighted Average Manure Separation (Attachment 5 - 9c)**
Decade Dairy	Dairy Cow (freestall)	3,000	80%	Weeping Wall	45%	36.0%	16.9%
Richard Westra Dairy	Dairy Cow (freestall)	1,500	80%	None	0%	0.0%	
Clear Lake	Dairy Cow (freestall)	2,050	80%	Stationary Screen	17%	13.6%	
Lakeside	Dairy Cow (freestall)	3,965	80%	Stationary Screen	17%	13.6%	
Dixie	Dairy Cow (freestall)	4,600	80%	Stationary Screen	17%	13.6%	
Double L	Dairy Cow (freestall)	2,590	80%	Stationary Screen	17%	13.6%	
High Roller	Dairy Cow (freestall)	1,900	80%	Vibrating Screen	15%	12.0%	
Lone Oak #1	Dairy Cow (freestall)	4,200	80%	None	0%	0.0%	
Poplar Lane	Dairy Cow (freestall)	2,126	80%	Stationary Screen	17%	13.6%	
River Ranch	Dairy Cow (freestall)	5,258	80%	Weeping Wall	45%	36.0%	
Decade Dairy	Dairy Cow (Open Lot)	-	30%	Weeping Wall	45%	13.5%	6.2%
Richard Westra Dairy	Dairy Cow (Open Lot)	250	30%	None	0%	0.0%	
Clear Lake	Dairy Cow (Open Lot)	-	30%	Stationary Screen	17%	5.1%	
Lakeside	Dairy Cow (Open Lot)	-	30%	Stationary Screen	17%	5.1%	
Dixie	Dairy Cow (Open Lot)	400	30%	Stationary Screen	17%	5.1%	
Double L	Dairy Cow (Open Lot)	-	30%	Stationary Screen	17%	5.1%	
High Roller	Dairy Cow (Open Lot)	-	30%	Vibrating Screen	15%	4.5%	
Lone Oak #1	Dairy Cow (Open Lot)	-	30%	None	0%	0.0%	
Poplar Lane	Dairy Cow (Open Lot)	-	30%	Stationary Screen	17%	5.1%	
River Ranch	Dairy Cow (Open Lot)	278	30%	Weeping Wall	45%	13.5%	
Decade Dairy	Dry Cow (Open Lot)	300	30%	Weeping Wall	45%	13.5%	5.6%
Richard Westra Dairy	Dry Cow (Open Lot)	250	30%	None	0%	0.0%	
Clear Lake	Dry Cow (Open Lot)	400	30%	Stationary Screen	17%	5.1%	
Lakeside	Dry Cow (Open Lot)	442	30%	Stationary Screen	17%	5.1%	
Dixie	Dry Cow (Open Lot)	750	30%	Stationary Screen	17%	5.1%	
Double L	Dry Cow (Open Lot)	239	30%	Stationary Screen	17%	5.1%	
High Roller	Dry Cow (Open Lot)	265	30%	Vibrating Screen	15%	4.5%	
Lone Oak #1	Dry Cow (Open Lot)	700	30%	None	0%	0.0%	
Poplar Lane	Dry Cow (Open Lot)	284	30%	Stationary Screen	17%	5.1%	
River Ranch	Dry Cow (Open Lot)	548	30%	Weeping Wall	45%	13.5%	
Decade Dairy	Heifer (Open Lot)	1,400	30%	Weeping Wall	45%	13.5%	6.2%
Richard Westra Dairy	Heifer (Open Lot)	1,500	30%	None	0%	0.0%	
Clear Lake	Heifer (Open Lot)	2,000	30%	Stationary Screen	17%	5.1%	
Lakeside	Heifer (Open Lot)	3,676	30%	Stationary Screen	17%	5.1%	
Dixie	Heifer (Open Lot)	500	30%	Stationary Screen	17%	5.1%	
Double L	Heifer (Open Lot)	2,640	30%	Stationary Screen	17%	5.1%	
High Roller	Heifer (Open Lot)	1,975	30%	Vibrating Screen	15%	4.5%	
Lone Oak #1	Heifer (Open Lot)	4,500	30%	None	0%	0.0%	
Poplar Lane	Heifer (Open Lot)	2,115	30%	Stationary Screen	17%	5.1%	
River Ranch	Heifer (Open Lot)	5,787	30%	Weeping Wall	45%	13.5%	

Project Separation (weighted average calcs)							
Dairy	Herd Type	Herd Qty	% Manure Collected	Separation Type	ARB's Separator Efficiency	% of Manure Separated (% Manure Collected * Separator Efficiency)	Weighted Average Manure Separation (Attachment 5 - 12c)
Decade Dairy	Dairy Cow (freestall)	3,000	80%	Weeping Wall	45%	36.0%	19.1%
Richard Westra Dairy	Dairy Cow (freestall)	1,500	80%	Vibrating Screen	15%	12.0%	
Clear Lake	Dairy Cow (freestall)	2,050	80%	Stationary Screen	17%	13.6%	
Lakeside	Dairy Cow (freestall)	3,965	80%	Stationary Screen	17%	13.6%	
Dixie	Dairy Cow (freestall)	4,600	80%	Stationary Screen	17%	13.6%	
Double L	Dairy Cow (freestall)	2,590	80%	Stationary Screen	17%	13.6%	
High Roller	Dairy Cow (freestall)	1,900	80%	Vibrating Screen	15%	12.0%	
Lone Oak #1	Dairy Cow (freestall)	4,200	80%	Vibrating Screen	15%	12.0%	
Poplar Lane	Dairy Cow (freestall)	2,126	80%	Stationary Screen	17%	13.6%	
River Ranch	Dairy Cow (freestall)	5,258	80%	Weeping Wall	45%	36.0%	
Decade Dairy	Dairy Cow (Open Lot)	-	30%	Weeping Wall	45%	13.5%	7.5%
Richard Westra Dairy	Dairy Cow (Open Lot)	250	30%	Vibrating Screen	15%	4.5%	
Clear Lake	Dairy Cow (Open Lot)	-	30%	Stationary Screen	17%	5.1%	
Lakeside	Dairy Cow (Open Lot)	-	30%	Stationary Screen	17%	5.1%	
Dixie	Dairy Cow (Open Lot)	400	30%	Stationary Screen	17%	5.1%	
Double L	Dairy Cow (Open Lot)	-	30%	Stationary Screen	17%	5.1%	
High Roller	Dairy Cow (Open Lot)	-	30%	Vibrating Screen	15%	4.5%	
Lone Oak #1	Dairy Cow (Open Lot)	-	30%	Vibrating Screen	15%	4.5%	
Poplar Lane	Dairy Cow (Open Lot)	-	30%	Stationary Screen	17%	5.1%	
River Ranch	Dairy Cow (Open Lot)	278	30%	Weeping Wall	45%	13.5%	
Decade Dairy	Dry Cow (Open Lot)	300	30%	Weeping Wall	45%	13.5%	6.6%
Richard Westra Dairy	Dry Cow (Open Lot)	250	30%	Vibrating Screen	15%	4.5%	
Clear Lake	Dry Cow (Open Lot)	400	30%	Stationary Screen	17%	5.1%	
Lakeside	Dry Cow (Open Lot)	442	30%	Stationary Screen	17%	5.1%	
Dixie	Dry Cow (Open Lot)	750	30%	Stationary Screen	17%	5.1%	
Double L	Dry Cow (Open Lot)	239	30%	Stationary Screen	17%	5.1%	
High Roller	Dry Cow (Open Lot)	265	30%	Vibrating Screen	15%	4.5%	
Lone Oak #1	Dry Cow (Open Lot)	700	30%	Vibrating Screen	15%	4.5%	
Poplar Lane	Dry Cow (Open Lot)	284	30%	Stationary Screen	17%	5.1%	
River Ranch	Dry Cow (Open Lot)	548	30%	Weeping Wall	45%	13.5%	
Decade Dairy	Heifer (Open Lot)	1,400	30%	Weeping Wall	45%	13.5%	7.2%
Richard Westra Dairy	Heifer (Open Lot)	1,500	30%	Vibrating Screen	15%	4.5%	
Clear Lake	Heifer (Open Lot)	2,000	30%	Stationary Screen	17%	5.1%	
Lakeside	Heifer (Open Lot)	3,676	30%	Stationary Screen	17%	5.1%	
Dixie	Heifer (Open Lot)	500	30%	Stationary Screen	17%	5.1%	
Double L	Heifer (Open Lot)	2,640	30%	Stationary Screen	17%	5.1%	
High Roller	Heifer (Open Lot)	1,975	30%	Vibrating Screen	15%	4.5%	
Lone Oak #1	Heifer (Open Lot)	4,500	30%	Vibrating Screen	15%	4.5%	
Poplar Lane	Heifer (Open Lot)	2,115	30%	Stationary Screen	17%	5.1%	
River Ranch	Heifer (Open Lot)	5,787	30%	Weeping Wall	45%	13.5%	

The default values from the ARB Methodology are being used for the fat, protein, and lactose percentage of the milk content while the daily milk production numbers were derived from the 2017 CDFA California Dairy Statistics Annual Report. Because the Lakeside Cluster dairies are split between Kings and Tulare counties, the milk production number is the average between the two, using 15,016,892,657 pounds of milk from 650,381 cows. From these figures, an average of 63.26 pounds of milk is produced per cow per day for the two counties.

Due to these weighted average calculations and the way the Calculator Tool has been designed, "No Solid Separation" was selected for sections 3a. and 3b. in the tool in order that the corresponding sections of 9b.

and 12b.remain at 0%, while the weighted average percentages from the tables above we're entered in sections 9c. and 12c respectively. This most simply and most accurately reflects the volatile solids removal practices from all farms in the Lakeside Cluster when consolidated to one Calculator Tool.

Additionally, since only one county selection can be made in the entire cluster calculation tool despite farms and digesters being in both Tulare and Kings counties, Kings county was selected due to the location of the hub. The same calculation tool has selected the effluent pond as "not covered" despite one of the participating farms, Poplar Lane, having the effluent pond covered. Because of these limitations when consolidating nine digesters into one calculation tool, and because of rounding differences, the sum of the emissions reductions from the nine digester calculation tools does not equal the emissions reductions from the consolidated calculation tool but does come within less than 1% of it. The final 10-year GHG emission reductions for the project is 1,523,423 mtCO2e, as shown in the entire cluster calculation tool, while the sum of the GHG reductions for the nine participating digester totals 1,537,860 mtCO2e.

Electricity consumption, both in the baseline and project scenario, are estimated based on typical energy consumption of the existing and proposed waste management equipment including pumps, agitators, and separation equipment.

Diesel use reductions are calculated based on data of a 6,500-cow dairy that, by installing a digester, was able to reduce its diesel hours by 1,500 annually from tractor use for farming and lagoon cleanup. This project's diesel use was calculated assuming a direct relationship between cow head and hours reduced, an average tractor power of 150 bhp, and a fuel consumption rate of 18.5 bhp-hr/gal per the Carl Moyer program guidelines. These diesel use reductions are outlined in more detail in the supporting materials for environmental benefits.

MAAS ENERGY WORKS

Informational Presentation

5/23/18

Hanford-Lakeside Dairy Digester Cluster

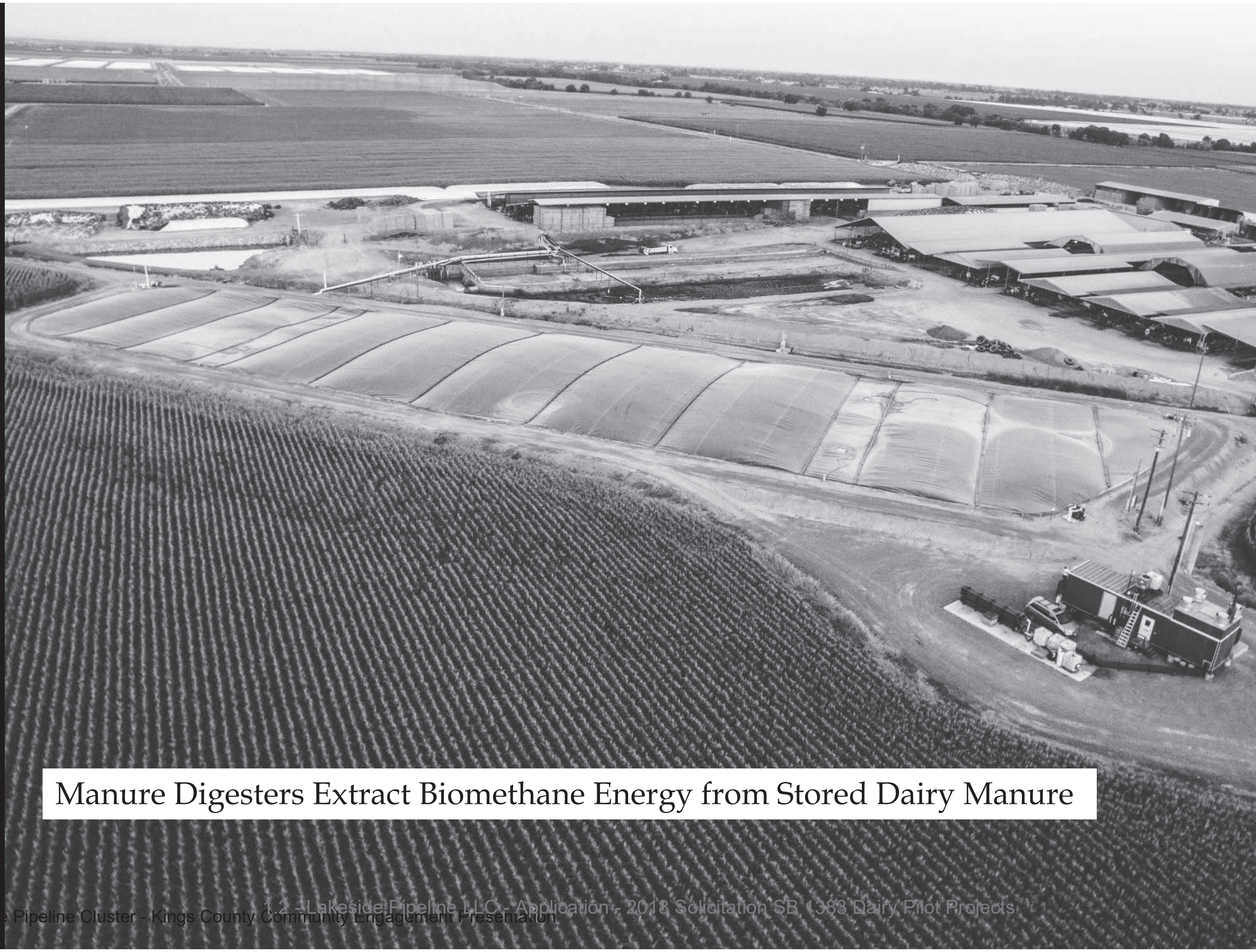
Maas Energy Works

"Renewable Energy that Works"

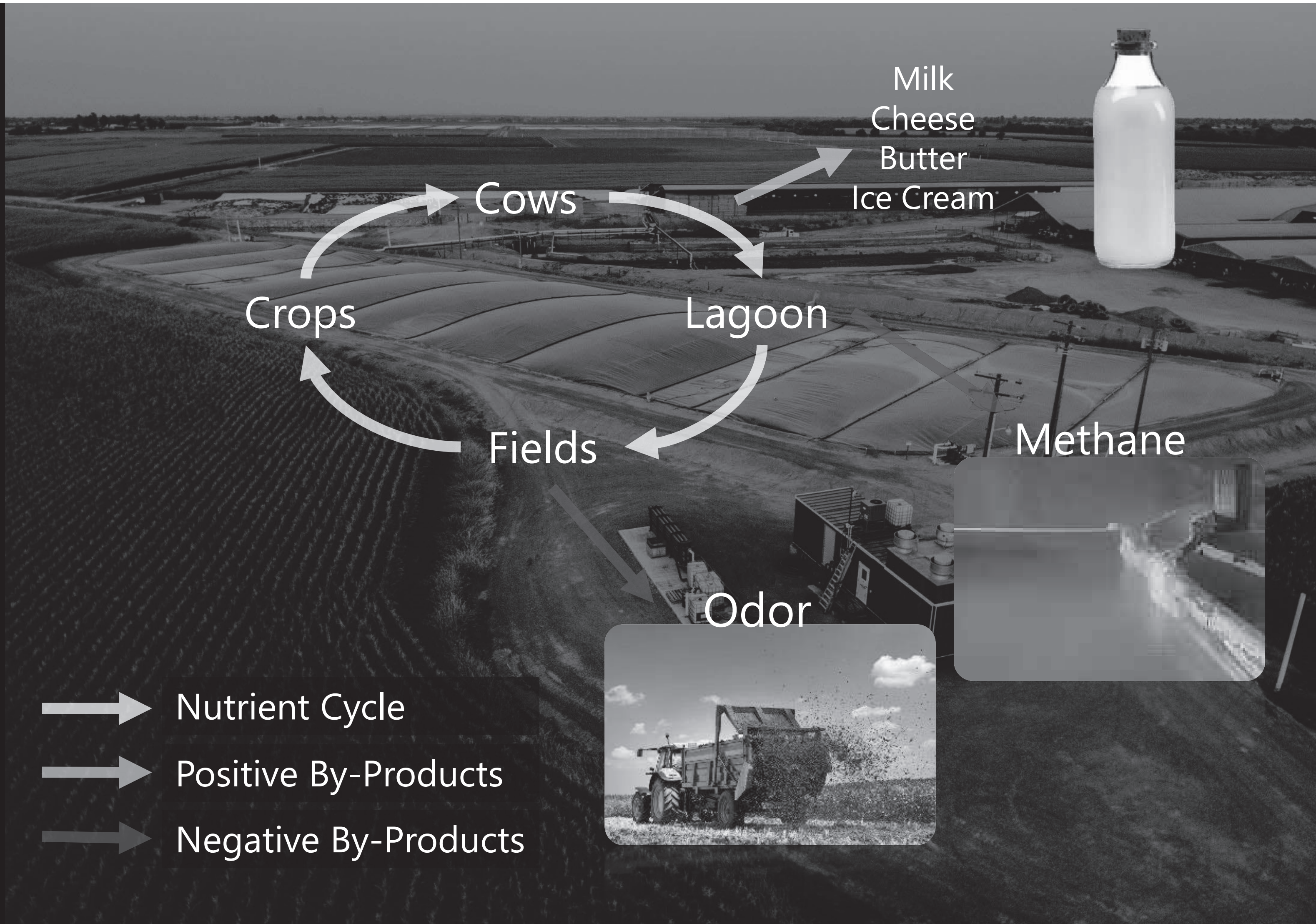
Proposed Construction of Digester Cluster in King's County

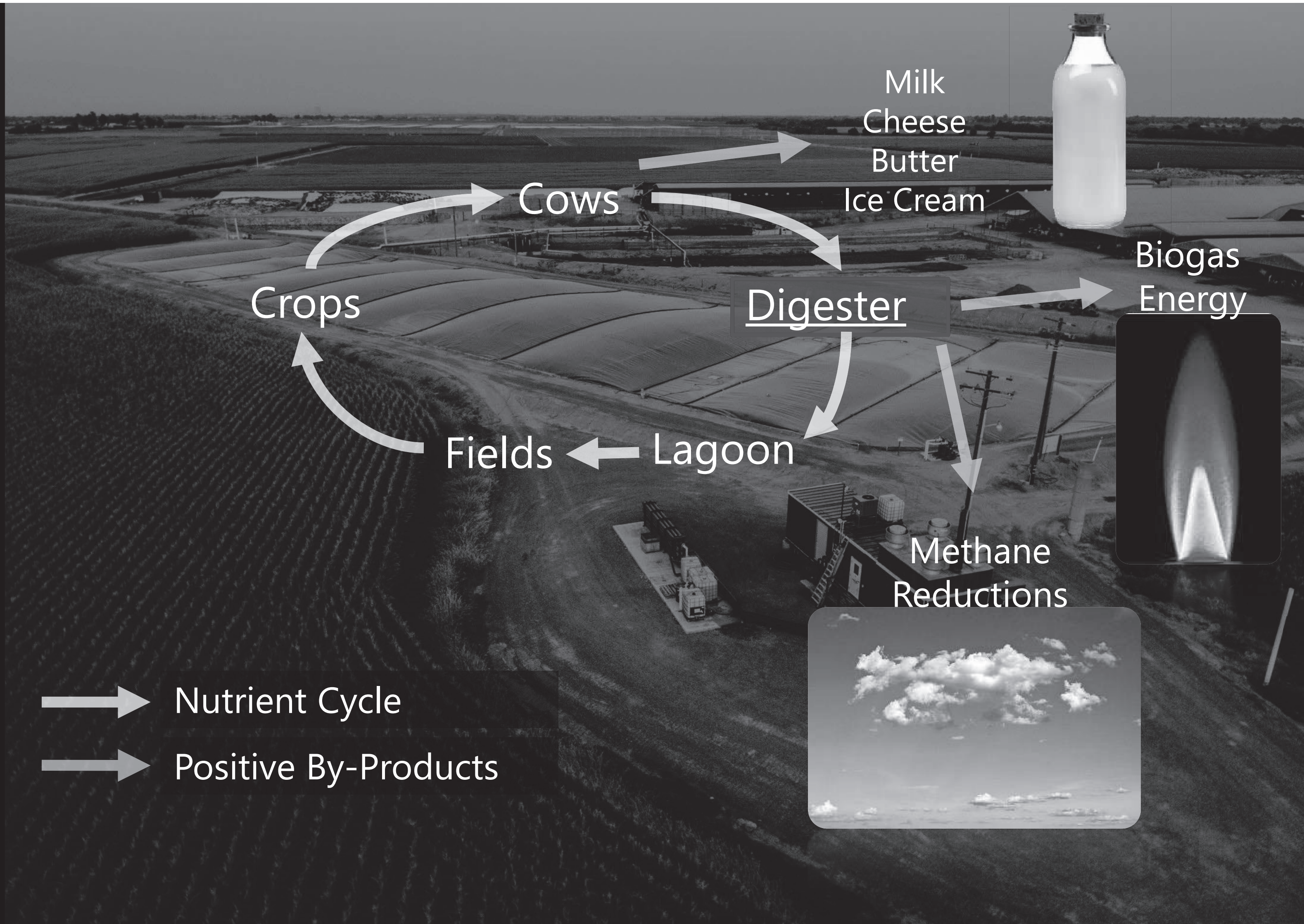
- 2,506,298 Total DGE (Diesel Gallon Equivalent) of renewable vehicle fuel.
- 32,187,301 new investment in Kings County
- 371 jobs.

What is a Manure Digester?



Manure Digesters Extract Biomethane Energy from Stored Dairy Manure


Milk
Cheese
Butter
Ice Cream
Cows
Crops
Lagoon
Fields
Methane
Odor
Nutrient Cycle
Positive By-Products
Negative By-Products


Milk
Cheese
Butter
Ice Cream
Cows
Crops
Digester
Biogas
Energy
Fields
Lagoon
Methane
Reductions
Nutrient Cycle
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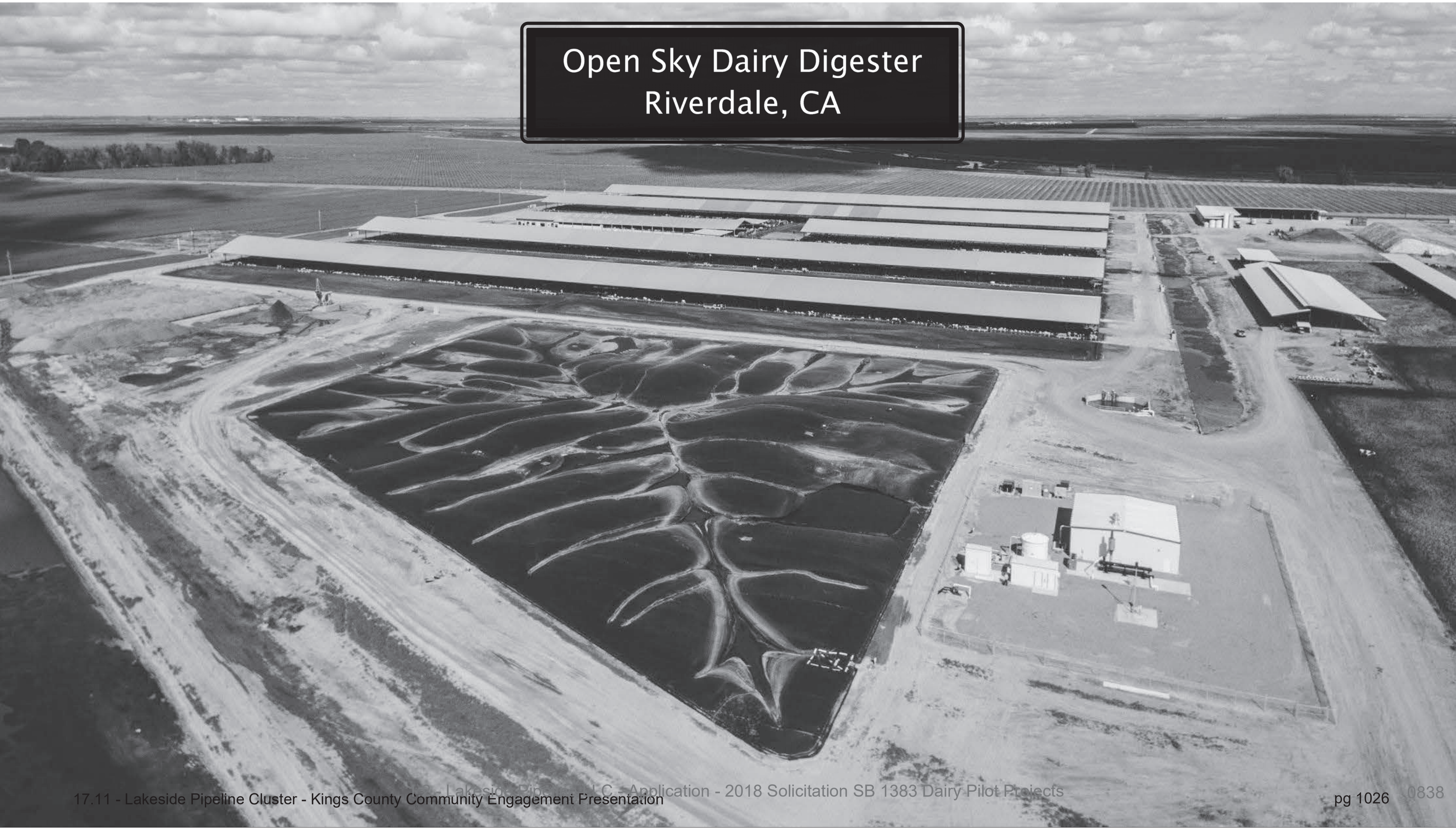
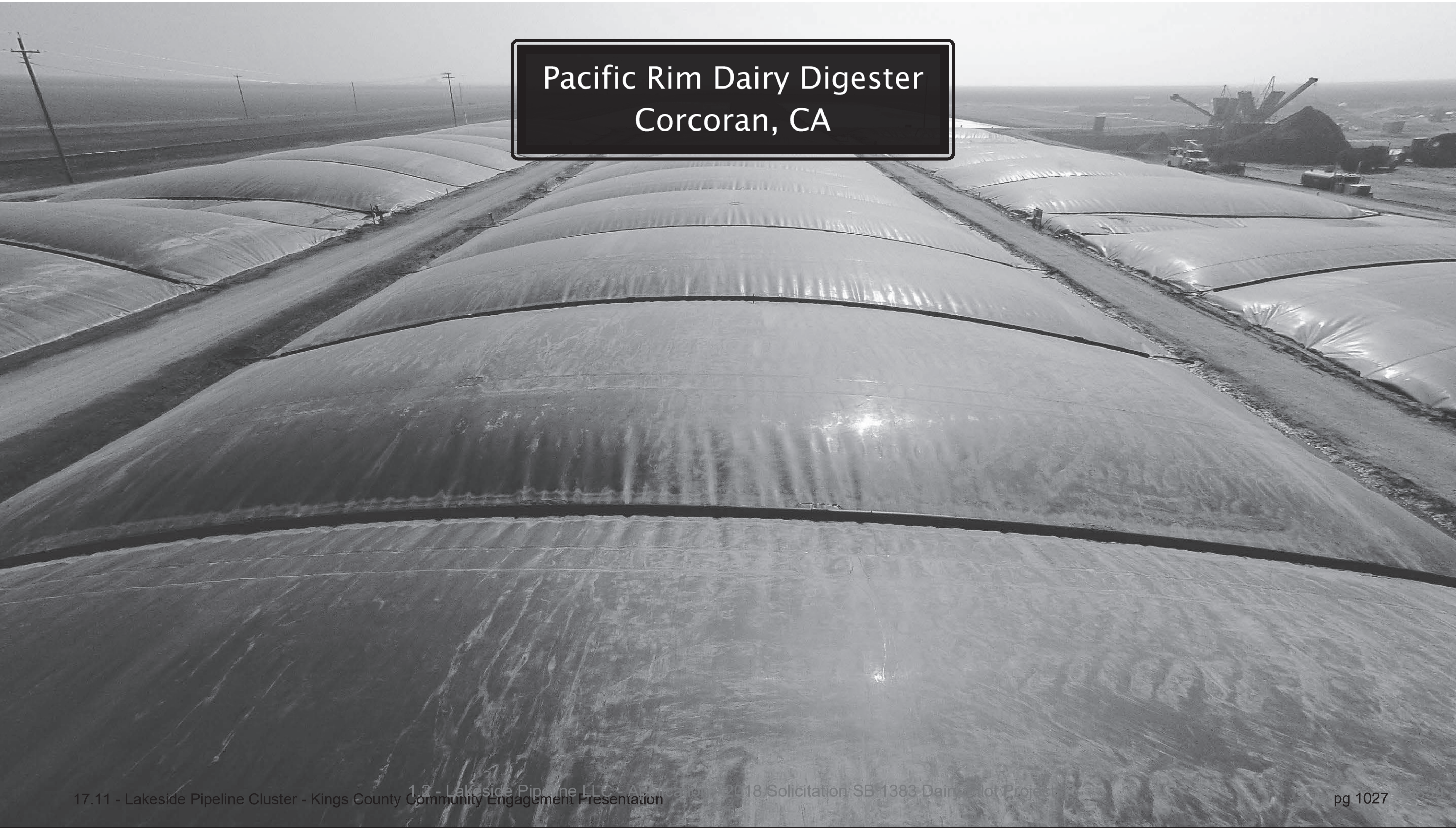
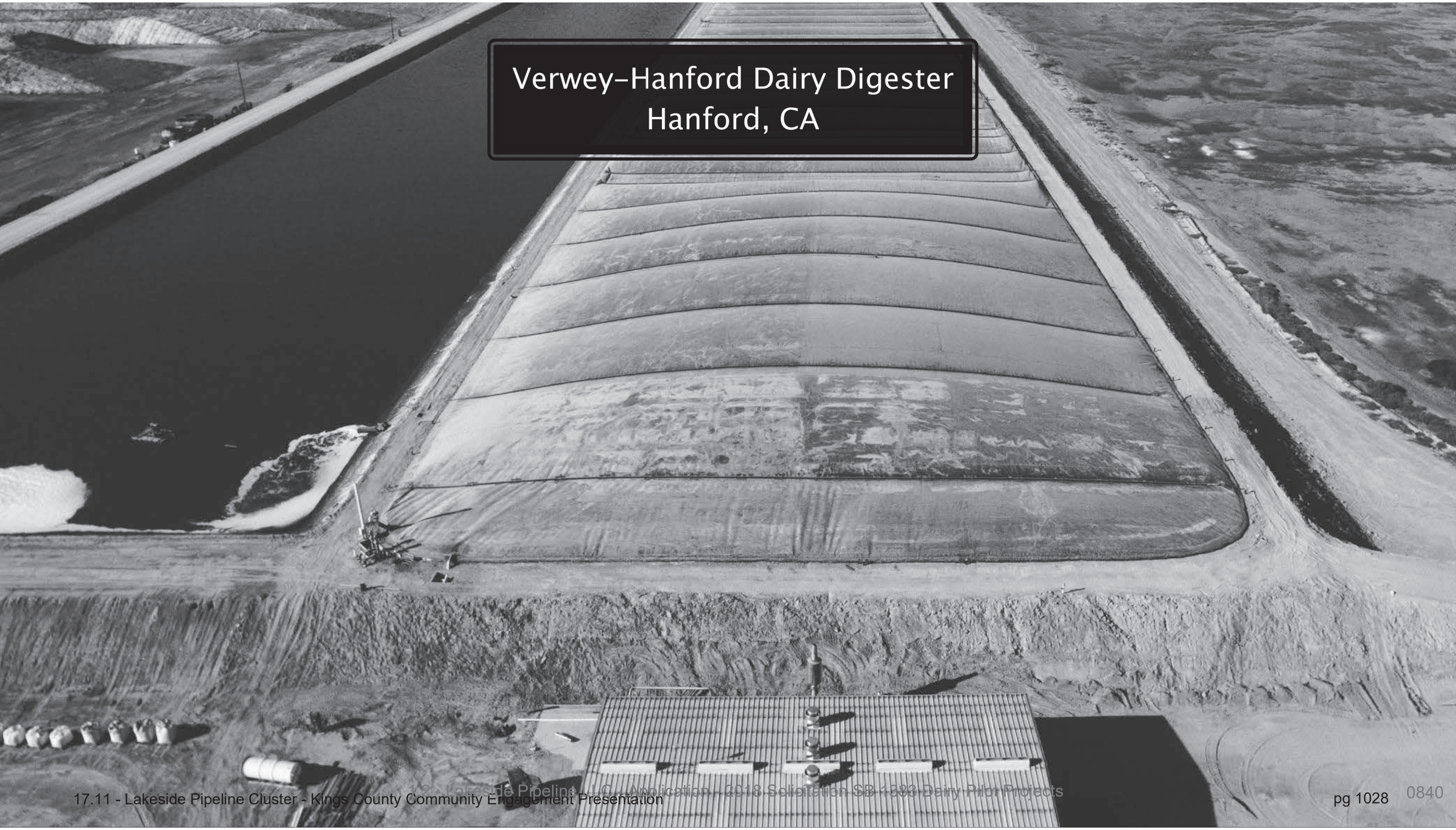


Lakeside Pipeline LLC - Application - 2018 Solicitation SB 1383 Dairy Pilot Projects 0838


Pacific Rim Dairy Digester
Corcoran, CA

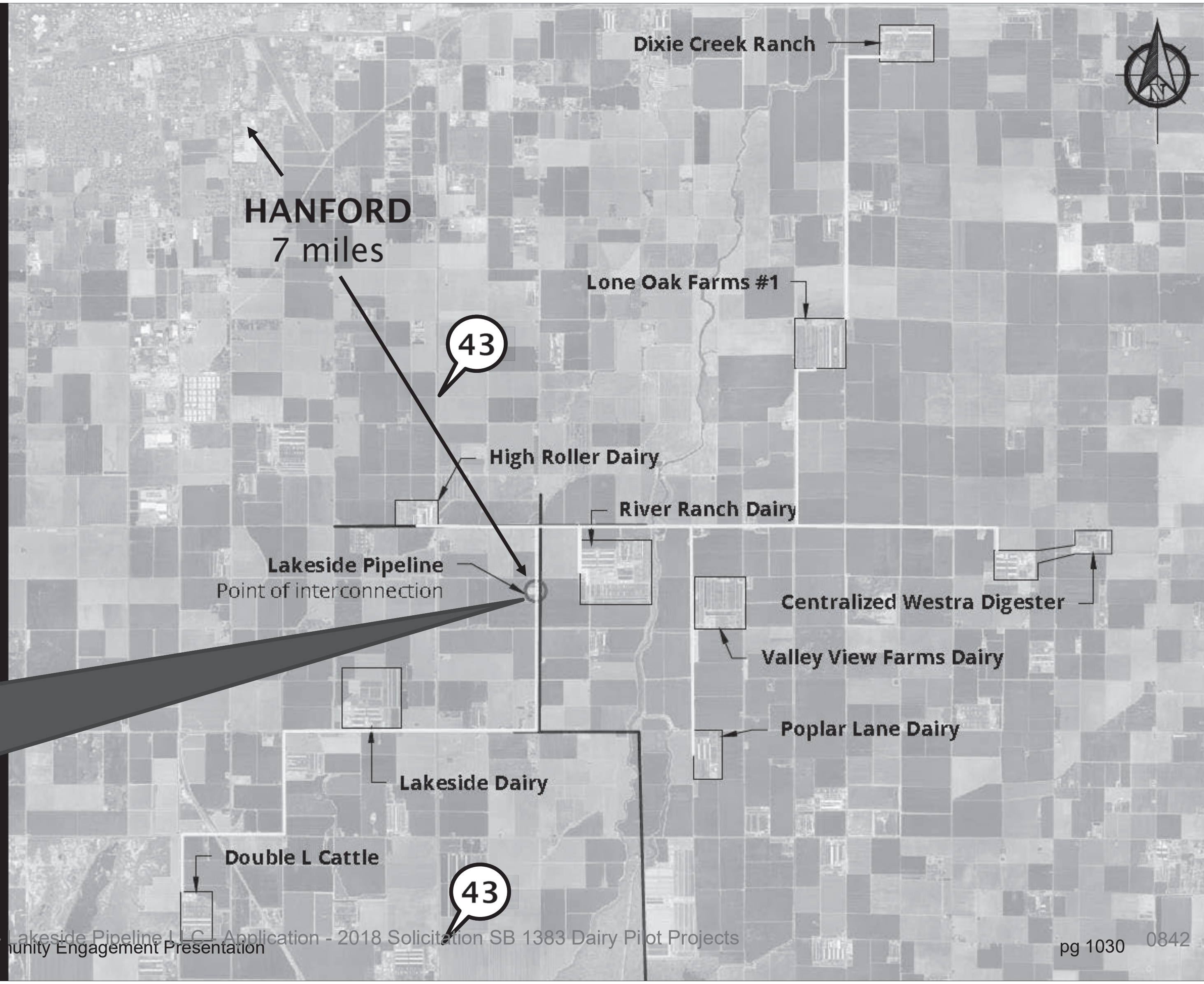

Verwey–Hanford Dairy Digester
Hanford, CA

Maas Energy Works
Digester Projects

California Sites

Washington & Oregon Sites

Lakeside Dairy Digester Pipeline Cluster



Cleaned Biogas to be Injected into PG&E Pipeline and Sent to CNG Filling Stations as truck fuel

Project Economic Impact

Costs: $32,187,301

Service Procurement:

- Excavation
- Earthwork
- Welding
- General construction
- Concrete
- Electrical
- Pipe fitting

Estimated Impact

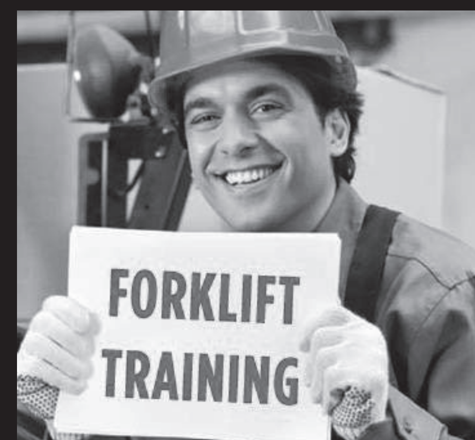
Total Direct Jobs: 228
Total Indirect Jobs: 143
Total Jobs: 371

All Project Contractors will have a minimum local hiring requirement.

PROTEUS INC.

. . . for Education, Employment and Community Services

Provides education, job training, job placement, and other support services to farm working families and other program participants.



www.proteusinc.org

Potential Project Impacts

Economic

- Local job creation
- Local spending
- Expand tax base
- Support to agriculture

Environmental

- Greenhouse gas reductions
- Odor control
- Protect water quality
- Water savings
- Emissions reductions in converted fleets

Potential Project Impacts

Potential negative impact

- Increased noise from construction
- Increased traffic during construction

Mitigation Efforts

- King's County CEQA Review
- Updated liquid manure handling permits at each dairy
- Updated Nutrient Management plans and Waste Management Plans
- Air Permit from San Joaquin Valley Air Pollution Control District for central hub
- Conversion of Diesel fueled fleets to CNG

Air quality improvement impacts

Our Project (kg/year)

Baseline Process	VOCs	CO	NOx	PM	Sox	H2S	NH3
Waste Collection							
Off-Road Equipment Operation	5	99.0	111	3.4	0.098	0	0
Uncovered Lagoon Emissions	7896	0.0	0	0.0	0.000	5675	45912
Waste Digestion							
Waste Mgmt Electricity Demand	2	29.8	34	7.3	31.969	0	0
Diesel Use							
ULSD Refining Emissions	77	301.8	443	82.4	131.286	0	0
ULSD T&D Emissions	4	15.4	39	2.1	6.746	0	0
Diesel Tailpipe Emissions	112	721.7	2330	328.7	28.572	0	0
Total Baseline Emissions	8096	1167.7	2957	424.0	198.670	5675	45912

Project Process	VOCs	CO	NOx	PM	Sox	H2S	NH3
Waste Collection							
Off-Road Equipment Operation	1	19.8	22	0.7	0.020	0	0
Covered Lagoon Emissions	3158	0.0	0	0.0	0.000	2270	18365
Waste Digestion							
Digester Electricity Demand	3	29.8	39	8.4	36.536	0	0
Biogas Transport and Upgrading							
Compression Electricity Demanc	1	8.7	10	1.4	0.783	0	0
Upgrading Electricity Demand	6	81.1	93	12.6	7.313	0	0
Sales Gas Compr. Elect. Demanc	0	6.4	7	1.0	0.576	0	0
CNG Use							
NG Transportation and Delivery	132	680.8	806	3.6	13.483	0	0
CNG Fueling Station Compressic	19	113.9	158	27.2	117.961	0	0
CNG Tailpipe Emissions	11	72.2	233	32.9	0.000	0	0
Total Project Emissions	3331	1012.6	1369	87.7	176.673	2270	18365

Total Reduction	4765	155.1	1589	336.3	21.998	3405	27547

How do I leave feedback on the projects?

Maas Energy Works

Visit ***www.****maasenergy.com/2018events* or email *info@maasenergy.com*

Please consider writing a letter of support for the project

Please send to

geo@maasenergy.com

Proyectos de Energía Renovable

Reunion Publica

Para presentación del proyectos, su diseño e impacto ambiental.

Se proveerá comida ligera / bocaditos & Traducción.

Hanford

January 22nd
4:00 PM

Proteus Community Service Center
216 W. 7th St.
Hanford, CA 93230

Visalia

January 22nd
11:00 AM

Proteus Community Service Center
224 NW 3rd Ave
Visalia, CA 93291

Renewable Energy Projects

Community Engagement Meeting

Public meeting to discuss design and environmental impacts of dairy digester contruction.

Translation services and light refreshments provided
Childcare not provided

June 25, 2018

Community Benefits Agreement for Lakeside Pipeline Dairy Digester Cluster

This Community Benefits Agreement ("Agreement") is made as of June 5, 2018 between Lakeside Pipeline LLC, and Kings County Economic Development Corporation ("EDC"), collectively, "Parties."

Recitals

1. Whereas EDC is a non-profit organization with over 50 years of experience in providing workforce and economic development services in Kings County; and

2. Whereas EDC works with local communities and institutions to improve the economy and quality of life of Kings County residents, including low income population and minorities; and

3. Whereas Developer is a private company engaged in the construction and operation of an interconnected cluster dairy digester renewable fuel generation facility (the "Project") on Kings County dairy farms; and

4. Whereas the Parties have successfully in the past collaborated with various institutions to facilitate job creation, hiring, and other community benefits; and

5. Whereas the Parties desire to collaborate to promote, demonstrate, and document various community benefits to be created by the Project.

NOW, THEREFORE, in consideration of the promises and conditions herein contained, the parties hereby covenant and agree as follows:

Purpose

The purpose of this Community Benefits Agreements for the Dairy Digester Cluster, centered at Hanford, in Kings County, is to provide for a coordinated effort between Parties to maximize the benefits of the Project to Kings County community and to demonstrate community support for the Project. This Community Benefits Agreement will, among other functions: provide living wage jobs and targeted local hiring and contracting; advocate environmentally sustainable practices; provide local procurement and technical assistance for small local businesses; and provide residents of rural Kings County with information on and access to employment opportunities with the Project.

The following dairy digesters are proposed as part of the project: