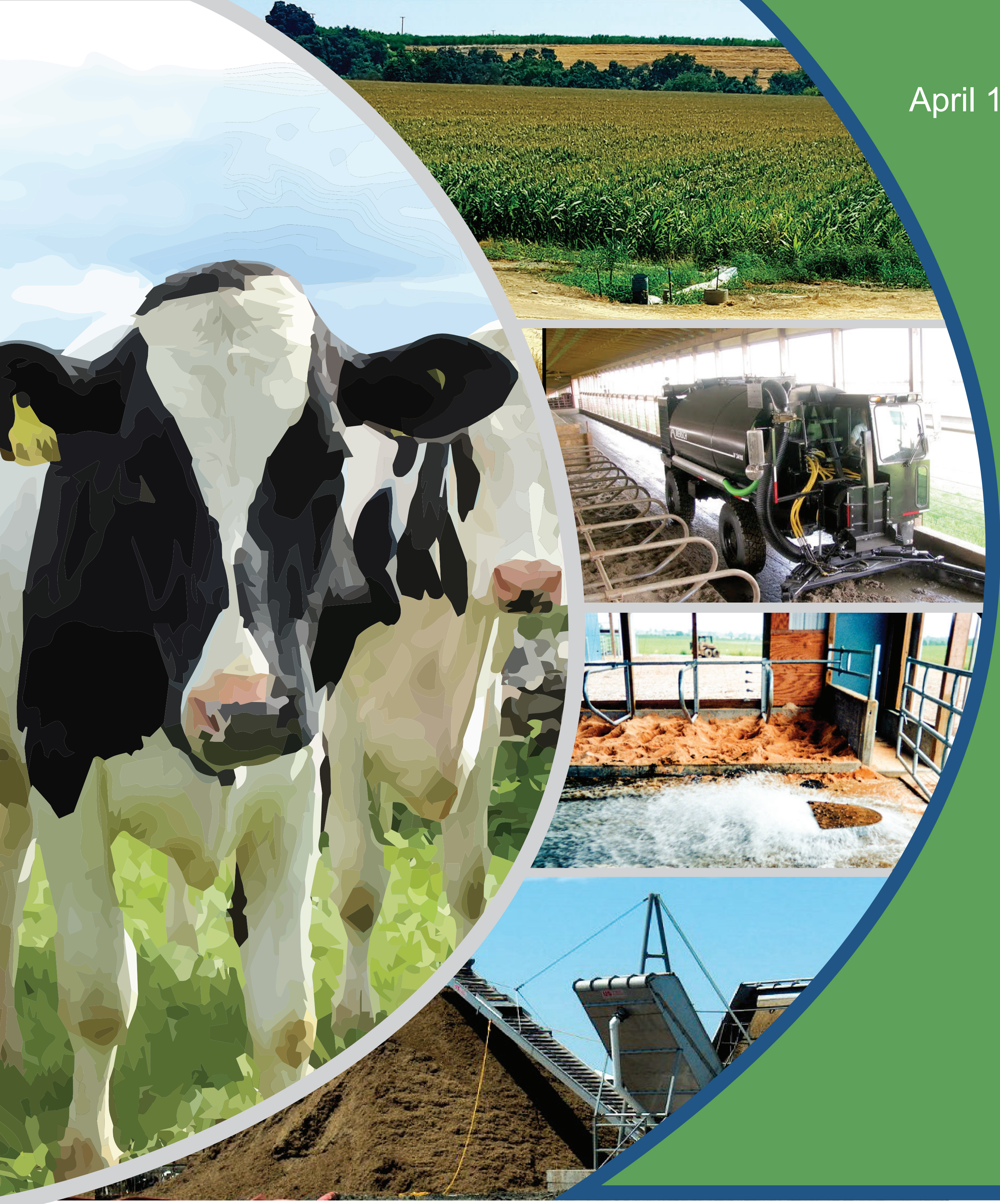

April 1, 2019

Summary Representative Monitoring Report

Prepared and submitted to the Central Valley Regional Water Quality Control Board by the Central Valley Dairy Representative Monitoring Program.

This Summary Representative Monitoring Report was prepared by and for the Central Valley Dairy Representative Monitoring Program as part of the program's obligations to the Central Valley Regional Water Quality Control Board under General Order R5-2013-0122.

Principal authors of this report include:

- J.P. Cativiela, CVDRMP Administrator
- Till Angermann, PG, CHG, CVDRMP Technical Program Manager – Luhdorff and Scalmanini Consulting Engineers
- Theresa Dunham, CVDRMP Legal Counsel – Somach, Simmons and Dunn.

Substantive conclusions regarding costs of different management practices were drawn from or based on estimates prepared by Provost and Pritchard Consulting Group, as well as interviews with other professional experts and individual dairy operators.

Suggested Citation: Central Valley Dairy Representative Monitoring Program. 2019. *Summary Representative Monitoring Report*. April 1, 2019.

LSCE File Number: 17-7-102

Central Valley Dairy Representative Monitoring Program

For the benefit of dairy producers and water quality across our valley

April 1, 2019

Doug Patteson
Program Manager, Confined Animal Facilities
Central Valley Regional Water Quality Control Board
1685 E Street
Fresno, CA 93706

Dear Mr. Patteson:

Per the requirements of General Order R5-2013-0122, "Reissued Waste Discharge Requirements for Existing Milk Cow Dairies," we hereby submit the attached Summary Representative Monitoring Report (SRMR).

This SRMR is based on data collected over thousands of hours of CVDRMP staff during the past several years. This work included collection and analysis of groundwater quality data, special studies and investigations, academic literature review, and consultation with academic and professional experts in a variety of fields, from engineering, hydrogeology, and agronomy to environmental law and policy. Equally important, our staff visited real dairies to confer with owners about their day-to-day practices, operational parameters, and potential opportunities and challenges related to changing manure management practices.

Our board carefully reviewed the facts and options presented by our staff, asked many questions, and deliberated at length before deciding on the recommendations contained herein. While these recommendations will be costly and difficult to implement, we believe they represent an ambitious, yet practical, good-faith effort by our industry to improve water quality protection and ensure safe drinking water for our communities and neighbors.

We appreciate the efforts of you and your staff to provide guidance as these recommendations were developed. Your insights were extremely helpful and were considered carefully as we finalized our report. We look forward to discussing these recommendations with you, as well as continuing to collaborate with you moving forward to implement these recommendations in a timely manner.

Finally, and on behalf of the CVDRMP Board of Directors, I certify under penalty of law that we have personally examined and are familiar with the information submitted in this document and all attachments and that, based on my inquiry of those individuals immediately responsible for obtaining the information, I believe that the information is true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment.

Sincerely,

Justin Gioletti
Chairman

915 L Street, #C-431 • Sacramento, CA 95814 • (916) 594-9450

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Tables and Figures

EXECUTIVE SUMMARY

As required by the Central Valley Regional Water Quality Control Board (Regional Board) through its Reissued Waste Discharge Requirements Order for Existing Milk Cow Dairies, R5-2013-0122 (Dairy Order)[1], Representative Monitoring Programs must submit a Summary Representative Monitoring Report (SRMR) to the Regional Board by April 1, 2019. The Central Valley Dairy Representative Monitoring Program (CVDRMP) is an approved Representative Monitoring Program (RMP), and as such, must submit an SRMR to the Regional Board by April 1, 2019.

This SRMR is the culmination of a series of detailed technical reports provided to the Regional Board since CVDRMP's inception in 2010. CVDRMP submitted a proposed monitoring plan to the Regional Board in 2011, receiving approval and commencing well installation that year. In 2012, while sampling its initial wells, CVDRMP expanded its network to include dairies spanning nearly the entire Central Valley. With new wells in place, CVDRMP continued its sampling efforts and submitted its first Annual Representative Monitoring Report (ARMR) on April 1, 2013. CVDRMP has submitted additional detailed ARMRs in each year since, providing a wealth of data and analysis related to groundwater monitoring within our network.

Notably, CVDRMP efforts did not begin and end with well monitoring. CVDRMP conducted numerous additional special technical studies to improve the understanding of current Central Valley dairy management practices in manure storage areas, cropped fields and animal housing areas, and how these practices have impacted soils and groundwater quality. The ARMRs described, and this SRMR summarizes, the results of studies that evaluated manure retention pond seepage rates, nutrient use efficiency in forage crops, soil and water impacts associated with animal housing, analysis of annual nutrient application reports submitted by CVDRMP members and more. These studies were conducted directly by CVDRMP and were supplemented by information gleaned from comparisons to the ongoing similar work of our peers and extensive literature reviews.

The result of all this work is a greatly improved understanding of current dairy management practices, their resulting impacts on groundwater, and most importantly, opportunities to mitigate these impacts. As required by the Dairy Order, this SRMR identifies potential solutions and upgrades to management practices, a feasibility analysis for these solutions, and realistic timeframes for implementation. Going beyond that, the SRMR identifies the potential to create additional, more effective and feasible solutions that do not exist today and suggests a program to pursue development of those options.

The data accompanying this report and submitted to the Regional Board over the past several years demonstrate that dairy farming impacts to groundwater can vary dramatically depending on soil types, depth to groundwater, site-specific management choices and other factors. However, groundwater

[1] *General Order No. R5-2013-0122* rescinds and replaces the 2007 General Order (Central Valley Regional Board, 2007). In this document, the term 'Dairy 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, when needed, by identifying the years of adoption (i.e., 2007 Dairy Order and 2013 Dairy Order).

impacts of dairies are not limited to a single geographical area but were found throughout the representative network of wells monitored by CVDRMP. These data outline a challenge of a scale that requires thoughtful, expansive solutions backed by strategic planning, sustained effort, and long-term commitment.

Some of these solutions, such as use of better measurement devices like flow meters, improved reporting tools and sampling methods, increased education on nitrogen use efficiency (NUE) and enhanced planning through Irrigation and Nitrogen Management Plans, are at hand and may be implemented in relatively short order.

Other solutions, such as increasing export of manure nitrogen from dairies to other irrigated croplands – where it can provide soil and water quality benefits simultaneously – or new technologies that may denitrify manure – are promising but face considerable economic, technical and regulatory barriers at this time. As such they will require substantial efforts to reach scale, including changes in the way many dairies are operated today, and significant investment. To accomplish those changes without severe consequences to the viability of our dairy economy, we recommend a staged, collaborative effort between the dairy community, various government agencies, academia and supporting industries. To be successful, this effort must address several interlocking challenges, including but not limited to advancing research, development and pilot-testing of manure processing technology, developing off-dairy markets for manure-based products, and incentive programs to speed adoption of the most promising alternatives.

Success in the above efforts does not guarantee how quickly or to what degree improvements in groundwater quality will be achieved. The Dairy Order aspired to assure all dairy farming was conducted with management practices that would neither result in impacts above the Regional Board's water quality objectives for groundwater, nor degrade high quality groundwater beyond the limitations of the State's Anti-Degradation Policy (otherwise referred to as the Resolution 68-16). However, since adoption of the Dairy Order, a growing body of evidence has suggested that currently available and feasible agricultural technology and practices cannot be expected to eliminate discharges into groundwater from dairies, nor alter volume or character of those discharges so that they are at or below some applicable water quality objectives. Likewise, currently available and feasible technologies and practices are not expected to result in returning groundwater quality to drinking water standards in many aquifers. In fact, information developed through the CV SALTS (Central Valley Salinity Alternatives for Long-Term Sustainability) stakeholder process suggested that in some areas, even if all farming was permanently stopped, it would take many decades for groundwater nitrate-N concentrations in the production aquifer to decline below the Maximum Contamination Limit of 10 mg/L (LWA 2016).

In recognition of these realities, the Regional Board in May 2018 adopted revisions to its Water Quality Control Plans (Basin Plans) to include Salt and Nitrate Control Programs that apply throughout the Central Valley). These amendments are currently pending approval by the State Water Resources Control Board before becoming effective. The Basin Plan amendments attempt to strike a balance between the need for the Central Valley to maintain the economic viability of farming while progressively improving management practices – even if those practices are not yet capable of restoring groundwater aquifers to drinking water quality – while also meeting the immediate need for safe drinking water supplies. The Amendments require that best efforts be made to control discharges, while also offering alternative compliance pathways for dischargers who contribute to providing drinking water solutions through compliance with the Nitrate Control Program, and through implementation of Nitrate Control Program Management Zones (Management Zones).

The adoption of the Basin Plan Amendments is a monumental shift in policy that cannot be ignored in the context of this SRMR. As such, we conclude that some of the specific requirements of the Dairy Order, such as its requirement that CVDRMP propose time frames for implementing practices that meet certain water quality objectives (i.e., nitrate) within a time frame no longer than 10 years, are unrealistic and should be addressed in a revised Dairy Order.

Overall, we suggest a prioritized strategy, similar to that expressed in the Basin Plan Amendments, which prioritizes early actions, improves surveillance and monitoring, develops new and improved control strategies, and measures and reports results to help steer future decision-making. Also guided by the policy imperatives expressed in the Basin Plan Amendments, we recommend several specific actions to be taken by CVDRMP and its members that are consistent with compliance options in the Nitrate Control Program, including participation in drinking water solutions, participation in Management Zones by our members, funding of salinity studies being overseen by the Central Valley Salinity Coalition, and funding of the Surveillance and Monitoring Program (SAMP).

The Central Valley's world-leading agricultural industry, including dairies, has provided incalculable economic and social benefits to the people of California. Yet the impacts to groundwater quality caused by decades of producing crops with irrigation, synthetic fertilizers and manures cannot be denied. CVDRMP recognizes that dairy farmers must be part of the solution, taking reasonable steps to reduce and control discharges, while also contributing and cooperating with other stakeholders to ensure a safe drinking water supply for all Central Valley residents. CVDRMP stands ready to continue assisting the dairy industry and our partners in government and academia in identifying steps and implementing programs to reach these important goals.

Guide to Executive Summary Tables

Implementation timelines for many of the recommendations in this SRMR begin immediately and include milestones and performance targets (**Table ES1**). Costs for these recommendations and continuing compliance costs are significant (**Table ES2**). Importantly, an analysis of different strategies to reduce nitrogen loading to groundwater across the industry indicates that manure export strategies are by far the most effective in terms of (i) total potential nitrogen loading reduction and (i) expended cost per ton of avoided N subsurface loading (**Table ES3**).

Table ES1: Implementation timelines

Recommendation	Anticipated Effective Date	First Milestone	Second or Continuing Milestones	Long-term Performance Target
Provide drinking water through Management Zones (MZ), Alternative Compliance Pathways (ACP) or legislation or combination	January 2020 (a)	Implementation of Priority 1 Basins, late 2020	Lower-priority basins by 2022	Continued participation in MZs or ACPs for all CVDRMP members
Nitrogen Use Efficiency Education	February 2020 (b)	Curriculum offered – October 2020	Curriculum completed – September 2022	Report ongoing outreach and education through at least 2029
Installation of liquid manure flow meters on all dairies	February 2020 (b)	Install flowmeters by May 2022	Not applicable/fully implemented	Continuous use
Irrigation and Nitrogen Management Plan	February 2020 (b)	Complete plan by October 2021	Update plan annually	Continuous use
New reporting template	February 2020 (b)	Develop web portal in 2020	Use required by December 2021	Continuous use
Modified sampling and testing requirements	February 2020 (b)	Utilize in winter crop 2020-2021	Continuous use	Continuous use
Whole-farm nutrient balance industry-wide and on individual farms	February 2020 (b)	Use new reporting form in December 2021	Annual reports documenting individual and coalition progress	Whole-farm balance, date for achievement TBD based on annual progress reviews
Contribute to Basin Plan Amendment salinity studies and Surveillance and Monitoring Program	Immediate	Initial contribution in 2019	Annual contributions	Complete studies in 10 to 15 years
Continued representative groundwater monitoring	January 2020 (c)	Submit revised work plan in late 2019	Begin updated monitoring schedule in January 2020	Continuous monitoring

a) Estimated based on potential effective date of Safe Drinking Water Fund Legislation and/or Salt and Nitrate Control Program Basin Plan Amendments. Could take longer based on factors outside of CVDRMP control, such as regulatory approvals. CVDRMP intends to include participation in Management Zones as a requirement of membership after January 1, 2020.
b) Anticipated adoption of General Order requirement by Central Valley Regional Water Quality Control Board.
c) Upon approval of revised work plan by Central Valley Regional Water Quality Control Board.

Table ES2: Annualized costs of CVDRMP's recommendations and continuing compliance (a)

Recommendation	Cost to Industry	Cost to Individual Dairies
Coalition costs: Continued groundwater monitoring, develop and administer web-based portal, annual reports, salinity studies, Surveillance and Monitoring Program for salt and nitrate	$955,345	$869
Nitrogen Use Efficiency Education and related education and outreach	$220,000	$200 (b)
Installation of liquid manure flow meters on all dairies	$660,000	$300-$1,000
Irrigation and Nitrogen Management Plan	$11,000,000	$5,000-$15,000
Waste Discharge Permit Fund fees	$3,774,544 (c)	$0-$14,069 $3,260 (mean) $2,110 (median)
Modified sampling and testing requirements (manure and harvested crops)	$797,500	$420-$1,030
Contribution to drinking water through Safe Drinking Water Fund, Management Zones or both	$3,802,890 (d)	$230-$23,000 $3,457 (mean)
Total	$21,210,279	$7,019-$55,168

a) Costs annualized over a 10-year period. A more detailed version of this table is included in *Section 3.1*.
b) Does not include value of dairy operators' time to attend and complete course.
c) Assumes that approximately 91 percent of fees invoiced to dairies by the State Water Resources Control Board in 2018-2019 were for Central Valley dairies.
d) Detailed explanation of assumptions in *Section 3.1*.

Table ES3: Nitrogen leaching avoidance costs (a)

Recommendation	Cost per Ton of Nitrogen Avoided (b)
Exporting unprocessed solid manure or solid manure with limited processing (windrow drying) (c)	No cost (d)
Partial diversion of liquid manure via vacuuming and windrow drying, followed by export	No cost (d)
Extend pipelines to allow application of liquid manure to more distant fields, replacing need to use synthetic nitrogen fertilizer on those fields	\$68 to \$454
Haul liquid manure in truck to apply to distant 80-acre crop field (low = 1 mile haul; high = 10-20 mile haul) (e)	\$3,092 to \$12,645
Line existing earthen lagoons with a single synthetic liner (Tier 2) followed by agronomic application of N (avoided from lagoon leaching) at an AR ratio of 1.4	\$324,617 (f)
Line existing earthen lagoons with a (Tier 1) double synthetic liner and leachate collection and removal system followed by agronomic application of N (avoided from lagoon leaching) at an AR ratio of 1.4	\$476,407 (f)
Replace earthen corrals with concrete-floor corrals	\$6.8 million

a) This table greatly simplifies cost analyses to provide an overview. Detailed cost information is provided in *Section 3*. All cost estimates are preliminary.

b) Annualized over 10-year period. Some strategies have significant costs in year 1, but costs diminish or are eliminated over time due to other cost savings (such as reduced need for synthetic fertilizer sources of nitrogen) or offsetting revenue (from sale of manure or manure-based products).

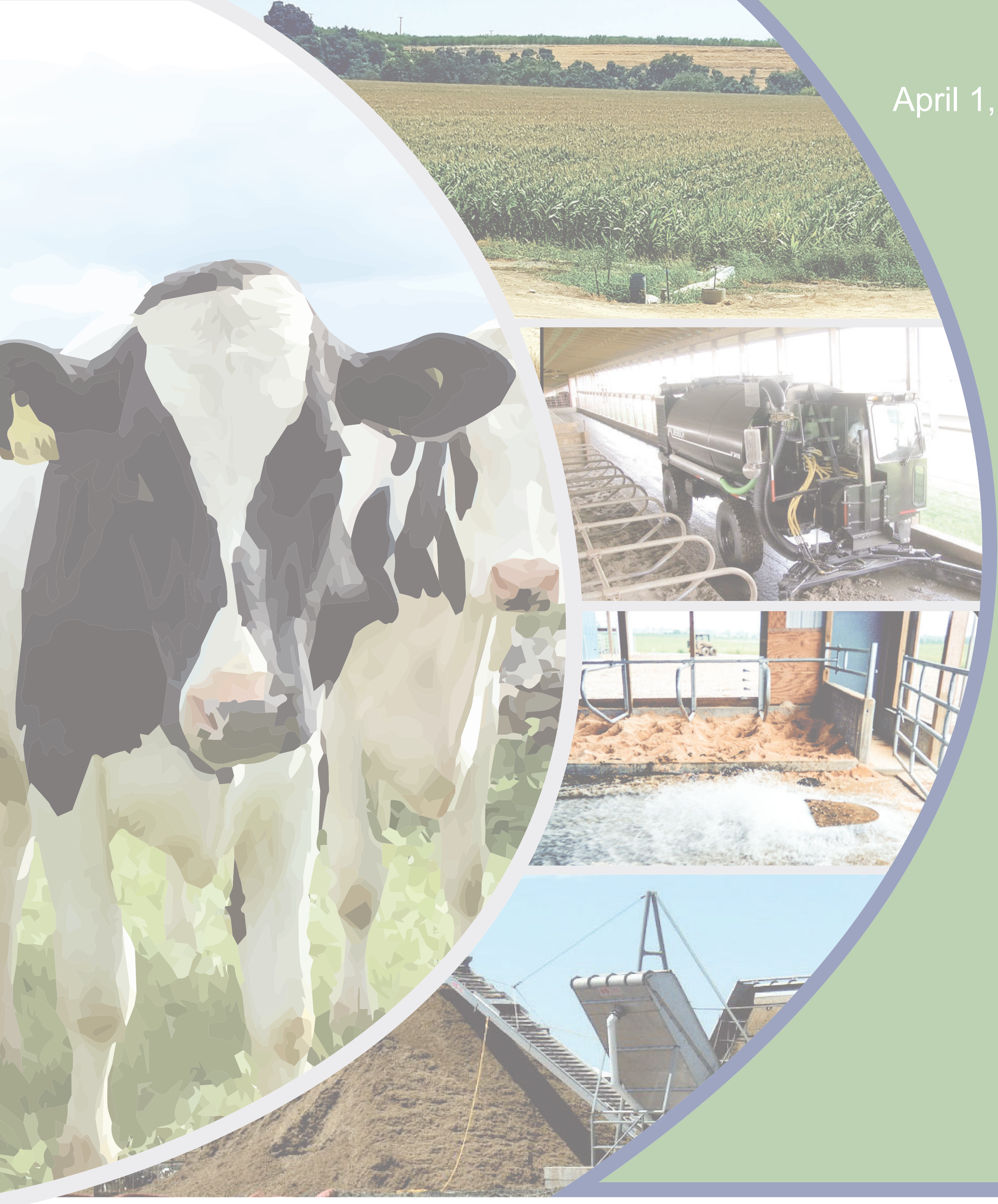
c) Ability to export solid manure is currently limited on many dairies by the need to use this manure as a source of cattle bedding. Only the solid manure that exceeds the dairy's bedding needs may be exported, unless the dairy is able to secure alternate sources of cattle bedding. Importing other materials to serve as cattle bedding involves additional costs that are not estimated here.

d) "No cost" means no net cost over a period of 10 years. This assumes offsetting revenue from manure/manure product sales will be able to offset labor and equipment costs related to any changes needed in manure management.

e) Based on current hauling costs; some analysts believe hauling costs will increase greatly – perhaps doubling – as the California Air Resources Board continues to implement rules to replace older agriculture trucks with newer, lower-emissions models.

f) Cost estimate is considered a lower bound on the total cost for this strategy because major components (e.g., improved fiber and sand separation) were not included. Costs were based on lagoon construction in a new location to allow uninterrupted dairy operation; may not be possible if space-limited, see *Section 3.2.5* for more detail.

April 1, 2019



Section 1

CVDRMP Findings and Recommendations

1 CVDRMP Findings and Recommendations

1.1 Charge to CVDRMP

CVDRMP is a non-profit group of dairy owners and operators organized in 2010 to conduct representative groundwater monitoring on behalf of member dairies, to conduct related assessments of dairy operational impacts to groundwater quality, and to develop management practice recommendations toward minimizing such impacts. CVDRMP activities generally, and this report specifically, are intended to fulfill requirements for Representative Monitoring Programs (RMPs) as defined in the Dairy Order, adopted by the Central Valley Regional Water Quality Control Board (Central Valley Regional Board) on October 3, 2013.

Per the Dairy Order, the RMP examines conditions in first encountered groundwater (i.e., groundwater near the water table directly beneath dairy facilities). Therefore, the design of the dedicated monitoring wells is fundamentally different from that of drinking water wells, and data from the monitoring wells are not indicative of actual impacts to drinking water sources. The RMP was not designed for, and does not address, monitoring and assessment of drinking water sources.

The key regulatory requirement that CVDRMP seeks to satisfy is the identification of on-farm management practices that are protective of groundwater quality for the range of conditions found at participating facilities by April 1, 2019[2]. This SRMR presents and discusses the cumulative data collected since January 2012 through December 2018. Results are consistent with findings of previous research by the University of California (Harter, Davis et al. 2001; Harter, Mathews et al. 2001; Mathews, Swenson et al. 2001; Harter, Davis et al. 2002; Harter, Meyer et al. 2002; Harter, Onsoy et al. 2006; Van der Schans, Harter et al. 2009). Specifically, RMP observations confirm that first-encountered groundwater is affected by historical and/or current dairy farming practices and strongly indicate crop fields as the primary source of subsurface mass emissions.

Also, per the Dairy Order, the examination of the characteristics of first-encountered groundwater is coupled with examinations of dairy operations and management practices, particularly as related to nitrogen and salt management, to facilitate the evaluation of cause-and-effect relationships between subsurface loading of nitrogen and salts, and groundwater conditions.

1.2 Legal and Regulatory Background

Division 7 of the Water Code contains California's Porter-Cologne Water Quality Control Act (Porter-Cologne). The Legislature enacted Porter-Cologne in 1969, providing "activities and factors which may affect the quality of the waters of the state shall be regulated to attain the highest water quality which is reasonable, considering all demands being made and to be made on those waters and the total values involved, beneficial and detrimental, economic and social, tangible and intangible." (Wat. Code, § 13000) The Legislature designated the State Water Resources Control Board (State Board) and nine Regional Water Quality Control Boards (Regional Boards) as the agencies responsible for regulation of

[2] This is the regulatory due date for the Summary Representative Monitoring Report (SRMR) (i.e., six years after the submittal of the first Annual Representative Monitoring Report (ARMR)).

water quality under Porter-Cologne. (Id., § 13001.) Each Regional Board is responsible for water quality protection, permitting, inspection, and enforcement within its region. (Id., § 13225(a).)

Porter-Cologne provides two primary tools to Regional Boards to regulate the discharge of waste into waters of the state. Regional Boards may: (1) issue Waste Discharge Requirements (WDRs) prescribing conditions under which a person may discharge waste (Wat. Code, § 13263), or (2) adopt a waiver of WDRs (Wat. Code, § 13269). Porter-Cologne's permitting requirements apply to any "person discharging waste, or proposing to discharge waste, within any region that could affect the quality of the waters of the state, other than into a community sewer system." (Id., § 13260(a)(1).)

Sometimes WDRs are issued to an individual discharger who has filed a "report of waste discharge" and requested the permit. (Wat. Code, § 13260.) Other times, a Regional Board may issue general WDRs for a category of dischargers if the Regional Board determines that (i) the discharges are produced by the same or similar operations; (ii) the discharges involve the same or similar types of waste; (iii) the discharges require the same or similar treatment standards; and, (iv) the discharges are more appropriately regulated under general discharge requirements than under individual discharge requirements. (Id., § 13263(i).) The Dairy Order falls into this category. When issuing WDRs, a Regional Board is required to consider several factors, including those specified in Water Code section 13241, which includes achievability as well as economic consideration. (Wat. Code, §§ 13263(a), 13241(d).)

Porter-Cologne further authorizes Regional Boards to conduct investigations and inspections to verify compliance with the act and with the terms of WDRs. (Wat. Code, § 13267(e).) A Regional Board may also require dischargers to furnish technical or monitoring reports. (Id., § 13267(b).) This SRMR, as discussed further below, responds to a monitoring and reporting requirement issued by the Regional Board on February 23, 2011 (rescinded and replaced by the 2013 Dairy Order, referred to throughout this report as the Dairy Order).

Besides requiring Regional Boards to issue WDRs, Porter-Cologne also requires each Regional Board to adopt "water quality control plans" or "Basin Plans" for areas within each region. (Wat. Code, § 13240.) Basin Plans are required to conform to the policies set forth in Chapter 1 of Porter-Cologne, including the legislative mandate that activities affecting water quality be regulated to the highest quality that is reasonable considering all the demands being made and to be made upon the waters. (Id. §§ 13000, 13240.) Further, Basin Plans identify and designate the "beneficial uses" for each water body in the region. (Id., § 13050(j).) Examples of "beneficial uses" for groundwater include municipal supply, agricultural supply, and industrial supply. Basin Plans also establish water quality objectives (WQOs), which are defined to mean, "the limits or levels of water quality constituents or characteristics which are established for the reasonable protection of beneficial uses of water or the prevention of nuisance within a specific area." (Wat. Code, § 13050(h).) WQOs may be numeric or narrative standards. Further, Basin Plans are to include a program of implementation to achieve the adopted WQOs. (Id., § 13242.)

When a Regional Board issues WDRs, it must do so consistent with applicable Basin Plans. (Wat. Code, §§ 13263(a).) However, instantaneous compliance with WQOs is logically not required by Porter-Cologne. (Ibid. as to both cites) Rather, the Regional Board is given discretion to achieve this consistency, including setting of time schedules. (Id., § 13263(c).) The Central Valley Regional Board adopted two Basin Plans under Porter-Cologne in 1975. They include the Water Quality Control Plan for the Sacramento and San Joaquin River Basins (Sacramento-San Joaquin Basin Plan) and the Water

Quality Control Plan for the Tulare Lake Basin (Tulare Lake Basin Plan). Both Basin Plans have been amended several times over the years and are subject to regular review approximately every three years.

Recently, various stakeholders in the Central Valley (including dairy industry representatives) led and funded an initiative to develop a Central Valley-wide Salt and Nitrate Management Plan (SNMP). The initiative is referred to as the Central Valley Salinity Alternatives for Long-term Sustainability (CV-SALTS), and one of its primary objectives was to provide the basis for amendments to the Sacramento-San Joaquin and Tulare Lake Basin Plans to address ongoing salinity and nitrogen concerns in the Central Valley Region. The information developed and gathered through this effort was accepted by the Regional Board in March 2017 as part of the basis for developing Basin Plan amendments with respect to salt and nitrogen concerns, and the development of long-term plans for addressing such concerns. In May 2018, the Regional Board adopted the "Central Valley-Wide Salt and Nitrate Control Program," into both Basin Plans. The State Board is in the process of considering these changes to the Basin Plans and is expected to take these matters up in Spring 2019.

1.3 Procedural and Chronological Background

The Dairy Order defines an existing milk cow dairy as a dairy that (i) was operating as of October 17, 2005, (ii) filed a complete Report of Waste Discharge in response to the Central Valley Regional Board's August 8, 2005 Report of Waste Discharge Request Letter, and (iii) has not expanded since October 17, 2005 (i.e., its herd size has not increased by more than 15%). The Dairy Order regulates waste discharges to land and imposes significantly more stringent requirements than in the past.

Relative to groundwater monitoring, the 2007 Dairy Order and its accompanying Monitoring and Reporting Program (MRP) specified two requirements: (1) monitoring of domestic and agricultural supply wells at dairies, and (2) additional groundwater monitoring. The latter requirement is initiated by the Executive Officer ordering individual dairies to install monitoring wells ("site-by-site approach"). However, the 2007 Dairy Order also authorized the Executive Officer to approve alternative monitoring methods; its Information Sheet (page IS-8) states:

> *In the future, the Executive Officer or Central Valley Water Board may determine that a proposed alternative method of environmental monitoring is appropriate to determine if groundwater protection is being achieved. One suggested alternative has been to allow regional groundwater monitoring as a substitute for groundwater monitoring at individual dairies. Any proposed alternative will require sufficient details for consideration by either the Executive Officer or Central Valley Water Board. The Executive Officer or the Central Valley Water Board must issue a monitoring and reporting program order for any alternative environmental monitoring.*

To further the development of an alternative environmental monitoring method, Dairy Cares, a non-profit coalition of California dairy industry groups (www.dairycares.com) submitted a proposal on October 5, 2009 (Dairy Cares, 2009) to the Regional Board's Executive Officer for the development of a collaborative plan that would allow a representative groundwater monitoring approach to satisfy the additional groundwater monitoring requirements in lieu of the site-by-site approach of the 2007 Dairy Order MRP.

The Regional Board held a February 4, 2010 stakeholder meeting in Rancho Cordova where Luhdorff and Scalmanini, Consulting Engineers (LSCE) presented an initial outline of the representative groundwater monitoring approach, which was developed based on more than a decade of dairy-specific and groundwater-related research in the Central Valley and a regional monitoring approach proposed by Dr. Thomas Harter of the University of California Cooperative Extension (UCCE) in September 2008. The monitoring approach was discussed in greater detail at the meeting of the Regional Board's Groundwater Advisory Workgroup in Rancho Cordova on March 9, 2010.

Concurrently, LSCE evaluated dairy farm characteristics along with environmental parameters to determine an area in the Central Valley that is most sensitive to dairy management practices in the *Report of Results* (LSCE 2010). This area was identified to be in Stanislaus and Merced Counties between the San Joaquin River and Highway 99, and was selected for initiating the RMP based on delineation of those areas in the Central Valley where high groundwater nitrogen and salt concentrations are thought to be substantially attributable to dairy operations and where changes in water quality are most likely to be detected quickly due to adoption of management practices required by the 2007 Dairy Order. The analysis included comparison of key information such as:

- Relative dairy farm/milk cow densities and other historical livestock operations data
- Historical average depths to groundwater
- Soil permeability
- Historical recharge to groundwater
- Observed historical groundwater nitrate and total dissolved solids (TDS) concentrations
- Whole farm nitrogen balances submitted to the Central Valley Regional Board in response to the Dairy Order

This work effort recommended that the representative groundwater monitoring be initiated in Stanislaus and Merced Counties (i.e., from the Stanislaus River in the north and the Chowchilla River in the south) between the San Joaquin River and Highway 99 (this area is referred to as the high priority area). Results of this work effort were presented at the April 5, 2010 stakeholder meeting held at the Central Valley Regional Board's offices in Rancho Cordova.

Subsequently, two concurrent work efforts ensued. One was the formation of an administrative body to manage the RMP. This occurred on May 17, 2010 with the founding of the CVDRMP. The other effort concerned the modification of the MRP to provide regulatory support for the RMP. The revised Dairy Order MRP was issued by the Central Valley Executive Officer on February 23, 2011 (Central Valley Regional Board, 2011a).

On June 16, 2011, CVDRMP submitted the *Public Review Draft Monitoring and Reporting Workplan and Monitoring Well Installation and Sampling Plan Phase 1: Initiation of Representative Groundwater Monitoring Network Design & Monitoring Program, Existing Milk Cow Dairies – Stanislaus and Merced Counties, California* (finalized without changes January 11, 2012 (LSCE 2012b), which was followed by a 30-day public review period and subsequent conditional approval on September 9, 2011 (CVRWQCB 2011). The Phase 1 well installation campaign commenced without delay and was concluded with the installation of 216 nested monitoring wells at 108 well locations in November 2011. The Phase 1 RMP well network also includes 18 pre-existing monitoring wells. The results of this work effort were described in the *Monitoring Well Installation Completion Report Phase 1 Representative Monitoring Program, Existing Milk Cow Dairies – Stanislaus and Merced Counties, California* (LSCE 2012c).

On June 6, 2012, CVDRMP submitted the *Public Review Draft Monitoring and Reporting Workplan and Monitoring Well Installation and Sampling Plan, Phase 2: Representative Groundwater Monitoring Network Design & Monitoring Program, Existing Milk Cow Dairies – Central Valley, California* (LSCE 2013c), which was followed by a 30-day public review period and the *Addendum Monitoring and Reporting Workplan and Monitoring Well Installation and Sampling Plan, Phase 2: Representative Groundwater Monitoring Network Design & Monitoring Program, Existing Milk Cow Dairies – Central Valley, California* (LSCE 2012a). Conditional approval was given on August 27, 2012 (CVRWQCB 2012). The Phase 2 well installation campaign commenced without delay and was concluded with the installation of 55 nested monitoring wells at 30 well locations in October 2012. The Phase 2 RMP well network also includes 118 pre-existing monitoring well sites. Groundwater data collection in the Phase 1 network of wells commenced in January 2012. Groundwater data collection in the Phase 2 network of wells commenced in January 2013.

CVDRMP submitted its first annual report on April 1, 2013 (LSCE 2013b). The representativeness of the program was comprehensively evaluated and confirmed after the 2012 Phase 2 expansion in the *Central Valley Dairy Representative Monitoring Program Evaluation of Representativeness* (LSCE 2013a) and was revisited by the Multidisciplinary Advisory Committee at its January 2014 meeting. As a result of this concerted effort, including independent external review, it was concluded that the 42 actively monitored RMP dairies exhibit the range of pertinent site conditions and farm practices that are presently employed on Central Valley dairies.

In 2014, CVDRMP carried out well network improvements including several new well installations and the abandonment of one pre-existing monitoring well in Stanislaus and Merced Counties (LSCE 2015). The total current program encompasses 42 dairies[3] and a total of 443 wells distributed over 250 well sites.[4]

The Dairy Order was reissued on October 3, 2013, to comply with a Writ of Mandate issued by the Superior Court due to the appellate court's decision in *Asociacion de Gente Unida por el Agua v. Central Valley Regional Water Quality Control Bd. (AGUA)* ((2012) 210 Cal. App. 4th 1255). With the reissuance of the Dairy Order, the Regional Board also adopted more explicit language than the previous Dairy Order and the revised MRP regarding the options of individual groundwater monitoring and participation in a Representative Monitoring Program. Specifically, *Item 23* (page 6) states**.**

> *Under the MRP, Dischargers have the option of either implementing individual groundwater monitoring or participating in a Representative Monitoring Program (RMP) to identify whether or not their specific management practices are resulting in adverse impacts to groundwater (i.e., whether the discharge is in compliance with the groundwater limitations of this Order).*

[3] One dairy converted to a heifer ranch and two dairies converted to a farm without livestock. Monitoring wells remain in place and continue to be part of this program.

[4] A well site is a location where one or more dedicated wells of different depths are located.

1.4 Summary of Monitoring and Special Studies Findings

1.4.1 Groundwater Monitoring

CVDRMP started groundwater monitoring activities in January 2012 on 18 dairies in Stanislaus and Merced Counties. In January 2013, monitoring activities were expanded to a total of 42 dairies[5], including facilities as far north as Tehama County and as far south as Kern County. The monitoring well network on these dairies comprises of 443 dedicated monitoring wells that are distributed over 250 well sites. At most of these well sites, individual wells are arranged in nested facilities (i.e., two or more wells of different depth in one borehole) or in well clusters (i.e., two or more wells installed adjacent to each other) to facilitate groundwater sample retrieval from the uppermost zone of first-encountered groundwater under variable groundwater level conditions. Monitoring wells were located and designed such that they intercept groundwater that originates from individual management units (i.e., downgradient of lagoons, corrals, and crop fields).

The well network and the associated sampling activities and frequencies were designed with input from an external Groundwater Technical Advisory Committee, which included scientists from Lawrence Livermore National Laboratory and faculty from the University of California with extensive groundwater related research experience on Central Valley dairies. A comprehensive report affirmed the network's representativeness in 2013 (LSCE 2013a).

CVDRMP conducts monthly groundwater level monitoring campaigns including all wells. These data are analyzed to characterize local hydrologic conditions, including seasonal and longer-term groundwater level fluctuations, the thickness of the unsaturated zone, lateral groundwater flow directions and gradients, and vertical groundwater gradients. On an annual basis, this analysis establishes individual wells' association with a specific management unit, mixed sources, or off-site sources, as applicable.

CVDRMP conducts quarterly groundwater sampling campaigns from all 250 well sites. At each well site, a sample is retrieved from the well with the shallowest groundwater occurrence. Groundwater quality results are then attributed to specific management units according to the hydrologic analysis.

CVDRMP's data set documents that elevated nitrate-N (i.e., as nitrogen) concentrations[6] were present beneath all monitored dairies. In 2018, the mean groundwater nitrate-N concentration beneath dairies overlaying shallow groundwater (<55 feet deep) was 48 mg/L (median=35 mg/L) and 38 mg/L in deeper groundwater (median=35 mg/L). The mean groundwater nitrate-N concentration in areas of permeable soils was 59 mg/L (median=46 mg/L) and 29 mg/L (median=21 mg/L) in areas of clay-rich soils. These observations are consistent with the potential mitigating effects of thick unsaturated zones and the potential for denitrification associated with clay-rich soils. The median nitrate-N concentrations at off-site locations was 20 mg/L less than beneath dairies. The totality of the data set from 2012 to 2018 indicates that median nitrate-N concentrations beneath dairies increased at the same rate as at off-site locations (i.e., 5 mg/L in seven years).

Importantly, the entirety of the groundwater quality record since 2012 indicates relatively stable conditions. To date, implementation of the Dairy Order does not appear to have resulted in a trend to

[5] Since then, one dairy converted to a heifer ranch and two dairies converted to farms without livestock. Monitoring wells remain in place and continue to be part of this program.

[6] In some wells, nitrogen occurs in the ammoniacal form.

lower nitrate-N concentrations across the industry. This includes areas of very shallow groundwater occurrence and highly permeable soils.

1.4.2 Special Studies

CVDRMP has carried out substantial work efforts that go above and beyond the RMP requirements in the Dairy Order. These additional efforts have included literature review and field data collection in addition to requirements for data collection set forth in the Dairy Order. The purpose of these additional efforts was to help generate technical information that supports the development of recommendations for improved management practices, solutions and upgrades. Most importantly, these initiatives (i) were successful in developing robust estimates of N-loading rates to groundwater from earthen lagoons and corrals and (ii) confirmed technical limitations of groundwater monitoring as a means to evaluate management practices on dairies that were discussed on theoretical grounds as early as in CVDRMP's first Annual Report.

CVDRMP's initiatives regarding lagoons include:

- 50 whole-lagoon seepage tests on 17 earthen lagoons
- Advance of 53 soil borings along the perimeter of 12 lagoons to first-encountered groundwater and retrieval of 51 groundwater samples from the bottom of these borings
- Extensive geophysical testing around 12 lagoons including electrical resistivity profiling and electromagnetic profiling
- Comprehensive review of existing guidelines pertaining to the siting, construction, operation and maintenance of earthen lagoons; and evaluation of their scientific basis and efficacy

Key findings include:

- The mean subsurface N-loading rate was 1,045 lbs/ac/year. The associated mean seepage rate was 1.1 mm/day with a median of 0.7 mm/day. For comparison, the most recent and stringent NRCS design seepage rate for earthen lagoons storing agricultural waste is 0.86 mm/day.
- Seepage rates exhibited a relatively narrow range. This is attributed to the moderating effect of a sludge layer with extremely low hydraulic conductivity that develops on the bottom of dairy lagoons. This phenomenon also explains why variables such as the ambient soil texture, age of the lagoon, and depth of the waste column did not correlate to the magnitude of the seepage rate.
- Dedicated monitoring wells, even if installed with great care and foresight, are not an effective means to detect impacts from lagoons on groundwater quality, including in areas of favorable hydrogeologic conditions.
- Groundwater quality concentrations do not provide information on the rate of seepage or mass 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."
- The lateral extent of discernable impacts is restricted to the near vicinity of lagoons and little or no impact was found at distances of 50-150 feet from the lagoons, including in areas of favorable hydrogeologic conditions.
- Quantitative information indicating the effectiveness of specific management measures in reducing seepage of earthen lagoons below existing levels was not found. Most existing

management measures (i.e., those that are published in government guidance documents) appear to be based on what is considered common sense.

CVDRMP's special study reports pertaining to lagoons are posted on the Regional Board's website at https://www.waterboards.ca.gov/centralvalley/water_issues/confined_animal_facilities/groundwater_monitoring/, except the June 2016 *Literature Review and Workplan, Controlling Seepage from Liquid Dairy Manure Lagoons in the Central Valley of California*.

In the addition to the above, CVDRMP commissioned several other work efforts pertaining to lagoons:

- Efforts to ascertain potential actions to further reduce already small seepage losses from earthen lagoons concluded that neither soil treatment of the side slopes nor installation of partial synthetic liners provide viable options.
- A survey concluded that risks and issues associated with synthetically lined lagoons generally have solutions or mitigation available. Two issues remained inconclusive: Long-term accumulation of solids and their removal, and the necessity to drain the lagoon for potential liner repair.
- Water covered electric leak location surveys were conducted on five synthetically lined lagoons. ASTM D7007-15 was modified to make it applicable to dairy lagoons filled with wastewater. The modified method was successful in identifying leaks and was used as a follow-up check after identified leaks were repaired.

CVDRMP conducted a Corral Subsurface Hydrogeologic Investigation (CorSHI) including the advancement of 51 continuous soil cores on 13 dairies. Cores were advanced on corrals and at on-site background locations not associated with corrals, crop fields, or lagoons. A total of 187 soil samples were submitted to the laboratory. Soil samples were retrieved to a depth of 20 feet or first-encountered groundwater, whatever occurred first. Groundwater was encountered at eight dairies and samples were retrieved. Key findings of this investigation include:

- Based on groundwater nitrogen concentrations in samples retrieved from the boreholes and an estimate of groundwater recharge beneath corrals, a groundwater-N loading rate of 121 lbs/ac/year was estimated. To avoid incidental underestimation of the loading rate, the estimate was made with a relatively high recharge rate (i.e., 40% of liquid deposition composed of urine, feces, and precipitation) and assumed year-round corral occupation (i.e., open lot dairy) in an area of comparatively high annual precipitation (i.e., 22 in) such as the northern Sacramento Valley.
- Groundwater samples retrieved from the uppermost few inches of the shallow water table in the corral boreholes exhibited greater nitrogen, phosphorous, and potassium concentrations than dedicated corral monitoring wells. This observation is consistent with processes such as dispersion, dilution, sorption, cation exchange, and denitrification along particle path lines between the water table and monitoring wells. The same observation was previously made in the context of lagoon special studies.
- Soils beneath the corrals were characterized by increased salinity and accumulation of macro nutrients such as nitrogen, phosphorus, and potassium. However, mass accumulation compared to background locations was relatively modest. Specifically, the nitrogen mass stored beneath corrals was the same as at background locations. Phosphorous and potassium mass was 1.7 and 2.2 times greater than at background locations (median values).

- Despite the intensive land use, there are several mechanisms that can contribute to substantially limit the overall effect on soils and groundwater:
    - Atmospheric N losses from corrals, including NH3-N volatilization, and NOx and N2 emissions from denitrification. Research suggests that atmospheric N losses likely exceed 30% of excreted N on an annualized basis on Central Valley dairy corrals.
    - Reduced infiltration capacity due to altered surface soil characteristics, including a highly compacted organic manure pack, which can absorb large amounts of water, and a compacted organic-mineral soil interface layer.
    - Reduced infiltration due to limited intake opportunity time achieved through maintenance of sloped corral surfaces.
    - Limited occupancy during wet times (California freestall dairies)
    - Limited occupancy during hot temperatures (California freestall dairies)
    - Frequent harvest of manure

CVDRMP is finishing up NUE studies on four commercial dairies and a research facility with access to a liquid manure source. These studies intend to:

- Demonstrate that the concept of NUE is universally applicable, while actions to achieve improvements may differ from site to site
- Document currently achieved NUEs under different conditions (as-is conditions)
- Show the extent of improvement under different conditions
- Document the level of effort and challenges associated with improvement under different conditions

Data published in a comprehensive study by the University of California, Davis, suggest that manured crop fields on dairies contribute approximately 368 lbs N/ac/year. This study also conducted a comprehensive digitizing effort of the manured acreage reported to the Regional Board in dairies' Annual Reports (see *Nitrogen Fertilizer Loading to Groundwater in the Central Valley* at http://groundwater.ucdavis.edu/People/tharter_resume/#publications. The resulting acreage was as follows:

- Corrals: 30,254 ac
- Lagoons including settling basins: 5,877 ac
- Manured cropland: 429,424 ac

The above acreages in combination with the associated per-acre nitrogen-loading rates yield proportional nitrogen loading contributions of 94%, 4%, and 2% for manured cropland, lagoons, and corrals, respectively. Therefore, CVDRMP's technical recommendations for solutions and upgrades focus on achieving higher nitrogen use efficiencies on dairy croplands.

1.5 Recommendations

1.5.1 Overall Approach

This section briefly summarizes our recommendations; more detail is included in subsequent sections.

1.5.1.1 Focus on Whole-Farm Nitrogen Balance

CVDRMP's major recommendations in this SRMR are built on the concept of a "whole-farm nitrogen balance." As summarized in the previous section, CVDRMP estimates that approximately 94 percent of the nitrogen loading on dairies (that is, the portion of nitrogen that enters the soil and is not recovered by plants) occurs in croplands, where primarily forage crops are grown. As such, our largest area of focus is how to reduce nitrogen leaching, as doing so will have the most benefit to groundwater.

Evidence garnered from annual reports to the Regional Board by individual dairies suggests a substantial amount of "unaccounted-for" manure nitrogen exists on many dairies. This unaccounted-for portion is essentially the difference between nitrogen excreted by cows (supply) and what is reported as being applied to agricultural fields to fertilize crops (demand) and/or exported from the dairy. Some of the unaccounted-for portion of nitrogen can be attributed to volatilization of nitrogen as ammonia and other gases, but those pathways don't fully explain the difference between excreted nitrogen and applied nitrogen. Large amounts of unaccounted-for nitrogen, combined with imprecision in measurement of applied nitrogen and irrigation water, can result in overapplication of nitrogen to crops and reduced NUE.

CVDRMP believes one critical strategy for reducing nitrogen loading on croplands is clarifying the information available to on-farm decision-makers regarding their overall nitrogen supply and demand. This will help dairy operators understand, as early as possible in the process, the amount of excess supply of nitrogen that may exist on their dairies. Balancing supply and demand is an essential first step toward avoiding overapplication of manure nitrogen to crops and reducing nitrogen leaching below the root zone. CVDRMP's technical recommendations provide an approach for calculating more accurate whole-farm calculation of nitrogen excreted, and for understanding solid and liquid manure nitrogen demands for crops grown on the dairy (*Section 2*). That same approach better quantifies the portion of manure nitrogen that cannot be beneficially used on the dairy and should instead be targeted for export to off-dairy croplands or other appropriate treatment.

1.5.1.2 Increase NUE Across the Industry

Overapplication of manure N, poorly timed applications or inaccurate measurement of applications can all lead to poor NUE. Achieving a whole-farm balance is critical to improve NUE. Once balance has been achieved, NUE can be improved by pursuing increased precision in measuring applications of water and nitrogen, properly timing applications to crop needs, achieving irrigation distribution uniformity, and managing inorganic-to-organic nitrogen ratios. Beyond efforts to achieve a whole-farm balance of nitrogen, CVDRMP recommends promoting improved NUE through specific enhanced technical recommendations, education, incentives and research, development and piloting of improved irrigation systems specific to dairy forage systems.

1.5.1.3 Build Capacity to Export Manure Nitrogen

A fundamental necessity to achieving whole-farm balance of nitrogen produced and used on dairies the ability to either transport excess manure from the dairy to a willing recipient in an economically sustainable way, or to achieve environmentally safe denitrification on the dairy. Currently, that ability is not established.

CVDRMP recognizes it cannot alone create the conditions needed to achieve exports of manure nitrogen at the scales necessary to achieve whole-farm balance across the Central Valley dairy industry. Instead, a major collaboration is needed involving the dairy community, government, academia and private industry, such as manure management technology providers and soil amendment manufacturers and distributors, and the broader agricultural industry. Such a collaboration is needed to understand and develop markets for manure and manure-based products, and to develop and incentivize technologies and systems for producing and delivering those products to market.

1.5.1.4 Enhanced Technical Recommendations

This SRMR includes a detailed package of technical recommendations. Collectively, these measures will greatly improve whole-farm estimates of nitrogen supply and demand, through use of better measurement tools, such as flow meters, improved sampling and analysis methods, and improved reporting forms, including separate accounting for liquid and solid manure streams, and setting specific targets for manure nitrogen exports.

1.5.1.5 Increase Education Requirement and Educational Offerings

Working in collaboration with the award-winning California Dairy Quality Assurance Program (CDQAP) and in consultation with the Regional Board, CVDRMP recommends a greatly expanded educational effort in the area of improving NUE. First and foremost, CVDRMP recommends development and delivery of a basic educational curriculum aimed at helping dairies understand how to calculate their whole-farm nitrogen supply and demand, strategies to manage and export solid and liquid manure where needed and achieving improved NUE with the nitrogen supply that remains on farm. We recommend that completing this basic course be a permit requirement.

Further, CVDRMP recommends additional voluntary education offerings to provide dairy operators more detailed and specialized information on a variety of issues relevant to increasing NUE. This program would be developed in consultation with stakeholders but could cover subjects such as training on how to properly use flowmeters, proper manure and harvest sampling techniques, how to use new reporting methods, strategies for increasing irrigation efficiency and distribution uniformity, introduction to innovative irrigation systems, manure management alternative strategies, available grant funding and more.

1.5.1.6 Changed Role for CVDRMP

CVDRMP proposes to take on an increased role in the future, including evolving its role to be more like that of an Irrigated Lands Regulatory Program (ILRP) coalition. Specifically, CVDRMP recommends that it be allowed to develop and administer a Web-Based Portal and Data Management System on behalf of its members and accept annual reports from members via that portal (the portal would also be available to non-members through a licensing agreement). CVDRMP would pass on most individual dairy data to the Regional Board in a standardized format but would also retain the data for evaluating industry trends and compliance with membership terms.

CVDRMP would continue reporting annually to the Regional Board on groundwater monitoring results but would add additional information on a variety of topics related to implementing the SRMR recommendations, including but not limited to industry data on manure nitrogen export trends, status of technology, manure markets and incentive programs, technology programs, and other relevant data. CVDRMP also proposes to play a role in implementing the Salt and Nitrate Control Programs that have been adopted into the Basin Plans, by collecting and passing on fees to support the salinity studies, salinity and nitrate monitoring, and by requiring and verifying member participation in Management Zones where appropriate.

1.5.1.7 Recommended Changes in the Dairy Order and Monitoring and Reporting

CVDRMP recommends several specific modifications and additions to the current Dairy Order to assist in implementing the recommendations in this SRMR. Listed in more detail later in this report, these include creating a new Dairy Order for coalition members while retaining a separate order for those who do not wish to voluntarily participate in the coalition and instead pursue independent compliance options.

Other recommended changes in the Dairy Order include replacing the current annual reporting method with a more consistent, relevant approach focused on achieving whole-farm balance and facilitating tracking of industry trends. CVDRMP also recommends new methods for sampling liquid and solid manure and harvested crops, use of flowmeters for measuring applications of liquid manure, use of enhanced Irrigation and Nitrogen Management Plans (INMPs), new lagoon liner standards and a requirement for dairy operator education in the area of improving NUE. CVDRMP also recommends continued groundwater monitoring to watch trends over time, but at reduced frequency.

1.5.2 Building Capacity to Export or Transform Manure Nitrogen

Achieving appropriate whole-farm balance of manure nitrogen depends on reliable, environmentally safe and cost-effective methods to either export that nitrogen for use elsewhere, such as on non-dairy croplands, or to denitrify manure by converting reactive nitrogen to inert nitrogen gas. To date, these solutions do not exist at a scale sufficient to meet the needs for achieving industry-wide whole-farm nitrogen balance.

Exporting excess manure nitrogen to non-dairy cropland is hampered by several factors. Demand for raw manure is limited because of concerns about pathogens, which compromise food safety, and weed seeds. Composting can address these concerns by destroying weed seeds and pathogens, but leads to additional costs, air emissions of volatile organic compounds (VOCs) and ammonia that contribute to regional air pollution, regulatory barriers (e.g., air permitting) and uncertain markets and pricing. There is potential to produce other value-added manure-based products, such as fertilizer pellets, but technologies to do so are still being developed and there is significant uncertainty related to potential markets, economic and technical feasibility and potential regulatory barriers.

Even if all solid manure could be easily exported from dairies, a significant amount of manure nitrogen stored on dairies is in the liquid form. While liquid manure presents certain advantages – including the ability to apply it via fertigation throughout the crop growing season and not just pre-plant – it is extremely difficult and expensive to export excess liquid manure. New technologies are developing that could more easily extract nitrogen from liquid manure to facilitate export, but their economic and technical feasibility remains untested in California.

Some technologies and practices exist, such as vermiculture (cultivating worms in a bed of organic material to which diluted liquid manure is added) that could denitrify manure on the dairy, converting reactive nitrogen compounds into harmless, inert nitrogen gas. However, vermiculture comes with high costs and its ability to generate offsetting revenue streams has not yet been demonstrated, especially in California.

Despite these challenges, CVDRMP believes a significant opportunity exists to capture the resource potential of excess manure on dairies as a source of renewable nitrogen (and other nutrients) for use on other farms. Doing so could help dairies move toward whole-farm nutrient balances while building healthy soils on other farms by increasing organic matter in those soils.

Achieving this goal will require addressing several interlocking challenges, including understanding the agronomics of other crop farmers and the scale of potential demand, and opportunities to build markets for manure-based products, and developing technology and systems to process manure on dairies and transport it to distribution facilities and farms. Importantly, the California Dairy Research Foundation (www.cdrf.org) has already recognized a need for this type of work and in early 2019 launched a research project to study potential markets for manure-based products, in collaboration with a national dairy industry organization that is promoting advances in manure management technology, Newtrient LLC (www.newtrient.com).

Research to understand potential environmental tradeoffs associated with changing manure management practices are needed, along with education and incentive programs to encourage desired practice changes. As markets for manure-based products become better understood, reliable, environmentally friendly and cost-effective technology will be needed to help service those markets. Examples could include improved composting systems, manure pelletizers, advanced solids-liquids separation and nutrient extraction systems, and other technologies. Significant and sustained effort will be needed to identify those technologies which are most appropriate for servicing the market.

A major collaborative effort is needed, involving the entire dairy community, government, academia, non-governmental organizations (NGOs), and technology and service providers, especially within the agriculture and soil amendments sector. To this end, we recommend an interagency and interdisciplinary effort – similar to ongoing efforts to reduce greenhouse gas emissions on the state's dairies to comply with Assembly Bill 1383[7] – to realize the equally important goals of building healthy soils and protecting water quality by increasing the capacity to export this important resource for use off of dairies.

While CVDRMP cannot accomplish this effort alone, our organization is willing to remain an active partner. We propose to include in future annual reports to the Regional Board an ongoing section that reports on the status of efforts to achieve whole-farm nitrogen balance, data about export trends, and information and status of efforts to develop markets, technology and incentives. We foresee this information being useful to both public and private sector decision-makers as they prioritize efforts in areas of research, education, market building, technology development, policy and incentive programs.

1.5.3 Enhanced Technical Recommendations

CVDRMP recognizes that progress toward achieving industry-wide whole-farm nitrogen balance cannot be achieved without an adequate system in place that allows farmers, our coalition and regulators to gather useful and accurate data. In fact, such a system is necessary not only to achieve that goal, but to understand the current state of the balance and progress toward the balance in future years.

[7] https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB1383

To achieve and support setting goals and measuring progress, CVDRMP proposes a package of detailed technical recommendations. Most important among these is an overhaul of the current reporting system, which suffers from extremely inconsistent quality of data. We propose that CVDRMP develop, for use by our coalition members and other regulated Central Valley Dairies, a new web portal and data management system that records essential data such as herd size, cattle ages, characterizing manure handled in liquid and solid forms, cropped acreages, and crop demand for liquid and solid manure.

A central goal of the new system is to develop clear manure nitrogen export targets for dairies, while allowing time for them to learn about their options and progress toward achieving a whole-farm balance. We propose that reporting of actual nitrogen exports be phased in over time with known future milestones, so that dairy operators can immediately understand the need to act, while allowing them time to consider options.

CVDRMP's technical recommendations also include suggested tools and practices for collecting data, including use of flow meters to measure applied liquid manure, improved nitrogen calculators embedded in reporting tools, and improved sampling methods for harvested plant tissue and liquid and solid manure. A summary of technical recommendations is provided in **Table 1**. Technical recommendations are discussed in detail in *Section 2*.

Table 1: Summary of technical recommendations

Technical Recommendation	Description
1. Overarching recommendations <u>Objective:</u> To provide a reporting and data analysis framework within which the more detailed recommendations set forth herein make sense and are likely to succeed in substantially reducing N loading to groundwater efficiently and effectively.	**Internet portal and centralized data management system (DMS)** 1. Replace different reporting formats with a unified format and make coalition membership contingent on the use of the Portal 2. Facilitate comprehensive and rapid data analysis
	Individual dairies continue to report to Regional Board via the DMS Includes recommendations for the types of data to be submitted and reported to the Regional Board; coalition will also retain this data to analyze trends and progress.
	Coalition reporting to the Regional Board Includes recommendations for additional data to be collected by coalition from members and other sources for inclusion in coalition's annual report to the Regional Board.
	Third-party coalition Assume broader responsibilities than CVDRMP currently has, including the creation of an internet Portal and centralized DMS and data management.
2. Improved field-scale N accounting <u>Objective:</u> Provide a metric to dairy operators that helps them in their INMP (see Technical Recommendation 6) efforts. This metric constitutes an improvement over the presently used AR ratio because it eliminates confusing and trifling variables, and it provides the farmer with flexibility that makes operational sense. However, significant limitations remain and they cannot be reconciled. Therefore, this metric is not intended to be used as a regulatory end point.	**Modified computation of AR ratio** Use AR ratio as set forth by the *Conclusions of the Agricultural Expert Panel*
	Reporting Unit Replace strict field-by-field accounting scheme with the flexibility to group fields in a customized manner that is practical for the dairy, consistent with the *Conclusions of the Agricultural Expert Panel*.
	Alfalfa and other legumes Do not compute AR ratio for alfalfa or other legumes but track N applications.
	Interpretation of AR ratio (and difference) 1. Coalition to track long-term trends in nitrogen use efficiencies on individual dairies as part of the Irrigation and Nitrogen Management Plan while remaining cognizant of this diagnostic's limitations 2. Coalition to aggregate data across the industry to assess as-is conditions, industry trends, and progress toward higher nitrogen use efficiencies

Table 1: Summary of technical recommendations *(continued)*

Technical Recommendation	Description
3. Improved estimation of available manure-N <u>Objectives:</u> 1. Provide an option for increased accuracy of the estimate of manure N that is generated on the farm in cases where data are available. 2. Estimate the amount of manure N stored in the liquid and solid manure streams. This is important to support better N planning for growing crops and the development of differentiated strategies to adress excess N.	**Improved estimation of N excretion per animal** 1. Continue use of fixed N excretion value of 0.26 lbs/animal/day for heifers as default but Portal to also offer ASAE D384.2 MAR2005, Section 5.3.9, equation 19 (p.8) 2. Continue use of fixed N excretion value of 0.14 lbs/animal/day but only for calves aged 3-6 months (instead of 0-6 months) 3. Use fixed N excretion value of 0.017 lbs/animal/day for calves aged 0-2 months
	Improved estimation of N excretion by the herd 1. Use representative average number of animals in each age group for the reporting period instead of the maximum number of animals 2. Modify calf age groups (0-2 and 3-6 months)
	N partitioning into liquid and solid manure streams 1. Calculated ranges based on the type of dairy, associated manure collection, and animal residence times 2. Fine tune based on dairy operator's site-specific knowledge
	Atmospheric N loss factor 1. Continue use of a 30% atmospheric N loss factor *2. Be cognizant that the actual site-specific amount of atmospheric N loss may be substantially different from 30% when interpreting whole-farm manure N balances*

Table 1: Summary of technical recommendations *(continued)*

Technical Recommendation	Description
4. Diagnostics <u>Objective:</u> Provide robust information about a dairy's manure N balance and potential fate. These diagnostics are robust because they are only minimally affected by on-farm measurements. They convey potential risk of manure N over-application. In combination with manifested manure exports, they can be used to track progress across the industry.	**Maximum average farm-scale manure N loading rates, "MaxLR" (lbs/ac)** 1. Relates available manure N to the land application area 2. Uses the most reliable information available 3. Provides differentiated insight for LM, SM, and total manure N 4. Separately deals with alfalfa 5. Communicates maximum average risk by not accounting for manure exports
	Maximum average farm-scale manure N application removal ratios and differences 1. Relates the MaxLR to harvest removal 2. Provides a more customized estimate of potential risk, while introducing uncertainty by incorporating harvest removal 3. Retains differentiated insight for LM, SM, and total manure N 4. Separately deals with alfalfa 5. Communicates maximum average risk by not accounting for manure exports
	Whole farm manure N balance sheet 1. Captures the manure N balance by relating available manure N to the manure N demand that is determined in the Irrigation and Nitrogen Management Plan 2. Export goals are computed by difference 3. Compares export goals to actual exports 4. Differentiated insight for LM and SM without affecting the total manure N balance
5. Improved sampling protocols <u>Objective</u> Support improved N planning and whole-farm N balance with more reliable on-farm measurements, where possible and effective.	**Solid manure** Specific protocol to attain a ±10% precision around the true dry matter and N concentration
	Liquid manure Specifications for flow meters, their installation and maintenance
	Harvest removal Specific protocol to attain a ±10% precision around the true dry matter yield; use of published, crop-specific, dry matter N-content in harvested biomass

Table 1: Summary of technical recommendations *(continued)*

Technical Recommendation	Description
6. Irrigation and Nitrogen Management Plan (INMP) and implementation	Improved planning and plan implementation, ongoing evaluation and improvement
7. Existing earthen lagoons <u>Objective</u> Effectively address environmental concern, while recognizing overall small lagoon contributions to subsurface N loading across the industry.	Allow continued use of existing earthen lagoons, except where they intersect the groundwater table
	Earthen lagoons that intersect groundwater are outside of CVDRMP's purview. CVDRMP can provide input regarding technical solutions, timelines, education, outreach.
	Do not fully aerate lagoons
	Do not use oxidation ditches
	Minimize drying of lagoons in preparation for sludge removal
8. New and reconstructed lagoons <u>Objective</u> Allow a lagoon design with a single synthetic membrane that provides a more realistic option for dairy farmers and can be considered consistent with Resolution 68-18.	Single-membrane liner with leachate collection and removal system in conjunction with long-term quality control using electrical leak detection (modified ASTM D7007-15).
9. Corrals	CVDRMP considers management practices described in the current Dairy Order for the maintenance and operation of earthen corrals BPTC.
10. Long-term representative groundwater monitoring This program eliminates unneeded data redundancy while effectively documenting long-term groundwater quality trends associated with specific dairy management units.	1. Quarterly depth-to-water readings 2. Annual groundwater quality sampling (field measurements: specific conductance, temperature, pH, dissolved oxygen, and oxygen reduction potential; lab analyses: TDS, nitrate-N, selective total Kjeldahl nitrogen) 3. Triennial groundwater quality sampling (annual suite plus general mineral suite)
11. Technical modifications to the Dairy Order	1. Remove any target for a N application removal ratio or difference 2. Remove requirement for soil sampling 3. Remove requirement for P, K, and salt sampling in manure and plant tissue

1.5.4 Increased Education

The value of education in achieving better irrigation and nitrogen management should not be underestimated. Indeed, it was one of the key recommendations of the Agricultural Expert Panel convened by the State Water Resources Control Board, whose 2014 Final Report[8] included among its recommendation that any regulatory programs include:

> *Development of a very strong, comprehensive, and sustained educational and outreach program. Such a program will require different materials and presentation techniques for different audiences, such as individuals who may need certification, managers of irrigation/nutrient plans, irrigators, and farmers/managers.*[9]

The California dairy industry has long invested in education and outreach to assist dairy operators in understanding how to achieve regulatory compliance. The California Dairy Quality Assurance Program (CDQAP), now 20 years old, offers free classroom education and educational materials to assist dairy producers in achieving compliance with air and water quality permits. CDQAP's Environmental Stewardship Program offers dairy operators compliance certification. The program is recognized by the State Water Resources Control Board and certified dairies are awarded a 50 percent discount on water quality permitting fees.

Upon adoption of the first Dairy Order in 2007, CDQAP launched a series of dozens of informational classes and workshops across the Central Valley and was credited with assisting producers in achieving a high compliance rate (over 99 percent)[10] with the new regulations.

CVDRMP recommends building on the success of past CDQAP efforts by asking the program to develop – in consultation with the Regional Board, CVDRMP, University of California Cooperative Extension and other stakeholders – a new curriculum intended to educate dairy operators about how to achieve whole-farm nitrogen balance via exports or other strategies, while improving NUE in forage crops managed by the dairy. CVDRMP further recommends, as did the Agricultural Expert Panel, that a basic requirement for NUE education be included in a revised Dairy Order to prompt dairy operators to take advantage of basic educational offerings.

Beyond basic education, CVDRMP recommends a broader voluntary education and outreach effort to assist dairy producers in gaining a more detailed understanding of options and strategies. For example, we envision that field days, classroom experiences, webinars, videos, newsletters and online content could cover a wide variety of topics, such as:

- "How-to" courses for proper use of flowmeters and sample collection methods, and using new reporting forms and the web portal;
- Training in irrigation efficiency training; and
- Updates on new incentive programs, new technology and demonstration projects and more.

We envision that both CVDRMP and CDQAP could play a role in leading these efforts, in cooperation with non-governmental organizational (NGO) partners, government agencies such as the California Department of Food and Agriculture and the United States Department of Agriculture's (USDA) Natural Resources Conservation Service, trade organizations and others. CVDRMP plans to be an active partner

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[8] https://www.waterboards.ca.gov/water_issues/programs/agriculture/docs/ILRP_expert_panel_final_report.pdf
[9] Ibid., page iv.
[10] https://www.waterboards.ca.gov/water_issues/programs/npdes/cafo.html

in developing and advising content for such programs and would report on activity in this area in its future annual reports to the Regional Board.

1.5.5 Changed Role for CVDRMP

To carry out its role in implementing the recommendations in this SRMR, CVDRMP contemplates continuing some of its present duties, while taking on additional responsibilities.

The most significant changes we recommend is evolving the CVDRMP from solely carrying out the role of a Representative Monitoring Program (RMP),[11] to taking on responsibilities like those of Irrigated Lands Regulatory Program (ILRP) coalitions. Doing this would require modification and re-issuance of the current Dairy Order, along with adoption of a parallel third-party based General Order.

Under this new role, CVDRMP proposes to develop and implement a new reporting system, including elements described in our technical recommendations (*Section 2*). The reporting system would include a web portal and data management system to be administered by CVDRMP and used by coalition members. Reports would be submitted to the coalition, with most data from individual dairies being forwarded on to the Regional Board in a standardized, digitized report. For certain data, such as reports on manure nitrogen exports, we propose to phase in the reporting of this information for individual dairies over time.

CVDRMP proposes to continue to collect and evaluate groundwater monitoring data, and include that information in future annual reports, albeit at reduced frequency (see **Table 1**). CVDRMP also proposes to develop and track other industry-wide performance markers, including qualitative and quantitative metrics. We contemplate that these would include:

- Tracking trends in industry-wide exports of manure nitrogen, as well as corresponding and corroborating data when possible from ILRPs and industries (e.g. compost facilities, large farms, soil amendment distributors and others as appropriate) receiving shipped manure nitrogen.
- Tracking trends in installation of projects that facilitate export or transformation of manure from dairies, such as permitted composting facilities, in-vessel composting, nutrient extraction technology, conversion from flush systems to facilitate export, and similar activities.
- Tracking development of incentive programs, including trends in offering and awarding grants to approved technologies and practices and research and development of innovative practices. Assess whether funding is enough to assure adequate progress in meeting goals related to whole-farm nitrogen balance.

Besides the above efforts, which are primarily geared at promoting efforts to reduce and control waste discharges on dairies, CVDRMP also proposes to support its members in implementation of the Salt and Nitrate Control Programs adopted by the Regional Board in 2018. The purpose of this effort is to facilitate efforts by our dairy coalition members to contribute, along with other stakeholders, toward efforts to provide safe drinking water to Central Valley residents that are impacted by elevated nitrate levels in domestic and public water supply wells.

Specifically, like most ILRP coalitions, CVDRMP proposes to collect from its members and pass on to the Central Valley Salinity Coalition, funds necessary to conduct a salinity study known as the Prioritization

[11] As defined in the Dairy Order, R5-2013-0122.

and Optimization Study[12] as an alternative compliance pathway under the Salt Control Program for dairy permit holders. Similarly, CVDRMP proposes to collect fees and fund a related Surveillance and Monitoring Program (SAMP).

In addition, CVDRMP intends work with local Management Zones, as described in the Nitrate Control Program to verify that all CVDRMP members are participating in their respective Management Zones, where applicable. It is the intent of CVDRMP to require all members contribute to safe drinking water in the communities where they operate by participating in Management Zones or Alternative Compliance Projects, and to pay reasonable costs associated with doing so.[13]

In summary, CVDRMP believes that the interests of improved water quality, a safe drinking water supply, and an economically viable dairy community are best served by a more hands-on, strategic, and collaborative approach in the future. The current system – based on a one-on-one relationship between the Regional Board and individual dischargers – does not leverage the full power of the broader dairy community, working with other stakeholders, to make improvements both in managing and reducing the impacts of dairies to water quality, and in providing drinking water to those that are affected by nitrates in groundwater. However, a re-envisioned process that increases CVDRMP's collaborative role, empowering the coalition not only to assist in implementation of the Dairy Order but also the Salt and Nitrate Control Programs, greatly increases our chances for success and progress.

1.5.6 Suggested Dairy Order Revisions

To fully carry out the recommendations in this SRMR as well as other goals of the Regional Board, we expect numerous changes will be needed in the Dairy Order(s), some of which are anticipated here. We recommend the following changes be considered to facilitate implementation of the recommendations:

1. Modify the current Dairy Order to allow continued enrollment of individuals with the changes described below (except those specific to the coalition order). This order would be open to dairies that meet any one or more of the following:
    a. Do not wish to enroll in the coalition
    b. Wish to continue submitting their annual reports directly to the Regional Board
    c. Do not wish to participate in available Nitrate Management Zones and believe they can demonstrate compliance with "Pathway A" under the Nitrate Control Program
    d. Do not wish to help fund salinity-related monitoring and research for alternative compliance purposes, such as the Prioritization and Optimization Study
2. Create a parallel Dairy Order that allows coalition members to enroll with similar requirements (below), except:
    a. Coalition order allows/requires enrolled to submit their annual reports to the coalition instead of the Regional Board, and makes the coalition responsible for relaying some of the information in the reports to the Regional Board

[12] https://www.cvsalinity.org/docs/agendas-notes-and-materials/meeting-materials/3968-prioritizationoptimizationstudyfinaldraft-9-11-18/file.html

[13] Because costs and requirements for individual Management Zones have not yet been determined, CVDRMP reserves the right to reconsider this membership requirement in cases where CVDRMP Board of Directors finds that it is impossible or impractical for a member or members to participate in such zones due to circumstances that are currently unforeseeable.

3. Modify both orders to replace current annual reporting requirement with a different annual reporting method, to be developed by CVDRMP and approved by the Regional Board, that focuses on whole-farm balance of manure N, eliminates field-by-field reporting, eliminates a specified application/removal (A/R) regulatory target (e.g. 1.4), and utilizes a Web Portal and Data Management System. Non-coalition members can be licensed to use the system. This system would be developed during 2020 (assuming Regional Board support is established by mid-2020) and ready for utilization mid-2021.
4. Modify MRPs in both orders to allow revised sampling protocols to determine nitrogen content of:
    a. Solid manure
    b. Liquid manure (process wastewater)
    c. Harvested crops
5. Require installation of flowmeters (one flow meter for every transfer pump or irrigation outlet that conveys liquid from a wastewater source to land application), to be installed within 27 months after new Dairy Order adoption
6. Require completion of a certified Irrigation and Nitrogen Management Plan (INMP) around October 1, 2021, assuming timely adoption of the orders (e.g. early 2020)
7. Allow single synthetic liners for new and expanded lagoons without requiring groundwater quality modeling or installation of monitoring wells
8. Require dairy operators (or at least one responsible party from each permitted dairy) to complete basic educational curriculum on fundamentals and principles of improving Nitrogen Use Efficiency (NUE) in dairy cropping systems (CVDRMP intends that these classes would begin being offered within 12 months of adoption of a new Dairy Order, and dairy operators/responsible parties would be required to complete the curriculum within the first two years it is offered. The intent is that the course would be developed with input from Regional Board and be approved by both CVDRMP and CDQAP.

1.5.7 Monitoring and Reporting Recommendations

CVDRMP proposes to reduce frequency of monitoring in its well network in the future. This will in no way compromise our ability to track trends in groundwater quality in the network. Rather, the recommendations will eliminate unneeded data redundancy. The recommended long-term program is summarized below:

1. Quarterly depth-to-water measurements (e.g., Feb, May, Aug, Nov)
2. Annual groundwater quality sampling (e.g., May) including field measurements (specific conductance, temperature, pH, dissolved oxygen, and oxygen reduction potential) and laboratory analyses of total dissolved solids and nitrate-N. Wells with a record of TKN contributing more than 10% to total nitrogen will also be sampled for total nitrogen.
3. Triennial groundwater quality sampling including the annual field measurements and laboratory analyses plus Na, K, Mg, Ca, Cl, SO_4, PO_4, HCO_3, CO_3, and OH.

Additional detail and a more complete rationale for this recommendation is included in the Technical Recommendations (*Section 2*).

1.6 The State Anti-Degradation Policy as Applied to Recommendations

1.6.1 State Anti-Degradation Policy Summary

The Dairy Order summarizes Resolution 68-16 (aka State Anti-Degradation Policy), which is applicable to discharges regulated by the Dairy Order. (Dairy Order, Information Sheet, pps. IS-9 to IS-14.) The key components of the State Anti-Degradation Policy are as follows:

1. Whenever the existing quality of water is better than the quality established in policies as of the date on which such policies become effective, such existing high quality will be maintained until it has been demonstrated to the State that any change will be consistent with maximum benefit to the people of the State, will not unreasonably affect present and anticipated beneficial use of such water, and will not result in water quality less than that prescribed in the policies.
2. Any activity which produces or may produce a waste or increased volume or concentration of waste and which discharges or proposes to discharge to existing high quality waters will be required to meet waste discharge requirements which will result in the best practicable treatment or control of the discharge necessary to assure that (a) pollution or nuisance will not occur and (b) the highest water quality consistent with the maximum benefit to the people of the State will be maintained.

As explained in the Dairy Order, these provisions require the Regional Board to adopt waste discharge requirements to ensure that the discharger controls the discharge by employing "best practicable treatment or control" methodologies to limit the extent of degradation, and that the Regional Board carefully consider whether the permitted degradation inheres to the maximum benefit to the people of the State when the discharge will result in degradation to high quality waters. The Dairy Order describes the step-by-step approach that the Regional Board must take when applying the State Anti-Degradation Policy. (Dairy Order, IS-11 to IS-12.)

Steps one (1) through five (5) are the preliminary steps taken to determine if the State Anti-Degradation Policy is triggered. By applying these steps, the Dairy Order found evidence in the Administrative Record that indicated wastes discharged from the regulated dairies will degrade high-quality water, thereby triggering the State Anti-Degradation Policy.

Step six (6) consists of applying the State Anti-Degradation Policy, and in particular prescribing requirements that will result in best practicable treatment or control (BPTC) of the wastes in the discharge. BPTC is an evolving concept that takes into account changes in the technological feasibility of deploying new or improved treatment or control methodologies, new scientific insights regarding the effect of pollutants, and the economic realities faced by regulated industries. As an ever-evolving concept, standard industry practices that are considered BPTC today may not be considered BPTC in the future.

The term BPTC is not defined in the Water Code or in the Policy; however, the State Water Resources Control Board has stated that one factor to be considered is the water quality achieved by other similarly situated dischargers, and the methods used to achieve that water quality. (See Order WQ 2000-07, at pp. 10-11.) The State Water Board has further interpreted BPTC to include, "[a] comparison of the proposed method to existing proven technology; evaluation of performance data (through treatability studies); comparison of alternative methods of treatment or control, and consideration of methods currently used by the discharger or similarly situated dischargers." (See Questions and Answers Document.) Further, the term "practicable" means that the Regional Board must consider costs associated with the treatment or control measures when prescribing requirements.

Step seven (7) requires the Regional Board to consider if the degradation being authorized is consistent with the maximum benefit to the people of the state. This may include consideration of the following factors: "economic and social costs, tangible and intangible, of the proposed discharge, as well as the environmental aspects of the proposed discharge, including benefits to be achieved by enhanced pollution controls." (Dairy Order, p. IS-13.) Under this step, the Regional Board may allow degradation to occur following a demonstration that the degradation is consistent with the maximum benefit to the people of the state. However, the Regional Board's allowance of such degradation cannot cause unreasonable affects to beneficial uses, which is part of step eight (8).

Step eight (8), the final step, requires that the Regional Board ensure that discharges not unreasonably affect present and anticipated beneficial uses, not result in water quality less than that prescribed in relevant policies, and not cause pollution or nuisance. "The [Regional] Board ensures that this component of the *State Anti-Degradation Policy* is met by requiring a discharger to comply with water quality objectives designed to protect all designated beneficial uses, thereby protecting those who rely on the quality of groundwater and surface waters." (Dairy Order, p. IS-14.) When issuing requirements to comply with water quality objectives, including ensuring compliance with the State Anti-Degradation Policy, the Regional Board has the authority and discretion for requirements to contain a time schedule. (Wat. Code, § 13263(c).)

1.6.2 Waters that are Not High Quality: The "Best Efforts" Approach

Where a water body is at or exceeding water quality objectives due to naturally-occurring conditions or due to prior Regional Board authorized activities, it is not considered a high-quality water and is not subject to the requirements of the State Anti-Degradation Policy. However, as summarized in the Dairy Order, "where a groundwater constituent exceeds or just meets the applicable water quality objective, the [Regional] Board must set limitations no higher than the objectives set forth in the Basin Plan." (Dairy Order, pp. IS-22.) Moreover, according to State Water Board direction, such limitations should be set at levels that are more stringent than applicable water quality objectives if the more stringent limits can be met with the use of "best efforts." (State Water Board Order No. WQ 81-5, *City of Lompoc*.)

As explained in the Dairy Order, the "best efforts" approach involves "the establishment of requirements that require the implementation of reasonable control measures." (Dairy Order, IS-22.) The factors to be analyzed under the "best efforts" approach are similar to those for BPTC, and include the following: water quality achieved by other similarly situated dischargers, good faith efforts to limit the discharge of the constituent, and the measures necessary to achieve compliance.

1.6.3 Application of State Anti-Degradation Policy in Dairy Order

In the Dairy Order, the Regional Board applied the State Anti-Degradation Policy by looking at waste management practices for three distinct areas of a dairy: production areas (e.g., milk barns, and corrals), wastewater ponds, and land application areas. (Dairy Order, IS-14 – IS-20.) For the production areas, the Regional Board found that application of Title 3 of the California Code of Regulations (Title

3), sections 645 et seq., plus the additional Dairy Order requirements for such facilities collectively constituted BPTC.

For the land application areas, the Regional Board found that the key Dairy Order requirement for ensuring BPTC was that for development and implementation of an effective Nutrient Management Plan that specifies the volume and composition of wastewater that can be applied to the land application areas without causing adverse groundwater impacts. Other land application related requirements for ensuring compliance with BPTC include: mandates to implement management practices required by Title 40 of the Code of Federal Regulations Section 122.42(e)(1)(vi)-(ix); well and surface water setbacks; certification of backflow prevention devices for all irrigation wells; and, requirements regarding waste infiltration and soil moisture capacity limits for waste application.

BPTC for ponds included general requirements that apply to all ponds, and distinct requirements for new or expanded ponds as compared to existing ponds. The general requirements include: Engineer verifications for adequate capacity and structural integrity to hold wastewater and precipitation; management and maintenance actions that prevent breeding of mosquitos and other vectors; elimination of small coves and perimeter irregularities; management actions to minimize weeds and to prevent accumulation of dead algae, vegetation and debris on the water surface.

For new or expanding ponds, the Dairy Order considers a number of pond design standards to be BPTC. These include more stringent design requirements than those currently existing in Title 27 of the California Code of Regulations as well as ponds that meet other design requirements approved by Regional Board staff. Other pond designs also considered to satisfy BPTC are those consistent with Title 27, California Code of Regulations, section 20340, and those designed in accordance with California Natural Resource Conservation Service (NRCS) Conservation Practice Standard 313 or equivalent where the discharger has been able to demonstrate through submittal of technical reports that the alternative design is protective of groundwater quality.

For existing ponds (i.e., ponds in operation as of 3 May 2007), the Regional Board found BPTC to consist of "an iterative process of evaluation that includes groundwater monitoring through the RMP, assessment of data collected, evaluation of Existing Pond conditions and their impact on groundwater quality, and case studies that evaluate potential changes in management practices and/or activities that may be necessary to further protect groundwater quality from existing ponds." (Dairy Order, IS-18.) This approach was found appropriate because requiring retrofitting of existing ponds would have been beyond practicable economic limits for most dairies, and would have had significant regional and state economic impacts. The Regional Board further stated that it would use the SRMR to determine if upgrades to existing ponds would be required, and, if upgrades are required, they would be on a time schedule that is as short as practicable. In no case could such time schedules extend beyond 10 years from the date that the SRMR is approved by the Executive Officer.

In its application of steps 7 and 8, the Regional Board found it appropriate to allow degradation to the maximum extent allowed by law, and to structure the Dairy Order in a way that would compel the dairy industry to focus on meeting water quality objectives. Furthermore, the Regional Board found that allowing degradation was consistent with maximum benefit to the people of the region and the state because of the economic significance of the Central Valley dairy industry. It also recognized that it may be impracticable to make changes overnight, and that practices found not to be protective of underlying groundwater would need to be upgraded to ensure compliance with water quality objectives on a time schedule.

1.6.4 Application of State Anti-Degradation Policy to SRMR Recommendations

Given the previous finding in the Dairy Order that the State Anti-Degradation Policy applies, and considering the data and information collected by the CVDRMP over the past six years, the SRMR concludes that the State Anti-Degradation Policy continues to apply to discharges from dairies regulated under the Dairy Order. Thus, it is not necessary to apply steps 1 through 5 as part of the SRMR. Rather, the SRMR looks to apply steps 6, 7 and 8 to the SRMR recommendations for Regional Board consideration.

With respect to application of the "best efforts" approach, the SRMR acknowledges that its recommendations should also account for the fact that even where a water body is not high quality, limitations more stringent than the objectives in the Basin Plans should be set if those limits can be met by "best efforts." Considering the overlap and similarity between BPTC and "best efforts," the SRMR's recommendations regarding BPTC also fulfill the State Water Board's "best efforts" approach, where applicable.

As stated previously, BPTC is an evolving concept that takes into account changes in the technological feasibility of deploying new or improved treatment or control methodologies, new scientific insights regarding the effect of pollutants, and the economic realities faced by regulated industries. Over the last seven (7) years, and as documented in other sections of the SRMR, the CVDRMP has conducted extensive sampling and analysis of groundwater data collected throughout the Central Valley from 42 actively monitoring dairies, and has taken significant additional efforts to conduct special studies. The CVDRMP has also evaluated costs for implementation of the SRMR's recommendations as well as costs associated with certain practices for some of the management units. With this new information in mind, the SRMR hereby evaluates its recommendations under steps 6, 7 and 8 of the State Anti-Degradation Policy.

Step 6

Whole-Farm Nitrogen Balance

The SRMR includes a number of recommendations that taken (and implemented) collectively will result in Central Valley dairies achieving whole-farm nitrogen balance. Accordingly, this collection of recommendations needs to be evaluated under the concept of BPTC. As already stated previously, the CVDRMP estimates that 94 percent of nitrogen loading on dairies occurs on the croplands. There is also evidence available that suggests there is "unaccounted-for" manure nitrogen on many dairies. To address this significant nitrogen load and address the issue of the unaccounted-for manure, the SRMR includes a series of recommendations. They include in part the following:

- Improve calculations of nitrogen excreted;
- Partition N into liquid and solid manure streams;
- Improve whole-farm N balance accounting scheme;
- Improve liquid and solid manure sampling protocols, including requiring flow meters for measuring liquid manure applications;

- Improve harvest removal sampling and calculations;
- Require enhanced Irrigation and Nitrogen Management Plans;
- Require education for calculation of whole farm nitrogen supply and demand;
- Participate in Nitrate Control Program Management Zones (Management Zones), as applicable;
- Fund drinking water efforts through Safe Drinking Water Act fees and/or participation in Management Zones;
- Broad-scale industry collaboration and efforts to build nitrogen exports;
- Efforts to improve on farm technologies for nitrogen extraction to facilitate export, or denitrification;
- Increased role for CVDRMP to develop and administer a Web-Based Portal and Data Management System; and,
- CVDRMP analysis of data and trends, including reporting on industry efforts for building nitrogen exports, improved technologies, incentive programs, etc.

Through the coordinated, and likely phased, implementation of these efforts, Central Valley dairies would ultimately achieve whole farm balance for nitrogen, and dairy discharges to groundwater would not unreasonably impact beneficial uses. This means that the amount of manure N generated on the dairy would be applied to crops at proper rates (recognizing and accounting for the differences between liquid and solid manure forms), and excess manure N that exceeds crop needs would either be exported or denitrified on farm. Further, through implementation of Management Zones or other drinking water efforts, users of groundwater that have drinking water wells impaired for nitrate will have safe drinking water.

With respect to timing of implementation, some recommendations may be implemented immediately upon Executive Officer approval of the SRMR (e.g., development of a Web-Based Portal and Data Management System); others are anticipated to apply immediately upon adoption of a renewed Dairy General Order (enhanced INMPs); and, others would apply over time (e.g., meeting whole farm N balance).

Notably, the SRMR recommends that the individual dairy requirement to achieve whole farm N balance be subject to an appropriate time schedule that allows sufficient time for the dairy industry and others to build the capacity for nitrogen exports off farm, and/or to develop or on-farm technology to facilitate export of manure or denitrification. Time to achieve whole farm N balance is necessary considering the current state of technology, existing limitations on the export of unprocessed or improved solid manure and economic realities. As described in *Section 3*, the present demand for unprocessed solid manure is relatively small and available revenue is limited. If a dairy was required to achieve whole farm N balance immediately, it would likely trigger the need to haul unprocessed liquid manure as well as solid manure. Based on the information provided in *Section 3*, the hauling of unprocessed liquid manure at this time would be costly and impracticable, while hauling of unprocessed solid manure may or may not be practicable. Further, there is tremendous uncertainty with respect to there being a market for such waste products. Additional industry research efforts are underway to evaluate market opportunities for dairy manure and manure products. However, until such market analyses are completed and market opportunities are real, it is not practicable for most Central Valley dairies to export sufficiently large amounts of dairy manure and manure products. Without this developed option, Central Valley dairies will be unable to achieve whole farm N balance immediately. Thus, time schedules for achieving whole farm N balance are a necessary component of the SRMR recommendation.

With respect to meeting BPTC, these recommendations (collectively and individually) reflect the status of currently available technology, latest scientific information and methodologies, and economic realities facing Central Valley dairies. *Section 2* of the SRMR provides significant documentation as to how these recommendations are in line with currently available technology and the latest scientific information and methodologies. *Section 3* provides some relevant cost information.

Existing Earthen Lagoons

The CVDRMP directed significant study efforts on the issue of lagoons. These initiatives included whole-lagoon seepage tests, soil borings, extensive geophysical testing, and comprehensive review of existing guidelines for the siting, construction, operation and maintenance of earthen lagoons. From these studies, the CVDRMP was able to make key findings, which are expressed above in the SRMR. Most significantly, studied earthen lagoons exhibit a narrow seepage rate, and the lateral extent of impacts is limited to the near vicinity of the lagoon. Moreover, N subsurface loading from dairy lagoons throughout the whole of the Central Valley is estimated to be 3,071 tons/year, or just four (4) percent of N loading from dairies (see *Section 3.2*). The industry-wide cost for replacing existing earthen lagoons with either single or double synthetic membrane liners is over $752 million and $1.1 billion, respectively. The resulting amount of N avoided in subsurface loading for each $1,000 expended is approximately 0.0021 to 0.0031 ton (i.e., 4.2 to 6.2 lbs).

In light of the cost as compared to the environmental benefit to be gained (i.e., avoided N subsurface loading), the SRMR recommends the continued use of existing earthen lagoons, with the exception of lagoons that intersect groundwater (*Section 2.7* and *Section 2.7.4*). The SRMR further recommends changes in some earthen lagoon operation and maintenance practices to decrease subsurface N emissions: (1) do not fully aerate lagoons; (2) do not use oxidation ditches; and, (3) minimize drying of lagoons in preparation for sludge removal (*Sections 2.7.1 – 2.7.3*).

Considering the current economic realities of lining existing earthen lagoons with single or double synthetic membrane liners, the Regional Board's previous BPTC findings are still appropriate because requiring retrofitting of existing ponds is beyond the practicable economic limits for most dairies, and would have significant regional and state economic impacts. However, as discussed previously, BPTC is an ever-evolving concept. Changes in technology and the availability of public funding for installation of single or double liners in the near future may very well transform what is currently impracticable into something that is BPTC. Accordingly, the SRMR recommends that the Dairy Order findings regarding existing earthen dairy lagoons generally remain, and that such lagoons be considered BPTC now and for some significant time into the future. More specifically, existing earthen lagoons should continue to be considered BPTC until at least 2029. Then, at that time, the Regional Board should re-evaluate existing earthen lagoons to determine if they are BPTC, or if they are not, then the Regional Board should set appropriate time schedules for improvements to lagoons that are found to not be protective of groundwater. Alternatively, dairies that are participating in a Management Zone may show that other actions within the zone constitute BPTC rather than lining earthen lagoons. This determination will be made at the time of Management Zone Implementation Plan approval.

For earthen lagoons that intersect the groundwater table, the SRMR does not find that these lagoons meet BPTC. When a lagoon intersects the groundwater table, there is direct hydraulic contact. Thus, groundwater can enter the lagoon, and of greater concern, lagoon water can directly enter the aquifer. This greatly increases the risk of groundwater pollution and at greater distances from the lagoon itself. Thus, for existing earthen lagoons to be considered BPTC, they must not intersect groundwater. For those lagoons that do not meet this requirement, and have not previously been subject to this requirement, the CVDRMP recommends that the Regional Board provide these operations with a reasonable amount of time to address the issue and implement appropriate actions to ensure that the lagoon is not intersecting groundwater.

New and Reconstructed Lagoons

The Dairy Order includes a tiered approach for new and reconstructed lagoons. However, the practical application of this approach has resulted in extremely high costs for tier 1 lagoons, which are 40 to 50 percent more costly than single-membrane lagoons. As a result, most Tier 1 lagoons have been built as part of a project to install an anaerobic digester and have involved significant financial assistance. Tier 2 lagoons can include a single synthetic liner or compacted clay liners so long as they meet certain standards. Tier 2 lagoons are generally less expensive to construct, but additional requirements, which include groundwater flow modeling pre-construction and groundwater monitoring post construction, also make this option extraordinarily costly.

For the above reasons and due to recent engineering advances, the SRMR recommends that for newly constructed (or reconstructed) lagoons, single-layer synthetic membrane liners as well as Tier 1 lagoons be found to meet BPTC without additional groundwater modeling or monitoring. Single-lined lagoons can now be considered BPTC for new or reconstructed ponds because current technology, improved construction quality control mechanisms, proper operation and maintenance and long-term quality control through electrical leak location surveys make these lagoons approach zero-leakage. Further, extensive monitoring of two lagoons with single-layer synthetic liners (constructed where there is shallow groundwater) indicates that there is no lagoon seepage occurring as the groundwater chemistry is not changing. Finally, installation of single-layer synthetic liners is 30 to 40 percent less costly than Tier 1 double-liners, but provides an approximately equal amount of protection. As such, they could be included as either an additional option under Tier 1, or an additional tier could be created for this option.

Corrals

The CVDRMP's extensive studies show that open earthen corrals that are operated in accordance with the requirements of the Dairy Order currently account for two (2) percent of N subsurface loading from all Central Valley dairies. Even if such facilities could be changed to no longer account for any N subsurface loading, this would equate to only six (6) percent of improvement.

Costs associated with the replacement of open earthen corrals with concrete corrals are on the order of $6.4 billion for the whole of the Central Valley (*Section 3.2.6*). For each $1,000 expended, this results in approximately 0.00016 ton (i.e., 0.31 lbs) of avoided N subsurface loading. In light of the cost, compared to the environmental benefit to be gained, the SRMR finds existing earthen corrals and the Dairy Order's current requirement requirements to be BPTC. Such findings are appropriate because requiring retrofitting of existing earthen open corrals is beyond the practicable economic limits for most dairies, and would have significant regional and state economic impacts. Like with existing earthen lagoons, the SRMR recommends that existing earthen corrals be considered BPTC now and for some significant time into the future. More specifically, existing earthen corrals should continue to be considered BPTC until at least 2029. Then, at that time, the Regional Board should re-evaluate existing earthen corrals to determine if they are BPTC, or if they are not, then the Regional Board should set appropriate time schedules for improvements to such corrals that are found to not be protective of groundwater. Alternatively, dairies that are participating in a Management Zone may show that other actions within the zone constitute BPTC rather than replacing such corrals with alternative animal housing structures. This determination will be made at the time of Management Zone Implementation Plan approval.

Steps 7 and 8

The SRMR demonstrates that allowing some continuation of degradation is to the maximum benefit to the people of the state. The Central Valley dairy industry continues to have significant economic value in California, and in the Central Valley. The overall California dairy industry is responsible for a total of 190,000 jobs and contributed $21 billion in gross state product,[14] with most of the industry – including 91 percent of the milk production – based in the Central Valley. economic activity. As such, the Central Valley provides for nearly a fifth of the nation's milk supply, and plays an important role in food and nutrition security for California and the nation.

Moreover, the recommended whole farm N balance approach, along with participation in Management Zones (where applicable), will help to ensure that beneficial uses are not unreasonably impacted by dairy discharges. A key component here is ensuring safe drinking water through legislative or Management Zone efforts while dairies and the dairy industry work towards achieving whole farm N balance.

Thus, the SRMR recommendations taken collectively, including the recommendations for continued monitoring and reporting at both the dairy level and industry level, provide for compliance with the State Anti-Degradation Policy.

1.7 Conclusion

As required by the Dairy Order, this SRMR evaluates the range of management practices and operating conditions existing today on Central Valley dairies. CVDRMP was unable to conclude that existing practices taken as a whole are protective of groundwater. Therefore, we propose solutions and upgrades that taken collectively are likely to significantly strengthen the ability of dairies to reduce impacts to groundwater, while also increasing the ability of the Regional Board and CVDRMP to assess overall trends in improvement going forward.

To implement a Whole Farm Nitrogen Balance approach for individual dairies as well as Central Valley dairies generally, we recommend specific measures, some to be implemented by individual dairies and others by the CVDRMP, that can be implemented in the near term and are accompanied by

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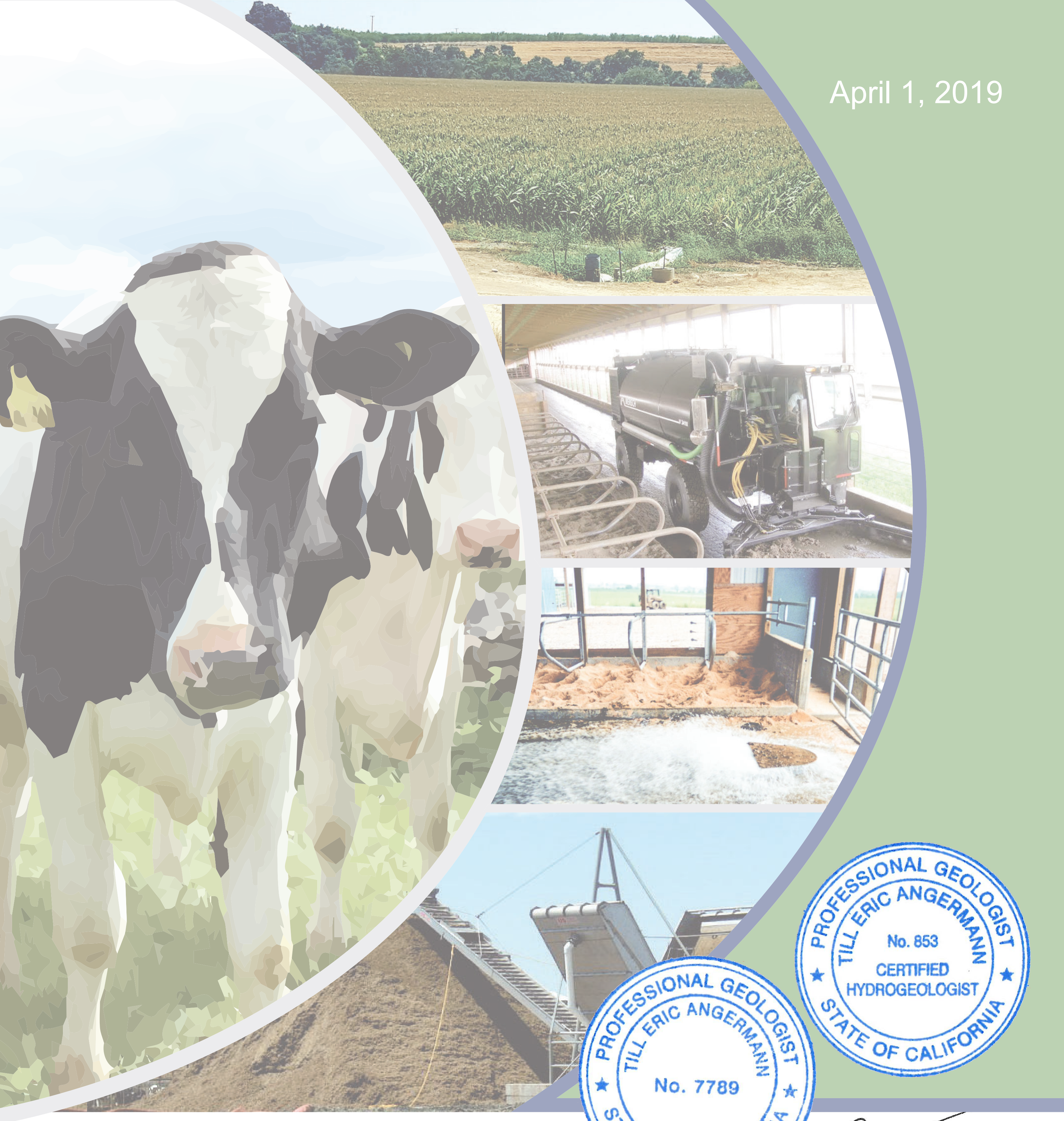
[14] See "Contributions of the California Dairy Industry to the California Economy," Sumner et al., May 2015 https://aic.ucdavis.edu/publications/CMABReport2015.pdf

recommended implementation schedules and cost estimates. In addition, we define a process that we expect will lead to a better understanding of industry performance on an ongoing basis and changes over time, and which will systematically identify and attempt to address challenges and obstacles to further progress.

Concurrent with the dairy community implementing changes to minimize impacts to water quality, the Central Valley dairy community must also share responsibility with other stakeholders, to help ensure access to a safe drinking water supply for Central Valley residents who are affected by nitrates in groundwater. As such, CVDRMP has identified specific measures to assist the Regional Board and our coalition members in successfully implementing the Regional Board's Salt and Nitrate Control Programs, adopted in May 2018.



Section 2

Technical Recommendations, Analysis and Support

2 Technical Recommendations and Support

The technical recommendations set forth herein apply to all Central Valley dairies that have coverage under the Dairy Order. Furthermore, recommendations are consistent with the rationale and conclusions of the Agricultural Expert Panel (Burt, Hutmacher et al. 2014).

> The pursuit of high-resolution nitrogen application information resulted in severely compromised accuracy on both the field scale and the whole-farm scale.
>
> CVDRMP devised robust diagnostics that reconcile this critical shortcoming.

The current Central Valley Regional Water Quality Control Board (Regional Board) regulatory approach emphasizes and relies on field-by-field quantification of manure nitrogen applications. The Central Valley Dairy Representative Monitoring Program's (CVDRMP) compilation and analysis of data generated on its 42 monitored member dairies (2012-2018) suggest that this approach is ineffective. The primary technical reason for this is the difficulty of accurately estimating individual crop field nitrogen applications from liquid manure. The inaccuracies propagate through the sum of hundreds of irrigations/fertigations per year on an average dairy and result in questionable whole-farm N balances that are unreliable. This finding is consistent with recent research conducted on Central Valley dairies by the University of California, Davis. Parsons (2018) comprehensively reviewed 2007-2014 annual reports of the regulated dairy community in the Central Valley. Miller, Price et al. (2017) conducted their research on a subset of 62 dairies (2011-2013 annual reports). Both investigation's mass balance analyses of nutrients revealed large inconsistencies and recommend that the quality of data should be evaluated before revisions are made to current and future Waste Discharge Requirements for dairies. These research efforts demonstrate the advantages of data aggregation across the Central Valley dairy industry for effective analysis.

CVDRMP's recommended approach emphasizes improved quantification of the herd's excretion rate, bifurcates manure-N into liquid and solid storage based on dairy facility type and operation, and then relates these quantities to the farm's available cropland in a differentiated fashion. This approach results in several new diagnostics, including robust diagnostics that are unaffected by on-farm measurements of actual manure applications or harvest removals.

CVDRMP's technical recommendations for solutions and upgrades focus on achieving higher nitrogen use efficiencies on dairies' cropland because cropland has been found to contribute 94% of N loading to groundwater across the industry, while lagoons and corrals were found to contribute 4% and 2%, respectively (LSCE 2019b). This work is summarized in the Year 7 Annual Report (LSCE 2019a). These findings are congruent with earlier quantitative evaluations by Harter, Lund et al. (2012). These authors identified sources of nitrate loading 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. Their 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. The authors estimated that 96% of human/animal-generated nitrogen sources to groundwater are from cropland in the study area and less than 1% stems from liquid manure lagoons and earthen animal housing (corrals) combined. Specifically, nitrogen mass loading from lagoons was estimated to be 1,000 times less than from cropland in the study area (i.e., including dairy cropland and cropland not associated with dairies).

Nonetheless, CVDRMP's technical recommendations include several Best Practicable Treatment or Control (BPTC) measures for lagoons. For corrals, existing management practices described and required in the current Dairy Order are considered BPTC.

2.1 Overarching Recommendations

2.1.1 Implementation of Internet Portal & Data Management System (DMS)

Currently, dairy farmers submit annual reports using different formats (i.e., Merced County Tool and at least three other unique reporting formats created by three private consulting firms). This creates inconsistencies between how certain quantities are being computed and undermines comparability between dairies. Furthermore, dairy farmers typically submit their annual reports as PDF files or paper copies. This has effectively prevented comprehensive, industry-wide evaluation of a large data set that has been accumulating since 2007.

The implementation of an internet portal and data management system (DMS) for use by the regulated community in the Central Valley would reconcile these shortcomings. Such a tool could help swiftly analyze long-term records and inform dairy farmers of their standing in relation to their peers, including groupings by crop, soil type, N inputs (e.g., organic vs. synthetic), and others.

2.1.2 Third-Party Coalition

The State Board and Central Valley Regional Board have embraced and promoted the formation of third-party coalitions in the context of the Irrigated Lands Regulatory Program (ILRP) and this approach has garnered support from the Agricultural Expert Panel (Burt, Hutmacher et al. 2014).

CVDRMP recommends that the dairy community form a third-party coalition similar to those that have been formed in the ILRP. The coalition would create and implement an internet portal backed by a DMS (see *Section 2.1.1*). Use of this portal will be a requirement for coalition members to maintain in good standing. The coalition will assume broader responsibilities than CVDRMP currently has. For example, the coalition will:

1. Analyze its members' submitted data
2. Track the industry's performance
3. Monitor individuals' progress with respect to their whole-farm N balance
4. Identify outliers and stragglers and work to help them identify strategies to move them toward whole-farm N balance
5. Monitor compliance with educational requirements
6. Continue groundwater monitoring and reporting activities

2.1.3 Member Reporting to the Third-Party Coalition

The Dairy Order currently requires the submittal of a variety of data including irrigation volumes for all irrigation events, estimates of every fertigation and fertilization event, and supporting laboratory analytical reports. This amount of detail is not warranted for regulatory reporting or even reporting to the coalition as it amounts to an enormous volume of information of questionable utility to the Regional Board or the coalition. For example, border irrigated corn on sandy soil may receive a dozen irrigations and half a dozen fertigations. Corn on subsurface drip may receive more than 30 irrigations and upwards of a dozen fertigations.

CVDRMP agrees that dairy operators need to be knowledgeable about these details as part of their irrigation and nitrogen management planning and strategies. Records of individual irrigation and fertigation events need to be kept on the farm and made available for review by Regional Board staff during on-site inspections. However, transferring this type of information from the various types of farm records into a regulatory report adds an undue burden. Also, farmers should be encouraged to employ visual observations as well as user-friendly handheld tools to support timely, in-season decisions about irrigation and fertigation without a requirement to report or even document every single measurement. This is consistent with the recognition that laboratory analyses do not provide a means to validate an estimate or provide evidence for its accuracy (*Section 2.2.4*).

The reporting scheme recommended herein also recognizes that the uncertainty surrounding individual manure-N applications will remain very high and this uncertainty cannot be reasonably addressed by the intensification of sampling efforts for liquid manure even with the installation of flow meters (*Section 2.5.2*). Reasonably accurate quantification of the N content of individual liquid manure applications requires research-level efforts with a high degree of customization, and this is not a viable option for implementation on dairies.[15]

Coalition members will use the portal to submit updated information on an annual basis (i.e., reporting period), for example:

1. Herd information
2. Milk production
3. Facility type
4. Manure N demand based on the Irrigation and Nitrogen Management Plan (INMP)
5. Actual manure N export during the last reporting period
6. Differentiated acreage (e.g., according to the ability to deliver liquid manure)
7. Crops grown and reporting units with supporting rationale (e.g., predominant soil texture, irrigation system and strategy)
8. Estimates of N inputs by source, crop, and reporting unit aggregated over a growing season
9. Yield and N removed with the harvest and/or sequestered in the perennial wood of a perennial crop by crop and reporting unit

Consistent with the conclusions of the Agricultural Expert Panel, this list does not include irrigation and precipitation water volumes, "because the impact of good water management is evidenced by the nitrogen applied versus removal ratio. Those volumes are essential elements of an irrigation and nitrogen management plan, however." (Section 4.6.1, p.39, Burt, Hutmacher et al. (2014)).

From this information, the DMS will compute estimates of:

1. Herd N-excretion rate (see *Sections 2.3.1* and *2.3.2*)

[15] The degree of accuracy is actually unknown for LM applications because the true nutrient content is unknown.

2. Manure-N partitioning and manure-N available for application (*Sections 2.3.3 and 2.3.4*)
3. AR ratios and differences by reporting unit
4. Differentiated diagnostics
    a. Maximum average farm-scale manure N loading rates (*Section 2.4.1*)
    b. Maximum average farm-scale manure N AR ratios and differences (*Section 2.4.2*)
    c. Manure-N export goal and export balance (*Section 2.4.3*)

2.1.4 Third-Party Coalition Reporting to the Regional Board

Starting with the first year of implementation, the coalition will process submitted member information and provide comprehensive descriptive statistical analyses to track industry characteristics, including:

1. Herd characteristics, milk production, and facility types
2. Crops grown and associated acreages, predominant soil types, and irrigation systems
3. Manure nitrogen available for application and export goals (partitioned in liquid and solid manure streams)
4. AR ratios and differences by reporting unit

The coalition will also report on its long-term groundwater monitoring activities and results.

2.2 Improvements to Field-Scale N Accounting

CVDRMP makes several recommendations to improve the utility of a field-scale N accounting scheme, four of which are described in this section:

1. Mathematical representation
2. Reporting unit
3. Special treatment of leguminous crops
4. Interpretation of results

2.2.1 Modified Computation of AR Ratio

Application Removal Ratio Dairy farmers need to be knowledgeable about managed N inputs and outputs to their cropland to make informed decisions toward optimizing nitrogen applications. It is recommended to adopt the AR ratio as defined by the Agricultural Expert Panel:

$$\frac{A}{R} = \frac{N\ applied}{(N\ removed\ via\ harvest) + (N\ sequestered\ in\ the\ permanent\ wood\ of\ perennial\ crops)}$$

Nitrogen applications include all managed inputs such as:

- Organic materials (e.g., liquid manure, solid manure, and compost)
- Synthetic fertilizers
- Irrigation water

In contrast to the AR ratio that is currently employed in the Dairy Order, the Agricultural Expert Panel explicitly did not include atmospheric N deposition and N in storage in the soil profile in its accounting scheme. Atmospheric N deposition constitutes a negligibly small input (presently estimated at 14 lbs/ac for Central Valley dairies) in comparison to managed inputs, and it does not meaningfully contribute to the overall accuracy of the estimate. Instead, its inclusion has caused consternation and confusion among dairy farmers. The mass of residual nitrogen in the soil profile is difficult to quantify unless research-level sampling protocols are being employed and farmers do not have time and resources to reliably implement such a data collection effort. In addition, the amount of nitrogen in soil storage is subject to potentially very large fluctuations in between crops and seasons. Single irrigations can constitute major flushing events such that post-harvest soil nitrogen concentrations may not be remotely comparable to soil N concentrations after the pre-irrigation (in preparation for the seeding of the next crop) let alone at the time after seeding when an adequate root system has developed.

Soil sampling should not be a regulatory requirement.

Therefore, in the context of an AR ratio, the quantification of N storage in the soil profile, is unnecessary. There is no evidence of a continuous build-up of soil organic matter in manured cropland on Central Valley dairies. Therefore, long-term steady state conditions can be reasonably assumed. This is consistent with recommendations regarding reporting units and multi-year aggregation of data.

Application Removal Difference The AR ratio conveys proportional environmental N losses. For a given AR ratio, absolute environmental N losses depend on the portion that was removed with the harvest. Therefore, it is equally important to estimate absolute environmental N losses calculated by difference.

$$\begin{aligned} Environmental\ Nitrogen\ Loss &= A - R \\ &= N\ applied - N\ removed\ via\ harvest \\ &\quad - N\ sequestered\ in\ the\ permanent\ wood\ of\ perennial\ crops \end{aligned}$$

The loss term represents an upper bound on the amount of N lost to deep percolation as it also includes atmospheric N losses from the soil surface and from plant surfaces. Deep percolating N may still be subject to denitrification, thus, reducing the flux to groundwater.

2.2.2 Reporting Units for AR Ratio and AR Difference

> Under current conditions, most reported AR ratios do not represent true, field-scale conditions but rather they are estimates based on averaging or other allocation schemes. CVDRMP recommends recognizing this fact explicitly and allowing logical grouping of fields into Reporting Units.

The Dairy Order requires dairy farmers to account for nitrogen inputs and outputs separately for each field that receives manure applications (i.e., on a field-scale). This is not practical because in many cases, inputs/outputs cannot be quantified on a per-field basis for different reasons. The Dairy Order explicitly recognizes this by allowing dairy farmers to use quarterly liquid manure samples to estimate N applications of possibly hundreds of fertigation events over several months and spread over all a dairy's fields. Furthermore, on many dairies, multiple fields may be irrigated and receive nitrogen applications simultaneously without the infrastructure to separately quantify these applications. On many dairies, tailwater runoff from one field becomes part of the irrigation water input to another field until it is ultimately routed back to the lagoon system. Crops are often harvested not on a per-field basis but in an overlapping fashion; the dairy farmer has no control over this when an outside service is hired. Also, some dairies split or combine fields depending on the crops grown and the season, which causes additional difficulties for reporting purposes. Consequently, under current conditions, most reported AR ratios do not represent true, field-scale conditions but rather they are estimates based on averaging or other allocation schemes.

To recognize existing facts regarding the difficulties associated with field-by-field N mass accounting and reporting, CVDRMP recommends that dairy farmers be given flexibility to group fields in a customized manner that is practical for the dairy operation. For example, a group may consist of several corn fields on similar soil that share the same irrigation method and irrigation/nitrogen management styles. Such a group of fields should be allowed to be combined into a Reporting Unit. This is consistent with the Conclusions of the Agricultural Expert Panel (Burt, Hutmacher et al. 2014).

2.2.3 Alfalfa and other Legumes

Alfalfa is a common perennial crop grown on Central Valley dairies and takes up approximately 11% of their cropland (Parsons 2018). Alfalfa, like other legumes, obtains N from the atmosphere through a symbiotic relationship with bacteria (Rhizobia) in the root nodules. Since this N input is not quantifiable by dairy operators, reported AR ratios are often significantly smaller than 1.0 (as small as 0.1 or less). Also, substantial N reserves remain in the non-harvested portion of the crop, i.e., the root system. As a result, N-accounting cannot be used to infer environmental losses even when the AR ratio moderately exceeds 1.0.

Therefore, it is recommended to not compute AR ratios for legumes. Importantly, planned N applications to legumes are part of the Irrigation and Nitrogen Management Plan (*Section 2.6*) and they are separately dealt with by the recommended diagnostics (*Section 2.4*).

2.2.4 Interpretation of AR Ratio and Difference

> CVDRMP finds that the AR ratio is ineffective as a regulatory end point, whether it has a numerical value associated with it or not. This is congruent with the *Conclusions of the Agricultural Expert Panel*.

Quantities currently reported to the Regional Board for regulatory purposes are estimates, supported by certain measurements. For example, the mass of N in exported or crop-applied solid manure is estimated based on the water content and N concentration in a sample retrieved from a manure pile and the weighed mass of that manure. The accuracy of the individual measurements can be controlled based on calibration of instrumentation. However, that accuracy is of relatively minor importance if the sample is not representative of the "population" (i.e., the entirety of the estimated quantity). Fundamentally, the intensification of sampling protocols or the requirement for laboratory analyses (as opposed to field measurements) do not provide a means to validate an estimate or provide evidence for its accuracy in the context of the Dairy Order. The Agricultural Expert Panel (Burt, Hutmacher et al. 2014) cautioned Regional Boards against making regulatory decisions based on application and removal ratios, "because the possibility of regulatory consequences will compromise the accuracy of the data."

The Dairy Order specifies that total nitrogen applied to the land application areas shall not exceed "1.4 times the nitrogen that will be removed from the field in the harvested portion of the crop." We find this metric ineffective as a regulatory end-point due to inherent imprecision and other factors.

The origin of the Dairy Order's AR ratio is a report by the Committee of Experts on Dairy Manure Management (Chang, Harter et al. 2005). The authors concluded based on the review and implementation of field and modeling studies "that the N input requirements for forage crops will generally be in the range of 140% to 165% of the crop N harvest removal, assuming that the manure application would consist of lagoon water which is approximately 75% NH_4-N". The authors also cautioned:

> *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.*

Regardless of the authors' explicit limitation on the range's generality and their cautionary note, the Regional Board selected the lower bound of the range, namely an AR ratio of 1.4, when it adopted Waste Discharge Requirements (WDRs) for dairies in 2007 and when re-issuing WDRs in 2013. The achievability of this ratio remains questionable. The Agricultural Expert Panel (Burt, Hutmacher et al. 2014) noted in the context of the Irrigated Lands Regulatory Program that (i) for the great majority of crops grown in California, the range of presently achieved AR ratios is unknown and (ii) the magnitude of feasible improvements is unknown. For example, CDFA stated in its December 2014 FREP Request for Proposal that "very little California information is available for corn" with regard to nitrogen management.

Chang, Harter et al. (2005) give a hypothetical N balance for a forage crop (Section 5.7.3, page 47) with 153 lbs N input and 100 lbs N harvest removal (i.e., AR ratio = 1.53). In their example, the only N inputs to the crop-soil system are fertilizer and dairy manure. Outputs are harvest removal, leaching losses, and gaseous losses. In practice, atmospheric N deposition and N in the irrigation water constitute additional inputs. Considering a small inaccuracy of ±15% on the input yields AR ratios ranging from 1.30 to 1.76. The same ±15% inaccuracy on the harvest removal yields AR ratios ranging from 1.33 to 1.80. Additive and subtractive 15% inaccuracies yield AR ratios of 2.07 and 1.13, respectively.

The AR ratio should not be used as a regulatory end point but rather as an educational tool.

In summary, the achievability of an AR ratio of 1.4 in highly productive forage systems that rely on manure as a primary N input remains highly questionable. Furthermore, the AR ratio's inherent imprecision renders it unsuitable for use as a site-specific regulatory end-point.

Therefore, it is recommended that the focus of evaluation should not be on year-to-year variability of AR ratios/differences associated with individual fields (i.e., reporting units) but rather on longer term trends (e.g., 3-year moving averages) and logically aggregated information. This can become an effective learning tool for dairy operators. For example, by using aggregated information (i.e., from many dairies), individual dairy operator standing can be compared to their peers in the region and Central Valley wide including comparisons by crop, soil type, or N inputs (e.g., organic vs. synthetic). This type of analysis would be greatly facilitated by a third-party approach using a single data submission format and DMS.

2.3 Improved Estimation of Available Manure N

The recommendations in this section intend to do two things:

1. Increase the accuracy of the estimate of manure N that is generated on the farm and is available for use.
2. Partition manure N into liquid and solid manure streams based on facility type.

2.3.1 Improved Estimation of N Excretion per Animal

The Dairy Order collects information specific to six animal groups: lactating cows, dry cows, heifers (aged from 15-24 months), heifers (7-14 months), calves (4-6 months), and calves (birth to 3 months) (**Table 2**). The Merced County Tool adopted nitrogen excretion rates from ASAE (2005). Specifically, the Dairy Order computes N excretion for lactating cows with equation 16 (Section 5.3.7, p.8), which includes the cow's milk production as the sole independent variable. The inter-study and residual errors associated with this regression equation are 57.8 and 110.8 g/animal/day. ASAE (2005) provides two other regression equations. However, these equations provide no compelling advantage for purposes of the whole-farm manure N mass accounting over equation 16 in terms of their inter-study and residual errors, while requiring several other input variables in addition to the milk production (i.e., days in milk, body weight, and the concentration of crude protein of total ration, plus either the dry matter intake (DMI) or the milk true protein). Therefore, continued use of equation 16 is recommended.

For the other animal groups, the Dairy Order uses fixed values from Table 1.b of ASAE (2005). These values are based on average animal body weights and they do not have error estimates associated with them. Nitrogen excretion of dry cows is approximately one half that of lactating cows. Improved excretion rates (e.g., Central Valley specific, breed-specific) for dry cows would have only marginal effect on improving the accuracy of whole-farm excretion contributions by this animal group on Central Valley dairies. Therefore, no change is recommended for the dry cow excretion rate. Chang, Harter et al. (2005) note:

> "Uncertainties about exact N excretion levels in dry cows have only a minor impact on dairy herd excretion estimates. Because dairy cows, on average, lactate for 305 days and are dry for 60 days per year, dry cows are a relatively small contributor to the total adult dairy herd N output on a commercial dairy. Hence, a 20% error in N excretion estimates from dry cows represents only a 1.5% error in N excretion estimates from all dry and lactating cows."

Uncertainties about N excretion in heifers have only a minor effect on overall dairy herd excretion estimates on Central Valley dairies that raise their own support stock. For example, for a dairy with a heifer population of one half of the mature cow population (i.e., both lactating and dry), a 20% deviation of the actual heifer N excretion rate from the excretion rate used by the Dairy Order (i.e., 0.26 lbs/animal/day) results in a 2.5% error in N excretion estimates from the herd. This error could potentially be amplified on facilities that house only one of the heifer age groups (e.g., only 15-24 months old heifers but not 7-14 months old heifers) because the current Dairy Order applies the same N excretion rate to both age groups under the assumption of an average animal weight of 970 lbs.

Equation 19 (ASAE 2005) more accurately determines heifer excretion rates based on the animals' dry matter intake (DMI) and the concentration of crude protein in the total ration. Dairy farmers and operators of heifer ranches are knowledgeable about these quantities as they work closely with nutritionists, and the animals' rations are formulated to optimize growth and input costs. Use of these equations would address regional feed differences, individual farmers' feed formula preferences, differences between breeds (e.g., Holstein, Jersey, cross breeds), the trend to smaller animals that has been observed over the last decade, and it would eliminate the application of a single animal body weight to two animal groups that do not have the same average body weight.

Uncertainties about exact N excretion levels in calves have even less of an effect on dairy herd excretion estimates than uncertainties associated with heifer excretion rates. However, for a custom calf ranch, the effect can be significant. The Dairy Order applies a single N excretion rate of 0.14 lbs/animal/day to calves ranging in age from birth to 6 months, assuming a representative body weight of 330 lbs. Calves' birth weight is approximately 100 lbs and they weigh approximately 400 lbs by the end of 6 months, indicating that an average weight of 330 lbs is an overestimate. However, more importantly, calves are milk-fed for the first 6-8 weeks, and for this period, an N excretion of 0.017 lbs/animal/day is appropriate (ASAE 2005). Failure to account for the lower excretion rate of milk-fed cows can potentially result in a ~41% overestimation of excreted N from the calf herd. For the older calves, an average representative body weight of 330 lbs remains realistic.

Table 2: Nitrogen excretion for mass accounting

Dairy Order Animal Group	Total nitrogen excretion per animal per day (N_E) †	
	Merced County Tool	Proposed Change
Lactating Cow	N_E = Milk x 4.204 + 283.300 ‡ Inter-study error = 57.7 Residual error = 110.8	No Change
Dry Cow	N_E = 0.5 (lbs/animal/day) § Assumes animal weight of 1,660 lbs ¶	No Change
Heifer (15-24 months)	N_E = 0.26 (lbs/animal/day) § Assumes animal weight of 970 lbs ¶#	Keep N_E = 0.26 (lbs/animal/day) as default. Provide option: N_E = DMI x C_{CP} x 78.390 + 51.350 * Inter-study error = 24.47 Residual error = 10.76
Heifer (7-14 months)		
Calf (4-6 months)	N_E = 0.14 (lbs/animal/day) § Assumes animal weight of 330 lbs ¶#	Continue use of N_E = 0.14 (lbs/animal/day), Extend age group to 3-6 month
Calf (0-3 months)		Reduce age group to 0-2 months, N_E = 0.017 (lbs/animal/day) §

† In g/animal/day unless stated otherwise
‡ ASAE D384.2 MAR2005, Section 5.3.7, equation 16 (p.8); Milk=milk production (kg/animal/day)
§ ASAE D384.2 MAR2005, Table 1.b (p.2)
¶ Agricultural Waste Management Field Handbook, Chapter 4, Table 4-5 (p.4-13)
# Representative weight for this growth period, see Agricultural Waste Management Field Handbook, Chapter 4 (p.4-8)
* ASAE D384.2 MAR2005, Section 5.3.9, equation 19 (p.8); DMI=dry matter intake (kg dry feed/ animal/day); C_{CP} = concentration of crude protein of total ration (g crude protein/g dry feed)

2.3.2 Improved Estimation of N Excretion by the Herd

The Dairy Order requires that the N excretion for each animal group is computed using the maximum number of animals present on the dairy during the reporting period (**Table 3**). Consequently, herd excretion estimates tend to be systematically overestimated. The appropriate statistic for the computation of the herd's total N excretion is the arithmetic average computed from daily records.

Table 3: Animal count for the computation of nitrogen excretion by animal group

Animal Group	Dairy Order Variable	Proposed Change
Lactating Cow	MaxMilkCowCount	Representative average value for the reporting period; modify calf groups (0-2 and 3-6 months)
Dry Cow	MaxDryCowCount	
Heifer (15-24 months)	MaxHeifer15To24Count	
Heifer (7-14 months)	MaxHeifer7To14Count	
Calf (3-6 months)	MaxCalf4To6Count	
Calf (0-3 months)	MaxCalfTo3Count	

2.3.3 N Partitioning into Liquid and Solid Manure Streams

The purpose of the partitioning is to provide dairy farmers with estimates of upper and lower bounds on the proportional nitrogen content in their liquid and solid manure. These bookends can be further refined by the farmer based on farm-specific operational knowledge.

The current whole-farm nitrogen accounting scheme does not inform the farmer about nitrogen content according to storage. However, the type of manure storage (i.e., as liquid manure (LM) or solid manure (SM)) has important implications for its availability for crop application. The storage of nitrogen in liquid form bears an enormous management advantage over SM. LM can be applied to the crop throughout the growing season to match crop demand with supply. This is particularly advantageous in the Central Valley where dairies grow feed 12 months a year in double- or triple-cropped forage rotations, which provide a variable but essentially year-round demand for nitrogen. In contrast, SM cannot be injected into the irrigation water stream. Instead, its field application relies on heavy equipment such as tractors or broadcasting trucks. Therefore, SM is generally only applied pre-planting, which may be weeks and several irrigations or rain events prior to significant crop nitrogen uptake. This may make nitrogen vulnerable to leaching. Pre-plant applications of SM are most likely not sufficient to maintain current production levels of silage corn (i.e., the most wide-spread forage crop associated with Central Valley dairies and a crop with high N-demand and highly variable rates of N-uptake during different growth stages) unless followed by LM or synthetic fertilizer applications later in the growing season. Consequently, a dairy with all of its manure N in the form of LM has the ability to field-apply much more of its manure N compared to a dairy that has all of its manure N in the SM form (other variables unchanged).

The type of manure storage has also implications for treatment options (e.g., solids separation, aerobic and anaerobic digestion, composting) and exportability. SM can and is already exported from dairies.

LM cannot be economically exported unless conveyance infrastructure exists. In practice, this essentially limits LM exports to the dairy's neighbors.

The partitioning of manure N from lactating cows into liquid and solid forms follows the approach of Chang, Harter et al. (2005) and is based on the animals' estimated residence time on concrete surfaces. This relates to the type of dairy (**Table 4**). For a freestall dairy without corrals, 100% of manure is collected in LM form. At open-lot dairies that do not have flush lanes associated with their corrals, most of the manure is deposited on earthen surfaces, and only the manure excreted in the milking parlor and walkways to the milking parlor is flushed. Therefore, the range of LM is relatively small (11%) because it solely depends on the variability of residence times associated with milking the cows (i.e., frequency and efficiency of milking).

At dairies that have corrals with associated flush lanes, the range of LM is greater (27%) because it depends on the variability of residence times associated with milking the cows plus feeding. At this type of dairy, although all lactating cows are housed on corrals, there are many factors that can influence where cows spend their time, how long, and at what time of day (e.g., location of water troughs and shade structures, use of soakers associated with feed lanes, frequency of milking, etc.).

Freestall dairies with corrals have the greatest range of LM (58%) because it depends on the variability of residence times associated with milking the cows (same as for the other types of dairies) plus freestalls (including feeding, socializing, loafing, seeking shade and cooling). The entirety of this range can be caused by the latter component, and seasonal variability may be the primary factor affecting the time that lactating cows spend in corrals on many dairies. For example, lactating cows may be kept entirely out of the corrals for weeks or months in the winter when earthen surfaces are wet, soft, and muddy. During this time, LM collection would be 100%. In the summer, the location of water troughs and shade structures, use of soakers associated with feed lanes, frequency of milking, and other infrastructure and operational characteristics of individual dairies can shift the residence time on concrete in one direction or another.

Table 4: Estimated liquid manure collection as percentage of total manure collection based on residence time of lactating cows (modified from Chang, Harter et al. (2005))

Type of Dairy	Minimum & Maximum	Range
Corrals without flush lanes	8-19%	11%
Corrals with flush lanes	21-48%	27%
Freestalls without corrals	100%	0%
Freestalls with corrals	42-100%	58%

2.3.4 Continue Use of 30% Atmospheric N Loss Factor, be Cognizant of its Limitations

Chang, Harter et al. (2005) report three methods for estimating atmospheric N losses from LM.

1. The N:P ratio method is based on a comparison of the ratio between N and P in fresh manure vs. in the lagoon. This method yields an estimate of atmospheric N losses from the production area (i.e., freestalls, flush lanes, and lagoons). Results from 20 dairies in Merced County indicated atmospheric N losses ranging from 20 to 35% (**Table 5**).
2. The readily hydrolyzable organic nitrogen (N-org) method yields an upper limit of atmospheric N losses that occur before lagoon storage. The authors assumed that 50% of N is excreted in urine and that 70% of that is in the form of urea, which is readily hydrolyzed to ammonia, which then can volatilize. Thus, an upper ceiling of 35% was calculated (0.5 x 0.7 = 0.35). However, data collected from high and low performing strings in four California counties indicated a higher proportion of N excreted in urine (i.e., 59-64%), Table 2-2 (Chang, Harter et al. 2005). This would result in an upper ceiling of 44.8% (0.64 x 0.7 = 0.448). On the other hand, if feed protein is at recommended ration levels, urea content will be nearer to 55% (personal communication with Dr. Deanne Meyer, December 1, 2017), which yields an upper limit that is as low as 27.5% (0.5 x 0.55 = 0.275).
3. Atmospheric N losses from anaerobic, uncovered lagoons was evaluated with process-based modeling including variables such as ambient temperature, lagoon depth and pH, and N concentration in the lagoon. Results for climate conditions representative of Fresno County indicated annual atmospheric N losses ranging from 2-37% with an average of 12% over the course of a year.

Table 5: Estimated atmospheric nitrogen losses from liquid manure (modified from Chang, Harter et al. (2005))

Method	Loss Estimate For	Range	Average
N:P ratio (20 Merced County dairies)	freestalls+ flush lanes+ lagoon	20-35%	30%
Readily hydrolyzable N-org. (theoretical biological ceiling)	freestalls+ flush lanes	35% (27.5-44.8%)	35%
Process-based model (Fresno County climate conditions)	lagoon	2-37%	12%

Chang, Harter et al. (2005) suggest that, "… atmospheric N losses from liquid manure (i.e., freestalls and flush lanes and lagoons) used for dairy planning and permitting purposes, are considered to range between 20% and 40%. The use of a single number ("emission factor") is strongly discouraged. Note, that these losses do not include atmospheric N losses in the land application (crop production) area, …".

Technically, this range only applies to the type of dairy that has freestalls without corrals because the authors do not address atmospheric N losses from earthen corrals. Todd, Cole et al. (2005) estimated via direct measurements NH_3 emission rates ranging from 27% in the winter to 55% in the summer in comparison to fed N. Their research was carried out on a cattle feedlot in the Texas Panhandle where climate is similar to the San Joaquin Valley. The authors also used the N:P ratio method and computed

44 to 45% total atmospheric N losses (i.e., NH_3, NO, N_2O, and N_2) in the winter and summer, respectively. Microbially facilitated denitrification in the soil profile has been reported as another pathway of N-loss from corral soils under a combination of certain environmental conditions (Stewart, Viets et al. 1967a; Stewart, Viets et al. 1967b; Mielke, Ellis et al. 1970; Elliott and McCalla 1972; Elliott, McCalla et al. 1972; Chang, Adriano et al. 1973; Elliott, McCalla et al. 1973; Mielke, Swanson et al. 1974; Coote and Hore 1979; Norstadt and Duke 1982; Woodbury, Miller et al. 2001). This process depends on the prior nitrification of ammoniacal-N, and it is very sensitive to soil temperature, soil salinity, soil water content and pH, redox-conditions, and soil carbon content. Patrick and Wyatt (1964) showed that repeated wetting and drying of soil drastically increased N losses over a control soil that was kept at optimum water content. Under Central Valley conditions, repeated wetting and drying may occur many times in the uppermost soil profile during the winter due to a significant number of dry, clear, windy, and warm days with low relative humidity (see literature review in LSCE (2019c)).

The Dairy Order uses a loss term for NH_3-N emissions of 30% of excreted N. This proportion represents the midpoint of a likely range (i.e., 20-40%) that was established for the liquid waste management system associated with Central Valley dairies. Atmospheric N emissions (including NH_3, NO, N_2O, and N_2) likely exceed 30% of excreted N on dairy corrals. However, CVDRMP is not aware of an authoritative scientific body of work that could be relied upon to revise the whole-farm N-loss computations based on the type of dairy or industry-wide. Therefore, it is recommended to continue use of the current loss factor of 30%, while recognizing its limitations. This yields estimates of Manure Nitrogen Available for Application (MNAA) including partitions into LM and SM (**Table 6**).

Table 6: Estimated N-excretion quantities [lbs/y] †

Quantity	Symbol
Herd's total excreted N (improved)	N_{E_total}
Herd's excreted N managed in liquid form	N_{E_LM}
Herd's excreted N managed in solid form	N_{E_SM}
Herd's total excreted N after volatilization losses (i.e., Manure Nitrogen Available for Application)	MNAA
Herd's excreted N managed in liquid form after volatilization losses	$MNAA_{LM}$
Herd's excreted N managed in solid form after volatilization losses	$MNAA_{SM}$

† N-excretion quantities are computed for an annual reporting period but this need not be a calendar year. Instead, it should be based on crop rotations (e.g., from the planting of winter oats to the harvest of next year's summer corn).

2.4 Diagnostics

The Dairy Order's whole-farm N accounting scheme (i.e., Merced County Tool) sums field-scale information. This approach compounds the limitations of its field-scale accounting scheme. Specifically, it relies on field-specific estimates of N storage in the root zone (i.e., soil N content and plowdown credit from preceding leguminous crops), N applied to fields in dry manure, liquid manure, synthetic fertilizer, other organic inputs, N in irrigation water, and atmospheric N deposition and the N removed with the crop. Some of these quantities contribute negligibly to the overall mass fluxes on a dairy scale whereas others represent enormous uncertainty associated with their estimation, even after the implementation of improved sampling protocols proposed herein.

To address this issue, CVDRMP recommends replacing the currently employed whole-farm N accounting scheme with three more reliable and meaningful diagnostics that are discussed herein.

2.4.1 Maximum Average Farm-Scale Manure N Loading Rates

This diagnostic relates the Manure Nitrogen Available for Application (MNAA) to the farm's available land base to compute maximum average loading rates, which represent the best possible estimation of the central tendency. This approach neither systematically overestimates nor systematically underestimates the maximum average farm-scale manure N loading rates because the total application is fixed. This diagnostic communicates potential risk based on the most reliable data available. It differentiates LM and SM without effect on MNAA. It can be used by the farmer as a starting point for nitrogen application planning.

The entirety of a dairy's controlled acreage (A_c) does not necessarily receive manure (**Table 7**). Acreage that receives LM (A_{LM}) may also receive SM, whereas acreage that receives SM (A_{no_LM}) is not equipped to receive LM. This is an important separation of lands as it relates to the farmer's ability to disperse LM and SM. The sum of A_{LM} and A_{no-LM} is the manured acreage, A_m. Some dairies have access to third-party land for LM applications (A_{LM3}). These arrangements are typically longer-lasting than arrangements for SM exports; they typically have permanent conveyance infrastructure associated with them and a specific application area. Therefore, this land was quantified to refine maximum average loading rates.

Table 7: Physical acreage [ac]

Physical Acreage †	Symbol & Relationships	Comment
Controlled acreage	A_c	This is the croppable acreage, not the actually cropped acreage regardless of the type of crop or the number of crops per year. It includes fallowed land, land planted in crops that do not receive manure, and land planted in alfalfa (regardless of whether manure is applied or not).
Manured acreage ‡	A_m $A_m = A_{LM} + A_{no\_LM}$ $A_m \leq A_c$	This is the portion of the controlled acreage where manure is applied (LM and/or SM).
LM manured acreage ‡	A_{LM} $A_{LM} \leq A_m \leq A_c$	This is the portion of the controlled acreage that is accessed by permanent/semi-permanent LM piping/conveyance infrastructure **and** receives LM.
Third-party acreage receiving LM ‡	A_{LM3}	This is not a portion of the controlled acreage. It is a neighbor's property that is accessed with permanent/semi-permanent LM piping/conveyance infrastructure; needs third-party agreement.
SM manured acreage ‡	A_{no_LM} $A_{no\_LM} \leq A_m \leq A_c$	This is the portion of the controlled acreage that is not accessed by permanent/semi-permanent LM piping/conveyance infrastructure **and** receives SM.
Acreage planted in leguminous crops	$A_{alf} \leq A_c$	This is the portion of A_c, that is planted in alfalfa or any other leguminous crop. It is not part of A_m, regardless of whether it receives LM and/or SM. Harvest removal from this acreage is not used in any of the diagnostics or N-accounting schemes recommended herein.

† All acreages are true areas. For example, a 48-acre field is counted as 48 acres regardless of how many crops were planted on the field in the reporting period. All acreages are to be quantified for a specific reporting period.
‡ Excluding fallowed land, crops that do not receive manure, alfalfa, and other crops that fix atmospheric N.

The proportionality between these different acreages can vary widely within limits, as expressed in **Table 7**. One possible scenario is depicted diagrammatically in **Figure 1**.

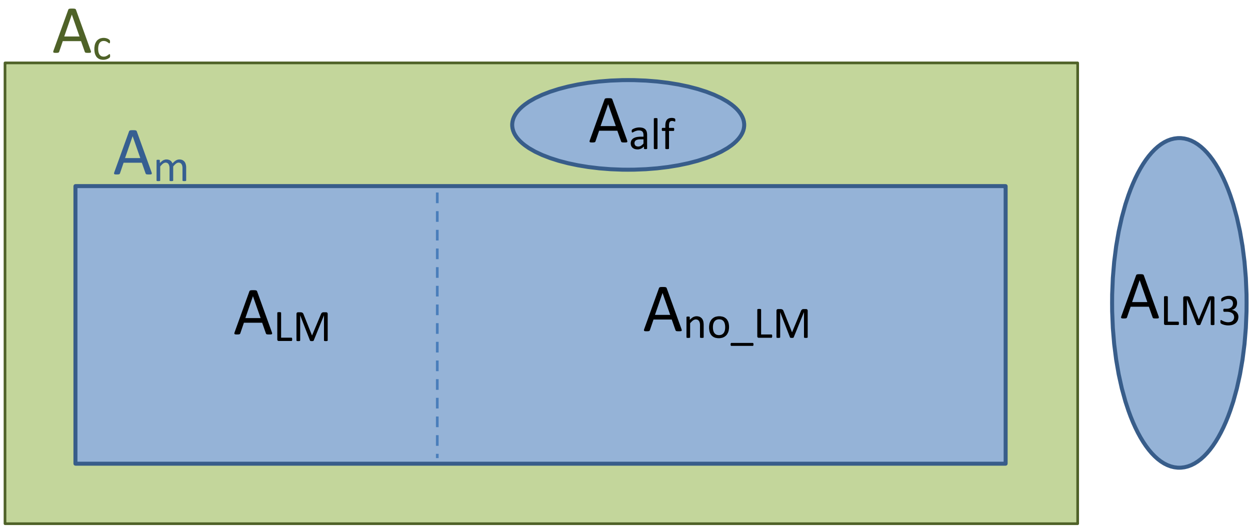


Figure 1: Diagram of the proportionality between acreages (example)

Since MNAA is not necessarily equal to the actually applied manure N, the computed loading rates represent a maximum average on the farm-scale. There are four farm-scale manure N loading rates of use (**Table 8** and **Figure 2**).

1. $MaxLR_{LM}$ is the maximum average loading rate of liquid manure to acreage that receives LM (incl. possibly SM). It does not account for LM applications to third-party acreage and it does not account for potential SM applications.
2. $MaxLR_{LM\_adj}$ is the maximum average loading rate of liquid manure to the sum of acreage that receives LM (incl. possibly SM) and third-party land for LM applications. It accounts for potential LM applications to third-party acreage and, therefore, it is smaller than $MaxLR_{LM}$. It does not account for potential SM applications.
3. $MaxLR_{SM}$ is the maximum average loading rate of solid manure to the manured acreage. For A_{no_LM}, it represents the total maximum average loading rate. For A_{LM}, it represents a lower bound on the total maximum average loading rate.
4. $MaxLR_{LM+}$ is the total maximum average loading rate to acreage that receives LM (incl. possibly SM). It accounts for potential LM applications to third-party acreage. This diagnostic is superior to MNAA ÷ A_{LM} or MNAA ÷ A_m because it properly allocates LM only to those lands that have the infrastructure to receive LM and actually receive LM.

Table 8: Definitions for maximum average farm-scale manure N loading rates [lbs/ac]

Symbol	Comment
$MaxLR_{LM} = MNAA_{LM} \div A_{LM}$	Relationship between the dairy's MNAA managed in liquid form and the LM manured acreage.
$MaxLR_{LM\_adj} = MNAA_{LM} \div (A_{LM} + A_{LM3})$	Relationship between the dairy's MNAA managed in liquid form and the sum of LM manured acreage and LM3 manured acreage.
$MaxLR_{SM} = MNAA_{SM} \div A_m$	Relationship between dairy's MNAA managed in solid form and the manured acreage.
$MaxLR_{LM+} = MaxLR_{LM\_adj} + MaxLR_{SM}$	Relationship between total maximum average manure applications (both LM and SM) and the LM manured acreage (A_{LM}). This is not the same as MNAA ÷ A_{LM} or MNAA ÷ A_m

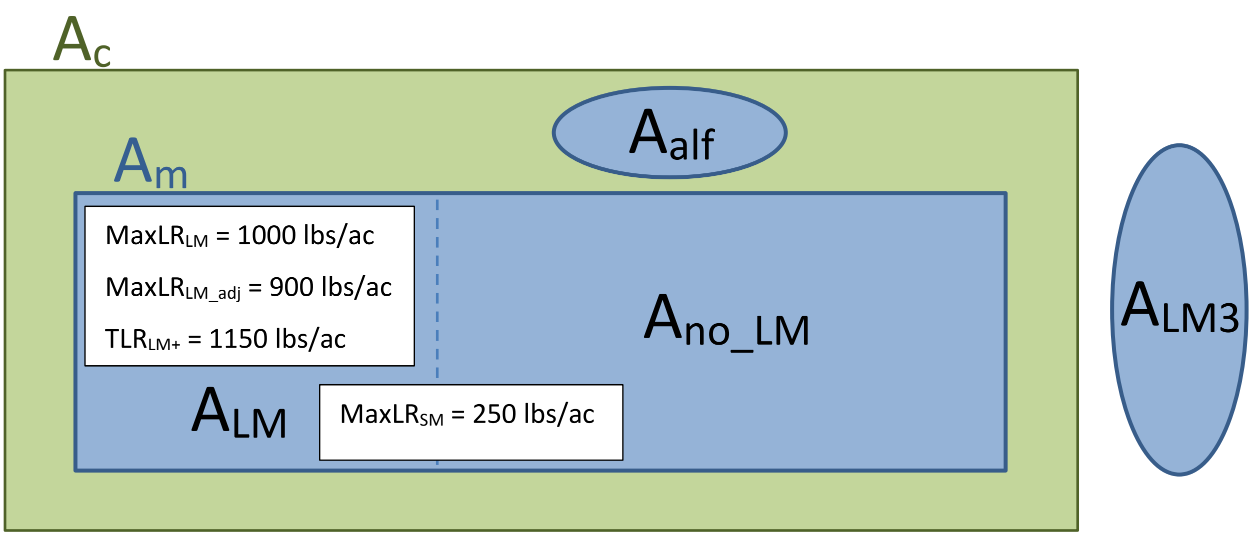


Figure 2: Example of maximum average loading rates

2.4.2 Maximum Average Farm-Scale Manure N AR Ratios and AR Differences

This diagnostic relates maximum average loading rates to harvest removal. This diagnostic provides a more customized estimate of potential risk, but it also introduces additional uncertainty due to the incorporation of estimates of harvest removal. It differentiates LM and SM without effect on MNAA.

For the computation of maximum average farm-scale manure N AR ratios and differences, harvest N removals from A_m, A_{LM}, and A_{no_LM} are needed (**Table 9**). Nitrogen management associated with A_{LM3} is not the responsibility of the dairy farmer and is, therefore, not further considered herein.

Table 9: Definitions for N harvest removal rates from manured acreages [lbs/ac]

Symbol	Comment
$N_R(A_m) = N_R(A_{LM}) + N_R(A_{no\_LM})$	Harvest N removal from manured acreage
$N_R(A_{LM})$	N harvest removal from A_{LM}
$N_R(A_{no\_LM})$	N harvest removal from A_{no_LM}

There are four maximum average farm-scale manure N AR ratios of use with associated differences (**Table 10**):

1. $MaxMAR_{LM}$ is the maximum average manure AR ratio pertaining to LM (i.e., it applies only to A_{LM}). It does not account for potential LM applications to third-party acreage and it does not account for potential SM applications.
    a. The associated farm-scale difference (in lbs) is $Maxdiff_{LM} = (A_{LM})(MaxLR_{LM} - N_R(A_{LM}))$
2. $MaxMAR_{LM\_adj}$ is the maximum average manure AR ratio pertaining to LM (i.e., it applies only to A_{LM}), while accounting for potential LM applications to third-party acreage. It makes no assumption about harvest removal from the third-party acreage and it does not account for potential SM applications.
    a. The associated farm-scale difference (in lbs) is $Maxdiff_{LM\_adj} = (A_{LM})(MaxLR_{LM\_adj} - N_R(A_{LM}))$
3. $MaxMAR_{SM}$ is the maximum average manure AR ratio pertaining to SM (i.e., it applies to A_m). For A_{no_LM}, it represents the total maximum average manure AR ratio. For A_{LM}, it represents a lower bound on the total maximum average manure AR ratio.
    a. The associated farm-scale difference (in lbs) is $Maxdiff_{SM} = (A_m)(MaxLR_{SM} - N_R(A_m))$
4. $MaxMAR_{LM+}$ is the total maximum average manure AR ratio on land that receives LM (incl. possibly SM) because it properly allocates LM only to those lands that have the infrastructure to receive LM and actually receive LM.
    a. The associated farm-scale difference (in lbs) is $Maxdiff_{LM+} = (A_{LM})(MaxLR_{LM+} - N_R(A_{LM}))$

Table 10: Definitions for maximum average farm-scale manure N AR ratios

Symbol	Comment
$MaxMAR_{LM} = MaxLR_{LM} \div N_R(A_{LM})$	Relationship between the dairy's MNAA managed in liquid form and the harvest removal from A_{LM}.
$MaxMAR_{LM\_adj} = MaxLR_{LM\_adj} \div N_R(A_{LM})$	Relationship between the adjusted liquid manure loading rate and the harvest removal from A_{LM}.
$MaxMAR_{SM} = MaxLR_{SM} \div N_R(A_m)$	Relationship between the dairy's MNAA managed in solid form and the harvest removal from the manured acreage (A_m).
$MaxMAR_{LM+} = MaxLR_{LM+} \div N_R(A_{LM})$	Relationship between the dairy's total maximum average manure applications (both LM and SM) and the harvest removal from A_{LM}. This is not the same as MNAA $\div N_R(A_{LM})$ or MNAA $\div N_R(A_m)$.

2.4.3 Whole-Farm Manure N Balance Sheet

> The magnitude of the implicitly reported industry-wide atmospheric N losses within the framework of the current reporting scheme is not consistent with known loss pathways.

Miller, Price et al. (2017) conducted a mass balance analysis of nutrients, including nitrogen, with data submitted to the Regional Board in annual reports by 62 Central Valley dairies over a three-year period (2011-2013). The authors compared two methods to estimate apparent atmospheric N losses. Method A equates to an implicitly reported atmospheric N loss by assuming that any excreted N that was not reported as exported or applied to cropland was lost to the atmosphere. Method B uses N:P ratios in both fresh and aged manure. Method A revealed that half of the annual reports implicitly reported atmospheric N losses greater than 69% of excreted N (mean=58%)[16]. In comparison, Method B yielded a median of 35%.

CVDRMP reviewed 2014-2016 annual reports from those monitored member dairies that use the online Merced County reporting tool. This group of 36 dairies constitutes a subset of dairies that were investigated by Miller, Price et al. (2017). Using Method A (described in the introductory paragraph) yielded a median atmospheric N loss of 60% (mean=58%, i.e., identical to Miller, Price et al. (2017)).

Parsons (2018) aggregated annual N fluxes on dairies from 2007 to 2014 from a total of 9,066 annual reports and her tabulated annual information (Table 19, p. 92) indicates a mean atmospheric N loss of 59% (n=5,727).[17]

[16] The mean was strongly depressed by small outliers, which were considered suspect because they suggest that farmers gained substantial N during storage.
[17] Excluding 2007, 2008, and 2010 due to an obviously compromised data set. The median cannot be computed based on the tabulated data.

CVDRMP expects that the recommended improved whole-farm manure N balance accounting scheme will reveal a need for an industry-wide increase of manure exports. It will become an indispensable educational tool and regulatory metric.

The magnitude of the implicitly reported industry-wide atmospheric N losses within the framework of the current reporting scheme (e.g., Merced County Tool) is not consistent with known loss pathways (Chang, Harter et al. 2006; LSCE 2019b). This puts into question the entirety of the current reporting scheme. Inaccuracies surrounding manure N applications to fields, especially liquid manure applications, are deemed to be the root cause for this condition. CVDRMP recommends to reconcile this condition by relating the manure nitrogen available for application (MNAA) to the manure N demand that is determined in the Irrigation and Nitrogen Management Plan (INMP) for a given reporting period (i.e., a full crop rotation) (**Table 11**). The difference of these two quantities yields clear, differentiated export goals for both LM and SM. Comparison to the actually exported manure N then yields the export balance. This diagnostic clearly communicates as-is conditions and provides an effective way to track industry-wide progress toward export goals. This diagnostic is not affected by a reliance on field-by-field measurements of manure N applications. CVDRMP expects that the improved whole-farm manure N balance sheet will reveal a need for an industry-wide increase of manure exports (or treatment).

Interpretation of Export Balance. Given the uncertainty inherent in the N fluxes on a dairy, it is not expected that individual dairies' export balances will be zero. Rather, if dairies meet their export goals, the aggregate of dairies' export balances should be described by a statistical distribution such as the Gaussian distribution with an average of zero. The statistical distribution can effectively serve as an industry-wide, quantitative regulatory end point. The third-party coalition can then identify statistical outliers and work with its members toward the zero-average. This is the same analytical approach that is employed by third-party coalitions under the ILRP. This approach also lends itself to the comprehensive investigation of the presently used loss-term for ammonia volatilization. It is expected that improvements to its accuracy and representativeness can be achieved.

Table 11: Whole-farm manure N balance sheet. Values (lbs) are for demonstration purposes, only.

Source	MNAA	INMP Demand	Export Goal	Export Actual	Export Balance
Liquid Manure	420,000	200,000	220,000	0	220,000
Solid Manure	140,000	100,000	40,000	37,000	3,000
Total	560,000	300,000	260,000	37,000	223,000

MNAA=manure nitrogen available for application; INMP=irrigation and nitrogen management plan

2.5 Improved Sampling Protocols

2.5.1 Solid Manure

Current estimates of N in solid manure (SM) lack consistent accuracy and precision across dairy farms. Reasonably accurate estimation of SM-N content is particularly important for the quantification of N exports because this is a critical component of the whole-farm manure-N balance, and it will help refine farm-scale LM/SM bifurcation.

Miller, Heguy et al. (2019) used the methodology developed for forage crop harvest removal (Miller, Fadel et al. 2018) (*Section 2.5.3*) to investigate the accuracy of different solid manure sampling protocols using a Dutch style augur. The authors investigated homogeneous, single-source manure piles and heterogeneous, multi-source piles that were built over extended periods of time. They found that DM and N concentrations can be determined within approximately ±10% of the true value at the 95% confidence interval by compositing 5 (homogeneous piles) or 10 (heterogeneous piles) subsamples, respectively. Minimum bias was observed when 70-80% of the subsamples were obtained from the interior of the pile (i.e., deeper than 40 cm into the pile) and the remaining subsamples from the exterior of the pile (i.e., 0-40 cm depth). To obtain this accuracy for the estimation of exported SM-N or to quantify SM-N field applications, all loads need to be weighed.

CVDRMP believes that it is a reasonable goal for dairy farmers to strive for a SM sampling protocol that attains a ±10% precision around the true DM and N yield. Therefore, the recommended sampling protocol consists of:

- For homogeneous piles: Obtaining and compositing 5 subsamples into one sample that is submitted to a laboratory. 4 of the subsamples are to be retrieved from interior of the pile (i.e., deeper than 40 cm into the pile) and the remaining subsample is to be retrieved from the exterior of the pile (i.e., 0-40 cm depth).
- For heterogeneous piles: Obtaining and compositing 10 subsamples into one sample that is submitted to a laboratory. 7 to 8 of the subsamples are to be retrieved from interior of the pile (i.e., deeper than 40 cm into the pile) and the remaining samples are to be retrieved from the exterior of the pile (i.e., 0-40 cm depth).

The DM and NPK contents are determined in the laboratory from the submitted composite sample.

2.5.2 Liquid Manure

Current field applications of liquid manure lack consistent accuracy and precision across dairies. Therefore, it is recommended that dairies that apply liquid wastewater/process water must directly (i.e., before any dilution with other water sources) meter all flow from a wastewater source to a land application area (or treatment or export). We recommend that each flowmeter be maintained in working order for a minimum of 11 months during any 12-month period. Mechanical flow meters such as propeller meters, paddle wheel, or turbine meters are not recommended. Flow meters should be electronic flow meters designed for wastewater service such as magnetic flow meters or acoustic Doppler flow meters. Flow meters should have local indication of flowrate and totalized flow. The size of the flow meters selected should conform to the recommended range of flowrates by the meter manufacturer. Flow totalizer should be non-resettable. Flow meters should provide minimum accuracy of +/- 2% and repeatability of +/- 2%.

Implementation of the above will yield accurate volumetric measurements of the LM removed from the lagoon system over the course of a reporting period. It will also have a strong educational value by providing the farmer with reliable information on the injection rate of LM into the irrigation water stream.

The uncertainty surrounding individual manure-N applications will remain very high and this uncertainty cannot be reasonably addressed by the intensification of sampling efforts for LM. Reasonably accurate quantification of the nitrogen content of individual LM applications requires research-level efforts with a high degree of customization, and this is not a viable option for implementation on dairies.[18] Importantly, the estimate of total nitrogen content in the lagoon will be significantly improved (*Section 2.3*). This improved knowledge will help guide individual farmers as they determine how to apply nitrogen to land over the course of a growing season. We recommend farmers employ devices and field measurements at their discretion (e.g., ion-selective electrodes for the measurement of ammoniacal-N). The success with which this task is mastered by the farmer will be reflected in the nitrogen use efficiencies realized on the farm. This is part of the implementation cycle of INMPs (*Section 2.6*).

2.5.3 Harvest Removal

Current estimates of NPK in the harvest removed from fields lack consistent accuracy and precision across dairies. Miller, Fadel et al. (2018) investigated the accuracy of different sampling protocols. They established the "true" dry matter (DM) and nutrient yields of three fields each of corn, sorghum, and small grain by weighing and sampling every truckload of harvested forage. The authors conducted Monte Carlo style simulations to quantify the accuracy of practical sampling protocols. This was done by repeatedly subsampling the complete dataset for each field to estimate the average truckload weight, average DM, and average nutrient concentrations. Uncertainty was then propagated to DM, N, P, and K yield calculations using standard error equations. Yields measured using current industry protocols diverged from the true yields of some fields by more than ±40%.

The study showed that improving the average load weight measurement protocol is the single most influential way to improve the accuracy of all yield calculations. Forage producers have little control over the consistency of truck fill because, typically, the harvest contractor makes decisions about when to switch between trucks based on many factors including field conditions and equipment limitations. Therefore, farmers need to overcome the measurement uncertainty caused by variability in truck fill by weighing all trucks. For corn silage, this is already practiced at 62% of dairies in the San Joaquin Valley (Heguy, Meyer et al. 2016).

The authors observed a reduction in DM concentration over the course of some harvests. This was accurately captured by making a single composite of load samples collected at equal intervals throughout a harvest campaign. A composite sample that consists of three load samples collected in this manner brought the precision of the average DM estimate for all investigated crops within ±10% of the true value (95% confidence interval). Individual results for small grain, corn, and sorghum were slightly different but not statistically different from the overall results.

[18] The degree of accuracy is actually unknown for LM applications because the true nutrient content is unknown.

CVDRMP believes that dairy farmers can reasonably strive for a harvest sampling protocol that attains a ±10% precision around the true DM yield. Therefore, the recommended sampling protocol consists of:

- Weighing all loads and
- Preparing one composite sample from three load samples to be collected over the duration of the harvest campaign (pertaining to the reporting unit) at equal intervals.

The DM content should be determined in the laboratory. NPK yield should be computed with the aid of readily available, established, crop-specific, representative values to avoid the introduction of additional imprecisions associated with laboratory analyses.

2.6 Irrigation and Nitrogen Management Plan (INMP) and Implementation

Having a well-designed and implemented customized INMP is a fundamental and good farming practice. These plans include provisions for data collection and analysis, with the goal of identifying actions to improve performance in the following year's plan. The process to annually evaluate the effectiveness of the plan should be described; this should focus on basic indicators such as the N applied versus removed. Basic topics to be covered in an INMP include:

- Identify actions to improve performance based on the analysis of data collected as part of the previous year's or cropping cycle's plan, as appropriate
- Crops and cropped acreages
- Yield goals
- Estimates of required N
- Estimates of N harvest removal
- N application schedule (mode of application, material, rate)
- Irrigation systems
- Irrigation water sources and estimates of N content
- Irrigation schedule (based on estimates of expected ET, rainfall, and infiltration)
- Irrigation system maintenance procedures
- Wellhead protection procedures
- Procedures for maintaining fertigation equipment
- Description of data collection efforts
    - Must be sufficient to compare plan objectives with actual conditions (e.g., yield goal vs. actual yield) and to support in-season modifications to irrigation and N application schedules
    - Must describe sampling procedures
    - Every measurement or observation should help make an on-farm decision

The data collected in a given year or cropping cycle will be used to compare plan objectives with actual conditions or outcomes. This will be used to identify if plan goals need to be adjusted or if other modifications need to be made. The Regional Board should agree on the qualifications of the individuals who will create and evaluate INMPs, and the requirements of these plans. However, INMPs should not be subject to Regional Board approval.

2.7 Earthen Lagoons

The decommissioning and replacement of all existing earthen lagoons, including settling basins, with synthetically-lined lagoons would reduce industry-wide N-loading to groundwater by approximately 4% (LSCE 2019b), while being extremely expensive. The low environmental benefit combined with the high cost make this option ineffective and inefficient. Consequently, CVDRMP recommends allowing the continued use of existing earthen lagoons, with the exception of those lagoons that intersect the groundwater table (*Section 2.7.4*).

2.7.1 Do Not Fully Aerate Lagoons

Aeration can lead to increased subsurface nitrogen emissions because the oxidation of animal waste and subsurface soils causes ammoniacal nitrogen to be oxidized to nitrate. Ammoniacal-N is positively charged and sorbs to negatively charged soil particles. As a result, ammoniacal-N has been found to accumulate in shallow soils just beneath the lagoon's floor. In contrast, nitrate is negatively charged and, as a result, it is easily flushed into groundwater, where it is highly mobile.

Therefore, it is recommended to not fully aerate lagoons. This recommendation does not intend to discourage partial aeration (e.g., aeration of the upper waste column for odor control or as part of waste water treatment).

2.7.2 Do Not Use Oxidation Ditches

Oxidation ditches are shallow, long ditches designed to increase the surface area of the waste and minimize waste depth to promote aeration. From a groundwater perspective, the concerns are the same as with aeration of lagoons. Therefore, it is recommended to not use oxidation ditches.

2.7.3 Minimize Drying of Lagoons in Preparation for Sludge Removal

From a groundwater perspective, the concerns are the same as with full aeration of lagoons and the operation of oxidation ditches (*Sections 2.7.1* and *2.7.2*). Specifically, direct exposure of nitrogen-rich soils to the atmosphere and the opportunity for air to penetrate the desaturating soil profile increases the potential for the formation of nitrate.

Therefore, it is recommended that lagoon drying time in preparation for sludge removal is minimized. This recommendation recognizes that lagoons are operated to provide maximum storage capacity prior to the winter months in preparation for precipitation runoff during times when crop nitrogen demand is small. However, this operational need does not necessitate drying. This recommendation recognizes that drying may be needed infrequently for maintenance purposes.

2.7.4 Existing Earthen Liquid Manure Lagoons that Intersect Groundwater

There are areas in the Central Valley of shallow groundwater occurrence where existing earthen lagoons may intersect the groundwater table seasonally or year-round such that there is no perennial unsaturated zone between the floor of the lagoon and the water table. When a lagoon intersects the water table, it is in direct hydraulic contact with groundwater. This means that groundwater can enter the lagoon and lagoon water can enter the aquifer. In the latter case, lagoon water is passed to the aquifer without the benefit of the mitigating characteristics of the unsaturated zone (e.g., sorption, cation exchange, oxidation, denitrification, retention of and ultimate die-off of pathogens). This condition results in increased risk of groundwater pollution and at greater distances from the lagoon itself.

There are difficulties associated with the identification of specific lagoons that intersect groundwater for two reasons:

1. While data exist and have previously been used to identify general areas of shallow groundwater (LSCE 2010), the site-specific depth to groundwater and its seasonal variability are not known unless a groundwater level record from nearby monitoring wells exists.
2. Information in Waste Management Plans (WMP) that dairies submitted to the Regional Board to comply with the Dairy Order is typically not sufficient to establish the lagoon floor elevation in areas of shallow groundwater. In those areas, above ground lagoons have typically been built. This type of lagoon is surrounded by berms built from material that was excavated during the lagoon construction. While the depth of these lagoons was typically reported in the WMPs, it was measured from the top of the berms. However, the height of the berms above the surrounding land surface was not included in the WMPs. Therefore, the elevation of the lagoon floor with respect to the land surface is not known.

A necessary step to addressing earthen lagoons that intersect the water table is an orderly process for identifying the location and number of those lagoons. Also, because there are no explicit Regional Board prohibitions for these types of lagoons outside of the Tulare Lake Basin, clarifying the Regional Board's authority to address these situations outside of the Tulare Lake Basin, and the expected technical standards for preventing such intersection, is another step toward addressing the situation. Finally, a directive for dairies with such lagoons to address the situation appropriately and within a specified timeline would clarify the expected actions and time frame for completing them.

The above actions are outside of CVDRMP's purview, however, CVDRMP can provide input regarding technical solutions, factors to consider when determining appropriate timelines, and education and outreach:

- Technical solutions that are available to address lagoons that intersect groundwater include rebuilding the lagoon above ground to create sufficient separation to the water table, or changing manure management practices to reduce or remove the need to flush housing areas, or a combination of these practices. Partially filling the lagoon with clay soil to create a separation layer could be a solution in some cases, but will reduce lagoon capacity; therefore, doing so should be done in a manner that ensures the Dairy Order's requirements for storage of process water and stormwater can be maintained.
- CVDRMP and/or other dairy industry groups could assist in implementation of required actions by identifying options, strategies and funding through its education and outreach process.
- Timelines for addressing the lagoons that intersect groundwater should consider several factors including the number of dairies that are affected, access to partial financial assistance through programs like the USDA-Natural Resources Conservation Service's Environmental Quality Incentives Program (EQIP) and the California Department of Food and Agriculture's Alternative Manure Management Practices Program (AMMP), and a dairy's individual site-specific situation, including its financial situation, proposed plan to address the situation, and its proximity to off-

property drinking water sources. CVDRMP does not have information about the number of dairies that have lagoons intersecting groundwater and therefore is not in a position to make a useful assessment of how much time is needed to assess the situation.

2.8 New and Reconstructed Lagoons

For new and reconstructed lagoons, the Dairy Order (Section C.5, p. 17) provides a tiered approach that was intended to provide an option (i.e., Tier 1) that would significantly reduce the time required for approval by the Executive Officer:

> "i. 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.
>
> ii. 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."

Since adoption of the Dairy Order, practice has shown that construction of a Tier 2 lagoon, which includes single synthetic membrane designs with leachate collection and removal systems (LCRS), is not a realistic option for most dairymen for two reasons:

1. The Regional Board requires that the design report include a groundwater model that demonstrates that the lagoon is "in compliance with the groundwater limitations". Since the material of synthetic membranes has an inherent hydraulic conductivity, some seepage occurs even through a defect-free membrane.[19] In areas where groundwater nitrate-N concentrations are equal to or greater than 10 mg/L, such a design has not been acceptable to the Regional Board.
2. The Regional Board requires installation of monitoring wells, groundwater quality monitoring, and reporting activities in association with Tier 2 lagoons. This can add significant up-front capital cost to the construction project and adds ongoing cost for monitoring and reporting. It also bears risk for the dairyman because in the case that groundwater nitrate-N concentrations were to increase in the future, the fate of the lagoon becomes uncertain. This is particularly problematic in areas of deep vadose zones, where the cause-and-effect relationship between a potentially minute amount of lagoon seepage/leakage and groundwater quality is uncertain.

As a result, only a very few Tier 2 lagoons have been built since the adoption of the Dairy Order. Furthermore, the construction of Tier 1 lagoons is roughly 40 to 50% more expensive than single-membrane lagoons (Provost 2013; Provost 2019c) and, consequently, few Tier 1 lagoons have been built since adoption of the Dairy Order. Most Tier 1 lagoons have been built as part of digester projects, which have been made possible by substantial government financial support.

[19] Seepage in the context of synthetic membranes is the passing of a liquid or gas through small openings in the intact membrane. Leakage is the passing of a liquid or gas through holes in the membrane (i.e., defects).

CVDRMP recommends that the Regional Board modifies the Dairy Order to consider single-membrane lagoons consistent with Resolution 68-16, BPTC, or otherwise make the construction of single-membrane lagoons more feasible to dairymen. Approaching zero-leakage using a single-membrane design is achievable with current technology, improved construction quality control mechanisms, proper operation and maintenance, and long-term quality control through electrical leak location surveys (Beck ; Beck 2014; Beck 2015; MasonGeoscience 2017; DeNovoPacific 2018). In addition, CVDRMP has been monitoring groundwater chemistry in three dedicated monitoring wells around two lagoons with single synthetic liners (40-mil HDPE, constructed in 2005). The depth to groundwater is less than 20 feet and groundwater chemistry is not indicative of lagoon seepage (LSCE 2019a).

2.9 Corrals

CVDRMP considers the management practices described in the current Dairy Order for the maintenance and operation of earthen corrals BPTC. Specifically, corrals have been found to contribute 2% of N loading to groundwater across the industry (LSCE 2019c), while the replacement of earthen corrals with concrete corrals has been found to be the most expensive N-leaching avoidance strategy (*Section 3.2.6*).

2.10 Long-Term Representative Groundwater Monitoring

CVDRMP's high-frequency groundwater monitoring activities, consisting of monthly depth-to-water readings and quarterly water quality sampling, support the detailed characterization of the seasonal variability of (i) water table elevation fluctuations, (ii) groundwater flow directions and source areas, and (iii) water quality. Key observations from seven years of groundwater monitoring are:

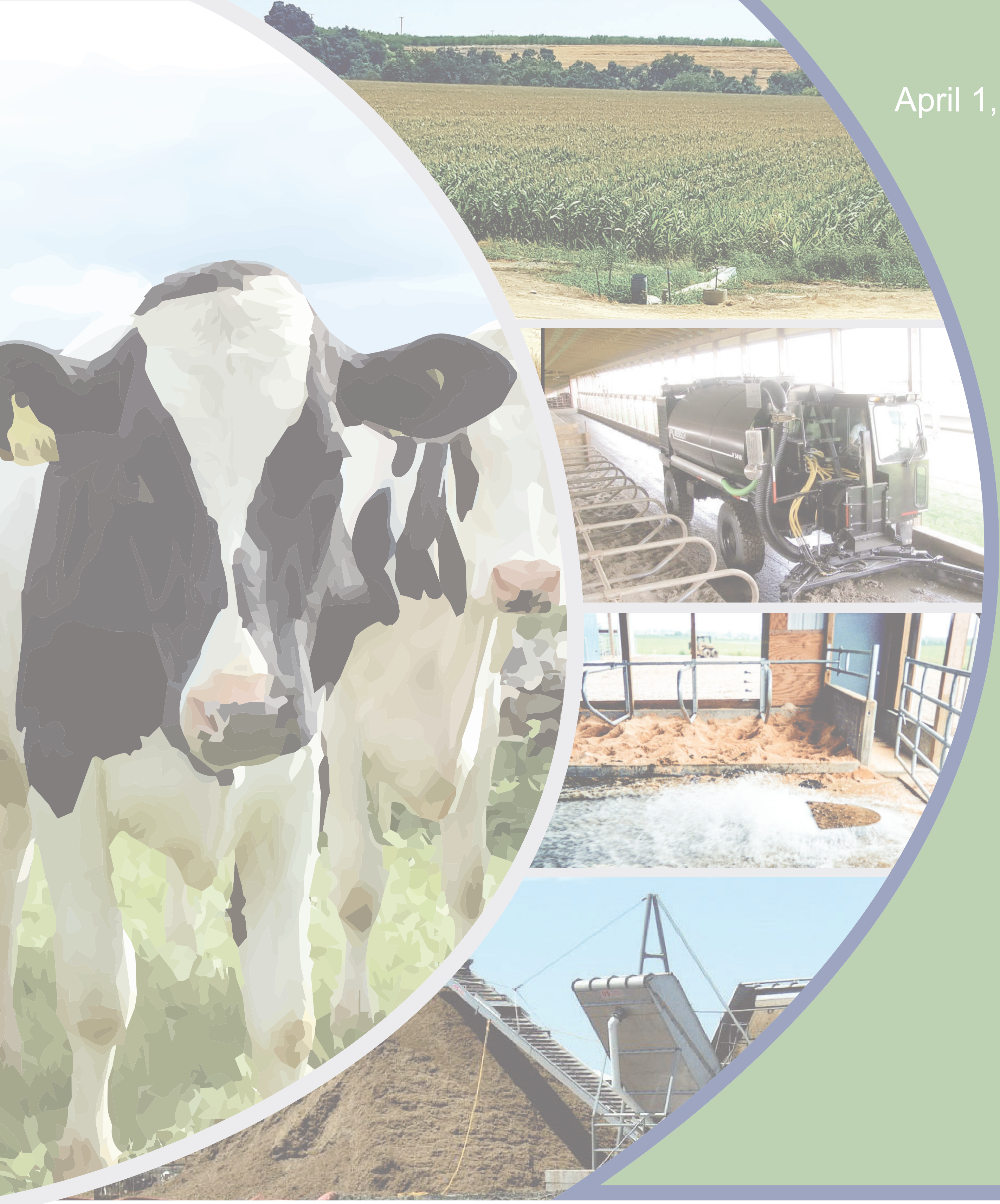
1. Many monitoring wells in areas of relatively shallow groundwater exhibit seasonal water level fluctuations (i.e., mainly in the North and Central Areas). Most monitoring wells in areas where first encountered groundwater is significantly deeper (i.e., mainly in the South Area) exhibit seasonal water level fluctuations that are substantially subdued by longer-term water level trends. The range of seasonal water table elevation fluctuations can be effectively captured with quarterly measurements.
2. On some dairies, particularly in areas of very shallow groundwater, seasonal components to the direction of groundwater flow and associated source area contributions have been documented. The range of seasonal groundwater flow directions and source area contributions can be effectively captured with quarterly measurements.
3. None of CVDRMP's monitoring wells exhibits a consistent seasonal pattern of total nitrogen or TDS concentrations. Therefore, annual measurements are sufficient to evaluate long-term trends, for example, in the form of three-year moving averages.

In addition, CVDRMP's groundwater monitoring activities and special studies confirmed technical limitations of groundwater monitoring as a means to evaluate management practices on dairies that were discussed on theoretical grounds as early as in CVDRMP's first Annual Report (LSCE 2013b). This is exacerbated by the non-unique effect of individual management practices on groundwater quality. CVDRMP has demonstrated that the notion to identify specific management practices that are either protective or not protective of groundwater quality via groundwater monitoring is not realistic. Consequently:

1. Annual reports have generally not attempted to explain groundwater quality based on management practices.
2. Annual reports have not attempted to infer the adequacy of management practices for the protection of groundwater based on groundwater quality.
3. CVDRMP's recommendations for solutions and upgrades aim at improving nitrogen use efficiency on dairies regardless of constituent concentrations in first encountered groundwater, and at increasing manure exports from dairies.

Consistent with the above observations, CVDRMP recommends modifications to its representative groundwater monitoring activities that will eliminate unneeded data redundancy while being congruent with the objective to effectively document long-term groundwater quality trends associated with specific dairy management units. The recommended long-term program is summarized below:

- Quarterly depth-to-water measurements (e.g., Feb, May, Aug, Nov)
- Annual groundwater quality sampling (e.g., May) including field measurements (specific conductance, temperature, pH, dissolved oxygen, and oxygen reduction potential) and laboratory analyses of total dissolved solids and nitrate-N. Wells with a record of TKN contributing more than 10% to total nitrogen will also be sampled for total nitrogen.
- Triennial groundwater quality sampling including the annual field measurements and laboratory analyses plus Na, K, Mg, Ca, Cl, SO_4, PO_4, HCO_3, CO_3, and OH.



April 1, 2019

Section 3

Cost Estimates for Recommended and Non-Recommended Actions

3 COST ESTIMATES FOR RECOMMENDED AND NON-RECOMMENDED ACTIONS

To fully understand and appreciate the recommendations contained in the SRMR and the SRMR's findings with respect to what qualifies as BPTC, it is imperative to understand costs associated with those actions that are being recommended, and even more importantly, to understand costs associated with actions that are not being recommended. In this section, the SRMR provides an array of cost estimates for both the industry generally, as well as costs directly attributed to individual dairy implementation of recommendations. To facilitate comparison of different management practices/ strategies, the cost of a strategy is related to the amount of N that it prevents from leaching into the ground, where applicable. This is expressed as the avoided N subsurface loading (in tons) per $1,000 expended. Alternatively, these figures can be expressed as an expenditure per one ton of avoided N subsurface leaching, and the latter expression was chosen for the Executive Summary. By calculating the cost per ton for avoiding N as associated with certain practices, it is easier to understand which practices are practicable as compared to others.

3.1 Preliminary Cost Estimates for Recommended Actions and Continuing Compliance

Industry costs are ultimately borne by individual dairies. Members of a third-party coalition also pay membership fees (**Table 12**). Future costs to run a third-party coalition include (i) administration, (ii) technical program management (TPM), (iii) continued long-term representative groundwater monitoring according to the recommended reduced sampling frequency, (iv) coalition reporting to the Regional Board on groundwater conditions, on dairy specific key information and industry wide trends, and (v) professional services from the fields of agronomy and agricultural engineering. Additional coalition costs arise from the development of (i) an internet portal with centralized data management system and (ii) payment toward a Salinity Prioritization and Optimization Study and Surveillance and Monitoring Plan. Mean member fees were calculated by assuming a membership of 1,100 dairies. All costs were developed on an annualized basis over 10 years to account for high initial and one-time costs and make cost estimates comparable.

A preliminary cost estimate for education includes the development and implementation of a base education workshop combined with single subject education sessions including in-person workshops/sessions, video productions, and conversion to online formats. The focus of this effort is expected to change as program needs evolve. However, it was assumed that the general effort and need for education (regardless of the curriculum's content) will not diminish during the first decade.

For the installation of lagoon water flow meters, an instrumentation and installation cost of $3,000-$5,000 was assumed per meter. Many dairies are expected to have to install more than one flow meter, while a few may already be equipped with acceptable flow meters. To compute industry costs, 1.5 flow meters per dairy were assumed at $4,000 each. For the low estimate, one flow meter installation per dairy at a cost of $3,000 each was assumed. For the high estimate, two flow meter installations per dairy at a cost of $5,000 each were assumed.

For the Irrigation and Nitrogen Management Plan (INMP), an annually recurring expense between $5,000-$15,000 was estimated. For individual dairies, costs will vary widely based on their size, the complexity of their cropping operation, and the professionals with whom they elect to consult. The costs for the INMP are not limited to its preparation but include labor time for sample collection, agronomic advice throughout the year, and review of the plan with an agronomic professional versus actual activities and outcomes at the end of a reporting period. To compute industry costs, an annual expense of $10,000 was assumed per dairy (low=$5,000 and high=$15,000).

Improved sampling protocols for solid manure and harvest will require more standardized sample retrieval and rigorous weighing. For sample retrieval, a Dutch auger was assumed at a cost of $200-$300 each. To compute industry costs, a mean auger price of $250 was assumed per dairy (low=$200 and high=$300). Some dairies have permanent scales that could be used for weighing manure and harvest, but it is expected that most will need additional capacity. Existing on-site scales may not lend themselves for weighing harvest in all cases, if fields are too distant from the production area. Portable truck axle scale systems appropriate for weighing loads encountered on dairies sell for approximately $4,000-$10,000. To compute industry costs, a mean scale price of $7,000 was assumed per dairy (low=$4,000 and high=$10,000).

Costs for retrofitting lagoons that intersect groundwater do not affect all dairies. For affected dairies, costs may be very high. As a result, per dairy costs will range from $0 to >$1,000,000. Due to the large uncertainty, these costs were not included in the summed costs (i.e., including low and high estimates).

Cost for the Waste Discharge Permit Fund was based on statewide fees collected from dairies in fiscal year 2018-19 and assumes that the State Water Resources Control Board invoiced 91% of such fees to Central Valley dairies. There are no low and high estimates associated with this item on the industry scale. However, on a dairy level, fees range from $0 to $14,069 per year.

The cost estimate for contributing to safe drinking water was based on the pending legislation[20] for the Safe Drinking Water Fund, which intends to collect money from numerous sources, including dairies, to provide safe drinking water where needed. While the legislation is still under consideration and its passage and final details remain undecided, for the purposes of this report, we used a rough approximation of cost at $0.01 per hundredweight[21] of milk produced from the previous iterations of the legislation.[22] Statewide milk production in 2017 was 38.8 billion lbs, 91% of which was produced in the Central Valley.[23] The cost estimate assumes, speculatively, that collected funds would be distributed to Management Zones to carry out drinking water projects, but would not be used to administer Management Zones. Therefore, the estimate includes an additional 5% Management Zone

[20] See https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201920200SB200.

[21] A hundredweight is 100 pounds.

[22] See http://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180SB623. The legislation, which failed to pass, included a $.01355 per hundredweight assessment for dairies; therefore, the 1-cent per hundredweight estimate contained in this report is considered a conservative lower boundary,

[23] https://www.cdfa.ca.gov/dairy/dairystats_annual.html

administration fee. There are no low and high estimates associated with this item on the industry scale. However, on a dairy level, fees range from $230 to $23,000 per year, based on a range of dairy sizes from 100 milking cows to 10,000 milking cows, which captures the great majority of likely Central Valley dairy sizes. Alternatively, we considered a scenario where no legislation passes but Salt and Nitrate Control Program Basin Plan Amendments that were adopted by the Regional Board are also adopted by the State Water Resources Control Board. In this alternative scenario, we speculate that dairies would still contribute to drinking water, but at the local level through Management Zones. Costs of implementing drinking water projects through Management Zones are unknown; however, we assumed that dairies would contribute a roughly similar share in this scenario compared to a scenario in which legislation was adopted.

Table 12: Preliminary cost estimates

Item	Description	Annualized 10-Year Cost			
		Coalition	Industry	Dairy	
Third-party coalition	Administration, TPM, continued groundwater monitoring and reporting, coalition reporting to RB5, other professional services	$792,600	$792,600	$721	a
Internet portal DMS	Per planning level quote	$87,745	$87,745	$80	a
P&O Study and SAMP Contribution	Salinity Prioritization and Optimization Study and Surveillance and Monitoring Plan	$75,000	$75,000	$68	a
Education	Development and implementation of base education workshop and single subject education sessions	na	$220,000	$200	a
Flow meters for lagoon water	$3,000-5,000 per flow meter (incl. installation); assume 1.5 new flow meters per dairy, industry-wide	na	$660,000	$300-$1,000	b c
Irrigation and Nitrogen Management Plan	Individual dairies' costs may fall outside of given range depending number of fields, complexity of work, and other factors	na	$11,000,000	$5,000-$15,000	c
Improved sampling: solid manure	Dutch auger: $200-300 (ea); portable truck axle scale system: see harvest removal	na	$27,500	$20-$30	
Improved harvest sampling protocol	Portable truck axle scale system: $4,000-$10,000	na	$770,000	$400-$1,000	c
Earthen lagoons intersecting groundwater	Not applicable to all dairies. Upper end of range may be much greater than stated. Unknown number of affected dairies	na	na	$0->$1,000,000	d
Waste Discharge Permit Fund	Based on fiscal year 2018/19 allocation for Central Valley dairies	na	$3,774,544	$0-$14,069 $3,260 (mean)	ce
Contribution to drinking water solutions	Based on pending legislation for Safe Drinking Water Fund, Central Valley milk production, and 5% administration cost (Management Zones or otherwise)	na	$3,802,890	$230-$23,000 $3,457 (mean)	a
	SUM	$955,345	$21,210,279	$19,282	
		Low	$15,044,779	$7,018	f
		High	$27,485,779	$55,167	f

a) Dairy-specific cost based on industry cost divided by 1,100
b) Dairy-specific range; low: one flow meter at low cost, high: two units at high cost
c) Mean value of range used for industry total
d) Due to the large range and applicability to only a subgroup of dairies, this component is not included in sums
e) Dairy-specific range based on actual fee structure
f) The low and high industry estimates exhibit narrower ranges than individual dairies due to the moderating effect of the larger group (i.e., low/high dairy-scale estimates would not be realistic on the industry scale.

3.2 Cost Estimates for Nitrogen Subsurface Loading Avoidance Strategies

Costs developed herein for different strategies were related to their associated Avoided N Subsurface Loading. As discussed in (LSCE 2019c) and summarized in this report's companion document, CVDRMP's Year 7 Annual Report (LSCE 2019a), the proportional contribution to N subsurface loading from corrals, lagoons, and manured cropland on dairies was estimated to be 2% (1,830 t/year), 4% (3,071 t/year), and 94% (78,991 t/year). Due to the uneven proportional contributions, a unit improvement on corrals will have much less of an industry-wide effect on avoided N Subsurface Loading than the same unit improvement on cropland. The concept of the Contribution to Improvement (CTI) reconciles this by properly reflecting industry-wide efficacy of a certain strategy as described below.

On the one hand, for corrals and lagoons, strategies are discussed that are assumed to completely stop N leaching from these management units (MU). However, a 100%-reduction on these MUs would reduce the total industry-wide N subsurface loading by only 2% and 4% respectively. On the other hand, N leaching from cropland cannot be stopped completely. Therefore, we computed a goal for an industry-wide nitrogen use efficiency (NUE), to be used as a basis for comparing the potential of various N subsurface loading avoidance strategies. Given an estimated industry-wide N application/removal ratio of 1.7 (Harter, Dzurella et al. 2017), we assumed a future achievable ratio of 1.4. This yields 24,181 t/year of avoided N leaching from cropland and a total assumed achievable N subsurface loading reduction of 29,089 t/year. Therefore, cropland's CTI is 83%, whereas, corrals' and lagoons' CTIs are 6% and 11%, respectively.

3.2.1 Export of Solid Manure

In this section, two strategies were examined, the export of unprocessed solid manure and the export of partially processed (windrow-dried) solid manure.

3.2.1.1 Unprocessed Solid Manure

An informal survey of dairy owners and operators indicated that the price for unprocessed solid manure (i.e., most typically, this is manure that has been deposited and dried in corrals and is also referred to as corral solids) presently fluctuates from $0.00 to $5.00 per yard in 11 different regions in the San Joaquin Valley (**Table 13**). No information was available for the Sacramento Valley. These are freight-on-board (FOB) prices, meaning that the buyer picks up the solid manure at the dairy, while the dairy operator loads the material. Importantly, the prices are a collection of individuals' own recent experiences. They do not represent mean values for the given regions. However, it is noteworthy that low prices ($0.00 to $1.25/yard) dominate in both frequency and geographic distribution. These low prices are encountered from San Joaquin to Tulare counties. Best prices are presently obtained in the area southwest of the City of Fresno. The price information from Tulare County suggests that significant differences can exist within small distances.

Table 13: Current free-on-board prices for unprocessed solid manure (corral solids)

Location (City, County)	Zip Code	$/yard	$/lbs-N
Escalon, San Joaquin	95320	$1.00	$0.14
Modesto, Stanislaus	95358	$1.00	$0.14
Turlock, Stanislaus	95380	$0.00	$0.00
Livingston, Merced	95334	$0.75	$0.11
Chowchilla, Madera	93610	$0.00	$0.00
Fresno, Fresno	93706	$5.00	$0.72
Riverdale, Fresno	93656	$3.75	$0.54
Lemoore, Kings	93245	$4.00	$0.58
Tulare, Tulare	93274	$2.50	$0.36
Porterville, Tulare	93257	$1.00	$0.14
Pixley, Tulare	93256	$1.25	$0.18

Giving away excess[24] unprocessed solid manure away at no charge (i.e., $0.00/yard) may be considered a break-even scenario for the dairy operator because the loading of the material does not incur greater costs than loading it on his own vehicles for on-site cropland application. Technically, there is a small cost savings involved due to not applying the material to his own land (i.e., no on-farm trucking cost) so long as the dairy maintains an adequate source of bedding for cattle housed in freestall barns.

Assuming a solid manure bulk weight[25] of 900 lbs/yard in combination with a water content of 45% and an N-content of 1.5% of dry matter (DM) yields 6.9 lbs-N/yard. Therefore, the range of $0.00 to $5.00 per yard of solid manure yields a revenue from $0.00 to $0.72/lbs-N (i.e., per pound of exported N).

Based on the review of annual reports from a mean of 1,199 dairies (2011-2014) submitted to the Regional Board, dairies exported approximately 80,000,000 lbs-N/year during this four-year period with little annual variability.[26] Using the following assumptions, avoided N subsurface loading can be estimated:

- The exported 80,000,000 lbs-N/year constitutes excess N. If applied on the dairy, it would constitute over-application and 100% of it would be subject to subsurface loading.

[24] To the degree corral solids are used to supply cattle bedding for freestall barns, they are not considered "excess." Exporting solids that are needed for cattle bedding would create a deficit of bedding materials and therefore creates a cost to provide alternative bedding materials, such as sand, almond shells, waterbeds, etc.

[25] The bulk weight of 900 lbs/yard was derived from information obtained from a manure hauler in Tulare County and may underestimate a Central Valley wide mean bulk weight.

[26] This includes solid manure and liquid manure exports (Parsons 2018). However, for purposes of this cost estimate, it was assumed to all be in the solid form.

- The exported N is agronomically applied off-site with an application-removal ratio of 1.4. This yields an N subsurface loading of approximately 23,000,000 lbs/year or Avoided N Subsurface Loading of 57,000,000 lbs-N/year.

At $0.14/lbs-N, an Avoided N Subsurface Loading of 57,000,000 lbs-N/year equates to a revenue of $280 per ton of Avoided N Subsurface Loading. This revenue implicitly assumes that exported manure-N is not subject to leaching to groundwater (i.e., comparable to Case 1, *Section 3.2.2*). This strategy is not adjusted for its CTI because it is achieved already and not part of an assumed future achievable N subsurface loading reduction.

3.2.1.1.1 Limitations

For some dairies, SM export may be sufficient to achieve their manure-N export goals. However, the present demand for SM is relatively small, as reflected by its low price. Consequently, increasing the hauling distance is expected to quickly become an obstacle to exporting SM. This could to become a major difficulty in areas of high dairy production. Also, the ability to export solid manure is currently limited on many dairies by the need to use this manure as a source of cattle bedding. Only the solid manure that exceeds the dairy's bedding needs may be exported, unless the dairy is able to secure alternate sources of cattle bedding. Importing other materials to serve as cattle bedding involves additional costs that are not estimated here. Last, it is expected that many, if not most dairies will realize that a large proportion of their excess manure N is stored in liquid manure (LM), and therefore, that SM exports will not suffice to achieve export goals.

Limitations of the cost estimate:

1. Limited and anecdotal character of price information in combination with uncertain actual representative price structure and export volume across the industry
2. Uncertain potential for the industry's ability to expand SM exports and its effects on price
3. Bulk weight of manure, DM content, and N content vary widely

3.2.1.2 Export of Improved Solid Manure

Improved SM is not comparable to certifiable manure compost. Here, it is defined as a manure product that received some treatment or processing, such as windrow drying with turning, which may resemble composting activities but does not include other key components of true composting, such as temperature monitoring, addition of carbon sources, and addition of water during the initial phases to enhance biological activity. The effort that dairy operators expend into improving SM varies widely and is poorly defined, but the effort is generally intended to produce higher-quality cattle bedding. Besides spreading and harrowing for drying, arrangement of windrows, and manure turning, activity may include the addition of LM via tanker truck (e.g., vacuumed flush lane excretions or lagoon water), but it is not comparable to rigorous moisture and temperature control required for production of certified compost.

Based on information from one dairy in Kings County that sells improved SM for $15.00-$18.00/ton (i.e., $6.75-$8.10/yard at a bulk weight of 900 lbs/yard), a value-added can be estimated by comparing to the SM price of $4.00/yard (see **Table 13**). The effort to produce the improved SM was quantified as one-time turning (5 hours of labor at $50/hour for 440 yards).[27] This adds an incremental cost of

[27] The hourly labor rate includes equipment maintenance and other overhead but not the cost of the equipment itself

$0.57/yard over simple SM. Subtraction of this expense from the sale price yields a revenue of $6.18-$7.53/yard, i.e., an incremental value-added of $2.18-$3.53/yard. Assuming the same N content on a DM basis as for corral solids (i.e., 1.5%)[28] yields the same N content per yard of improved SM (i.e., 6.9 lbs-N/yard) and a revenue of $0.89-$1.09/lbs-N compared to $0.58/lbs-N for corral solids in that area (i.e., 53-88% value added).

Therefore, for corral solids ($0.58/lbs-N), an Avoided N Subsurface Loading of 57,000,000 lbs-N/year equates to a revenue of $1,160 per ton of Avoided N Subsurface Loading. For improved SM ($0.89-$1.09/lbs-N), an Avoided N Subsurface Loading of 57,000,000 lbs-N/y equates to a revenue of $1,780-$2,180 per ton of Avoided N Subsurface Loading. These revenue estimates implicitly assume that exported manure-N is not subject to leaching to groundwater (i.e., comparable to Case 1, *Section 3.2.2*). This strategy is not adjusted for its CTI because it is achieved already and not part of an assumed future achievable N subsurface loading reduction.

3.2.1.2.1 Limitations

The limitations for exporting improved SM are identical to those encountered when considering the export of unimproved SM. Some of the limitations of the cost estimate are similar but there are additional limitations:

1. Poorly understood improved SM properties and expected wide range of effort to produce improved SM
2. Cost information available for only one dairy
3. It is unknown how this example translates to other regions
4. Uncertain potential for the industry's ability to expand improved SM exports, and the effects of such expansion on supply-and-demand dynamics and price.[29] Additional compost supply is expected to be created over the next several years, potentially further affecting market dynamics, through implementation of laws like Assembly Bill 1045 (2015), which requires CalRecycle and other state agencies to develop and implement policies that keep organic waste out of landfills, including promoting composting and alternative uses for the material.
5. Loss of income from other potential land use (e.g., agricultural production on land that would need to be used for windrow drying of manure) was not taken into account.

3.2.2 Diversion of Nitrogen from Liquid to Solid Storage and Export

This strategy is beginning to be employed by dairymen who recognize excess-N in LM, or who are attempting to reduce anaerobic storage of manure to reduce methane emissions to comply with requirements of California laws,[30] but find the export of LM cost prohibitive or otherwise infeasible.

The estimate was made under consideration of a typical freestall dairy with 2,500 milk cows and support stock with 70% of its manure-N in liquid storage and 30% in solid storage (**Table 14**). This

[28] 50% volume reduction and 50% atmospheric N losses.
[29] The California Dairy Research Foundation has commissioned a comprehensive market analysis assessing the opportunities for California dairy manure and manure products. The final report is to provide actionable recommendations to address current economic, environmental, and regulatory barriers impeding wider adoption and market growth. The report is expected to rank, compare, and quantify the various market opportunities and include the opportunity cost and opportunity loss for the most economical and sustainable market opportunities.
[30] See Senate Bill 1383 (2016), https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB1383

strategy diverts 29% of LM-N to SM by vacuuming all flush lanes two days per week. The vacuumed manure is then added to SM in windrows to generate an improved SM product as discussed in *Section 3.2.1.2*. A sale price of $6.75/yard (freight-on-board) of finished product was chosen, which represents the lower end of the range used for Kings County (see *Section 3.2.1.2*). The volume of the finished product was based on the same parameters as used in the earlier example (i.e., 900 lbs/yard in combination with a water content of 45% and an N-content of 1.5% of dry matter (DM)). Based on these assumptions, Avoided N Subsurface Loading was computed for two cases.

- Case 1 constitutes an idealized case in which the fate of exported SM-N does not include off-site leaching to groundwater.
- Case 2 constitutes a more realistic scenario in which the exported material would be crop applied with an AR ratio of 1.4.

The production costs in this example include the price of equipment (i.e., vacuum truck, tractor and implement for manure turning) and labor. Based on conversations with dairymen who operate vacuum trucks and engage in windrow drying, it was determined that for the size of this dairy, this operational modification would require the equivalent of one full-time position to perform vacuuming, on-site hauling, turning and windrow maintenance activities, loading, and any other related activities. Equipment maintenance and fuel was not accounted for in this cost estimate because it was deemed minor with respect to the complete depreciation over a 7-year period. This was the upper end of a quoted 5 to 7-year operational life for manure equipment. The operational life of equipment that is in constant contact with manure is relatively short due to severe corrosion, which also results in a near-zero salvage value.

The above parameters result in an annualized (10 years) production cost of $110,394 and a net revenue of $20,995/year. For Case 1, this translates to a revenue of $313 per ton of avoided N subsurface loading ($260 adjusted for CTI). For Case 2, this translates to a revenue of only $223 per ton of avoided N subsurface loading ($186 adjusted for CTI) because only 71% of the exported manure-N will not contribute to subsurface loading.

Table 14: Estimates of cost and associated avoided nitrogen (N) subsurface loading, diversion of N from liquid to solid storage and export

Dairy characteristics (support stock not listed but included in total N and N partitioning)		
Lactating cows	2,050	head
Dry cows	450	head
LM-N (70%) after volatilization	470,082	lbs
SM-N (30%) after volatilization	201,464	lbs
Vacuum freestalls twice per week to divert 29% of N from liquid manure (LM) to solid manure (SM)		
Diverted N	134,309	lbs
Diverted N	67	tons
Volume of finished product (a)	19,465	yards
N-content of finished product	6.9	lbs-N/yard
Avoided N Subsurface Loading		
Case 1: No consideration of fate (b)	67	tons
Case 2: Followed by agronomic application (c)	48	tons
Cost to make finished product and avoided N subsurface loading (d)		
Vacuum truck (new sale price)	$428,571	
Tractor and implement (new sale price)	$238,571	
Annual labor ($21/hr @ full time employment)	$43,680	
Annualized costs and revenue over 10 years		
Production cost per year	$110,394	
Production cost	5.67	$/yard
Freight-on-board price for improved solid manure	6.75	$/yard
Net revenue per yard	1.08	$/yard
Net revenue per lbs of N exported	0.16	$/lbs-N
Net revenue per year	$20,995	
Revenue per ton of Avoided N Subsurface Loading (annualized over 10 years)		**Adjusted for CTI (e)**
Case 1: No consideration of fate	$313	$260
Case 2: Followed by agronomic application	$223	$186

a) Improved solid manure with a bulk weight of 900 lbs/yard @ 45% water content and an N-content of 1.5% of dry matter (DM).

b) Case 1 constitutes an idealized case in which environmental losses associated with the fate of avoided N leaching from exported improved SM exclude leaching into groundwater.

c) Case 2 assumes an AR ratio of 1.4.

d) Equipment cost assumes 7 years of operational life followed by 100% replacement cost, which was prorated over 3 years to facilitate 10-year annualization.

e) CTI=contribution to improvement

3.2.3 Liquid Manure Conveyance Infrastructure Expansion

Some dairies may not have the infrastructure in place to distribute LM to all of their cropland. If excess-N exists in liquid storage, extending infrastructure may provide a viable option to make better use of manure-N while reducing synthetic fertilizer inputs. Cost estimates were prepared for three options, including extension of pipeline for blended and pumped lagoon/irrigation water and for pumped lagoon water (via a smaller diameter pipeline) to be mixed at with irrigation water near the irrigated field (Provost (2019b), provided in the **Appendix**).

The estimate was made under consideration of a dairy that presently manures 500 ac and achieves an AR ratio of 1.7 (**Table 15**). An additional 80 ac are not manured and receive only synthetic fertilizer N. Due to the more precise nature of synthetic fertilizer applications, an AR ratio of 1.4 is achieved on the 80 ac field. The resulting subsurface N loading rates are 183,853 lbs/year (associated with 500 ac) and 16,809 lbs/year (associated with 80 ac).

Extension of infrastructure results in avoidance of cost for synthetic fertilizer products ($24,394), better distribution of manure-N, and an improved mean AR ratio. The AR ratio on the 80 ac field actually decreases. This is consistent with the composition of LM including both plant available inorganic N and organic N, which is not plant available and makes nitrogen management more challenging. This scenario yields 58,833 lbs of avoided N subsurface loading on an annual basis.

For Option B (annualized over 10 years), adjusted for CTI, this results in 2.2 tons of avoided N subsurface loading per $1,000 expended (i.e., $454 per ton of avoided N subsurface loading. For Option C (annualized over 10 years) with a reduced pipeline length and adjusted for CTI, this results in 15 tons of avoided N subsurface loading per $1,000 expended (i.e., $68 per ton of avoided N subsurface loading).

Importantly, these examples indicate that the savings in synthetic fertilizer purchases may pay for the capital costs of the infrastructure improvements within 4-6 years.

Table 15: Estimates of cost for liquid manure (LM) infrastructure expansion (a)

Description	Distance (miles)	Cost
Option A. Extend pipeline for blended lagoon/irrigation water (gravity flow) (b)	1	$110,300
Option B. Extend pipeline for blended lagoon/irrigation water (pumped) (c)	1	$135,300
Option C. Extend pipeline for lagoon water (pumped) (d)	1	$81,900

Example

1. As-is Conditions, Annual Figures		
Acreage where liquid manure is applied	500	ac
Application rate (LM, only) (e)	893	lbs-N/ac
Harvest removal (e)	525	lbs-N/ac
Subsurface loading (e)	368	lbs-N/ac
Application-Removal Ratio (e)	1.70	
Total N subsurface loading	183,853	lbs
Acreage not reached by LM infrastructure	80	ac
Application rate (anhydrous ammonia [AA] @ $680/ton, 82%-N)	735	lbs-N/ac
Harvest removal	525	lbs-N/ac
Subsurface loading	210	lbs-N/ac
Application-Removal Ratio	1.40	
Total N subsurface loading	16,809	lbs
2. New Condition: LM Infrastructure Extended to 80 ac Field, Avoided N Subsurface Loading and Cost Savings, Annual Figures		
New application rate (LM, only) on 580 acres (f)	770	lbs-N/ac
Harvest removal	525	lbs-N/ac
Subsurface loading	245	lbs-N/ac
Application-Removal Ratio	1.47	
Total N subsurface loading	141,829	lbs
Avoided N Subsurface Loading	58,833	lbs
Cost savings (avoidance of AA purchase)	$24,394	

3. Resulting Avoided N Subsurface Loading (tons) per $1,000 expended (including cost savings from synthetic fertilizer)		Adjusted for CTI (h)
Option B: Year 1	0.27	0.22
Option B: 10 Years	2.7	2.2
Option C, half-mile extension: Year 1 (g)	1.8	1.5
Option C, half-mile extension: 10 Years (g)	18	15

a) Provost and Pritchard (2019b)
b) Assume 15-inch buried PVC irrigation pipe, lagoon water mixed with irrigation water near lagoon
c) Same as Option 'A' but add 40hp booster pump station
d) Same as Option 'B' but 8-inch buried PVC irrigation pipe for lagoon water, only. Lagoon water mixed with irrigation water at the field
e) Values derived from Central Valley wide analysis by Harter, Dzurella et al. (2017)
f) The same volume of LM is now applied to 580 ac instead of only 500 ac. The yield stays the same. The resulting AR of 1.47 is an improvement over 1.70 but falls short of the higher nitrogen use efficiency that was achieved with synthetic fertilizer on the 80 ac field
g) LM conveyance infrastructure need not be extended from the lagoon to distant fields. Instead, existing infrastructure is simply extended
h) CTI=contribution to improvement

3.2.4 Liquid Manure Hauling

Some dairies may not have the infrastructure in place to distribute LM to all of their cropland. If such cropland is noncontiguous to the dairy, extending conveyance infrastructure may not be feasible due to the difficulty to obtain construction permits. In this case, hauling of LM via tanker truck or trailer may provide an alternative. Cost estimates were prepared for the application of one acre-inch of lagoon water for three hauling distances: 1, 5, and 10-20 miles (Provost (2019b), provided in the **Appendix**). For this strategy, the example as-is conditions from *Section 3.2.3* (see **Table 15**) were used again.

Hauling LM has a major disadvantage over extending conveyance infrastructure. Tankers can apply LM only between harvest and planting of the next crop; it cannot be applied during the growing season, and this greatly diminishes the amount of LM that can reasonably be applied. This is reflected in the "new condition" described in **Table 16**, where two pre-plant tanker LM applications (each 50-lbs/ac) replace a total of only 60 lbs-N of anhydrous ammonia over the course of two crops. For each application, a lagoon water N concentration of 443 mg/L was assumed, which is near the median concentration of 179 unique lagoon water samples retrieved between 1999 to 2000 (Campbell-Mathews, Frate et al. 2001), and yields 100 lbs-N in an acre-inch of water. This was split over two half-inch pre-plant applications.

Harvest N removal remains steady and the resulting AR ratio on the 80 ac field increases from 1.40 to 1.48, which reflects the diminished nitrogen use efficiency associated with manure-N. At the same time, the improved distribution of LM over the entirety of the dairy's cropland results in an improved AR ratio on the 500 ac (from 1.70 to 1.67).

This scenario yields 4,800 lbs of avoided N subsurface loading on an annual basis and a moderate avoidance of cost for synthetic fertilizer products ($1,990).

Annualized over 10 years and adjusted for CTI:

- Option A results in 0.32 tons of avoided N subsurface loading per $1,000 expended (i.e., $3,092 per ton of avoided N subsurface loading.
- Option B results in 0.18 tons of per $1,000 expended (i.e., $5,547 per ton of avoided N subsurface loading.
- Option C results in 0.08 tons of avoided N subsurface loading per $1,000 expended (i.e., $12,645 per ton of avoided N subsurface loading.

The Avoided N Subsurface Loading per $1,000 expended does not improve with time because the expense for LM hauling recurs every year as opposed to a one-time infrastructure expense (see *Section 3.2.3*).

Table 16: Estimates of cost for liquid manure (LM) hauling (a)

Description	Distance (miles)	Cost
Option A. Transport lagoon water via tanker trailer (1 acre-inch to 40 ac field) (b)	1	$8,150
Option B. Transport lagoon water via tanker trailer (1 acre-inch to 40 ac field) (b)	5	$13,040
Option C. Transport lagoon water via tanker trailer (1 acre-inch to 40 ac field) (b)	10-20	$27,180

Example

1. As-is Conditions, Annual Figures		
Same as in Table 15		
2. New Condition: Transport Lagoon Water via Tanker Trailer to 80 ac Field, Avoided N Subsurface Loading and Cost Savings, Annual Figures		
Two 50-lbs/ac LM applications (pre-plant) replace 60 lbs/ac in-season AA apps. (c)	775	lbs-N/ac
Harvest removal	525	lbs-N/ac
Subsurface loading	250	lbs-N/ac
Application-Removal Ratio	1.48	
Total N subsurface loading	20,009	lbs
Reduced application rate on 500 acres	877	lbs-N/ac
Harvest removal	525	lbs-N/ac
Subsurface loading	352	lbs-N/ac
Application-Removal Ratio	1.67	
Total N subsurface loading	175,853	lbs
Avoided N Subsurface Loading	4,800	lbs
Cost savings (avoidance of AA purchase)	$1,990	

3. Resulting Avoided N Subsurface Loading (tons) per $1,000 expended (including cost savings from synthetic fertilizer)		Adjusted for CTI (e)
Option A: Year 1	0.39	0.32
Option A: 10 Years (d)	0.39	0.32
Option B: Year 1	0.22	0.18
Option B: 10 Years (d)	0.22	0.18
Option C: Year 1	0.10	0.08
Option C: 10 Years (d)	0.10	0.08

a) Provost and Pritchard (2019b)
b) This method of application is likely too slow under most circumstances to mix lagoon water with irrigation water in real-time. Therefore, lagoon water could only be spread on the field similar to solid manure between crops
c) Pre-plant LM applications may be subject to high leakage losses during pre-irrigation, and early irrigations or rain due to undeveloped root system. Assume two half-inch applications are equal in price to one 1-inch application
d) The Avoided N Subsurface Loading per $1,000 expended does not improve with time because the expense for LM hauling recurs every year (as opposed to a one-time infrastructure expense)
e) CTI=contribution to improvement

3.2.5 Replacement of Earthen Lagoons

Provost (2019c) (**Appendix**) estimated Central Valley wide costs for the replacement of earthen lagoons with synthetically lined lagoons based on data published by Harter, Dzurella et al. (2017), which includes detailed by-county herd information and the area occupied by lagoons, which was quantified with a comprehensive digitizing effort. Harter, Dzurella et al. (2017) largely relied on data from 2005 to 2009. Based on this information, a representative number of cows per acre of lagoon were calculated for three regions, the Sacramento Valley, San Joaquin Valley, and Tulare Lake Basin. This approach addresses general regional dairy facility differences such as the predominance of large open-lot dairies with below-ground lagoons (i.e., constructed without berms) in the Tulare Lake Basin versus dairies in the Sacramento Valley with more roofed corral areas to deal with higher annual rainfall. For their cost estimation, Provost (2019c) included:

- Location engineering (volume verification, site selection, survey, geotechnical report, lagoon design report, lagoon construction drawings, and Continuous Quality Assurance (CQA) specifications),
- Excavation with geotechnical oversight and testing, and
- Lining installation (liner materials purchased, tested & installed, leachate collection and recovery (LCRS) and geonet for double liner, anchor trench, inlet and outlet pipe boots, level gauge, CQA oversight, and final CQA report).

Based on the above, the authors estimated a total Central Valley wide replacement cost for Tier 1 (double synthetic liner) and Tier 2 (single synthetic liner) at $1.54 and $1.05 billion, respectively. These cost estimates are considered a lower bound on the total cost associated with this strategy because several associated components were not included. Most importantly, the replacement of an earthen lagoon system (often including one or more settling basins) with a synthetically lined lagoon will almost certainly require enhanced mechanical solids separation via screens. In addition, sand separation may become necessary. These two items were not costed but have the potential to double the price for individual dairies. There are other related costs that were not included relating to hook-ups to the existing piping system, agency permitting, and others. Importantly, the replacement costs were based on the assumption that new lagoons would be constructed outside the footprint of the earthen lagoon so that the dairy could continue to operate during construction. This may not be possible in space-limited conditions.

For purposes of the cost estimates herein, PPCG's (2019c) estimates were down-adjusted by 28.3% to reflect the industry contraction in the Central Valley that occurred between 2007-2009 (mean of 1,513 dairies) to 2017 (1,085 dairies)[31] to yield $1.10 billion (Tier 1) and $752 million (Tier 2) (**Table 17**). Three cases were analyzed to evaluate the avoided N subsurface loading:

- Case 1 constitutes an idealized case in which the fate of the avoided N leaching from the lagoons does not include leaching to groundwater.
- Case 2 constitutes a more realistic scenario in which the avoided N leaching would be crop applied with an AR ratio of 1.4.
- Case 3 constitutes a "worst" case in which the fate of the avoided N leaching is on-site overapplication (no crop uptake), which results in no environmental benefit.

[31] https://www.cdfa.ca.gov/dairy/dairystats_annual.html

Table 17: Estimates of cost and associated nitrogen subsurface loading, replacement of earthen lagoons

Current N Subsurface Loading by Management Unit (a)	tons/year	Proportion		
Cropland	78,991	94%		
Lagoons	3,071	4%		
Corrals	1,830	2%		
Assumed Achievable N Subsurface Loading (b)	**tons/year**	**Proportion**	**Contribution to Improvement (CTI)**	
Cropland	54,810	100%	83%	
Lagoons	0	0%	11%	
Corrals	0	0%	6%	
Total Subsurface N Loading Reduction	29,082			
Avoided N Subsurface Loading from Lagoons	**tons/year**			
Case 1: No consideration of fate (c)	3,071			
Case 2: Followed by agronomic application (d)	2,194			
Case 3: Followed by over-application (e)	0			
Estimated Cost for the Replacement of Existing Earthen Lagoons with Synthetically Lined Lagoons (f)				
A. Single Synthetic Membrane	$751,935,413			
B. Double Synthetic Membrane	$1,103,537,098			

Avoided N Subsurface Loading (tons) per $1,000 expended	Year 1	10 Years	Adjusted for CTI Year 1	Adjusted for CTI 10 Years
A. Single Synthetic Membrane				
Case 1: No consideration of fate	0.0041	0.041	0.00043	0.0043
Case 2: Followed by agronomic application	0.0029	0.029	0.00031	0.0031
Case 3: Followed by over-application	0	0	0	0
B. Double Synthetic Membrane				
Case 1: No consideration of fate	0.0028	0.028	0.00029	0.0029
Case 2: Followed by agronomic application	0.0020	0.020	0.00021	0.0021
Case 3: Followed by over-application	0	0	0	0

a) Tons are short tons (i.e., 2,000 lbs)
b) Cropland estimate assumes application-removal ratio of 1.4; zero-estimates for lagoons and corrals intend to convey near-zero leakage, not true zero-leakage
c) Case 1 constitutes an idealized case in which environmental losses associated with the fate of avoided N leaching from lagoons exclude leaching into groundwater
d) Case 2 assumes an AR ratio of 1.4
e) Case 3 assumes no additional crop uptake (i.e., over-application)
f) Cost developed by Provost (2019c) and adjusted herein for industry contraction between 2007-09 and 2017. Cost estimates are considered a lower bound on the total cost for this strategy because major components (e.g., improved fiber and sand separation) were not included. Costs based on lagoon construction in a new location to allow uninterrupted dairy operation; may not be possible if space-limited, see text for more detail.

Annualized over 10 years and adjusted for CTI, the Avoided N Subsurface Loading per $1,000 expended (industry-wide) with single synthetic membrane lagoons (Tier 2) is as follows:

- Case 1: 0.0043 (i.e., $231,869 per ton of avoided N subsurface loading)
- Case 2: 0.0031 (i.e., $324,617 per ton of avoided N subsurface loading)

For Tier 1 (double synthetic membrane lagoons):

- Case 1: 0.0029 (i.e., $340,290 per ton of avoided N subsurface loading)
- Case 2: 0.0021 (i.e., $476,407 per ton of avoided N subsurface loading)

3.2.6 Replacement of Open Earthen Corrals

Provost (2019a)(**Appendix**) estimated Central Valley wide costs for the replacement of open, earthen corrals with alternative housing under consideration of data published by Harter, Dzurella et al. (2017), which includes detailed by-county herd information. Cost estimates were developed based on each county's herd profile assuming a full heifer replacement program after returning from a calf ranch at approximately 2-3 months of age. Harter, Dzurella et al. (2017) largely relied on data from 2005 to 2009.

Provost (2019a) provide cost estimates for five different housing strategies, the most important of which is the replacement of existing earthen corrals with concrete corrals. This strategy makes use of existing roofed animal housing and includes costs for site preparation and engineering, material and construction costs, construction oversight, and CQA specifications. It does not include ancillary costs related to increased stormwater runoff.

For purposes of the cost estimates herein, PPCG's (2019a) estimates were down-adjusted by 28.3% to reflect the industry contraction in the Central Valley that occurred between 2007-2009 (mean of 1,513 dairies) to 2017 (1,085 dairies).[32] This yielded a range from $3.68 billion (conversion to all-freestall dairies) to $5.75 billion (conversion to compost barns), excluding the hypothetical Alternative 5 (**Table 18**). Conversion to open concrete corrals across the Central Valley dairy industry was estimated at $5.27 billion.

Annualized over 10 years and adjusted for CTI, the Avoided N Subsurface Loading per $1,000 expended (industry-wide) for Case 2 is 0.00016 (i.e., $6.4 million per ton of Avoided N Subsurface Loading)

[32] https://www.cdfa.ca.gov/dairy/dairystats_annual.html

Table 18: Estimates of cost and associated nitrogen subsurface loading, replacement of open earthen corrals with concrete corrals

Current N Subsurface Loading by Management Unit (a)	tons/year	Proportion		
Cropland	78,991	94%		
Lagoons	3,071	4%		
Corrals	1,830	2%		
Assumed Achievable N Subsurface Loading (b)	**tons/year**	**Proportion**	**Contribution to Improvement (CTI)**	
Cropland	54,810	100%	83%	
Lagoons	0	0%	11%	
Corrals	0	0%	6%	
Total Nitrogen Loading Reduction	29,082			
Avoided N Subsurface Loading from Corrals	**tons/year**			
Case 1: No consideration of fate (c)	1,830			
Case 2: Followed by agronomic application (d)	1,307			
Case 3: Followed by over-application (e)	0			
Estimated Cost for the Replacement of Open Earthen Corrals with Concrete Corrals (f)				
Open Concrete Corrals	$5,267,329,727			
Avoided N Subsurface Loading (tons) per $1,000 expended			**Adjusted for CTI**	
	Year 1	**10 Years**	**Year 1**	**10 Years**
Case 1: No consideration of fate	0.00035	0.0035	0.000022	0.00022
Case 2: Followed by agronomic application	0.00025	0.0025	0.000016	0.00016
Case 3: Followed by over-application	0	0	0	0

a) Tons are short tons (i.e., 2,000 lbs)
b) Cropland estimate assumes application-removal ratio of 1.4; zero-estimates for lagoons and corrals intend to convey near-zero leakage, not true zero-leakage
c) Case 1 constitutes an idealized case in which environmental losses associated with the fate of avoided N leaching from lagoons exclude leaching into groundwater
d) Case 2 assumes an AR ratio of 1.4
e) Case 3 assumes no additional crop uptake (i.e., over-application)
f) Cost developed by Provost (2019a) and adjusted herein for industry contraction (see *Section 3.2.5*)

April 1, 2019

Section 4

References

4 REFERENCES

ASAE, 2005: D384.2 MAR 2005. Manure Production and Characteristics *ASAE Standard. pp.* 20. American Society of Agricultural Engineers.

Beck, A., A Statistical Approach to Minimizing Landfill Leakage. Solid Waste Association of North America.

Beck, A., 2014: Designing to Minimize Geomembrane Leakage. Geosynthetics **32**, 7.

Beck, A., 2015: Available Technologies to Approach Zero Leaks. Geosythetics 2015 Conference, 10.

Burt, C., R. Hutmacher, T. Angermann, B. Brush, D. Munk, J. duBois, M. McKean and L. Zelinski, 2014: Conclusions of the Agricultural Expert Panel, Recommendations to the State Water Resources Control Board pertaining to the Irrigated Lands Regulatory Program. In fulfillment of Senate Bill X2 1. September 9, 2014.

Campbell-Mathews, C., C. Frate, T. Harter and S. Sather, Year: Lagoon water composition, sampling and field analysis. In, Fresno, CA, February 7-8, 2001.

Chang, A., T. Harter, J. Letey, D. Meyer, R. D. Meyer, M. Campbell-Mathews, F. Mitloehner, G. S. Pettygrove, P. Robinson and R. Zhang, 2005: Managing Dairy Manure in the Central Valley of California. University of California Division of Agriculture and Natural Resources, Committee of Experts on Dairy Manure Management.

Chang, A., T. Harter, J. Letey, D. Meyer, R. D. Meyer, M. Campbell-Mathews, F. Mitloehner, G. S. Pettygrove, P. Robinson and R. Zhang, 2006: Managing Dairy Manure in the Central Valley of California. University of California Division of Agriculture and Natural Resources, Committee of Experts on Dairy Manure Management. UC ANR Publication 9004.

Chang, A. C., D. C. Adriano and P. F. Pratt, 1973: Waste Accumulation on a Selected Dairy Corral and its Effect on the Nitrate and Salt of the Underlying Soil Strata. Journal of Environmental Quality **2**, 233-237.

Coote, D. R. and F. Hore, 1979: Contamination of shallow groundwater by an unpaved feedlot. Canadian Journal of Soil Science **59**, 401-412.

CVRWQCB, 2011: Conditional Approval of Monitoring and Reporting Workplan and Monitoring Well Installation and Sampling Plan - Phase 1, Existing Milk Cow Dairies.

CVRWQCB, 2012: Conditional Approval of Monitoring and Reporting Workplan and Monitoring Well Installation and Sampling Plan, Phase 2.

DeNovoPacific, 2018: Supplemental Electrical Leak Location Report - Pond D. De Novo Pacific. February 8, 2018.

Elliott, L. F. and T. M. McCalla, 1972: The Composition of the Soil Atmosphere Beneath a Beef Cattle Feedlot and a Cropped Field. Soil Science Society of America Proceedings **36**, 68-70.

Elliott, L. F., T. M. McCalla, L. N. Mielke and T. A. Travis, 1972: Ammonium, nitrate, and total nitrogen in the soil water of feedlot and field soil profiles. Applied microbiology **23**, 810-813.

Elliott, L. F., T. M. McCalla, N. P. Swanson, L. N. Mielke and T. A. Travis, 1973: Soil water nitrate beneath a broad-basin terraced feedlot. Transactions of the ASAE **16**, 285-286.

Harter, T., H. Davis, M. C. Mathews and R. D. Meyer, 2001: Monitoring Shallow Groundwater Nitrogen Loading from Dairy Facilities with Irrigated Forage Crops. 2001 ASAE Annual International Meeting, 11.

Harter, T., H. Davis, M. C. Mathews and R. D. Meyer, 2002: Shallow groundwater quality on dairy farms with irrigated forage crops. Journal of Contaminant Hydrology **55**, 287-315.

Harter, T., K. Dzurella, G. Kourakos, A. Hollander, A. Bell, N. Santos, Q. Hart, A. King, J. Quinn, G. Lampinen, D. Liptzin, T. Rosenstock, M. Zhang, G. S. Pettygrove and T. Tomich, 2017: Nitrogen Fertilizer Loading to Groundwater in the Central Valley. Final Report to the Fertilizer Research and Education Program, Projects 11-0301 and 15-0454. *pp.* 333. California Department of Food and Agriculture and University of California, Davis.

Harter, T., J. Lund, J. Darby, G. E. Fogg, R. Howitt, K. K. Jessoe, S. Pettygrove, J. F. Quinn and J. H. Viers, 2012: Addressing Nitrate in California's Drinking Water: With a Focus on Tulare Lake Basin and Salinas Valley Groundwater *Report for the State Water Resources Control Board Report to the Legislature. pp.* 78. Center for Watershed Sciences. University of California, Davis.

Harter, T., M. C. Mathews and R. D. Meyer, 2001: Effects of Dairy Manure Nutrient Management on Shallow Groundwater Nitrate: A Case Study. 2001 ASAE Annual International Meeting, 10.

Harter, T., R. D. Meyer and M. C. Mathews, 2002: Nonpoint Source Pollution from Animal Farming in Semi-Arid Regions: Spatio-Temporal Variability and Groundwater Monitoring Strategies. Future Groundwater Resources at Risk, Proceedings of the 3rd International Conference, 10.

Harter, T., Y. S. Onsoy, K. Heeren, M. Denton, G. Weissmann and J. W. Hopmans, 2006: Deep vadose zone hydrology demonstrates fate of nitrate in eastern San Joaquin Valley. California Agriculture **59**, 10.

Heguy, J. M., D. Meyer and N. Silva-del-Rio, 2016: A survey of silage management practices on California dairies. Journal of Dairy Science **99**, 1649-1654.

LSCE, 2010: Report of Results – Delineation of an Area for the Design and Initiation of a Representative Groundwater Monitoring Network for Existing Milk Cow Dairies, Central Valley, CA. Luhdorff and Scalmanini Consulting Engineers. August 31, 2010.

LSCE, 2012a: Addendum Monitoring and Reporting Workplan and Monitoring Well Installation and Sampling Plan, Phase 2: Representative Groundwater Monitoring Network Design & Monitoring Program, Existing Milk Cow Dairies – Central Valley, California. Luhdorff and Scalmanini Consulting Engineers. August 8, 2012.

LSCE, 2012b: Monitoring and Reporting Workplan and Monitoring Well Installation and Sampling Plan Phase 1: Initiation of Representative Groundwater Monitoring Network Design & Monitoring Program, Existing Milk Cow Dairies – Stanislaus and Merced Counties, California. Public Review Draft. Luhdorff and Scalmanini Consulting Engineers. June 16, 2011. Finalized without changes January 11, 2012.

LSCE, 2012c: Monitoring Well Installation Completion Report Phase 1 Representative Monitoring Program, Existing Milk Cow Dairies – Stanislaus and Merced Counties, California. Luhdorff and Scalmanini Consulting Engineers. February 10, 2012.

LSCE, 2013a: Central Valley Dairy Representative Monitoring Program Evaluation of Representativeness. Bound in two parts. May 15, 2013. Luhdorff and Scalmanini Consulting Engineers.

LSCE, 2013b: Central Valley Dairy Representative Monitoring Program Year 1 Annual Report (2012). Bound in four parts. Luhdorff and Scalmanini Consulting Engineers. April 1, 2013.

LSCE, 2013c: Monitoring and Reporting Workplan and Monitoring Well Installation and Sampling Plan, Phase 2: Representative Groundwater Monitoring Network Design & Monitoring Program, Existing Milk Cow Dairies – Central Valley, California. Public Review Draft. Luhdorff and Scalmanini Consulting Engineers. June 6, 2012. Finalized without changes June 28, 2013.

LSCE, 2015: Central Valley Dairy Representative Monitoring Program – 2014 Monitoring Well Installation Completion Report, Central Area. Luhdorff and Scalmanini, Consulting Engineers. February 26, 2015.
LSCE, 2019a: Central Valley Dairy Representative Monitoring Program Year 7 Annual Report (2018). Companion document to the Summary Representative Monitoring Report. Bound in five parts. Luhdorff and Scalmanini Consulting Engineers.
LSCE, 2019b: Corral Subsurface Hydrogeologic Investigation Including Literature Review. Luhdorff and Scalmanini Consulting Engineers. February 21, 2019.
LSCE, 2019c: Corral Subsurface Hydrogeologic Investigation Including Literature Review (Redacted). Luhdorff and Scalmanini Consulting Engineers. February 21, 2019.
LWA, 2016: CV-SALTS Alta Irrigation District - Extreme Management Scenario. Larry Walker Associates in association with Luhdorff and Scalmanini Consulting Engineers, Plan Tierra, Formation Environmental, and Giorgios Kourakos. May 2016.
MasonGeoscience, 2017: Dairy Pond Electrical Leak Location Report. Mason Geoscience. October 4, 2017.
Mathews, M. C., E. Swenson, T. Harter and R. D. Meyer, 2001: Matching Dairy Lagoon Nutrient Application to Crop Nitrogen Uptake Using A Flow Meter and Control Valve. American Society of Agricultural Engineers, 19.
Mielke, L. N., J. R. Ellis, N. P. Swanson, J. C. Lorimor and T. M. McCalla, Year: Groundwater Quality and Fluctuation in a Shallow Unconfined Aquifer Under a Level Feedlot. In: Relationship of agriculture to soil and water pollution, Proceedings, Cornell University Conference on Agricultural Waste Management, Rochester, NY, January 19-21, 1970.
Mielke, L. N., N. P. Swanson and T. M. McCalla, 1974: Soil profile conditions of cattle feedlots. Journal of Environmental Quality **3**, 14-17.
Miller, C. M. F., J. G. Fadel, J. M. Heguy, B. M. Karle, P. L. Price and D. Meyer, 2018: Optimizing accuracy of protocols for measuring dry matter and nutrient yield of forage crops. Science of the Total Environment **624**, 180-188.
Miller, C. M. F., J. M. Heguy, B. M. Karle, P. L. Price and D. Meyer, 2019: Optimizing accuracy of sampling protocols to measure nutrient content of solid manure. Waste Management **85**, 121-130.
Miller, C. M. F., P. L. Price and D. Meyer, 2017: Mass balance analyses of nutrients on California dairies to evaluate data quality for regulatory review. Science of the Total Environment, 10.
Norstadt, F. A. and H. R. Duke, 1982: Stratified Profiles: Characteristics of Simulated Soils in a Beef Cattle Feedlot. Soil Science Society of America Journal **46**, 827-832.
Parsons, T. E., 2018: Fate of Nitrogen on California's Central Valley Dairies as Measures by Regulatory Reporting. *MS Thesis in Agricultural and Environmental Chemistry.* University of California, Davis.
Patrick, W. H. J. and R. Wyatt, 1964: Soil Nitrogen Loss as a Result of Alternate Submergence and Drying. Soil Science Society of America Journal **28**.
Provost, 2013: Costs to retrofit existing dairies that do not have Tier 1 or Tier 2 lagoons. Provost and Pritchard Consulting Group.
Provost, 2019a: Central Valley Dairy Alternative Housing Estimates. Provost and Pritchard Consulting Group.
Provost, 2019b: Central Valley Dairy Alternative Liquid Manure Handling Estimates. Provost and Pritchard Consulting Group.

Provost, 2019c: Central Valley Dairy Lagoon Replacement Estimates. Provost and Pritchard Consulting Group.

Stewart, B. A., F. G. J. Viets, G. L. Hutchinson and W. D. Kemper, 1967a: Nitrate and Other Water Pollutants under Fields and Feedlots. Environmental Science & Technology **1**, 736-739.

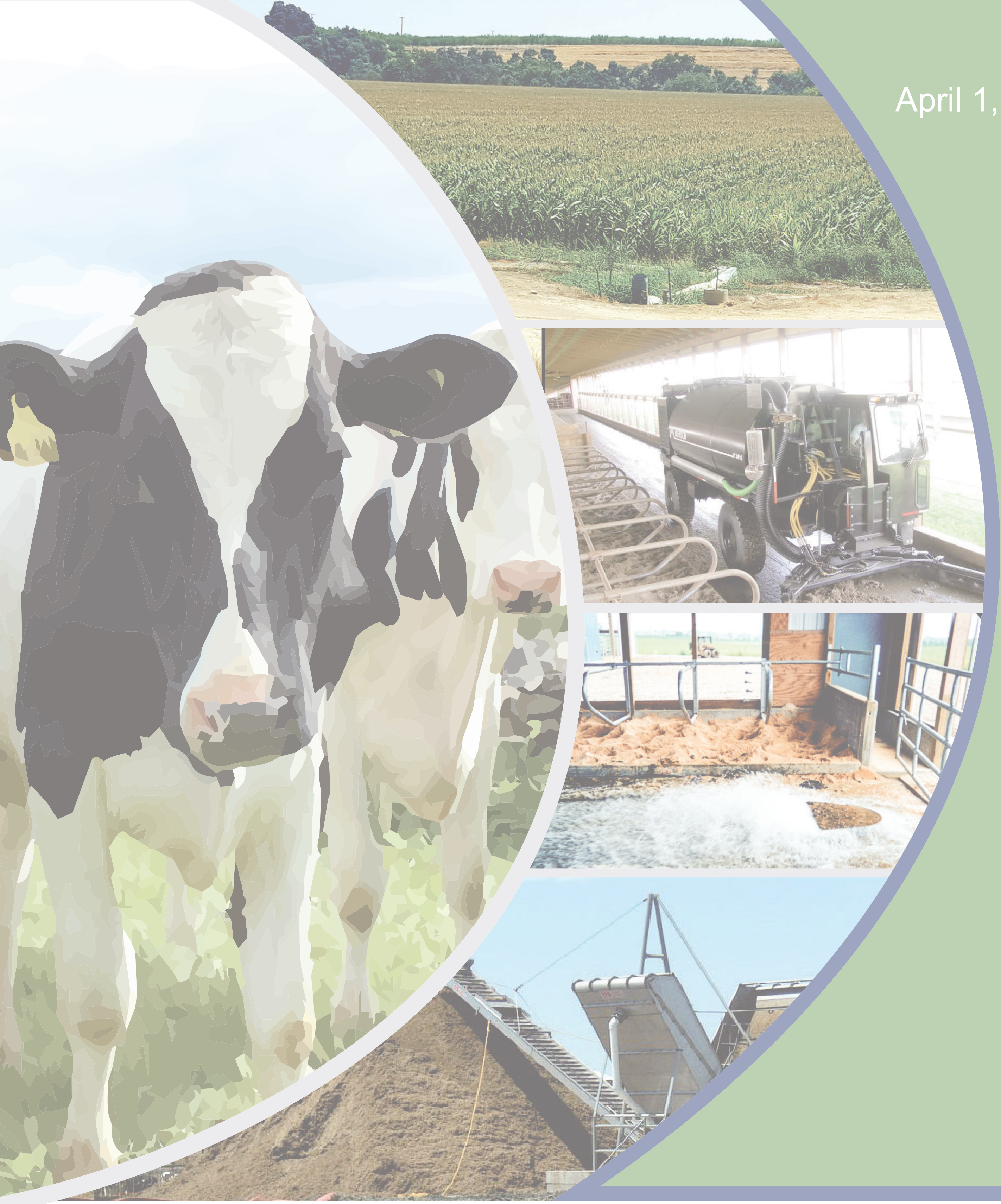
Stewart, B. A., F. G. J. Viets, G. L. Hutchinson, W. D. Kemper, F. E. Clark, M. L. Fairbourn and F. Strauch, 1967b: Distribution of Nitrates and Other Water Pollutants under Fields and Corrals in the Middle South Platte Valley of Colorado. *pp.* 206 p. USDA-ARS 41-134.

Todd, R. W., N. A. Cole, L. A. Harper, T. K. Flesch and B. H. Baek, Year: Ammonia and gaseous nitrogen emissions from a commercial beef cattle feedyard estimated using the flux-gradient method and N:P ratio analysis. In, Proceedings of the Symposium on State of Science: Animal and Waste Management, San Antonio, Texas, 2005.

Van der Schans, M. L., T. Harter, A. Leijnse, M. C. Mathews and R. D. Meyer, 2009: Characterizing sources of nitrate leaching from an irrigated dairy farm in Merced County, California. Journal of Contaminant Hydrology **110**, 9-21.

Woodbury, B., D. Miller, J. Nienaber and R. Eigenberg, 2001: Seasonal and spatial variations of denitrifying enzyme activity in feedlot soil. Transactions of the ASAE **44**, 1635-1642.

April 1, 2019



Appendix

EST. 1968
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March 20, 2019

Central Valley Dairy Representative Monitoring Program
915 L Street, C-431
Sacramento, CA 95814

RE: Central Valley Dairy Alternative Liquid Manure Handling Estimates

Dear Mr. Angermann:

Per your request, Provost & Pritchard developed general cost estimates for liquid manure application infrastructure to more distant fields. During times of continuous or nearly continuous irrigations, a common pipeline system has difficulty in delivering lagoon water to more distant fields from the dairy site.

Four alternatives were considered.

- Blend lagoon and irrigation water adjacent to the lagoon and gravity push on a dedicated line
- Same alternative as above but using a booster pump station instead of gravity
- Pump lagoon water only on a dedicated line to mixing stations at field wells
- Transport lagoon water by trailer

In each of these cases, it is assumed that the nearby fields will still be irrigated with an existing lagoon pump (floating or fixed) and blended with an adjacent irrigation well. These systems described are for fields further away that need irrigation independence from the closer fields.

Estimates are based on equivalency to similar projects. Actual sizing, location, integration, material acquisition, contractor experience, etc. can alter these estimates.

Blend Lagoon and Irrigation Water, Deliver by Head Pressure

For this alternative a dedicated agricultural well is needed in an area adjacent to the lagoon. This well cannot be simultaneously needed for irrigating fields that are close to the dairy site.

This alternative assumes that enough head pressure is developed by a standpipe to deliver the blended water to the far-out fields. It assumes a dedicated entry point 30-inch standpipe connected to a 15-inch PVC delivery line will be installed to reach a connect point of an isolated field irrigation system. The actual diameter of the delivery pipeline should be adjusted for total flow rates and head loss based on lagoon pump and well pump. If the velocity of manure laden water within the pipeline is too low, solids will fall out of suspension and eventually plug the pipeline.

15” Irrigation Pipe (Installed)	$19.70/ft
Concrete Standpipe	$3,000
Isolation Valves	$1,600 each
Air Vent Standpipe	$400 (every ¼ mile or any high points)

For a pipeline to deliver water 1 mile away to a single connection point an estimate would be $110,300.

Blend Lagoon and Irrigation Water, Deliver by Pump Station

This alternative is like the prior alternative except that a booster pump is needed to deliver the blended water to the far-out fields.

In this configuration a dedicated standpipe should be used to feed the booster pump to ensure no cavitation of the pump. The booster pump will need to be variable speed and operate at the combined flow of the well and lagoon pump. Until full flow of the two supplies are established and the booster pump is throttled, the overflow of the standpipe should route into the lagoon. Or maintain a slight overfill condition to ensure no booster pump cavitation through the irrigation set. The actual diameter of the delivery pipeline should be adjusted for total flow rates and head loss based on lagoon pump and well pump. And depending on the overall head loss, booster pump horsepower can be adjusted to the actual design of a system.

40hp Booster Pump Station	$25,000 (electrical controls, flowmeter)
15” Irrigation Pipe (Installed)	$19.70/ft
Concrete Standpipe	$3,000
Isolation Valves	$1,600 each
Air Vent Valves	$400 (every ¼ mile or any high points)

For a pipeline to deliver water 1 mile away to a single connection point an estimate would be $135,300.

Lagoon Water Only Delivered by Pump Station to Field Mixing Location

This alternative is needed when there isn’t an available dedicated irrigation well located near the lagoon. Only lagoon water will be pumped out to irrigation well standpipes and the water will be blended within the existing field standpipes.

This type of setup is also good for delivery to wastewater agreement land and/or long distances. We have designed systems that have traveled over 2 ½ miles (4 mixing stations along the way) while increasing in elevation 20 feet and delivering 525 gpm which was a good blending volume for the wells at that site. Further distances are possible, this is just an example.

A smaller delivery line, 8-inch assumed for this example, is used to keep the internal water velocity high and the manure solids in suspension to prevent the line from plugging. The booster pump station is set up in a similar manner with a feeding standpipe to prevent pump cavitation and route overflow into the lagoon. And depending on the overall head loss, booster pump horsepower can be adjusted to the actual design of a system.

40hp Booster Pump Station	$25,000 (electrical controls, flowmeter)
8" Irrigation Pipe (Installed)	$9.90/ft
Concrete Standpipe	$3,000
Isolation Valves	$800 each
Air Vent Valves	$200 (every ¼ mile or any high points)

For a pipeline to deliver water 1 mile away to a single connection point an estimate would be $81,900.

Transport Lagoon Water by Tanker Trailer

This alternative is a high cost method to deliver water. It would be needed when there isn't a path to install a pipeline to outer fields. Only lagoon water will be pumped into tanker trailers and transported to fields and placed by the trailers. The quantity of trucks/tankers needed to keep up blending directly with an irrigation well is highly unlikely.

Along with this option, the field would have to be in-between crops in order for the tanker trailers to pass through the field, therefore the storage lagoon at the dairy will have to be sized appropriately to contain water in-between field irrigations in this manner.

To put these costs into perspective, an example of delivering 1 inch of lagoon water to a 40-acre field, those costs are also presented.

Transport within 1 mile	$0.0075/gallon	$8,150
Transport within 5 miles	$0.012/gallon	$13,040
Transport 10 to 20 miles	$0.025/gallon	$27,180

Additional Costs

The estimates shown do not include any design costs. Some irrigation companies may have a stand-alone design cost or include design into their installation costs. For more complicated systems, distance, elevation, etc., an independent engineer may be needed to design a complete system, or to use as a basis and then seek an installer.

Respectfully,

Steven Bommelje
Project Manager

Ed Caminata
RCE 88473

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March 18, 2019

Central Valley Dairy Representative Monitoring Program
915 L Street, C-431
Sacramento, CA 95814

RE: Central Valley Dairy Lagoon Replacement Estimates

Dear Mr. Angermann:

Per your request Provost & Pritchard has expanded our previous lagoon replacement estimates that were provided on August 5, 2013 and incorporated into the *Information Section of the Dairy General Order R5-2013-0122*. This current evaluation is to provide overall general cost estimates for the dairies in the Central Valley to replace their existing lagoons with a single new lined lagoon.

The previous presentation was based on 4 different herd sizes, a southern valley dairy location with average water generation, footprint, and Kings/Tulare type weather conditions resulting in a typical situation for that area. This related to approximately half of the milking herd population in the valley. In order to broaden the conditions to the entire Central Valley, a research document was provided - *Nitrogen Fertilizer Loading to Groundwater in the Central Valley, Final Report Update October 2017, FREP Projects 11-0301 and 15-0454, by Harter et al UC Davis*.

Utilizing FREP Data

Section 11.6 - Dairy Sources of Nitrogen of this FREP report provides two tables of data *(Tables 11.11 and 11.12)* that are helpful in generating a county by county cost estimate in relation to the year 2005. The report groups dairy areas into 3 regions - Sacramento Valley, San Joaquin Valley, and Tulare Lake Basin. Within each region, county level data is presented.

Table 1. Lagoon Relevant Data from FREP Report

Areas	Number of		Lagoon	
	Dairies	Cows	Area (ac)	N Load (t/y)
Sacramento Valley	130	66,054	113	60
Butte	4	1,513	2.3	1.2
Colusa				
Glenn	47	24,505		
Placer	1		1.8	1.0
Sacramento	39	23,578	52.0	27.0
Shasta	1	297		
Solano	3	4,736	3.9	2.0
Sutter	1			
Tehama	27	5,069	38.0	20.0
Yolo	3	2,414	2.8	1.4
Yuba	4	3,942	12.0	7.0

Table 1 (cont.). Lagoon Relevant Data from FREP Report

Areas	Number of		Lagoon	
	Dairies	Cows	Area (ac)	N Load (t/y)
San Joaquin Valley	789	726,949	2,748	1,436
Contra Costa				
Madera	49	78,385	237	124
Merced	318	303,920	1,058	553
San Joaquin	130	128,418	397	207
Stanislaus	292	216,226	1,056	552
Tulare Lake Basin	616	975,573	3,016	1,576
Fresno	104	126,097	336	176
Kern	53	125,684	439	229
Kings	149	184,172	624	326
Tulare	310	539,620	1,617	845
Total Central Valley	1,535	1,768,576	5,877	3,072

Lagoon Area Analysis

The lagoon area presented in acres used by the FREP report was obtained by GIS mapping. A lagoon identification within GIS was obtained with a clarity of a 50m x 50m area, approximately 62% of an acre. The FREP report describes that a visual aerial tally of observed lagoon area was performed and resulted with the GIS mapping ability oversizing lagoon area by 2.7 times, so the GIS data was decreased by this factor. With a resulting dairy lagoon area ranging from less than 1 acre to 8 acres, a division of data collected by 2.7 makes for some lack of resolution in the FREP data presented. But using this data in general, an average "number of cows per lagoon acre" can be determined for the three regions of the Central Valley.

Sacramento Valley	586 cows per acre of lagoon area
San Joaquin Valley	258 cows per acre of lagoon area
Tulare Lake Basin	324 cows per acre of lagoon area

The reason for using this cow per lagoon acre average is that the style of dairies differs in these 3 regions. Many factors go into sizing a lagoon, making each dairy unique. So, this feature was used to find some common method through the available data to base a replacement cost estimation.

In the south region of the valley, Tulare Lake Basin, the typical dairy style is large open lots and the ability for full depth lagoons in the 20-foot deep range. The design of these open lots from about the 1980s on were usually based on research of open corral animal density for the arid southwest. In the north valley region, Sacramento Valley, with larger annual rainfall amounts dairies tend to be smaller in herd size with full or nearly full roof over smaller footprint corrals. The resulting data set obtained from the FREP report shows an average ability for twice as many cows per acre of lagoon by these facilities over the southern end of the valley.

In the middle region of the valley, San Joaquin Valley, there is a mixture of the north and south styles in this transition area. Along with that, there are areas of high ground water making it difficult to have a deeper lagoon. Many lagoons are above ground in this region with only a few feet of space below surface grade. For a given amount of storage volume, this requires a larger footprint area. And this style seems to show up in the average smaller number of cows per acre of lagoon area found in the FREP data set. Again, remembering the clarity of the data retrieved by GIS.

Using the county herd average size and the number of cows per acre of lagoon in the region, a consistent estimating method can be determined with the data from the FREP report. Again, as in our 2013 evaluation some consistency was used in the remaining variables that make up a storage volume determination for a dairy. Also updates to 2013 construction costs associated with individual factors of a lagoon build were included.

Lagoon Replacement Cost Estimates

Shown in Tables 2 and 3 are the results of the lagoon replacement estimates on an average county level herd size. Costs included in these estimates are; location engineering (volume verification, site selection, survey, geotechnical report, lagoon design report, lagoon construction drawings, and CQA specifications), excavation with Geotech oversight and testing, lining installation (liner materials purchased, tested & installed, LRCS and geonet for double liner, anchor trench, inlet and outlet pipe boots, level gauge, CQA oversight, and final CQA report).

Table 2 shows the estimates for the Tier 1 double lined lagoon both below ground and an equivalent storage volume for an above ground lagoon for the areas that may need them. And Table 3 shows the same for the Tier 2 single lined lagoon. Estimates are based on equivalency to similar projects. Actual sizing, location, integration, material acquisition, contractor experience, etc. can alter these estimates.

Both tables present the estimated costs for locating a single replacement lagoon in a new area. There are factors that limit the ability to retrofit in a current location such as construction time period wastewater storage, volume alterations for adjusting side slope and incorporating a sloped floor, exterior room needed for an anchor trench to hold the liner in place, and exterior room needed to construct the liner. In general, to retrofit in the same location of an existing lagoon, the estimated cost increases by 10% to prepare the area for lining.

Multiple lagoons for the same amount of storage volume also increases the cost per dairy. This is due to the loss of volume per footprint area due to the internal side slopes. However, a scenario can be envisioned that a full new lagoon area is not possible within the dairy footprint or adjacent to a dairy site. This could result in making a new small lagoon in a new area that can be used during reconstruction of the existing lagoon and then once this new small lagoon is in service, the original lagoon is retrofitted to be a lined lagoon, slightly smaller due to liner construction needs, and then the two together achieve the full storage needed.

The FREP report also provided an anticipated nitrogen loss based on current lagoon sizes. For an understanding of the impact costs to replace dairy lagoons based on this amount, a result is shown of the replacement cost per ton of nitrogen over a 15-year time period.

Table 2. Cost for Replacing Storage by a New Double Lined Lagoon

Areas	New Below Ground Lagoon			Additional Costs for Above Ground		
	$ Each	15yr $/N t	$ County	$ Each	15yr $/N t	$ County
Sacramento Valley						
Butte	225,700	50,100	902,800			
Colusa						
Glenn(2)	274,600	40,400	12,906,200			
Placer	445,000	31,600	445,000			
Sacramento(3)	300,800	28,800	11,731,200	143,800	13,800	5,608,200
Shasta						
Solano(3)	610,000	59,900	1,830,000	304,900	30,000	914,700
Sutter						
Tehama	158,600	14,400	4,282,200			
Yolo(3)	365,100	50,000	1,095,300	182,400	25,000	547,200
Yuba	420,100	17,900	1,680,400			
San Joaquin Valley						
Contra Costa						
Madera(1)	995,600	26,300	48,784,400			
Merced(3)	797,400	30,600	253,573,200	403,600	15,500	128,344,800
San Joaquin(3)	814,200	34,100	105,846,000	416,100	17,400	54,093,000
Stanislaus(3)	638,500	22,600	186,442,000	327,800	11,600	95,717,600
Tulare Lake Basin						
Fresno	805,700	31,900	83,792,800			
Kern	1,451,200	22,400	76,913,600			
Kings	814,200	24,900	121,315,800			
Tulare	1,102,400	27,000	341,744,000			
Total Central Valley			1,253,284,900			285,225,500

1 Calculated with Tulare Basin for cow to lagoon acre averaging
2 Used county averages to complete evaluation
3 Some areas within county may require above ground lagoons in a retrofit

Table 3. Cost for Replacing Storage by a New Single Lined Lagoon

Areas	New Below Ground Lagoon			Additional Costs for Above Ground		
	$ Each	15yr $/N t	$ County	$ Each	15yr $/N t	$ County
Sacramento Valley						
Butte	159,700	35,500	638,800			
Colusa						
Glenn[(2)]	190,600	28,100	8,958,200			
Placer	298,700	21,200	298,700			
Sacramento[(3)]	207,500	19,900	8,092,500	125,100	12,000	4,878,900
Shasta						
Solano[(3)]	404,700	39,800	1,214,100	240,900	23,700	722,700
Sutter						
Tehama	122,200	11,100	3,299,400			
Yolo[(3)]	247,100	33,800	741,300	155,100	21,300	465,300
Yuba	282,000	12,000	1,128,000			
San Joaquin Valley						
Contra Costa						
Madera[(1)]	656,800	17,400	32,183,200			
Merced[(3)]	526,900	20,300	167,554,200	306,100	11,800	97,339,800
San Joaquin[(3)]	537,900	22,500	69,927,000	314,900	13,200	40,937,000
Stanislaus[(3)]	423,400	15,000	123,632,800	256,500	9,100	74,898,000
Tulare Lake Basin						
Fresno	532,300	21,100	55,359,200			
Kern	956,400	14,800	50,689,200			
Kings	537,900	16,400	80,147,100			
Tulare	726,500	17,800	225,215,000			
Total Central Valley			829,078,700			219,241,700

1 Calculated with Tulare Basin for cow to lagoon acre averaging
2 Used county averages to complete evaluation
3 Some areas within county may require above ground lagoons in a retrofit

Additional Wastewater Handling Costs

There are other wastewater handling "accessories" not presented in these estimates that should be considered in any lagoon replacement. Costs become highly variable for each given situation so a common estimation at a county level is impractical.

Lagoon Size

Not really an accessory but deserves consideration is lagoon size. When designing a new lagoon this is the time to consider lengthening the storage period. An additional 10% in construction cost could add a couple weeks of storage time by making the new lagoon slightly larger. Also, visual observation finds that some lagoons are severely loaded with solids build-up while others are not. Some of this build-up has to do with the mixture ratio (manure:water) of the influent and the treatment volume a lagoon provides. While cutting back on milk barn water generation reduces storage volume needed, it also increases the mixture ratio and decreases the treatment ability and that can result in solids build-up. Sizing a lagoon to allow for some additional new water could result in a larger lagoon but when retrofitting this should be considered to reduce the interval for lagoon cleanouts.

Manure Separation

Manure separation is an accessory that should be considered when operating a synthetically lined lagoon. Cleanout poses inherent risks to damaging the liner and should be as infrequent as possible. Manure separation, if not already present should be added to the wastewater system before using a retrofitted lagoon. A common method of non-mechanical manure separation currently is utilizing a settling basin which must be cleaned out annually or some level of frequency. These also are considered “lagoons” and have the same seepage concerns. If plastic lined, they become a severe cleanout/damage repair problem and should be replaced by another solids separation method. These alternatives could be - concrete settling basin, weeping wall, screen separation, screw press separation, etc. Costs for adding a typical screen separation system can range from $375,000 to $620,000 when you consider – pits, pumps, separator, drying slab, and electrical service.

Sand Separation

A sand lane or some type of sand separation should also be considered. Although sand is a tiny portion of water within a well supplying water troughs or coming in from the corral surfaces or even feed, sand volume can add up quickly in a lagoon. Again, cleanout of a lined lagoon needs to be avoided if possible. Some areas of the valley are more severe than others, but sand removal should be considered especially if currently sand accumulation is observed. A 300’ sand lane operating at flush flow rates can cost in the range of $300,000 plus or minus.

Connections to Current System

Another accessary not included in the estimates but is a mandatory item is the connection of the new retrofitted lagoon into the current wastewater system. Given the variety of connections of pipe sizes and distance to a new lagoon, it is difficult to compile and estimate prior to completing drawings on how the wastewater flow will be integrated into a specific dairy. These costs can range from $10,000 to $70,000 or more.

Agency Permit Fees

For the estimates given, it was assumed that a dairy is enrolled within an Individual or General Order. The Regional Water Quality Control Board does not charge any additional fees for their lagoon design review work if the dairy is enrolled in an existing Order. There would be additional consultant engineering fees if application into a different Order occurs, such as applying for the Digester General Order.

Dairies from San Joaquin County south to Kern County are under the jurisdiction of the San Joaquin Valley Air Pollution Control District. No construction of a lagoon retrofit can begin prior to issuing an Authority To Construct permit for the modifications to the dairy facility. The Air District has engineering evaluation costs billed directly to the permit holder at the issuing of the

ATC. This could add up to several thousand dollars in fees depending on what is being changed in addition to the lagoon retrofit.

A variety of county permit application fees are experienced but usually fall within a few thousand dollars. Each county has their own criteria for modifying a dairy site use permit which can range from very little to needing a full Site Plan Review or EIR. Going outside of the current dairy footprint often triggers more permit application work by a consultant. Then there is more variety county to county in additional permits needed. Many counties are now including engineering grading permits along with building or structure permits. The inclusion of grading permits usually triggers the need for a certified QSD person to prepare a Stormwater Pollution Prevention Plan (SWPPP). And plan then this also requires field technicians for site reporting through rain events encountered. Construction in a rainy season, not only has construction delays with potential additional costs, but these SWPPP inspections and controls as well.

Additional Support for Site Alterations

Today, modifying a dairy in many areas of the valley requires consulting support through all phases of a project from design through construction. Based on recent experience of integrating digesters on dairies, the costs encountered for additional site design for integration of manure separation and sand separation, drainage alterations to existing flush systems, additional grading plans, air and county permit support, SWPPP preparation and support, and general construction support. These costs could range from $20,000 to $80,000. And that can be higher if a full Site Plan Review or an EIR is needed by the county.

<u>Potential Liner Issues</u>

A well designed and constructed HDPE lined lagoon, if not operationally damaged, should last 40 or more years in the sun and heat of this valley according to research.

Leaks should be identified on first fill and liner installers repair these under warranty. Currently the water board requires a letter from the engineer verifying that it is leak free after first fill.

After that, it is important to keep all items out of the pond that could cause damage. Floating pumps need to be fitted with something such that contact with the liner won't cause rub wear or a puncture. There are other features that engineers add to the design to help prevent future leaks and set it up to be able to test and find leaks.

If a leak is encountered, it must be located, the pond drained, and cleaned of manure sludge in order to work on the liner. This could be expensive depending on if you rent an additional pump, the costs to redirect incoming water flow, the costs to remove the sludge – without further damages, the actual repair, and then return the system back to normal.

"Whaling" is another issue. "Whaling" occurs when gas builds up under the liner and lifts the liner to the surface of the water. From the surface it looks like the back of a whale sticking out of the water. If you have ever tried to hold a beach ball on the bottom of a swimming pool you realize how little gas it takes to lift a liner. A good design of a lagoon should include proper venting or other methods to minimize the chance of this occurring.

If "whaling" does occur, the liner at this point has been severely stretched out of position and realignment is nearly impossible. The liner layer, or at least the areas dislodged, likely needs to be replaced. But the bigger problem is that the cause of the gas buildup needs to be understood and fixed. Was it caused by high ground water rising, displacing the voids in the soil forcing gas up and out of the soil? Was it a leak allowing organics to pass though into the soil? Or was it caused by leftover organics in the soil if the lined lagoon was built over an old lagoon area without good over-excavation? To fix a "whale" it is the same situation as a leak however the repairs to underlying soil and damaged liner must be reworked as well. To bring in excavation equipment to replace underlying soil could entail the removal of all the liner material.

Respectfully,

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Project Manager

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March 19, 2019

Central Valley Dairy Representative Monitoring Program
915 L Street, C-431
Sacramento, CA 95814

RE: Central Valley Dairy Alternative Housing Estimates

Dear Mr. Angermann:

Per your request, Provost & Pritchard developed general cost estimates to replace existing open, earthen, unlined corrals with alternative animal housing. The estimates cover the potential costs for all the dairies in the Central Valley. A research document was provided for a basis of dairies in this area - *Nitrogen Fertilizer Loading to Groundwater in the Central Valley, Final Report Update October 2017, FREP Projects 11-0301 and 15-0454, by Harter et al UC Davis*.

The following five alternate animal housing types were considered – freestall, loafing barn, compost barn, concrete surfaced open corral, and HDPE lined corral with a protective soil covering.

Utilizing FREP Data

Section 11.6 - Dairy Sources of Nitrogen of this FREP report provides two tables *(Tables 11.11 and 11.12)* that are helpful in generating a county by county cost estimate in relation to the year 2005. The report groups dairy areas into 3 regions - Sacramento Valley, San Joaquin Valley, and Tulare Lake Basin. Within each region, county level data is presented.

Table 1. Dairy Relevant Data from FREP Report

Areas	Number of Dairies	Number of Cows
Sacramento Valley	130	66,054
Butte	4	1,513
Colusa		
Glenn	47	24,505
Placer	1	
Sacramento	39	23,578
Shasta	1	297
Solano	3	4,736
Sutter	1	
Tehama	27	5,069
Yolo	3	2,414
Yuba	4	3,942

Table 1 (cont.). Dairy Relevant Data from FREP Report

Areas	Number of Dairies	Number of Cows
San Joaquin Valley	789	726,949
Contra Costa		
Madera	49	78,385
Merced	318	303,920
San Joaquin	130	128,418
Stanislaus	292	216,226
Tulare Lake Basin	616	975,573
Fresno	104	126,097
Kern	53	125,684
Kings	149	184,172
Tulare	310	539,620
Total Central Valley	1,535	1,768,576

Basis of Cost Estimation

A representative full herd profile can be calculated from the number of milk cows per dairy given typical breeding intervals. The data provided by the FREP report gives an average milk cow number for each county.

For this evaluation, it was assumed that each dairy will house all the milk cows, dry cows, and a full heifer replacement program after returning from a calf ranch at approximately 2 ½ to 3 months of age, which is a common practice. For about the first two months of age calves are housed in hutches and are not housed in corrals. Therefore, this animal age group, and the associated animal housing (i.e. hutches) was excluded from the evaluation.

Costs for each of the five alternative housing types were determined for the herd profile based on each county's average herd size. In actual practice a dairy could choose to replace existing housing with more than one housing type. Or if they already have housing that is equivalent to the alternative those wouldn't need to be retrofitted. Table 2 presents the anticipated construction costs for the five alternatives for an average dairy within a county. Table 3 presents the anticipated construction costs for the total county. Estimates are based on equivalency to similar projects. Actual sizing, location, integration, material acquisition, contractor experience, etc. can alter these estimates.

For the housing alternatives that are completely under roof (freestall, loafing barn, and compost barn), it was assumed for this evaluation that existing feed lanes would require replacement in a new configuration to fit within columns and footings supporting the roof structures. Therefore, the estimates include minor grading, feed and drive lanes, roof structure, and bedding stalls for the freestall or perimeter retaining wall for the compost barn. 4-row freestalls were assumed for mature cows and larger heifers and 6-row freestalls for the younger heifers. These structures are typically 6 columns per bay supporting the roof (located at stanchion line of feed lane, beds, outside edge for both sides). Loafing and compost barns typically have 4 columns per bay (located at the back of the feed lane, outside edge for both sides) requiring stronger roof structure than 6 columns to allow for an open lounging area and unobtrusive to bedding maintenance.

For this evaluation of the 3 building types, it is assumed that there would be no outside exercise area conforming to the evaluation basis of reducing unlined open corral exposure to rainfall. If a dairy selects to include outside exercise areas, costs like the two unroofed housing alternatives would have to be added to these estimates for the unroofed additional area. The roofed building estimates also do not include a concrete surface under the bedding area. For the case of freestalls, it is the intent of the bed size per age group to minimize wet manure in the bed area. To maintain composting activity, moisture needs to remain under 55%, when moisture can come out of manure at about 70% or higher. Given the thickness of the compost pack and the maximum moisture levels, the underlying ground surface should be maintained dry. For the loafing barn, replacement of bedding materials will be needed to maintain a dry underlying surface and given the depth of bedding etc., an underlying surface may be needed.

For the two corral alternatives of concrete or HDPE liner, the estimates include grading of the corral areas and installing the new liner type. The estimates for these two housing types are significantly dependent on corral area which has norms but can vary from dairy to dairy. In general, the southern portion of the Central Valley typically has large open corrals with small shades while the northern portion of the valley has smaller corrals with larger roof area. For the estimates presented, from Madera south a larger corral area factor was used.

Table 2. Alternative Estimated Costs - $ Per Average Dairy

Areas	County Average Dairy Size[1]				
	Freestall Barn	Loafing Barn	Compost Barn	Concrete Corral	HDPE Corral
Sacramento Valley					
Butte	1,119,230	1,464,890	1,748,490	1,111,840	698,440
Colusa					
Glenn	1,562,150	2,049,860	2,446,920	1,555,050	976,960
Placer					
Sacramento	1,787,580	2,346,510	2,800,240	1,778,590	1,117,200
Shasta	884,740	1,156,570	1,380,090	877,490	551,100
Solano	4,572,060	5,989,870	7,147,490	4,541,450	2,852,440
Sutter					
Tehama	591,310	785,190	938,770	596,250	375,070
Yolo	2,368,720	3,107,170	3,707,670	2,355,080	1,479,220
Yuba	2,871,700	3,763,810	4,491,070	2,853,130	1,791,990
San Joaquin Valley					
Contra Costa					
Madera	4,623,060	6,049,360	7,216,890	8,020,270	4,615,860
Merced	2,793,530	3,659,280	4,366,540	2,774,680	1,742,740
San Joaquin	2,871,700	3,763,810	4,491,070	2,853,130	1,791,990
Stanislaus	2,177,290	2,850,520	3,400,950	2,160,890	1,357,080
Tulare Lake Basin					
Fresno	3,503,830	4,584,470	5,468,400	6,076,060	3,496,660
Kern	6,825,280	8,928,720	10,649,860	11,833,380	6,809,750
Kings	3,565,000	4,669,000	5,569,640	6,187,200	3,560,800
Tulare	5,003,710	6,551,730	7,812,420	8,675,280	4,991,750
Total Central Valley					

1 Calves in hutches not included

Table 3. Alternative Estimated Costs - $ Per County

Areas	Total County(1)				
	Freestall Barn	Loafing Barn	Compost Barn	Concrete Corral	HDPE Corral
Sacramento Valley					
Butte	4,476,920	5,859,560	6,993,960	4,447,360	2,793,760
Colusa					
Glenn	73,421,050	96,343,420	115,005,240	73,087,350	45,917,120
Placer					
Sacramento	69,715,620	91,513,890	109,209,360	69,365,010	43,570,800
Shasta	884,740	1,156,570	1,380,090	877,490	551,100
Solano	13,716,180	17,969,610	21,442,470	13,624,350	8,557,320
Sutter					
Tehama	15,965,370	21,200,130	25,346,790	16,098,750	10,126,890
Yolo	7,106,160	9,321,510	11,123,010	7,065,240	4,437,660
Yuba	11,486,800	15,055,240	17,964,280	11,412,520	7,167,960
San Joaquin Valley					
Contra Costa					
Madera	226,529,940	296,418,640	353,627,610	392,993,230	226,177,140
Merced	888,342,540	1,163,651,040	1,388,559,720	882,348,240	554,191,320
San Joaquin	373,321,000	489,295,300	583,839,100	370,906,900	232,958,700
Stanislaus	635,768,680	832,351,840	993,077,400	630,979,880	396,267,360
Tulare Lake Basin					
Fresno	364,398,320	476,784,880	568,713,600	631,910,240	363,652,640
Kern	361,739,840	473,222,160	564,442,580	627,169,140	360,916,750
Kings	531,185,000	695,681,000	829,876,360	921,892,800	530,559,200
Tulare	1,551,150,100	2,031,036,300	2,421,850,200	2,689,336,800	1,547,442,500
Total Central Valley	5,129,208,260	6,716,861,090	8,012,451,770	7,343,515,300	4,335,288,220

1 Calves in hutches not included

Additional Costs

There are other costs or considerations not presented in these estimates that are general to a construction project and not specific to dairy size or type of housing alternative selected.

Agency Permit Fees

It was assumed that a dairy is enrolled within an Individual or General Order. Currently these types of Orders don’t outline a need for a consultant to prepare an engineering design report to submit for review prior to construction, but that would likely change if a requirement for corral alternatives is enacted. The Regional Water Quality Control Board does not currently charge any additional fees for design review work if the dairy is enrolled in an existing Order. There would be additional consultant engineering fees if application into a different Order occurs, such as applying for the Digester General Order.

Dairies from San Joaquin County south to Kern County are under the jurisdiction of the San Joaquin Valley Air Pollution Control District. No construction can begin prior to issuing an Authority To Construct permit for the modifications to the dairy facility. The Air District has engineering evaluation costs billed directly to the permit holder at the issuing of the ATC. This could add up to several thousand dollars in fees depending on what is being changed in addition to the corrals.

County use permit updates will likely be limited to pertaining to building and grading permits, unless the dairy is expanding outside of the current footprint. A variety of county permit application fees are experienced but usually fall within a few thousand dollars. Each county has their own criteria for modifying a dairy site use permit which can range from very little to needing a full Site Plan Review or EIR. Most counties at this point are requiring current building structure calculations for structures over animal housing. Many counties are now including engineering grading permits along with building or structure permits. The inclusion of grading permits usually triggers the need for a certified QSD person to prepare a Stormwater Pollution Prevention Plan (SWPPP). And then this also requires field technicians for site reporting through rain events encountered. Construction in a rainy season, not only has construction delays with potential additional costs, but these SWPPP inspections and controls as well.

Additional Consulting Support for Site Alterations

Today to modify a dairy in many areas of the valley requires consulting support through all phases of a project from design through construction. Changing corrals within existing footprint and connecting to existing flush and drainage systems may need very little engineering support. On the other side, if the new housing is significantly modified, it could be as extensive of a change as a new facility. Engineering and permitting support could range from $5,000 to $50,000 to reconfigure the corrals and drainage systems. And that could be higher if a full Site Plan Review or an EIR is needed by the county.

Advantages and Disadvantages of the Five Alternative Animal Housing Types

Housing Type 1 - Freestall

While this type of housing is common for milking cows it is presently uncommon in the Central Valley for the remainder of the herd. But in other parts of the world, freestalls are used where either cold or extremely hot temperatures are encountered, and the whole herd must remain inside a building.

The beds should be groomed daily, and bedding materials replenished often, such as weekly. Since the milk cows are removed multiple times per day to go to the milk barn, this provides the open space needed to perform these maintenance tasks. For the dry cows and heifers, this will not be the case.

If this alternative housing style is selected for the support stock portion of the herd, temporary additional housing space may be needed to perform the bedding grooming tasks. Displacing animals lying in the bed area could take a long time if they are all contained yet within the same pen. The simplest solution could be a concreted open corral area adjacent to several freestalls with access to water and some feed for the temporary duration. This option has not been included in the estimates provided.

Bedding is typically separated and dried manure since that is readily available, but it can also be sand, saw dust, or mattress. Some mattresses can eliminate the need for the alternative housing area for bedding maintenance since they do not need bedding materials as a cover, which could be a suitable choice for dry cows and heifers.

Sand as a bedding option requires different design in flush flow rate, slope of the freestall, slope of the flush drain lines, and sand separation. Switching a flushed freestall from manure to sand bedding will cause sand build-up in all areas of the flush system and is basically not feasible to do. However, if scraping or vacuuming, then the manure processing will require a mechanical sand separation system.

Rainfall runoff from the roof, if it had no contact with manure, could be directed into a different storage pond than the dairy wastewater. And without the use of exercise pens, the rainfall exposure area can be greatly reduced, and reduce the storage pond capacity requirements.

Housing Type 2 - Loafing Barn

A loafing barn housing area (parallel to the feed lane) is a roofed open area that is usually wider than a freestall barn and comparable to a compost barn or even wider. The size of the overall roof structure can be a preference of the dairyman.

This housing type does not necessarily take advantage of the heating process of composting to maintain suitable surface moisture. Daily grooming maintenance isn't necessary; however, bedding materials would need to be removed and replaced to maintain a dry surface for good animal health. And depending on bedding depth and maintenance, a concrete or equivalent liner under the housing area surface may be needed to keep the underlying soil dry. This could significantly increase the cost of this alternative housing type.

Rainfall and runoff storage issues are the same as a freestall barn.

Housing Type 3 - Compost Barn

Compost barns are not common in the Central Valley but are becoming popular in the eastern United States and other places around the world.

A compost barn housing area (parallel to a feed lane) is a covered area sized in relation to excretion rates of the age group. This means that the number of animals per pen needs to be maintained within the designed size. If properly sized, and with proper ventilation, the moisture of the bedded pack will remain in the 45-55% moisture range needed to support composting. With the summer temperature and humidity levels of the Central Valley, this may not be possible to maintain, but the routine tilling will keep the overall surface dry for cow comfort during this period.

This is a high maintenance housing type. Twice daily grooming is needed to 12 inches deep keeping the temperature at that depth near 110 – 140 degrees F. But with good maintenance this can keep the mastitis levels near the occurrence rates of sand bedded freestalls (*Compost-Bedded Pack Barns in Kentucky, University of Kentucky, Jeffrey Bewley PhD*). 12 to 18 inches of bedding should be the base minimum level. A perimeter concrete wall of about 4 foot allows for a deep pack to begin a cycle and build deeper over time. This allows for a once or twice a year cleanout, which could match pre-plant manure applications to the fields.

Rainfall and runoff storage issues are the same as a freestall barn.

Housing Type 4 - Concrete Surface Open Corral

This alternative animal housing type is preparing the existing corral area for a good drainage slope and laying down concrete.

Manure on concrete especially exposed to rainfall or long durations of fog, creates manure slop. As winter rains come manure will need to be removed from the corral and relocated to some acceptable area. The percent of total solids in this condition is too high for placement in a lagoon without diluting. And if stored on the ground it is too wet to stack into piles and could take up about as much footprint as the corral it is removed from. However, it could be mixed with dry or composted manure to reduce the amount of area needed for storage. Estimates provided do not include additional potential area needed for removed manure storage. A plan for what to do with this manure needs to be considered prior to implementing this type of housing.

Herd health (utter and hoof) could be issues with this alternative as well because of the constant contact with moist manure and the concrete.

This housing type would likely increase the storage capacity needs of a dairy since the rainfall runoff coefficients are higher for this type of surface.

Housing Type 5 - HDPE Lined with Soil Cover

This housing alternative is potentially not viable.

The plastic liner would have to be placed deep enough into the soil such that moisture occurring at the surface does not saturate the soil cover all the way to the plastic liner. The installation excavation costs significantly increase with depth of soil cover and could exceed the cost of concrete. Without further investigation, this could be in excess of 5 or 6 feet to ensure protection of the liner material.

Large back to back rainfall events could make saturation an issue especially with foggy conditions as well. Hooves have a high loading pressure that can penetrate wet soil and could end up damaging the plastic liner. Also corral surface grooming equipment would be limited from use in wet conditions. There would need to be drainage at the plastic layer to remove any liquid that penetrates that far. And it is difficult over the years to keep clay particles out of a geocomposite filtering drainage piping, resulting in plugging of the drainage system, and then aiding an oversaturation condition of the cover soil.

These corrals should have good slope to shed rainfall quickly to minimize penetration. But this could cause slumping of the soil on top of the plastic to the lower side of the corral over the years of high impact foot traffic of the animals in the corral. Geogrids or geocells could reduce potential slumping effects, but that additional cost has not been factored in at this time.

This lining system should have some investigative research prior to making this a viable alternative.

Respectfully,

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