REPORT OF RESULTS

DELINEATION OF AN AREA RECOMMENDED FOR THE DESIGN AND INITIATION OF A REPRESENTATIVE GROUNDWATER MONITORING NETWORK FOR EXISTING MILK COW DAIRIES, CENTRAL VALLEY, CA

Prepared for

Dairy Cares

August 31, 2010

LUHDORFF AND SCALMANINI, CONSULTING ENGINEERS
WOODLAND, CA

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1 EXECUTIVE SUMMARY

On May 3, 2007, the Central Valley Regional Water Quality Control Board (CVRWQCB) adopted *Waste Discharge Requirements General Order No. R5-2007-0035 for Existing Milk Cow Dairies* (General Order). The General Order regulates waste discharges to land at the majority of 1,429 existing dairies of all sizes and imposes significantly more stringent requirements than in the past.

Relative to groundwater monitoring, the General Order and its accompanying Monitoring and Reporting Program (MRP) specify two requirements: (1) monitoring of domestic and agricultural supply wells at dairies, and (2) additional groundwater monitoring. The latter requirement can be implemented by the Executive Officer ordering individual dairies to install monitoring wells on a phased basis. However, the General Order also authorizes the Executive Officer to approve alternative monitoring methods. The 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."

Dr. Thomas Harter of the University of California Cooperative Extension (UCCE) prepared a formal proposal outlining an alternative groundwater monitoring approach for regulatory compliance, and presented it to CVRWQCB staff and stakeholders in September 2008. A central aspect of Dr. Harter's proposal was the concept that groundwater monitoring would not be performed on every single dairy in the Central Valley, but rather be performed on a representative subset of dairies.

The CVRWQCB is presently proceeding with implementation of the General Order by issuing directives, under California Water Code Section 13267, to individual dairies that require the installation of groundwater monitoring wells. In October 2009, and parallel to this ongoing process, Dairy Cares submitted a proposal to the Executive Officer for the development of a collaborative plan that would allow representative groundwater monitoring networks to satisfy the additional groundwater monitoring requirements of the General Order.

Dairy Cares commissioned Luhdorff and Scalmanini, Consulting Engineers (LSCE) to further develop the concept of representative groundwater monitoring. LSCE presented an initial outline of the representative groundwater monitoring approach and the process for selecting a geographic region well-suited to initiate this approach to CVRWQCB staff and stakeholders in February 2010. Subsequently, the monitoring approach was presented and discussed in greater detail with the CVRWQCB's Groundwater Advisory Workgroup in March 2010.

This report discusses the technical approach that leads to the recommendation of a particular geographic region well-suited to initiate the representative groundwater monitoring approach. The technical approach (i.e., methodology), individual data components employed in the analysis, their sources, their benefits and limitations, analytical methods, and limitations of the analysis are described herein. In general, the methodology invokes parameters that are either widespread (e.g., groundwater quality data, whole farm nitrogen balance) or were derived via extensive data collection, analysis, and scaled averaging by others (e.g., recharge to groundwater, depth to groundwater, soil survey information). Therefore, the methodology places little significance on any individual data point. Instead, it places emphasis on regional comparisons.

Based on the data and analysis provided herein, the area in Stanislaus and Merced Counties between the San Joaquin River and Highway 99, is recommended as the region to initiate the representative groundwater monitoring program approach for a group of to-be-selected dairies. This region emerged as an area of very high dairy farm density and milk cow density. These two counties have consistently had the second and third largest overall herd size while other livestock operations have been comparatively minor. Based on California Department of Water Resources depth-to-groundwater contour maps and the groundwater level output from the Central Valley Hydrologic Model (CVHM), this dairy farm area overlies very shallow groundwater (i.e., <20 feet below ground surface). Soil survey data indicate a prevalence of high permeability soils in this area, and CVHM groundwater recharge estimates for this area indicate

moderate to moderately high annual recharge. Greatly elevated groundwater nitrate-N concentrations occur in this area, and an overall increase in nitrate-N concentrations is apparent since the 1980s. The recent (2000-2008) dairy-specific nitrate monitoring, most of which has predominantly been conducted in accordance with the General Order, also show elevated groundwater nitrate concentrations in this area. Lastly, Stanislaus and Merced Counties are characterized by relatively high nitrogen balances in comparison to other San Joaquin Valley dairy farms.

In coordination with Dairy Cares, UCCE, and the CVRWQCB, a group of approximately 15 to 20 dairy farms would be selected for the design and initiation of the representative groundwater monitoring program in the Stanislaus/Merced County area between the San Joaquin River and Highway 99. The dairy farms would be selected based on the review of the dairies' Preliminary Dairy Facility Assessment, Waste Management Plan, Nutrient Management Plan, Salinity Report, Annual Reports, and other pertinent documents as appropriate. Considerations in the selection process would include (but not necessarily be limited to) facility layout, facility infrastructure and operation, existing groundwater monitoring facilities and data records, and adjacent land uses. The work effort would include the retrieval and processing of site maps from potentially several dozen dairy farms.

For the selected group of dairy farms, a comprehensive monitoring well network would be designed and proposed to the CVRWQCB in a Representative Groundwater Monitoring Network Well Installation and Sampling Plan, which would be prepared in compliance with General Order Attachment A, Item B – including (but not limited to) mapped well locations, specific monitoring objectives for each well and preliminary well design(s).

It is anticipated that a comprehensive data request can be placed 2 weeks after approval to proceed. Further, it is anticipated that the Representative Groundwater Monitoring Network Well Installation and Sampling Plan can be submitted in draft format to Dairy Cares within approximately 4-6 weeks following receipt of information summarized above.

2 INTRODUCTION AND BACKGROUND

On May 3, 2007, the Central Valley Regional Water Quality Control Board (CVRWQCB) adopted *Waste Discharge Requirements General Order No. R5-2007-0035 for Existing Milk Cow Dairies* (General Order) (CVRWQCB, 2007). The General 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 CVRWQCB'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 General Order regulates waste discharges to land at the majority of 1,429 existing dairies[1] of all sizes and imposes significantly more stringent requirements than in the past.

Relative to groundwater monitoring, the General Order and its accompanying Monitoring and Reporting Program (MRP) specify two requirements: (1) monitoring of domestic and agricultural supply wells at dairies, and (2) additional groundwater monitoring. The latter requirement can be implemented by the Executive Officer ordering individual dairies to install monitoring wells on a phased basis. However, the General Order also authorizes the Executive Officer to approve alternative monitoring methods. The 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."

A formal proposal outlining an alternative groundwater monitoring approach for regulatory compliance was prepared by Dr. Thomas Harter of the University of California Cooperative Extension (UCCE) (Harter, 2008). This included a recommendation for the replacement of numerous site-by-site investigations in favor of a targeted regional monitoring approach that accounts for dairy management units (e.g., corral, manure storage lagoon, and cropland receiving manure applications) and the hydrogeologic region characterized by similar soil, climate, and hydrogeologic conditions (e.g., soil type, aquifer material, irrigation efficiency/net recharge, depth to groundwater, and groundwater flow dynamics). A

[1] As of January 2010 (personal communication with J.P. Cativiela, Dairy Cares, April 2, 2010.

central aspect of Dr. Harter's proposal was the concept that groundwater monitoring would not be performed on every single dairy in the Central Valley. Monitoring would rather be performed on a subset of dairies that would be representative of both a range of pertinent hydrogeologic conditions encountered in the Central Valley and common management practices. Dr. Harter formally presented his alternative groundwater monitoring approach to the CVRWQCB at the September 4, 2008 stakeholder meeting held at the CVRWQCB's offices in Rancho Cordova, CA. In the June 4, 2009 draft staff report on alternative groundwater monitoring options, the CVRWQCB found Dr. Harter's proposal to be infeasible, chiefly due to legal, enforcement, and funding challenges; no technical objections were raised (CVRWQCB, 2009).

The CVRWQCB is presently proceeding with the enforcement of the General Order by issuing directives, under California Water Code Section 13267, to individual dairies that require the installation of groundwater monitoring wells. Parallel to this ongoing process, Dairy Cares submitted a proposal on October 5, 2009 (Dairy Cares, 2009) to the Executive Officer for the development of a collaborative plan that would allow representative groundwater monitoring networks in a region to satisfy the additional groundwater monitoring requirements of the General Order.

Dairy Cares commissioned Luhdorff and Scalmanini, Consulting Engineers (LSCE) to further develop the concept of representative groundwater monitoring. At the February 4, 2010 stakeholder meeting held at the CVRWQCB's offices in Rancho Cordova, LSCE presented an initial outline of the representative groundwater monitoring approach and the process for selecting a geographic area well-suited to initiate the approach. Subsequently, the monitoring approach was presented and discussed in greater detail at the March 9, 2010 meeting of the Groundwater Advisory Workgroup, also held at the CVRWQCB's offices in Rancho Cordova.

3 PURPOSE OF THIS REPORT

The primary purposes of this report is to recommend a favorable area for initiating the representative groundwater monitoring approach, by identifying those areas of 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 General Order.

A secondary purpose of the work described herein is to identify areas of relatively lower priority where subsequent efforts could expand the representative groundwater monitoring approach.

4 METHODOLOGY

This section describes the methods employed to identify a favorable area where the representative groundwater monitoring program approach would be initiated. The methodology includes the (i) use and organization of readily available pertinent data, (ii) identification of favorable conditions in an area where monitoring well installation would begin, (iii) utilization of spatial analyses which use a Geographic Information System (GIS) database and mapping tool, and (iv) application of non-spatial analyses.

The methodology was developed with the recognition that existing groundwater quality conditions are the result of historical processes. It invokes parameters that are either widespread (e.g., groundwater quality data, whole farm nitrogen balance) or were derived via extensive data collection, analysis, and scaled averaging by others (e.g., recharge to groundwater, depth to groundwater, soil survey information). Therefore, the methodology places little significance on any individual data point. Instead, it places emphasis on regional comparisons.

4.1 Data Components

The following seven data components were considered:

1. Dairy locations and population densities of dairy cows
2. Non-dairy land use information
3. Depth to groundwater
4. Recharge to groundwater
5. Soil survey information
6. Shallow groundwater nitrate and salt concentrations
7. Whole farm nitrogen balance

These data components are further described below.

4.1.1 Dairy Locations and Population Densities of Dairy Cows

Rationale

Given similar management practices and hydrogeologic conditions, the number of dairy farms and the number of dairy cows in specific areas (i.e., population densities) give an indication of where impacts to groundwater are most likely to occur (i.e., in high population, high density areas) and where impacts are less likely to occur (i.e., in low population, low density areas).

Sources

- CVRWQCB
- USDA NASS

Data Description

Map coordinates for dairy farms were obtained by CVRWQCB staff via site visits and Geographic Positioning System (GPS) measurements. Dairy operators provided the maximum number of mature cows residing at their dairy to the CVRWQCB in a Report of Waste Discharge in response to the 2005 Report of Waste Discharge Request Letter[2]. Historical information on herd sizes per county is available from the United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS)[3].

Benefits

1. Knowledge of the location of dairy cow populations is critical to the spatial analysis of proportional contribution to existing groundwater quality conditions.
2. Data are widespread throughout the Central Valley (i.e., good coverage).
3. Large data volume moderates the significance of individual values and facilitates statistical evaluation.
4. Historical data record available.

Limitations

1. Knowledge of individual dairy herd sizes is not conducive to dairy-specific assessment (e.g., a small, poorly operated dairy may pose a greater risk to groundwater quality than a large, well operated dairy).
2. Total dairy sizes (i.e., their acreages) were not available for the computation of dairy-specific population densities. Population densities were approximated using a spatial algorithm.

4.1.2 Non-Dairy Land Use Information

Rationale

Human activities associated with certain land uses unrelated to dairies have been identified as potentially contributing to nutrient and salinity increases in groundwater, including non-dairy agriculture, ranches, and other livestock operations (e.g., beef, hog, sheep, and poultry farms). Consideration of non-dairy land use types is useful in the evaluation of the proportional non-dairy contribution to existing groundwater conditions.

Sources

- USGS's CVHM
- DWR
- USDA NASS

Data Description

[2] A comprehensive spreadsheet was received from CVRWQCB containing dairy farm map coordinates and herd sizes. Values for herd sizes submitted to different RWQCB offices in the Central Valley were uniformly entered in the spreadsheet.
[3] Data accessed December 1, 2009 at http://www.nass.usda.gov:80/Statistics_by_State/California/index.asp

The U.S. Geological Survey's (USGS) Central Valley Hydrologic Model (CVHM) (Faunt, Claudia C., ed., 2009) includes model input files with extensive land use information.[4] In addition, the California Department of Water Resources (DWR) gathers and compiles land use information on a county-wide basis. This information is available for some counties but inter-county differences exist between land use categorization, scales and mapping accuracy, and the times of the mapping efforts. USDA NASS maintains annual records by county on livestock herd sizes (e.g., beef cows, hogs, sheep and lambs).

Benefits
1. Facilitates the evaluation of the proportional non-dairy contribution to existing groundwater conditions.
2. Land use data are available for the entire Central Valley (i.e., good coverage).
3. Large-scale averaging ensures representation of majority land use types and facilitates regional analysis.
4. Historical data record available.

Limitations
1. Spatial accuracy of data varies.
2. Uncertain relationship between land use and proportional groundwater effects.
3. CVHM land use coverages do not differentiate dairies from feedlots and other livestock operations.
4. DWR county-wide data require substantial pre-processing prior to input to the GIS database.

4.1.3 Depth to Groundwater

Rationale
The depth to first encountered groundwater gives an indication of the thickness of the unsaturated zone. The thickness of the unsaturated zone can give an indication of the comparative sensitivity of groundwater to surface water percolation. For example, a thin unsaturated zone may be expected to provide less protection for groundwater resources than a thick unsaturated zone, which provides greater opportunity for natural attenuation to occur (other variables constant). The thickness of the unsaturated zone can also provide an indication of the relative travel time of vertical unsaturated flow to reach groundwater. Therefore, the depth to groundwater is an important component within the framework of the proposed methodology.

Sources
- USGS's CVHM
- DWR

Data Description
Hydraulic head output files from CVHM and DWR's mapped contours of equal depth to first encountered groundwater (identified as the unconfined aquifer).

Benefits
1. CVHM output synthesizes the relative effects of a large number of environmental variables estimated over the entire Central Valley (e.g., three-dimensional subsurface grain size distribution, vertical hydraulic conductivities, evaporation, topography (slope and aspect), precipitation, streamflow, land use, irrigation applications, and crop root depths).
2. Numerical values available (i.e., facilitates quantitative analysis as opposed to categorical comparison).
3. Simulated groundwater levels from CVHM were checked against field measurements during calibration.
4. Data record (1960 – 2003) supports historical assessment.

Limitation
1. CVHM output and DWR data are not applicable for site-specific assessment due to large-scale averaging.

4.1.4 Recharge to Groundwater

Rationale

[4] CVHM's land use input files are a comprehensive source of information as they were compiled from many different sources such as California Department of Water Resources (DWR), USGS Geographic Information Retrieval and Analysis System (GIRAS), and USGS North American Land Class Data.

The rate of recharge represents the link between surface water and groundwater and gives an indication of aquifer vulnerability to surface water percolation. Under certain assumptions and a given constituent concentration, the rate of recharge determines the constituent's mass loading rate to groundwater. For example, an area of low groundwater recharge is expected to be less vulnerable to contamination from surface water percolation than an area of high recharge (other variables constant). Therefore, knowledge of the vertical flux to groundwater is a useful component within the framework of the proposed methodology.

Source
- USGS's CVHM

Data Description
Vertical flux output files from CVHM[5].

Benefits
1. Synthesizes the relative effects of a large number of environmental variables over the entire Central Valley (e.g., three-dimensional subsurface grain size distribution, vertical hydraulic conductivities, evaporation, topography (slope and aspect), precipitation, streamflow, land use, irrigation applications, and crop root depths).
2. Numerical values available (i.e., facilitates quantitative analysis as opposed to categorical comparison).
3. Data record (1960 – 2003) supports historical assessment.

Limitations
1. Simulated recharge not checked against field measurements during calibration.
2. Extraction and compilation of cell-by-cell output data is very time consuming.
3. Not applicable for site-specific assessment because the modeled quantity is subject to large-scale averaging.

4.1.5 Soil Survey Information

Rationale
Soil survey information includes soil textural data that can be related to the soil's permeability. Farming practices may vary according to soil type, and soil permeability plays a key role affecting irrigation practices and efficiencies, the potential for leaching, and the availability of oxygen in shallow groundwater, which affects the fate of nitrogen components. Therefore, soil survey information was used to complement recharge rates simulated with CVHM.

Source
- Natural Resources Conservation Service's (NRCS) Soil Survey Geographic Database (SSURGO)[6]

Data Description
Compilation of extensive, detailed soil descriptions, which were generally to a maximum depth of 6 feet. 512 soil textural classes were organized according to their relative permeability and abundance in the vertical soil profile into 3 permeability categories.

Benefits
1. Data are widespread throughout the Central Valley (i.e., good coverage).
2. Soil survey data provide very detailed spatial information based on extensive field observations, sample collection, and laboratory analyses, and testing.

Limitation
1. Soil surveys are prepared on a county-by-county basis and may not use consistent textural descriptions across county boundaries.

[5] In hydrologic wet years, recharge of excess applied irrigation water is estimated to be approximately 2 times greater than stream losses. In hydrologic dry years, this ratio is amplified to approximately 6:1 (Faunt, 2009). The proportional magnitude of recharge from irrigation to groundwater demonstrates the enormous influence of irrigated agriculture on groundwater resources in the Central Valley.
[6] Data accessed March 2, 1010 at http://soildatamart.nrcs.usda.gov/

4.1.6 Shallow Groundwater Nitrate and Salt Concentrations

Rationale

Nitrogen and salts are recognized groundwater pollutants associated with confined animal facilities, including dairies. Information on shallow groundwater nitrate and salt concentrations gives an indication of existing groundwater conditions at a moment in time. The evaluation of existing conditions is a key component of the proposed methodology because it provides a relative measure of potential groundwater quality impacts associated with dairies.

Sources

- USGS National Water Information System (NWIS) including its Groundwater Ambient Monitoring and Assessment (GAMA) Priority Basins Project (implemented by the California State Water Resources Control Board [SWRCB]).
- SWRCB GeoTracker, including the newly available GeoTracker GAMA (Beta version) groundwater quality download option to spreadsheet.
- CVRWQCB

Data Description

USGS groundwater quality data are provided on-line and can be searched, for example, by region, date, constituent (e.g., nitrate and total dissolved solids), and total well depth.

SWRCB GeoTracker GAMA (Beta version) contains groundwater monitoring records from SWRCB/RWQCB, the GAMA domestic well program, USGS GAMA, Lawrence Livermore National Laboratory (LLNL) GAMA, California Department of Pesticide Regulation (DPR), DWR, and Electronic Data File (EDF) submittals from regulated facilities. These data were recently made available on-line. Data can be searched, for example, by region, date, and constituent (e.g., nitrate and total dissolved solids).

CVRWQCB data are composed of maximum nitrate concentration analytical results reported for non-barn domestic wells and on-site production wells (2007 and 2008) that were submitted by individual dairies to the CVRWQCB (Fresno and Sacramento offices) in response to the General Order. Data from a limited number of monitoring well networks on individual dairies were also available.

Benefits

1. Most of the data are readily available from various sources.
2. Data are widespread throughout the Central Valley (i.e., good coverage for wells with well depth information).
3. Large data volume moderates the significance of individual values and facilitates statistical evaluation.
4. Historical data record supports historical assessment.
5. USGS database is searchable by total well depth (i.e., facilitates analysis of targeted shallow groundwater conditions).
6. Groundwater quality data submitted by individual dairies to the CVRWQCB in response to General Order requirements provide indication of near-dairy groundwater conditions.

Limitations

1. Possible bias due to varying data density and different/unknown well construction details (e.g., location of groundwater intake sections of the wells, extent of the gravel envelope, lack of sanitary seals especially in older non-domestic wells, and damaged well casings).
2. The vast majority of data was obtained from wells that were not specifically designed to examine groundwater quality impacts. Depending on construction details, the source areas for these wells may be several miles away from the sampling point and groundwater quality data will in most cases represent a mixture of contributing sources.

4.1.7 Whole Farm Nitrogen Balance

Rationale

The whole farm nitrogen balance (N-balance) evaluated herein relates the recent annual amount of nitrogen generated on the farm to the amount of nitrogen removed with the crop harvest(s). The N-balance is expressed as a ratio including nitrogen produced by the livestock via excretion, nitrogen exports and imports, nitrogen present in irrigation water, and processes such as atmospheric deposition and volatilization of nitrogen. The N-balance is a useful, albeit approximate, indicator of the overall balance between nitrogen application to crop land and nitrogen removal from crop land.

Source
- CVRWQCB

Data Description
The N-balance is a component of the Preliminary Dairy Assessment in the Existing Dairy Conditions Report, which was due at the CVRWQCB December 31, 2007 (i.e., a required submittal under the General Order). Due to leaching losses and gaseous nitrogen losses, the N application typically exceeds the amount of N removed with the harvest. Therefore, the N-balance is typically larger than 1. The Committee of Experts on Dairy Manure Management (2006) suggested that a field N-balance of 1.4 to 1.65 is feasible in a dairy farm setting in the Central Valley. The General Order uses the value of 1.65 as an important threshold value, an exceedance of which triggers applicability of certain regulatory requirements.

Benefits
1. Dairy-specific parameter that yields a reasonable overall proportional measure of the existing nitrogen balance in 2007 (i.e., existing conditions rather than desired future conditions to be accomplished via best management practices).
2. Data are widespread throughout the Central Valley (i.e., good coverage).
3. Large data volume moderates the significance of individual values and facilitates statistical evaluation.

Limitation
1. Individual values for the whole farm nitrogen balance do not provide conclusive evidence regarding groundwater impacts.

4.2 Selection Criteria

It is important that the area selected for the initiation and demonstration of the representative groundwater monitoring approach yield adequate data to evaluate sources of potential groundwater nitrate and salt loading on dairies (e.g., corrals, manure storage lagoons, and cropland) with sufficient confidence. The area would also have attributes that allow focused evaluation of the effect of changes in farming/operational practices on groundwater quality.

A region well suited for the initial demonstration of the representative groundwater monitoring approach should have a relatively high milk cow density in combination with minor presence of other livestock operations such as to correlate high nitrate and salinity concentrations in groundwater with more certainty to dairy operations compared to other land uses. For the same reason, a preponderance of high whole farm nitrogen balances (i.e., indicating a surplus of applied nitrogen) in the area is favorable. In terms of hydrogeologic conditions, the region should exhibit high groundwater nitrate and salinity concentrations to help identify an area of impact. Further, shallow groundwater occurrence, high recharge to groundwater, and permeable soils are desirable as they reduce the lag time between surface processes and the effects on underlying groundwater, and they enhance the confidence in the delineation of cause-and-effect relationships.

5 DATA EVALUATION

5.1 Geographic Distribution of Dairy Farms and Livestock

5.1.1 Clustering and Total Head Counts

92 percent of dairies for which coordinates were available from the CVRWQCB (n=1,554)[7] are located in the San Joaquin Valley, defined here as the area extending south of the county line between Sacramento and San Joaquin Counties (**Figure 1**). Two major clusters of dairies are apparent. One extends for approximately 90 miles from southern San Joaquin County to Madera County, with the highest density of dairies along the eastern side of the San Joaquin River throughout Stanislaus County and northern Merced County. The great majority of the dairies are located east of the San Joaquin River. The second cluster extends from Fresno County into Kings and Tulare Counties. Within this large cluster, the highest density of dairies is located along the western side of Highway 99 in Kings and Tulare Counties, and also east of Highway 99 in the area south of Visalia. The remaining 8 percent of dairies are located in the Sacramento Valley and, with the exception of a few dairies, most of them are located in Glenn and Sacramento Counties.

[7] Coordinates were made available in a .shp file dated July 2009.

Based on 2005 herd size information submitted to the CVRWQCB by 1,469 dairies, 1.843 million (97 percent) of the 1.903 million mature milk cows (milk cows) in the Central Valley reside in the San Joaquin Valley, and only 59,800 head (3 percent) reside in the Sacramento Valley[8] (**Table 1**). The three most populous counties are Tulare (574,146 head), Merced (315,090 head) and Stanislaus (236,919 head), and these account for 61 percent of the milk cows in the San Joaquin Valley (**Figure 2**). Mean herd sizes are substantially skewed toward high values due to several very large dairies in most counties. The above three counties account for 65 percent of dairies in the San Joaquin Valley and have median herd sizes of 1,380, 690, and 665, respectively. Kern County (50 dairies) has by far the largest median herd size (3,278 head) with its smallest herd (535 head) not much smaller than Stanislaus County's median herd size. The overall median herd size in the San Joaquin Valley is 863 head. The median herd size clearly increases from the northern to the southern San Joaquin Valley (**Figure 3**).

Data obtained from USDA NASS[9] show that milk cow herd sizes have grown in all San Joaquin Valley counties since 1975 and that the three counties identified above as the most populous in 2005 have also historically been the most populous (**Figure 4**). In Tulare County, the milk cow population increased by a factor of 5.6 from 86,800 head in 1975 to 483,500 head in 2009 (**Attachment 1**). Over the same period of record, the milk cow population in Merced and Stanislaus Counties increased by factors of 4.0 (64,600 – 260,300 head) and 2.2 (80,400 – 179,600 head), respectively. Kings County has historically had 30,000 to 50,000 milk cows less than Stanislaus County; however, this gap has closed in recent years. Kern County, historically having one of the lowest cow populations, has experienced the most rapid growth since 2005 and now has a cow population similar to that of Stanislaus and Kings Counties.

In the Sacramento Valley, the two most populous counties are Glenn (25,024 head) and Sacramento (21,541 head) with median herd sizes of 380 and 460, respectively (see **Table 1**). These two dairies account for 78 percent of the milk cows and 88 percent of the dairies in the Sacramento Valley (see **Figure 2**). Compared to the San Joaquin Valley, cow populations have remained fairly stable in the Sacramento Valley. The milk cow population has actually decreased in several counties (see **Figure 4**). In Sacramento County, the cow population in 2009 was similar to that in 1975 (approximately 15,000 head) after temporarily increasing to 27,000 in 1989.

5.1.2 Milk Cow Densities

Large portions of counties are not occupied by dairy farms. To estimate a realistic area for each county within which dairy cows reside, a buffer was set up around every dairy. Where buffers overlapped, the area was not double counted. Therefore, this approach does not merely attach an area to each dairy; it does not equate to the simple multiplication of the number of dairies and a certain acreage (unless there is no buffer overlap such as in Butte or Placer Counties). Instead, the computation yields a density index for each county for comparative purposes. The density index is not related to the amount of cropland supporting the cow population. However, under the assumptions that only a negligible amount of manure is applied to fields outside of the buffer and only a negligible amount of manure is exported out of the total buffer area for each county, the total buffer area can be understood as the area within which most of the manure-receiving cropland is located.

This approach breaks down when the buffer radius is too small and little overlap occurs, as is essentially the case in all of the Sacramento Valley. Even in the San Joaquin Valley, where dairies are densely clustered, for a buffer radius of r = 0.5 mile, the density index (ranging from 2.3 to 7.7 head acre^{-1}) precisely mirrors the mean herd sizes (i.e., from largest to smallest: Kern, Tulare, Madera, Fresno, Kings, Merced, San Joaquin, Stanislaus) (see **Table 1**). This occurs because buffer overlap is very small.

For a buffer radius of r = 2.0 miles, the range of the density index was much smaller (from 0.39 to 1.09 head acre^{-1}) (see **Table 1**). Ranked from highest to lowest, the order of counties is Tulare, Kern, Kings, Stanislaus, Merced, Madera, Fresno, and San Joaquin. Several observations can be made. Stanislaus and Merced Counties, i.e., counties with relatively small mean herd sizes and previously ranked the lowest and third lowest, moved up to the mid range. Kings County moved up to having the third highest density index. This phenomenon is particularly striking in the case of

[8] The dairies with available herd size information do not represent a perfect subset of the 1,554 dairies provided in the 2009 .shp file; both data sets contain a small number of mutually exclusive entries.
[9] The fact that 2005 milk cow population data from USDA NASS do not match data obtained from CVRWQCB does not limit the comparative assessments among data sets.

Stanislaus County and indicates the effect of increasing buffer overlay (due to high dairy farm density), which results in the computation of a proportionally higher density in comparison to the counties where dairies are spaced farther apart (i.e., San Joaquin, Fresno, and Madera Counties – all of which have a decreased density index). Tulare County, where the mean herd size is relatively large and clustering is significant, has the highest density index (i.e., it moved up from the second highest density index). The very large mean herd size in Kern County compensates the moderate clustering in this county and results in the second highest density index.

Overall, the buffer analysis indicates that the areas of highest dairy farm densities (i.e., Stanislaus and northern Merced Counties and Kings and Tulare Counties; see **Figure 1**) also roughly coincide with the areas of highest cow population densities.

5.1.3 Other Livestock

For comparative purposes, historical records were obtained from USDA NASS for beef cows (data for 1975-1992 and 2001-2009), hogs (data from 1974-1991), and sheep and lambs (data from 1975-1992). Whereas the population of milk cows increased in all San Joaquin Valley counties, other livestock populations remained relatively stable (**Figure 5**). In most counties, milk cows have always been more populous than other livestock. Exceptions are Madera County, where an approximately equal amount of milk cows, beef cows, and sheep and lambs have been reported; Fresno County, where sheep and lambs were historically approximately twice as abundant as milk cows; and Kern County, where 9 times more sheep and lambs and twice as many beef cows than milk cows have been reported in the past.

On the other end of the spectrum, milk cows recently outnumbered beef cows by 455,500 head in Tulare County. In the other two counties with the highest milk cow population, i.e., Merced and Stanislaus, milk cows outnumbered beef cows by 230,300 and 142,600 head, respectively. In Kings County, milk cows outnumbered the very small beef cow population (7,000 head) by 173,100 head. In Kern County, where the milk cow population has grown rapidly over the past 5 years, there are now 140,100 more milk cows than beef cows.

In contrast, in the Sacramento Valley, milk cows constitute only a small proportion of all livestock (**Figures 6** and **7**). Glenn and Sacramento Counties are the only counties where milk cow and beef cow populations have been relatively similar over the period of record.

5.1.4 Summary Discussion

The geographic distribution of dairy farms in the Central Valley is one of several key factors being used to recommend an area to initiate the representative groundwater monitoring approach. In the northern San Joaquin Valley, the area in Stanislaus County between the San Joaquin River and Highway 99, and extending south into Merced County, emerged as an area of very high dairy farm density and milk cow density. These two counties have consistently had the second and third largest overall herd size, while other livestock operations have been comparatively minor. These are favorable conditions for implementation of the representative monitoring program because elevated concentrations of nitrate and salts in groundwater in such an area are more likely attributable to dairy operations than other livestock or agricultural operations (see *Section 4.2*).

In the southern San Joaquin Valley, the area west and east of Highway 99 in Kings and Tulare Counties also emerged as an area of very high dairy farm density and milk cow density. Within the period of record, Tulare County has always had the largest herd size (1.8 times larger than Merced County's herd size in 2005), has experienced rapid growth over the last two decades, and other livestock operations have been very minor. Kings County has also experienced large increases in cow population, ranks fourth in terms of its herd size, and other livestock operations have been minor.

Only 3 percent of the Central Valley milk cow population resides in the Sacramento Valley, cow populations have remained fairly stable in the Sacramento Valley, and milk cows constitute a comparatively small proportion of the total livestock.

5.2 Depth to Groundwater

Spring 2000 contours of equal depth to groundwater in the unconfined aquifer of the San Joaquin Valley were compiled from several individually prepared DWR documents, georeferenced, and mapped (**Figure 8**)[10]. The individual documents are provided in **Attachment 2**. DWR's contouring effort is limited primarily to the east side of the San Joaquin Valley. Most generally, in Stanislaus, Merced, and Madera Counties, the depth to groundwater decreases in a southwesterly direction from more than 100 feet below ground surface (bgs) near the foothills to less than 10 feet (bgs) along the San Joaquin River. Although information west of the San Joaquin River is limited, it indicates that shallow depths to groundwater are present near the valley trough on the western side of the river.

In contrast, south of the San Joaquin River in Fresno County, the depth to groundwater generally increases from the area due east of Fresno, where the Kings River flows onto the alluvial sediments of the valley floor and very shallow groundwater is indicated (i.e., less than 20 feet, bgs) toward the center of the valley trough. However, patterns appear more complex with a cone of depression beneath the City of Fresno, which is separated by a ridge of shallower groundwater from another very large cone of depression southwest of Fresno (toward the center of the valley trough) where the depth to water increases to over 180 feet (bgs). A smaller cone of depression is located southeast of Fresno.

The depth to groundwater in Tulare County generally increases from 10 to 20 feet (bgs) in the east to over 90 feet (bgs) in western Tulare County and Kings County. Beneath the Kaweah River, the depth to groundwater tends to be shallower. Many small and larger cones of depression characterize this region, and the depth to groundwater steeply declines to over 180 feet (bgs) south of the Tule River and Lake Success.

In Kern County, similar to the northern San Joaquin Valley (i.e., Stanislaus, Merced, and Madera Counties), groundwater is deep near the foothills and becomes shallower toward the valley floor. Specifically, the depth to groundwater in northern Kern County decreases from approximately 600 feet (bgs) in the east to less than 200 feet (bgs) west of Highway 99. In the southernmost portion of the valley, groundwater is about 600 feet (bgs), and it is approximately 40 feet (bgs) west of Bakersfield beneath the Kern River. North of the Kern River, the depth to groundwater is over 200 feet (bgs).

The groundwater level trends observed during Spring 2000 are generally also reflected in the decadal average depth to groundwater computed for the 1990s based on CVHM output files (**Figure 9**). For example, a pattern of decreasing depth to groundwater from more than 100 feet (bgs) to less than 20 feet (bgs) is shown for much of the east side of the San Joaquin Valley, the groundwater ridge southwest of Fresno is clearly shown, and shallow groundwater is also indicated west of the San Joaquin River. Further, the decadal map agrees with shallower groundwater existing beneath the Kaweah River and the deepening of groundwater levels toward Kern County. In contrast, the relatively deep groundwater depicted east and south of Fresno does not coincide with DWR's Spring 2000 water levels in the unconfined aquifer.

In the area of the ancient Tulare lakebed in Kings County (for which DWR water level contours are not available), CVHM output indicates very shallow groundwater[11]. Historically, the CVHM output shows a contiguous area along the longitudinal axis of the Central Valley of very shallow groundwater (**Attachment 3**). The historical decadal average depth to groundwater has been relatively stable with a trend to deeper groundwater over time in some areas such as the Tulare lakebed area and Fresno County.

Contours of equal depth to groundwater in the unconfined aquifer of the Sacramento Valley were not available from DWR. Based on CVHM output only, dairies in Sacramento County and most other places in the Sacramento Valley are situated on very shallow groundwater. Overall, groundwater levels have been relatively stable in the Sacramento Valley.

5.2.1 Summary Discussion

[10] The DWR maps are of moderate resolution, and the moderate quality of the source is reflected in Figure 8. Contoured depth to groundwater is not available for the Sacramento Valley from DWR.

[11] These very shallow groundwater conditions appear reasonable (personal communication with Dr. Thomas Harter, UCCE, March 2010). In some areas, the CVHM output files incorrectly suggested flowing artesian conditions in the unconfined aquifer; and these areas were included in the "<20 foot (bgs)" category.

Based on the DWR contour maps and the CVHM output, the area, or dairy cluster, identified as having the highest density of dairies (i.e., in Stanislaus and northern Merced Counties, between the San Joaquin River and Highway 99; see *Section 5.1*) overlies an area of very shallow groundwater. Under the dairy farm cluster in Fresno, Tulare, and Kings Counties, the depth to groundwater is more heterogeneous and ranges mainly from 40 to 80 feet (bgs), with shallower groundwater beneath the dairies located near the Tulare lakebed and deeper groundwater beneath the dairies located south of the Tule River.

Contours of equal depth to groundwater in the unconfined aquifer of the Sacramento Valley were not available from DWR. Based on CVHM output only, dairies in Sacramento County and most other places in the Sacramento Valley are situated on very shallow groundwater. Overall, groundwater levels have been relatively stable in the Sacramento Valley.

5.3 Groundwater Recharge

Simulated annual groundwater recharge was computed for DWR Water Supply Planning Regions (WSPR) and averaged over 10-year periods. According to the CVHM simulation results, the highest average annual groundwater recharge (i.e., >1.0 ft y^{-1}) in the 1990s occurred in the northern Sacramento Valley in the northern parts of Glenn and Butte Counties, Tehama, and Shasta Counties (**Figure 10**). High recharge rates (i.e., 0.76 – 1.0 ft y^{-1}) occurred along the east side of the Sacramento Valley from Butte County into much of San Joaquin County, on the west side of the Sacramento Valley in parts of Yolo and Solano Counties, and in the southern San Joaquin Valley in Fresno, Kings, and Tulare Counties. Moderately high recharge rates (0.51 – 0.75 ft y^{-1}) prevailed in most of the remaining parts of the eastern San Joaquin Valley and the western Sacramento Valley from Glenn to Yolo County. The lowest recharge rates (<0.26 ft y^{-1}) occurred on the west side from Solano County south to the Mendota area (due west of Fresno) and in the center of the Sacramento Valley in the area of the Sutter Buttes. Moderate recharge rates (0.26 – 0.50 ft y^{-1}) occurred south of Mendota in Westlands Water District and further south to Bakersfield.

The simulated groundwater recharge estimates for the 1990s and also for earlier time periods (**Appendix 4**) provide a relatively rudimentary outline of recharge patterns. This may be partly due to the substantial spatial and temporal averaging involved in the data processing. For example, very high perennial streambed infiltration may substantially increase the average recharge in a given DWR subregion, thus, giving the misleading impression that relatively high groundwater recharge occurs over a large area. This is confounded by other variables beyond soil textural properties, such as precipitation patterns (both spatial distribution and temporal variation), variable land uses, and irrigation practices. Despite these limitations, several observations can be made. First, high to very high recharge rates occur consistently in the northern Sacramento Valley, namely in the northern parts of Glenn and Butte Counties, Tehama, and Shasta Counties. Second, as a whole, recharge rates on the east side of the San Joaquin Valley are consistently higher than on the west side. Third, moderately high to high recharge rates are more common in the area of high dairy farm density in Tulare and Kings Counties than in the area of high dairy farm density in Stanislaus and Merced Counties.

5.4 Soil Permeability

Soil texture classes are most commonly specified for the upper 6 feet of the soil profile and the relative soil permeability was estimated based on 512 soil texture classes (**Attachment 5**). The soil texture of the thickest identified soil horizon was categorized and mapped. As shown in **Figure 11**, there is a sharp transition from high permeability soils on the east side of the valley (not including the foothills) to low permeability soils on the west side. This correlates well with the earlier observation that recharge rates on the east side of the San Joaquin Valley are consistently higher than on the west side (see *Section 5.3*). On the east side, a sizable area of low permeability soils is located in San Joaquin County. A second area of low (and medium) permeability is located beneath a portion of the dairy farm cluster in Kings and Tulare Counties. Overall, most dairy farms in the San Joaquin Valley appear to be located on high permeability soils. In western Merced County, between I-5 and the San Joaquin River, a large number of dairies is situated on low permeability soils.

In the northern Sacramento Valley (north of Glenn County) high permeability soils prevail. This correlates well with the earlier observation that high to very high recharge rates occur consistently in the northern Sacramento Valley. South of Tehama County, medium to high permeability soils are prevalent east of Sacramento River, whereas low permeability soils dominate on the west side. This too, correlates well to recharge patterns simulated by CVHM.

5.5 Groundwater Quality

Nitrogen and salts are recognized groundwater pollutants associated with confined animal facilities including dairies. Of the various nitrogen components that can occur in groundwater, only nitrate was considered for the purposes of this report, as it is the most mobile and abundant nitrogen form in groundwater systems. Natural nitrate concentrations in groundwater are typically very low; and high nitrate concentrations are often the result of anthropogenic activities. In contrast, chloride concentrations fluctuate widely due to natural variability of the lithologic make up of the aquifer, so it can be more difficult to distinguish contributing sources.

As discussed in *Section 4.1.6*, groundwater nitrate and chloride concentrations were obtained from three sources: (i) USGS (NWIS) including its Groundwater Ambient Monitoring and Assessment (GAMA) Priority Basins Project, (ii) SWRCB GeoTracker, and (iii) dairy-specific groundwater quality data directly from CVRWQCB. Only the USGS database is searchable by well depth, and concentrations were obtained for wells up to a total depth of 100 feet. The groundwater quality data were predominantly retrieved from wells that were not intended and constructed to yield information representative of potential dairy impacts (see *Section 4.1.6*). For example, groundwater quality data from the USGS database are collected from a variety of wells such as agricultural wells, domestic wells, municipal wells, and monitoring wells. In comparison, most of the wells in the DPH database are municipal water supply wells. These wells are typically constructed to draw water from deeper confined aquifers, and their source areas may be many miles upgradient of the wellhead where the sample is retrieved. Also, they are sited and designed to minimize potential adverse water quality impacts from anthropogenic surface processes. Finally, the data set from DPH is systematically biased toward nitrate-N concentrations below the maximum contaminant level (MCL) of 10 mg/L because sampling in wells exceeding this threshold is commonly discontinued when the well is no longer actively used as a source of supply. As a result, the data evaluated in *Sections 5.5.1* and *5.5.3* yield less focused information than data obtained from on-site dairy agricultural wells, domestic, and monitoring wells (*Section 5.5.2*).

5.5.1 Nitrate Monitoring

Nitrate-N concentrations discussed in this section are maximum concentrations summarized for 10-year increments starting in the 1960s. The well coverage of the Central Valley has changed significantly over the past 50 years. For the 1960s, nitrate concentration data were available only from the USGS and covered much of the Central Valley floor from Tehama to Kings Counties (**Figure 12**). At that time, maximum nitrate-N concentrations were below the regulatory threshold (i.e., the maximum contaminant level [MCL] for drinking water) of 10 mg/L (as N) in most wells, and most concentrations were less than half the MCL. This is also true for Stanislaus and Merced Counties. However, these two counties exhibit a proportionally higher number of concentrations between 5 and 10 mg/L compared to other counties in the Central Valley.

Nitrate data for the 1970s were also largely retrieved from the USGS database. The volume of data generated during this time had increased but monitoring efforts had clearly shifted to the Sacramento Valley where an abundance of very low (<5 mg/L) nitrate-N concentrations are documented (including the area in Glenn and Tehama Counties, where almost half of the Sacramento Valley dairy farms were located in 2005) as well as a few concentrations exceeding the MCL in areas were dairy farms are not located (**Figure 13**). Similarly low concentrations are documented in San Joaquin County, and little information is available south of San Joaquin County.

The well coverage across the valley floor increased substantially during the 1980s, as data were collected from many additional wells (**Figure 14**). Nearly all wells monitored by the USGS in the Sacramento Valley in the 1970s were subsequently discontinued. There was also very little overlap between USGS wells monitored in the 1960s and 1980s. Further, well data obtained from DPH largely covers areas in the Central Valley for which previous groundwater quality data do not exist. Nitrate-N concentrations in the 1980s were entirely below the MCL in the Sacramento Valley and this is most likely explained by the discontinued USGS effort in favor of DPH data (see *Section 5.5*). Similarly, the discrepancy between mostly low concentrations on the east side of the San Joaquin Valley (mostly DPH data) to mostly elevated concentrations in the Westlands Water District area in western Fresno County (mostly USGS data) and the Tulare Lake bed area in Kings County (mostly USGS data), is likely due, in part, to the different data sources (see *Section 5.5*). Lower recharge rates and well documented drainage challenges on the west side of the San Joaquin Valley, also contribute to comparatively elevated nitrate-N concentrations.

Data retrieved from the 1990s indicate continued reductions in the USGS monitoring program (**Figure 15**). At the same time, DPH's database experienced a moderate expansion. In general, in the areas where sufficient data overlap exists, groundwater quality conditions appear relatively similar to those during the 1980s. However, in Stanislaus County, a trend to higher concentrations is apparent.

The data collection effort substantially increased in the 2000s. Groundwater nitrate data were available from many different agencies, although the vast majority of the data were obtained from DPH (**Figure 16**). In the 2000s, the concentration of wells with reported maximum nitrate-N concentrations in excess of the MCL is apparent in the core area of the dairy farm cluster in Stanislaus and northern Merced Counties, and in the eastern area of the dairy cluster in the southern San Joaquin Valley (see *Section 5.1*).

5.5.2 Dairy-Specific Nitrate Monitoring

Nitrate-N concentrations discussed in this section constitute maximum concentrations observed in agricultural and domestic wells during 2007 and 2008, and some additional data for monitoring wells dating back to 2000. These data were submitted by dairy farms to the CVRWQCB in response to the General Order. Well construction information was not available. While monitoring wells were specifically constructed to monitor conditions in first encountered groundwater with relatively short well screen (presumably in locations where groundwater impacts were expected), domestic and agricultural wells are commonly constructed with longer intake sections, and represent a mix of shallow and deeper groundwater. Therefore, greater impacts are expected in the data obtained from monitoring wells.

5.5.2.1 Agricultural (Non-Domestic Wells)

Maximum nitrate-N concentrations in dairy agricultural wells in the Sacramento Valley were overwhelmingly below the MCL of 10 mg/L (**Figure 17**). In the dairy cluster located in the northern San Joaquin Valley, elevated concentrations were reported for a substantial amount of agricultural wells with many concentrations in excess of 20 mg/L (**Figure 18**). Elevated concentrations were especially common in the area of highest dairy farm density (in southern Stanislaus and northern Merced Counties between the San Joaquin River and Highway 99) where few values were reported below the MCL, many were reported to be 2 to 4 times greater than the MCL, and many of the very high values occurred (4 to 6 times the MCL or greater).

Nitrate-N concentrations in agricultural wells located in the dairy cluster in the southern San Joaquin Valley appear very similar (**Figure 19**). Concentrations between exceeding the MCL and up to 40 mg/L are most abundant, and a significant number of wells have concentrations above 40 and 60 mg/L. Nitrate-N concentrations tend to be lower (often below the MCL) in the southern portion of Tulare County (were the depth to groundwater increases, see *Section 5.2*) and in parts of Kings County, toward the Tulare Lake bed.

5.5.2.2 Domestic Wells

Similar to the results for agricultural wells, maximum nitrate-N concentrations in dairy domestic wells in the Sacramento Valley were overwhelmingly below the MCL of 10 mg/L (**Figure 20**). While concentrations of 2 to 4 times the MCL are common in San Joaquin, Stanislaus, and Merced Counties, such elevated concentrations are especially abundant in the area of highest dairy farm density in southern Stanislaus and northern Merced Counties (**Figure 21**). In this area, concentrations ranging from 4 to 6 times the MCL occur frequently, and concentrations in excess of 60 mg/L are common.

Although elevated nitrate-N concentrations (2 to 4 times the MCL) in dairy domestic wells located in the dairy cluster in the southern San Joaquin Valley are common, they are not nearly as prevalent as in the dairy farm area in southern Stanislaus and northern Merced Counties. A large number of concentrations below the MCL are reported in Fresno and Kings Counties (**Figure 22**). Also, similar to a trend observed in agricultural wells, Nitrate-N concentrations tend to be lower (often below the MCL) in the southern portion of Tulare County (were the depth to groundwater increases, see *Section 5.2*). In general, high concentrations (i.e., in excess of 40 mg/L) are less common in domestic wells than in agricultural wells.

5.5.2.3 Monitoring Wells

The data set for monitoring well nitrate-N results is much smaller than for agricultural and domestic wells and focuses on the southern San Joaquin Valley; only one data point is available north of Madera County (**Figure 23**). At nearly all

dairies where monitoring well samples were retrieved, elevated nitrate-N concentrations were reported. This is not the case for several dairies in southern Kern County.

5.5.3 Chloride Monitoring

The dataset for chloride is similarly affected by changes in well coverage of the Central Valley as discussed in *Section 5.5.1* for nitrate. For the 1960s, chloride concentration data were available only from the USGS and covered much of the Central Valley floor from Tehama to Kings Counties (**Figure 24**). At that time, maximum chloride concentrations were very low (<50 mg/L) to low (50 - <150 mg/L) in the Sacramento Valley and most of the San Joaquin Valley east of the San Joaquin River. The abundance of high chloride concentrations is apparent on the west side of the San Joaquin River.

Chloride data for the 1970s were also largely retrieved from the USGS database. The volume of data generated during this time had increased but monitoring efforts had clearly shifted to the Sacramento Valley with an abundance of data indicating predominantly very low chloride concentrations (**Figure 25**). Some higher chloride concentrations are apparent in the Natomas area in Sutter County, an area where no dairies exist. As in the 1960s, some higher chloride concentrations are also documented in San Joaquin County, west of the San Joaquin River. Little information is available south of San Joaquin County.

The well coverage across the valley floor increased substantially during the 1980s, as data were collected from many additional wells (**Figure 26**). In the 1980s, most of the wells in the Sacramento Valley that had been monitored by the USGS in the 1970s were no longer monitored. However, the data volume increased in Yolo and Solano Counties (both counties historically had very little dairy farming activities, but they do have a proportionally bigger sheep and beef industries). There was also very little overlap between USGS wells monitored in the 1960s and 1980s. Further, data obtained from DPH largely covers areas in the Central Valley that were not previously covered. The discrepancy between mostly low concentrations on the east side of the San Joaquin Valley (mostly DPH data) to mostly elevated concentrations in the Westlands Water District area in western Fresno County (mostly USGS data) and the Tulare Lake Bed area in Kings County (mostly USGS data), is likely due, in part, to the different data sources (see *Section 5.5*). Lower recharge rates and well documented drainage challenges on the west side of the San Joaquin Valley, also contribute to comparatively elevated nitrate-N concentrations. Lastly, shallow groundwater in the Westlands Water District area and the vicinity of the Tulare lakebed has naturally high salinity. Higher chloride concentrations are also documented south of Bakersfield.

Data retrieved from the 1990s indicate continued reductions in the USGS monitoring program and an increase in DWR data (**Figure 27**). Chloride concentrations in the Sacramento Valley remained predominantly low in the 1990s. In general, in the areas where sufficient data overlap exists, groundwater quality conditions appear similar to those during the 1980s. Slight trends to higher chloride concentrations are apparent in Stanislaus and Tulare Counties along Highway 99.

The data collection effort substantially increased in the 2000s. Groundwater chloride data were available from many different agencies, although the vast majority of the data were obtained from DPH (**Figure 28**). Due to the increased data density, generally higher chloride concentrations are apparent on the west side of the San Joaquin Valley compared to the east side.

5.5.4 Summary Discussion

The most recent nitrate data (not specific to dairy farms), i.e., for the 2000s, are useful as they exhibit a correlation between elevated groundwater nitrate-N concentrations in the two areas with the highest milk cow populations (i.e., in Stanislaus and northern Merced Counties between the San Joaquin River and Highway 99 and in Kings and Tulare Counties west and east of Highway 99. In the area of the dairy farm cluster in Stanislaus and northern Merced Counties, a trend to higher nitrate-N concentrations is apparent since the 1980s. In the area of the dairy farm cluster in Kings and Tulare Counties, comparison of 1990s data to conditions in the 2000s shows a trend to higher nitrate-N concentrations. This increase occurred during a time when the herd size in Tulare County more than doubled.

The chloride data (not specific to dairy farms) identified historically higher salinities on the west side of the San Joaquin Valley than on its east side, and generally low concentrations in the Sacramento Valley. A slight trend to higher chloride concentrations in the area of the dairy farm cluster in Stanislaus and northern Merced Counties is apparent in the 1990s.

Overall, the chloride data do not significantly contribute to the identification of areas potentially impacted by dairy farm operations.

The results from the recent dairy-specific nitrate monitoring clearly identify the dairy farm area in Stanislaus and northern Merced Counties between the San Joaquin River and Highway 99 as being correlated with the greatest number of elevated groundwater nitrate concentrations.

5.6 Whole Farm Nitrogen Balance

The whole farm nitrogen balance (N-balance) evaluated herein relates the recent annual amount of nitrogen generated on the farm to the amount of nitrogen removed with the crop harvest(s) over the same time period. The N-balance is expressed as a ratio including nitrogen produced by the livestock via excretion, nitrogen exports and imports, nitrogen present in irrigation water, and processes such as atmospheric deposition and volatilization of nitrogen.

As stated in *Section 4.1.7*, the application of nitrogen to the crop fields typically exceeds the amount of nitrogen removed with the harvest to account for leaching losses and gaseous nitrogen losses. Consequently, the N-balance is typically larger than 1.00. An N-balance smaller than 1.00 indicates that less nitrogen (either from manure, commercial fertilizers, or both) was applied to the fields (on a whole farm scale) than removed by the crop harvest. This condition implies a depletion of soil nitrogen and is not sustainable. In most cases, these balances are believed to be the result of a systematic error in the computation of the N-balance (personal communication with Dr. Thomas Harter, UCCE, March 5, 2010). The General Order uses the value of 1.65 as an important threshold value, an exceedance of which triggers applicability of certain regulatory requirements.

While dairies in the San Joaquin Valley reported the greatest values for N-balances, these occurrences were few. With the exception of a few outliers, the N-balance distributions for the Sacramento and San Joaquin Valleys are very similar with first quartile values of 1.15 and 1.21, medians of 1.60 and 1.61, and third quartile values of 2.08 and 2.43, respectively (see **Table 1**). In the Sacramento Valley, 22 percent of dairies have an N-balance smaller than 1.00 (in the San Joaquin Valley, it is 17 percent). In both the Sacramento and San Joaquin Valleys, 54 percent of dairies have an N-balance smaller than 1.65. This means that the N-balance exceeds the threshold value of 1.65 at 46 percent of all dairies for which N-balances were submitted to the CVRWQCB.

A scatter plot of the whole farm N-balance in relation to dairy herd size shows that herd size is not a useful predictor for the N-balance and demonstrates the similarity between Sacramento and San Joaquin Valley dairies (**Figure 29**). Among larger dairies (i.e., dairies with more than approximately 2000 head), fewer dairies exist with high N-balances. Also, dairy farms in Stanislaus and Merced Counties exhibit proportionally more high N-balances than Kings and Tulare Counties.

The similarity of the N-balances from dairies in the Sacramento and San Joaquin Valleys is shown with box-and-whisker plots and supported by the low confidence in the Kruskal-Wallis H-statistic[12] (**Attachment 6**). In contrast, grouping by county yields significant differences (very high H-statistic supported by high confidence) although median values are relatively similar. Merced and Stanislaus Counties stand out as counties with relatively high median N-balances, and the most outliers and extreme values.

5.7 Summary of Key Findings and Identification of High Priority Region

In the northern San Joaquin Valley, the area in Stanislaus County between the San Joaquin River and Highway 99, and extending south into Merced County, emerged as an area of very high dairy farm density and milk cow density. These two counties have consistently had the second and third largest overall herd size while other livestock operations have been comparatively minor. Based on the DWR depth-to-groundwater contour maps and the CVHM groundwater level output, the above Stanislaus/Merced dairy farm area overlies very shallow groundwater (i.e., <20 feet, bgs). SSURGO soil data indicate a prevalence of high permeability soils in this area, and CVHM groundwater recharge estimates for this area indicate moderate to moderately high annual recharge. Greatly elevated groundwater nitrate-N concentrations occur in this area, and an overall increase of nitrate-N concentrations is apparent since the 1980s. The results from the recent

[12] The nonparametric Kruskal-Wallis group comparison indicates the rejection of the null hypothesis (the null hypothesis states that there is no difference between groups) by an H-statistic greater than 1.00. However, the confidence in this result is low, as indicated by a high p-value (0.1714).

(2007-2008) dairy-specific nitrate monitoring also show elevated groundwater nitrate concentrations in this area. Lastly, Stanislaus and Merced Counties are characterized by relatively high N-balances in comparison to other San Joaquin Valley dairy farms.

In the southern San Joaquin Valley, the area west and east of Highway 99 in Kings and Tulare Counties also emerged as an area of very high dairy farm density and milk cow density. Tulare County has always had the largest herd size (1.8 times larger than Merced County's herd size in 2005), has experienced substantial growth of the milk cow population over the last two decades while other livestock operations have been very minor. Kings County has also experienced large increases in cow population and ranks fourth in terms of its herd size; other livestock operations have been very minor. Based on the DWR depth-to-groundwater contour maps and the CVHM groundwater level output, the depth to groundwater beneath the Tulare/Kings dairy farm cluster is deeper and more heterogeneous (ranging mainly from 40 to 80 feet, bgs) than beneath the high density dairy farm area in Stanislaus and northern Merced Counties, with shallower groundwater beneath dairies near the Tulare lakebed and substantially deeper groundwater south of Tule River. CVHM recharge estimates for this area indicate predominantly high annual recharge. These model results are consistent with the prevalence of high permeability soils in this area. The area of low permeability soils west of Highway 99 in Tulare County also roughly corresponds to deeper water levels. Groundwater nitrate-N concentrations from the 1990s compared to those from the 2000s indicate an increasing trend. This increase occurred during a time when the herd size in Tulare County more than doubled. The results from the recent (2007-2008) dairy-specific nitrate monitoring also indicate elevated nitrate-N concentrations in this area. Lastly, N-balances in this area are similar to the rest of the San Joaquin Valley.

Only 3 percent of the Central Valley milk cow population resides in the Sacramento Valley, cow populations have remained fairly stable in the Sacramento Valley, and milk cows constitute a comparatively small proportion of all livestock. Contours of equal depth to groundwater in the unconfined aquifer of the Sacramento Valley were not available from DWR. Based on CVHM groundwater level output only, dairies in Sacramento County and most other places in the Sacramento Valley are situated on very shallow groundwater. However, the recent maximum nitrate-N concentrations in agricultural and domestic wells located on dairy farms in the Sacramento Valley are predominantly below the MCL.

The analyses and findings presented in this report indicate that elevated nitrogen-N concentrations in the area in Stanislaus and Merced Counties between the San Joaquin River and Highway 99 area are substantially attributable to dairy operations. Furthermore, the prevalence of high permeability soils in combination with very shallow depths to groundwater, high nitrate-N concentrations, and relatively high N-balances present favorable baseline conditions, as future changes in field and management practices are likely to positively affect groundwater quality more rapidly than in other regions. Therefore, this area is recommended as the region to initiate the representative groundwater monitoring program approach for a group of to-be-selected dairies (**Figure 30**).

6 LIMITATIONS OF THE ANALYSIS

Two data components used in the analysis were less useful than initially expected. First, the groundwater recharge estimates simulated with CVHM provided a relatively rudimentary outline of recharge patterns. This may have been partly due to the substantial spatial and temporal averaging involved in the data processing, and was likely confounded by other variables, such as precipitation patterns (both spatial distribution and temporal variation) and variability of land uses and irrigation practices, i.e., variables beyond soil textural properties. Second, the chloride data did not significantly contribute to the identification of areas potentially impacted by dairy farm operations due to the naturally high spatial variability of chloride in groundwater and its ubiquitous nature. Overall, the above data limitations did not affect the confidence in the recommendation summarized in *Section 5.7*.

7 PREPARATION OF REPRESENTATIVE MONITORING NETWORK DESIGN

In coordination with Dairy Cares, UCCE, and the CVRWQCB, a group of approximately 15 to 20 dairy farms would be selected for the design and initiation of the representative groundwater monitoring program in the Stanislaus/Merced County area between the San Joaquin River and Highway 99 (see **Figure 30**). The dairy farms would be selected based on the review of the dairies' Preliminary Dairy Facility Assessment, Waste Management Plan, Nutrient Management Plan, Salinity Report, Annual Reports, and other pertinent documents as appropriate. Considerations in the selection process would include (but not necessarily be limited to) facility layout, facility infrastructure and operation, existing groundwater monitoring facilities and data records, and adjacent land uses. The work effort would include the retrieval

and processing of site maps from potentially several dozen dairy farms. Individual dairy site maps would be prepared to show all of the following (as available):

- existing groundwater wells (e.g., domestic, agricultural, and monitoring wells),
- corrals, freestalls, exercise areas, milking parlors, and other areas where cows reside,
- manure holding ponds and other manure drying and/or storage areas,
- storage and handling areas for commercial fertilizers,
- crop land with an indication of the slope of the ground and location of tile drains,
- above ground and underground conveyance facilities for manure, stormwater, and any other wastes,
- septic systems and leach lines,
- roads, buildings, property lines,
- existing and/or past dumping areas, and
- any other facilities or items that may be relevant to the design of the monitoring well network.

For the selected group of dairy farms, a comprehensive monitoring well network would be designed and proposed to the CVRWQCB in a Representative Groundwater Monitoring Network Well Installation and Sampling Plan, which would be prepared in compliance with General Order Attachment A, Item B – including (but not limited to) mapped well locations, specific monitoring objectives for each well and preliminary well design(s).

It is anticipated that a comprehensive data request can be placed 2 weeks after approval to proceed. Further, it is anticipated that the Representative Groundwater Monitoring Network Well Installation and Sampling Plan can be submitted in draft format to Dairy Cares within approximately 4-6 weeks following receipt of information summarized above.

8 REFERENCES

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Tables

Table 1: Dairy Farm Statistical Information by County

		Sacramento Valley Counties								San Joaquin Valley Counties								
Statistic	All Dairies	Glenn	Placer	Sacramento	Solano	Sutter	Yolo	Yuba	***Total***	Fresno	Kern	Kings	Madera	Merced	San Joaquin	Stanislaus	Tulare	***Total***
No. of dairies who submitted herd size	1,469	47	1	41	3	1	3	4	*100*	101	50	143	45	309	134	286	301	*1,369*
Total Head	1,903,035	25,024	1,093	21,541	4,161	633	3,773	3,619	*59,843*	151,142	177,546	188,330	77,673	315,090	122,347	236,919	574,146	*1,843,193*
Density Index ($r_{2.0}$ = 2 mi)	-	0.2	0.1	0.2	0.2	0.1	0.2	0.2	-	0.42	0.86	0.72	0.46	0.57	0.39	0.60	1.09	-
Density Index ($r_{0.5}$ = 0.5 mi)	-	1.2	1.7	1.3	2.2	1.0	2.9	1.9	-	3.3	7.7	3.3	3.5	2.7	2.5	2.3	4.6	-
Herd Size (mean)	1,295	532	na	525	1,387	na	1,258	905	*598*	1,496	3,551	1,317	1,726	1,020	913	828	1,907	*1,346*
Herd Size (median)	805	380	na	460	1,084	na	407	990	*405*	1,041	3,278	1,001	863	690	656	665	1,380	*863*
Herd Size (min)	58	58	na	130	288	na	146	351	*58*	161	535	117	265	92	127	115	92	*92*
Herd Size (max)	11,242	3,450	na	1,668	2,789	na	3,220	1,288	*3,450*	10,457	10,230	6,797	8,137	7,173	3,790	4,140	11,242	*11,242*
Herd Size (0.25 percentile)	495	170	na	276	686	na	277	700	*253*	500	1,806	678	575	403	403	403	863	*529*
Herd Size (0.75 percentile)	1,553	661	na	633	1,937	na	1,814	1,195	*770*	1,955	4,514	1,478	2,530	1,141	1,205	1,028	2,318	*1,610*
No. of dairies who submitted N-balance	1317	44	1	39	3	1	3	4	*95*	84	46	119	41	274	118	251	289	*1,222*
N-balance (mean)	3.55	1.80	2.11	1.73	2.91	1.13	1.94	1.61	*1.80*	18.7	1.62	5.57	2.03	2.84	1.93	2.66	1.54	*3.69*
N-balance (median)	1.61	1.58	na	1.60	2.23	na	1.95	1.74	*1.60*	1.52	1.47	1.51	1.67	2.06	1.56	1.98	1.48	*1.61*
N-balance (min)	-12.3	0.49	na	0.03	0.99	na	0.90	-0.66	*-0.66*	0.17	0.64	0.02	0.38	-12.3	-8.48	-6.17	0.01	*-12.30*
N-balance (max)	1,292	8.41	na	9.55	5.50	na	2.96	3.61	*9.55*	1,292	3.78	440	7.56	53.5	23.3	16.7	8.11	*1,292*
N-balance (0.25)	1.20	1.14	na	1.22	1.61	na	1.43	1.02	*1.15*	0.99	1.19	1.15	1.20	1.27	1.29	1.30	1.14	*1.21*
N-balance (0.75)	2.39	2.08	na	1.86	3.87	na	2.46	2.32	*2.08*	2.36	1.73	2.00	2.35	3.25	2.28	3.36	1.73	*2.43*
N-balance (N <= 1.00)	232	10	0	8	1	0	1	1	*21*	23	7	21	7	46	17	43	47	*211*
N-balance (1.00 < N <= 1.65)	481	13	0	15	0	1	0	1	*30*	30	25	56	13	58	47	61	161	*451*
N-balance (1.65 < N <= 3.00)	387	17	1	14	1	0	2	1	*36*	16	11	30	15	92	41	73	73	*351*
N-balance (N > 3.00)	217	4	0	2	1	0	0	1	*8*	15	3	12	6	78	13	74	8	*209*

Herd size (i.e., maximum number of mature cows) according to Report of Waste Discharge submitted in response to CVRWQCB 2005 Report of Waste Discharge letter.

Whole farm nitrogen balance according to Preliminary Dairy Assessment in the Existing Dairy Conditions Report due December 31, 2007.