UNITED STATES DISTRICT COURT
EASTERN DISTRICT OF WASHINGTON

UNITED STATES OF AMERICA,

Plaintiff,

v.

COW PALACE, LLC, *et al.*,

Defendants.

Civil No. 24-cv-03092-TOR

DECLARATION OF GREGORY SCHNAAR IN SUPPORT OF PLAINTIFF UNITED STATES' MOTION FOR PRELIMINARY INJUNCTION

I, Gregory Schnaar, hereby declare:

1. My name is Gregory Schnaar.

2. I am over 18 years of age and I am competent to make this Declaration on behalf of Plaintiff United States.

3. I am a Principal Hydrogeologist with Daniel B. Stephens & Associates, Inc. I received a B.S. degree in Environmental Science and Policy (magna cum laude) from the University of Maryland, College Park in 2002 and a

PhD in Soil, Water and Environmental Science, with a minor in Hydrology, from the University of Arizona in 2006. I specialize in watershed-scale hydrologic studies, groundwater and vadose zone modeling, contaminant transport, and carbon capture and storage ("CCS"). I have managed a variety of environmental and water resource investigations throughout the United States. I am an Associate Editor of the peer-reviewed journal *Groundwater*, and have taught courses in Environmental Science and Water Resources as a faculty member (2014 to 2017) and adjunct faculty member (2021) at the University of Maryland, College Park and an adjunct faculty member at George Washington University. I am a Certified Professional Geologist in Virginia.

4. I have been retained by the United States Department of Justice and offer this Declaration in support of the United States' Motion for Preliminary Injunction in the above-captioned matter.

5. I have previously evaluated nitrogen transport in groundwater and the vadose zone from concentrated animal feeding operations ("CAFOs"), septic systems, agricultural operations, food processing facilities, and other sources. For example, I previously developed a regional-scale linked watershed/groundwater model of the Ventura River watershed in California and an associated nitrogen loading and transport model to assess impacts of various land uses and operations on nitrogen loading to groundwater and surface water. I also previously evaluated

nitrogen transport in the vadose zone, groundwater, and groundwater discharging to surface water at an equestrian facility (CAFO) in southern California.

6. My previous expert witness oral testimony (deposition, trial and arbitration hearings) has included the following:

- Commonwealth of Pennsylvania, etc. v. Exxon Mobil Corporation, et al. In Re: MTBE Products Liability Litigation MDL 1358, Case No. 14-cv-06228. United States District Court, Southern District of New York. Deposition July 2022.
- Santa Barbara Channelkeeper, Petitioner, vs. State Water Resources Control Board, City of San Buena Ventura, Respondents; City of San Buena Ventura, Cross-Complainant vs Duncan Abbott et al., Cross Defendant. Case No. 19STCP01176. Superior Court of the State of California for the County of Los Angeles, Complex Civil Division. Deposition February 2022.
- BASF Corporation, Claimant vs. Ferro Corporation, Respondent. Arbitration, CPR – International Institute for Conflict Prevention and Resolution. April 2021 Deposition, July 2021 Arbitration Hearing.
- Clean Harbors, Inc., Plaintiff, vs. Union Pacific Corporation, Defendant. Case No. C.A. No. N15C-07-081 MMJ CCLD. Superior Court of the State of Delaware. January 2017 Deposition, May 2017 Trial.

Questions Posed

7. I was asked to answer the following questions regarding certain Dairies in the Lower Yakima Valley ("LYV"):

8. Where is the groundwater nitrate contamination in the vicinity of "the Dairies" (as defined in Paragraph 17) coming from, are the Dairies likely a significant source, and what is the likelihood that there are sources other than the Dairies?

9. What is the likely spatial extent of nitrate contamination emanating from the Dairies?

10. Based on available data, can you discern any trends in the concentrations and/or areal extent of groundwater nitrate contamination since the Dairies' implementation of the 2013 Administrative Order on Consent (Consent Order; EPA, 2013a)?

11. Are you able to quantify or otherwise evaluate the effects on groundwater nitrate contamination, if any, of source control and other measures the Dairies were required to implement pursuant to the 2015 Consent Decrees resolving the Community Association for Restoration of the Environment ("CARE") litigation?

12. What ongoing nitrate groundwater monitoring activities should be performed at the Dairies and downgradient areas?

Information Reviewed

13. I reviewed documents provided to me by the Department of Justice, including the 2013 Administrative Order on Consent ("Consent Order") related to the Dairies (EPA, 2013a), quarterly and annual Dairies monitoring reports, CARE litigation consent decrees, U.S. Geological Survey ("USGS") reports, the EPA (2013b) investigation of nitrate contamination in the LYV, and a residential well sampling report (Arcadis, 2014). In addition, I independently obtained separate USGS studies of the Yakima Valley, and coordinated with USGS staff to obtain USGS modeling files (discussed below). I obtained nitrate concentration and well information data from the Washington State Department of Ecology Environmental Information Management ("EIM") database. Data and studies I have relied on in forming opinions in this matter are cited within this declaration and are listed in the references section.

14. I received MODFLOW modeling files from the USGS corresponding to the report N*umerical Simulation of Groundwater Flow for the Yakima River Basin Aquifer System, Washington* (Ely et al., 2011) and MODPATH modeling files corresponding to the report *Particle Tracking for Selected Groundwater Wells in the Lower Yakima River Basin, Washington* (Bachmann, 2015). The MODFLOW model of the Yakima River Basin encompasses the entire Yakima River Valley including groundwater in shallow basin fill aquifers and basalt flows.

On a regional basis, the MODFLOW model met industry standards for adequate model calibration as documented in Ely et al. (2011). The relevant area surrounding the Dairies is a small portion of the larger regional Yakima River Basin and MODFLOW model. Based on my review of the USGS MODFLOW files, model-simulated groundwater levels in the vicinity of the Dairies are significantly lower than observed values (reported in groundwater elevation monitoring data provided by the Dairies and from Vaccaro et al., 2009), and the model calibration is not adequate for the model to be used for detailed site-specific groundwater flow and transport predictions in this particular area. Therefore, I have not relied on the USGS numerical modeling results or model files to form the basis of my opinions.

15. My opinions are based on the data that were available to me at the time these opinions were rendered. As additional reports or information become available, I may supplement or modify the contents and opinions in this declaration or add other opinions.

Background Hydrogeology

16. The Dairies are located within the LYV, which is a portion of the larger Yakima River Valley in central Washington State (Exhibit 1). Several groundwater basins are present within the Yakima River Valley that overlie basalt flow geologic units. The Dairies are located within the Extended Toppenish Basin

(Vaccaro et al., 2009), which consists of unconsolidated coarse and fine-grained sediments ("basin fill") that are thin near the basalt outcrops and as thick as several hundred feet in the vicinity of the Dairies. Groundwater is present in the basin fill and underlying basalt geologic units that is used for domestic and irrigation supply.

17. The Dairies consist of Cow Palace, LLC ("Cow Palace Dairy"), George DeRuyter and Son Dairy, L.L.C., George & Margaret, L.L.C., and D and J Dairy, L.L.C. (f/k/a D and A Dairy, L.L.C.) ("DeRuyter Dairy"), and Liberty Dairy, LLC and its associated Dairy Facility H&S Bosma Dairy ("Bosma Dairy"), and include land parcels used in connection with the Dairies' operations. As reflected in the attached Exhibits, reports by the Dairies' consultant, Anchor QEA, refer to DeRuyter Dairy as: "George DeRuyter & Son/D&A Dairies" or "George Dairy/D&A Dairy" or "GDS/D&A"; and Bosma Dairy as "Liberty/H&S Bosma Dairies" or "Liberty/Bosma Dairy." The approximate boundary of the Dairies, as given in Anchor QEA (2023c), is displayed on Exhibit 2, and the approximate Dairies boundaries modified based on geographic data provided by EPA (2024) is displayed on Exhibit 3.

18. The Dairies are located 4 miles north of the Yakima River. Land surface generally slopes toward the south from the basalt outcrops north of the Dairies toward the Yakima River, and groundwater in the basin fill units generally also flows toward the south. Exhibit 3 displays groundwater elevation contours

from Vaccaro et al. (2009) at the Dairies and surrounding area, and shows that groundwater flows toward the south, southwest, and south-southwest with an approximate hydraulic gradient ranging from 0.001 to 0.01 (unitless, or feet per feet; groundwater flows perpendicular to elevation contour lines). Groundwater elevation surface maps developed by Dairies' consultants similarly show groundwater flows to the south-southwest (Exhibit 2). Depth to groundwater generally ranges from 20 to 230 feet below ground surface at the Dairies and occurs at an elevation of 850 to 1,050 feet above mean sea level (Anchor QEA, 2023c).

19. Basin fill sediments where groundwater occurs beneath the Dairies are generally described as sands and gravels. For example, Exhibit 4 is a cross section location map for cross sections developed by Arcadis (consultants to the Dairies), and Exhibit 5 displays one Arcadis cross section (G-G') that is oriented north-to-south in the center of the Dairies. On the Arcadis cross section, the groundwater table (upper surface of the water saturated zone) is interpreted to occur within weathered basalts/basalts to the north and sands and gravels throughout the remainder of the section. Anchor QEA (2023a) reports that approximately 0.5 miles south of the Dairies the basin-fill aquifer transitions from unconfined (no low permeability silt/clay layer present above the aquifer) to confined/semi-confined.

20. I developed two additional cross-sectional diagrams to display the thickness of basin fill sediments, groundwater surface elevation, observed nitrate concentrations, and well locations at the Dairies and downgradient. Cross section A-A' extends from north of the Dairies to 3 miles south of the Dairies (Exhibit 6), and cross section B-B' is oriented from west-to-east along the Dairies' southern boundary (Exhibit 7). These cross sections demonstrate that land surface elevation and groundwater elevation slope from north to south toward the Yakima River. Basin fill thickness increases moving southward, to a maximum of approximately 340 feet at the southern extent of the Dairies, and then thins somewhat moving farther south toward the Yakima River. The Dairies' monitoring wells and several supply wells are plotted on the cross sections that are screened within the basin fill.

Opinion 1: The Dairies are a source of nitrate to groundwater in the LYV in addition to other sources that are present.

21. Sources of nitrate at the Dairies have included lagoons, animal waste storage facilities, and liquid manure sprayed on fields. High-nitrogen facility wastewater has historically been held or disposed of in settling ponds and lagoons, where it recharges groundwater. The Dairies' manure typically exceeds 500 milligrams per liter (mg/L) total nitrogen in lagoon water, and 5,000 milligrams per kilogram (mg/kg) total nitrogen in solid compost (Anchor QEA, 2023c). As recently as Fall 2022, total nitrogen was as great as 2,055 mg/L in lagoon water

(Bosma Lagoon 7, see Anchor QEA, 2023c Table 8a). Nitrogen is carried downwards past the ground surface into the soil in percolating wastewaters, irrigation waters, and precipitation that contacts high-nitrogen solids (Exhibit 8). Nitrogen that infiltrates into the soil is present in various inorganic and organic forms. Some nitrogen in the vadose zone (i.e., the vertical interval below the ground surface and above the groundwater table) is converted to the nitrate inorganic form via a process referred to as nitrification. Some nitrogen will be immobilized in the vadose zone by plants or microbial uptake and some will be converted to nitrogen gas and emitted to the atmosphere ("denitrification"). However, it is typically assumed that only 10 to 25% of nitrogen in wastewaters will be lost from the subsurface due to denitrification and uptake by plants and microbes is minor (e.g., Hantzsche and Finnemore, 1992). Nitrate will percolate downwards and discharge to groundwater if no continuous low-permeability lenses are present in the vadose zone to restrict downwards migration. Nitrate does not sorb on to the solid soil fraction and is therefore considered to be highly mobile in soils and the vadose zone, leaching readily into groundwater (Brady and Weil, 1999).

22. Once in the groundwater, nitrate is transported in the direction of groundwater flow and is spread throughout portions of the aquifer forming groundwater plumes. Nitrate is highly mobile in groundwater, with no sorption

onto aquifer solids (Rivett et al., 2008) and typically only minor denitrification occurs within unconfined groundwater aquifers (e.g., Green et al. 2008). Therefore, nitrate emanating from the Dairies migrates downgradient and contaminates off-site groundwater.

23. In addition to the Dairies, other potential sources of nitrate in the LYV include separate dairy operations, septic systems, irrigated agriculture, residential fertilizer, compost areas, and atmospheric deposition (WSDA, 2017).

24. Exhibit 9 displays a map of the Dairies overlaid with known locations of residential and commercial septic systems, settling ponds, lagoons, CAFOs and compost areas. I developed Exhibit 9 using GIS data created by the Washington State Department of Agriculture ("WSDA") from review of 2013 aerial imagery, known dairy locations registered by WSDA, and random sampling via windshield surveys (Yakima County, 2020). Facility locations mapped on Exhibit 9 may not be current, and other nitrate sources may be present. However, Exhibit 9 shows that the Dairies are in an area that has historically included other potential nitrate sources, including lagoons that are not on the Dairies' property. Where multiple nitrate sources are present and contaminate groundwater, the resulting nitrate contamination from each of the facilities will blend together and form commingled plumes.

25. I further evaluated the locations of nitrate sources by compiling available nitrate groundwater data and developing maps of nitrate concentrations in groundwater. Source areas are identified on nitrate concentration maps as areas that exhibit relatively higher concentrations than the surrounding areas ("hot-spots"). Nitrate data were obtained from Dairies' quarterly monitoring reports (Anchor QEA, 2023a; 2023b) and from Washington Department of Ecology's Ambient Groundwater Monitoring Network (EIM database). Exhibit 10 provides a map of maximum nitrate concentrations in groundwater for 2022. Data on Exhibit 10 indicate higher nitrate concentrations at the Dairies (greater than 50 milligrams per liter nitrate as nitrogen [mg/L-N]) than in surrounding areas, which supports that the Dairies are a source of nitrate to groundwater. Nitrate concentrations upgradient of the Dairies and at the Dairies' upgradient (northern) property boundary are generally low (less than the maximum contaminant level [MCL] of 10 mg/L-N), indicating that the Dairies are the predominant source of nitrate within the Dairies' properties themselves and at the Dairies' downgradient (southern) boundary. The highest nitrate concentration observed is at DC-03, which is located at the Dairies' southern property boundary downgradient of Dairy sources and exhibits nitrate on average more than 15 times greater than the MCL.

26. Exhibit 11 displays nitrate concentration contours interpolated by kriging from the 2022 data (kriging is an interpolation technique in which the

surrounding measured values are weighted to derive a predicted value for an unmeasured location [ESRI, 2024]). Concentration contours assist with visually identifying hot-spots. Nitrate concentration contours are highest (greater than 50 mg/L-N) at the Dairies, and higher concentration contours (greater than 10 mg/L-N) extend south-southwest from the Dairies in the direction of groundwater flow. This also supports that the Dairies are a source of nitrate contamination that spreads outside of the facility boundary in the downgradient direction. Additional nitrate contamination (greater than 20 mg/L-N) is present east and west of the Dairies that is likely not associated with the Dairies given the direction of groundwater flow to the south-southwest. Nitrate concentrations decrease moving southward from the Dairies to concentrations between 10 and 20 mg/L-N, and then increase again to concentrations greater than 20 mg/L-N (this is also shown in cross-section view on Exhibit 6). These data indicate that additional nitrate sources are likely present south of the Dairies, and that the plumes from the Dairies and other facilities are commingled.

Opinion 2: Contamination emanating from the Dairies encompasses an area within the Dairies' properties and areas downgradient.

27. As described above, the Dairies are a source of nitrate to groundwater, and are located in an area that also includes other nitrate sources. Plumes from all nitrate sources are commingled. For this reason, observed nitrate plume extent in

the vicinity (Exhibit 11) may not be attributable solely to the Dairies. I therefore employed analytical contaminant fate and transport modeling to estimate the present-day size and orientation of nitrate plumes emanating solely from the Dairies. Analytical contaminant transport modeling is a standard methodology for estimating groundwater plume size (e.g., Aziz et al., 2000).

28. I used the code ATRANS to conduct analytical contaminant transport modeling (Neville, 2005), which is recommended for groundwater contaminant fate and transport modeling in peer-reviewed scientific literature (West et al., 2007) and regulatory guidance (PADEP, 2014). ATRANS is an analytical solution for three-dimensional solute transport from a "patch source," which is an assumed rectangular source zone oriented perpendicular to the groundwater flow direction. Exhibit 12 shows the ATRANS conceptual model. ATRANS simulates the following transport processes:

- Advection, which is the process of contaminants migrating with groundwater in the direction of groundwater flow.
- Dispersion, which is the spreading of contaminants along the direction of groundwater flow (longitudinal dispersion), perpendicular to the direction of groundwater flow (transverse dispersion), and vertically (vertical dispersion).

- Transformation, which in this case relates to denitrification (nitrate transformation to nitrogen gas) and is represented as a first-order decay reaction.
- Sorption, which is binding of contaminants on the aquifer solid phase that slows contaminant migration in groundwater. Nitrate does not sorb to aquifer media (e.g., Rivett et al., 2008), and therefore sorption was not simulated in the nitrate analytical modeling.

Boundary conditions are specified for the ATRANS patch source, including the width and thickness of the source and the source concentration. ATRANS model results for a single patch source consist of estimates of groundwater plume concentrations downgradient of the source and how that changes over time. Cumulative impact from multiple patch sources is determined based on the principal of superposition, wherein the concentrations estimated from multiple sources are added to each other. I used the software TS-CHEM to run the ATRANS model and assist in plotting model results (McLane Environmental, 2022).

29. I performed ATRANS modeling to estimate groundwater plume migration emanating downgradient from the Dairies’ southern property boundaries. The model timeframe was specified to be 25 years. Dairies’ operations began in the 1970s, and therefore they have been present for approximately 50 years. Based

on review of historical aerial imagery, the Dairies' operation footprint, including the presence of animal housing and lagoons, expanded from the early 1980s to present day (Exhibits 13a through 13f and Exhibits 14a through 14e). By 1996 lagoon and animal housing footprints were similar to present day. ATRANS modeling was therefore performed for a 25-year period (corresponding to source loading beginning in 1998 and running through 2022).

30. I assumed thirteen separate patch sources as shown on Exhibit 15 based on the location of groundwater monitoring wells along the Dairies' southern boundary. Twelve of the thirteen source locations were assumed approximately at the location of cross section B-B' on Exhibit 7, and one was specified further south at the location of monitoring well YVD-29 (well location shown on Exhibit 10). Patch source dimensions and source concentrations were based on monitoring well locations, depths, and observed nitrate concentrations.

31. Patch source concentrations were assumed to increase over time, consistent with the Dairies' liquid manure, solid manure, and wastewater volume increasing from the late 1990s to present (Winiecki Decl. at ¶¶ 16-19; Winiecki Exs. E, G). For shallow monitoring wells, simulated concentrations for 2013 through 2022 were taken as the average observed nitrate concentration from 2013 to 2023 at each location. For deeper patch sources, 2013–2022 source concentration was also taken as the average of observed concentration where

deeper wells are present (YVD-18, DC-03D, DC-05D), other than for YVD-29 discussed below. Where deeper wells are not present, 2013–2022 source concentration was assumed to be 48% of the observed shallower concentrations (based on the average ratio of the deeper concentrations to the shallower concentrations where shallow and deep wells are present). For all wells other than YVD-29, source concentrations were assumed to be 50% of the average 2013–2023 value in 1998, increase to 75% of the average 2013–2023 value after 7.5 years, and then increase to the average 2013–2023 value after 15 years (corresponding to year 2013). YVD-29 is unique among the source-areas because data for this well was available beginning only in 2017 and since that time nitrate concentrations have steadily increased from less than the 10 mg/L-N MCL to greater than 30 mg/L-N. Therefore, YVD-29 simulated source concentrations were assigned to approximately match the observed trend at that location (a concentration of zero was assigned prior to 2017). Exhibit 16 displays model assumed source concentrations time-series charts for YVD-29 and DC-03, and the observed values at each well.

32. Contaminant fate and transport modeling results are dependent on several assigned parameters, and in particular the average groundwater flow velocity. Average aquifer flow velocity is in turn dependent on several attributes of the aquifer including the aquifer media type (e.g., silts, sands, or gravels).

Anchor QEA (2023b), consultant to the Dairies, reports a range of aquifer media types corresponding to average linear groundwater velocity ranging from 0.6 to 3.8 feet per day (ft/d; Exhibit 16). I performed four separate ATRANS model runs, designated as Runs A through D, to test model sensitivity to the Anchor QEA (2023b) reported values. Model input parameter values were otherwise obtained from standard scientific references and site-specific data where available. ATRANS Run A was assumed as the base-case scenario with an average groundwater velocity that falls within the middle of the reported range and is representative of medium sands to fine gravels. Sensitivity runs tested higher and lower average groundwater flow velocities. Exhibit 16 summarizes the assumed model parameters for each run. The following parameter values were assumed:

- Hydraulic conductivity represents properties of the aquifer sediments, and is used along with several other parameters described below to assign groundwater flow velocity in the model (Fetter, 1999). Anchor QEA (2023b) assume hydraulic conductivity values that range from 53 to 267 ft/d. Vaccaro et al. (2009) reports average hydraulic conductivity for the larger Yakima River basin aquifer system basin fill deposits from aquifer test data of 167 ft/d. I assumed the base-case ATRANS hydraulic conductivity value to be 131 ft/d (within the middle of values reported by Anchor QEA, 2023b), and additional runs were conducted testing a range of 53 to 267 ft/d.

- Effective porosity describes the fraction of the aquifer media where groundwater flows and is also used to calculate groundwater velocity. A base-case value of 0.32 (unitless, or cubic foot per cubic foot) was assumed based on Anchor QEA (2023b).
- Hydraulic gradient is the slope of the potentiometric surface elevation (also referred to as groundwater table elevation) and is also used to calculate groundwater flow velocity. Anchor QEA quarterly reports (e.g., Anchor QEA, 2023b) list hydraulic gradients along the southern Dairies area ranging from 0.003 to 0.0048, and most frequently report a value of 0.004. Vaccaro et al. (2009) groundwater elevation contours for the area (Exhibit 3) correspond to a range of 0.001 to 0.01 south of the Dairies. A value of 0.004 was assumed.
- First-order degradation rate dictates the modeled denitrification (nitrate loss) in the aquifer. The range of first-order rate constants for Yakima Valley groundwater from Green et al. (2008) was 0 to 3.8×10^{-5} day^{-1}. In general, the upper range of denitrification rate constants is more representative of groundwater with relatively lower dissolved oxygen concentrations (<1.6 mg/L-N). The majority of groundwater samples reported in Anchor QEA (2023a, 2023b) had higher measured dissolved oxygen concentrations (range of 0.2 to 13.4 mg/L-N, average of 5.6 mg/L-N) corresponding to lower

denitrification rates. Dissolved oxygen data available for areas south of the Dairies and north of the Yakima River in the EIM database (2021–2022) range from 0 to 11.4 mg/L-N, with an average of 2.5 mg/L-N. Denitrification rate was assumed to be 1.9 x 10^{-5} day^{-1}, the midpoint of the range reported by Green et al. (2008). Model testing indicated that model-estimated nitrate plume size was similar assuming larger or smaller denitrification rates within the range reported by Green et al. (2008).

- Dispersion (see Paragraph 28) is governed in the model by the parameter "dispersivity." Larger values of dispersivity result in more spread-out plumes (i.e., plumes that have a smaller peak concentration but cover a larger area). Dispersivity is given in units of length (feet), and is constant over the model timeframe. Dispersivity values are specified in three directions: in the direction of groundwater flow ("longitudinal"), perpendicular to the direction of groundwater flow ("transverse") and in the vertical direction. Longitudinal dispersivity was assumed to be 197 feet based on standard methods (Xu et al., 1995; Al-Suwaiyan, 1996). Transverse dispersivity and vertical dispersivity were assumed to be 20 and 10 feet, respectively, based on standard methods (Aziz et al., 2000).

33. All environmental models include limitations based on data gaps and mathematical simplifications necessary to represent complex systems. ATRANS

analytical modeling is subject to the limitations listed below. Notwithstanding these limitations, ATRANS model results represent a reliable estimate of groundwater plume sizes from the Dairies based on available data and standard scientific methods.

- Aquifer media are assumed to be homogenous; therefore, average properties representative of the heterogeneous environment are assumed. Model results are representative of nitrate transport in the basin-fill sands and gravels.
- Source concentration data are based on observations from monitoring wells and are assumed to be representative of a time period longer than that for which data have been collected in order to fill historical data gaps.
- Analytical groundwater models assume steady-state conditions, and do not incorporate variability in groundwater flow and contaminant concentrations due to aquifer recharge, pumping, and other factors.
- Hydraulic conductivity is a particularly sensitive model parameter, and reported ranges for the Dairies and the LYV range significantly, with limited reliable aquifer test data to constrain model estimates. This represents a data gap, and a middle value reported by the Dairies' consultants (Anchor QEA, 2013b; 131 ft/d) that is similar to the average from Vaccaro et al. (2009)

representative of medium sand to fine gravel aquifer media was assumed for the base-case model run.

- In some areas, monitoring wells are absent; this represents another data gap. For example, no monitoring wells are present along the southeastern boundary (see Exhibit 10). Residential well sampling data are available for this area from Arcadis (2014) indicating elevated nitrate concentrations (see wells RW-1227 and RW-1141). The Dairies' nitrate groundwater plumes may be wider than modeled if additional sources are present that are not accounted for in ATRANS modeling.
- Groundwater flow direction south of the Dairies was based on available data, but may vary somewhat within a range from southwest to south-southwest. Variation in groundwater flow direction would result in plumes oriented more to the west or south than those estimated.

34. ATRANS results are presented in Exhibit 17a for the base-case run (Run A). Results are presented as a contour map of simulated nitrate concentration emanating from the assumed patch contaminant sources at the end of the model run (25 years), and at a depth of 38 feet below the groundwater table (which is within the deeper portion of the aquifer monitored by the Dairies' monitoring wells; Exhibit 17c displays results at various depths ranging from 12.5 feet to 175 feet and shows that the model simulated plume extent does not vary significantly with

depth). Within the 10 mg/L-N contour lines in Exhibits 17a-c, the model estimated that the Dairies have contributed nitrate in concentrations greater than 10 mg/L-N to the groundwater. Between the 1 mg/L-N and 10 mg/L-N contour lines, the model estimated that the Dairies contributed nitrate in concentrations between 1 and 10 mg/L-N.

35. Model-estimated areas with nitrate concentrations attributable solely to the Dairies greater than 10 mg/L-N extend farther downgradient (1 mile or more) from patch sources at DC-03 and YVD-19 as compared to the other patch sources, which is expected given they exhibit higher observed nitrate concentrations. Model estimated areas with nitrate concentrations greater than 1 mg/L-N attributable solely to the Dairies extend a distance of approximately 3.5 miles from the Dairies' southern boundary, and incorporate an area of 7.4 square miles.

36. Exhibit 17b presents results from ATRANS sensitivity analysis model runs with greater and smaller average linear groundwater flow velocity. A smaller linear groundwater velocity results in a smaller affected area (Run B), while a larger linear groundwater flow velocity (Runs C, D) results in a larger estimated affected area. As described above, the base-case run (Run A) used aquifer parameter values and average linear groundwater velocity within the middle of reported values by the Dairies' consultant Anchor QEA (2023b), and represents a

reliable estimate of the groundwater plume length. However, as shown in the sensitivity runs, there is uncertainty regarding the estimated plume lengths within the range of the tested parameters. If further information becomes available indicating average groundwater velocity is greater or less than that assumed in the base case run the resulting estimated nitrate plumes solely attributable to the Dairies may increase or decrease accordingly.

37. I used ATRANS modeling results and other information (e.g., nitrate concentration data, facility locations) to delineate areas where the Dairies have contributed nitrate to groundwater. Specifically, I delineated four separate areas (Exhibit 18):

- Area A: The Dairies are estimated to contribute nitrate to groundwater at a concentration greater than 10 mg/L-N.
- Area B: The Dairies are estimated to contribute nitrate to groundwater between 1 and 10 mg/L-N.
- Area C: Lack of nitrate data on the Dairies' boundaries to estimate groundwater plume extents; within 1-mile hydraulically downgradient of the Dairies.
- Area D: Dairies and parcels surrounded by Dairies' properties where nitrate concentrations in groundwater are estimated to exceed 10 mg/L-N based on interpolation, or where there is a lack of data.

38. Areas A and B were delineated based on ATRANS modeling results—specifically, the outermost contour of the 1 and 10 mg/L-N contour lines from Run A (Exhibit 17a). Reported typical background groundwater nitrate concentration ranges from less than 0.3 to 1.1 mg/L-N (EPA, 2013b; WSDA et al., 2010).

39. Area C represents areas hydraulically downgradient and within 1 mile of the Dairies where there is little or no source data to estimate plume lengths. Nitrate has exceeded the 10 mg/L-N MCL in portions of these areas (see Exhibits 19a and 19b). A 1-mile boundary has previously been used to inform the extent of residential well sampling and water treatment downgradient of the Dairies (e.g., Arcadis, 2014). Modeling results indicate that plume lengths (greater than 10 mg/L-N) solely attributable to the Dairies can exceed 1 mile from larger concentration sources (i.e., at DC-03 and YVD-19 see Exhibit 17a). Lack of monitoring well data at the Dairies' western and southeastern boundaries to estimate plume lengths is a data gap, and additional data should be collected in these areas to inform source concentration assumptions and conclusions regarding the areal extent of contamination.

40. Area D represents areas within or completely surrounded by the Dairies' properties where nitrate concentrations in groundwater are estimated to exceed the MCL based on nitrate concentration contours interpolated by kriging or

there is a lack of data. The kriging interpolation used 2022 well data (see Paragraph 26). Given that upgradient boundary nitrate concentrations are typically less than 10 mg/L-N (e.g., at YVD-03, YVD-04; see Exhibit 10), the Dairies are likely the predominant source of nitrate contamination exceedance within the Dairies' property boundaries. There are parcels within Area D that are not operated by the Dairies but are completely surrounded by the Dairies (see Exhibit 3). Given those properties' limited size within the area relative to the Dairies' sources, it is likely that Dairies nitrate sources predominate. The extent of Area D is defined based on the area greater than 10 mg/L-N interpolated by kriging that overlies the Dairies' properties or areas completely surrounded by the Dairies' properties (see Paragraph 26, Exhibit 11), with the exception of areas with no recent data to inform the kriging interpolation. Dairies' properties with no recent data include the two non-contiguous northern parcels in the vicinity of well YVD-02 that has not been sampled since 2020 (see Exhibit 19a).

41. In summary, analytical modeling was performed to estimate the extent and concentrations of nitrate plumes downgradient of the Dairies. Model results are consistent with available nitrate data (e.g., Exhibit 11) indicating that the Dairies are a source of nitrate to downgradient areas. Estimated plume length for nitrate concentrations greater than 1 mg/L-N attributable only to the Dairies is 3.5 miles. Exhibit 18 displays areas where I estimate that the Dairies contribute nitrate

to groundwater and is based on the analytical modeling results and other information reviewed as described above. Areas A, B, and D comprise the "Affected Area," where residential wells are at risk of exceeding the nitrate MCL from either the Dairies' contribution alone or commingled with other nitrate sources. Area C comprises the "Potentially Affected Area," where residential wells are hydraulically downgradient and within 1 mile of the Dairies, but nitrate groundwater concentration in these areas cannot be estimated due to lack of data.

Opinion 3: Groundwater nitrate concentration trends at the Dairies are stable or increasing in several areas that exceed the MCL.

42. Contaminant concentration at a given monitoring well typically varies over time due to seasonal fluctuation and/or longer-term changes in contaminant loading rates and other factors. Increasing or stable trends above the MCL indicate that source loading from the surface and vadose zone to groundwater are ongoing, whereas decreasing trends indicate that corrective actions have been effective in reducing contaminant loading. I used standard statistical methods to evaluate contaminant trends at the Dairies' monitoring wells over the available data time period.

43. I applied Mann-Kendall statistical analysis for the presence of trend, an objective statistical test to determine if nitrate groundwater concentrations are increasing, decreasing, or steady at a specified confidence level of 95%. Mann-

Kendall analysis is commonly applied at contaminated sites as a component of evaluating contaminant trends (EPA, 2009). Mann-Kendall analysis was conducted for 2013 to 2023 (or a shorter period based on data availability). I compiled the Dairies' nitrate monitoring data through September 2023 from Anchor QEA quarterly monitoring reports (Anchor QEA, 2023a, 2023b, 2023d, 2023e).

44. Mann-Kendall analysis results are displayed graphically on Exhibit 20a and are overlaid with selected time-series charts in Exhibits 20b and 20c. Increasing or stable trends at concentrations greater than the MCL are observed in the western half of the Dairies (YVD-12, YVD-08, YVD-13, YVD-18, YVD-09, YVD-14R, DC-03, DC-03D, and DC-14). Decreasing trends (concentrations still greater than the MCL) are observed in a portion of the south-central area (YVD-10, YVD-15, and DC-04). Increasing or stable trends above the MCL are observed at several wells in the eastern portion of the Dairies (DC-05D, YVD-16, and YVD-11). Directly downgradient (south) of the Dairies, increasing trends are observed to the west (YVD-24, and YVD-23), and decreasing trends are observed in the central area (YVD-19, and YVD-22).

Opinion 4: Contaminant trends are decreasing in the Dairies' central area following corrective measures; however, stable or increasing trends are otherwise observed downgradient of former lagoon areas.

45. Several corrective measures at the Dairies have been required and implemented, including lagoon lining and abandonment. Exhibit 21 provides an Anchor QEA summary of the lagoon lining and abandonment timeline at each facility as of the end of 2022. Cow Palace Dairy implemented lagoon lining and abandonment from 2016 to 2020, and Bosma and DeRuyter Dairies implemented lagoon lining and abandonment from 2017 to 2022 (with some work ongoing as of the end of 2022).

46. Exhibits 22a through 22c display time-series charts and maps of the facility lagoons prepared by Anchor QEA. Cow Palace Dairy lagoons in the central area of the Dairies are shown on Exhibit 22a. Nitrate concentrations are increasing at DC-14, which is located at the lagoons; however, the nearest downgradient (south) monitoring well YVD-10 exhibits decreasing trends following the beginning of lagoon lining/abandonment in 2016. Note that although nitrate concentrations are decreasing at YVD-10, they are still elevated above the MCL (70.3 mg/L-N in September 2023 sampling; Anchor QEA, 2023d). YVD-09 is also located downgradient (south-southwest) of the Cow Palace Dairy lagoons and several Bosma Dairy lagoons and has exhibited an increasing trend.

47. DeRuyter Dairy lagoons in the eastern area of the Dairies are shown on Exhibit 22b. The nearest downgradient well is YVD-11, which has exhibited a stable trend overall since 2017 (with nitrate concentrations greater than the MCL),

with a decreasing trend from 2017 to 2019 and an increasing trend from 2019 to 2022.

48. DeRuyter Dairy lagoons are also shown on Exhibit 22b, labeled as "George Dairy/D&A Dairy." Although no time-series charts are shown downgradient of the DeRuyter Dairy lagoons, the nearest downgradient monitoring well is YVD-30 (Exhibit 20a). YVD-30 is a shallow monitoring well with nitrate concentrations below the MCL and has shown an overall stable trend. YVD-30 is located directly adjacent to the Sunnyside Canal, and nitrate concentrations at this location may be decreased by recharge from the canal that has lower levels of nitrate that mixes with shallow groundwater. Nitrate concentrations in deeper groundwater are less likely to be decreased by canal recharge, and therefore deeper nitrate concentrations may be higher; lack of a deeper monitoring well at the DeRuyter Dairy lagoons and downgradient is a data gap.

49. Bosma Dairy lagoons in the western area of the Dairies are shown on Exhibit 22c, labeled as "Liberty/Bosma Dairy." Monitoring wells downgradient of the lagoons include YVD-08, YVD-9, YVD-12, YVD-18, YVD-13, YVD-14R, DC-07, DC-03, and DC-03D. Nitrate concentration trends at each of these wells are stable or increasing over the time frame of the lagoon lining, and nitrate concentration is greater than the MCL (except at DC-07).

50. In summary, in the central area of the Dairies (Exhibit 20a), decreasing nitrate trends in one monitoring well downgradient (south) of lagoon locations have coincided with lagoon lining/abandonment (YVD-10). Otherwise, lagoon lining/abandonment activities have not to date corresponded to decreasing trends observed in downgradient monitoring wells. There may be several reasons for this, including the following: (1) other nitrate sources from the Dairies are present and continue to load to groundwater, (2) ineffective control measures were implemented, and/or (3) insufficient time has passed for the reduction to be observed in downgradient monitoring wells (this would not explain the observed increasing trends). Specific sources impacting particular monitoring wells is a data gap and the animal waste application to fields may be a significant remaining nitrate source (e.g., Harter et al., 2002).

Opinion 5: Monitoring should continue to assess nitrate presence and distribution in groundwater

51. My recommendations for the Dairies' groundwater monitoring program include the following:

- Quarterly groundwater monitoring should continue from the existing well network. Several wells exhibit fluctuating or variable nitrate concentrations (e.g., see YVD-28 on Exhibit 20c), and quarterly groundwater monitoring is more likely to capture the higher nitrate concentrations than less frequent sampling.

- Additional groundwater monitoring wells along the Dairies' property boundary would provide data on potential nitrate sources and downgradient plumes. Currently no wells are present along the south-eastern and western property boundaries (e.g., see Exhibit 10).
- Nitrate is the primary contaminant of concern. Field parameters (dissolved oxygen, specific conductance, pH, temperature, turbidity, oxidation-reduction potential) and total organic carbon data is useful for general understanding of contaminant fate and transport and should be collected during all sampling events. Nitrite, ammonia, and Total Kjeldahl Nitrogen ("TKN") are also useful for general understanding of nitrogen fate and transport.
- Sampling protocols should improve to ensure that samples are analyzed within the designated holding time requirements. Analytical results for samples analyzed after the designated holding time provide only estimated values. Holding-time exceedance errors have become common in recent sampling at the Dairies. For the fourth quarter 2023 sampling event, the majority of nitrate samples were analyzed outside of acceptable holding

time, and for several wells (e.g., DC-03) holding times were exceeded in June, September, and December 2023 sampling (Anchor QEA, 2024).

52. Several high-concentration nitrate hot-spots (greater than 50 mg/L-N) are present at the Dairies, including:

- DC-03 (maximum 2022 concentration 183 mg/L-N; see Exhibits 10 and 11), downgradient and near to Bosma Lagoons 2 and 3 (see Exhibit 22c),
- YVD-19 along the southern boundary,
- DC-14 downgradient and near to Cow Palace Lagoon 1 (see Exhibit 22a),
- YVD-10 south of the Cow Palace Dairy lagoons,
- YVD-14R, YVD-08, YVD-09, at the Bosma Lagoons, and
- YVD-11 at DeRuyter Dairy (see Exhibit 22b).

High-concentration source zones at the downgradient facility boundary (e.g., at DC-03 and YVD-19) pose a particular risk of downgradient nitrate migration at concentrations exceeding the MCL, as demonstrated by the analytical modeling results discussed above. Estimated plume lengths from the higher-concentration source areas are significantly longer than those from source areas with concentrations less than 40 mg/L-N. Ongoing monitoring is particularly important downgradient of the nitrate hot-spots.

Conclusion

A summary of my opinions is as follows:

(1) **Opinion 1**: The Dairies are a source of nitrate to groundwater in the LYV in addition to other sources that are present.

(2) **Opinion 2**: Contamination emanating from the Dairies encompasses an area within the Dairies' properties and areas downgradient.

(3) **Opinion 3**: Groundwater nitrate concentration trends at the Dairies are stable or increasing in several areas that exceed the MCL.

(4) **Opinion 4**: Contaminant trends are decreasing in the Dairies' central area following corrective measures; however, stable or increasing trends are otherwise observed downgradient of former lagoon areas.

(5) **Opinion 5**: Monitoring should continue to assess nitrate presence and distribution in groundwater.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on: 6-25-24

Date

Gregory Schnaar, PhD

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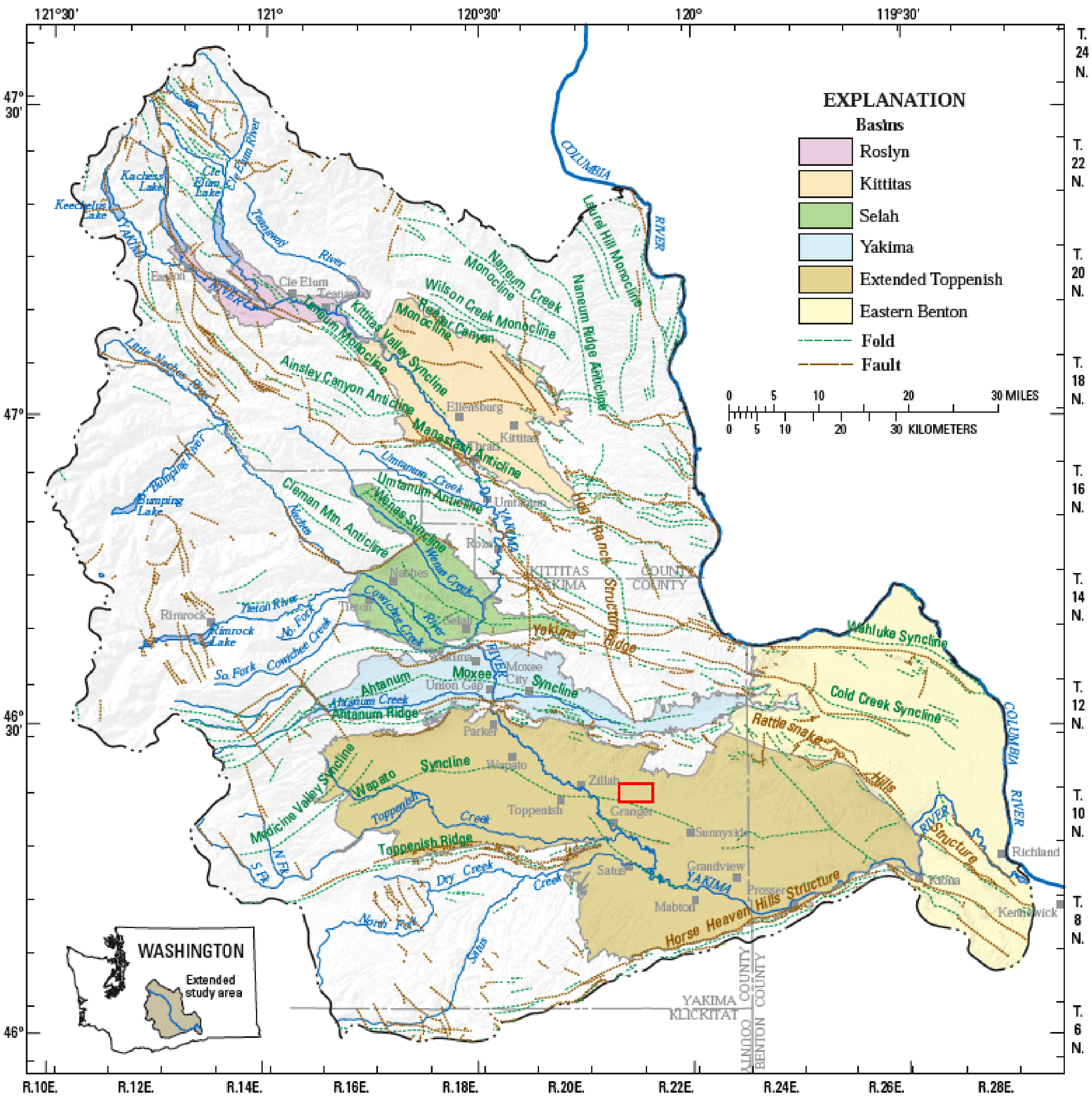
Exhibits



Note: Approximate Dairies location shown at red box

Source: Vacarro et al., 2009

YAKIMA VALLEY DAIRIES

Dairies Location and Yakima River Basin Aquifer System

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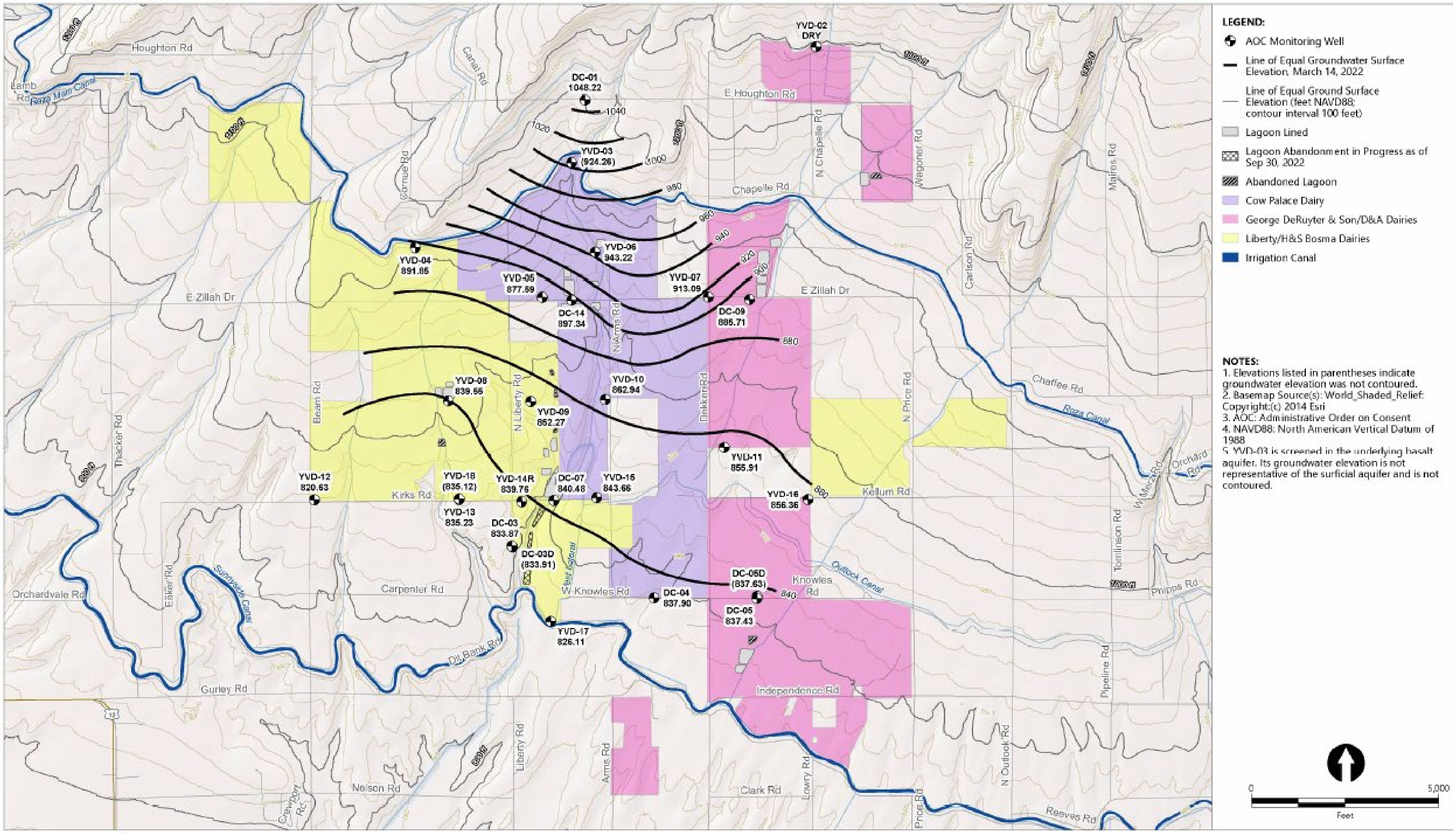
Exhibit 1



LEGEND:

- AOC Monitoring Well
- Line of Equal Groundwater Surface Elevation, March 14, 2022
- Line of Equal Ground Surface Elevation (feet NAVD88; contour interval 100 feet)
- Lagoon Lined
- Lagoon Abandonment in Progress as of Sep 30, 2022
- Abandoned Lagoon
- Cow Palace Dairy
- George DeRuyter & Son/D&A Dairies
- Liberty/H&S Bosma Dairies
- Irrigation Canal

NOTES:

1. Elevations listed in parentheses indicate groundwater elevation was not contoured.
2. Basemap Source(s): World_Shaded_Relief: Copyright:(c) 2014 Esri
3. AOC: Administrative Order on Consent
4. NAVD88: North American Vertical Datum of 1988
5. YVD-03 is screened in the underlying basalt aquifer. Its groundwater elevation is not representative of the surficial aquifer and is not contoured.

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ANCHOR QEA

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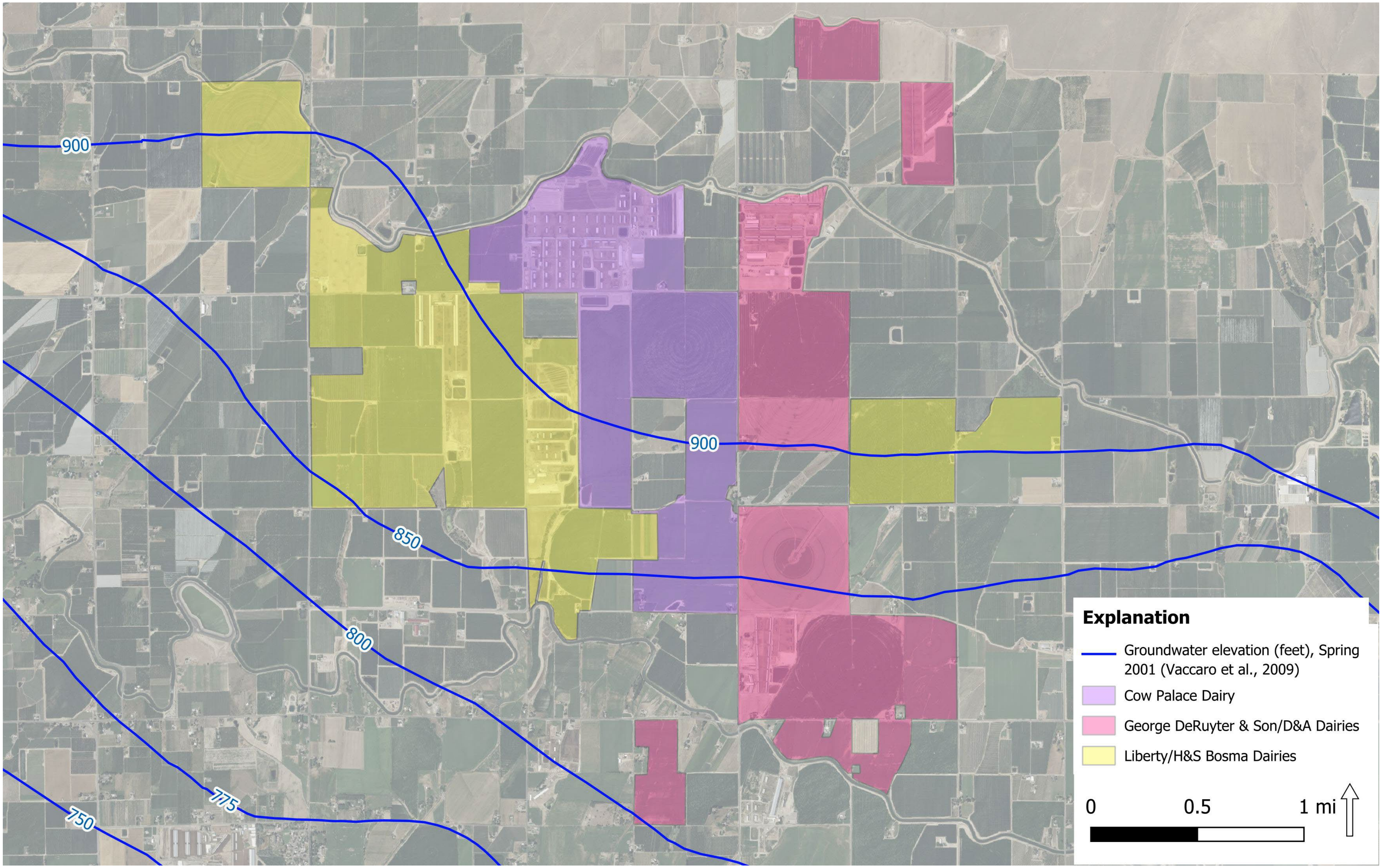
Source: Anchor QEA, 2023

YAKIMA VALLEY DAIRIES

Surficial Aquifer Groundwater Elevation Contour Map, First Quarter 2022

Exhibit 2



Source: Vaccaro et al. (2009). Dairies boundaries from Anchor QEA (2023c) and EPA (2024).

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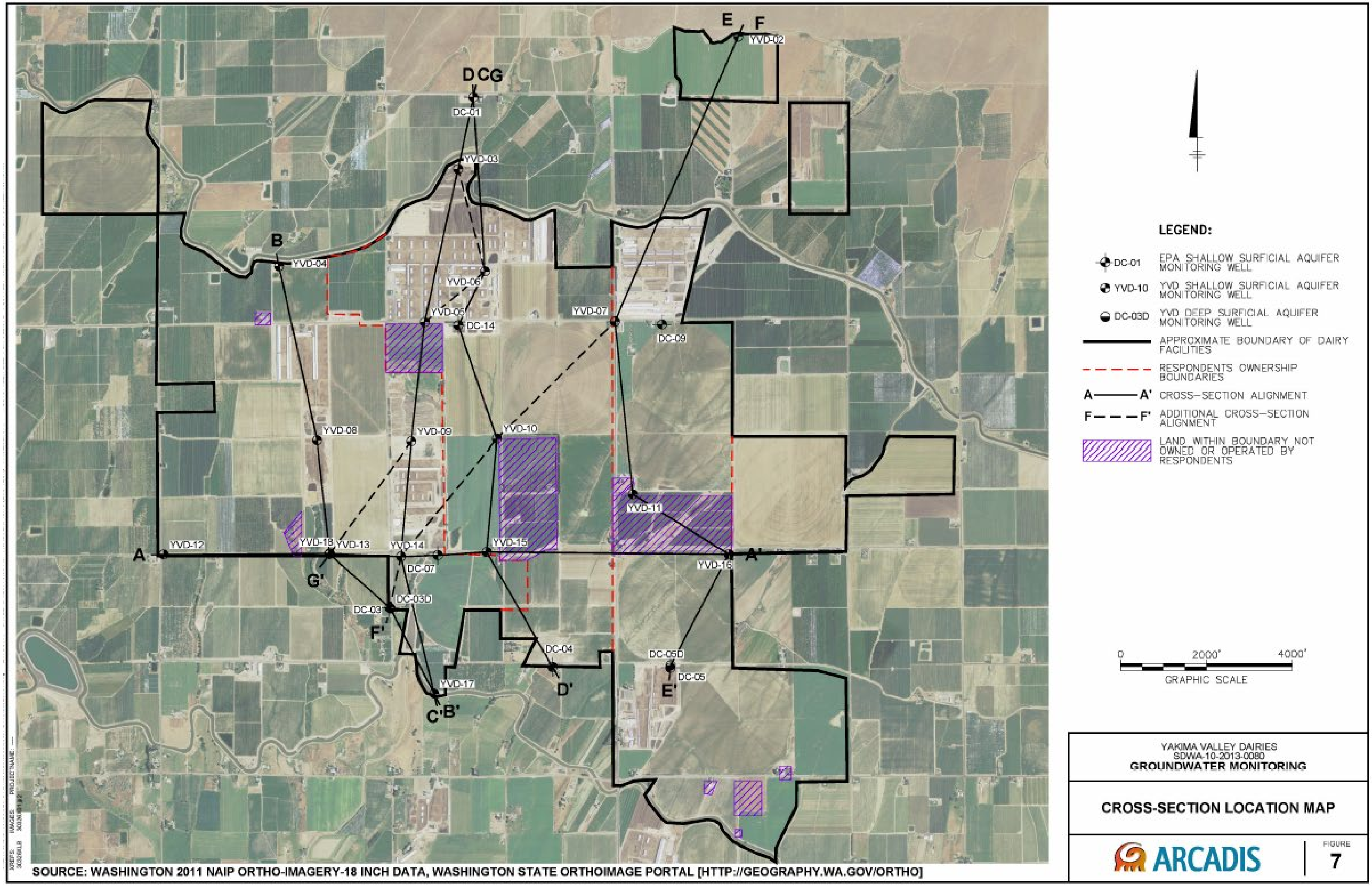
YAKIMA VALLEY DAIRIES

Spring 2001 Groundwater Elevation Contours

3/8/2024 DB23.1324

Exhibit 3



Source: Inland Earth Sciences, 2016

YAKIMA VALLEY DAIRIES

Arcadis Cross Section Location Map

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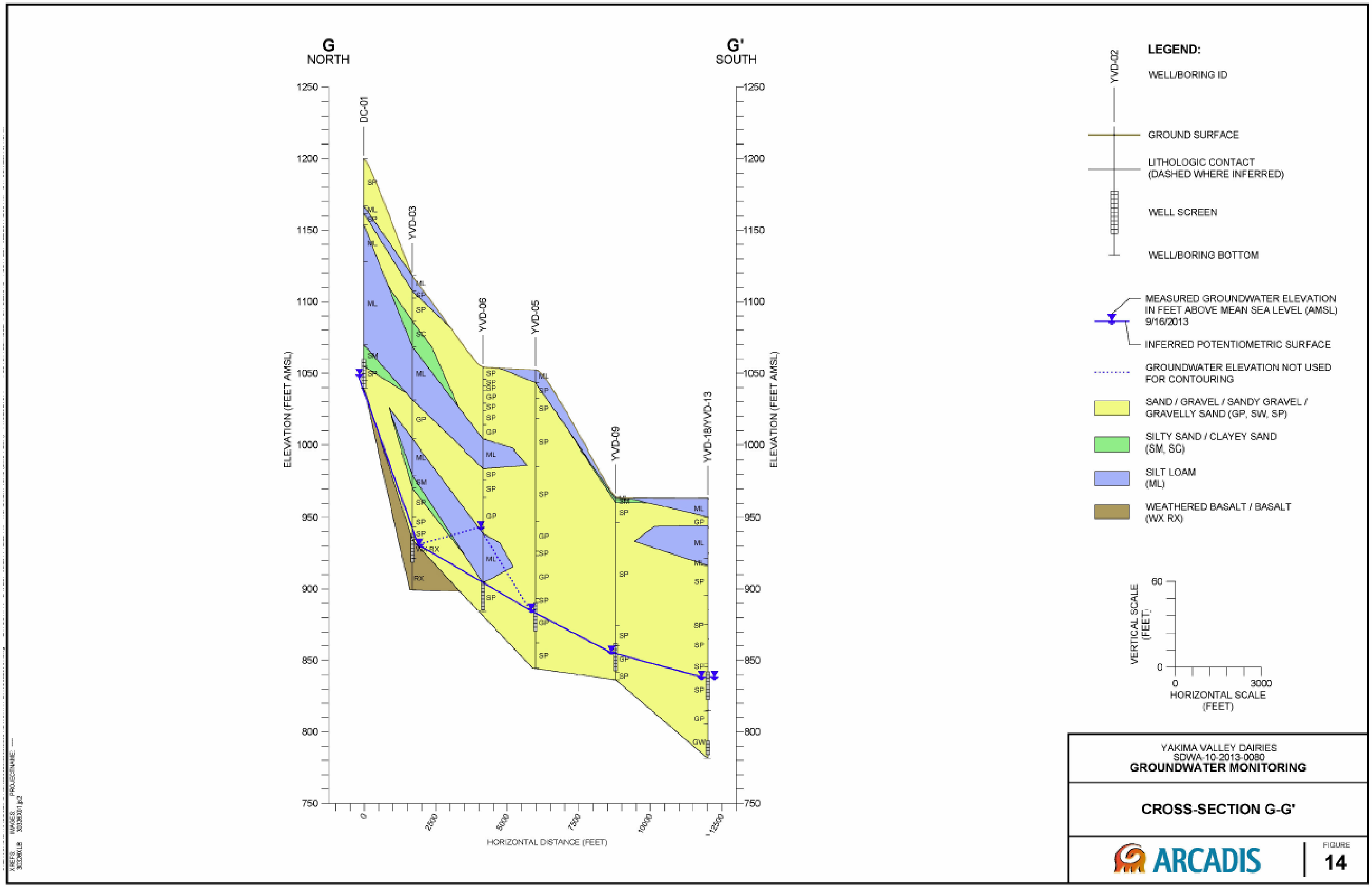
Exhibit 4



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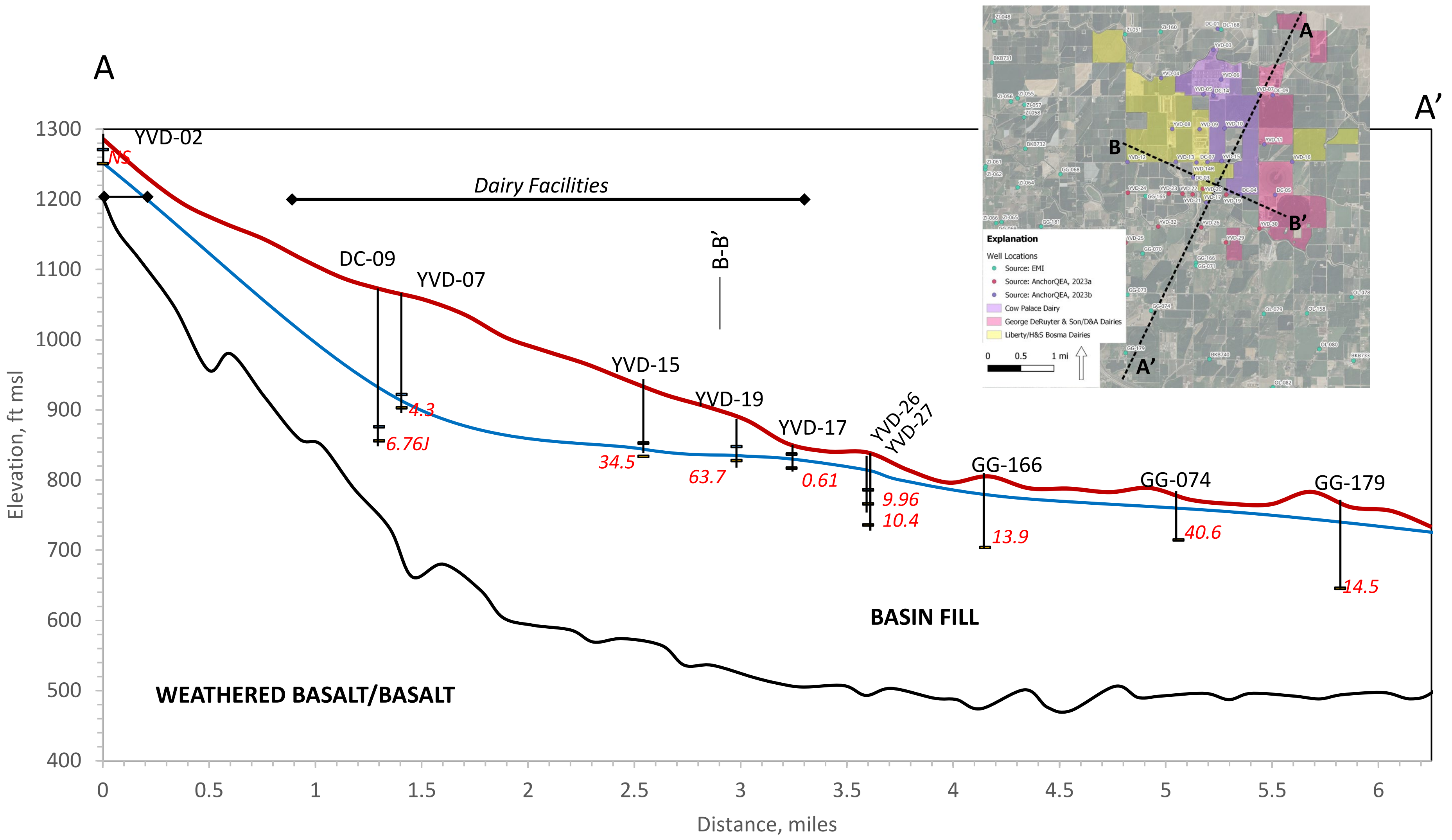
Source: Inland Earth Sciences, 2016

YAKIMA VALLEY DAIRIES

Arcadis Cross-Section G-G’

Exhibit 5



━ Ground surface
━ Potentiometric surface

Nitrate-as-N (mg/L), 2022 maximum

Well depth and perforated interval; if perforated interval is unknown, completion depth is shown

Sources: Potentiometric surface and nitrate concentrations from Anchor QEA (2023) for facility monitoring wells; potentiometric surface from Vaccaro et al. (2009) for downgradient locations; basalt unit elevation from USGS (2011); nitrate concentrations for supply wells from Washington State EIM database (reported in nitrate + nitrite as N).

Note: Vertical exaggeration 18x

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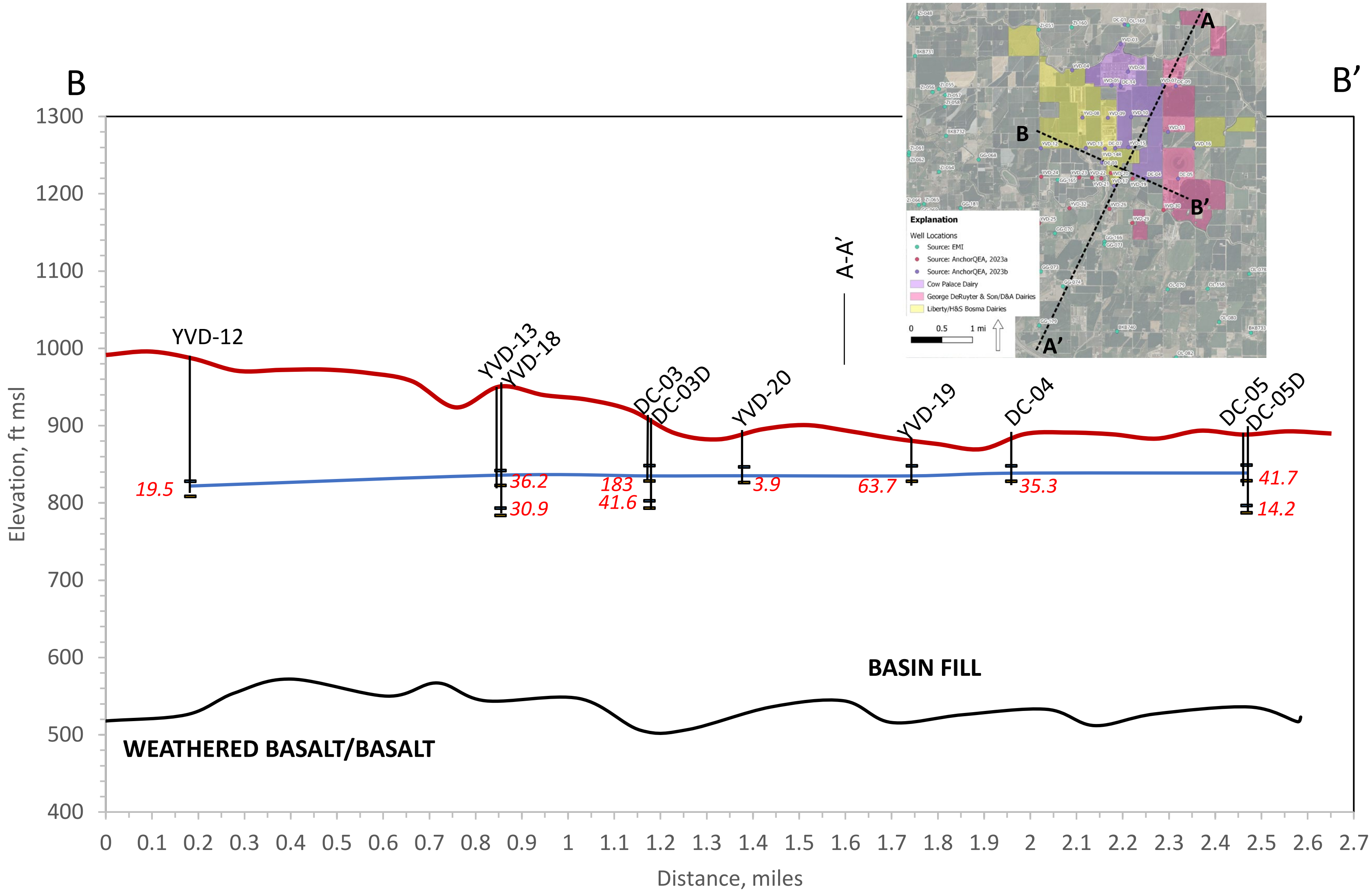
YAKIMA VALLEY DAIRIES

Cross-Section A-A’

2/2/2024 DB23.1324

Exhibit 6



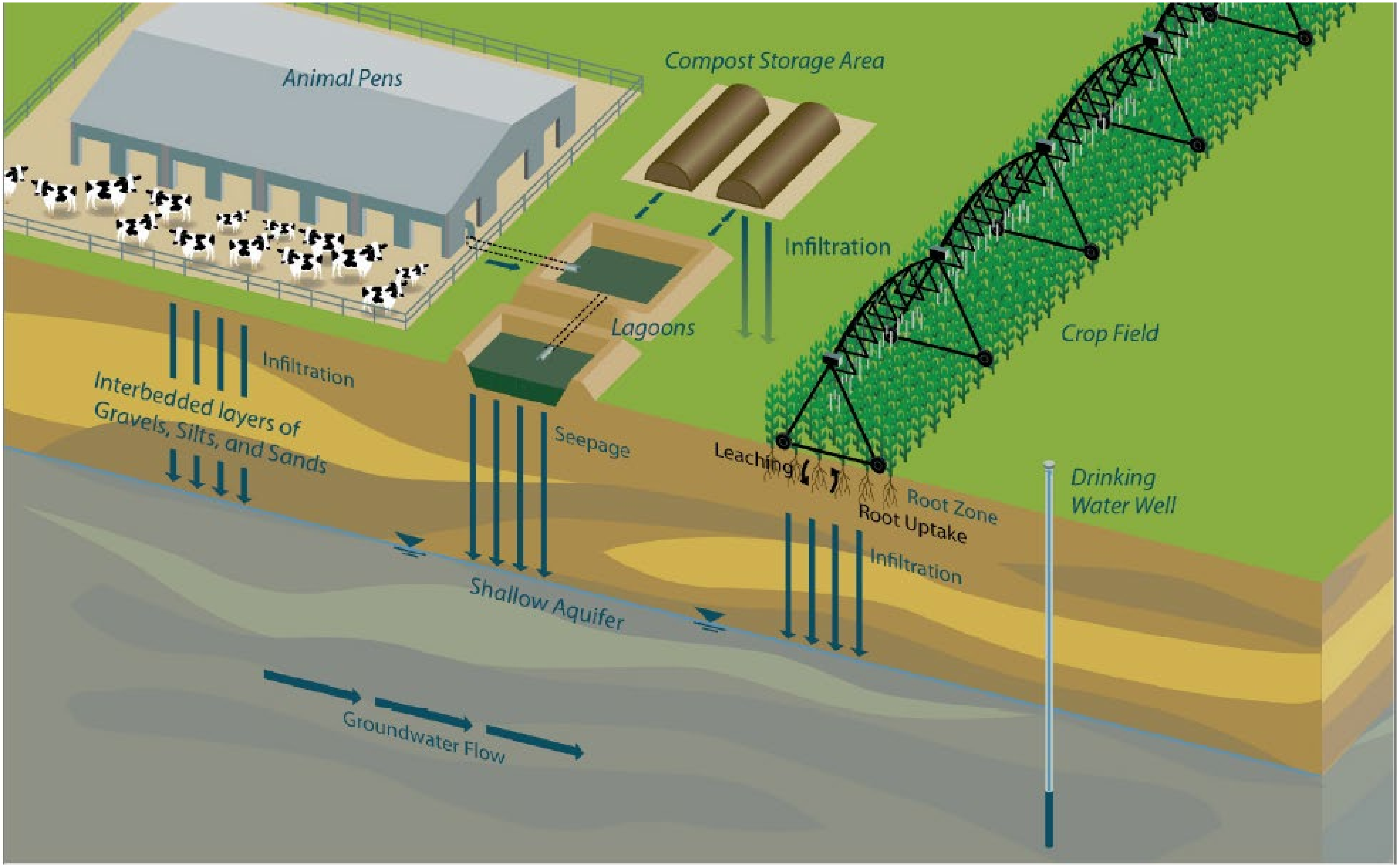
Sources: Potentiometric surface and nitrate concentrations from Anchor QEA (2023) for facility monitoring wells; basalt unit elevation from Ely et al. (2011)

Note: Vertical exaggeration 9x

YAKIMA VALLEY DAIRIES

Cross Section B-B'

Exhibit 7



Source: Anchor QEA, 2023c which states that figure is conceptual in nature and identifies potential nitrogen transport pathways identified by EPA for a typical dairy facility

YAKIMA VALLEY DAIRIES

Anchor QEA Conceptual Model, Nitrogen Transport Pathways

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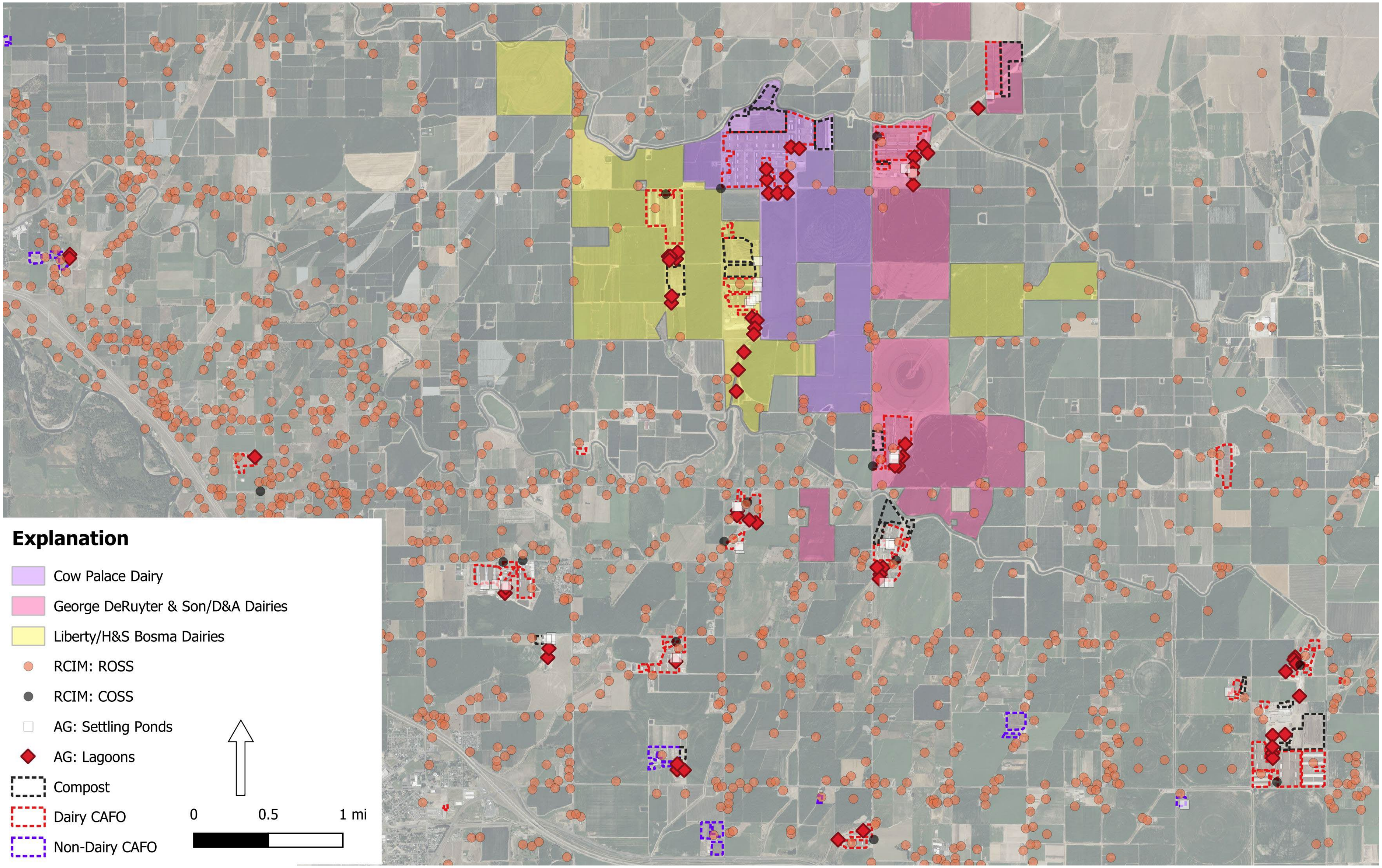
Exhibit 8



Source: Yakima County (2020). Notes: RCIM = Residential, Commercial, Industrial, Municipal Working Group; ROSS = Residential Onsite Septic Systems; COSS = Commercial Onsite Septic Systems; AG = agricultural; CAFO = concentrated animal feeding operation; Feature locations may not be current; other nitrate sources may be present.

YAKIMA VALLEY DAIRIES

Dairies and Potential Nitrate Sources to Groundwater

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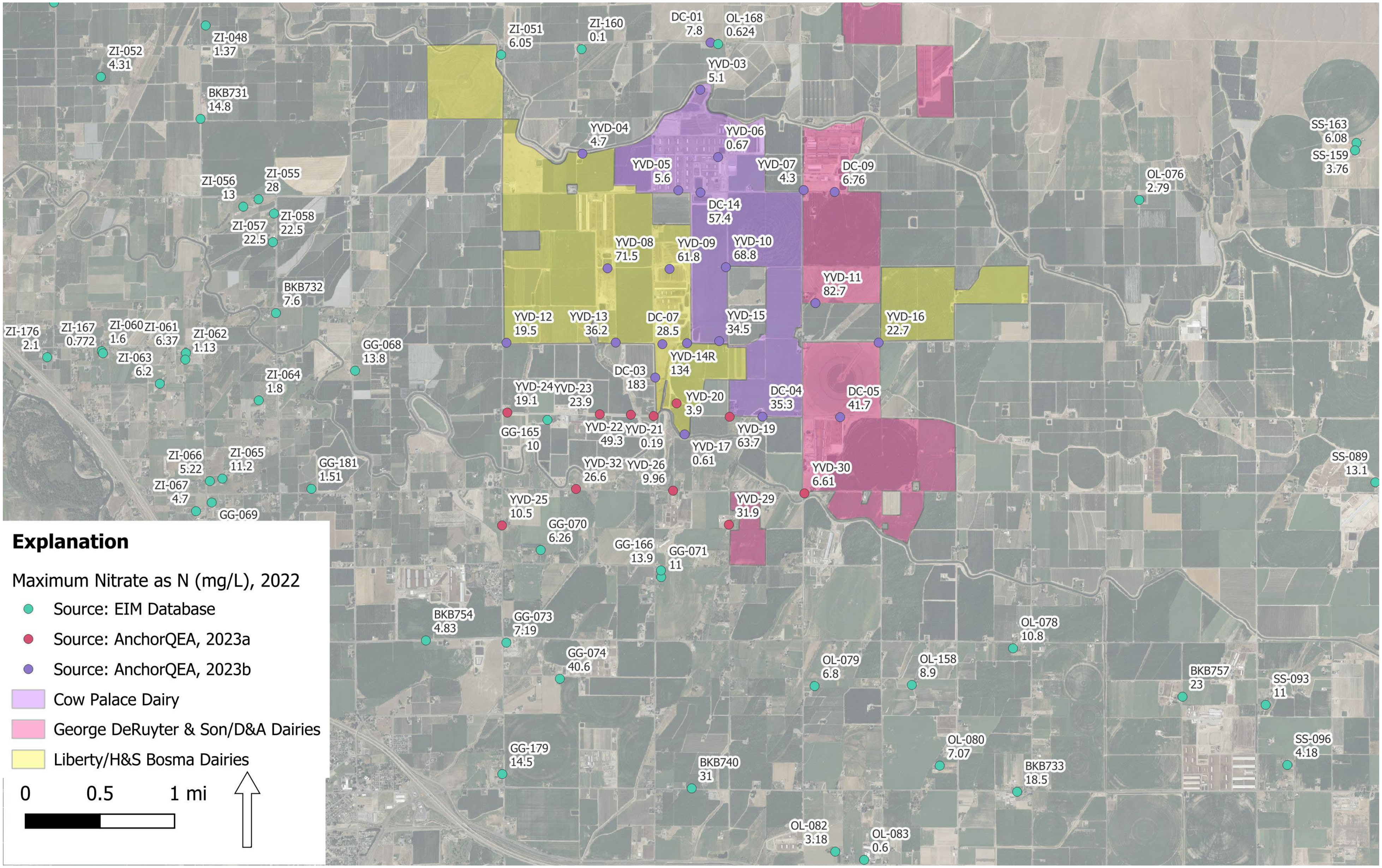
Exhibit 9



Notes: Wells not posted (co-located with other wells) include DC-03D, DC-05D, YVD-31, YVD-27, YVD-18, YVD-28; OL-081 not posted (greater than 200 feet deep); nitrate concentrations from EIM reported as Nitrate + Nitrite as N

YAKIMA VALLEY DAIRIES

Maximum Nitrate in Groundwater, 2022

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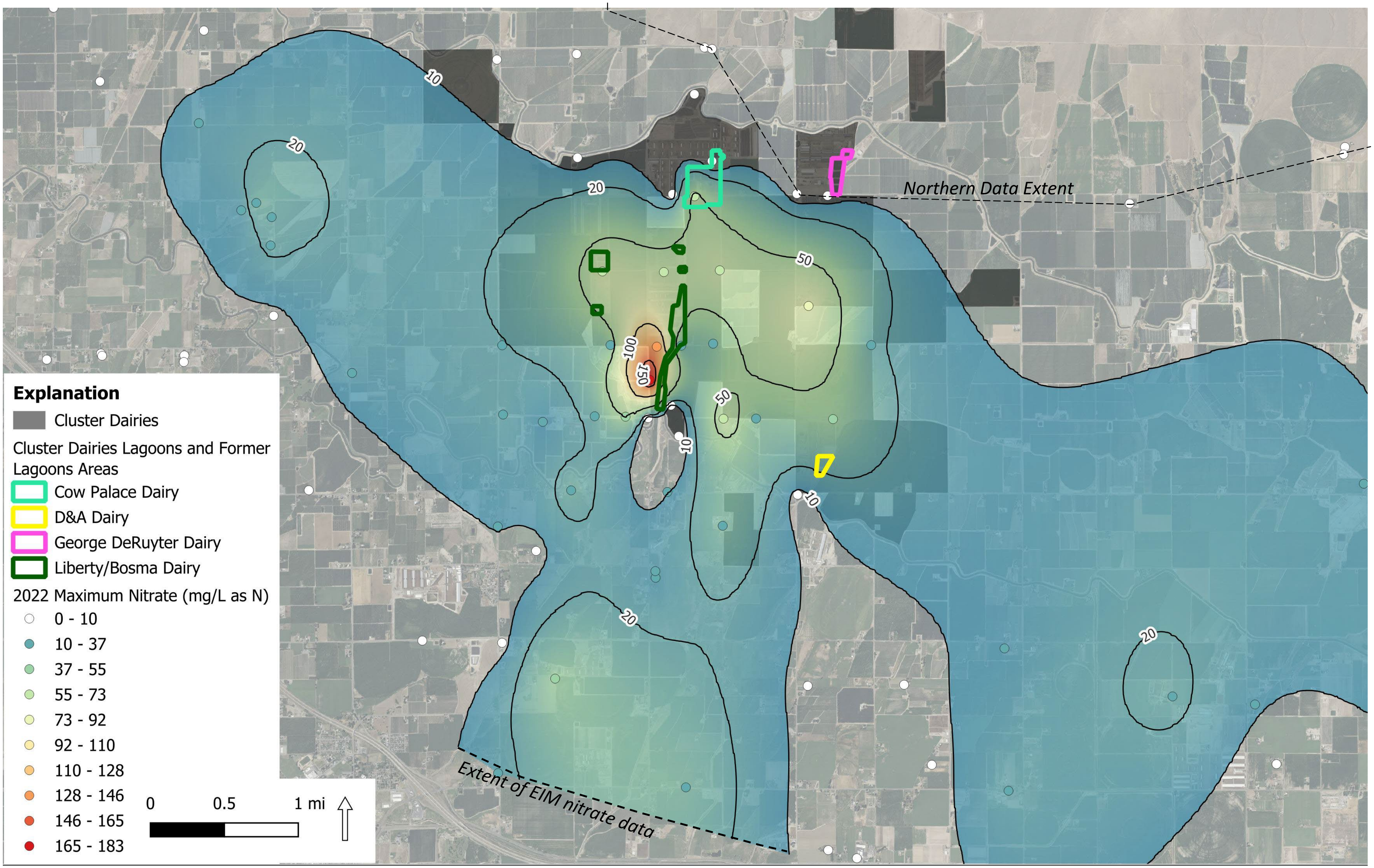
2/2/2024 DB23.1324

Exhibit 10



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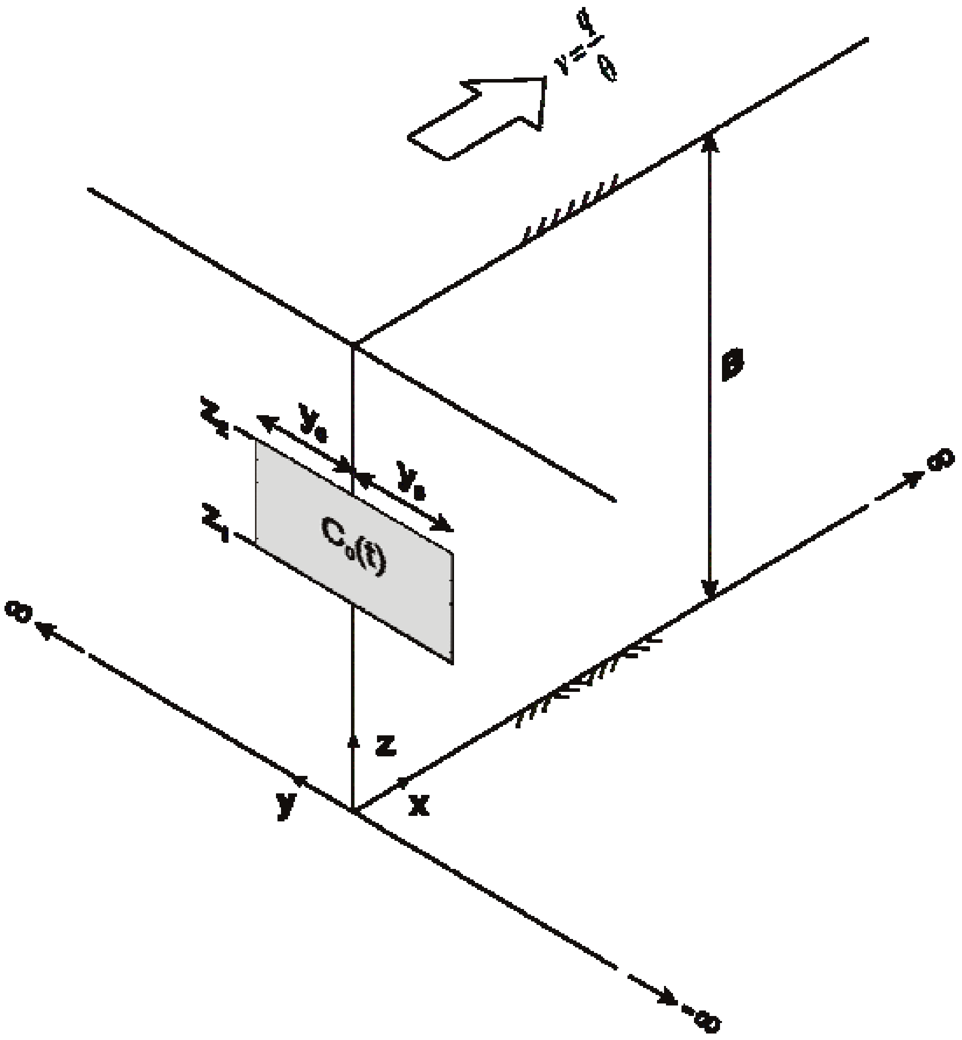
Data sources: Anchor QEA, 2023a, 2023b; EIM database
Notes: Interpolation by kriging (Golden Software Surfer); wells not posted (co-located with other wells) include DC-03D, DC-05D, YVD-31, YVD-27, YVD-18, YVD-28; OL-081 not posted (greater than 200 feet deep); nitrate concentrations from EIM reported as Nitrate + Nitrite as N; Lagoon locations from Anchor QEA, 2023c.

YAKIMA VALLEY DAIRIES

Maximum Nitrate in Groundwater, 2022 and Interpolated Contours with Lagoon Locations

2/2/2024 DB23.1324

Exhibit 11



Note:
C_o = source concentration
t = time
Z = thickness
y = width
x = length
v = linear velocity
q = groundwater velocity
θ = effective porosity
B = depth
Arrow shows direction of groundwater flow

Source: Neville, 2005

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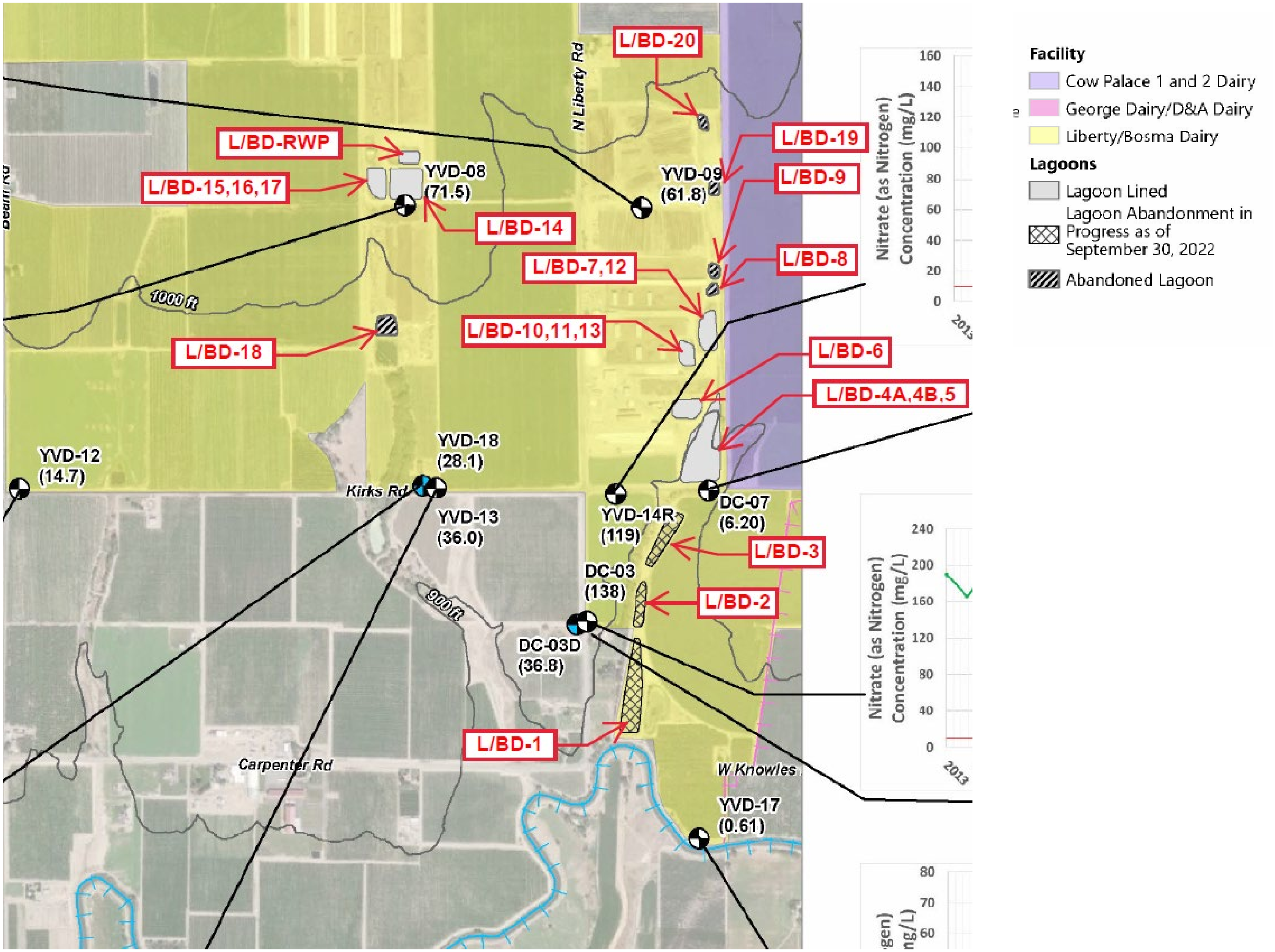
YAKIMA VALLEY DAIRIES

ATRANS Conceptual Model

Exhibit 12



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Source: Anchor QEA, 2023

YAKIMA VALLEY DAIRIES

Map of Lagoons in Vicinity of DC-03, 2022

Exhibit 13a

Source: USGS Earth Explorer, Image NC1NHAP810103029; red-color in original color-infrared imagery (see https://www.usgs.gov/faqs/what-do-different-colors-color-infrared-aerial-photograph-represent).

YAKIMA VALLEY DAIRIES

Lagoons in Vicinity of DC-03, 1981 (False Color)

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Exhibit 13b

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Source: USGS Earth Explorer, image N10NAPPW02901166

YAKIMA VALLEY DAIRIES

Lagoons in Vicinity of DC-03, 1990

1/9/2024 DB23.1324

Exhibit 13c

Source: Google Earth Pro

YAKIMA VALLEY DAIRIES

Lagoons in Vicinity of DC-03, 1996

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1/9/2024 DB23.1324

Exhibit 13d

Q:\Projects\DB23.1324_Yakima_Valley_Dairies\Final Documents\Schnaar Declaration

Source: Google Earth Pro

YAKIMA VALLEY DAIRIES

Lagoons in Vicinity of DC-03, 2005

1/9/2024 DB23.1324

Exhibit 13e

Source: Google Earth Pro

YAKIMA VALLEY DAIRIES

Lagoons in Vicinity of DC-03, 2023

Q:\Projects\DB23.1324_Yakima_Valley_Dairies\Final Documents\Schnaar Declaration

Exhibit 13f

Source: USGS Earth Explorer, Image NC1NHAP810103029; red-color in original color-infrared imagery (see https://www.usgs.gov/faqs/what-do-different-colors-color-infrared-aerial-photograph-represent).

YAKIMA VALLEY DAIRIES

Lagoons at Cow Palace and George-D&A Dairies, 1981

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1/9/2024 DB23.1324

Exhibit 14a

Source: USGS Earth Explorer, Image N10NAPPW02901166

YAKIMA VALLEY DAIRIES

Lagoons at Cow Palace and George-D&A Dairies, 1990

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Exhibit 14b

Q:\Projects\DB23.1324_Yakima_Valley_Dairies\Final Documents\Schnaar Declaration

Source: Google Earth Pro

YAKIMA VALLEY DAIRIES

Lagoons at Cow Palace and George-D&A Dairies, 1996

Exhibit 14c

Source: Google Earth Pro

YAKIMA VALLEY DAIRIES

Lagoons at Cow Palace and George-D&A Dairies, 2005

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Exhibit 14d

Source: Google Earth Pro

YAKIMA VALLEY DAIRIES

Lagoons at Cow Palace and George-D&A Dairies, 2023

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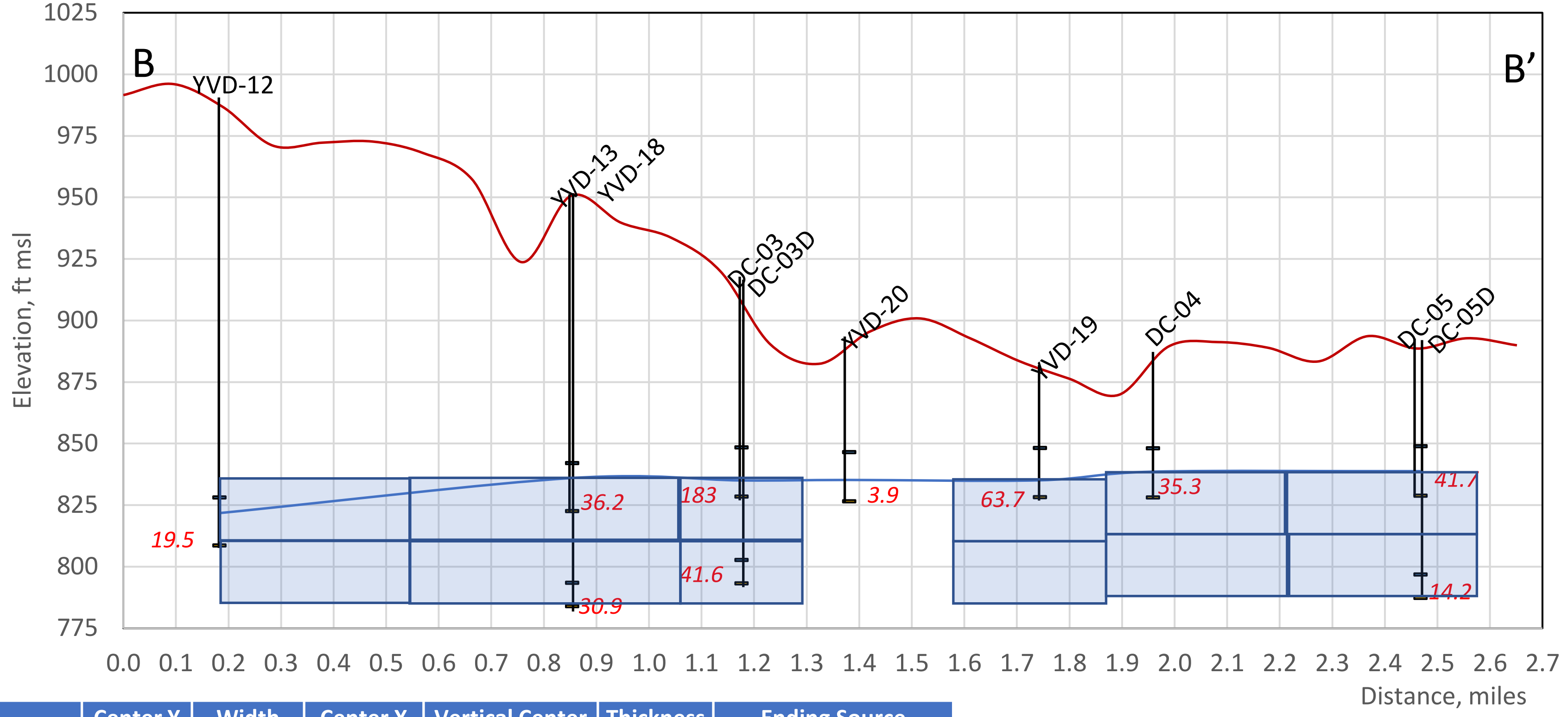
Exhibit 14e



Patch Source	Center Y (feet)	Width (feet)	Center X (feet)	Vertical Center (feet)	Thickness (feet)	Ending Source Concentration (mg/L)
YVD-12	1600	2200	2500	12.5	25	15
YVD-12(D)	1600	2200	2500	37.5	25	7.2
YVD-13	4000	2700	750	12.5	25	28
YVD-18	4000	2700	750	37.5	25	24
DC-03	6100	1500	1500	12.5	25	173
DC-03D	6100	1500	1500	37.5	25	37
YVD-19	9000	1500	1500	12.5	25	72
YVD-19(D)	9000	1500	1500	37.5	25	35
DC-04	10600	1800	1000	12.5	25	36
DC-04(D)	10600	1800	1000	37.5	25	17
DC-05	12400	1700	0	12.5	25	33
DC-05D	12400	1700	0	37.5	25	12
YVD-29 (not shown)	10700	1000	5250	37.5	25	20

Y: Perpendicular to groundwater flow; X: Groundwater flow direction; vertical center relative to groundwater table elevation

— Ground surface

— Potentiometric surface

Nitrate-as-N (mg/L), 2022 maximum

┼ Well depth and perforated interval

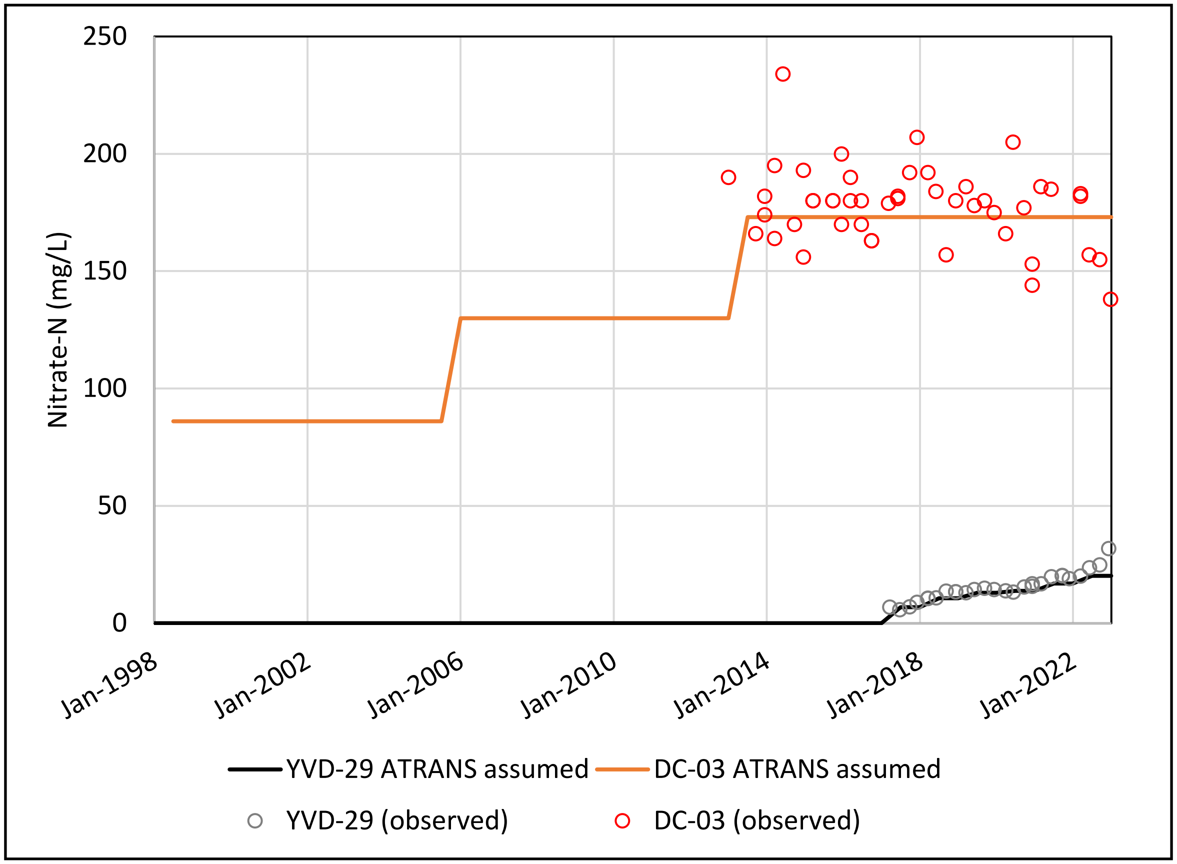
▨ Assumed Patch Sources

YAKIMA VALLEY DAIRIES

ATRANS Model Patch Source Configurations

Exhibit 15

Run	Anchor QEA (2023) Description	Hydraulic Conductivity (K), ft/d	Effective Porosity (n)	First Order Degradation (k), 1/d	Hydraulic Gradient (i)	Average Linear Groundwater Velocity (ft/d)	Time (years)	Longitudinal Dispersivity (feet)	Transverse Dispersivity (feet)	Vertical Dispersivity (feet)
A	**Medium sand to fine gravel (Base Case)**	**131**	**0.32**	**1.90E-05**	**0.004**	**1.6**	**25**	**197**	**20**	**10**
B	Fine sand	53	0.33	1.90E-05	0.004	0.6	25	197	20	10
C	Medium sand to coarse gravel	164	0.3	1.90E-05	0.004	2.2	25	197	20	10
D	Fine gravel	267	0.28	1.90E-05	0.004	3.8	25	197	20	10



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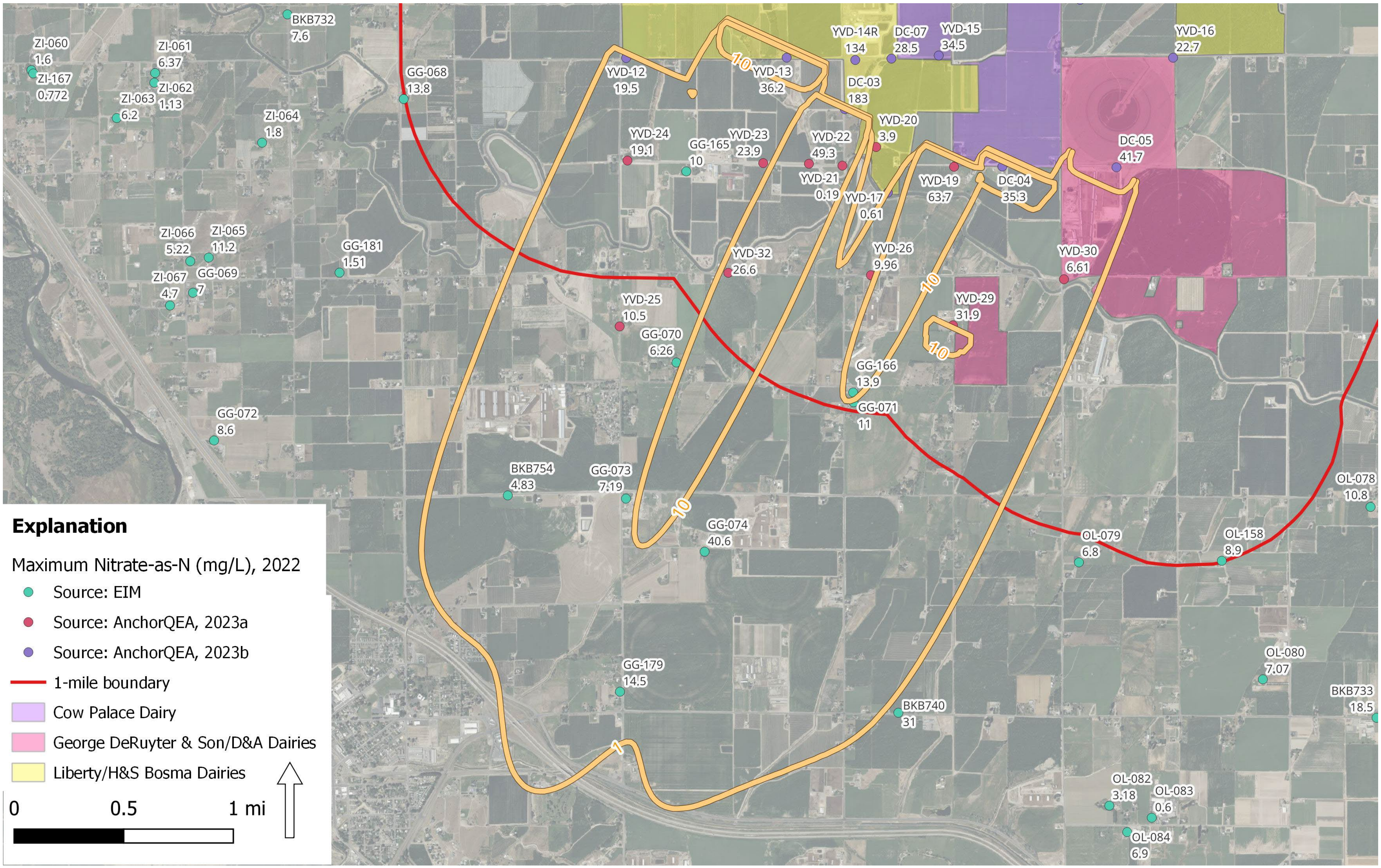
YAKIMA VALLEY DAIRIES

ATRANS Parameters and Example Source Concentration Plots

Exhibit 16

Q:\Projects\DB23.1324_Yakima_Valley_Dairies\Final Documents\Schnaar Declaration

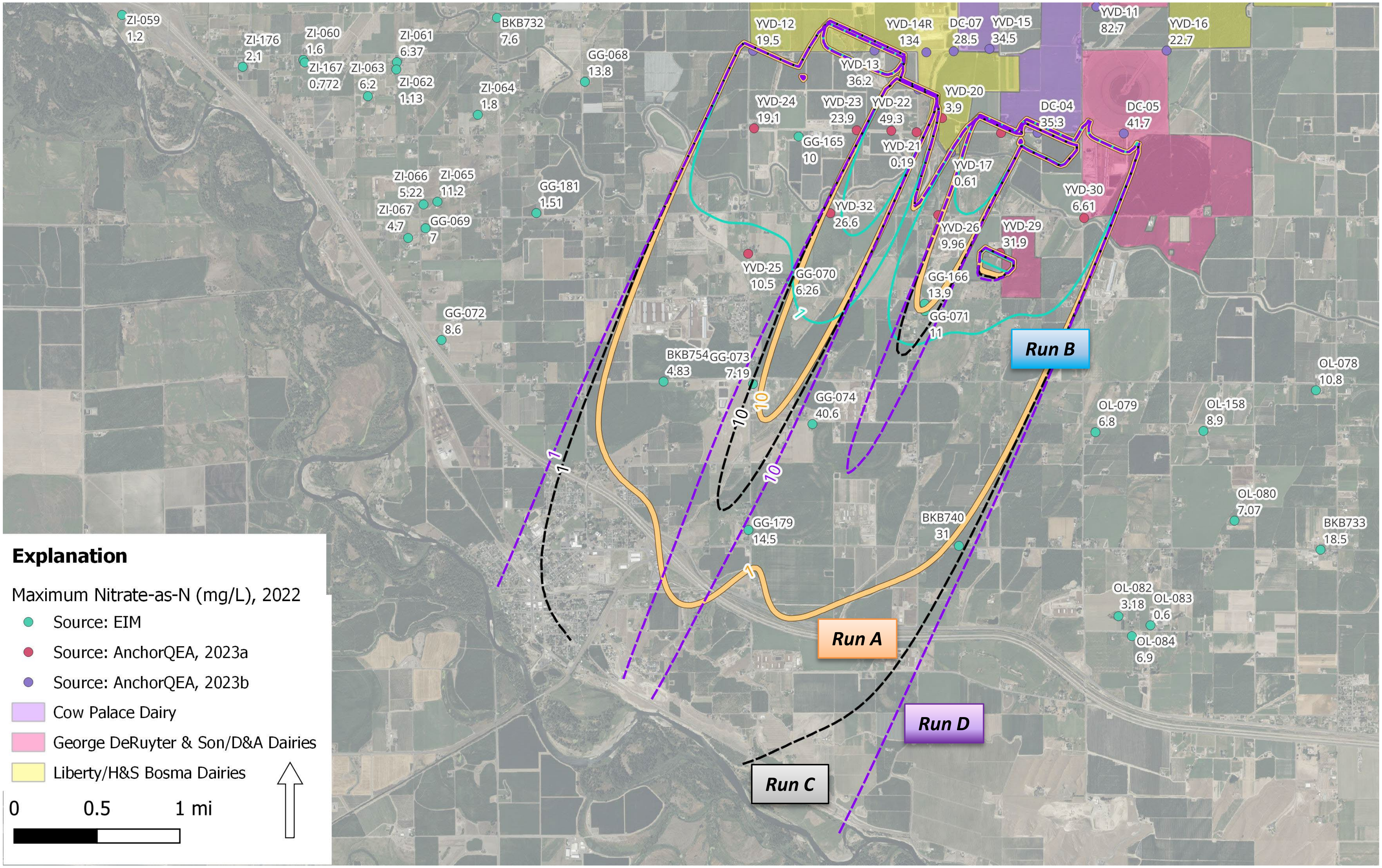


Notes: Contour values are estimated nitrate-as-N (mg/L); results plotted at 38-feet below groundwater table; wells not posted (co-located with other wells) include DC-03D, DC-05D, YVD-31, YVD-27, YVD-18, YVD-28; OL-081 not posted (greater than 200 feet deep); nitrate concentrations from EIM reported as Nitrate + Nitrite as N; 1-mile Boundary from Anchor QEA, 2023c

YAKIMA VALLEY DAIRIES

ATRANS Modeling Results, Base Case Run (A)

Exhibit 17a



Notes: Contour values are estimated nitrate-as-N (mg/L); results plotted at 38-feet below groundwater table; wells not posted (co-located with other wells) include DC-03D, DC-05D, YVD-31, YVD-27, YVD-18, YVD-28; OL-081 not posted (greater than 200 feet deep); nitrate concentrations from EIM reported as Nitrate + Nitrite as N. Model results not plotted south of Yakima River.

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YAKIMA VALLEY DAIRIES

ATRANS Sensitivity Results

4/1/2024 DB23.1324

Exhibit 17b

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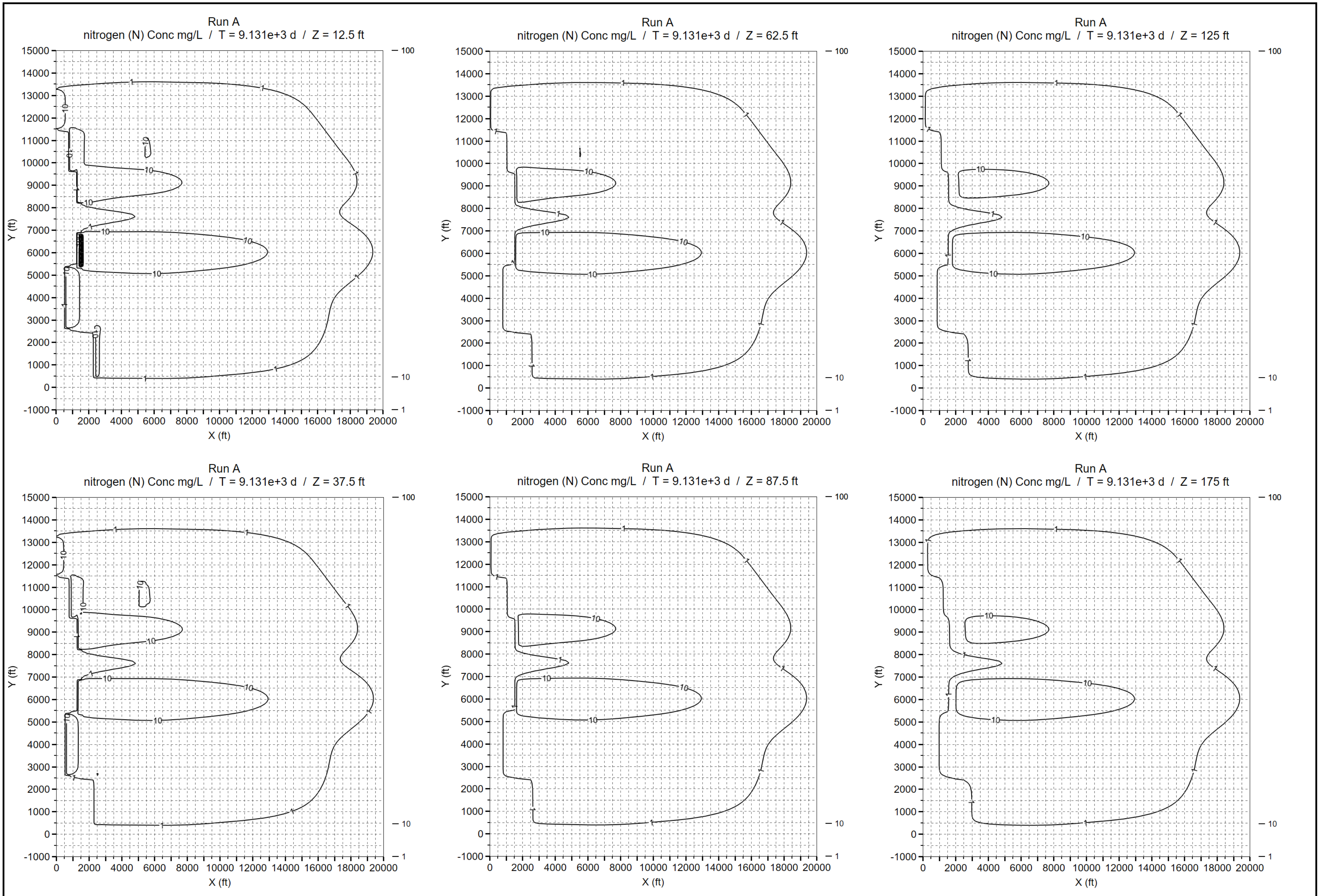
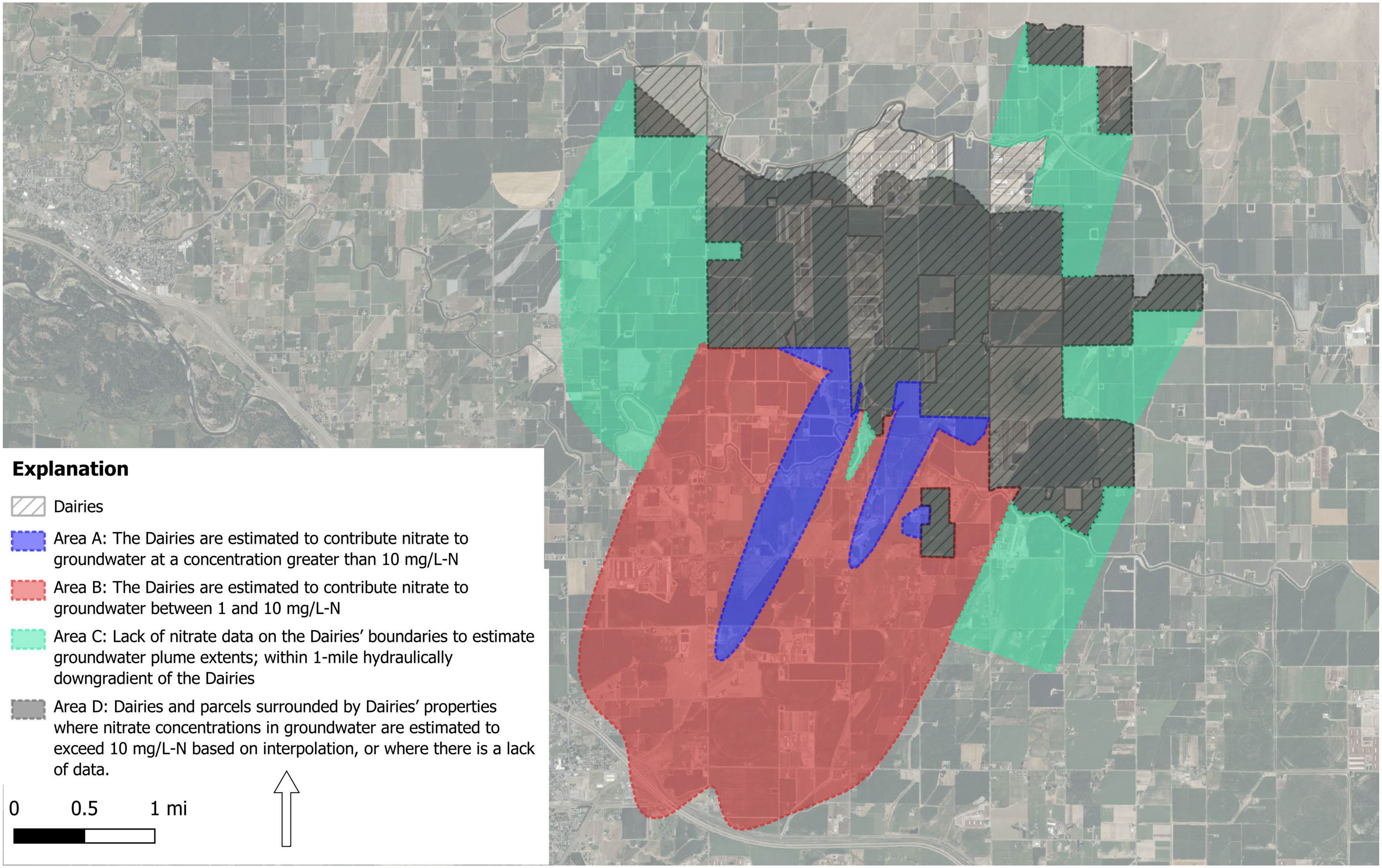


YAKIMA VALLEY DAIRIES

ATRANS Results, Base Case (Run A) at Various Depths

Exhibit 17c



Explanation

▨ Dairies

🟦 Area A: The Dairies are estimated to contribute nitrate to groundwater at a concentration greater than 10 mg/L-N

🟥 Area B: The Dairies are estimated to contribute nitrate to groundwater between 1 and 10 mg/L-N

🟩 Area C: Lack of nitrate data on the Dairies' boundaries to estimate groundwater plume extents; within 1-mile hydraulically downgradient of the Dairies

⬛ Area D: Dairies and parcels surrounded by Dairies' properties where nitrate concentrations in groundwater are estimated to exceed 10 mg/L-N based on interpolation, or where there is a lack of data.

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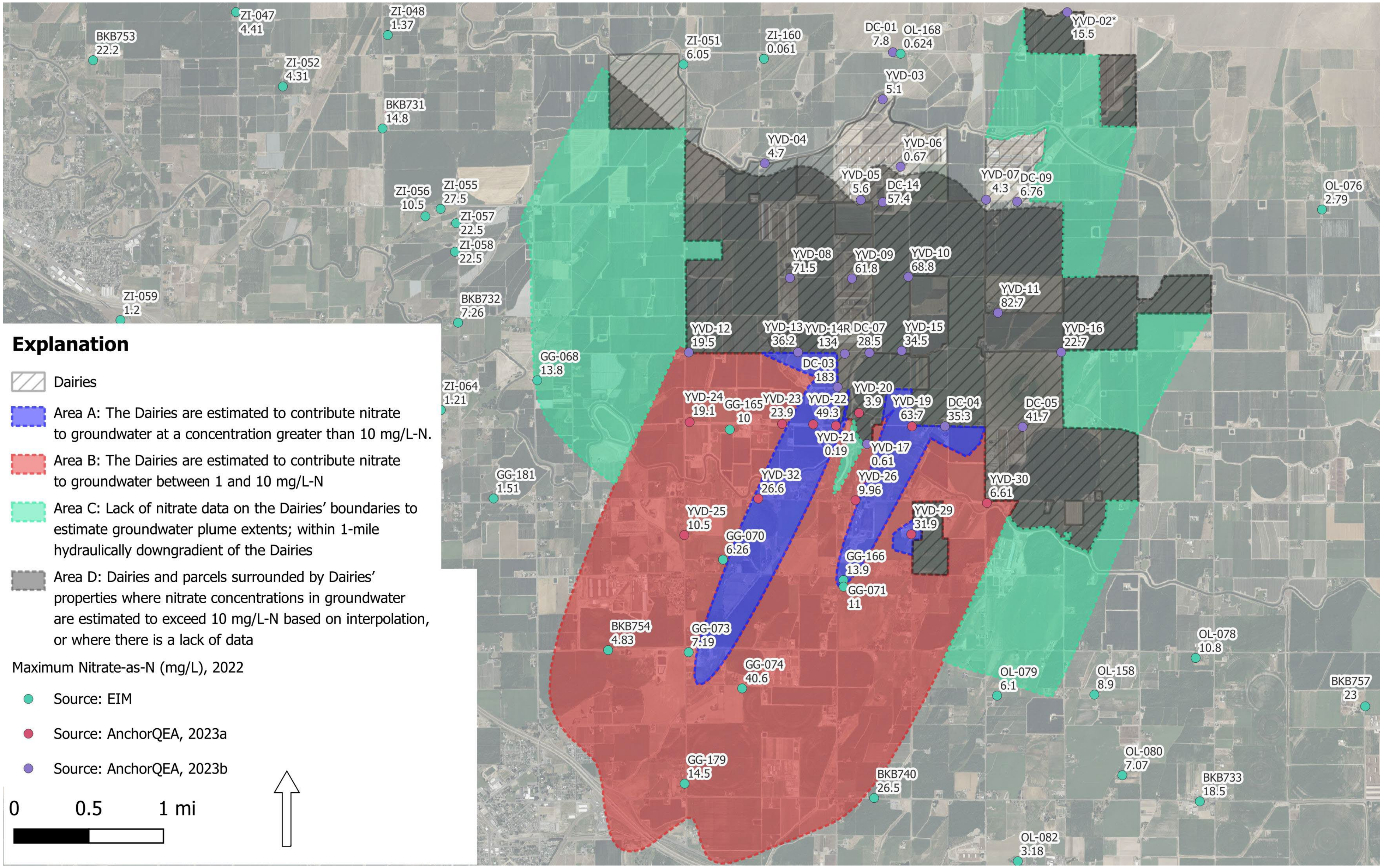
YAKIMA VALLEY DAIRIES

Potentially Affected and Affected Areas in Groundwater

5/3/2024 DB23.1324

Exhibit 18

Q:\Projects\DB23.1324_Yakima_Valley_Dairies\Final Documents\Schnaar Declaration



Note: Refers to groundwater in basin fill units; wells not posted (co-located with other wells) include DC-03D, DC-05D, YVD-31, YVD-27, YVD-18, YVD-28; OL-081 not posted (greater than 200 feet deep); nitrate concentrations from EIM reported as Nitrate + Nitrite as N. *YVD-02 results from most recent sampling in June 2020.

YAKIMA VALLEY DAIRIES

Potentially Affected and Affected Areas in Groundwater and 2022 Maximum Nitrate Data

5/3/2024 DB23.1324

Exhibit 19a

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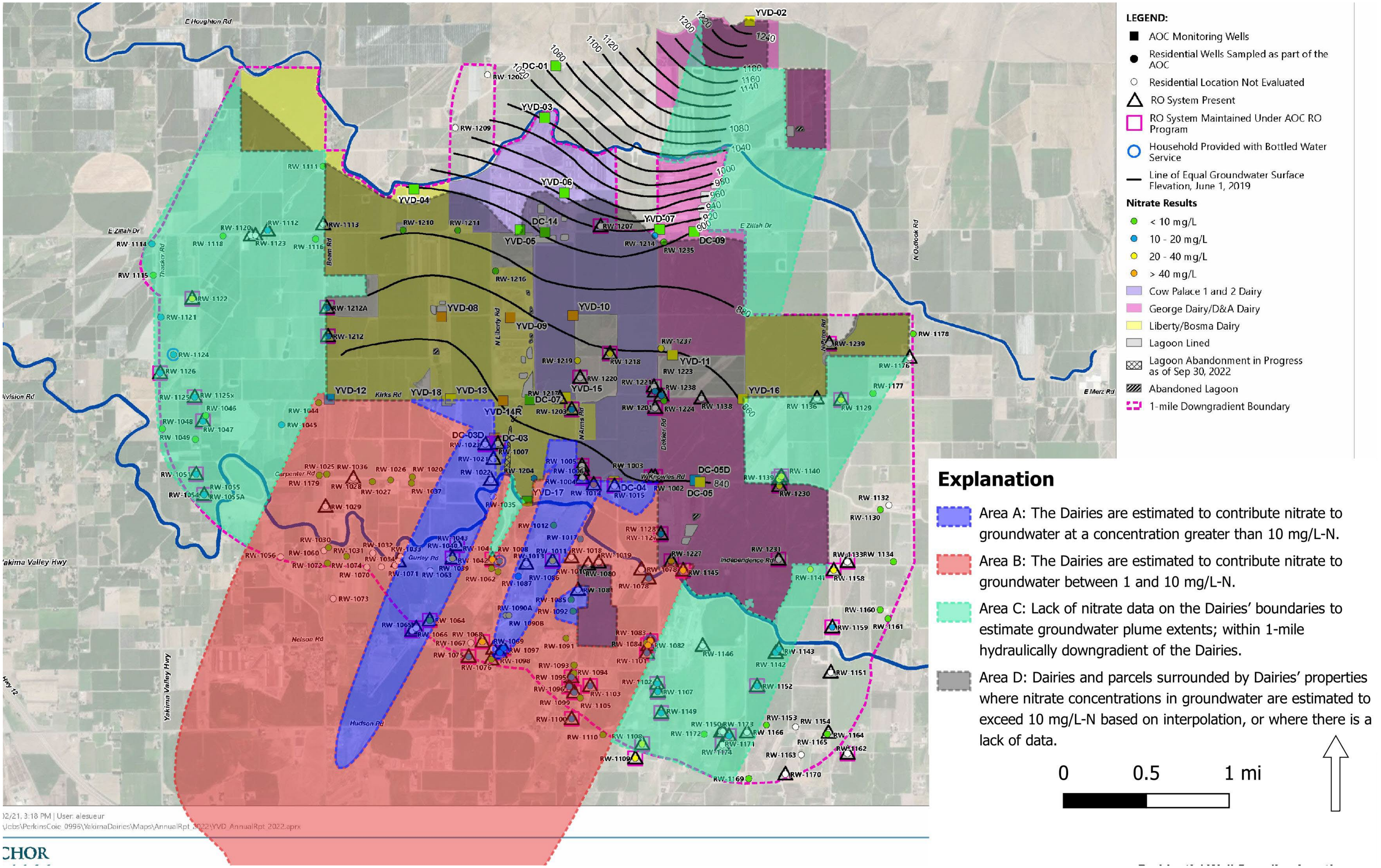


Explanation

🟦 Area A: The Dairies are estimated to contribute nitrate to groundwater at a concentration greater than 10 mg/L-N.

🟥 Area B: The Dairies are estimated to contribute nitrate to groundwater between 1 and 10 mg/L-N.

🟩 Area C: Lack of nitrate data on the Dairies' boundaries to estimate groundwater plume extents; within 1-mile hydraulically downgradient of the Dairies.

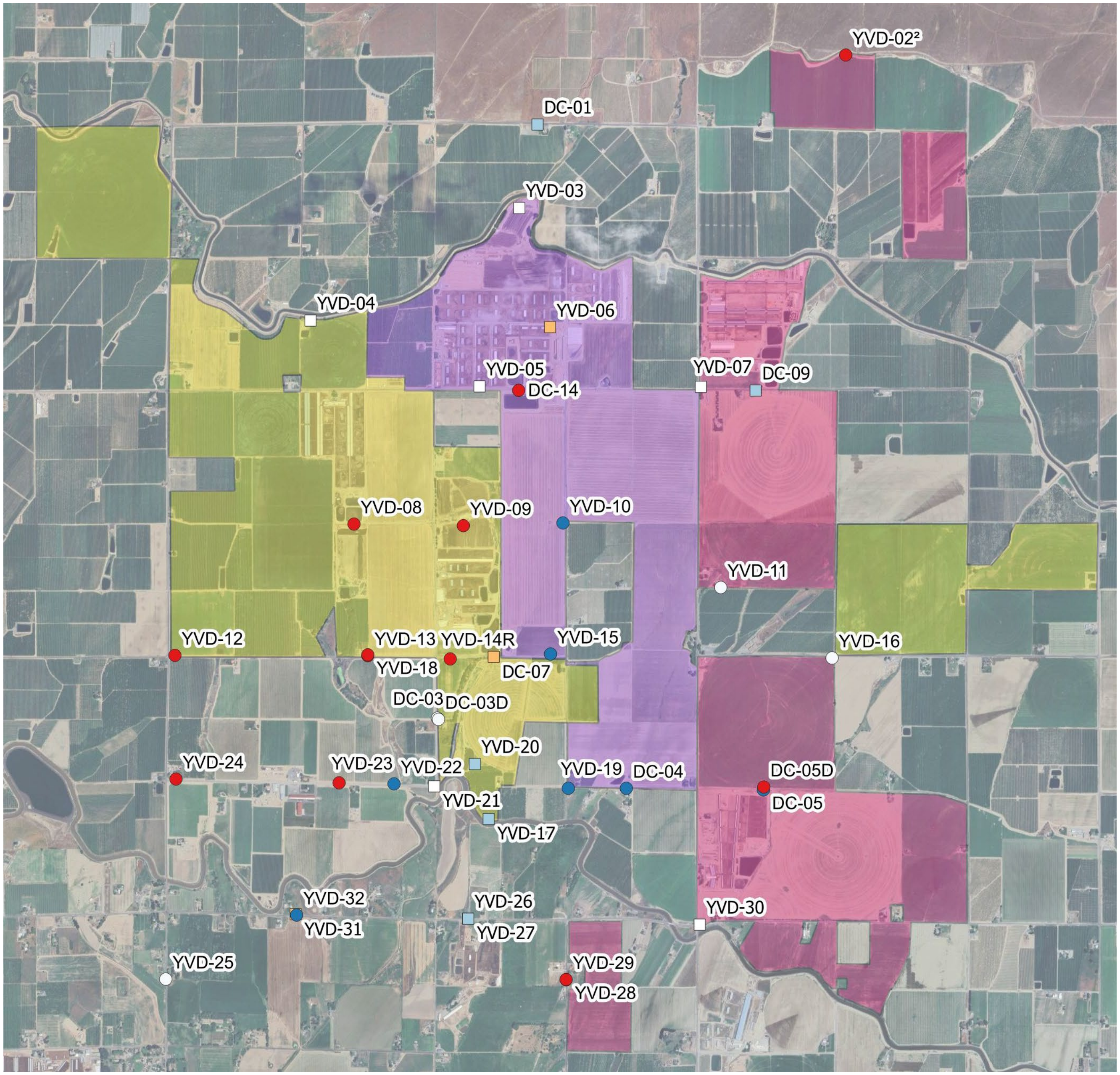
⬛ Area D: Dairies and parcels surrounded by Dairies' properties where nitrate concentrations in groundwater are estimated to exceed 10 mg/L-N based on interpolation, or where there is a lack of data.

Residential Sampling Map Source: Anchor QEA, 2023c

YAKIMA VALLEY DAIRIES

Potentially Affected and Affected Areas in Groundwater and Residential Well Sampling Map

Exhibit 19b



Co-located wells results:

○ DC-03
○ DC-03D

🔵 DC-05
🔴 DC-05D

🔴 YVD-13
🔴 YVD-18

□ YVD-26
🟦 YVD-27

🔴 YVD-28
🔴 YVD-29

🟧 YVD-31
🔵 YVD-32

Explanation

🟪 Cow Palace
🟥 GDS/D&A
🟨 Liberty/Bosma

Above MCL (10mg/L)	Below MCL (10 mg/L)
🔴 Increase	🟧 Increase
🔵 Decrease	🟦 Decrease
○ No Trend	□ No Trend

0 0.5 1 mi

Notes:
1. Location noted as above maximum contaminant level (MCL) of 10 mg/L if most recent measurement exceeded the MCL
2. YVD-02 last sampled in 2020
3. Trend results from first data available for each location

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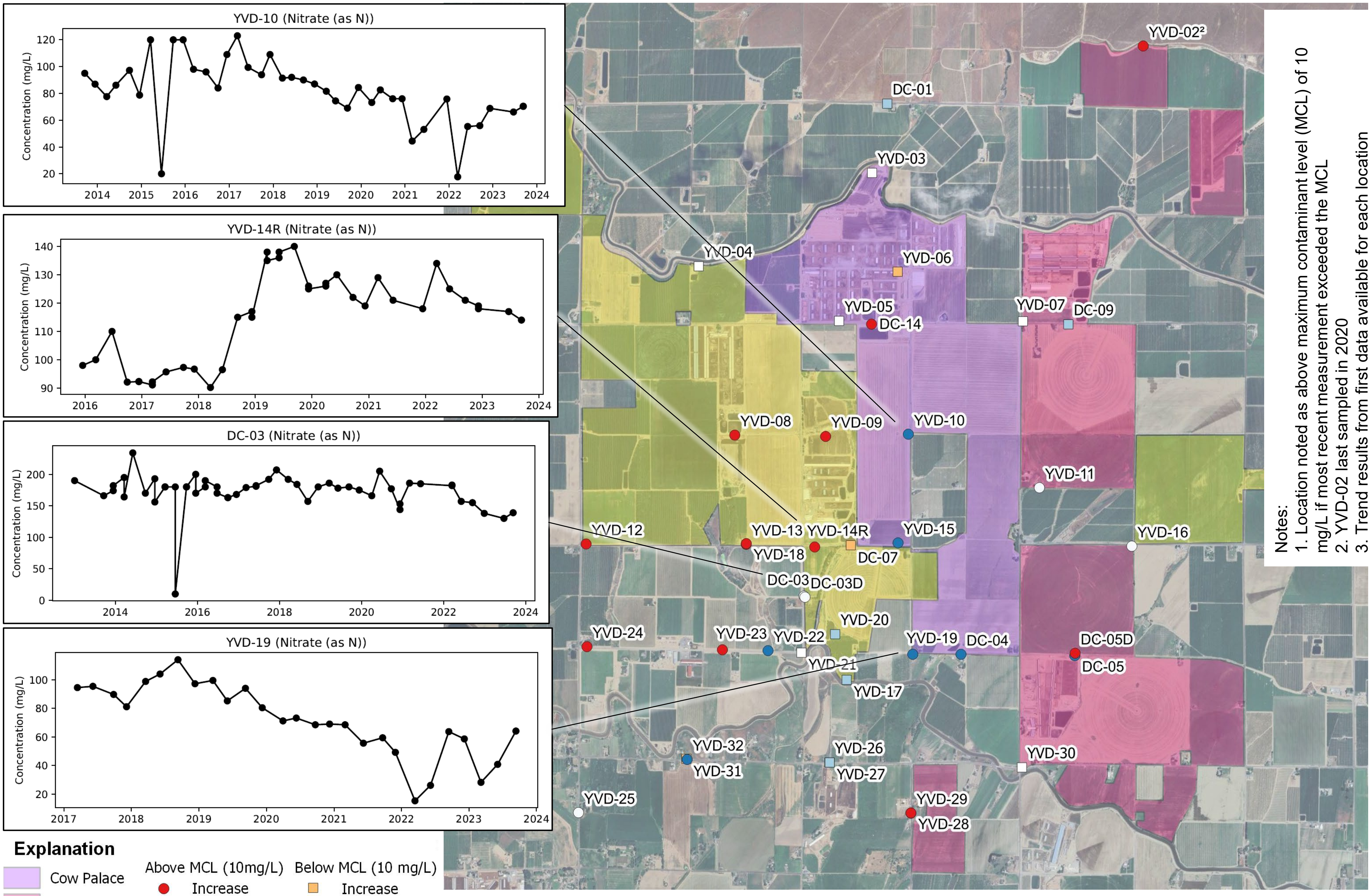
YAKIMA VALLEY DAIRIES

Mann-Kendall Trend Analysis Results, 2013 to September 2023

1/9/2024 DB23.1324

Exhibit 20a



Notes:
1. Location noted as above maximum contaminant level (MCL) of 10 mg/L if most recent measurement exceeded the MCL
2. YVD-02 last sampled in 2020
3. Trend results from first data available for each location

Explanation

	Above MCL (10mg/L)	Below MCL (10 mg/L)
▨ Cow Palace	● Increase	■ Increase
▨ GDS/D&A	● Decrease	■ Decrease
▨ Liberty/Bosma	○ No Trend	□ No Trend

0 0.5 1 mi

YAKIMA VALLEY DAIRIES

Mann-Kendall Trend Results (2013 – 2023) and Time Series Charts, Largest Concentration Wells

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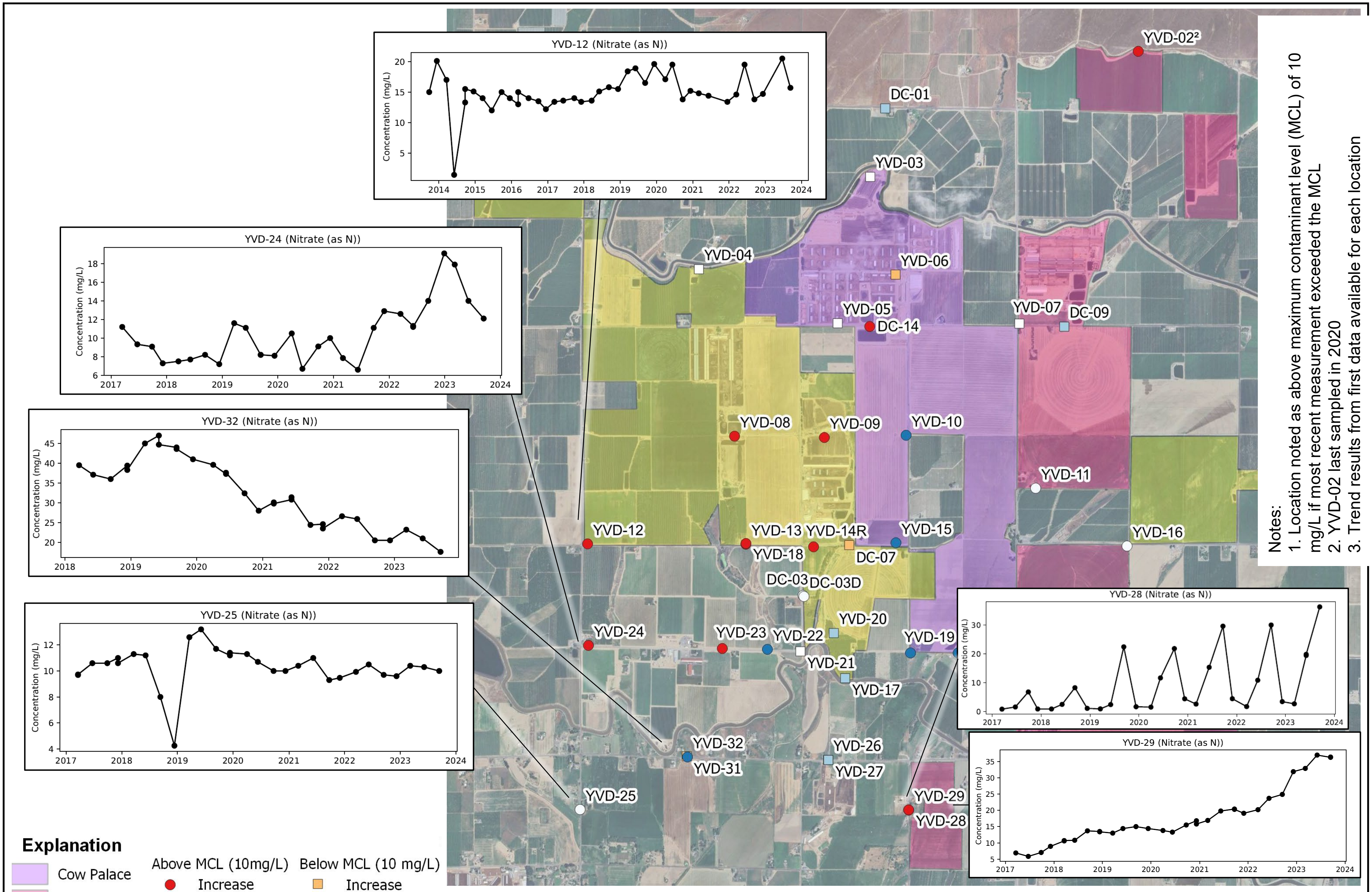
1/9/2024 DB23.1324

Exhibit 20b



Notes:
1. Location noted as above maximum contaminant level (MCL) of 10 mg/L if most recent measurement exceeded the MCL
2. YVD-02 last sampled in 2020
3. Trend results from first data available for each location

Explanation

	Above MCL (10mg/L)		Below MCL (10 mg/L)	
🟪 Cow Palace	🔴	Increase	🟧	Increase
🟥 GDS/D&A	🔵	Decrease	🟦	Decrease
🟨 Liberty/Bosma	○	No Trend	☐	No Trend

0 0.5 1 mi

YAKIMA VALLEY DAIRIES

Mann-Kendall Trend Results (2013 – 2023) and Time Series Charts, Downgradient Wells

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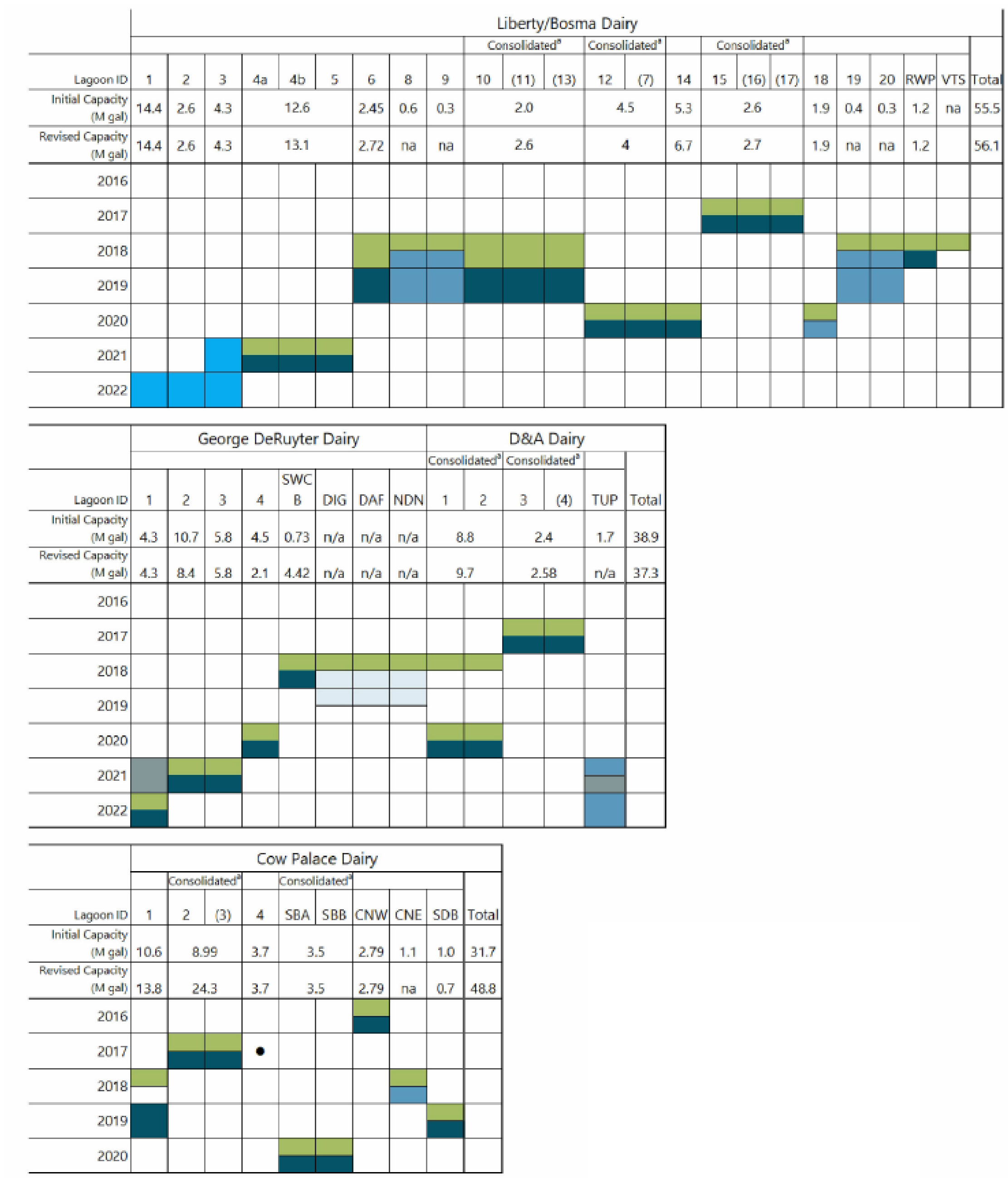
1/9/2024 DB23.1324

Exhibit 20c



	Liberty/Bosma Dairy																						
									Consolidated[a]			Consolidated[a]			Consolidated[a]								
Lagoon ID	1	2	3	4a	4b	5	6	8	9	10	(11)	(13)	12	(7)	14	15	(16)	(17)	18	19	20	RWP	VTS	Total
Initial Capacity (M gal)	14.4	2.6	4.3	12.6			2.45	0.6	0.3	2.0			4.5		5.3	2.6			1.9	0.4	0.3	1.2	na	55.5
Revised Capacity (M gal)	14.4	2.6	4.3	13.1			2.72	na	na	2.6			4		6.7	2.7			1.9	na	na	1.2		56.1
2016																								
2017																🟩 ⬛	🟩 ⬛	🟩 ⬛						
2018							🟩	🟩 🟦	🟩 🟦	🟩	🟩	🟩								🟩 🟦	🟩 🟦	🟩 ⬛	🟩	
2019							⬛	🟦	🟦	⬛	⬛	⬛								🟦	🟦			
2020													🟩 ⬛	🟩 ⬛	🟩 ⬛				🟩 🟦					
2021			🔷	🟩 ⬛	🟩 ⬛	🟩 ⬛																		
2022	🔷	🔷	🔷																					

	George DeRuyter Dairy								D&A Dairy					
									Consolidated[a]		Consolidated[a]			
Lagoon ID	1	2	3	4	SWC B	DIG	DAF	NDN	1	2	3	(4)	TUP	Total
Initial Capacity (M gal)	4.3	10.7	5.8	4.5	0.73	n/a	n/a	n/a	8.8		2.4		1.7	38.9
Revised Capacity (M gal)	4.3	8.4	5.8	2.1	4.42	n/a	n/a	n/a	9.7		2.58		n/a	37.3
2016														
2017											🟩 ⬛	🟩 ⬛		
2018					🟩 ⬛	🟩 ⬜	🟩 ⬜	🟩 ⬜	🟩	🟩				
2019						⬜	⬜	⬜						
2020				🟩 ⬛					🟩 ⬛	🟩 ⬛				
2021	▨	🟩 ⬛	🟩 ⬛										🟦 ▨	
2022	🟩 ⬛												🟦	

	Cow Palace Dairy									
		Consolidated[a]			Consolidated[a]					
Lagoon ID	1	2	(3)	4	SBA	SBB	CNW	CNE	SDB	Total
Initial Capacity (M gal)	10.6	8.99		3.7	3.5		2.79	1.1	1.0	31.7
Revised Capacity (M gal)	13.8	24.3		3.7	3.5		2.79	na	0.7	48.8
2016							🟩 ⬛			
2017		🟩 ⬛	🟩 ⬛	●						
2018	🟩							🟩 🟦		
2019	⬛								🟩 ⬛	
2020					🟩 ⬛	🟩 ⬛				

Notes:

- 🟩 Designed
- ▨ Scheduled work in progress
- ⬛ Lagoon Lined
- 🟦 Abandonment completed
- ⬜ Treatment system construction
- 🔷 Abandonment in progress

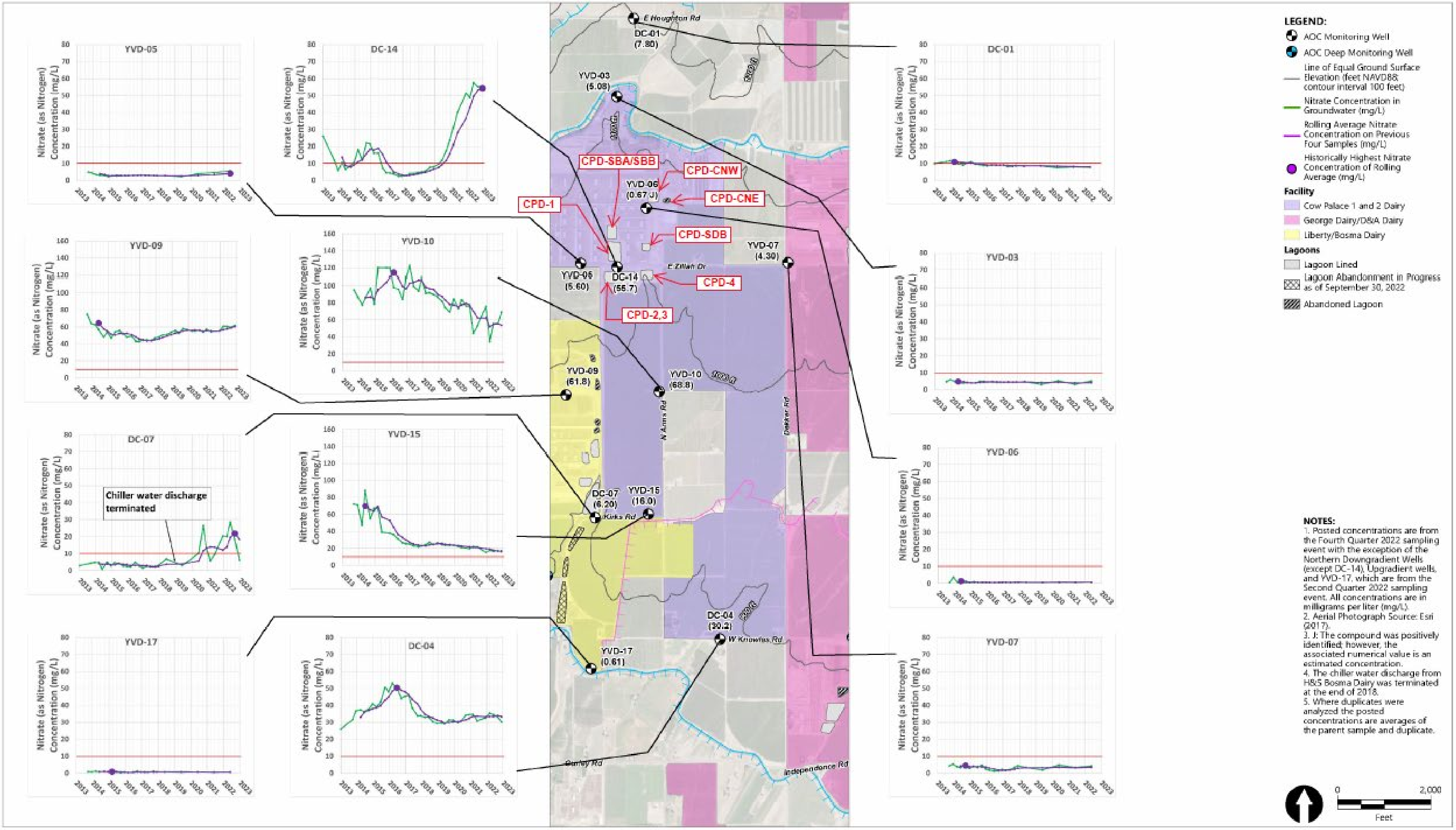
CNW:	Catch Basin NW
CNE:	Catch Basin NE
DIG:	Digester
DAF:	Dissolved Air Flotation Unit
NDN:	Nitrification/Denitrification System
RWP:	Red Water Pond
SBA:	Settling Basin A
SBB:	Settling Basin B
SDB:	Safety Debris Basin
SWCB:	Stormwater Catch Basin
TUP:	Take Up Pond
VTS:	Vermiculture Treatment System
●	Lagoon assessed, meets applicable NRCS standards
a.	Lagoon IDs show in parentheses are part of consolidated lagoons; black Lagoon IDs are the current lagoon ID number.
1.	Lagoon volumes are listed based on operational volumes (with min 2 feet of freeboard). Volumes are based on survey data where available. Where survey data are not available, volumes are based on the volumes listed in the Lagoon Work Plans.
2.	Completed volumes shown do not include lagoons taken out of service, emptied, and cleaned in 2021 and 2022 for abandonment since the abandonment work was not fully completed.

Source: Anchor QEA, 2023c

YAKIMA VALLEY DAIRIES

Progress of Lagoon Lining and Abandonments, 2022

Exhibit 21



NOTES:

1. Posted concentrations are from the Fourth Quarter 2022 sampling event with the exception of the Northern Downgradient Wells (except DC-14), Upgradient wells, and YVD-17, which are from the Second Quarter 2022 sampling event. All concentrations are in milligrams per liter (mg/L).
2. Aerial Photograph Source: Esri (2017).
3. J: The compound was positively identified; however, the associated numerical value is an estimated concentration.
4. The chiller water discharge from H&S Bosma Dairy was terminated at the end of 2018.
5. Where duplicates were analyzed the posted concentrations are averages of the parent sample and duplicate.

Source: Anchor QEA, 2023c (red annotations added)

YAKIMA VALLEY DAIRIES

Nitrate Trend Plots and Lagoon Locations, Central Area

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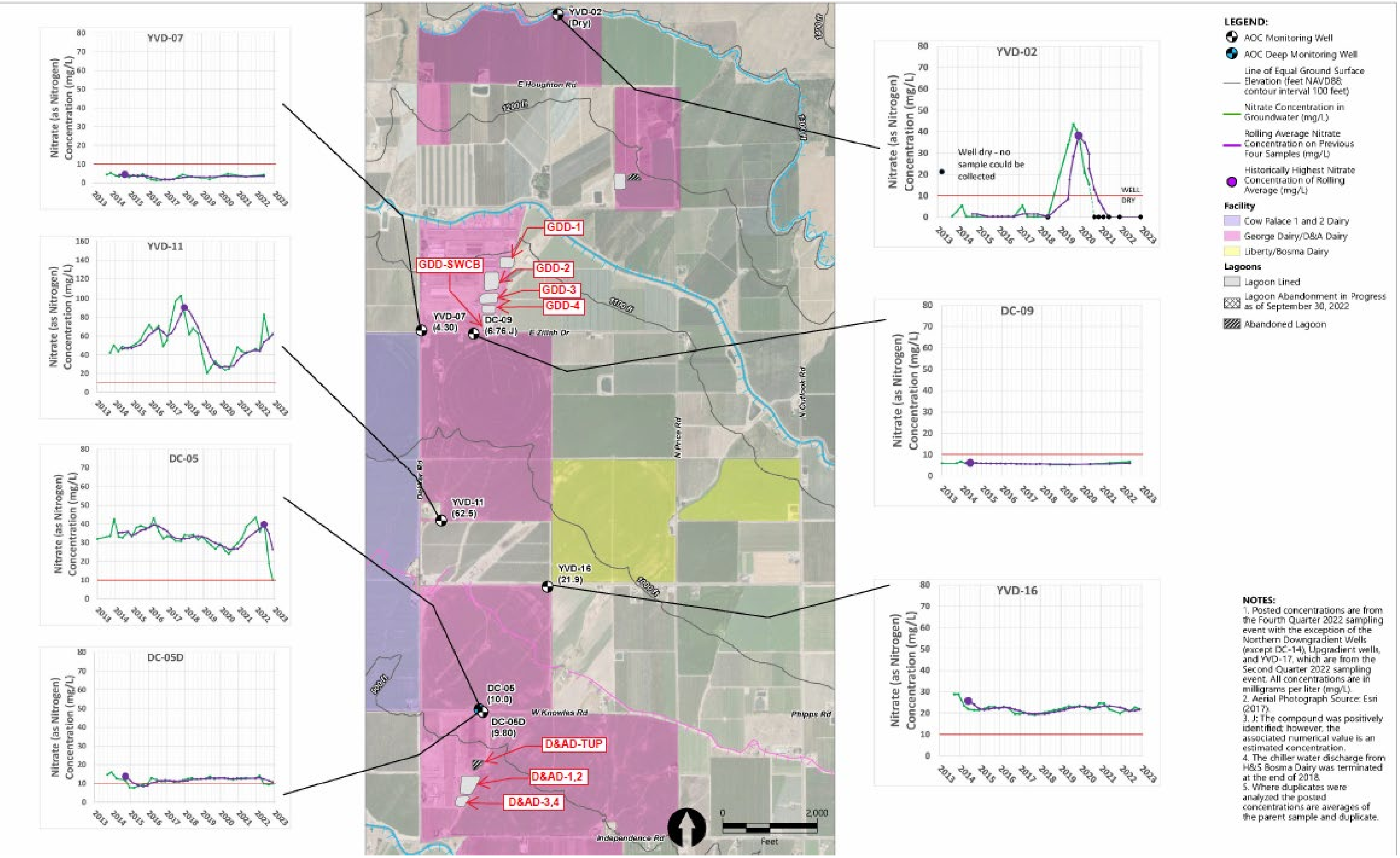
Exhibit 22a



NOTES:

1. Posted concentrations are from the Fourth Quarter 2022 sampling event with the exception of the Northern Downgradient Wells (except DC-14), Upgradient wells, and YVD-17, which are from the Second Quarter 2022 sampling event. All concentrations are in milligrams per liter (mg/L).
2. Aerial Photograph Source: Esri (2017).
3. J: The compound was positively identified; however, the associated numerical value is an estimated concentration.
4. The chiller water discharge from H&S Bosma Dairy was terminated at the end of 2018.
5. Where duplicates were analyzed the posted concentrations are averages of the parent sample and duplicate.

Source: Anchor QEA, 2023c (red annotations added)

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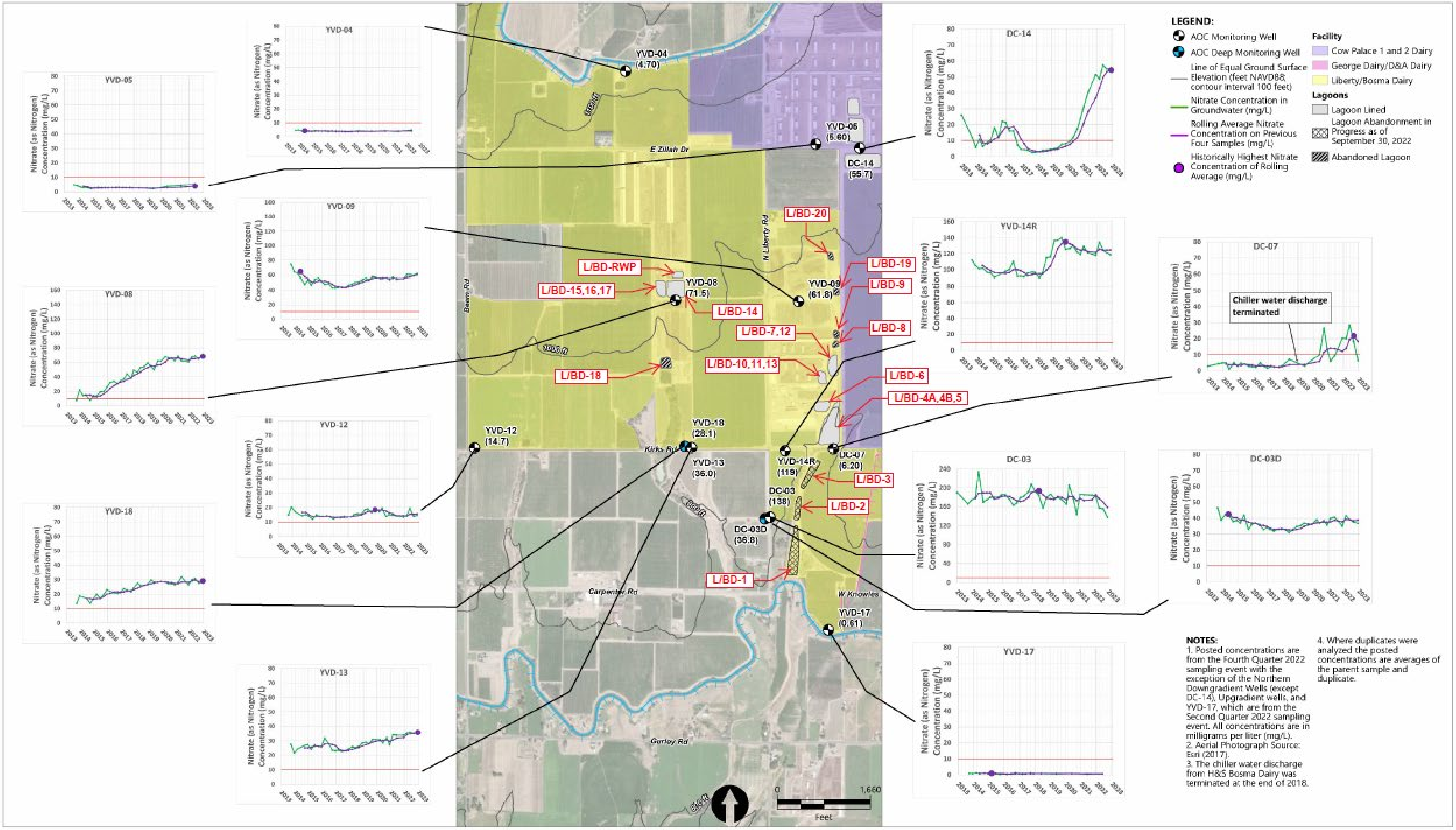
YAKIMA VALLEY DAIRIES

Nitrate Trend Plots and Lagoon Locations, Eastern Area

Exhibit 22b



NOTES:

1. Posted concentrations are from the Fourth Quarter 2022 sampling event with the exception of the Northern Downgradient Wells (except DC-14), Upgradient wells, and YVD-17, which are from the Second Quarter 2022 sampling event. All concentrations are in milligrams per liter (mg/L).
2. Aerial Photograph Source: Esri (2017).
3. The chiller water discharge from H&S Bosma Dairy was terminated at the end of 2018.
4. Where duplicates were analyzed the posted concentrations are averages of the parent sample and duplicate.

Publish Date: 2023/02/21, 8:24 AM | User: akeuer

Source: Anchor QEA, 2023c (red annotations added)

YAKIMA VALLEY DAIRIES

Nitrate Trend Plots and Lagoon Locations, Western Area

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Exhibit 22c

Gregory Schnaar, Ph.D., P.G.

Principal Environmental Scientist/Hydrologist

DBS&A
a Geo-Logic Company

EDUCATION

Ph.D., Soil, Water, and Environmental Science, University of Arizona, 2006

B.S., Environmental Science and Policy, University of Maryland, 2002

CERTIFICATION

Certified Professional Geologist, Virginia (License 2801002085)

Dr. Schnaar specializes in contaminant transport analysis in soil, groundwater, sediment and surface water, forensic environmental analyses, modeling, and watershed-scale hydrologic studies. He has managed a variety of environmental and water resource investigations, including quantitative evaluation of nutrients, chlorinated solvents, petroleum hydrocarbons, polychlorinated biphenyls (PCBs), poly- and perfluoroalkyl substance (PFAS), methyl tert-butyl ether (MTBE), perchlorate, metals, salts, and legacy pesticide-contamination, site investigations and remedial action alternatives analysis, vapor intrusion risk assessment, and development of cost allocations for remedial cost recovery.

Dr. Schnaar has served as an expert technical consultant to the U.S. Environmental Protection Agency (EPA) Office of Ground Water and Drinking Water, New Mexico Environment Department (NMED), and the California State Water Resources Control Board. He has provided expert witness testimony related to fate and transport of contaminants and historical site operations relating to the potential for contaminant releases. He has taught courses in Environmental Science and Water Resources as a faculty member (2014 to 2017) and adjunct faculty member (2021) at the University of Maryland, College Park and an adjunct faculty member at George Washington University.

Representative Experience

Nitrogen Contaminant Fate and Transport Evaluation

Development of Watershed-Scale Integrated Surface-Water Groundwater and Nitrate Transport Model, California State Water Resources Control Board, Ventura County, California

Developed a GSFLOW-based integrated surface water/groundwater model of the Ventura River watershed for evaluation of management options to enhance instream flows consistent with the California Water Action Plan and reduce nitrate impacts associated with a TMDL regulation. Nitrate modeling conducted with MT3D-USGS and evaluated loading from various land-use types (e.g., agriculture, animal operations) and septic systems, variable nitrate degradation rates, and calibration to nitrate data from groundwater wells and streams.

Nitrate Transport Evaluation from Equestrian Facility (CAFO) to Groundwater and Creek, Confidential Client, Orange County, California

Performed technical evaluation of nitrate transport to groundwater and surface water in compliance with consent decree that required evaluation of (1) if a the facility was capable of producing the functional equivalent of discharge to a local creek as defined in *County of Maui v. Hawaii Wildlife Fund*, and (2) evaluation of site-specific nitrate loading, vadose zone nitrate processes, nitrate loading to groundwater, groundwater flow rates and direction, and groundwater and nitrate discharge to the local creek. Oversaw collection of field data to inform groundwater flow direction and rates, streamflow and soil properties, and performed technical analysis including analytical modeling of nitrate transport in groundwater.

Pathogen and Nitrate Transport Evaluation from Septic Systems and Evaluation of Potential Groundwater Impacts, Crestview Mutual Water Company, Camarillo, California
Evaluated potential pathogen and nitrate transport from septic systems in the vicinity of a planned municipal groundwater supply well. Pathogen transport in the vadose zone evaluated with HYDRUS model, and also based on a scientific literature review.

Evaluation of Impacts from Poultry Processing Facility to Surface Water, Private Land Owner, Higgins Millpond, Dorchester County, Maryland
Evaluated historical facility nutrient discharges, including from discharge monitoring reports (DMRs), in order to evaluate the role of permitted discharges from point source on nutrient loading to the Transquaking River and Higgins Millpond in support of comments on Maryland Department of the Environment (MDE) tentative determination draft permit.

Evaluation of Nutrient Loading Dynamics, Chesapeake Bay, Confidential Client, Maryland
Supporting confidential client in evaluation of nutrient and sediment loading rates and hypoxic volumes as impacted by climate, dams and other factors in support of litigation and regulatory compliance. Obtained monitoring data from Chesapeake Bay Program and Susquehanna River Basin Commission to perform critical evaluation of Chesapeake Bay Program assumptions and modeling and perform analysis of loading from specific jurisdictions.

Environmental Permitting Support and Evaluation of Salt and Nutrient Loading, Hollandia Produce LLC, Ventura County, California
Managed environmental permitting support for hydroponic lettuce production operation, including Conditional Use Permit (CUP) for Ventura County and a Waste Discharge Requirement/Water Recycling Requirement (WDR/WRR) for the Regional Water Quality Control Board (RWQCB). Developed quantitative evaluation of potential salt and nutrient impacts to groundwater based on a modification of the published U.S. EPA two-dimensional mixing-model approach that incorporates salt and nutrient contribution from upgradient areas of the watershed.

Hydrogeologic Characterization, Groundwater Balance, and Selenium and Nutrient Transport Evaluation, Newport Bay Watershed, Orange County Public Works, Orange County, California
Technical lead on watershed-scale assessment of selenium loading to surface water channels leading into Upper Newport Bay. Project included watershed modeling of recharge from deep percolation, groundwater/surface water balance estimation, selenium and nutrient loading evaluation, identification of data gaps and recommendations for next steps for control of selenium and nutrient loading.

Nitrate Transport Evaluation from Agriculture and Septic Systems, Confidential Client, Monterey County, California
Evaluation of nitrate impacts to a community water well from agricultural sources and a commercial septic system to support response to a Regional Water Quality Control Board Cleanup and Abatement Order (CAO). Reviewed historical documents and data, performed spatial analysis of nearby sources, hydrogeologic evaluation and nitrate transport modeling.

Dairy Grazing Nitrate Contamination Study, University of Maryland, College Park, Maryland
As undergraduate research assistant assisted in field-scale study of nitrate contamination associated with intensive dairy grazing at farms in Maryland. Collected groundwater and unsaturated-zone water samples at dairy facilities throughout Maryland and prepared samples for laboratory analysis.

Contaminated Soil and Groundwater

Age-Dating of Chlorinated Solvent Release, Clean Harbors Kansas LLC, Wichita, Kansas

Testifying expert, reviewed historical facility records dating to 1970s, industrial practices and operations, and environmental data in soil and groundwater to determine location and timing of chlorinated solvent releases relative to property ownership transfer. Provided consultation and expert trial testimony in Delaware Superior Court jury trial.

1,4-Dioxane Transport Evaluation in Soil and Groundwater, Confidential Client, Louisiana

Testifying expert, evaluated 1,4-dioxane transport in soil and groundwater at former production facility to assess timing of releases in support of ongoing arbitration. Conducted vadose-zone model simulations using HYDRUS-2D to evaluate timing of 1,4-dioxane transport in soils under various scenarios including releases from a leaking sump and pipeline or stormwater swale. Submitted expert rebuttal reports and provided deposition and arbitration hearing testimony.

Evaluation of MTBE and Petroleum Hydrocarbon Impacts, Confidential Client, Pennsylvania

Testifying expert, evaluated MTBE impacts to groundwater associated with individual service stations in support of litigation. Analyses included review of MTBE data in groundwater monitoring wells, aerial photographs, historical records, groundwater flow evaluation, contaminant transport modeling and site visits.

Quality Assurance Manager, Griggs Walnut Superfund CERCLA Site, Las Cruces, New Mexico

Responsibilities include oversight and review of all project field sampling and reporting for federal Superfund Site with tetrachloroethene (PCE) as primary contaminant of concern. Identified issues in existing groundwater monitoring network (FLUTe wells) and developed strategy to revise groundwater monitoring program accordingly.

Evaluation of Mercury Contamination to Soils at former Chlor-Alkali Facility CERCLA Site, Confidential Client, New Jersey

Assisted confidential client in negotiations with U.S. EPA related to remedial cost allocation at CERCLA Site. Evaluated mercury impacts to soil and tidally influenced ditches as influenced by stormwater discharge and coastal flooding.

PFAS Investigation and Modeling at Cannon and Holloman Air Force Bases, New Mexico Environment Department, New Mexico

Investigation of the extent of PFAS impacts to surface water and groundwater in the vicinity of two Air Force Bases from use of AFFF. DBS&A performed field sampling to delineate the extent of PFAS impacts. Performed analytical and numerical modeling to predict future groundwater impacts under various scenarios and fill data gaps. Final technical reviewer of reports submitted to NMED.

Technical Reviewer, PFAS Site Characterization and Remediation, Northern Michigan

Retained by insurance company covering site characterization and remediation costs related to AFFF releases at municipal airport. Provided comment and direction regarding site characterization methods, data gaps, remedial approaches, potential additional PFAS sources and reasonableness of costs.

Source Identification, PFAS Contamination to Groundwater, Confidential Client, Maine

Evaluating available data regarding paper mill operations, waste water discharges, biosolids spreading, and surface and groundwater hydrology to assess impacts of paper mill waste disposal on domestic groundwater wells in support of litigation.

PFAS Rulemaking Comments Support, City of Las Cruces, New Mexico
Supported City of Las Cruces in developing technical comments on the U.S. EPA proposed PFAS National Primary Drinking Water Regulation. Comments covered topics related to Monitoring and Compliance Requirements, Treatment Technologies and Methods for Cost Estimating.

Source Identification, PFAS Contamination to Groundwater, Confidential Client, Michigan
Evaluated PFAS data in groundwater at municipal production, domestic, and monitoring wells to determine source(s) of contamination. Evaluated operational history associated with multiple facilities, aerial photography, PFAS occurrence and chemical signatures, groundwater flow directions and previously-developed well-head protection area mapping.

Technical Reviewer, PFAS Site Characterization and Interim Water Replacement Measures, Central California
Retained by insurance company covering site characterization, remediation, and water replacement costs related to aqueous film-forming foam (AFFF) releases at municipal airport. Provided detailed comments and technical direction regarding site characterization methods, potential additional PFAS sources, water replacement options for 50 residences and business with potentially impacted private wells (point-of-entry, point-of-treatment, and municipal water supply line extension) and negation of voluntary cleanup agreement with the Regional Water Board.

Technical Committee Member, North Bronson Industrial Area Superfund CERCLA Site, Bronson, Michigan
Member of technical oversight committee for Superfund site, including oversight of contractor Remedial Investigation/Feasibility Study (RI/FS) development and coordination with U.S. EPA and Michigan Department of Environmental Quality. Developed investigation and remedial-cost allocation strategy for four parties that disposed of wastes to the industrial sewer system. Potential contaminants of concern include metals, chlorinated solvents (TCE/PCE), and PFAS.

Dry Cleaner Investigation, San Roque Cleanup Trust, Former Dutchmaid Cleaners Perchloroethylene Site, Santa Barbara, California
Managed investigation of soil contamination impacts from an active dry-cleaning facility that historically used tetrachloroethene (PCE) in operations. Responsible for staff and sub-contractor management, site access and property manager/business owner coordination, budgeting, reporting, and soil sampling from direct-push soil cores.

Evaluation of PCE impacts from multiple dry-cleaner facilities, Confidential Client, Visalia, California
Performed soil-vapor transport modeling and evaluated facility records to ascertain PCE impacts to soil and groundwater from three separate dry-cleaning facilities, including from disposal of dry-cleaning wastewater to the sanitary sewer system and subsequent leakage.

Non-Aqueous Phase Liquid Infiltration and Vapor Transport Modeling, Confidential Client, Orange County, California
Developed numerical model to evaluate infiltration of chlorinated solvents for conditions representative of a contaminated property, and subsequent migration in vapor and pore-water (TOUGH2-T2VOC). Modeling was used to evaluate the fate of chlorinated solvents in the subsurface and potential groundwater impacts, and to support client in litigation.

Groundwater Treatment System and Perchlorate Impact Evaluation, San Bernardino County, California
Evaluated groundwater treatment system operation, including groundwater capture-zone width and capture in order to provide technical response to comments on County Operations Maintenance Monitoring Plan (OMMP) for the Rialto Groundwater Treatment System. Assessment included evaluation of perchlorate and VOC data from a network of several dozen multi-port wells and differentiation of impacts from a separate perchlorate plume from source east of Mid-Valley Sanitary Landfill.

Evaluation of Chromium Leaching from Industrial Disposal to Surface Water Channel and Allocation Analysis, Confidential Client, Los Angeles, California
Project manager for evaluation of historical chromium contamination to groundwater from several sources, including waste-water disposal to the Los Angeles River and channelized tributaries. Historical documents and aerial imagery used to develop timeline of channel construction and industrial operations from the 1920s to the 1960s. Multi-party remedial allocation conducted using several methodologies including based on area and mass of groundwater contamination associated with various facilities.

Evaluation of Natural Attenuation of Chlorinated Solvents in Groundwater from Former Landfill, Confidential Client, Contra Costa County, California
Evaluated groundwater geochemistry in regards to favorability for reductive dechlorination of chlorinated solvents released from a former landfill, in order to assess impacts to downgradient properties. Analysis was based on U.S. EPA guidance on the use of monitored natural attenuation at Superfund sites, and evaluated groundwater redox geochemistry, isotope analysis, the presence of degradation daughter products, and analytic biodegradation modeling.

Evaluation of Remedial Measures and Petroleum Hydrocarbon Migration from Leaking Pipeline, Confidential Client, Baltimore, Maryland
Petroleum hydrocarbons leaking from pipeline have migrated through soil to stormwater system, leading to release to the Baltimore Harbor. Evaluated appropriateness of remedial measures to repair stormwater system and recover petroleum hydrocarbons from water table.

Evaluation of Groundwater Impacts from Coal Fly-Ash Disposal in Former Gravel Mine and Numerical Modeling, Confidential Client, Anne Arundel County, Maryland
Evaluated potential downgradient groundwater impacts by sulfate, aluminum, and other inorganic constituents from leaching through fly-ash disposal pits. Previous numerical modeling was reviewed to assess assumptions regarding regional hydrogeology, groundwater flow and transport, and applicability of the model for assessing downgradient impacts.

Statistical Trend Analysis, Groundwater Modeling, and LNAPL Recovery Plan, Clean Harbors El Dorado Incineration Facility, El Dorado Arkansas
Support Clean Harbors El Dorado in annual RCRA groundwater monitoring requirements including statistical trend tests, numerical groundwater modeling, contaminant transport modeling, and LNAPL recovery analysis. Contaminants of concern include VOCs, SVOCs and metals.

RCRA Facility Investigation and Corrective Measures Study, Clean Harbors Arizona, LLC, Phoenix, Arizona
Manage development and implementation of RCRA Facility Investigation (RFI) and Corrective Measures Study (CMS) for facility with volatile organic compound (VOC) impacts in soil vapor and groundwater. Successfully negotiated with Arizona Department of Environmental Quality to continue interim remedial measures (soil

vapor extraction) performed at the site as ongoing corrective measure. Conducted SVE rebound testing in support of final Site closure.

Numerical Model Design for Evaluation of Vadose Zone Contamination from Petroleum Refinery, Confidential Client, Philadelphia, Pennsylvania
Designed a multiphase flow vadose zone model (TOUGH2-T2VOC) to evaluate impacts from release of large quantities of petroleum hydrocarbons from a refinery and adjacent property. The model was used to examine the behavior of light non-aqueous phase liquid (LNAPL) in the vadose zone and at the groundwater table over a period of several decades in support of allocating contribution from separate facilities to LNAPL contamination.

Evaluation of MTBE and Petroleum Hydrocarbon Impacts, Confidential Client, New York and New Hampshire
Evaluated MTBE impacts to groundwater associated with numerous individual service stations in support of litigation. Analyses included review of underground storage tightness testing, MTBE data in groundwater monitoring wells, aerial photographs, historical records, groundwater flow evaluation, and contaminant transport modeling.

Development of Remedial Cost Allocation for Multi-Party Contaminated Site, Confidential Client, Santa Clara County, California
Developed allocation for remedial costs associated with VOCs vadose zone and groundwater contamination. Allocation analysis also included assessment of previous remedial actions that likely exacerbated contamination and increased long-term remedial costs.

Groundwater Monitoring Program, San Roque Cleanup Trust, Former Dutchmaid Cleaners Perchloroethylene Site, Santa Barbara, California
Task manager for groundwater monitoring program at chlorinated solvent-contaminated site. Semi-annual monitoring program for standard volatile-organic compounds (VOCs), remedial performance indicator parameters, 1,4-dioxane and groundwater levels from a network of over fifty monitoring wells.

Numerical Model Design, Hexcel, Kent, Washington
Designed numerical groundwater model for investigation of groundwater flow and transport of chlorinated solvents at a facility located in Kent, Washington. The model was used to predict well capture zones associated with a pump-and-treat remedial effort and evaluate alternative remedial strategies.

Aquifer Testing and Analysis and Ambient Groundwater Monitoring Program, Freeport-McMoRan Sierrita Mine, Green Valley, Arizona
Conducted multiple aquifer tests in vicinity of properties impacted by copper mine tailings. Analyzed current and historic aquifer test results in order to develop a three-dimensional understanding of the variability of hydraulic conductivity and storage parameters downgradient of mine tailings.

Pore-Scale Imaging Research, National Institute of Environmental Health Sciences Superfund Basic Research Program, University of Arizona, Tucson, Arizona
Designed and conducted experiments for pore-scale imaging of non-aqueous phase liquid (NAPLs) in natural sands. Research project included use of a cutting-edge optical technique for imaging of pure-phase chlorinated solvents in natural sandy media in order to observe NAPL migration and dissolution at the pore scale.

Research on Non-Ideal Sorption of Volatile Organic Compounds in Soil, University of Arizona, Tucson Arizona

Conducted physical and numerical experiments investigating the impact of non-ideal sorption on low-concentration elution tailing of chlorinated solvents and pesticides. Research involved conducting laboratory column flushing experiments, sample chemical analysis, and data interpretation with a numerical model. Results have been published in several peer-reviewed journals and presented at various international scientific meetings.

Indoor Air Vapor Intrusion

LNAPL Remediation and Vapor Intrusion Assessment at Kirtland Air Force Base, New Mexico Environmental Department, Albuquerque, New Mexico

Reviewed historical data and documentation regarding LNAPL occurrence, petroleum hydrocarbons and BTEX to provide NMED with an independent assessment of the need for a vapor intrusion investigation and additional data needs for remedial planning associated with LNAPL in the vadose zone and submerged under the groundwater table.

Vapor Intrusion Risk Assessment, Freedom Blvd. & Vicinity, City of Watsonville, California

Performing a remedial investigation and vapor intrusion risk evaluation, including an indoor air/crawlspace/sub-slab sampling program for area downgradient of former dry-cleaning operations.

Vapor Intrusion Risk Assessment, San Roque Cleanup Trust, Former Dutchmaid Cleaners Perchloroethylene Site, Santa Barbara, California

Technical lead for vapor intrusion risk assessment for 22-acre chlorinated-solvent contaminated site with contribution from three separate dry-cleaning facilities. Oversaw field-testing for soil vapor diffusivity and soil moisture, which was used to justify a lower risk of vapor intrusion compared to default CalEPA assumptions. Vapor intrusion risk assessment approved by California state regulators with the Regional Water Quality Control Board (RWQCB), Department of Toxic Substances Control (DTSC), and Office of Environmental Health Hazard Assessment (OEHHA).

Vapor Intrusion Assessment, Confidential Client, Dayton, Ohio

Evaluated vapor intrusion at residential and commercial properties downgradient of a large chlorinated solvent contaminated site, and several smaller sites contributing minor plumes, in support of a class-action lawsuit. Performed extensive data analysis of indoor air and sub-slab vapor data collected from hundreds of residences, and groundwater data from a network of over fifty monitoring wells.

Vapor Intrusion Assessment, Confidential Client, Los Angeles County, California

Project manager and technical lead in vapor intrusion assessment at a low-income housing complex in Los Angeles County. Vapor intrusion modeling involved development of a spreadsheet based partitioning model to predict multi-component vapor concentrations in presence of liquid petroleum hydrocarbons, and Johnson-Ettinger modeling of sub-slab vapor transport to indoor air.

Contaminated Sediments and Waterways

Contaminated Sediment Source Identification (PCBs) and Evaluation of Allocation Approaches, Confidential Client, Lower Duwamish Waterway CERCLA Site, Washington State

Testifying expert, evaluated stormwater solids, sediment data, regional sediment transport modeling and facility history from multiple facilities located along the Lower Duwamish Waterway for source identification of PCBs and other contaminants found in sediment for source attribution and remedial cost allocation.

Contaminated Sediment Source Identification (PCBs) and Remedial Investigation Review, Confidential Client, Southern California

Retained as subject matter expert to assist confidential client in compliance with a Regional Water Quality Control Board mandated Investigative Order related to sediment contamination (including PCBs, PAHs and metals) and remedial cost allocation amongst several parties claimed to have contaminated bay sediments. Oversaw sediment characterization field activities (core and grab sampling).

Contaminated Sediment Source Identification/Attribution Analysis at CERCLA Site, Confidential Client, New York/New Jersey

Evaluated chemistry data in waterway to identify source(s) and demonstrate that client did not contribute mercury to sediments requiring remediation based on mercury and other contaminant distribution in sediments, ecological risk analysis results, history of operations and waste management practices, soil sampling data, review of flooding/hurricane impacts, and aerial photography review.

Pollutant Loading Analysis, Cottonwood Sand Mine and Sweetwater Reservoir, San Diego County, California

Developed pollutant load analysis for planned aggregate mine located upstream of Sweetwater Reservoir to evaluate potential water-quality impacts of sediment erosion on the reservoir. Performed sediment erosion modeling (WEPP) and sediment transport analysis in Sweetwater River upstream of the reservoir.

Evaluation of Remediation Options for Non-Point Watershed Legacy Contaminants (PCBs/pesticides) in Lakebed Sediment, Private Land Owner, McGrath Lake, Ventura County, California

Consulting expert for compliance with a total maximum daily load (TMDL) regulation regarding legacy pesticides and PCBs bound to lakebed sediments. Provided peer review comments on field methods and data analysis approaches used to characterize the lakebed sediment contamination by University of California researchers.

Evaluation of Groundwater and Surface Water Impacts to Chesapeake Bay tributary, Confidential Client, Virginia

Evaluated potential arsenic and PAH impacts from coal-fly landfill and natural background sources in groundwater and surface water for a major tidal tributary of the Chesapeake Bay in support of litigation under the Clean Water Act.

Contaminant Source Identification to Lake Calumet and Remedial Cost Allocation, Confidential Client, Chicago, Illinois

Performed quantitative analyses and reviewed historical documentary evidence regarding multiple parties that operated on constructed piers in Lake Calumet. Developed opinion on contaminant source and timing of releases. Provided testimony during settlement hearing in United States District Court, Northern District of Illinois. Additionally, performed surface-water modeling to estimate contaminant concentrations in Lake Calumet.

Water Resources and Regional Hydrologic Studies

Ventura River Watershed Adjudication, California Attorney General’s Office, Ventura County, California

Testifying expert, to date provided four opinion reports regarding connectivity of surface water and groundwater in the Ventura River Watershed.

Peer-Review of Groundwater Sustainability Plan, San Luis Obispo Valley, San Luis Obispo County, California
Performed independent peer review of groundwater and surface-water modeling in support of GSP. Provided comments on the adequacy of surface water and groundwater calibration, assumptions, and modeling approach.

Hydrogeologic Assessment and Numerical Watershed/Groundwater Flow Model Design, San Antonio Creek Watershed, Ojai Basin Groundwater Management Agency, Ojai, California
Project manager and lead modeler for development of a watershed-scale linked distributed parameter watershed-MODFLOW SURFACT groundwater model. Model calibration included transient effects of recharge from deep percolation, groundwater pumpage, and groundwater recharge from and discharge to San Antonio Creek and smaller tributaries.

Groundwater Balance Development for Groundwater Sustainability Plans (GSPs), Fox Canyon Groundwater Management Agency, Ventura County, California
Project manager for development of groundwater budgets for the Oxnard, Pleasant Valley, Arroyo Santa Rosa, and Las Posas Basins for Sustainable Groundwater Management Act compliance.

Santa Paula Basin Safe Yield Determination, United Water Conservation District, Ventura County, California
Managed development of watershed-scale distributed parameter watershed model of the Santa Paula Creek subwatershed and comprehensive water balance and safe yield evaluation for the Santa Paula Basin. Safe yield and hydrogeologic evaluation based on accounting for all significant groundwater inflow and outflows and changes in groundwater storage as evaluated from statistical analysis of available groundwater hydrographs.

Evaluation of Numerical Model Estimates of Aquifer Recharge, Indio Water Authority, Indio, California
Project manager for review of the Coachella Valley Groundwater Model, a MODFLOW model that has been used for groundwater management planning and estimates of groundwater recharge from water spreading pond facilities. Provided Indio Water Authority with independent evaluation of model assumptions and implementation, and resulting limitations of conclusions regarding groundwater recharge assessments.

Groundwater Level and Water Quality Sampling Program, Ventura County Watershed Protection District, Ventura County, California
Project manager for field sampling program initiated to satisfy California state requirements regarding groundwater monitoring, and gather important data for understanding transient groundwater levels, geologic occurrence, and groundwater quality in the Ojai Groundwater Basin. Authored monitoring plan, quality assurance project plan (QAPP), and semi-annual monitoring reports.

Hydrologic Investigation of Groundwater Flow at Salt River Landfill, Salt River Pima Maricopa Indian Community, Scottsdale, Arizona
Managed numerical model development and hydrologic investigation of groundwater flow at Salt River Landfill in Scottsdale, Arizona. Project entailed predicting the change in groundwater levels at the landfill as impacted by the Granite Reef Underground Storage Project (GRUSP) and flow in the Salt River due to concerns of raising groundwater levels breaching the bottom of the landfill.

Hydrologic and Water Quality System Project, U.S. EPA, Washington, D.C.
Provided support related to management of the Hydrologic and Water Quality System project, which aims to provide U.S. EPA with a state-of-the-art water quality computational model that is national and regional in

scope. Project work entailed review of project reports, coordination with partner agencies at U.S. EPA and the U.S. Department of Agriculture, and development of project scopes and timelines.

Geologic Sequestration of Carbon Dioxide

EPA Class VI, California CARB LCFS and EPA MRV Plans, Confidential Client, California

Retained to provide support to various permit applications for basins throughout California, including assistance with all permitting requirements.

California CARB LCFS and EPA MRV Plans, Confidential Client, Wyoming

Retained to provide support to CARB permit for basins in Wyoming, including assistance with all permitting requirements.

EPA Class VI, California CARB LCFS and EPA MRV Plans, Confidential Client, Nebraska

Retained to provide support to selected portions of permit applications for basin in Nebraska.

Geologic Sequestration Class VI Permit Application, Frontline Bioenergy LLC, San Joaquin Valley, California

Proposed facility will convert unwanted orchard residues into renewable natural gas and is evaluating geologic sequestration for disposal of generated carbon dioxide. Prepared and submitted Class VI permit application to U.S. EPA Region 9 and currently developing CARB permanence certification application.

Geologic Sequestration Technical Guidance Documents, The Cadmus Group/U.S. EPA Office of Ground Water and Drinking Water, Washington, D.C.

Expert technical contractor for five technical guidance documents published by U.S. EPA Underground Injection Control program regarding geologic sequestration of carbon dioxide, including modeling development and evaluation. The technical guidance documents provide permitting support to owners and operators of geologic sequestration facilities and state regulators as related to monitoring, multi-phase numerical modeling, operation, and injection well integrity testing.

Review and Technical Comments on FutureGen Underground Injection Control Permit Application for Class VI Wells, Illinois

Reviewed and provided technical comments on FutureGen permit applications on behalf of private landowner in vicinity of proposed project. Expert opinion reports submitted as public comment to U.S. EPA Region 5 and subsequently to the EPA Environmental Appeals Board.

Review of Archer Daniels Midland Company Underground Injection Control Permit Application for Class VI, Geologic Sequestration, The Cadmus Group/U.S. EPA Office of Ground Water and Drinking Water, Washington, D.C.

Provided assessment of permit application submitted to U.S. EPA Region 5 for injection of carbon dioxide for geologic sequestration. Evaluated completeness of permit application as compared to Underground Injection Control regulations and identified discrepancies in technical submittals. Specifically evaluated documentation of numerical modeling conducted to demonstrate non-endangerment of groundwater resources.

Additional Professional Training

OSHA 40-hour HAZWOPER Training

TOUGH2, including T2VOC

ESRI ArcGIS and QGIS

GSFLOW, MODFLOW, MODPATH, MT3D and Groundwater Vistas

Soil Water Assessment Tool (SWAT)

Publications and Presentations

Peer-Reviewed Journal Articles

Associate Editor, Groundwater, 2012 to present

Schnaar, G., J. Dodge and S.J. Cullen, 2016 (invited paper). Comprehensive groundwater balance development to characterize selenium loading to surface water channels in Orange County, California. Journal of Contemporary Water Research and Education, 159: 5-23.

Schnaar, G. and M.L. Brusseau. 2014. Nonideal transport of contaminants in heterogeneous porous media: 11. Testing the experiment condition dependency of the continuous distribution rate model for Sorption-Desorption. Water Air Soil Pollut (2014) 225:2136.

Schnaar, G., T. Umstot, and S.J. Cullen. 2013. Correction To: “Birkholzer, J.T. et al., 2011, Brine flow up a well caused by pressure perturbation from geologic carbon sequestration: Static and dynamic evaluations. International Journal Greenhouse Gas Control; Vol. 5: 850-861.” International Journal of Greenhouse Gas Control, 17: 542-543.

Schnaar, G., and M.L. Brusseau. 2013. Measuring equilibrium sorption coefficients with the miscible-displacement method. Journal of Environmental Science and Health, Part A, 48: 355-359.

Brusseau, M.L., G. Schnaar, G.R. Johnson, and A.E. Russo. 2012. 10 - Impact of co-solutes on sorption of tetrachloroethene by porous media with low organic-carbon contents. Chemosphere, 89: 1302-1306.

Brusseau, M.L., A.E. Russo and G. Schnaar. 2012. Nonideal transport of contaminants in heterogeneous porous media: 9 - Impact of contact time on desorption and elution tailing. Chemosphere, 89: 287-292.

Russo, A., Johnson, G.R., Schnaar, G., and M.L. Brusseau. 2010. Nonideal transport of contaminants in heterogeneous porous media: 8. Characterizing and modeling asymptotic contaminant-elution tailing for several soils and aquifer sediments. Chemosphere, 81(3): 366-371.

Schnaar, G. and D.C. Digiulio. 2009. Computational modeling of the geologic sequestration of carbon dioxide. Vadose Zone Journal 8: 389-403.

Brusseau, M.L., Narter, M., Schnaar, G. and Marble, J. 2009. Measurement and Estimation of Organic-liquid/Water Interfacial Areas for Several Natural Porous Media. Environmental Science & Technology, 43(10): 3619-3625.

Brusseau M.L., Janousek H., Murao A., and G. Schnaar. 2008. Synchrotron X-ray microtomography and interfacial partitioning tracer test measurements of NAPL-water interfacial areas. Water Resources Research. 44, W01411.

Brusseau, M.L., Peng, S., Schnaar, G., and A. Murao. 2007. Measuring air-water interfacial areas for a sandy porous medium: comparing X-ray microtomography and partitioning tracer tests. Environmental Science and Technology. 41(6) 1956-1961.

Schnaar, G. and M.L. Brusseau. 2006. Characterizing pore-scale dissolution of organic immiscible liquid in natural porous media using synchrotron X-ray microtomography. Environmental Science and Technology. 40(21) 6622-6629.

Schnaar, G. and M.L. Brusseau. 2006. Characterizing pore-scale configuration of organic immiscible-liquid in multi-phase systems with synchrotron X-ray microtomography. Vadose Zone Journal 5: 641-648.

Brusseau, M.L., Peng S., Schnaar, G., and M. Costanza-Robinson. 2006. Relationships among air-water interfacial area, capillary pressure, and water saturation for a sandy porous medium. Water Resources Research. 42, WO3501.

Schnaar, G. and M.L. Brusseau. 2005. Pore-scale characterization of organic immiscible-liquid morphology in natural porous media using synchrotron X-ray microtomography. Environmental Science and Technology. 39(21) 8403-8410.

Government Reports and Professional Trade Publications

Woodward N.B., Levine, A. D., Singer, M., Kobelski, B.J., Fries, J.S., Schnaar, G., Burruss, R.C., Duncan, D., Glynn, P., Neuzil, C., Huntsinger, R., Osvald, K.S., Carlson, C.P. 2008. Water Resources Research Needs Associated with Implementation of Geologic Sequestration of Carbon Dioxide. A report to the White House Office of Science and Technology Policy, Committee on Environment and Natural Resources, Subcommittee on Water Availability and Quality.

Schnaar, G. and D.C. Digiulio. 2008. Computational modeling of underground injection of carbon dioxide for determination of area of review and potential risk to underground sources of drinking water. Supporting document to: Federal Requirements Under the Underground Injection Control (UIC) Program for Carbon Dioxide (CO2) Geologic Sequestration (GS) Wells; Proposed Rule. Federal Register Vol. 73, No. 144, Friday, July 25, 2008.

Schnaar G., and S.J. Cullen. 2009. The Hydrology of Geologic Sequestration. Southwest Hydrology, 8: 20-21.

Schnaar, G. 2008. U.S. EPA Development of a Proposed UIC Rule for Geologic Sequestration of CO2. National Ground Water Association, AGWSE Newszine, July 16 2008.

Conference Presentations

Schnaar, G., C. Wolf, D. Schwartz, S. Finsterle. 2023. Permit Application Development for Planned Saline Formation Injection Project in San Joaquin Valley, California. Carbon Capture, Utilization and Storage (CCUS) Conference, University of Houston, Houston, TX. April 26, 2023.

Schnaar, G. 2022. Planned Geologic Sequestration of Carbon Dioxide at the San Joaquin Renewables Project and Class VI Application Process. American Groundwater Trust California Groundwater Conference. Lakewood, California, March 30, 2022.

Schnaar, G. 2019. PFAS Forensics: How to Identify Potentially Responsible Parties.

- Law Seminars International, PFAS Litigation Conference (webinar). New York, NY, October 29, 2020.
- Law Seminars International, PFAS Litigation Conference. San Diego, CA, December 9, 2019.

Schnaar, G. 2019. Poly- and Perfluoroalkyl Substances: Sources and Source Identification. National Groundwater Association PFAS Management, Mitigation, and Remediation Conference, Westerville, OH. June 19 2019.

Schnaar, G. 2019. Poly- and Perfluoroalkyl Substances: Wide-Ranging Sources and Impacts to Water Supplies.

- American Ground Water Trust, Managing Florida's Aquifers Annual Conference. Orlando, Florida, October 1, 2019.

- American Ground Water Trust Information Exchange Workshops "PFAS: Solutions to Legacy Groundwater Contamination" in Pittsburgh, PA (March 4, 2019), Mount Laurel, NJ (March 6, 2019), Phoenix, AZ (July 11, 2019), Albuquerque, NM (July 24, 2019), NJ/MD/DE (September 2, 2020 via webinar), Arizona (September 24, 2019 via webinar).
- American Ground Water Trust Texas Aquifer Conference. Austin, Texas, June 12 2019.
- American Ground Water Trust/Association of Ground Water Agencies joint Annual Conference. Ontario, California, February 12, 2019.

Schnaar, G. 2018. Use of Analytical Contaminant Fate and Transport Modeling in Forensic Source Evaluation. Annual Conference of the International Network of Environmental Forensics. Salt Lake City, Utah, June 25 - 27, 2018.

Schnaar, G. 2017. Lessons learned in developing defensible groundwater budgets and evaluating sustainability indicators. American Ground Water Trust/Association of Ground Water Agencies joint Annual Conference. Ontario, California, February 15-16, 2017.

Cullen, S.J., G. Schnaar, and M. Cruikshank, 2016. Groundwater Planning and Estimating Safe Yield in California under the Sustainable Groundwater Management Act. Hydrology and the Law, Law Seminars International, Santa Monica, California, September 16, 2016.

Schnaar, G. 2015. Selenium Loading from Groundwater to Newport Bay, Orange County, California. Presentation at the Geological Society of America 2015 Annual Meeting, Baltimore, Maryland. November 1, 2015.

Schnaar, G., Blandford, N., 2015. Not Under My Back Yard: The Looming Battle Over Underground Injection. Presentation at the American Bar Association Fall Conference, Chicago, Illinois. October 28-31, 2015.

Umstot, T., G. Schnaar, N. Blandford, S.J. Cullen, P. Kaiser, J. Ayrabe. 2015. Recharge estimates from a soil water-balance model improve groundwater model calibration. MODFLOW and More 2015: Modeling a Complex World. Golden, Colorado, May 31 – June 3, 2015.

Dodge, J.J., G. Schnaar, S.J. Cullen, and J. Peng, 2015. Selenium Geohydrology, Swamp of Frogs, Newport Bay Watershed, Orange County, California. Association for Environmental Health and Sciences (AEHS) 25th Annual International Conference on Soil, Water, Energy and Air. San Diego, California. March 23 – 26, 2015.

Sweetland, N.T., S.J. Cullen and G. Schnaar. Vapor Intrusion from Groundwater Plumes: Critical Technical and Regulatory Issues. 2015. 2015 National Ground Water Association (NGWA) Groundwater Summit, San Antonio, Texas. March 16 – 18, 2015.

Dodge, J.J., G. Schnaar, S.J. Cullen and J. Peng. 2014. Drainage Channels Remobilize Selenium, Swamp of the Frogs, Newport Bay Watershed, Orange County, California. Groundwater Resources Association of California/U.S. Society for Irrigation and Drainage Professionals. March 4-5, Sacramento, California.

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