Memorandum

To: Faisal Latif, Carbon TerraVault Holdings, LLC **Date:** November 18, 2025

From: Gregory Schnaar, Ph.D., P.G. (VA) and Todd Umstot

Subject: CTV VI Risk-Based Area of Review (AoR) Delineation

At the request of Carbon TerraVault Holdings, LLC (CTV), Daniel B. Stephens & Associates, Inc. (DBS&A) has conducted modeling and data analysis to develop a risk-based Area of Review (AoR) delineation for the CTV VI project in Fresno County, California.

Background

AoR delineation consists of determining the outermost extent of the separate-phase CO_2 plume and area of elevated pressure ("pressure front") that pose risk to underground sources of drinking water (USDWs) during the lifetime of the injection project. Elevated pressure may pose a risk to USDWs due to the potential for brine leakage from the injection zone into a USDW through a conduit if one is present (e.g., improperly abandoned well).

In most cases the AoR will at a minimum be defined by the carbon dioxide (CO_2) plume footprint and may be larger if the pressure front extends beyond the CO_2 plume. CO_2 plume extent and pressure increase are estimated based on computational modeling, and in the case of CTV VI project modeling was conducted by CTV with Computer Modeling Group's (CMG's) Equation of State Compositional Simulator (GEM)[1].

Various methods are available to determine the pressure threshold value that defines the outermost extent of the pressure front. In general, these methods are used to define a pressure at which brine will leak upward through an abandoned well, leak into a USDW, and endanger the USDW due to water quality impairment. Risk-based AoR delineation methods account for dilution and attenuation processes that minimize potential USDW impacts from hypothetical brine leakage. Risk-based AoR delineation strategies are supported by the U.S. EPA (2013) Class VI AoR and Corrective Action Guidance, which states (p. 42):

[1] CTV GEM modeling is documented in the CTV VI Class VI permit application Attachment B.

Possible methods to estimate an acceptable pressure increase for over-pressurized reservoirs include…

2. A multiphase numerical model may be designed to model leakage through a single well bore, or through multiple well bores in the formation (see e.g., Birkholzer et al., 2011). Additional pressure increases up to a certain point within an already over-pressurized injection zone may not cause an appreciable increase in fluid leakage rates through a hypothetical borehole. A sensitivity analysis may be conducted to bound the modeled leakage rates.

3. In conjunction with item #2 above, numerical or analytic ground water modeling may be conducted for the USDW to estimate how additional fluid leakage caused by the injection project is diluted within the USDW and attenuated. Dilution of fluid leakage from a borehole is impacted by the natural background flow rate of water within the USDW, which is in turn a function of the hydraulic gradient, aquifer thickness, and hydraulic conductivity. An additional pressure increase may be allowable if it can be demonstrated to the UIC Program Director that negligible degradation of the USDW would result from increased fluid leakage rates.

Risk-based methods are also discussed in Burton-Kelly et al. (2021) and Bacon et al. (2020). Generally, risk-based AoR delineation consists of three steps:

1. Model brine leakage rates through a potentially improperly abandoned well at specified pressure increases within the Injection Zone.
2. Assuming that the improperly abandoned well is open to the USDW, model the distribution of elevated salinity within the USDW resulting from leakage for pressure value(s) modeled in Step 1.
3. Compare estimated increase in USDW salinity to established screening levels and/or background values. Confirm which pressure value(s) do not result in unallowable USDW salinity exceedance.

DBS&A performed risk-based AoR delineation by applying these steps, as described below.

Brine Leakage Modeling

The U.S. Geological Survey (USGS) MODFLOW numerical groundwater flow model was used to estimate brine leakage rates based on conservative effective well permeabilities, pressure at the location of the well, and stratigraphy overlying the sequestration zone. MODFLOW is considered an international standard for simulating and predicting groundwater conditions (USGS, 2022). Specifically, MODFLOW 6 was used to estimate brine leakage (Langevin et al., 2017). MODFLOW is a modular three-dimensional finite-difference model and allows for numerical simulation of water flow upward through an abandoned well and into multiple aquifers based on assigned stratigraphy and hydraulic parameters. DBS&A developed a MODFLOW model for estimating brine leakage through an abandoned well, and validated the model by comparison to estimated brine leakage rates for a single-aquifer system from (1) National Risk Assessment Partnership's (NRAP[2]) open-source Integrated Assessment Model (NRAP-Open-IAM) Multisegmented Wellbore Component ("NRAP-MSW"; Vasylkivska et al., 2022) and (2) an analytical Darcy's Law calculation of brine flux upward through a wellbore. Results were found to be similar for the three methods. MODFLOW was chosen as the primary model for brine leakage estimation due to the capability of modeling brine discharge to multi-aquifer systems.

MODFLOW brine leakage modeling was focused on flow across large distances between the injection zone and the surface, and does not consider discrete features of the flow paths such as fractures. MODFLOW assumes uniform density and temperature, which are considered acceptable; for example, NRAP-MSW (developed for support of CO_2 and brine leakage risk estimation at carbon capture and storage [CCS] projects) has the same assumptions (Vasylkivska et al., 2022; Baek et al., 2021).

MODFLOW input parameters include overlying stratigraphy, aquifer properties, wellbore properties, and fluid properties. The model domain consists of a single wellbore that extends from the injection zone to the surface and surrounding aquifer and shale units. Figure 1 displays a typical stratigraphic log for the Class VI project. Model stratigraphy was conservatively based on geologic interface elevations at the location in the vicinity of the CTV VI CO_2 plume with the minimum distance between the base of the lowermost USDW and the Injection Zone. MODFLOW modeling considered the following stratigraphic units:

- USDW (Santa Margarita Sands and Miocene to recent sediments above the Santa Margarita sandstone)

[2]NRAP was developed by the Department of Energy National Energy Technology Laboratory (NETL) to support CCS project risk assessment and permitting. The National Risk Assessment Partnership (NRAP) is a multi-national laboratory collaborative research effort leveraging broad technical capabilities across the DOE complex to develop the integrated science base, computational tools, and protocols required to quantitatively assess and manage environmental risks at geologic carbon storage sites. NRAP involves five DOE national laboratories: NETL, Los Alamos National Laboratory (LANL), Lawrence Berkeley National Laboratory (LBNL), Lawrence Livermore National Laboratory (LLNL), and Pacific Northwest National Laboratory (PNNL).

- Santa Margarita Shale
- Zilch Dissipation Zone
- Kreyenhagen Shale (Confining Zone)
- Domengine Formation (Injection Zone)

Modeling considered leakage from the uppermost portion of the Injection Zone (Domengine Formation), which is more conservative than considering leakage form the deeper Injection Zone intervals.

Table 1 presents stratigraphic unit depth and thickness. The MODFLOW grid, stratigraphic units and conceptual model are displayed on Figure 2. The grid is 2,519 meters (m) x 2,519 m on a side horizontally (8,266 feet x 8,266 feet). Grid cell size increases from the wellbore outward; the largest cell is 100 m x 100 m (328 feet x 328 feet) and the smallest cell represents the wellbore and is 0.198 m x 0.198 m (0.65 foot x 0.65 foot).

Each stratigraphic unit was assigned as a model layer within MODFLOW, and the model was initialized at hydrostatic conditions within each layer. It was assumed that brine may leak from the wellbore along the full thickness of all aquifer units (Zilch, Santa Margarita Sands). Third-type or Cauchy boundary conditions, referred to as general head boundary (GHB) in MODFLOW, were assigned along the outer boundary of the aquifer-unit layers, which allows for brine flux out of the domain. Average GHB cell conductance was 13 square meters per day (m^2/d) in the Santa Margarita Sands, and 0.37 m^2/d for the Zilch (conductance is lower for the Zilch due to the smaller aquifer thickness). Shale units (Santa Margarita Shale, Kreyenhagen) were represented by no-flow boundary conditions.

A time series of injection-zone pressure was extracted from the GEM model at the location showing the greatest simulated pressure increase outside the CO_2 plume, which was 343 pounds per square inch (psi) within the Domengine. The pressure time series was then scaled so that its peak value was 350 psi above hydrostatic conditions, and the pressure input for MODFLOW is shown in Figure 3. The pressure boundary condition at the top of the Injection Zone is set as a MODFLOW specified head boundary condition corresponding to the pressure values at the top of the Domengine. The maximum head of 249 meters, corresponding to a 350 psi increase above hydrostatic at the top of the grid cell, was assigned at the end of the injection period (Figure 3). The specified head value combines the pressure above the hydrostatic level at the reservoir's top with an additional 5 meters of head that accounts for the additional pressure at the mid-point depth of the reservoir layer where the head is assigned.

Additional MODFLOW input parameter values were obtained from available project documentation, standard methods, literature sources, and NRAP recommended conservative defaults as summarized in Table 2. Key parameter model assumptions included:

- MODFLOW simulations were conducted for 50 years, which is 20 years longer than the planned CTV VI injection time frame.
- USDW permeability was assigned 128 millidarcies (mD) and Zilch permeability was assigned 77 mD based on the median of available permeability data in each formation.
- Borehole effective permeability was assumed to be 10^{-10} m^2, which is within or even higher than the highest range of values reported for potentially leaking abandoned wells from similar studies and is therefore conservative. For example, Celia et al. (2011) report four categories of wells for deep leakage potential ranging from "low" to "extreme." Extreme-category wells were reported to exhibit effective permeabilities from 8 to 10,000 millidarcies (8×10^{-15} to 1×10^{-13} m^2).

MODFLOW results for brine flux into the aquifer units had a peak of 9 cubic meters per day (m^3/d) for the Zilch and 0.0098 m^3/d for the USDW. The Zilch dissipation zone is predicted to receive the vast majority of brine leakage, as it is located nearest the Injection Zone.

USDW Salinity Concentration Increase Modeling

The analytical solutions of Hunt (1978) as modified by Wexler (1992) were used to model salinity transport in the USDW ("Hunt-Wexler model"). The Hunt-Wexler model is an analytical solution of the advection-dispersion equation based on a flux source boundary condition that accounts for advection, hydrodynamic dispersion, and solute retardation and decay (retardation and decay are neglected for the case of modeling salinity). The Hunt-Wexler model assumes a uniform, homogenous flow field and an infinite aquifer in all directions. DBS&A developed custom computer code scripts to run the Hunt-Wexler model with assigned brine flux rates (from MODFLOW) as the boundary condition at the leaking wellbore. Superposition/image theory was used to establish optional top and bottom boundary conditions (e.g., to account for the presence of a shale unit underlying the USDW leakage point) and to account for time-varying brine flux. Hunt-Wexler does not account for density-driven flow and assumes isothermal conditions.

The DBS&A custom Hunt-Wexler code was verified by comparison to a similar USGS program of the Hunt solution (POINT3D) (Wexler, 1992) for an infinite aquifer test problem and results were found to be identical. Hunt-Wexler solution results were also compared to USGS-MT3D numerical modeling results (Zheng and Wang, 1999) for two example test problems including (1) three-dimensional transport in a uniform flow field and (2) a variable flux boundary condition. In both cases analytical (Hunt-Wexler) and numerical (MT3D) results were essentially identical. Hunt-Wexler solution results were also compared to numerical modeling with MODFLOW-SEAWAT (Langevin et al., 2008) that can account for potential density-driven and non-isothermal effects for a test problem with a 15,000 milligram per liter (mg/L) source released into a freshwater aquifer (density 1,000 kilograms per cubic meter [kg/m^3]). Plume modeling results were essentially identical for the Hunt and MODFLOW-SEAWAT simulations, confirming that the Hunt-Wexler solution assumptions of no density-driven flow are acceptable for these conditions.

CTV VI Hunt-Wexler transport parameters for aquifer properties were taken from standard conservative defaults (Table 3). The MODFLOW-predicted brine flux rate was applied as the Hunt-Wexler boundary condition, with the brine flux having an assumed total dissolved solids (TDS) source concentration of 20,800 mg/L.

CTV VI Hunt-Wexler plume modeling results are presented as the increase in TDS concentrations as an average over the USDW thickness. Results indicate that after 31 years, the maximum TDS increase adjacent to the wellbore reaches 45 mg/L, then decreases to 30 mg/L after 50 years. TDS concentrations also decrease with distance from the wellbore (Figure 4). Additional data interpretation is presented below.

Sensitivity Analyses

MODFLOW/Hunt-Wexler sensitivity analyses were performed for the following:

- USDW permeability: Ranged from 68 mD to 371 mD, based on the range of available permeability data.
- USDW dispersivity: Longitudinal dispersivity was increased to 67 m (10% of the travel distance, where travel distance includes the borehole length within the USDW plus the mean transport distance into the aquifer). Transverse dispersivity was decreased to 6.7 m (1% of the travel distance), and vertical dispersivity was decreased to 0.67 m (10% of the transverse dispersivity; see Gelhar et al., 1992).
- USDW hydraulic gradient: Increased from 0.001 to 0.004. CTV VI is located within the Westside Groundwater Subbasin, which is in the western portion of the San Joaquin Valley Groundwater Basin. Local hydraulic gradients in the vicinity of CTV VI range from 0.0018 to

0.0042 based on potentiometric surface maps presented in Luhdorff & Scalmanini (2024). The base case conservatively assumes a low hydraulic gradient of 0.001 that is less than the range of local data, and a sensitivity case was conducted assuming a larger gradient of 0.004, consistent with the highest value from the local data.

- Borehole diameter: A range of 7.6 to 12 inches was tested.

Sensitivity results are presented in Table 4 and Figures 5a through 5f. The maximum TDS predicted adjacent to the wellbore for all sensitivity runs is 88 mg/L, with the highest value from the run with an assumed 12-inch diameter wellbore, compared to 8.8 inches in the base case. (see Figure 5e). These sensitivity analyses therefore further support the conclusion that no appreciable leakage will occur to the USDW.

Interpretation

The linked MODFLOW/Hunt-Wexler results provide an estimate of potential elevated TDS concentration emanating from a leaking borehole. Two methods were used to interpret these modeling results in order to provide a risk-based AoR delineation:

- Evaluate TDS concentration increase compared to regulatory groundwater quality standards
- Evaluate TDS concentration increase compared to typical TDS variability
  - Comparison to typical well concentration fluctuation
  - Statistical comparison (method of Last et al., 2016)

Method 1: Comparison to Water Quality Standards

TDS has a recommended drinking-water secondary maximum contaminant level (secondary MCL) of 500 mg/L (22 CCR 64449). Secondary MCLs are not health-based standards, but are guidelines for aesthetic considerations such as taste, color, and odor. California consumer acceptance contaminant ranges for TDS are a recommended concentration less than 500 mg/L, and an upper range of 1,000 mg/L. Constituent concentrations lower than the recommended contaminant level are desirable for a higher degree of consumer acceptance, and constituent concentrations ranging to the upper contaminant level are acceptable if it is neither reasonable nor feasible to provide a more suitable water supply.

The Westside Subbasin has established a minimum threshold goal of 1,000 mg/L TDS, and measurable objectives of 800 mg/L for agricultural users and 500 mg/L for drinking water users (Luhdorff & Scalmanini, 2022). Shallow aquifers in the Westside subbasin exhibit elevated TDS due at least in part to naturally occurring marine sediments that originated from the Coast Range. TDS in excess of 1,000 to 2,000 mg/L represents baseline conditions in the northern areas of subbasin in the vicinity of CTV VI (Figure 6). Groundwater quality data within 5 miles of the CTV VI CO_2 plume over the previous 10 years was also obtained from GAMA (2024), and median and mean TDS values were 3,585 mg/L and 3,520 mg/L, respectively (data shown on Figure 7).

Maximum TDS increase for up to the 350 psi pressure increase scenario from MODFLOW/Hunt-Wexler modeling over the USDW thickness is 45 mg/L. Given the already elevated TDS concentrations above regulatory standards and goals, significant TDS increase due to brine leakage that would cause exceedance of a regulatory standard or goal is not predicted to occur.

Method 2A: Comparison to Aquifer TDS Variability, Observed Fluctuation

TDS at local groundwater supply wells fluctuates over time due to natural variability and other factors. An example time-series TDS chart for a local supply well is shown on Figure 7. Average TDS range (maximum TDS – minimum TDS) is 1,112 mg/L for wells within 5 miles of the CTV VI project over the last 10-year period (GAMA, 2024). The maximum range for wells in this area and time period is 7,800 mg/L. From MODFLOW/Hunt-Wexler modeling presented above the maximum predicted TDS increase due to hypothetical leakage (outside of the CO_2 footprint) over the USDW thickness is 45 mg/L. This concentration increase is significantly less than the existing TDS fluctuation in local groundwater wells; therefore, predicted maximum TDS increase would not be detectable.

Method 2B: Comparison to Aquifer TDS Variability, Statistical Analysis

Last et al. (2016) provide a statistical methodology for derivation of groundwater threshold values for analysis of USDW impacts at CCS sites. The Last et al. (2016) methodology identifies an initial (pre-injection) condition for a chemical constituent in an aquifer and a threshold value above which the aquifer would be considered negatively impacted. Initially, the authors intended to set threshold values based on the drinking water regulatory standards and guidelines; however, the authors report that an NRAP stakeholder group indicated that additional threshold values were needed that could differentiate areas of no degradation from those areas that reflect some degree of change from background groundwater quality levels. Separate threshold concentrations were needed in part due to many areas (such as the Westside subbasin) already exceeding drinking water regulatory guidelines.

Last et al. (2016) used the median of available concentration data as the initial condition, and the no impact threshold value was taken as the upper tolerance limit with 95 percent confidence and 95 percent coverage (UTL95-95). The UTL95-95 and 95 upper confidence limit (95-UCL) are common statistics to identify the reasonable upper-end of background groundwater solute concentrations (U.S. EPA, 2009). The UTL95-95 threshold is expected to contain 95 percent of the distribution of all possible measurements in a population with a confidence probability of 95 percent. The 95-UCL is a value that equals or exceeds the actual average of a distribution 95 percent of the time. According to Last et al. (2016), the UTL95-95 is a good approximation of the upper limit of the background concentrations and can be used as a reasonable threshold for identification of significant change to the aquifer.

Figure 8 (reproduced from Last et al., 2016) displays an example TDS concentration histogram, the median of the population, and the UTL95-95 and 95-UCL. In this example, the difference between the median TDS (341) and the UTL95-95 (452) is 111 mg/L and brine leakage due to a CCS project that would increase aquifer concentrations more than 111 mg/L would therefore be considered to lead to exceedance of the pre-existing background threshold value.

The corresponding histogram and statistics for the Westside subbasin aquifer in the vicinity of CTV VI is shown on Figure 9. TDS data were obtained from GAMA (2024) for wells within 5 miles of CTV VI and over the previous 10 years. Statistics including the median, UTL95-95, and 95-UCL were calculated with the U.S. EPA software ProUCL (Neptune, 2022). Median TDS is 3,585 mg/L, mean is 3,520 mg/L, 95-UCL is 3,715 mg/L, and the UTL95-95 is 7,460 mg/L. The difference between the mean and the 95-UCL is 195 mg/L and the difference between the median and the UTL95-95 is 3,875 mg/L. Last et al. (2016) assumed that the median is the initial condition within the aquifer, and the UTL95-95 is the upper range of the regional background given spatial and temporal variability. Based on these assumptions, an increase of 3,875 mg/L would be needed to exceed the background threshold value. An alternative, more conservative statistical comparison would be between the mean and the 95-UCL; in this case, a 195 mg/L increase would be needed to exceed the background threshold value. An increase of 195 mg/L from brine leakage into the aquifer is not predicted to occur from the MODFLOW/Hunt-Wexler modeling. Therefore, similar to the simpler approach in Method 2A, any TDS change from leakage at the project is negligible.

Results

For each of the methods described above, TDS leakage into the USDW due to elevated pressure is not predicted to cause impairment outside of the CO_2 plume footprint. TDS leakage is not predicted to cause exceedance of water quality regulatory standards or goals or cause detectable impairment given existing concentration variability and the small brine flux, even under conservative assumptions. For these reasons, increased Injection Zone pressures do not risk water supply endangerment outside of the CO_2 plume footprint and the applicable AoR is the CO_2 plume areas.

Summary and Conclusions

Risk-based AoR delineation was conducted by first simulating brine leakage through a hypothetical borehole using a MODFLOW model with conservative assumptions, and then using those results to predict TDS plume migration from the leaking wellbore into the USDW with the Hunt-Wexler model. Modeling results indicate minor TDS increase in the USDW (maximum 45 mg/L over USDW thickness) that would be limited to the direct vicinity of the wellbore (Figure 4, Figures 5a – 5f). Several methods were used to interpret the modeling results and ascertain if TDS increase due to brine leakage would pose a risk to USDWs in consideration of existing aquifer water quality. Risk-based methods, including standard statistical techniques, indicate that brine leakage would not pose a risk to water supplies in the USDW.

Risk-based AoR delineation is consistent with the Class VI AoR and Corrective Action guidance, which states that "an additional pressure increase may be allowable if it can be demonstrated to the UIC Program Director that negligible degradation of the USDW would result from increased fluid leakage rates" (U.S. EPA, 2013). Methods used herein are considered conservative for the following reasons:

- Brine leakage modeling was conducted with conservative parameters and the MODFLOW model was validated against analytical calculations and tools developed by NRAP.
- Modeling accounts for the presence of the Zilch Formation located between the Injection Zone and the lowermost USDW sand that will receive most of the leakage via an open conduit. Assumed permeability values were based on site-specific data.
- MODFLOW simulations were conducted for 50 years, which is 20 years longer than the planned CTV VI injection time frame. Elevated pressure up to 350 psi increase was assumed, which is greater than the maximum expected outside of the CO_2 plume.
- Assumed wellbore permeability (10^{-10} m^2) is within or higher than the highest range from similar studies (e.g., Celia et al., 2011).
- Hunt-Wexler modeling is based on standard methods consistent with U.S. EPA approaches for evaluating contaminant plume attenuation.

- Interpretation of potential TDS impacts to the local aquifers was based on review of site-specific data. Standard methods were used in the risk-based data evaluation, including statistical methods developed by NRAP (Last et al., 2016).

Based on the risk-based analysis increased pressure from the injection project does not pose a risk to USDWs outside the CO_2 plume; therefore, the applicable AoR is the CO_2 plume areas.

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Figures

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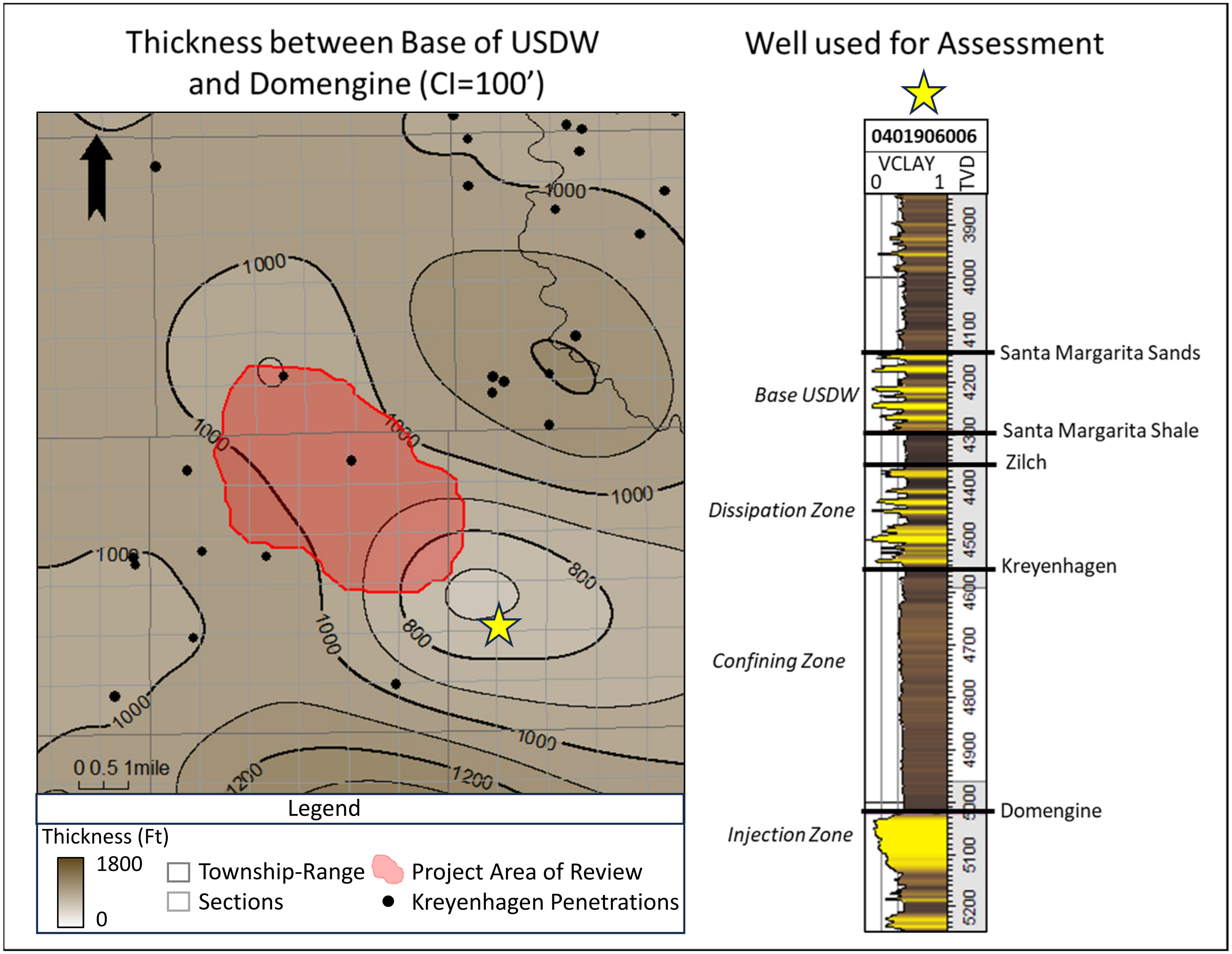

CTV VI RISK-BASED AOR DELINEATION

CTV VI Stratigraphic Log and Thickness Between Base of USDW and Domengine

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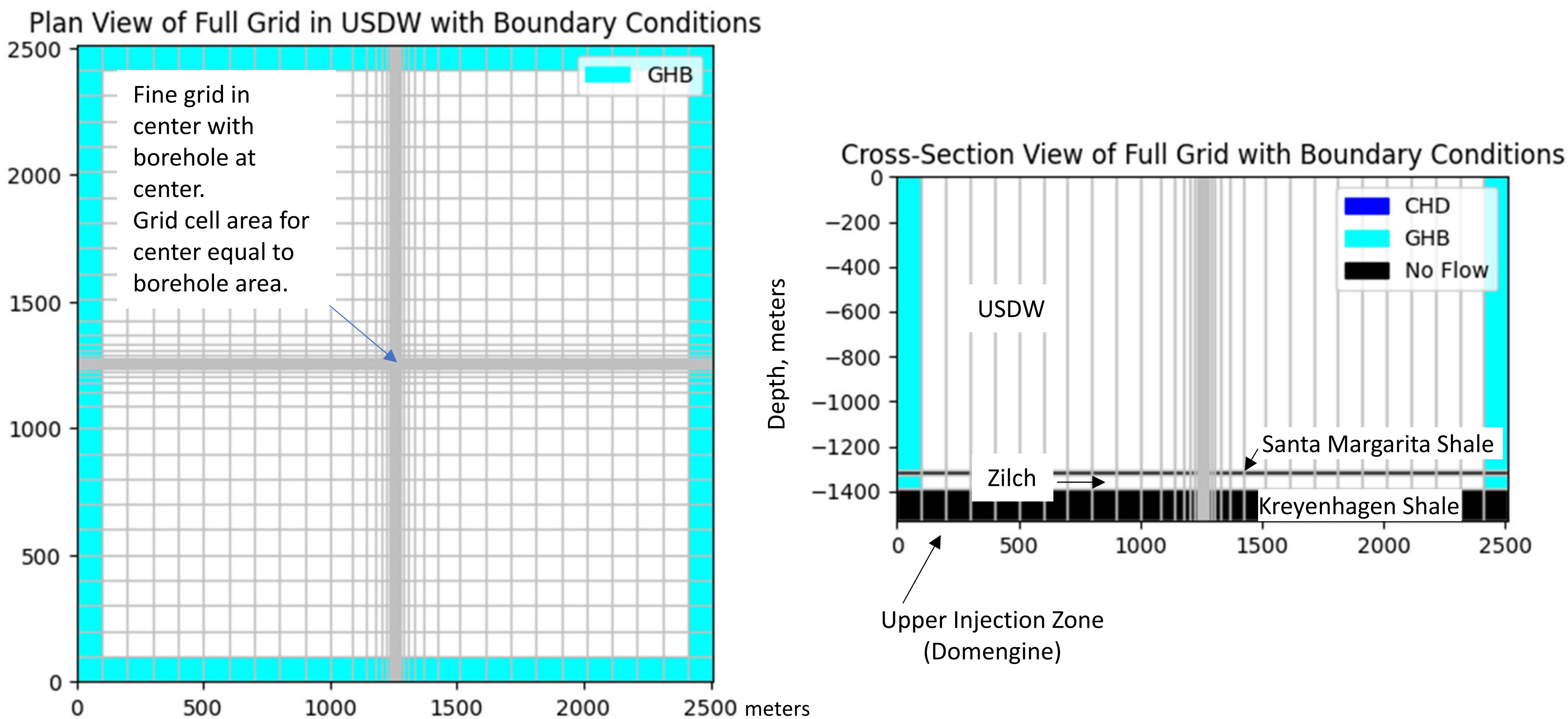
5/10/2024 DB24.1270

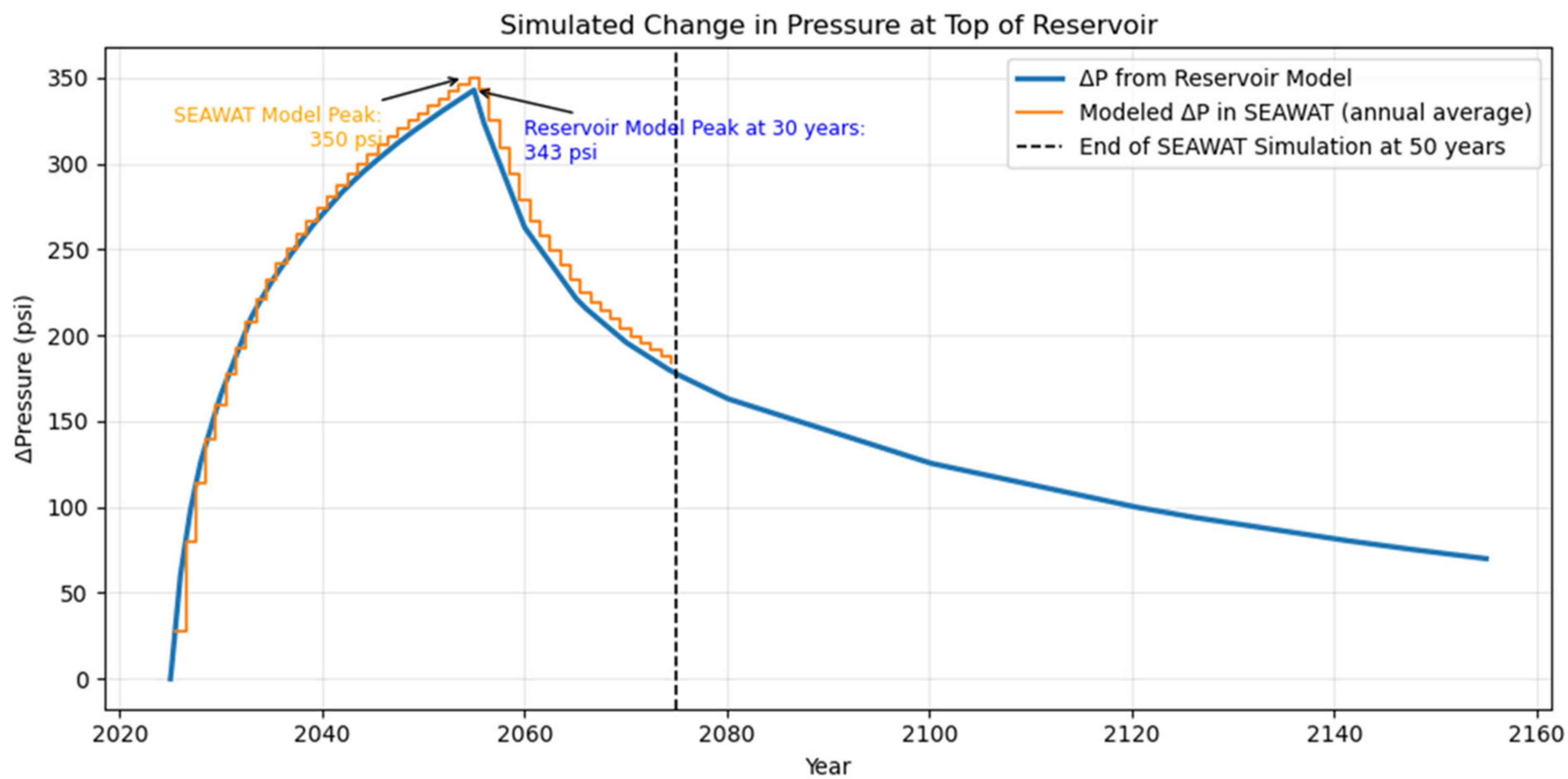
Figure 1



GHB = General Head Boundary
CHD = Specified Head Boundary

CTV VI RISK-BASED AOR DELINEATION

MODFLOW Grid and Conceptual Model



Notes: (1) GEM reservoir modeling results provided by CTV
(2) ΔP is change in pressure

CTV VI RISK-BASED AOR DELINEATION

Modeled Delta-Pressure, Domengine Formation

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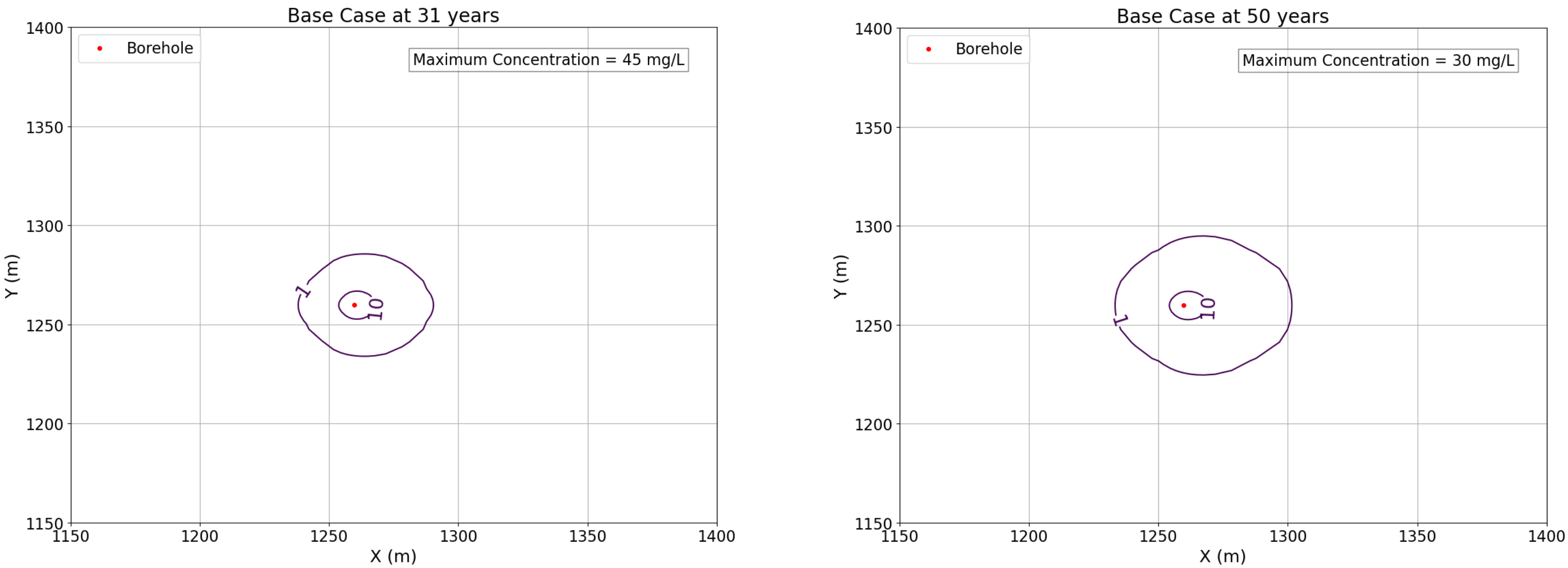
Figure 3



The maximum concentration increase averaged over the USDW thickness of 4,295 feet is 45 mg/L

CTV VI RISK-BASED AOR DELINEATION

MODFLOW/Hunt-Wexler Results: Plan View of Average TDS (mg/L) Increase over USDW Thickness (Base Case)

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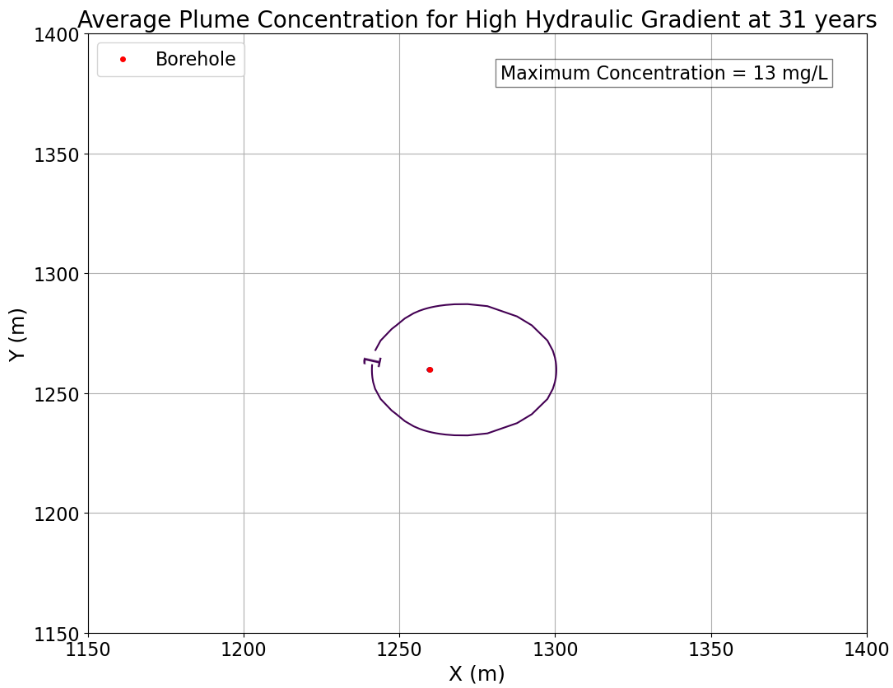
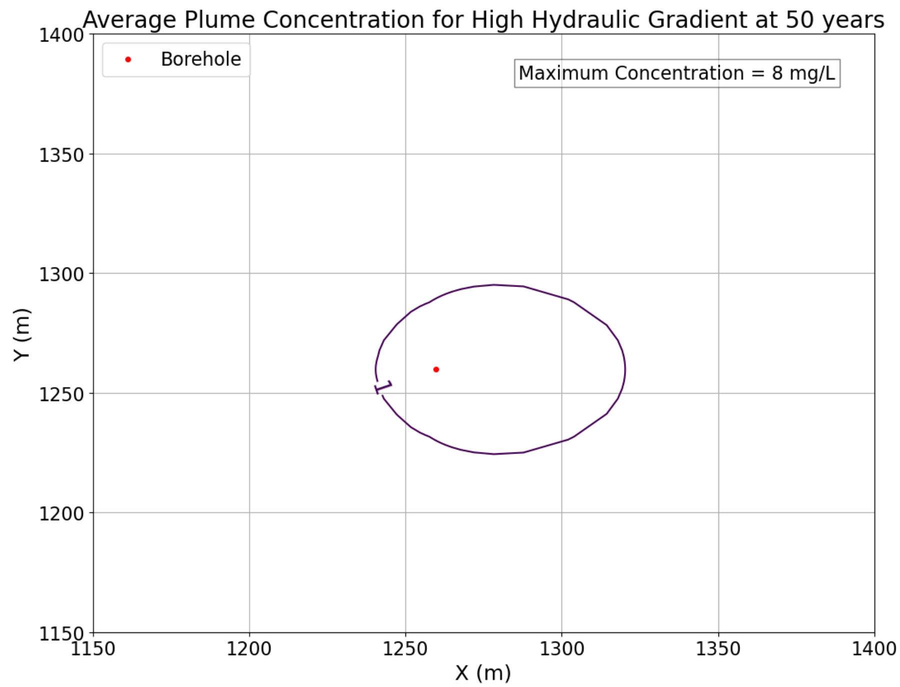
Figure 4





The maximum concentration increase averaged over the USDW thickness of 4,295 feet is 13 mg/L

CTV VI RISK-BASED AOR DELINEATION

MODFLOW/Hunt-Wexler Sensitivity: Plan View of Average TDS (mg/L) Increase over USDW Thickness, High Hydraulic Gradient

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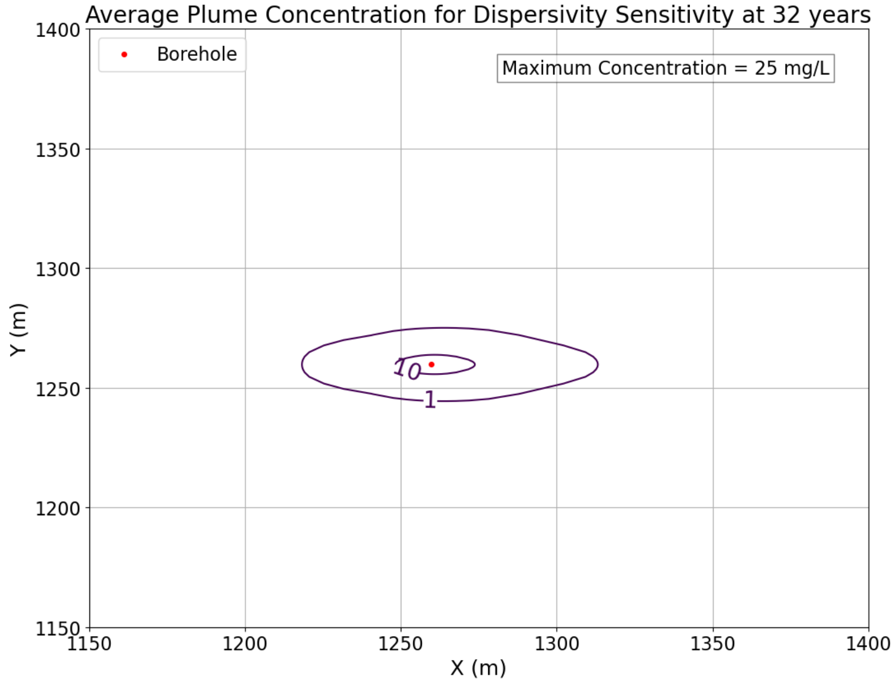
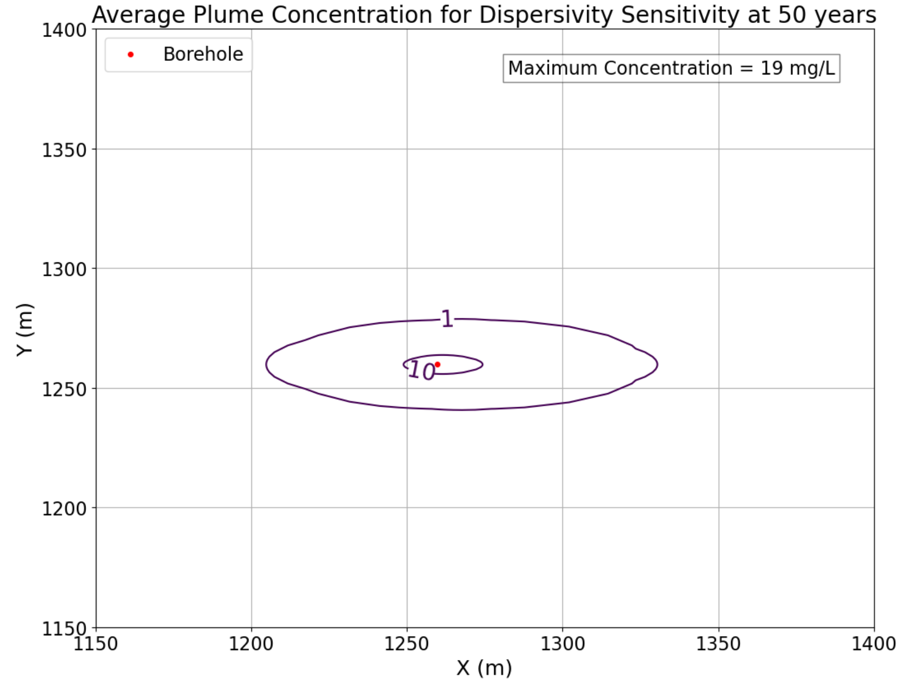
11/10/2025 DB24.1270

Figure 5a





The maximum concentration increase averaged over the USDW thickness of 4,295 feet is 25 mg/L

CTV VI RISK-BASED AOR DELINEATION

MODFLOW/Hunt-Wexler Sensitivity: Plan View of Average TDS (mg/L) Increase over USDW Thickness, Dispersivity

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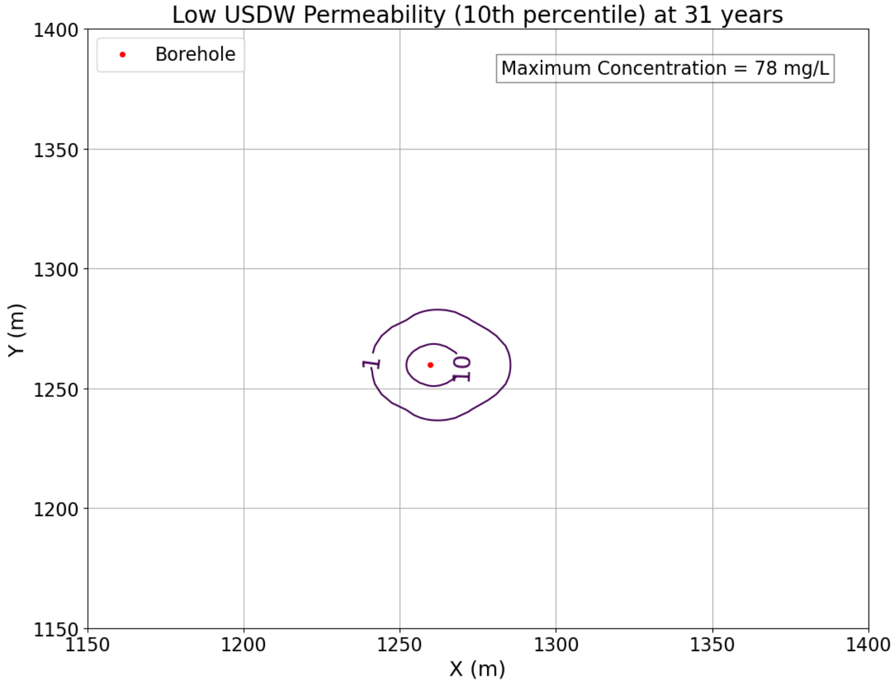
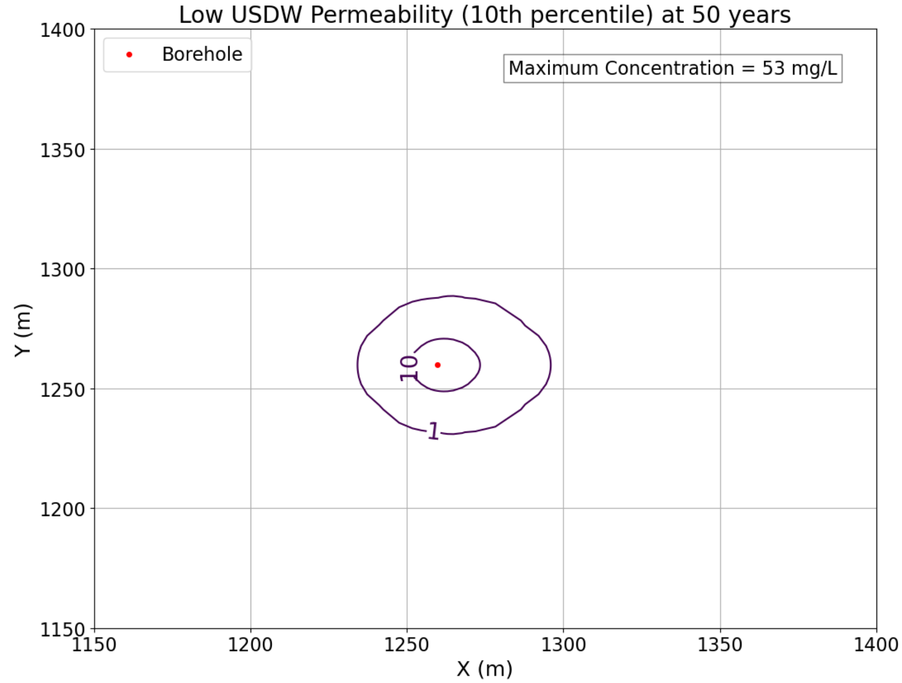
Figure 5b





The maximum concentration increase averaged over the USDW thickness of 4,295 feet is 78 mg/L

CTV VI RISK-BASED AOR DELINEATION

MODFLOW/Hunt-Wexler Sensitivity: Plan View of Average TDS (mg/L) Increase over USDW Thickness, Low USDW Permeability

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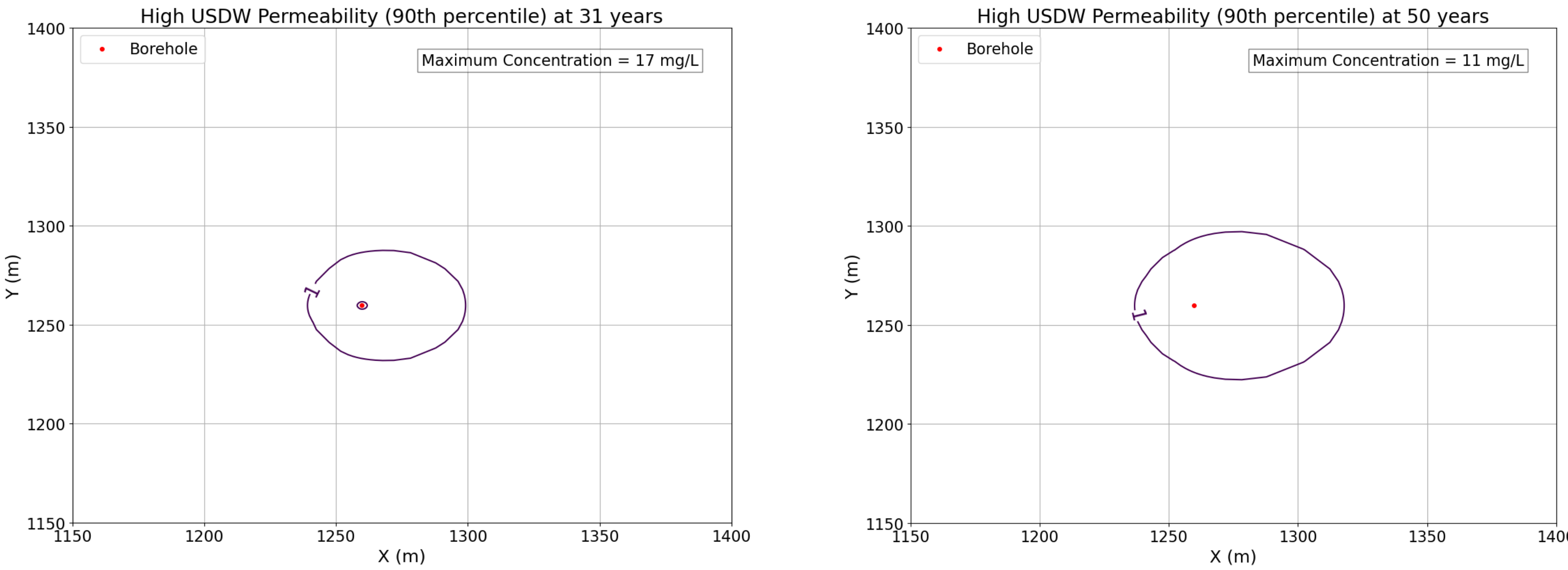
Figure 5c



The maximum concentration increase averaged over the USDW thickness of 4,295 feet is 17 mg/L

CTV VI RISK-BASED AOR DELINEATION

MODFLOW/Hunt-Wexler Sensitivity: Plan View of Average TDS (mg/L) Increase over USDW Thickness, High USDW Permeability

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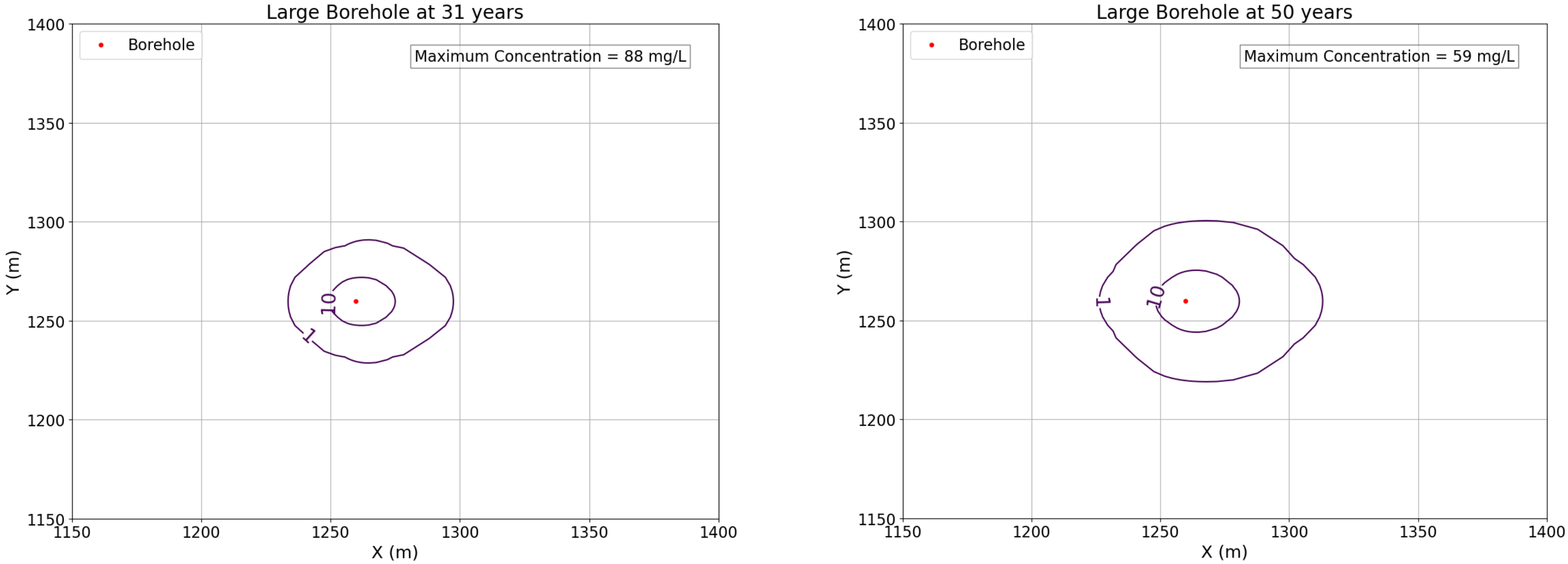
Figure 5d



The maximum concentration increase averaged over the USDW thickness of 4,295 feet is 88 mg/L

CTV VI RISK-BASED AOR DELINEATION

MODFLOW/Hunt-Wexler Sensitivity: Plan View of Average TDS (mg/L) Increase over USDW Thickness, Large Borehole

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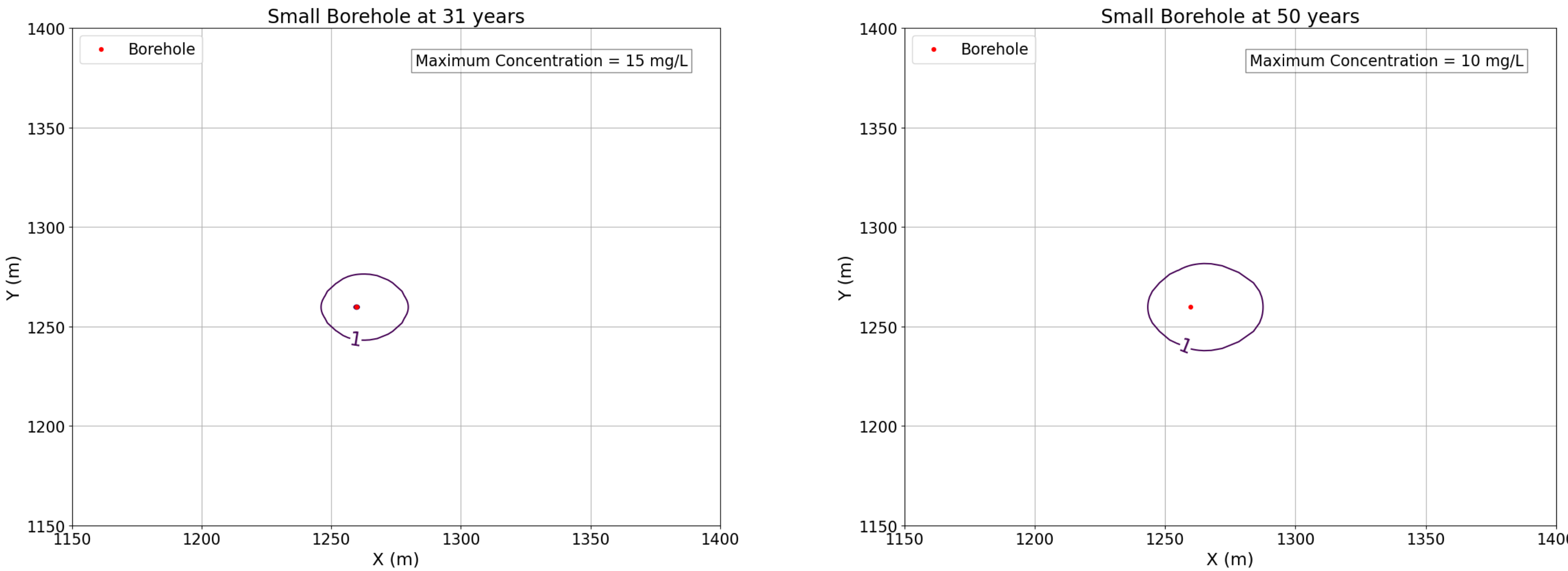
Figure 5e



The maximum concentration increase averaged over the USDW thickness of 4,295 feet is 15 mg/L

CTV VI RISK-BASED AOR DELINEATION

MODFLOW/Hunt-Wexler Sensitivity: Plan View of Average TDS (mg/L) Increase over USDW Thickness, Small Borehole

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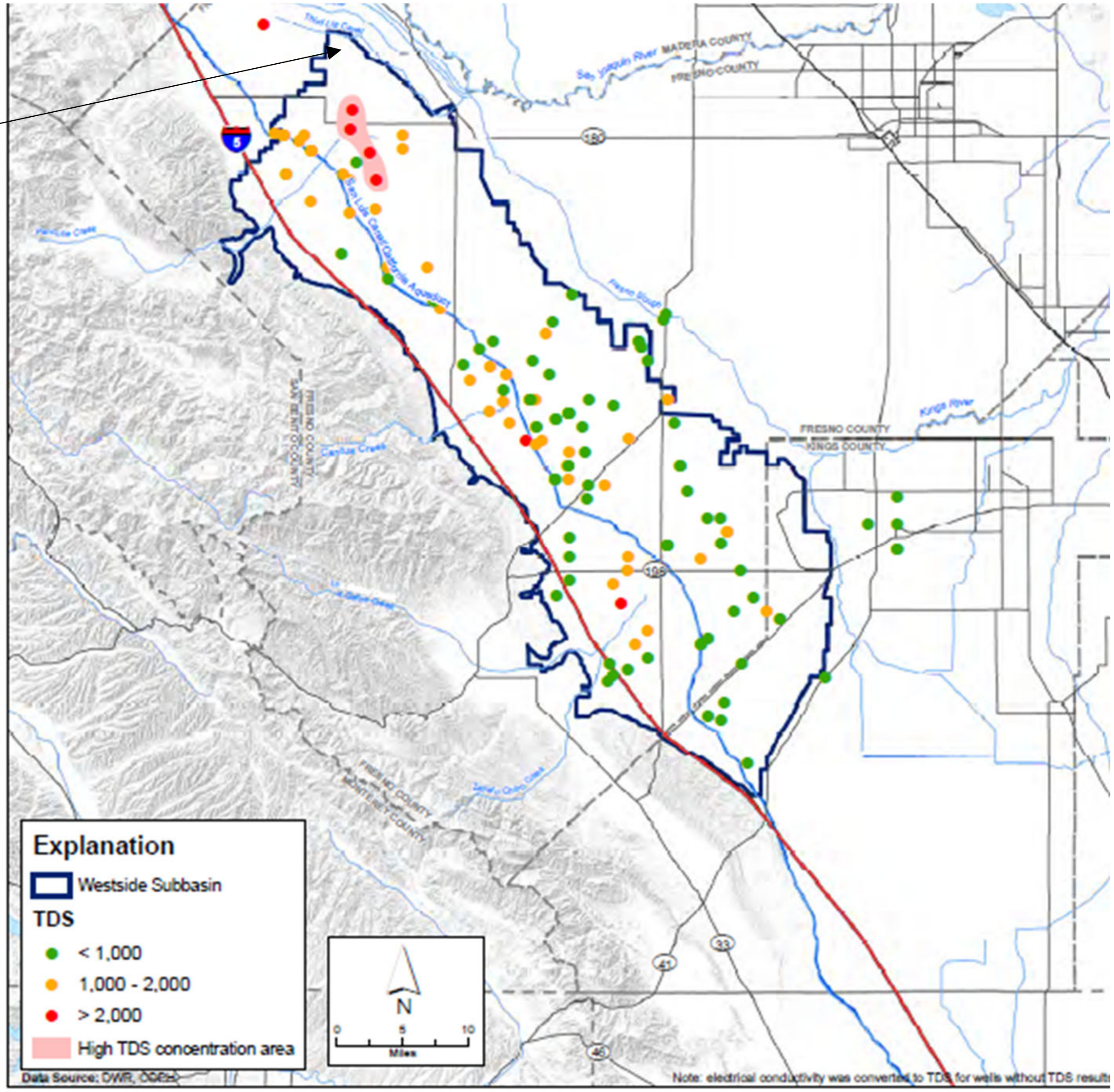
Figure 5f

CTV VI Project Location



Source: Luhdorff & Scalmanini, 2022

CTV VI RISK-BASED AOR DELINEATION

TDS Concentration in Westside Subbasin Groundwater Wells, Lower Aquifer (2005 to 2009)

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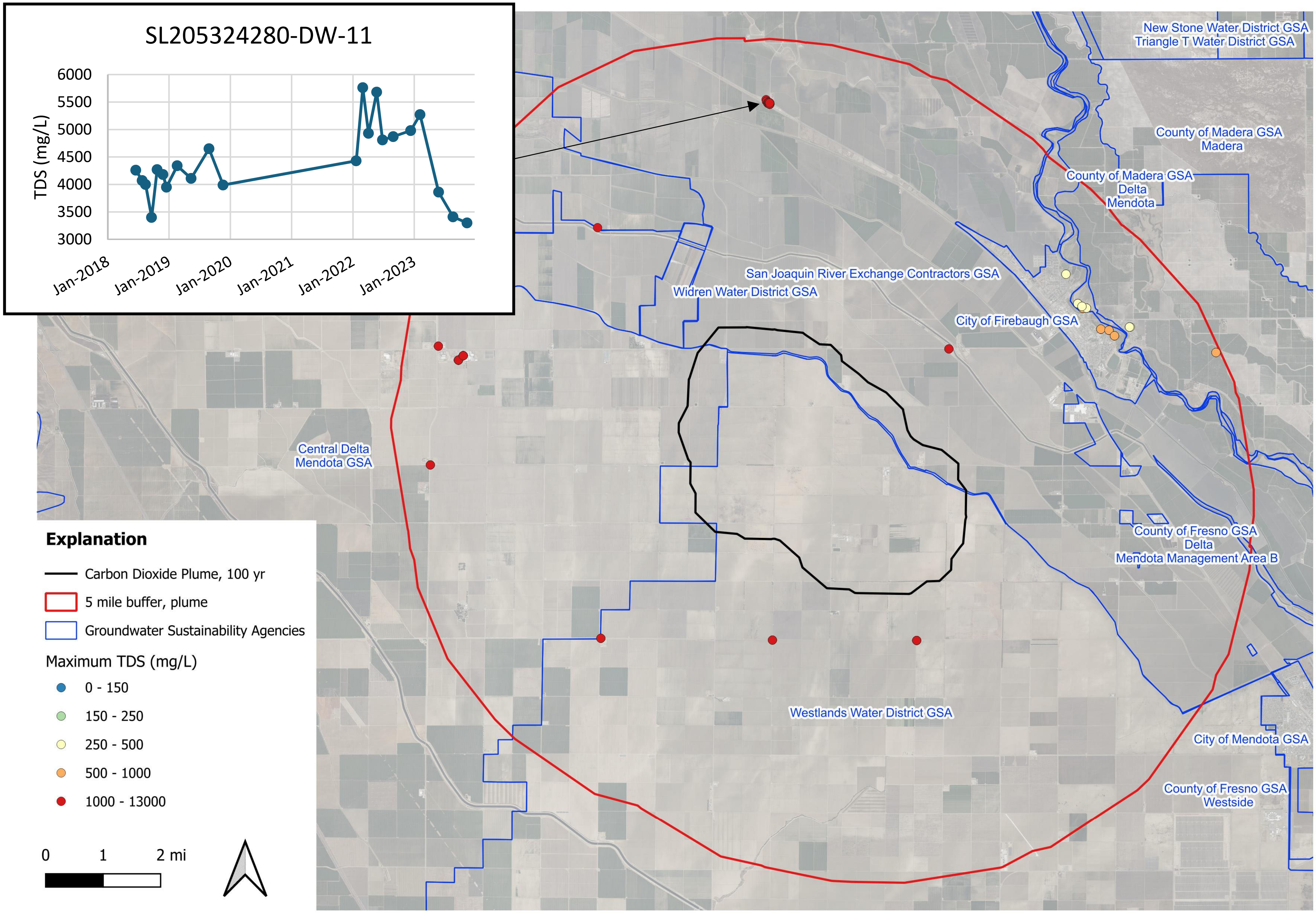
Figure 6



CTV VI RISK-BASED AOR DELINEATION

TDS Concentration in Groundwater Wells, Groundwater Ambient Monitoring and Assessment (GAMA) Program (2015 to 2024)

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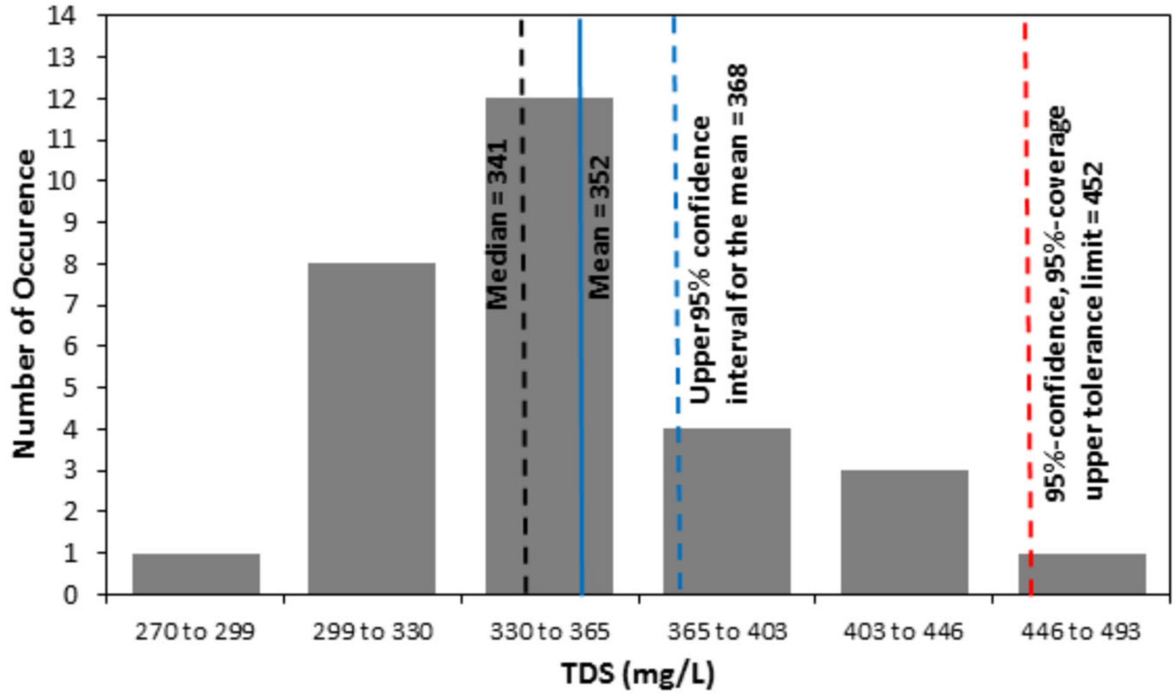
Figure 7



Source: Last et al, 2016

CTV VI RISK-BASED AOR DELINEATION

TDS Histogram, Median and 95-percent Upper Confidence Intervals, Literature Example

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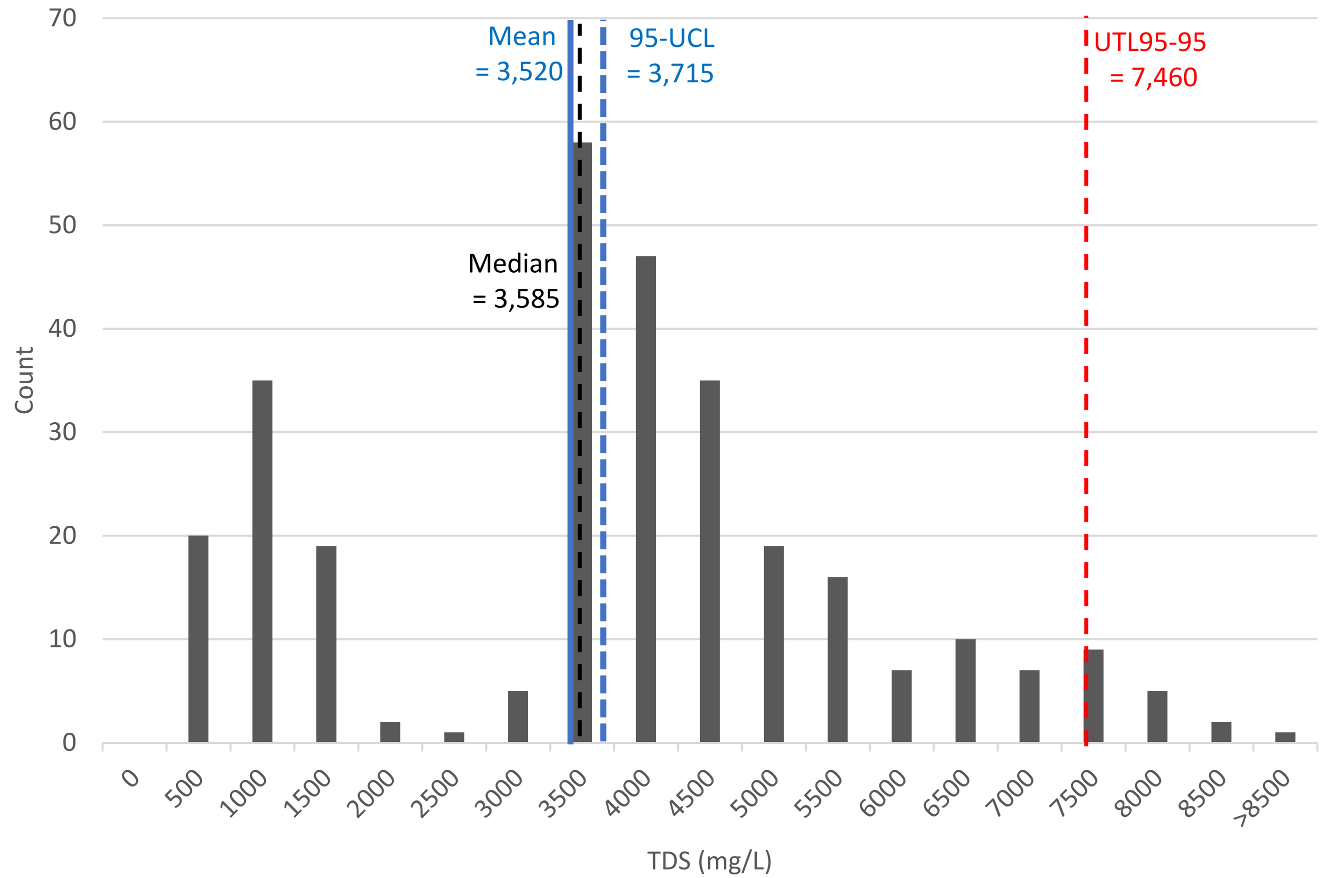
Figure 8



Notes:
TDS data from GAMA, within 5-miles of CTV VI plume collected within previous 10 years;
95-UCL = 95% upper confidence level of the mean
UTL95-95 = 95% upper tolerance limit with 95% coverage

CTV VI RISK-BASED AOR DELINEATION

CTV VI TDS Histogram and Summary Statistics

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Figure 9

Tables

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Table 1. MODFLOW Assumed Stratigraphy

Layer	Top Depth (feet TVD)	Thickness (feet)
USDW, Santa Margarita Sands Miocene to recent sediments above the Santa Margarita sandstone	0	4,295
Santa Margarita Shale	4,295	63
Top Dissipation Zone (Zilch)	4,358	198
Kreyenhagen Shale	4,556	466
Domengine [a]	5,021	33

[a] Domengine Injection Zone assigned 33 feet thickness at bottom of model domain.
TVD = Total vertical depth

Table 2. MODFLOW and Hunt/Wexler Input Parameters

Parameters	Value	Source/Notes
Permeability, USDW (mD)	128	Median of available data. Hydraulic conductivity in MODFLOW is 0.21 meters per day (m/d).
Permeability, Zilch (mD)	77	Median of available data. Hydraulic conductivity in MODFLOW is 0.13 m/d.
Wellbore permeability (log10 m^2)	–10	High end of reported ranges for leaking wellbores in previous studies (e.g., Burton-Kelly et al., 2021). Hydraulic conductivity in MODFLOW is 163 m/d.
Brine density (kg/m^3)	1,010	Calculated based on reservoir conditions, brine TDS of 20,800 mg/L
Brine viscosity (cp)	0.524	Calculated based on reservoir conditions
Specific storage (1/m)	6.90×10^{-5}	Anderson, Woessner and Hunt (2015)
Time of simulation (years)	50	Injection + 20 years
Well diameter (in)	8.8	Average of borehole diameters within 5 miles of CO_2 plume

mD = Millidarcies
kg/m^3 = Kilograms per cubic meter
cp = Centipoise

Table 3. Hunt-Wexler Transport Parameters

Parameter	Value	Unit	Source
Hydraulic Gradient	1.00×10^{-3}	—	Assumed
Effective Porosity	0.25	—	Assumed
Longitudinal Dispersivity	20	m	Assumed
Transverse Dispersivity	20	m	Assumed
Vertical Dispersivity	20	m	Assumed

Table 4. Sensitivity Analysis Results

Scenario	Maximum TDS Concentration (mg/L)	Comment
Base Case	45	USDW permeability = 128 mD; based on 50th percentile of available permeability data
High USDW hydraulic gradient	13	Higher end of local hydraulic gradient for Westside Subbasin, see Luhdorff & Scalmanini (2024).
Dispersivity based on travel distance	25	Longitudinal dispersivity = 66.66 m; transverse = 6.67 m; vertical = 0.67 m
High USDW permeability	17	USDW permeability = 371 mD ; based on 90th percentile of available permeability data
Low USDW permeability	78	USDW permeability 68 mD; based on 10th percentile of available permeability data
Large Borehole	88	12 inch diameter
Small Borehole	15	7.625 inch diameter

K = Hydraulic conductivity
mg/L = Milligrams per liter
mD = Millidarcies