Sentinel Monitoring Well Location Report

City of Ann Arbor
Ann Arbor, Michigan

March 27, 2020

TETRA TECH

Sentinel Monitoring Well Location Report

City of Ann Arbor
Ann Arbor, Michigan

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1. INTRODUCTION

Tetra Tech, Inc. (Tetra Tech) was contracted by the City of Ann Arbor (City) to assist with a contingency plan that will protect the City's drinking water supply in the event that the Gelman 1,4-dioxane plume were to impact Barton Pond. If the 1,4-dioxane plume migrates toward the City's drinking water supply intake at Barton Pond, the City will require sufficient time to upgrade the Water Treatment Plant to treat the contaminant. To determine if the plume is migrating to the north, sentinel monitoring wells will need to be installed.

A sentinel monitoring well is a groundwater monitoring well that is located between a known area of contamination and a drinking water supply. The well is intended to intersect the same aquifer in which the contamination is located. Routine sampling of the sentinel monitoring well will provide advance warning of the movement of the contaminant in the aquifer towards the drinking water supply. The sentinel monitoring well investigation will assist the City with developing a contingency plan that will protect the City's drinking water supply in the event that the Gelman 1,4-dioxane plume were to migrate towards Barton Pond. Tetra Tech focused on the area of the plume where groundwater flow changes from a more northeastern to eastern direction. This area is located north of the Dupont Circle area where the mass of 1,4-dioxane concentrations are high, a massive clay unit is present and where groundwater flow, if it continued to the northeast, could potentially impact the drinking water supply intake.

A six-phase plan was developed and implemented to locate potential sentinel monitoring well locations. The plan integrated publicly available data sources into a three-dimensional (3-D) modeling software program. The representation of the 1,4-dioxane plume aided in the design and recommendation of locations for the sentinel monitoring wells. The six phases are:

- Phase 1: Data Gathering and Split Sampling
- Phase 2: 3-D Model
- Phase 3: Third Party Technical Review of 3-D Model and Proposed Groundwater Split Sampling Plan
- Phase 4: Split Sampling
- Phase 5: Letter Report / Recommendations for Well Installation Locations
- Phase 6: Public Engagement

This report will describe each of the six phases in detail, including information on the model developed by Tetra Tech and the locations identified for potential sentinel monitoring wells.

2. PHASE 1 – DATA GATHERING AND SPLIT SAMPLING

Tetra Tech collected data from various stakeholders to integrate into the 3-D model. The purpose of compiling the data is to assist in interpreting the subsurface geology, potential groundwater flow to the north and potential contaminant migration. Prior to requesting information, the most recent representation of the 1,4-dioxane plume that was available on the Washtenaw County Health Department's (WCHD) website was reviewed to determine the spatial parameters. As depicted, the plume has a northeasterly trajectory from the source area on Wagner Road to Dupont Circle (north of I-94), where the plume then heads primarily east. The Dupont Circle area was targeted for this analysis for the following reasons:

- The area represents the highest concentrations furthest from the source area;
- If the contaminant and groundwater were to continue on the same northeasterly trajectory, it appears the groundwater and contaminant would migrate beyond the Groundwater use Prohibition Zone (PZ) to Barton Pond; and
- The geology in the area is primarily a massive clay unit; however, there may be thinner granular units that could transport contaminants northeast where the geology is largely not understood.

The WCHD 1,4-dioxane plume map that was reviewed is provided as **Figure 1** and includes a black boundary line that depicts the modeling space for the 3-D model. Numerous data inputs were gathered from several sources as described below:

1. Monitoring well network locations – Requested shapefile of latitudinal and longitudinal monitoring well network from WCHD and additional clarification information from Fleis and Vanderbrink (F&V); the consultant for Danaher Corporation (Danaher) who is the responsible party.
2. Soil Boring Logs – Requested from Michigan Department of Environment, Great Lakes, and Energy (EGLE) and Coalition for Action on Remediation of Dioxane (CARD).
3. Monitoring Well Elevation Data – Requested from F&V, EGLE and CARD.
4. Surface Elevation Data – Requested from F&V, CARD and from publicly available United States Geological Survey topographic quadrangle.
5. 1,4-dioxane concentrations – Obtained from EGLE's Repository and Pall Life Sciences data reports provided to City of Ann Arbor.
6. Potentiometric surfaces, groundwater flow direction, groundwater occurrence, timeline information and general site information – Obtained from EGLE Repository of published reports and summary data provided by EGLE in quarterly reports.

Each data type was compiled into individual spreadsheets for use in the model. The monitoring well elevation data was gathered from the sources referenced and minor inconsistencies were identified. In these cases, attempts were made to resolve these inconsistencies by comparing to surface topography, requesting validation from F&V and finally determining if those elevation inconsistencies made a difference in the cross-sectional analyses. A copy of the spreadsheet is included as **Attachment A**.

The soil boring logs were used for both interpreting the geology in the area and for the elevation data. The geological interpretation was simplified in the model into five major categories: gravel, sand and gravel, sand, silt and clay. These inputs are discussed in greater detail in Phase 2.

Surface topography was evaluated both in the area of the model space and in the area directly north of the model space and PZ. Groundwater flow generally mimics surface topography. Therefore, in the absence of geologic data in this area, the surface topography was evaluated to understand potential groundwater flow pathways north of the PZ.

Finally, ten monitoring wells were selected for split sampling with F&V for analysis of 1,4-dioxane using the United States Environmental Protection Agency (USEPA) Method 522 that has a method detection limit (MDL) of 0.07 micrograms per liter (ug/L). Currently, Pall Life Sciences analyzes their own groundwater samples using USEPA Method 1624C that has an MDL of 1.0 ug/L. Ten wells were chosen to provide some resolution in the groundwater concentration data that might aid in determining pathways that are not currently identified in the data set. The concentrations from these monitoring wells would be added to the model. The monitoring wells selected are as follows:

- MW-54d
- MW-120s/d
- MW-121s
- MW-123s/d
- MW-129i/d
- MW-130i/d

Where, s = shallow well; i = intermediate well; d = deep well; as defined by the owner.

3. PHASE 2 – 3-D MODEL

The existing data gathered in Phase 1 was used to guide the modeling; specifically, the extent of lithological units and 1,4-dioxane concentrations between the northern edge of the 1,4-dioxane plume and Groundwater Use Prohibition Zone in the Dupont Circle area. Earth Volumetric Studio (EVS) by C Tech Development Corporation was used to model this target area. This software was chosen for its robust customizable options and for its visualization capabilities that would allow the general public to understand the 3-D complexity of both the geology and the spatial distribution of the 1,4-dioxane. A USB drive has been provided that includes the model and a video clip of the model in rotation.

The model illustrates that the highest mass is in the west / southwest, migrating to the east and that the northeast boundary of the model space could have detectable concentrations of 1,4-dioxane. The model is deterministic, in that in has known inputs and provides one output as opposed to a stochastic model, which inherently includes some randomness leading to more than one output. The current deterministic model can be updated as monitoring wells are added but it does not provide concentrations over time. Additionally, the model is limited by the monitoring well network. Because the monitoring wells are widely spaced, the model interpolates between points to determine what the missing data is for both the geology and the 1,4-dioxane concentration. A description of the model construction and technical aspects are included as **Attachment B**. The following discussion focuses on the model findings.

Screen capture depictions of the model are included in **Attachment C**. The first figure is a plan view of the model space that includes three cross-sectional orientation lines. The lines represent slices of the model space depicting geologic units and the contaminant plume. Specifically, the cross-sections have the following orientations:

- A-A': Wagner to Dupont Roads
- B-B': Dupont Road to Veterans Park (Vets Park)
- C-C': Wagner to Maple Roads

Two sets of slices are contained within **Attachment C**; the first are geologic units only and the second set include the geologic units and the contaminant plume represented by a color scheme as discussed below. The geology is depicted in brown and yellow colors in the cross-sectional areas. These colors represent the difference between soil types, which correspond to the ability of water to flow through those soil units. The brown color depicts cohesive materials or aquitard units, composed primarily of clay and silt. Aquitards can be thought of as units restricting the movement of groundwater from one aquifer to another. The yellow color depicts granular units, composed primarily of sand and gravel. The yellow units include areas where aquifers would be located if groundwater is present. These yellow units are of particular interest in the model space because they can be preferential pathways in which the 1,4-dioxane can migrate.

The second set of cross-sectional areas included in **Attachment C** contain the geologic units overlaid by the 1,4-dioxane plume. Concentration data collected from monitoring wells between April and September 2019 were included in the model to create the plume. Additional details about the concentration data with regard to model inputs are included in **Attachment B**. The 1,4-dioxane mass is represented by the following color scheme:

- Dark blue to light blue – non-detect to 3 ug/L
- Green to light orange – 3 to 100 ug/L
- Light orange to dark orange – 100 to 1,000 ug/L
- Red – 1,000 to 2,100 ug/L

In general, the light orange to red areas represent concentrations greater than 100 ug/L. This area contains the highest 1,4-dioxane concentrations beyond the source area. In addition, a massive clay unit exists and increases in thickness toward the north and the Prohibition Zone. However, there are granular units along the northern boundary that could be a pathway for contaminants to the northeast. Each set of cross-sections is described below.

A-A’

The orientation of A-A’ is positioned along the western boundary of the plume defined as greater than 85 parts per billion (ppb) and is oriented as if one is viewing the cross section from the west looking east; or from M-14 toward downtown Ann Arbor. It generally parallels the path that the contaminant is flowing from southwest at MW-94D (near the source) to northeast toward the residential well at 465 Dupont Circle; the location of some of the highest concentrations identified in the plume. This cross-section generally represents a thickness of approximately 250-feet. Monitoring well MW-94D, located in the southwest is dominated by granular units. As you view the cross-section right to left and in the direction of groundwater flow; the granular units becoming shallower and thinner and are surrounded by a massive clay unit. Near the residential well at 465 Dupont Circle there are limited aquifer units occupying the 95-foot thick area between approximately 745 and 840 feet. When viewing the plume overlaid on the geology, the contaminant plume coincides with the granular units between approximately 700 and 875 feet. The highest concentrations in this depiction are shallow at monitoring well MW-94D between approximately 800 and 875 feet and appear deeper at the 465 Dupont residential well between approximately 725 and 775 feet. However, in the model space, these are the same aquifer and therefore connected.

The plume pinches out after this residential well likely because of the limited monitoring well network to the north and the edge of the model space.

B-B’

The orientation of B-B’ is northwest to southeast and is located in an area where groundwater flow largely moves toward the east after having traveled northeast from the source. This cross-section generally represents a thickness of approximately 330 feet. In reports produced by Pall Life Sciences, the 1,4-dioxane mass demonstrates this flow pattern; where a massive clay unit is encountered near the Prohibition Zone. This is the area where preferential pathways are most crucial to identify. On the northwest side, residential well 465 Dupont Circle is identified in the cross-section and in the southeast, monitoring well MW-83S is identified. Monitoring well MW-83S is the furthest eastern well in the model space. With minor exception, this cross-section is within the portion of the plume where the 1,4-dioxane concentration is greater than 85 ppb.

There is a large amount of clay that occupies the lower elevations of the cross-section area with a few isolated granular units. In addition, the model indicates that the aquifers are not connected through this slice; which may be a result of the distance between wells and the krigging (**Attachment B**) or they are not connected in this location of the cross-sectional area.

As depicted, the granular units generally occupy an area between 735 and 925 feet. When viewing the plume overlaid on the geology, the contaminant plume coincides with the aquifer between approximately 710 and 865 feet throughout this cross-section. The primary red and orange colors in this depiction indicate that a large mass of contaminant is present and flowing through the area to the east. It also indicates that the granular units are connected; if not in this particular plane.

C-C’

The orientation of C-C’ is west to east and is located and at the southern end of the model space. This cross-section generally represents a thickness of approximately 310 feet. The cross-sectional area is dominated by a large granular unit that thins toward the east near monitoring well MW-115. The granular unit is between approximately 700 and 925 feet in the west and 765 and 875 feet on the east with larger isolated clay units throughout, growing larger to the east. This entire cross-section is within the portion of the plume where the 1,4-dioxane concentration is greater than 85 ppb.

When viewing the plume overlaid on the geology, the contaminant plume coincides with the aquifer between approximately 710 and 925 feet; however, the plume is much thinner to the east. The model depiction of the plume indicates that the western extent is thickest near monitoring well MW-94D; thinning and dropping in elevation as it continues to the east before thinning and rising in elevation near monitoring well MW-115 where the clay is modeled at a higher elevation than to the west. The contaminant moving through this area may be influenced by a preferential pathway within the granular unit and the thinning aquifer. Evidence for this is the location of the higher concentrations depicted in red on the figure in **Attachment C**. As the contaminant travels east towards monitoring well MW-115, the granular unit thins, pushing the water through a thinner unit slightly higher in elevation and atop the restrictive clay unit.

4. PHASE 3 – THIRD PARTY TECHNICAL REVIEW OF 3-D MODEL AND PROPOSED GROUNDWATER

Dr. Larry Lemke is a Hydrogeologist and Environmental Engineer who chairs the Department of Earth and Atmospheric Sciences Institute for Great Lakes Research at Central Michigan University. He has studied the Gelman plume for a number of years and has completed a number of stochastic models. Dr. Lemke has a vast amount of institutional knowledge on the geology and the plume and is an invaluable source to provide an independent review.

Tetra Tech met with Dr. Lemke on September 24, 2019. The model parameters, calibration and inputs were reviewed with the model on display and Dr. Lemke was able to ask questions and provide technical feedback and guidance. His suggestions and thoughts for strengthening the model were incorporated into the final product.

The interpretation of the model output, topography and surface water divides in the area were discussed with Dr. Lemke as lines of evidence used in determining the general well location areas. Dr. Lemke concurred with the areas identified for the sentinel monitoring wells. Finally, the ten split sampling locations were discussed with Dr. Lemke and he agreed with the list of monitoring wells chosen for analyses with Method 522.

5. PHASE 4 – SPLIT SAMPLING

The City, Tetra Tech and F&V met on July 12, 2019 to discuss split sampling monitoring well locations. The F&V representative relayed the City's request to Danaher. On July 30, 2019 the F&V representative indicated that access to the monitoring wells for split sampling was denied. The denial is because the groundwater samples would be analyzed with EPA Method 522, which has a lower detection limit than Method 1624C currently used by Danaher.

6. PHASE 5 – LETTER REPORT - RECOMMENDATIONS FOR WELL INSTALLATION LOCATIONS

Tetra Tech considered the geology, groundwater flow, 1,4-dioxane concentrations and the surface geology for determining monitoring well locations that meet the City's objective. Three to four nested monitoring wells are recommended north of the PZ. The number of wells in the nest will depend on the number of aquifers that are present, but it is expected that two or three aquifers exist in this area. The initial location is recommended in an area near the intersection of N. Maple and Miller Roads (**Figure 2**). When reviewing the surface geology, two 950-ft elevation topographic reliefs or 'hills' are prominent just north of the PZ east and west of N Maple Road. These contours have been traced in a thicker contour on **Figure 2**. There is a visible channel or valley between the two hills where groundwater could be flowing preferentially from the northern end of the model space.

Tetra Tech recommends installing the first well nest in the orange circle identified as an 'Area of Interest' on **Figure 2**. During drilling, aquifer units encountered should be sampled as encountered and at regular intervals for 1,4-dioxane. This will assist in identifying if 1,4-dioxane is present, at what elevation and ultimately with setting the well screen for monitoring. In addition to the lithological data that will be obtained from the initial well installation, groundwater occurrence and 1,4-dioxane sampling should be completed using Method 522.

Following installation of the monitoring well nest, Tetra Tech recommends completing slug testing in each well to determine the properties of each aquifer; specifically, hydraulic conductivity. Hydraulic conductivity is necessary to calculate the velocity and therefore provide a time estimate for the movement of groundwater in each aquifer, specific to this area. Other aquifer properties will be estimated from the slug testing.

The surface elevation and top of casing elevation will need to be measured for each well after installation. Elevation survey data will be instrumental in determining groundwater flow and if a groundwater divide exists in the area. Finally, if 1,4-dioxane were present in the monitoring well installed, it provides an accessible sampling point for the City to continue to monitor the plume regularly and to calculate a time estimate and direction of contaminant transport. The compilation of this information will be invaluable to understanding the aquifer and contaminant in this area.

The final location of the initial monitoring well nest will also consider location based on City owned parcels and right-of-way to allow unencumbered access. Tetra Tech recommends collecting static water levels and sampling the monitoring wells with regularity across seasons and during similar sampling times of the existing monitoring well network to correlate the information with the Gelman data set.

With the additional geologic information gained from the installation of a monitoring well nest in this area, additional monitoring well nests, can be installed with greater understanding of the aquifer(s), as necessary. These additional monitoring well nests would be adaptable from those locations identified on **Figure 2**, as they would be informed by the information learned from the initial monitoring well nest. Tetra Tech has provided a probable opinions of costs for the drilling and installation for four nested well sets. A cost estimate for the overseeing the installation of the initial monitoring well nest and slug testing is being prepared separately.

Probable Opinion of Costs[1]	
Phase 1: Installation of One Well Nest	
Consulting Services[2]	$ 49,696
Drilling Contractor Services[3]	$ 93,500
Total Cost Phase 1:	***$ 143,196***
Phase 2: Installation of Three Additional Well Nests	
Consulting Services	$ 108,885
Drilling Contractor Services[4]	$ 189,700
Total Cost Phase 2:	***$ 298,585***
Phase 3: Monitoring, Reporting and Public Outreach	
Consulting Services[5]	$ 25,955
Cost Summary	
Cost Estimate Total:	***$ 467,736***

The probable opinion of costs incorporates the following assumptions:

1. Contingency costs are included on the subcontractor fees and consultant field oversight only.

2. Consulting fees include the cost of well design, permitting, drilling oversight, slug testing, aquifer analysis, and waste characterization.
3. The subcontracted drilling company will complete installation of a well nest (a well nest includes one deep and one shallow 2-inch well) and an exploratory borehole in one mobilization.
4. The subcontracted drilling company will complete installation of three well nests in one mobilization and no exploratory borehole is included.
5. Consultanting services in Phase 3 include groundwater sampling, water level measurements, reporting, client meetings and public engagement.

7. PHASE 6 – PUBLIC ENGAGEMENT

City and Tetra Tech personnel have been engaging stakeholders since this evaluation began. On June 20, 2019, City and Tetra Tech personnel met with the CARD President, Roger Rayle to inform him of the evaluation and request his assistance with data gathering. CARD maintains a large volume of information on the Gelman plume. Mr. Rayle has been involved since the early 1990s and has a tremendous amount of history and knowledge on the site. A follow-up meeting between CARD and Tetra Tech occurred in November to review the model.

Tetra Tech and City personnel have been attending the CARD monthly and quarterly meetings when possible to update the members of the modeling progress, understand the citizens' concerns and obtain updates from EGLE.

City and Tetra Tech personnel have had meetings with EGLE personnel, communicated regarding data needs and provided updates as needed.

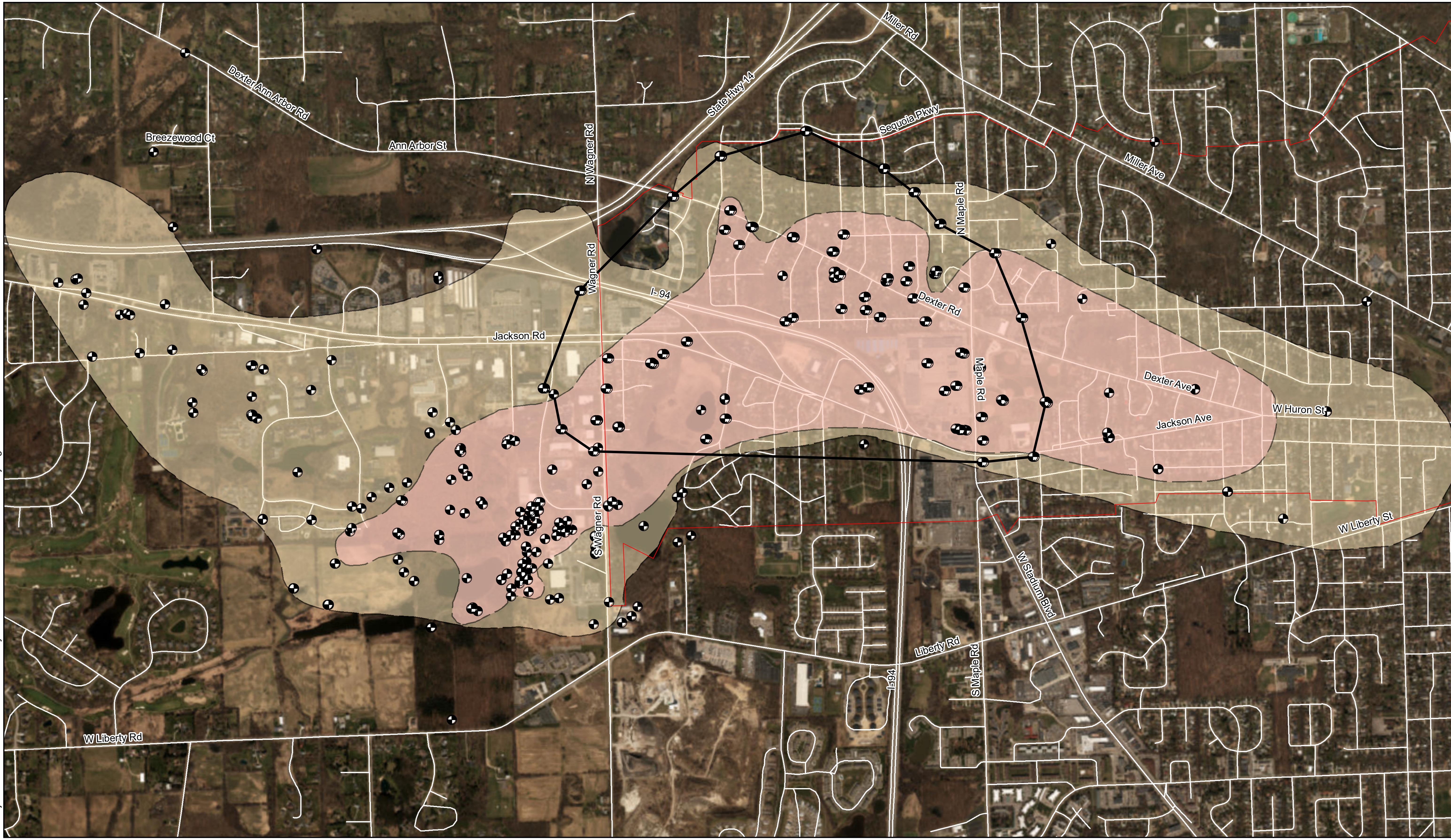
A public listening session was held on October 28, 2019 to inform the general public of the findings and provide an opportunity for citizens to ask questions. City and Tetra Tech personnel presented the findings of the model and the potential well installation locations. A separate presentation was provided at the CARD quarterly meeting on November 5, 2019. Cross sections that were presented at the public listening session and CARD quarterly meeting are included as **Attachment C**.

Finally, Tetra Tech has been documenting progress in two different submittals. The Water Treatment Plant has been distributing a monthly update entitled *2019 Timeline: Monitoring Well Location Study for Gelman Plume* to inform citizens of the progress made each month. A quarterly progress document is distributed internally to update City Council on not only the sentinel monitoring well evaluation, but other items related to Gelman, including but not limited to agency and CARD updates, meeting summaries and 1,4-dioxane mass removal.

8. CONCLUSIONS

The majority of the contaminant mass is flowing to the east from Dupont Circle. The 3-D model illustrates the massive clay located in the area. There are potential granular areas within the clay where groundwater and 1,4-dioxane could potentially migrate to the north/northeast. Tetra Tech recommends installing an initial well nest in this area and completing vertical aquifer sampling to identify if 1,4-dioxane is present and where. After the nested wells are set and developed, groundwater monitoring for 1,4-dioxane with EPA Method 522 should be completed. Further, Tetra Tech recommends completing slug testing on the nested wells to determine basic aquifer properties. If 1,4-dioxane is detected in the well nest, additional well locations will be determined.

FIGURES



Base Map Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

TETRA TECH

ORIGINAL BY: JDW
DATE: 3/26/2020
CHECKED BY: PJM
DATE: 3/26/2020

CITY OF ANN ARBOR
SENTINEL MONITORING WELL LOCATION REPORT
WASHTENAW COUNTY, MI

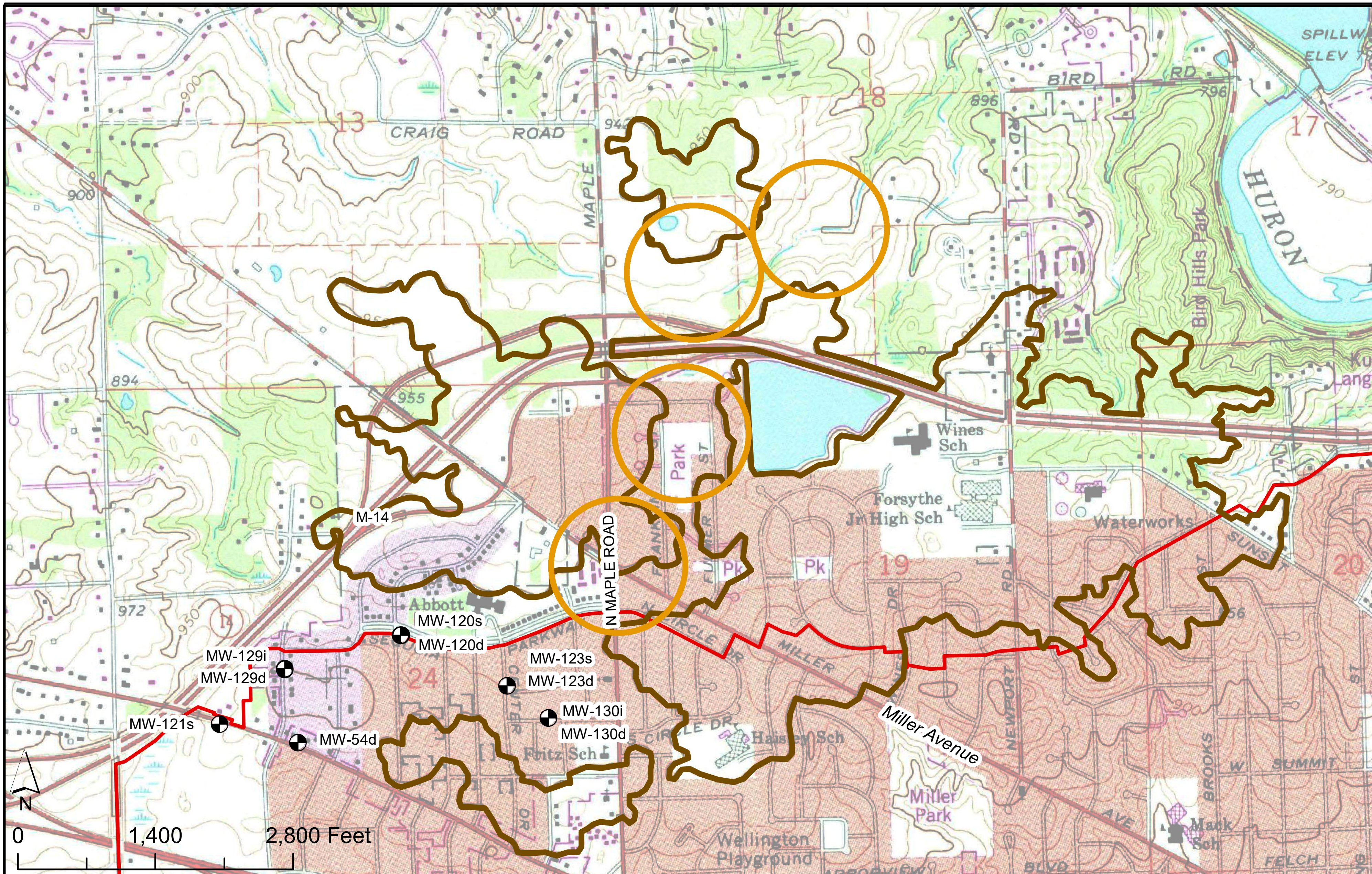
MODEL BOUNDARY MAP

Monitoring Well
3-D Model Domain
*Estimated Plume (>85 ppb)
Groundwater Use Prohibition Zone
*Estimated Plume (>1 ppb)

*Extent of groundwater plume approximated from Washtenaw County Health Department Gelman Sciences, Inc 1,4-Dioxane Plume Map (Accessed June 2019)

0 625 1,250 2,500 Feet
1 in = 1,250 ft
N

FIGURE
1



C:\Users\jared.walbert\Desktop\Topo Map.mxd

DESIGNED BY: JDW	CITY OF ANN ARBOR SENTINEL MONITORING WELL LOCATION REPORT WASHTENAW COUNTY, MI PROPOSED WELL LOCATIONS	Monitoring Well Prohibition Zone	950' Contour Line Area of Interest	FIGURE 2
DATE: 3/26/2020				
CHECKED BY: PJM				
DATE: 3/26/2020				

Source: U.S. Geological Survey, 1965, USGS 1:24000-scale Quadrangle for Ann Arbor West, MI 1965: U.S. Geological Survey.

ATTACHMENT A

Monitoring Well Location Data

Attachment A
Monitoring Well Location Data
Sentinel Monitoring Well Location Report
City of Ann Arbor

Well ID	3D Model Data			MDEQ Data			Fleis & Vandenbrink	
	Easting	Northing	Ground Surface	Easting	Northing	Ground Surface	Easting	Northing
MW-100	13279418.00	286855.00	941.52	13279418.00	286855.00	941.52		
175 Jackson Plaza	13276345.81	285337.37	930.50	13276345.81	285337.37	Unknown		
2819 Dexter	13280103.79	287545.01	941.00	13280103.79	287545.01	Unknown		
3161 Dexter	13278963.18	288162.21	935.00	13278963.18	288162.21	935.00		
3365 Jackson Rd	13277724.00	286405.00	938.07	13277724.00	286405.00	938.07		
373 Pinewood Deep	13279363.00	287490.00	935.00	13279363.00	287490.00	Unknown		
465 DuPont	13278574.80	288128.26	927.14	13278574.80	288128.26	927.14	13278574.80	288128.26
IW-1	13280193.00	287031.00	930.00	13280193.00	287031.00	930.00		
IW-2	13279517.04	286907.96	939.00	13279517.04	286907.96	939.00		
IW-3	13281843.90	285353.20	928.00	13281843.90	285353.20	928.00		
IW-4	13281884.00	286409.00	917.00	13281884.00	286409.00	917.00		
IW-5	13281790.70	285367.00	926.00	13281790.70	285367.00	Unknown		
LB-1	13280124.00	287474.00	944.00	13280124.00	287474.00	944.00		
LBOW-1	13281094.00	287415.00	953.00	13281094.00	287415.00	Unknown		
MW-101	13281896.00	287328.00	934.00	13281896.00	287328.00	933.45		
MW-106D	13277102.36	285397.28	923.00	13277102.36	285397.28	Unknown		
MW106S	13277109.89	285388.66	923.00	13277109.89	285388.66	Unknown		
MW-107	13281187.66	287175.76	945.00	13281187.66	287175.76	Unknown		
MW-108D	13278564.36	285789.94	911.00	13278564.36	285789.94	Unknown		
MW-108S	13278563.99	285774.15	911.00	13278563.99	285774.15	Unknown		
MW-110	13282324.01	287800.55	941.07	13282324.01	287800.55	Unknown		
MW-113	13280223.90	288059.90	945.00	13280223.90	288059.90	Unknown		
MW-115	13282139.13	285531.68	910.00	13282139.13	285531.68	Unknown		
MW-116	13282154.79	285205.13	937.00	13282154.79	285205.13	Unknown		
MW-117	13280728.30	286912.80	931.00	13280728.30	286912.80	Unknown		
MW-118	13276960.20	286347.30	930.50	13276960.20	286347.30	Unknown		
MW-119	13281385.48	286275.51	925.00	13281385.48	286275.51	Unknown		
MW-120S	13279701.29	289493.60	930.50	13279701.29	289493.60	Unknown	13279701.29	289493.60
MW-120D	13279707.68	289491.87	930.50	13279707.68	289491.87	Unknown	13279707.68	289491.87
MW-121S	13277860.02	288585.34	939.00	13277860.02	288585.34	Unknown	13277860.02	288585.34
MW-121D	13277856.91	288586.98	939.00	13277856.91	288586.98	Unknown	13277856.91	288586.98
MW-122S	13279520.10	288026.05	942.00	13279520.10	288026.05	Unknown	13279520.10	288026.05
MW-122D	13279527.63	288023.10	942.00	13279527.63	288023.10	Unknown	13279527.63	288023.10
MW-123S	13280785.19	288967.91	937.29	13280785.19	288967.91	937.29	13280785.19	288967.91
MW-123D	13280784.44	288978.31	937.10	13280784.44	288978.31	937.10	13280784.44	288978.31
MW-129S	13278520.00	289143.12	947.00	13278520.00	289143.12	N/A	13278520.00	289143.12
MW-129I	13278520.01	289150.56	947.00	13278520.01	289150.56	N/A	13278520.01	289150.56
MW-129D	13278519.82	289142.88	947.00	13278519.82	289142.88	N/A	13278519.82	289142.88
MW-130S	13281205.34	288648.55	941.50	13281205.34	288648.55	N/A	13281205.34	288648.55
MW-130I	13281205.50	288648.67	941.50	13281205.50	288648.67	N/A	13281205.50	288648.67
MW-130D	13281205.16	288648.83	941.50	13281205.16	288648.83	N/A	13281205.16	288648.83
MW-133S	13276576.09	287282.76	929.50	13276576.09	287282.76	N/A		
MW-133I	13276576.17	287283.03	929.50	13276576.17	287283.03	N/A		
MW-133D	13276576.36	287282.85	929.50	13276576.36	287282.85	N/A		

Attachment A
Monitoring Well Location Data
Sentinel Monitoring Well Location Report
City of Ann Arbor

Well ID	3D Model Data			MDEQ Data			Fleis & Vandenbrink	
	Easting	Northing	Ground Surface	Easting	Northing	Ground Surface	Easting	Northing
MW-134S	13276068.45	285929.66	929.50	13276068.45	285929.66	N/A		
MW-134I	13276068.64	285929.40	929.50	13276068.64	285929.40	N/A		
MW-134D	13276068.28	285929.52	929.50	13276068.28	285929.52	N/A		
MW-14S	13276185.00	285843.70	925.79	13276185.00	285843.70	925.79		
MW-14D	13276189.50	285848.40	920.74	13276189.50	285848.40	920.74		
MW-17	13278049.79	286577.11	930.14	13278049.79	286577.11	930.14	13278049.79	286577.11
MW-30i	13277557.00	286283.00	934.73	13277557.00	286283.00	934.73		
MW-30D	13277580.00	286269.00	934.60	13277580.00	286269.00	934.60		
MW-43	13278317.00	285228.00	906.00	13278317.00	285228.00	Unknown		
MW-47S	13281507.60	287555.43	950.00	13281507.60	287555.43	950.00		
MW-47D	13281488.51	287514.54	950.00	13281488.51	287514.54	950.00		
MW-54S	13278653.54	288393.30	941.60	13278653.54	288393.30	941.60	13278653.54	288393.30
MW-54D	13278656.36	288399.19	941.70	13278656.36	288399.19	941.70	13278656.36	288399.19
MW-55	13278947.93	288169.91	932.00	13278947.93	288169.91	932.00	13278947.93	288169.91
MW-69	13276946.80	285931.20	915.00	13276946.80	285931.20	915.00		
MW-71	13278587.55	285511.08	914.20	13278587.55	285511.08	914.20		
MW-72S	13280450.66	285914.03	943.00	13280450.66	285914.03	943.00	13280450.66	285914.03
MW-72D	13280561.00	285943.00	943.00	13280561.00	285943.00	943.00	13280561.00	285943.00
MW-77	13278775.12	287919.10	932.50	13278775.12	287919.10	932.50		
MW-79S	13282106.29	286211.64	907.50	13282106.29	286211.64	907.50	13282106.29	286211.64
MW-79D	13282114.72	286215.23	906.90	13282114.72	286215.23	906.90	13282114.72	286215.23
MW-81	13282694.70	286905.13	921.00	13282694.70	286905.13	921.00		
MW-83D	13283035.92	285727.65	927.50	13283035.92	285727.65	927.50		
MW-83S	13283020.96	285742.59	927.00	13283020.96	285742.59	927.00		
MW-84S	13282418.72	285770.49	906.00	13282418.72	285770.49	906.00		
MW-84D	13282430.28	285756.63	906.00	13282430.28	285756.63	906.00		
MW-85	13281625.11	285893.11	918.00	13281625.11	285893.11	918.00		
MW-87S	13281913.00	285349.00	928.00	13281913.00	285349.00	928.00		
MW-87D	13281893.88	285353.17	928.00	13281893.88	285353.17	928.00		
MW-88	13281851.24	286424.29	921.00	13281851.24	286424.29	921.00		
MW-89	13282153.20	284905.06	944.00	13282153.20	284905.06	944.00		
MW-90	13282875.60	284974.47	952.00	13282875.60	284974.47	952.00		
MW-92	13281561.60	288208.00	946.00	13281561.60	288208.00	Unknown		
MW-94S	13276795.40	285485.30	919.00	13276795.40	285485.30	919.00	13276795.40	285485.30
MW-94D	13276802.00	285484.00	919.00	13276802.00	285484.00	919.00	13276802.00	285484.00
MW-BE-1S	13280833.00	287457.00	943.40	13280833.00	287457.00	943.40		
MW-BE-1D	13280817.00	287412.00	943.40	13280817.00	287412.00	943.40		
MW-KD-1S	13280085.00	287821.00	940.40	13280085.00	287821.00	940.40		
MW-KD-1D	13280070.00	287821.00	940.40	13280070.00	287821.00	940.40		

Notes:

(yellow)	Data used in 3D model was sourced from MDEQ master list, last revised on 8/2/2019.
(blue)	Data used in 3D model was sourced from Fleis & Vandenbrink.
(green)	Data used in 3D model is in agreement with one or more with cited sources.
(white)	Ground surface elevations are estimated to the nearest half foot when surveyed elevations are not available.

ATTACHMENT B

3-D Model Construction Details

The model domain is a convex hull that is not offset beyond the input dataset and is divided into a 30 by 30 grid. The 3-D grid contains the cells and nodes that were used to interpolate the parameters of interest across the model's extents. The surfaces that are created using this method are the top (Ground Surface), bottom (fixed elevation surface below deepest boring) and middle surface representing the water table in the target area.

Lithological observations recorded in the soil and well boring logs were interpreted and grouped to define the hydrostratigraphic units incorporated into the geologic model as indicator classes. An indicator kriging module that utilizes geostatistics was used to assign cells in the 3-D volumetric grid, a lithologic material that corresponds to a hydrostratigraphic unit. The hydrostratigraphic units were either predominantly cohesive or granular lithologies. Cohesive lithologies represented by clay and silt indicator classes are aquitards or confining units, while granular lithologies represented by sand, gravel, and sand and gravel are aquifers. The Spherical Variogram parameters and anisotropy ratios for the most abundant indicator class (clay) in the model extent were modeled.

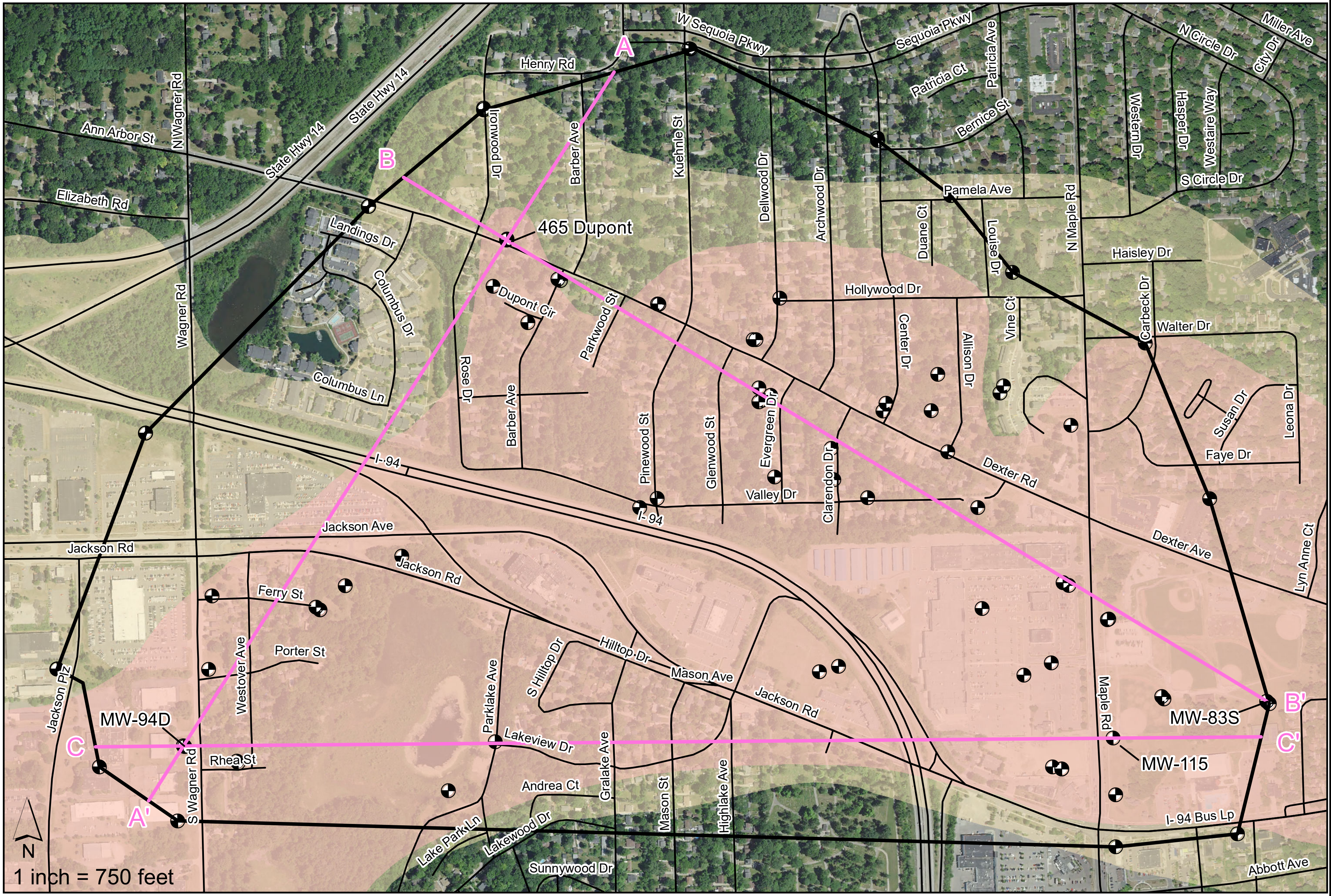
The 1,4-dioxane concentration data collected between April and September of 2019 was added to create a 3-D representation of the extent of the 1,4-dioxane plume in the target area. Analytical data were represented in the model space as point values assigned to the middle of the screened interval of monitoring wells. Non-detections were handled by placing a point value that was 1/10th of the detection limit. Parameter estimation at grid nodes utilized kriging to map 3-D analytical data onto the volumetric grid created by the convex hull of the monitoring and residential well data set. The upper boundary of the plume volume was defined by the surface created to represent the water table in the upper most aquifer. Variogram and anisotropy ratios for the 1,4-dioxane concentration data were evaluated and the values were selected based on the interpolated results and its fit within the Conceptual Site Model.

Cross-sections were generated at numerous locations by slicing planes through the interpolated model domain. Slices were oriented to investigate the modeled distribution of hydrostratigraphic units and 1,4-dioxane concentrations along planes that are in between wells of interest or perpendicular to the potential flow path of 1,4-dioxane to the northeast towards Barton Pond. These are provided as Attachment C.

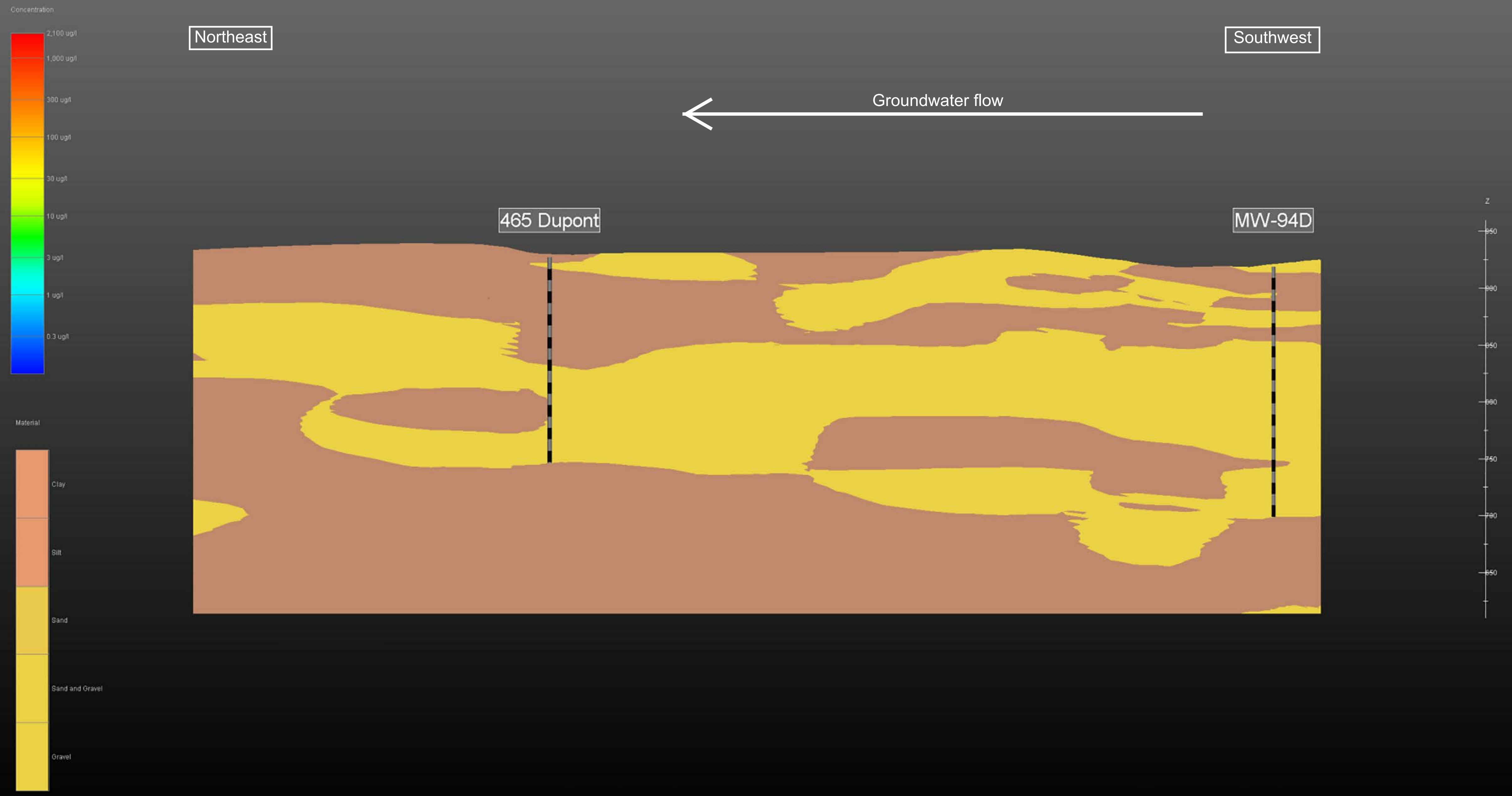
ATTACHMENT C

3-D Model Cross-Sections

P:\Projects\Ann Arbor\Pall Life Sciences City Assistance\GIS\City of Ann Arbor_Cross Section Orientation Map.mxd



DESIGNED BY: JDW DATE: 3/26/2020 CHECKED BY: PJM DATE: 3/26/2020	CITY OF ANN ARBOR SENTINEL WELL INVESTIGATION LOCATION REPORT WASHTENAW COUNTY, MI CROSS SECTION ORIENTATION MAP	Monitoring Well *Estimated Plume (>85 ppb) *Estimated Plume (>1 ppb) 3-D Model Domain *Extent of plume approximated from Washtenaw County Health Department Gelman Sciences, Inc 1,4-Dioxane Plume Map (Accessed June 2019)	ATTACHMENT C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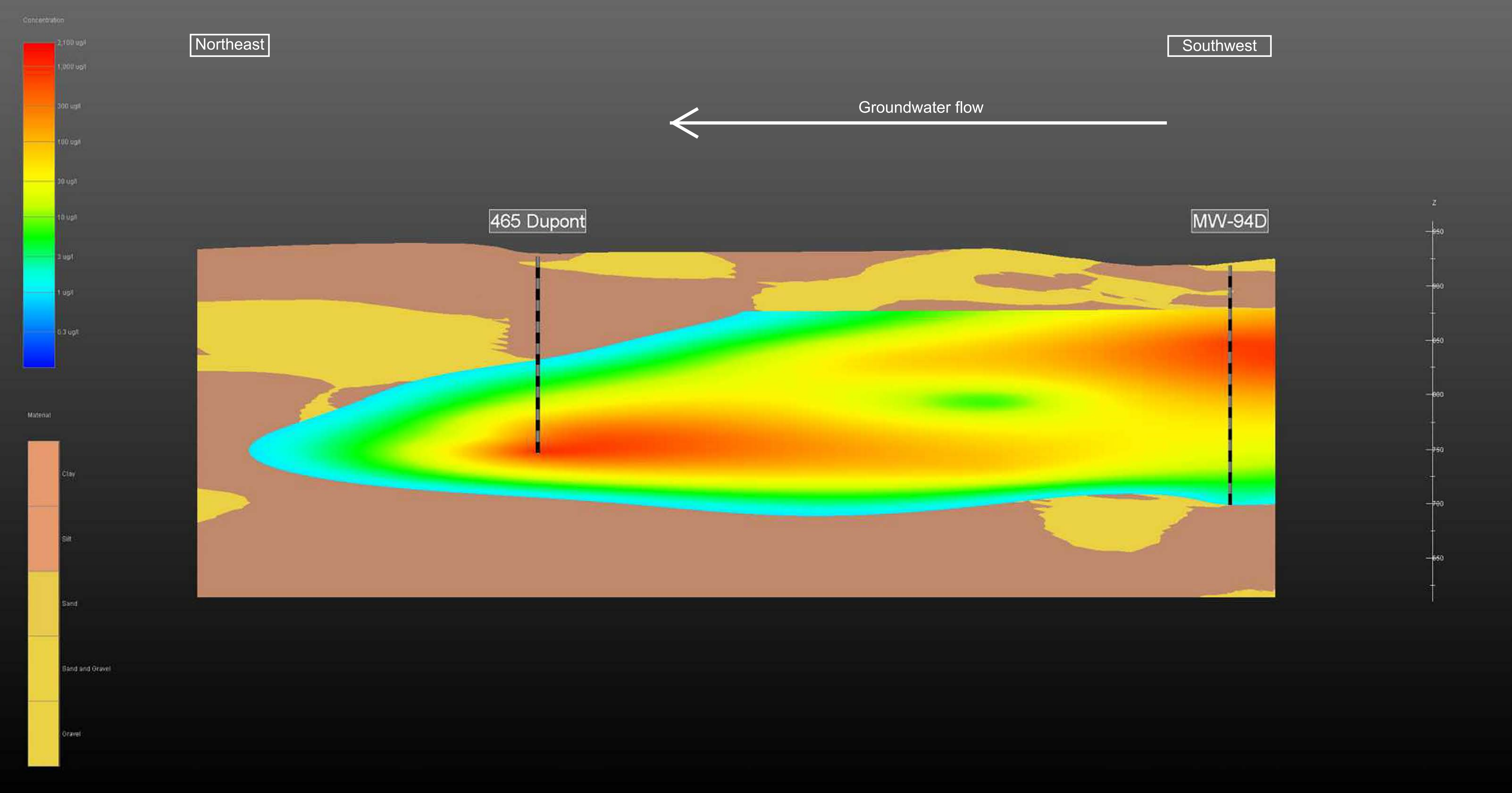
2,100 ug/l
1,000 ug/l
300 ug/l
100 ug/l
30 ug/l
10 ug/l
3 ug/l
1 ug/l
0.3 ug/l
Material
Clay
Silt
Sand
Sand and Gravel
Gravel
Northeast
Southwest
Groundwater flow
465 Dupont
MW-94D
Z
950
900
850
800
750
700
650


Concentration
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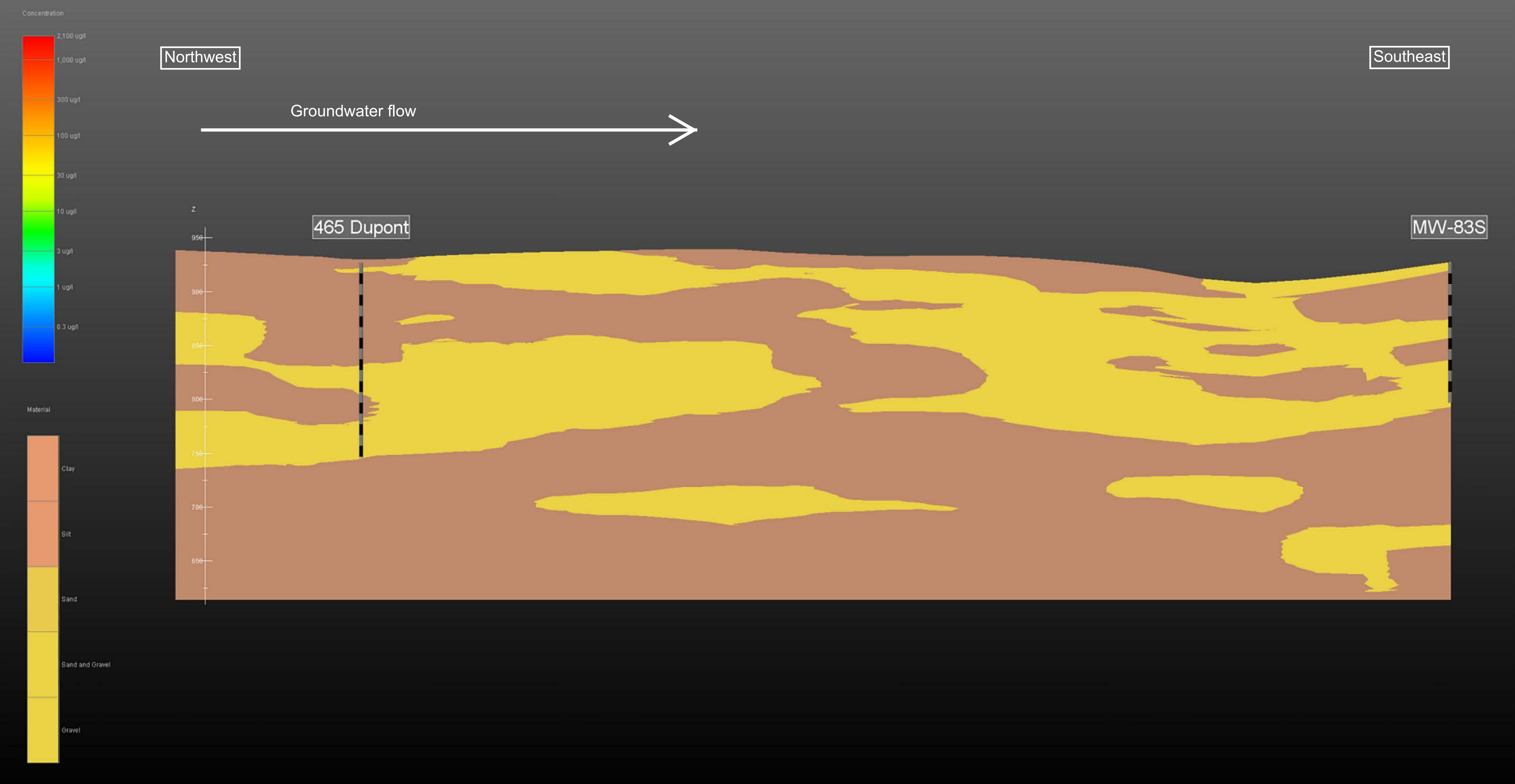
1,000 ug/l
300 ug/l
100 ug/l
30 ug/l
10 ug/l
3 ug/l
1 ug/l
0.3 ug/l
Material
Clay
Silt
Sand
Sand and Gravel
Gravel
Northeast
Southwest
Groundwater flow
465 Dupont
MW-94D
Z
750
700
650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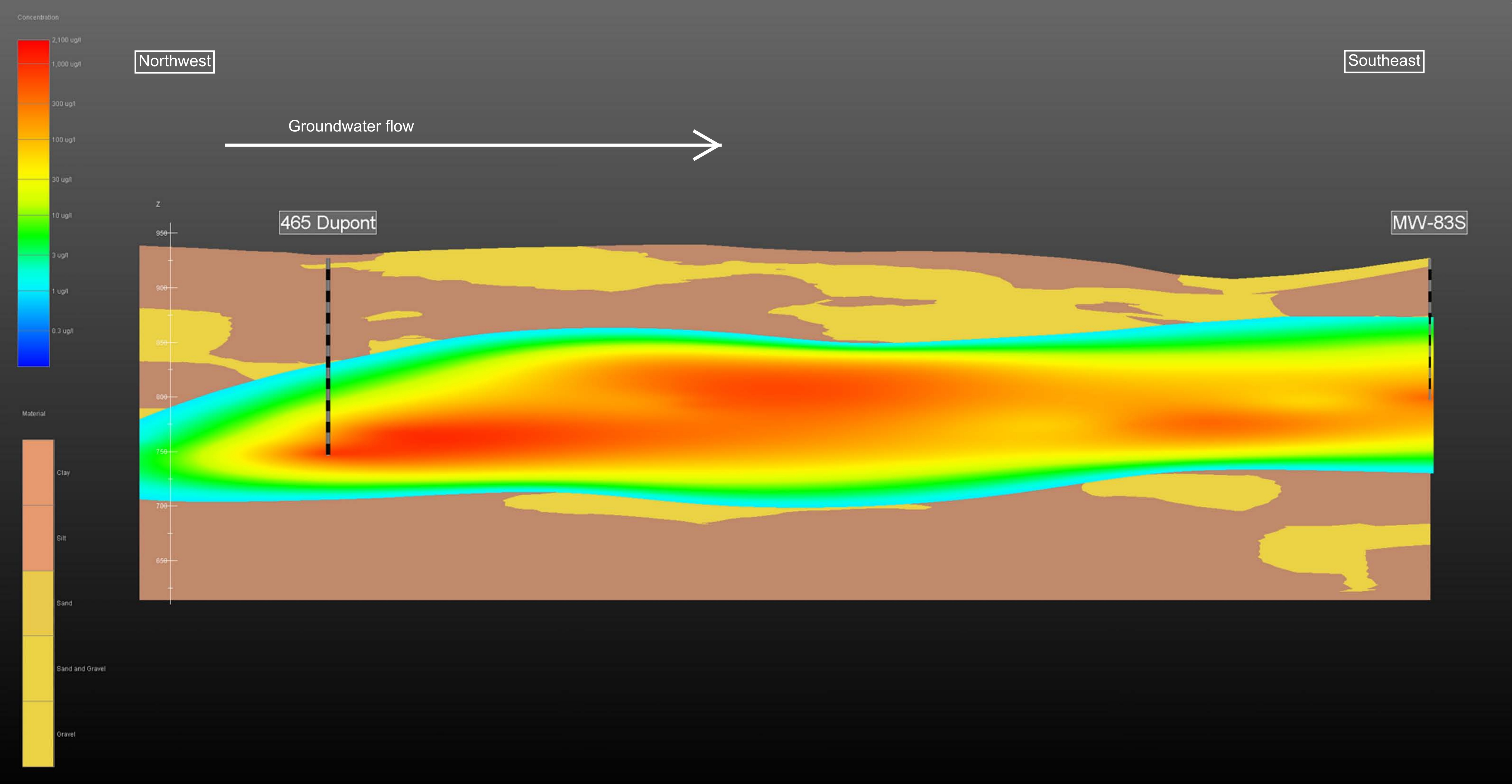
1,000 ug/l
300 ug/l
100 ug/l
30 ug/l
10 ug/l
3 ug/l
1 ug/l
0.3 ug/l
Material
Clay
Silt
Sand
Sand and Gravel
Gravel
Northwest
Southeast
Groundwater flow
Z
950
900
850
800
750
700
650
465 Dupont
MW-83S


Concentration
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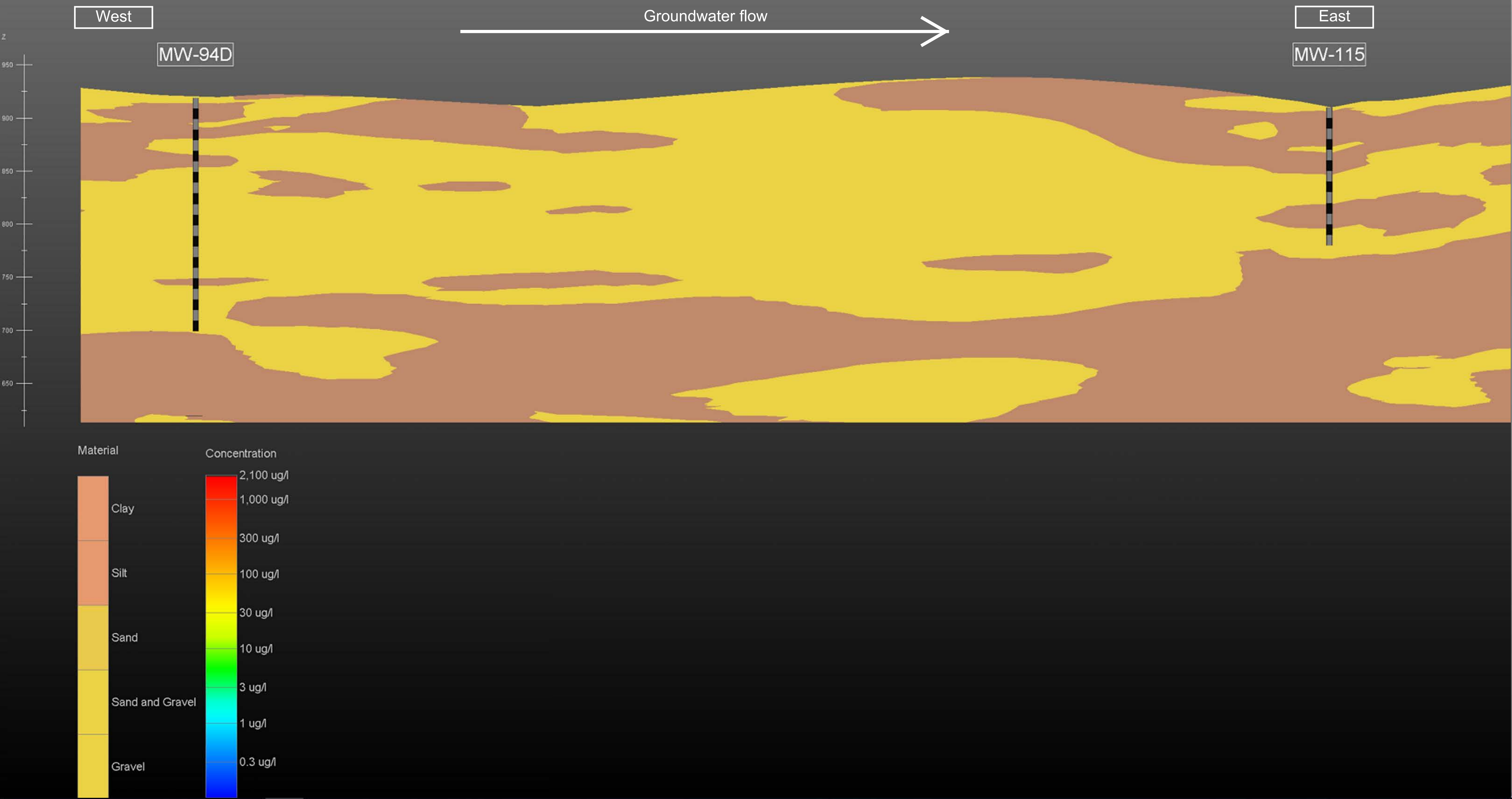
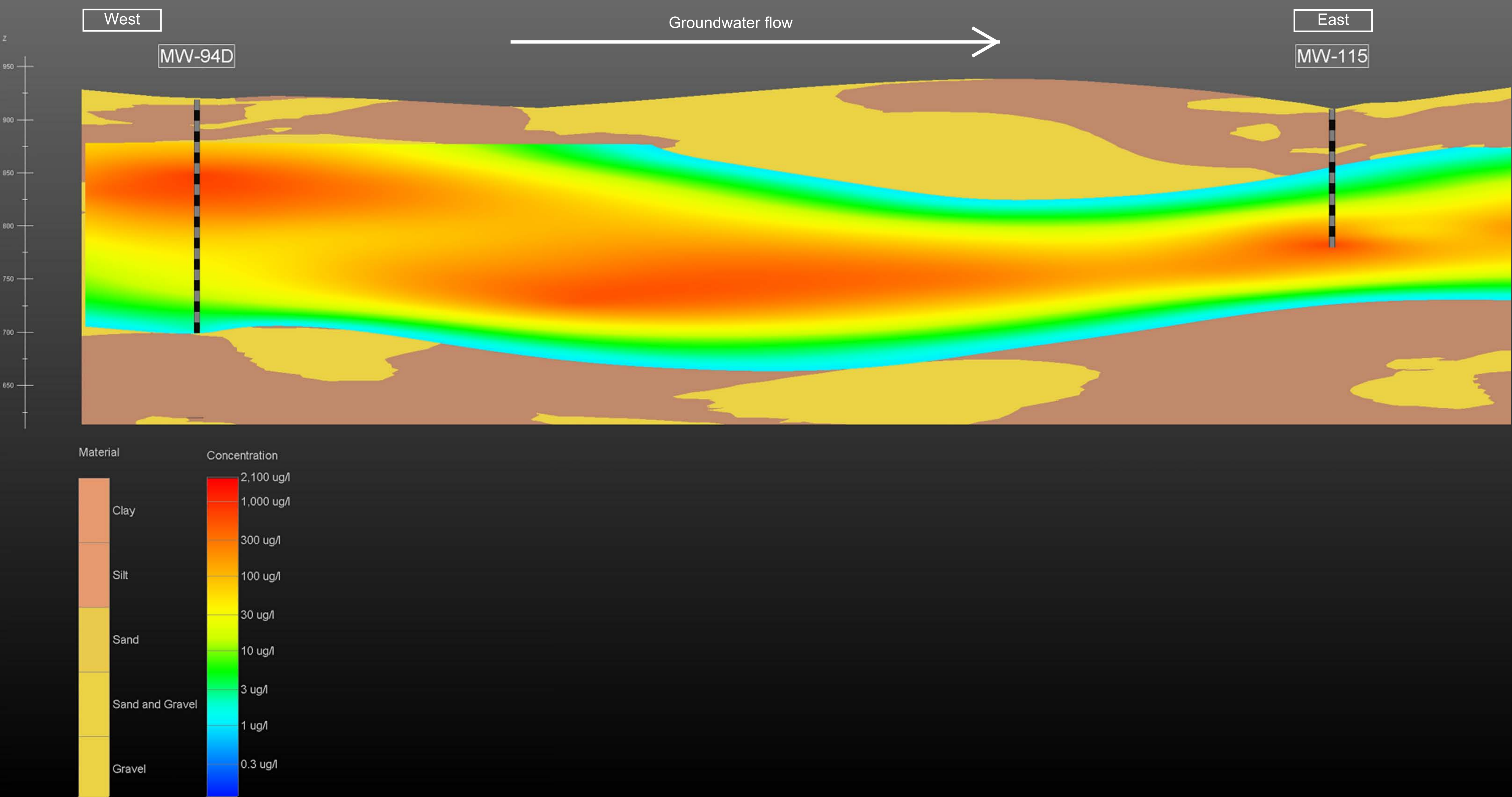
1,000 ug/l
300 ug/l
100 ug/l
30 ug/l
10 ug/l
3 ug/l
1 ug/l
0.3 ug/l
Material
Clay
Silt
Sand
Sand and Gravel
Gravel
Northwest
Southeast
Groundwater flow
Z
950
900
850
800
750
700
650
465 Dupont
MW-83S


West
Groundwater flow
East
MW-94D
MW-115
Z
950
900
850
800
750
700
650
Material
Clay
Silt
Sand
Sand and Gravel
Gravel
Concentration
2,100 ug/l
1,000 ug/l
300 ug/l
100 ug/l
30 ug/l
10 ug/l
3 ug/l
1 ug/l
0.3 ug/l


West
East
Groundwater flow
MW-94D
MW-115
950
900
850
800
750
700
650
Material
Clay
Silt
Sand
Sand and Gravel
Gravel
Concentration
2,100 ug/l
1,000 ug/l
300 ug/l
100 ug/l
30 ug/l
10 ug/l
3 ug/l
1 ug/l
0.3 ug/l