EXHIBIT 1

Expert Report of Kevin D. Lund, P.E.

The facts stated in this Report are based on my personal knowledge and I am competent to testify to them.

1. I am a former Senior Geologist for the Remediation and Redevelopment Division (RRD) of the Michigan Department of Environment, Great Lakes, and Energy (EGLE), and am currently a Licensed Professional Engineer for the Materials Management Division (MMD) located in Jackson, Michigan. While working in the Jackson District Office I have been employed by EGLE since March 2009. I received a Bachelor of Science degree in Geological Engineering from Michigan Technological University in 1983. While working in the mining industry and for Geraghty and Miller from 1984 to 1999, I received training in geology and groundwater modeling.

2. My primary responsibilities as Senior Geologist for RRD and Licensed Engineer for MMD involve review of complex hydrogeological reports required by Part 201, Environmental Remediation, and Part 111, Hazardous Waste, of the Natural Resources and Environmental Protection Act, 1994 PA 451, as amended, enforcing various court and EGLE orders in these programs.

3. I have been the RRD's District Geologist for the Gelman Sciences, Inc./ Pall Life Sciences Inc. (Gelman) Site of 1,4-dioxane (dioxane) contamination, 642 South Wagner Road, Ann Arbor, Michigan, for approximately five years and have supported the project technically with geological software since 2009.

4. My primary role is monitoring the work by Gelman conducting sampling and remediation of the Gelman Plume as technical reviewer. When Gelman submits a work plan or any report to EGLE, I review the plan/report assessing how it meets the requirements of Part 201, and how the plan meets the objectives in the current court order.

5. The geologic features in Ann Arbor have remained largely unchanged since glaciers receded north approximately 14,000 years ago. The continental glaciers that influenced the Ann Arbor area originated in Canada. The glacier moved south, at times the ice pack was estimated to be a mile thick over what is now Ann Arbor, leaving behind mixtures of rock fragments ranging from clay to boulders. When temperatures warmed, the ice melted, and the materials incorporated in the glacier were dropped (as jumbled unsorted deposits) or carried away from the glacier by the melt waters (sorted material, sand and gravel). The topography of Ann Arbor was influenced by the glacier. This resulted in a ridge of unsorted material being deposited on the west side of Ann Arbor. Geologists named this the Fort Wayne Moraine because it extends to Fort Wayne Indiana. The moraine consists of clay, silt, sand, and gravel mixtures and outwash that is principally sand and gravel. If you travel west on Liberty Road from the downtown to Stadium you would be climbing a gradual hill up the east side of this moraine. Continuing along Liberty Street to a point just beyond Saginaw Forest, you are now just south of the Gelman

facility, north of a sand and gravel pit, and near the western edge of the Fort Wayne Moraine. Before Ann Arbor was a city, the surface waters that drained off the eastern edge of the Fort Wayne Moraine followed what is today called Allen's Creek water shed, reaching West Park and then ultimately reaching the Huron River. In Ann Arbor's early days, mills and tanneries took advantage of Allen Creek's water energy. In the 1920s, the Allen Creek area was developed, and the creeks became a storm sewer conveyance. Concrete pipes now occupy the creek beds, while homes and roads built up what is now called Old West Side Ann Arbor. Some early homes are still standing. These homes have "Michigan" basements constructed using the rocks and boulders left by the glacier. Sometime after the glaciers retreated, the Huron River cut through the moraines to the present-day Lake Erie.

6. I described in some detail how glaciers influenced the growth of Ann Arbor. Not only did the glaciers influence how and where Ann Arbor was developed, but the glacial deposits determine where dioxane will migrate in the subsurface, likely reaching the Huron River. The glacial deposits of clay essentially allow no flow of groundwater and limit the ability of the dioxane contamination to migrate, while the saturated sand and gravel deposits are the flow path for dioxane. The area has been well studied, and I have incorporated the research recorded by Dr. George Kunkle in 1960, Geology of Michigan written by Mr. John Dorr and Mr. Don Eschman in 1970, and the U.S. Geological Survey open-file report written by Mr. William Fleck in in

1980. I also drew from articles by University of Michigan geology professors. The observations, research and interpretation of the glacial deposits is an essential element of the conceptual site model that informs EGLE's understanding of the Gelman Site dioxane contaminated groundwater.

7. Dioxane, is completely soluble in water and is held together by strong bonds that prevent it from breaking down readily in groundwater. The complex geology left by the glaciers in the vicinity of the Gelman facility contributed to the fate of the contamination.

8. As specified by state law, the relevant cleanup criteria for dioxane in groundwater are dependent on the potential exposure pathway. The generic residential cleanup criterion (GRCC) is 7.2 parts per billion (ppb) and is the concentration to which groundwater must be remediated to allow for unrestricted use, including use as drinking water. The GRCC is based on a 30-year exposure to drinking water, accepting an increased cancer risk of 1 in 100,000. In areas where restrictions are placed on use of the groundwater as drinking water, such as in the Prohibition Zone, the next relevant pathway is discharge to surface water. The dioxane plume is likely to discharge to the Allen Creek Drain and to the Huron River. The generic criterion for discharge of contaminated groundwater to surface water for dioxane is 280 ppb. This criterion would apply if the contamination discharges to the Huron River downstream of the City of Ann Arbor's water supply intake at Barton Pond,

Third Sister Lake, wetlands near the Gelman facility or the unnamed tributary of Honey Creek.

9. Accepted understandings about groundwater flow and the interaction of groundwater with surface water:
   a. Groundwater flows from a higher elevation to lower elevations.
   b. Monitoring wells are used to measure groundwater contamination and groundwater elevations.
   c. The groundwater elevation map is used as an indicator of the direction the groundwater will flow and the plume maps represent where it is at the time samples were collected.
   d. Groundwater and surface water often move in similar directions, but not always.
   e. Dioxane contamination in groundwater is estimated to move laterally 1 to 2 feet per day.

10. EGLE's primary objective of dioxane remediation is protection of human health and the environment. In the Gelman project, EGLE has continually evaluated Gelman's sampling plans as well as the need for additional monitoring wells or pumping wells as cleanup criteria have changed and additional information becomes available during the investigation\monitoring\pumping process. To review this data set, EGLE utilizes an MS Access database and RockWorks software.

11. In 2018, I was asked to evaluate the effect site development would have on the dioxane plume in the area of 3365 Jackson Road (east of First Sister Lake), specifically what impact proposed onsite storm water management would have on the plume and if the development would increase the risk to the public to be exposed to dioxane. Representatives of the Coalition for Action on Remediation of Dioxane (CARD) believed that development would adversely affect the plume. One argument CARD made to the City Planning Commission was that the land should not be developed because the City's and Washtenaw County's requirement for onsite below-ground storm water discharge would adversely change the plume. EGLE presented a case that developing the 3365 Jackson Road parcel or any parcel in the Prohibition Zone or anywhere west of Wagner Road would not adversely affect the plume, so there would be no increased exposure of dioxane to the public. EGLE presented this understanding with cross sections and maps to the City explaining that development would not affect the plume or put anyone at risk to encountering dioxane. The City denied the developer a permit to build on the property for several reasons, including the belief that development of the property would be a risk to encountering dioxane.

12. The experience telling the story about 3365 Jackson Road was overshadowed by misinformation and uncertainty. It was clear to me that EGLE needed better tools to describe the dioxane plume and better explain

EGLE's understanding of the plume. There is so much misunderstanding of information regarding the Gelman plume that, if 3365 Jackson Road were believed to be undevelopable due to the dioxane plume, how would that impact future development in Ann Arbor? EGLE needed to be more active with better tools that included public outreach in managing the misinformation.

13. The EGLE project manager for the Gelman Site, Dan Hamel, obtained approval and a budget for a plan to improve our visuals used to tell the Gelman Site story by improving upon hand-drawn cross sections and flat maps with an interactive 3D virtual conceptual site model (VCSM). EGLE retained Mannik & Smith Group, Inc. (MSG), located in Lansing, Michigan, to assist with the development of the VCSM. We added RockWare, Incorporated, located in Golden Colorado to the team to assist EGLE and MSG with RockWorks, a software platform that EGLE has been using since 1999 to review the Gelman data set. I led this team in the development of the VCSM and I will be using this tool to demonstrate EGLE's understanding of the Gelman Plume.

14. The objective of the VCSM was to consolidate, collate and validate the Gelman geologic library and water chemistry datasets into workable tables for import into a RockWorks project database and geographic information system (GIS) to allow for analysis and visualization of geologic and groundwater contamination, via an interactive VCSM. The VCSM was developed utilizing

over 40,000 feet of drilling data and over 24,000 groundwater samples. The samples were collected over several decades by Gelman and EGLE. I oversaw the compilation and validation of the lithologic, geochemical, and water level information from well logs, ground surface elevations, and interpreted bedrock contacts from seismic profiles used to create two-dimensional ground, bedrock, and potentiometric surface models and three-dimensional lithology, and annual dioxane geochemical models. MSG brought the data into a Microsoft Access RDBMS so that database concepts could be applied and utilized. Data was then transformed and exported to spreadsheets and validated to serve as the input files for the RockWorks project database. MSG, working with EGLE, established a data standardization, and developed a relational data structure. From this work we were able to establish an accurate spatial understanding of the Gelman contamination history as well as the current conditions via interactive maps.

15. EGLE will use the VCSM to meet EGLE's mission to enforce Part 201, to manage risk to exposure to dioxane, protect human health and the environment and, finally, as a tool to address misinformation. I expect the VCSM will be updated annually as new data are collected each year and shared publicly on the new EGLE GIS platform.

16. The VCSM applies to the Gelman project area, an area of five miles by one mile outlined in Figure 1. The Gelman property, Barton Pond and Allen Creek

are shown for reference.

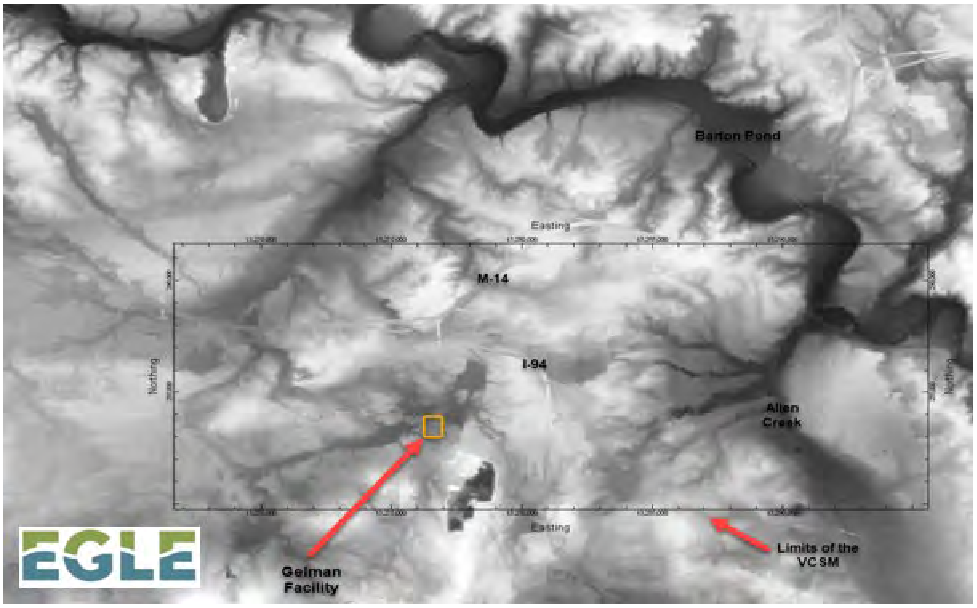


Figure 1, Limits of the VCSM on the ground surface map. shaded elevation relief SEMCOG LIDAR.

17. The glacial drift in the area ranges from 130 - 300 feet thick. The subsurface consists of glacial deposits that overlie the Coldwater Shale. The glacial drift consists of sand and gravel outwash, fine sands and clays, and hardpan glacial till deposits locally called Diamicton (poorly sorted rock fragments, sand, silt, and clay). Multiple glacial advances and retreat episodes in this area of Washtenaw County have resulted in a depositional environment that is extremely complex.

18. Assumptions regarding groundwater flow (vertically and horizontally), and contaminant migration, can not necessarily be extrapolated from one, three or

five monitoring well locations, due to the heterogeneity of glacial drift aquifer systems. The VCSM utilizes data from over 800 monitoring wells and residential wells to create a visualization of the geology and dioxane groundwater plume in 2D and 3D.

19. The U.S. Geological Survey open-file report written by Mr. William Fleck in in 1980 presented his research of the groundwater in Washtenaw County. Figure 2 presents a groundwater elevation map by Fleck showing the interpreted groundwater flow directions. This map presents the understanding of groundwater flow from the Gelman facility.

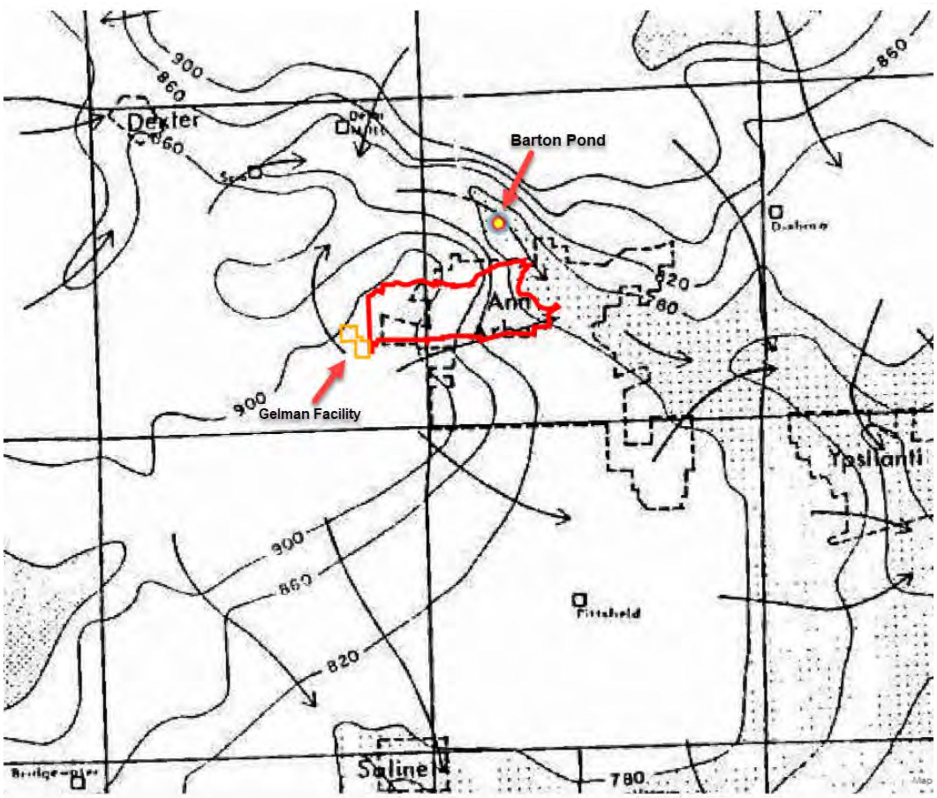


Figure 2. From the USGS report, USGS groundwater flow map (Fleck). The arrows drawn by Fleck depict the direction of groundwater flow near the

Gelman facility (orange) and Prohibition Zone (Red). Barton Pond is shown for reference.

20. In some cases groundwater flow will follow surface water flow direction. Figure 3 below deplitcts the ground elevations and surface flow of Honey Creek and Allen Creek, and Huron River.

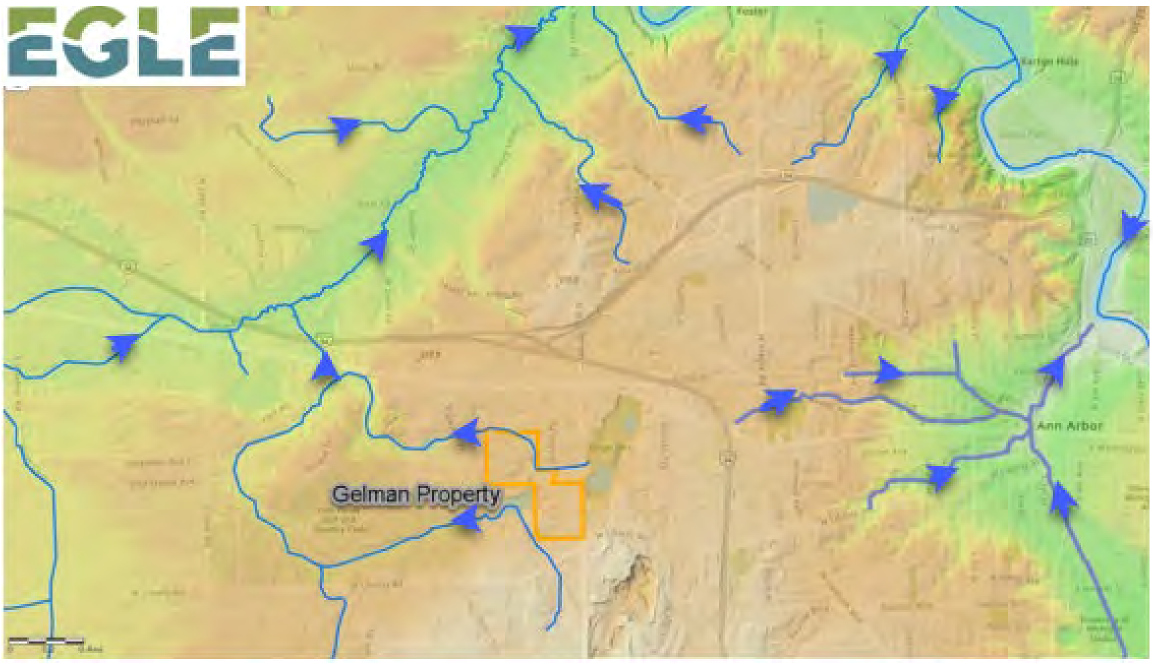


Figure 3, Surface water features and flow direction depicted with blue arrows on the shaded elevation relief SEMCOG LIDAR 2019.

21. During initial investigation in 1988, there were no existing wells nearby to guide groundwater flow directions, so the Fleck interpretation of groundwater flow and the surface water flow directions were relied on by EGLE and Gelman to make initial planning of the groundwater investigation.

22. During initial investigations by Gelman in March 1988, (Report of Phase III Hydrogeological Investigation, prepared by Keck Consulting Services, Inc. October 1987) groundwater flow maps for the shallow (C3) and intermediate (D2) aquifers were developed by Gelman. Gelman identified two aquifers, naming them the C3 and D2 aquifers, and it was believed that dioxane contamination deeper than D2 was limited by clay observed below the D2 aquifer. When EGLE requested Gelman investigators to drill deeper to test the clay horizon below the D2 aquifer, Gelman initially resisted EGLE's requests for investigations to test the clay found deeper than D2, and this investigation was not completed by Gelman until after 2000. The investigation identified the deeper sand and gravel unit that was contaminated by dioxane. Gelman named this deeper sand and gravel Unit E.

23. EGLE's understanding of the dioxane plume has evolved over 30 years of monitoring. The initial hypothesis presented by Gelman in 1988 and reviewed by EGLE was that dioxane contamination was limited to the shallow sand and gravel aquifer (Aquifers C3 and D2) and contained by a clay layers (Aquitards) protecting the deeper sand and gravel aquifer (Aquifer E). This was supported given the understanding at the time. As more data was collected, it has been recognized that the aquifers are more likely interconnected.

24. Two examples where EGLEs understanding has evolved with additional data:

a. Groundwater flow direction and pumping has been a contentious issue between Gelman, EGLE and the City of Ann Arbor since 2002. In 2003, EGLE asserted that groundwater and dioxane contamination might have a flow direction toward Barton Pond. The area was studied by several experts representing Gelman and City of Ann Arbor that concluded it was unlikely but if it occurred it could impact the City of Ann Arbor Water supply. To verify, EGLE insisted Gelman install several monitoring wells. The monitoring well were ageed upon by Gelman and EGLE, and Gelman installed these Monitoring wells between 2008 and 2009 (MW-120s&d, 121s&d, 122s&d, and 123s&d). Gelman has sampled these Monitor Wells quarterly (4 times a year). These monitoring wells have now been sampled over 60 times and continue to verify that dioxane levels are mostly below 1 ppb. These monitor wells are appoximatly 2 miles from Barton Pond. EGLE requested in 2016 that Gelman install three new monitoing well clusters in the area and reducing the distance between existing monitoring wells of approximatly 1000 to 1400 feet to 500 to 700 feet.

b. Since operation of the first extraction well began, Gelman has conducted groundwater pumping tests and produced groundwater models of pumping conditions to assess the potential capture areas of groundwater extraction wells. EGLE has reviewed Gelman’s work as part of the process. Pumping from an aquifer alters the natural flow patterns of groundwater, that alteration depends on many characteristics, some of which we need to estimate. These characteristics are modeled by making assumptions. Such assumptions may or may not be accurate. EGLE has not always agreed with Gelman's assumptions, but we have evolved to a process towards resolving differences by allowing Gelman operational control of pumping and providing the demonstration for EGLE review using groundwater monitoring. In 2011, EGLE agreed to allow Gelman to make the pumping rate decisions and, in return compliance monitoring wells would be used to demonstrate compliance with no expansion of the plume to the west. This was bolstered by enforcement of stipulated penalties if a compliance monitoring well exceeded criteria. Since 2011, Gelman has been in compliance with monitoring and the compliance wells demonstrate no expansion to the west.

25. As the historical file information reflects, prior assumptions regarding continuity of the confining unit (clay) and that the sands and gravels are not interconnected were not confirmed with borings to the bedrock during the 2001 site investigation activities. In 2001, it was discovered that there was no confining layer of clay separating the shallower aquifers (Unit C/D) from the deeper aquifer (Unit E) in an area west of the Gelman property. As a result,

EGLE has insisted that Gelman install all new borings to bedrock using Rotosonic drilling methods and vertically profiling for dioxane throughout the entire saturated interval to the bedrock. During well installation, EGLE reviews and approves the work plans and collaborates with Gelman on selecting the depths where monitoring wells screens are installed. In some locations, as many as three monitoring wells (shallow, intermediate and deep) are located at different depths in the water bearing sand and gravel units encountered during drilling. At EGLE's request, Gelman has installed 347 monitoring wells, extraction wells, horizontal borings and soil borings that represents over 40,000 feet of drilling.

26. The initial step in developing VCSM of the geology of the area was to plan the model area and boundaries. The model boundaries are shown on Figure 1, above.

27. Figure 4, below, represents all the monitoring wells and pumping wells in a heat map to show the relationship/separation between wells. The average separation distance is 473 feet between monitoring wells.

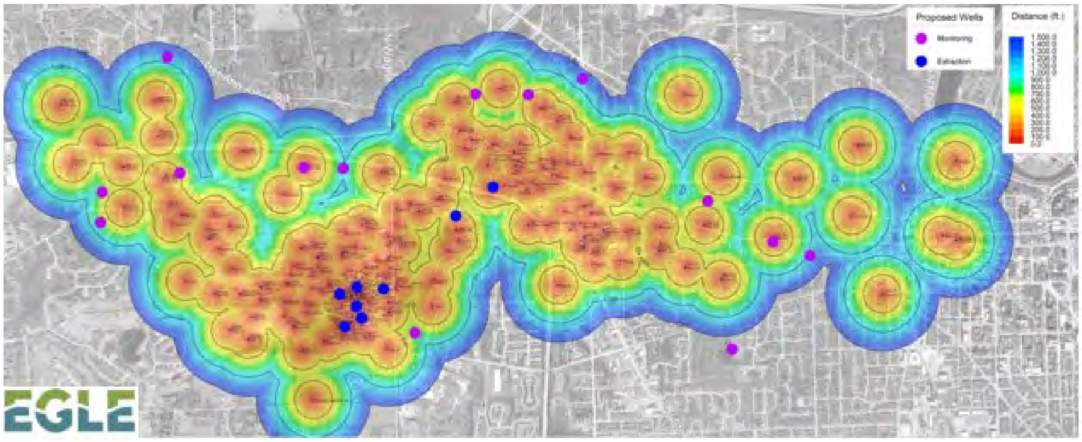


Figure 4. The separation distance between monitoring wells was used as part of planning the geology model.

28. EGLE created a bedrock surface model (Figure 5) using the depths from borings and monitoring wells that intersected the Coldwater Shale bedrock and a shallow seismic data set collected by the EGLE Oil and Gas unit in areas not drilled to establish the depth to the Coldwater Shale bedrock. The bedrock surface was used to contain the base of the geologic model and dioxane models.

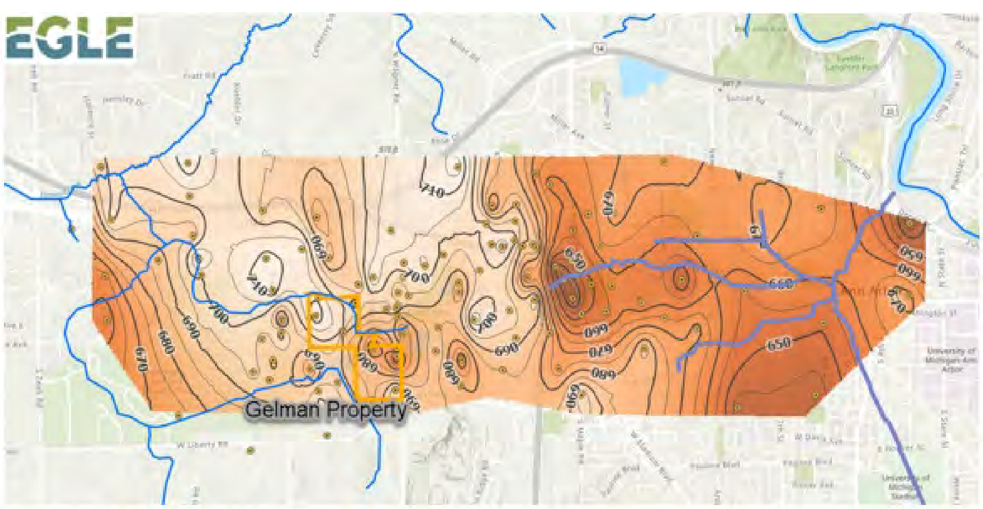


Figure 5. Bedrock surface model, with the surface water features

29. To establish the ground surface, EGLE utilized the SEMCOG_DEM_March 2019 surface also shown in Figure 1, and the same ground elevation features in 3D shown Figure 6.

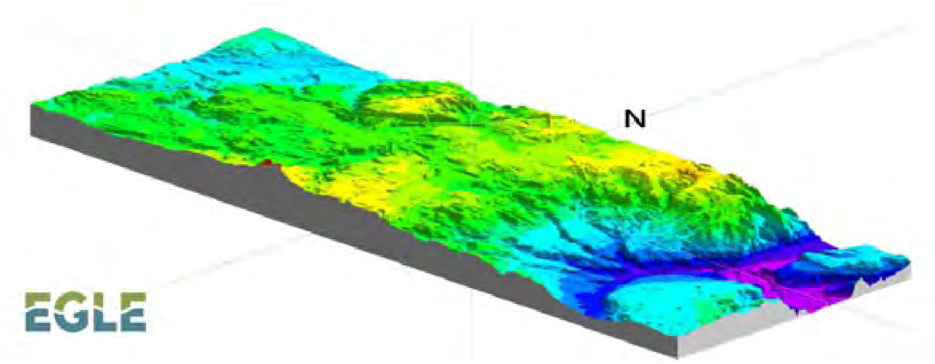


Figure 6. 3D display of the ground surface model. Vertical exageration =5X

30. The EGLE team created a maximum water table grid model using the highest groundwater elevation from each monitoring well over the history of sampling. The new maximum groundwater surface model shown in Figure 7 was used to assist with evaluating risk to groundwater exposure pathways (Vapor Intrusion and Groundwater Surface Water Interfase (GSI)) and to create an upper bound on the dioxane model.

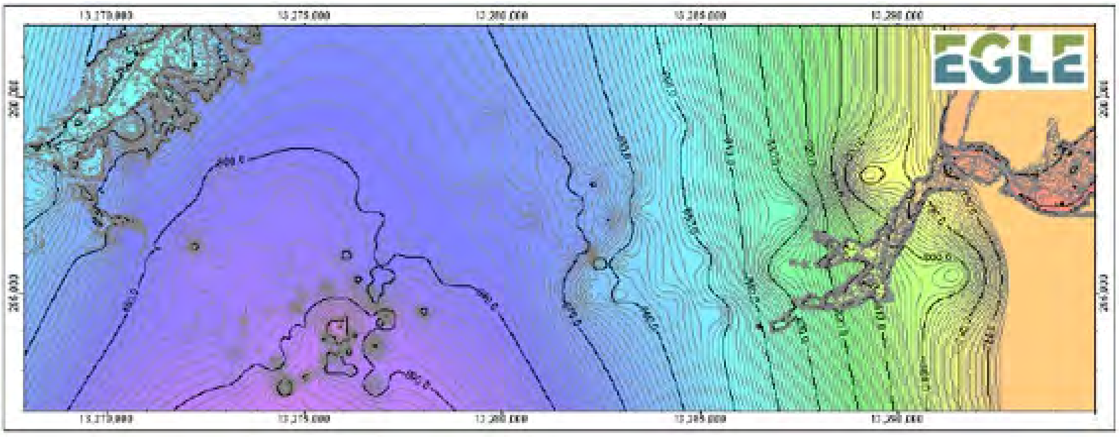


Figure 7 Maximum Groundwater Elevation model

31. Groundwater is not static. It is part of a dynamic flow system that is affected by natural means and human involvement. Groundwater-levels measured by Gelman fluctuate due to aquifer changes involving either the addition or extraction of groundwater from the aquifer. Actions that add water are rainfall and surface water leaking to the aquifer. Actions that reduce the aquifer groundwater levels are pumping groundwater, hardened surface development and areas where surface water is at or below groundwater levels. Where there is no pumping, changes in water levels are almost entirely due to gaining and losing groundwater from surface water features.

32. EGLE created a map of the thickness of glacial sediments above the groundwater, by subtracting the highest groundwater elevation grid from the digital ground elevation grid creating a new map that represents the thickness of glacial sediments to groundwater (Vadose Zone Isopach Map). Because the highest groundwater elevation observed over 30 years was used instead

of a recent groundwater elevation, it would be a conservative understanding of how close groundwater is to the ground surface or basements. The Vadose Zone Isopach map is presented in Figure 8, below. The orange to red depicted in the map represents areas where EGLE would expect groundwater is nearest to the ground surface. This map is useful to evaluate potential risk exposure pathways, such as vapor intrusion into a basement or the groundwater-surface water interface (GSI). Areas identified as red are expected to be less than 10 feet from the ground surface to groundwater. These areas were chosen in 2016 to conduct the shallow groundwater investigation to evaluate the potential vapor intrusion pathway. When the Vadose Zone Isopach Map is compared to the groundwater plume models and parcel maps, this map may be used to identify areas where the potential for exposure to dioxane in groundwater should be evaluated.

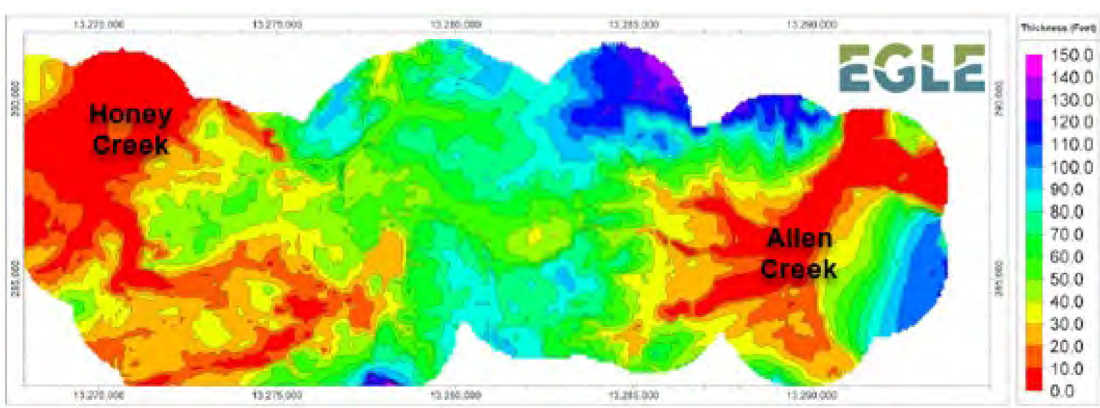


Figure 8. Vadose zone isopach map

33. The development of the 3D Geologic Static model is the first step to building an accurate geological static model for the entire Gelman plume area. The geologic static model is essential in the understanding of spatial

characteristics and features that control how dioxane moves through the subsurface. The goal was to develop a model with sufficient detail to represent the vertical and lateral heterogeneity. The first challenge was organizing all relevant information into a useful format, which took considerable time. Another challenge was to assess the reliability of this information, position of the measurement, and accuracy of the measurement. MSG's main responsibility assisting EGLE was ensuring that *Relational Integrity* and *Data Validation* met the fundamental requirements for utilizing Gelman's data to create a static geology model and static dioxane plume map of each year, from 1992 through 2021. A report by MSG describes *Data Management Summary Report, RockWorks Project, April 1, 2020.* (Attachment 1). A total of 814 borehole records were reviewed by MSG and these records are currently being managed within RockWorks. The records include residential wells, monitoring wells, extraction wells, seismic data, surface locations, soil borings and horizontal wells. This data was acquired by Gelman and EGLE from 1986 to 2021. After MSG organized the data for use, RockWare started the model construction phase, EGLE presented to the team a conceptual model, and decisions were made on the structure of the geologic static model itself. The purpose and use of the geologic static model required the model to be finely layered at 50' x 50' x 2' dimensions for all solid modeling while 50' x 50' cell dimensions were used for all grid modeling. The 2-foot interval improved the aesthetics of the lithologic cross sections by decreasing the pixelation associated with the solid model voxels. The average distance between wells (control points) is 473 feet. Typically, the horizontal dimensions of solid model voxels are set to half of the average minimum distance between the wells, which in this case would be 236.5 feet. However, after careful consideration, RockWare recommended to EGLE and MSG to use a 50-foot spacing to provide a higher resolution that would accommodate areas with closely spaced clustered wells. The total area of the model is 11.8 square miles, and the total volume of the model is 0.84 cubic miles. The process followed by RockWare to build the models is described in the report titled, *Gelman Chemical Site Ann Arbor, Michigan 1,4-Dioxane Plume Migration Modeling and Visualization by James Reed, RockWare Incorporated, March 30, 2020* (Attachment 2).

34. After several trials, RockWare provided a static geologic model for MSG and EGLE to qualitatively compare 28 cross sections drawn by Gelman's consultants and reviewed by EGLE's geologists, locations depicted in Figure 9. The static geologic model cross-sections generated by the model were collocated with the Gelman cross-sections.

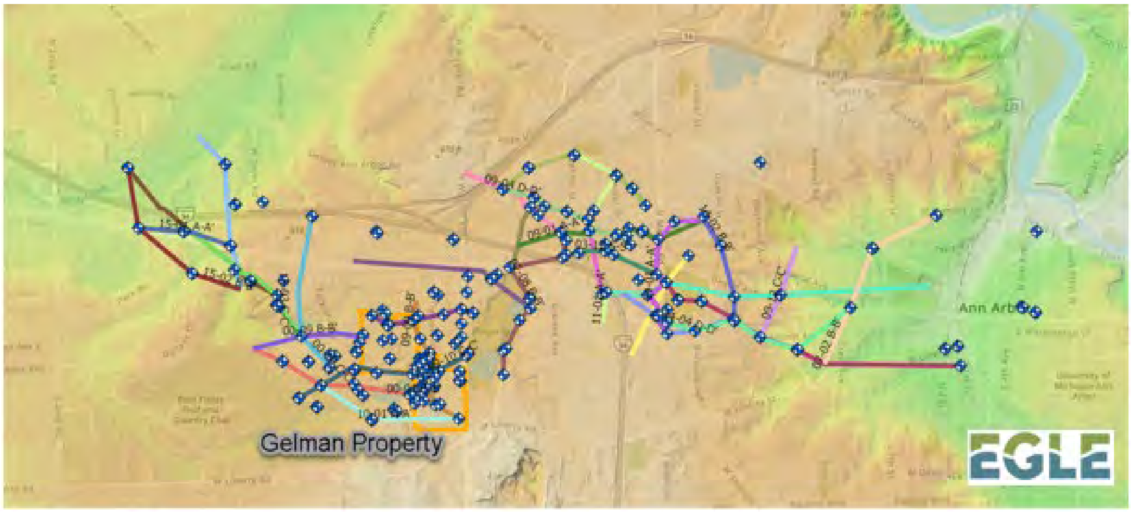


Figure 9. Location of the cross sections used to evaluate the geologic model.

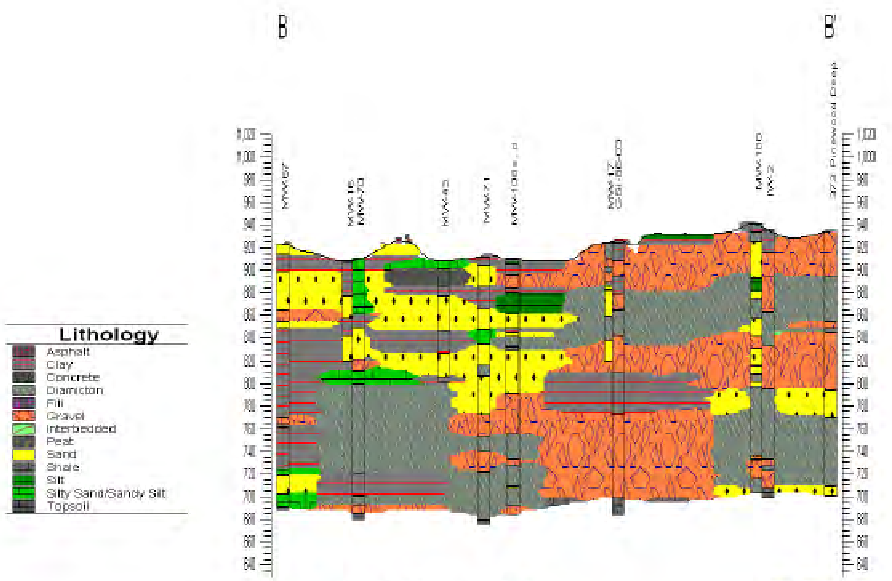
35. MSG graded each cross section for similarity as:

  a. **Good** – Lithologic correlations generally agree between the hand-drawn and model cross sections, subject to differences based on their different purposes.
  b. **Fair** – The general pattern of correlation generally agrees between the hand-drawn and model cross sections, but details and/or grouping of lithologies differ. Many of these differences dealt with correlations of thinner layers between boreholes.
  c. **Poor** – Little agreement between hand-drawn and model cross sections.

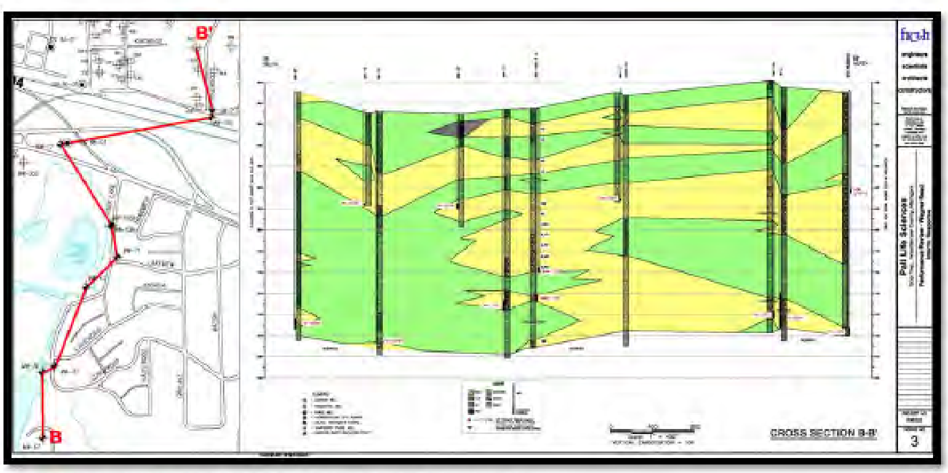
36. MSG determined 16 cross sections were rated as "Fair" for similarity and 12 cross sections were rated as "Good." No cross sections were rated "Poor" for similarity. During the cross-section review, refinements of the RockWorks

model were necessary. The refinements included changes to project node spacing and to the three bounding surfaces (i.e., ground surface, highest groundwater elevation and top of bedrock). The geology model was acceptable when MSG's review of the cross sections determined the differences between the hand-drawn and model cross sections were minor overall compared with the model cross sections. An example of the cross-section comparison is presented below in Figure 10. MSG describes the review in the MSG Data Management Summary Report found in Attachment 1. Review of the static geologic model in this manner provided confidence in using the geology static model for constraining the dioxane plume to the sand and gravel (flow) and clay (no flow).

CROSS-SECTION 07-08 B-B' Comparison



Cross-section exported December 2019



Cross-section from 07-08 B South MW-67 B' North 373 Pinewood.pdf

Figure 10. An example of the static geologic model cross section compared to the Gelman cross section.

37. On February 23, 2021, the Geologic Static Model and Gelman plume maps

were presented to the EGLE Groundwater Modeling Technical and Program Support (TAPS) Team for review. The Groundwater Modeling TAPS Team developed EGLEs Groundwater Modeling guidance, provides technical support to staff working with groundwater models, reviews groundwater models presented to EGLE for regulatory review and trains EGLE staff on reviewing and developing groundwater models. The Groundwater Modeling TAPS Team completed a peer review of the geologic static model and static dioxane models. The TAPS team commented:

a. *The static model of lithology/geology is appropriate used as a part of the conceptual site model. The TAPS team appreciate the attention paid to validate or compare the computer-generated geology model to the cross sections drawn by geologists. The reasoning and strategy to create a flow-no flow model using the geology model making the sand and gravel as flow areas and clay as no flow areas was appropriate. Creating an upper boundary using the maximum water level was appropriate to limit the dioxane plume. Mapping the bedrock elevation was appropriate to set a vertical no flow to limit the vertical extent of Dioxane plume. The strategy to limit the dioxane groundwater contamination to the flow areas using the geology model, groundwater table model, and bedrock model are science based and describe the extent of Dioxane in the Gelman Plume*.

b. *The TAPs team agree[s], the District has established an accurate spatial understanding of the Gelman groundwater contamination using the static models. The development of the static models along with the data validation and adequate calibration are an example of sound science. These static models will be a useful tool for EGLE to explain the Dioxane history as well as the current conditions via interactive maps that should be made public on the EGLE GIS platform.*

38. The complete EGLE Groundwater Modeling Taps Team review is presented in Attachment 3.

39. After the geologic static model was satisfactorily verified and peer reviewed by the EGLE Groundwater Modeling TAPS Team, I tested a working hypothesis on connectivity of the sand and gravel. RockWorks has an algorithm/filter called “Geobody.” This filter is used to identify contiguous "blobs" based on lithology or contaminant concentration in a 3D model. A “geobody” is a cluster of contiguous voxels with similar lithology. In a hydrogeologic sense, a geobody represents zones of hydraulic communication. The geobody and statistics from RockWorks are presented below in Figure 11. The largest geobody of sand and gravel (groundwater flow) constitutes 99.5% of the geologic static model. It is therefore accurate to say that almost all of the sand and gravel within the model are connected. It

should also be considered that the isolated geobodies shown in green, blue and yellow may connect if the geologic static model extents were expanded.

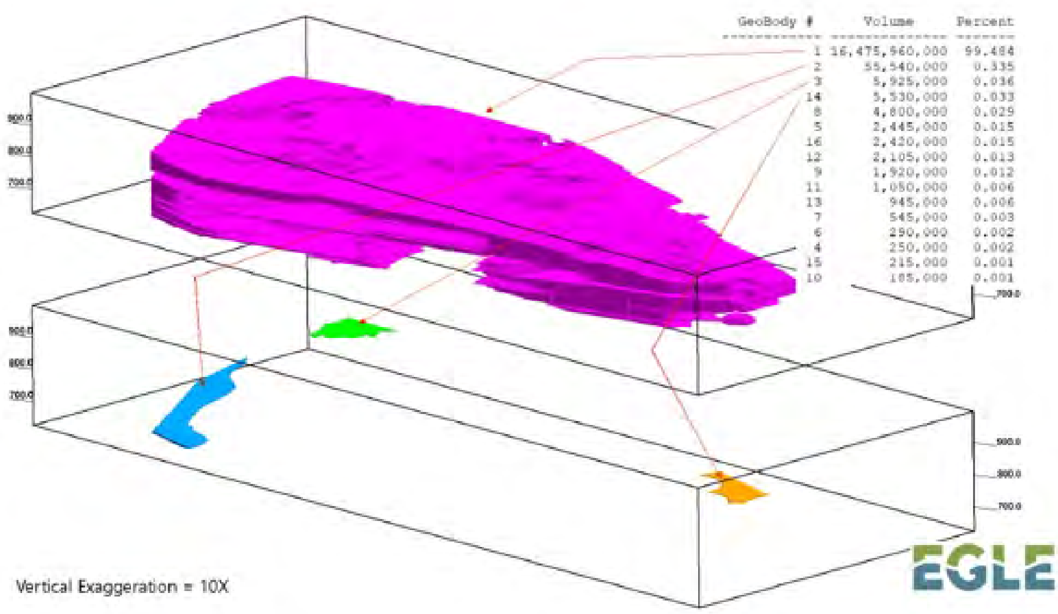


Figure 11. Four largest geobodies within the sand and gravel of the geologic model.

40. When the Geobody filter was applied to the gravel lithology only, two large geobodies were identified as interconnected. (Figure 12)

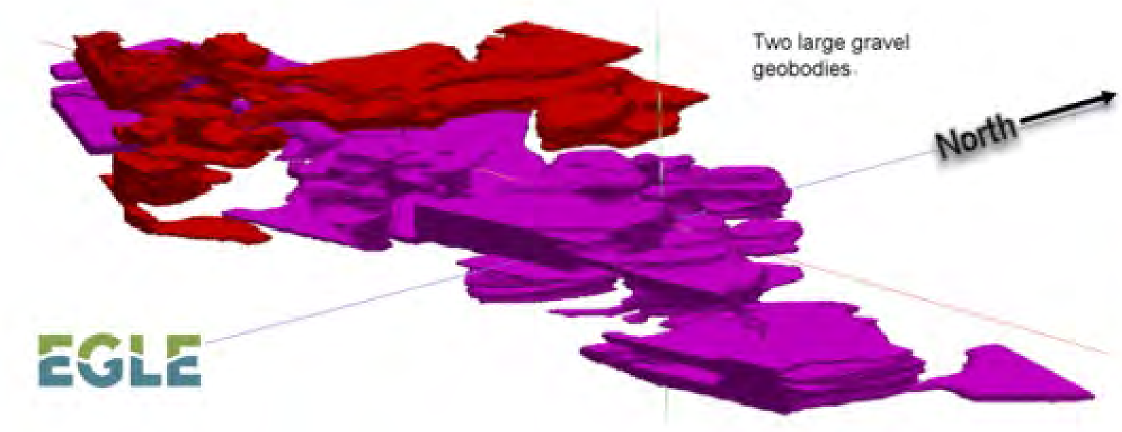


Figure 12. Two large gravel geobodies. This looks simular to Gelman's interpetation of the Unit D2 flowing to Evergreen and the Unit E plume moving toward Allen Creek.

41. A geobody analysis of the 2019 1,4-Dioxane model (Figure 13) indicates that the plume splits into isolated goebodies as it migrates into the Prohibition Zone. The colors assigned to each geobody are arbitrary (i.e., based on the order in which the geobodies are identified).

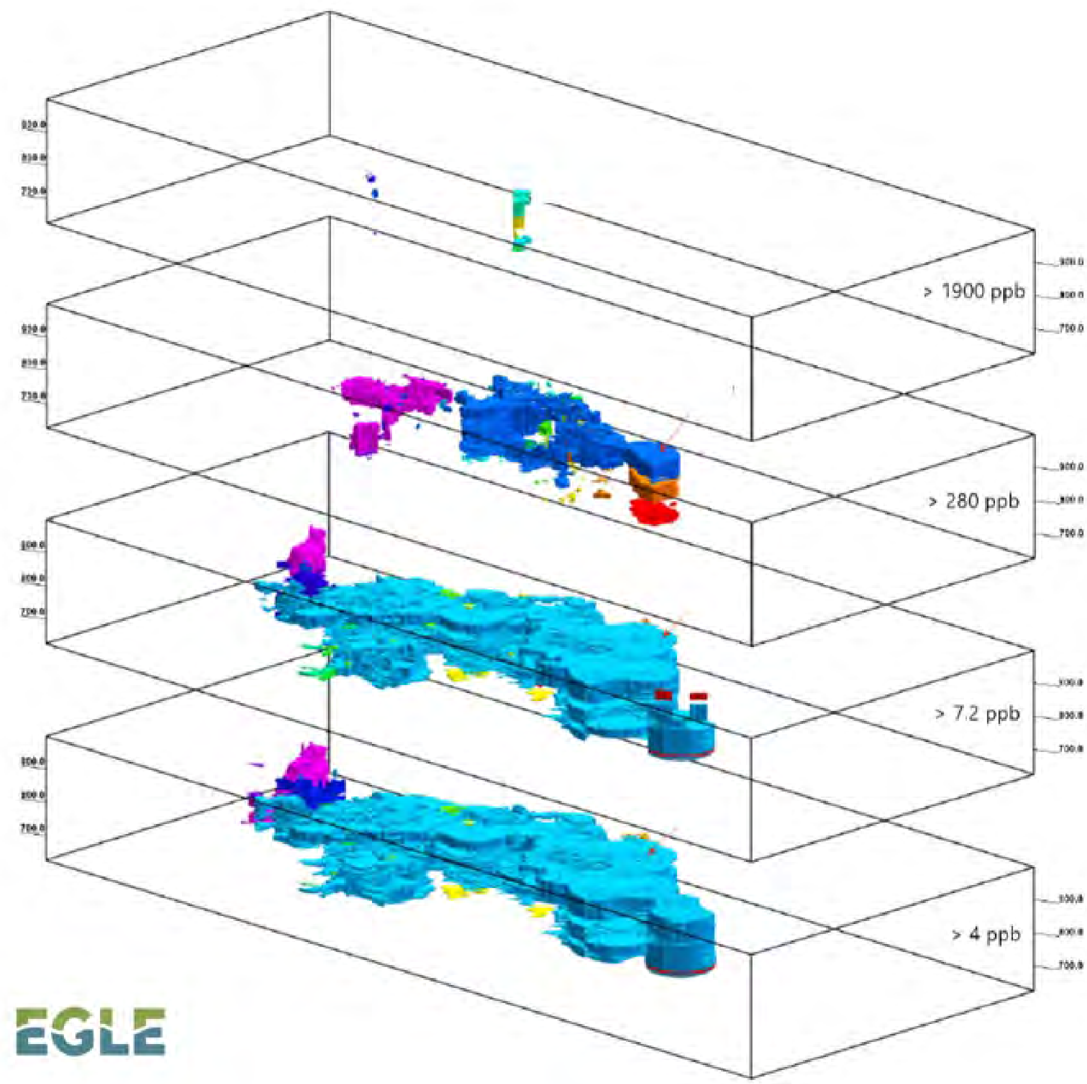


Figure 13. Geobody analysis of the 2019 1,4-Dioxane plume at different regulatory concentration cutoffs.

42. The development of the static geology model and dioxane plumes for each year is a first step to visually convey a complex geological glacial formation in 3D. Historically the Gelman geology was understood and simplified into a limited number of aquifer and aquitard layers in a groundwater flow system

that has assumed little interconnection due to physical boundaries. If all we only looked are the cross sections, these vertical barriers (Clay and Diamicton) to groundwater flow look very evident. However, when the same data is 3D modeled and carefully validated by cross section as interpreted by Gelman and EGLE geologists, we have an opportunity to see the groundwater flow system now as connected as demonstrated in the geobody analysis . This presents a different understanding of how connected the dioxane plume is, changing the thinking simplifies the flow processes. The modeling approach followed by EGLE is a tool to visualize the changes in extent and shape of the dioxane plume with time.

43. The dioxane plume has been contoured by Gelman over the years assuming there are three distinct groundwater units, C3, D2 and E units. EGLE geological experts challenged this belief as early as 2001. While the distinction between the distinct groundwater units vs connected sand and gravel does not materially change the interpretation of groundwater flow directions or the mapping of the plume in plan view, EGLE's representation of the groundwater flow and the dioxane plume may be different than Gelman's, but the overall interpretations are the same. Here are examples of the Gelman maps submitted to EGLE in the recent quarterly report depicting groundwater flow measured in October 2020 to March 2021 of Unit D and E in Figure 14 and Unit E in Figure 15.

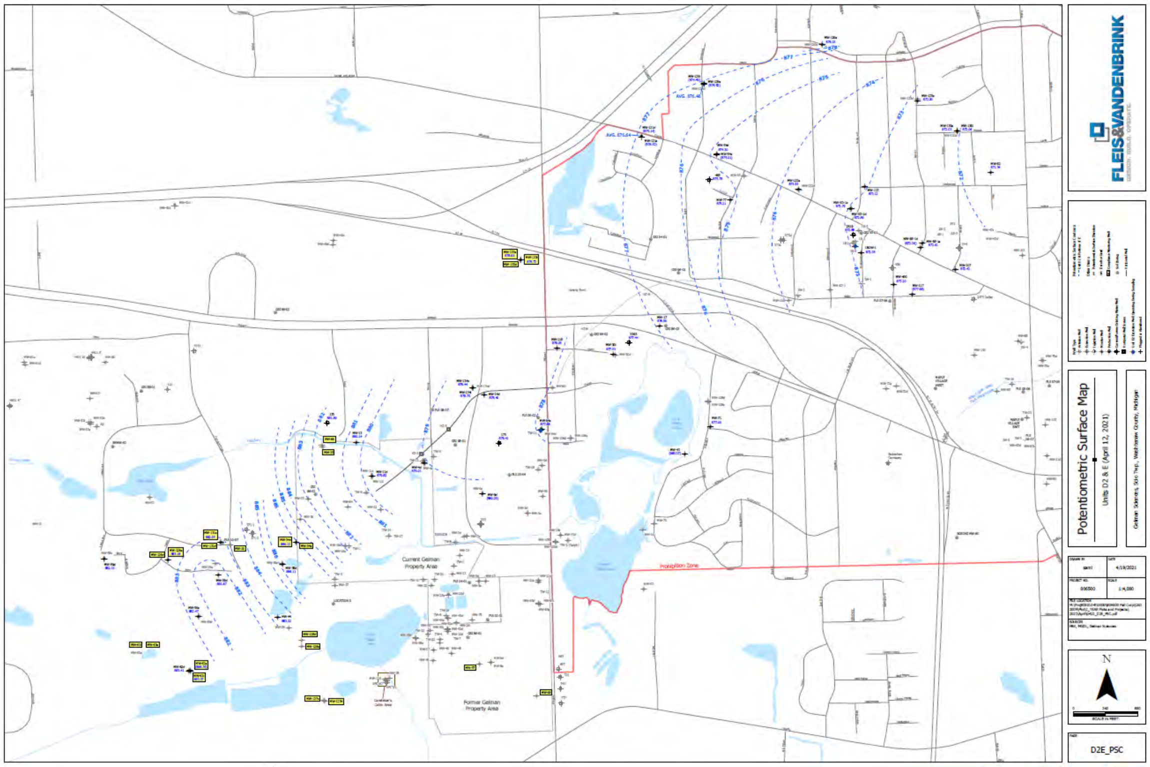


Figure 14. Gelman Units D2 & E April 12, 2021 potentiometric surface map

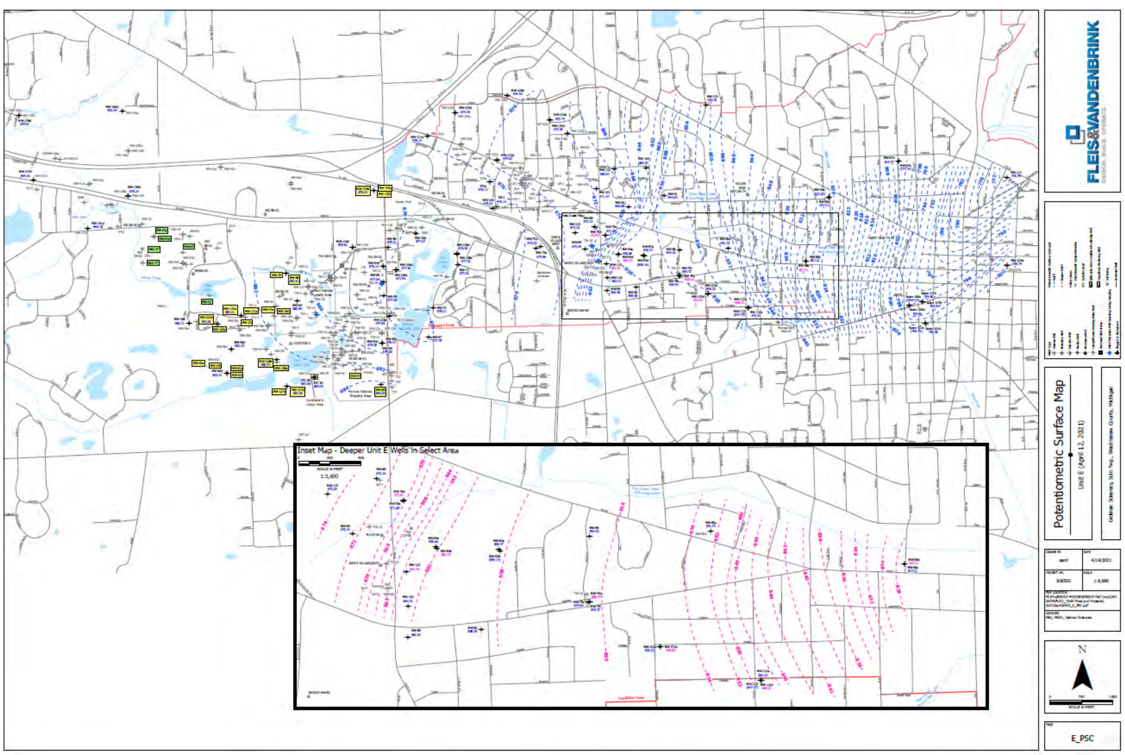


Figure 15. Gelman Unit E April 12, 2021 potentiometric surface map

44. For 30 years, the direction of groundwater flow has been determined from groundwater elevations measured by Gelman and reported in monitoring reports quarterly and annually. EGLE routinely prepared potentiometric surface maps as an independent check of Gelman's maps to check their work. Early in the project EGLE had disagreement over the groundwater flow interpretation by Gelman. Over the last 10 years, EGLE's reviews have agreed with Gelman's interpretation. Gelman's potentiometric surface maps present the actual water elevation so EGLE can verify Gelman's interpretation honors the data.

45. EGLE uses potentiometric surface maps to support its review in determining new the Monitoring Well and Pumping Well locations. Regular monitoring of groundwater level measurements is used to confirm the observed groundwater flow patterns year to year. The groundwater elevations measured in monitoring wells is developed as contour map with lines of equal groundwater level elevation, similar to how elevation contours are drawn on a topographical map. Given that the sand and gravels are connected, EGLE used the VCSM to create a shallow and deep potentiometric surface maps for 2000, 2005, 2011 and 2020 to present some observations. EGLE filtered monitoring wells gauging groundwater levels from less than 150 feet below ground surface as "Shallow" and deeper than 150 feet as "Deep". By contorting different depths, EGLE was testing the hypothesis that

groundwater in a connected sand and gravel unit as presented earlier, should flow in a similar direction. Figure 16 depicts the data for 2000 potentiometric surface map of the shallow groundwater, Figure 17 depicts 2005 potentiometric surface map of the shallow groundwater, Figure 18 depicts 2011 potentiometric surface map of the shallow groundwater and Figure 19 depicts 2020 potentiometric surface map of the shallow groundwater compared to the deep groundwater map. Both shallow and deep maps depict similar groundwater flow directions supporting the interconnection of the sand and gravel aquifer. The shallow potentiometric surface map is more sensitive to reflect areas of groundwater extraction as might be expected.

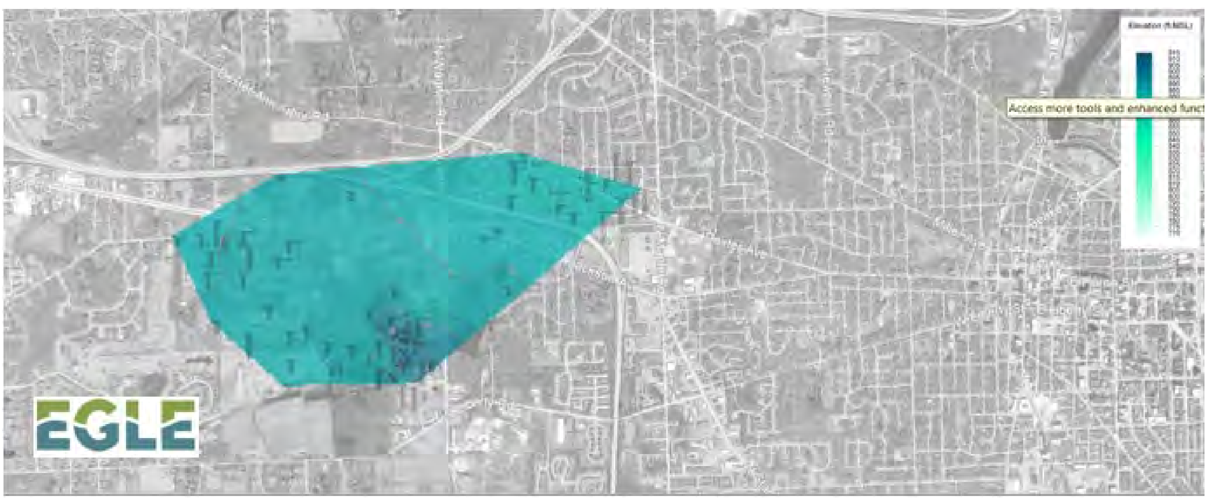


Figure 16. 2000 potentiometric surface map using shallow wells

46. Given the groundwater flow direction depicted in 2000, EGLE and others believed that groundwater continued to flow north to Barton Pond. It will be clearer as we progress through the years and add more monitoring wells to the network how our understanding of groundwater flow will evolve.

Figure 17. 2005 potentiometric surface map using shallow wells

47. In 2005, EGLE was not convinced on the groundwater flow direction and insisted on monitoring wells located north of the plume, between the plume and the proposed monitoring wells shown in Figure 17 and described later in this report. Monitoring wells 120, 121, 123 129 and 130 were installed in 2008 to 2010 at EGLE's request.

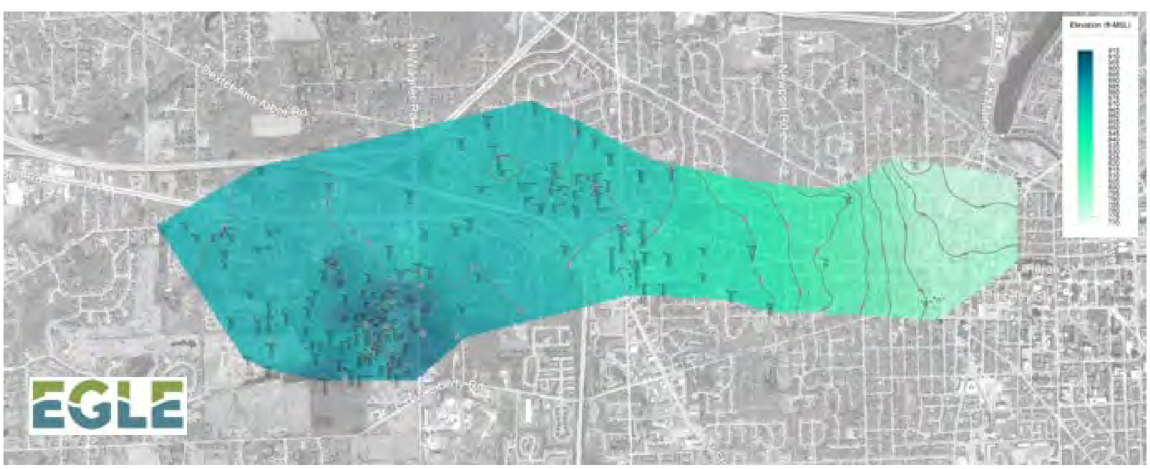


Figure 18. 2011 potentiometric surface map using shallow wells. Darker green depicts the highest groundwater elevation and the light green depicts the lowest elevation, in effect groundwater flow is from dark green to light green.

48. Between 2004 through 2011, several studies by EGLE, Gelman, and the City of Ann Arbor concluded that it was unlikely dioxane in groundwater flowed toward Barton Pond. Monitoring wells installed in 2008, near the northern boundary of the plume have not identified dioxane to validate the potential for dioxane movement north during testing between 2008 to 2011. Figure 19 depicts in the highlighted area the groundwater elevations measured in MWs 120, 121, 123 and 129 in 2020. The most northern MWs 120 and 129 recorded the highest groundwater elevations in the area and support the eastern groundwater flow direction.

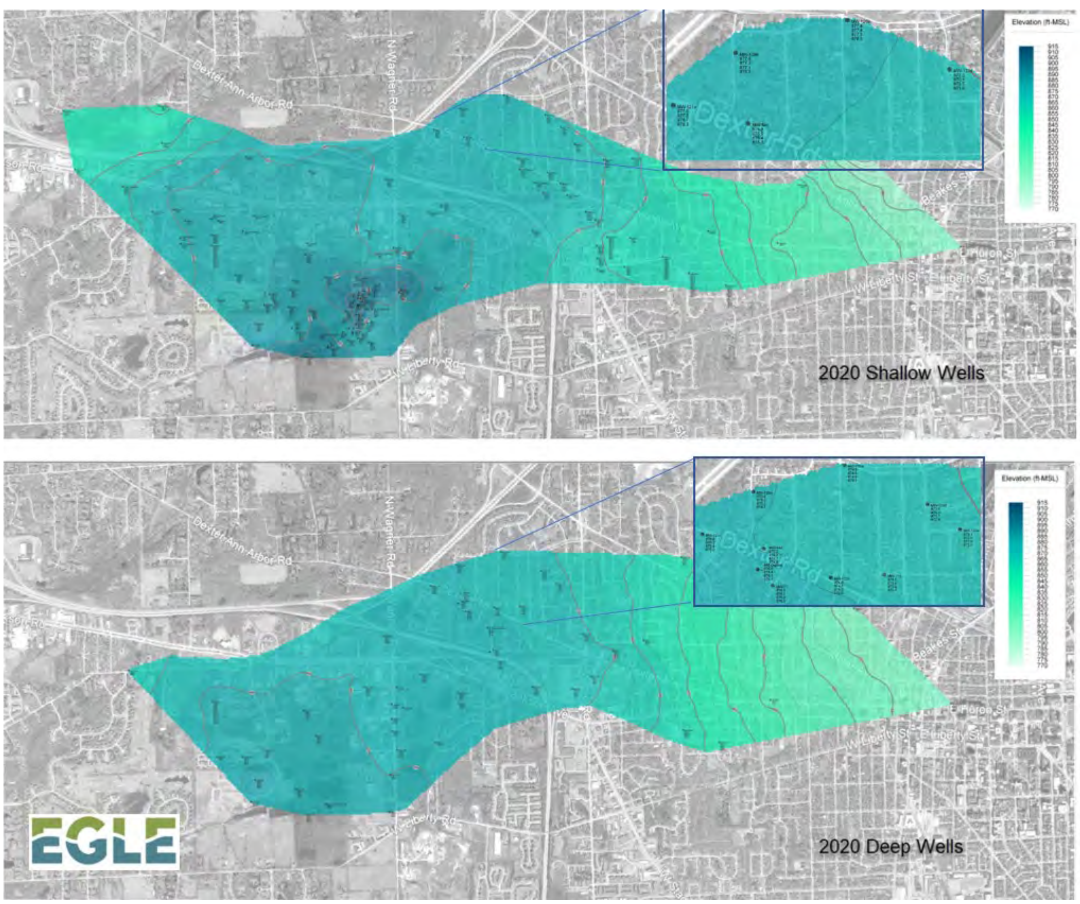


Figure 19. 2020 potentiometric surface map shallow and deep comparison

49. The 2020 potentiometric surface map represents a comparison of the monitoring wells gauging water in different elevations. Flow directions in the shallow and deep 2020 maps depict a similar flow direction. Groundwater flow directions in the 2020 maps compared to those flow directions depicted in the map made by Fleck in 1980 (Figure 2) are also similar. Neither flow direction represented in these maps support an interpretation groundwater flows from the Gelman property to Barton Pond. However, there is community concern, so in 2016, EGLE requested Gelman install three additional monitoring wells to reduce the separation distance between monitoring points and augment the existing monitoring wells and incorporated all these wells as a sentinel monitoring network, Gelman agreed to install the three new wells in the proposed Fourth Amended and Restated Consent Judgment (4th CJ).

50. The following is a comparison of EGLE's VCSM plume to the Unit E plume depicted in Gelman's Quarterly report and Washtenaw County maps. All the maps of the plume reflect accurate contouring to the control points (monitoring well data). Gelman's map (Figure 20) uses contour intervals 85, 250, 500, 1000 and 2000 ppb. This map is compliant with the current Consent Judgement signed in 2011. EGLE's plume was made using the VCSM and contoured at 4, 7.2, 85, 150, 280, 500, 1000, 1900. EGLE's map (Figure 21) is made for compliance evaluation using the contours of 7.2 (New Drinking water), 85 (CJ3 drinking water criteria), 280 (New GSI criteria), and

1900 (Vapor Intrusion criteria). EGLE is contouring the 4 ppb level to map because 4 ppb at these locations groundwater will be monitored quarterly by Gelman (four times per year). These locations could become the new sentinel wells triggered at 4.0 ug/L if the proposed 4th CJ is accepted. A trigger of 4 ppb (below criterion of 7.2 ug/L) was included in the proposed 4th CJ. Sentinel Wells exceeding 4 ppb of dioxane will require Gelman to complete response actions and implement contingencies described in the proposed 4th CJ. The combination of new wells and lower triggers were supported by EGLE as measures to address the potential for dioxane to migrate towards Barton Pond, located approximately 2 miles from the Prohibition Zone.

51. The Washtenaw County Map (Figure 22) is contoured at 1ppb and greater than 85 ppb, representing the dioxane plume as a single mass.

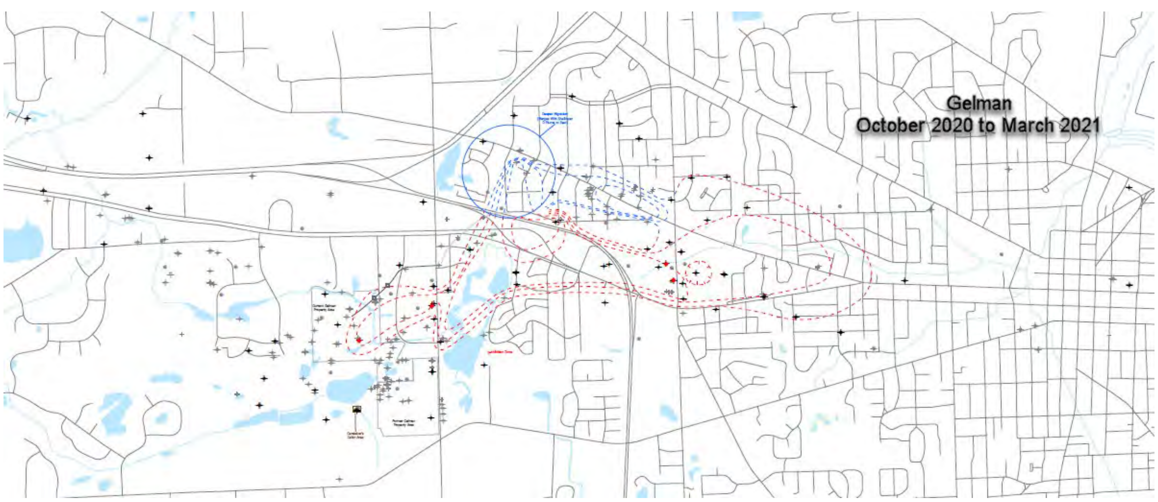
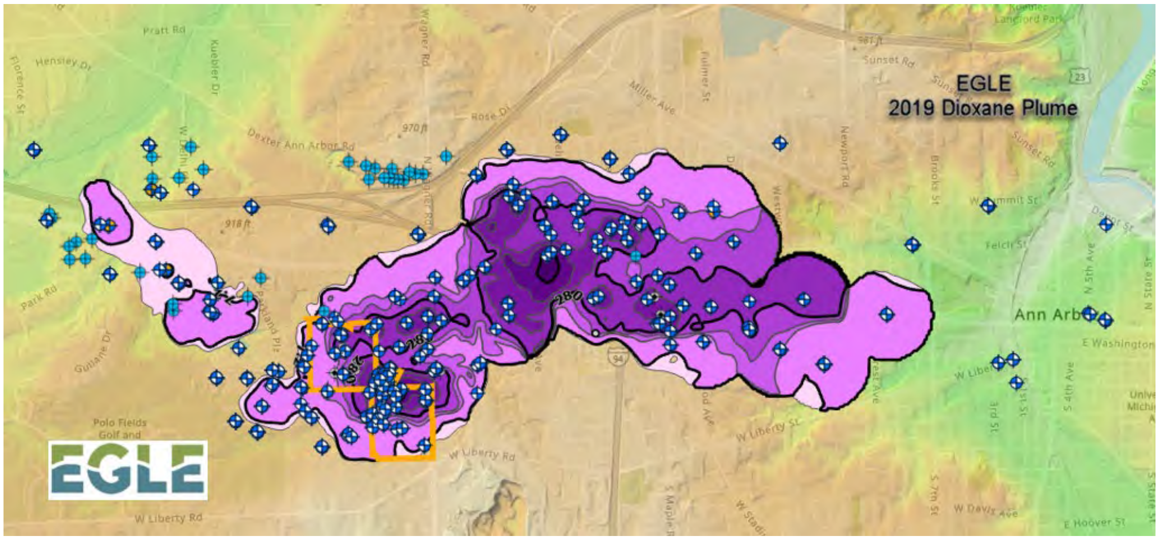


Figure 20. Gelman Unit E Plume submitted with the 2021 first quarter report. Dioxane extent countoured to 85 ppb.



Figue 21. EGLE 2019 Gelman Plume map, extent contoured to 4 ppb lightest purple.

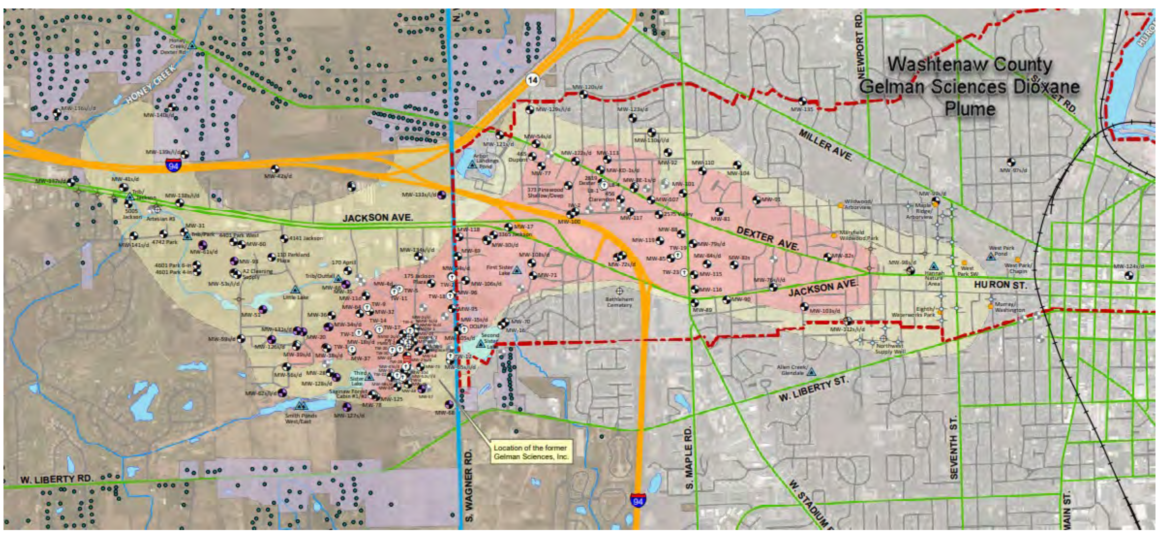


Figure 22. Washtenaw County Gelman Plume Map, extent contoured to 1 ppb.

52. There are a number of different maps found on the Internet. A google search identified over 50 maps, as shown in Figure 23, a screen shot of 27 different maps are depicted. Most are maps of the dioxane plume in Ann Arbor. Some represent older data, few references how the maps were made, and

most are using colors or shapes that are misleading.

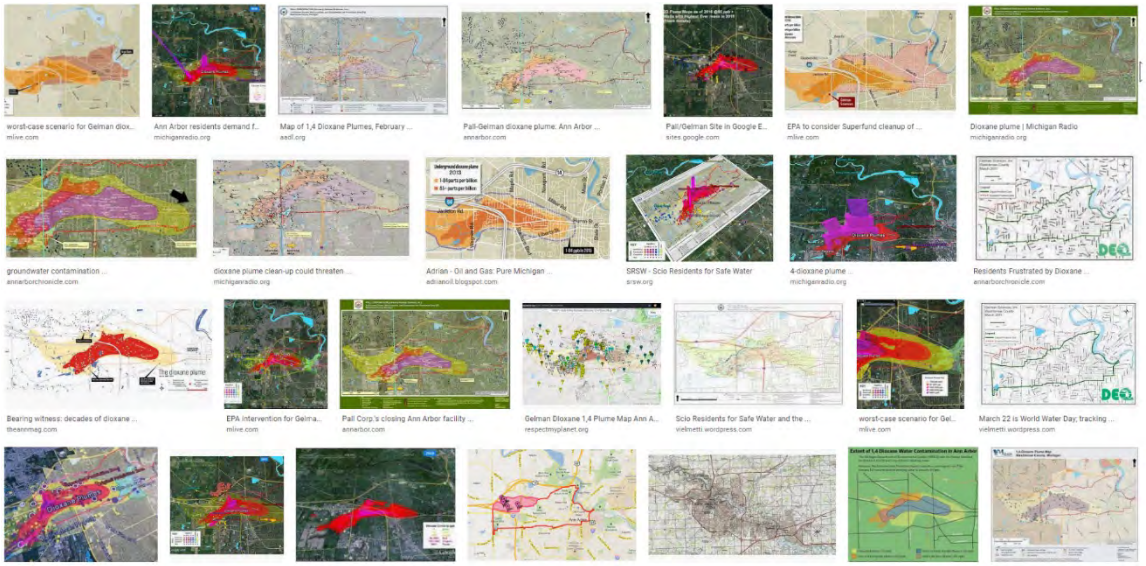


Figure 23. Screen shot of Google search for maps of the Dioxane Plume in Ann Arbor.

53. Development of the groundwater elevation models and dioxane models using the VCSM for each year is helpful to better understand the changes over time. Figure 24, below presents dioxane models for the years 2000, 2005, 2011 and 2020. These years were selected because in these years EGLE, Gelman and the court made decisions that affected how the plume was remediated and risks were managed.

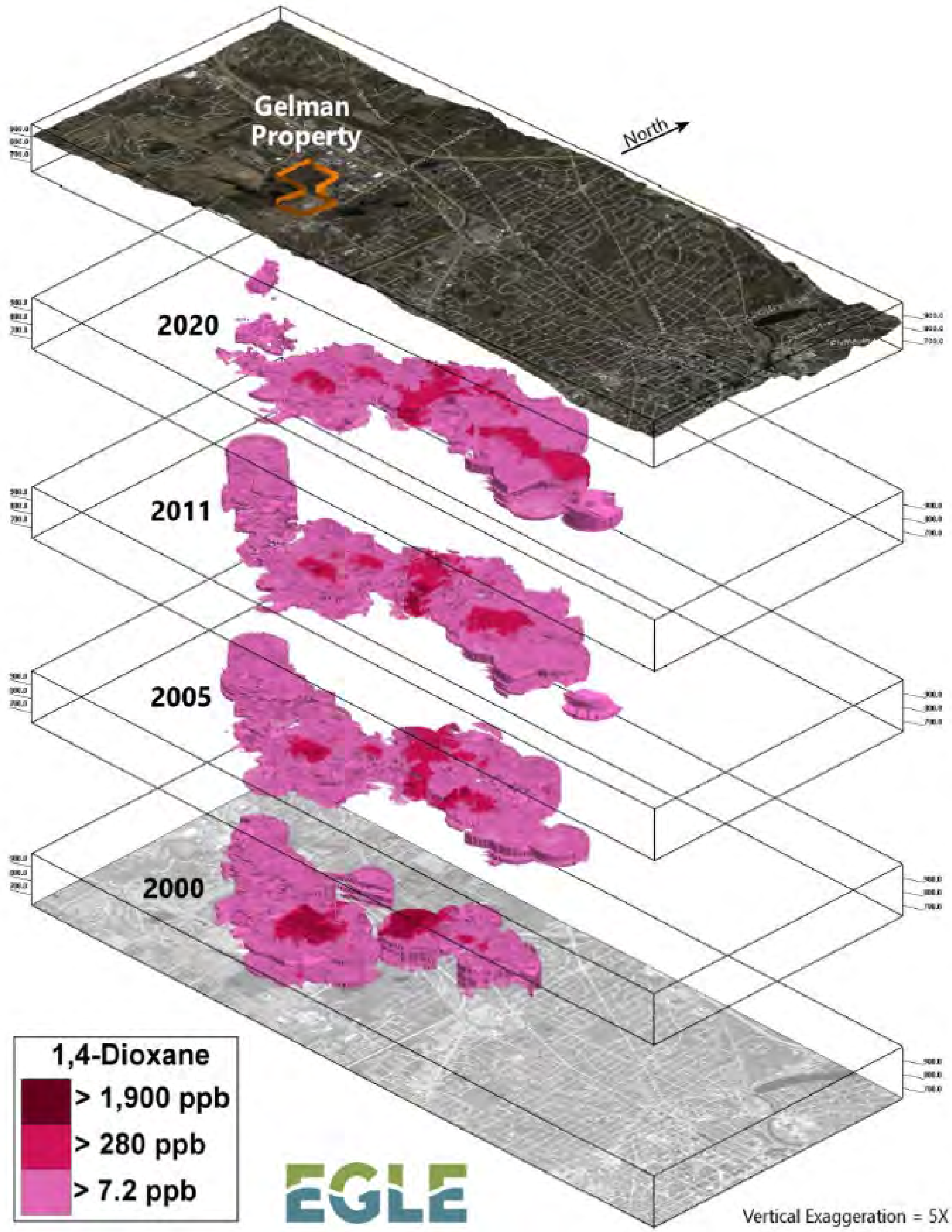


Figure 24. Changes in the dioxane plume from 2000 to 2020.

54. Since 2017, Gelman, EGLE and the Intervenors have been discussing changes to the proposed 4th CJ. The following revisions to the proposed 4th

CJ were presented by Dan Hamel, the EGLE project manager in the Gelman Consent Judgment Update Webinar held on September 14, 2020. EGLE presented an overview of the changes in the proposed 4th CJ that EGLE supports. The following discussion support the proposed changes discussed in the September 14th Webinar using the VCSM. Figure 25 is a map from the proposed 4th CJ depicting the proposed monitoring wells and pumping wells. Most of these locations shown on this map represent up to three new monitoring wells. This work will increase EGLEs understanding of the plume, help verify where the plume is and where it is not and take steps to reduce dioxane mass in the groundwater.

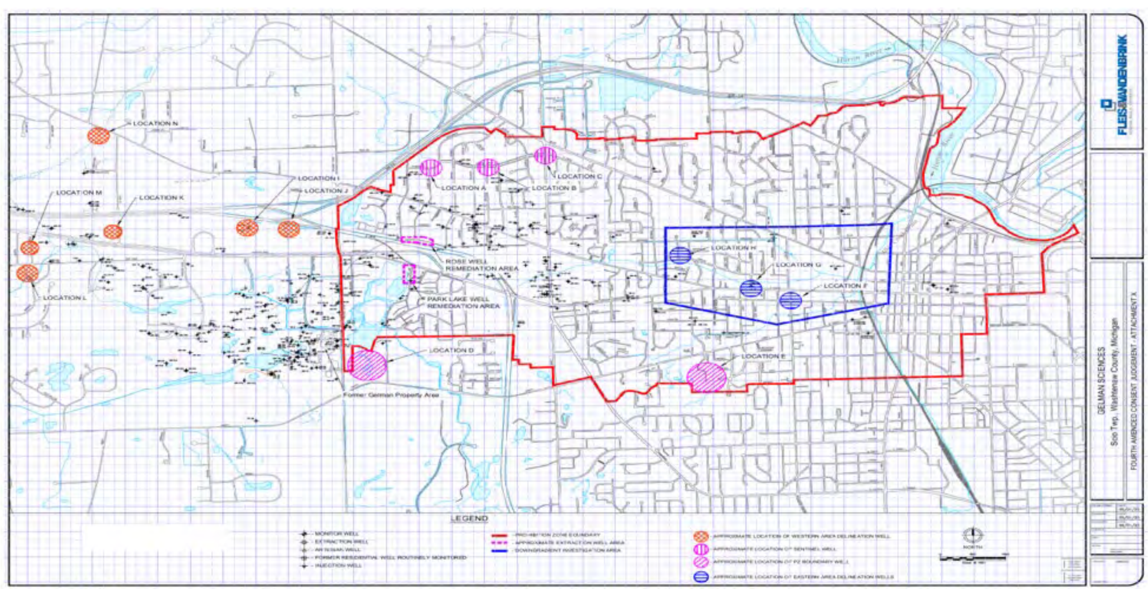


Figure 25. proposed groundwater monitoring and extraction program in proposed 4th CJ.

55. The proposed groundwater monitoring program in the proposed 4th CJ includes new sentinel monitoring wells A, B, and C. The new wells are cluster

well locations with wells at multiple depths as needed, located inside the new proposed Prohibition Zone's northern boundary and infill between groundwater monitoring nested wells between MWs 120, 129, 121, 123 and 130. (See Figure 26)

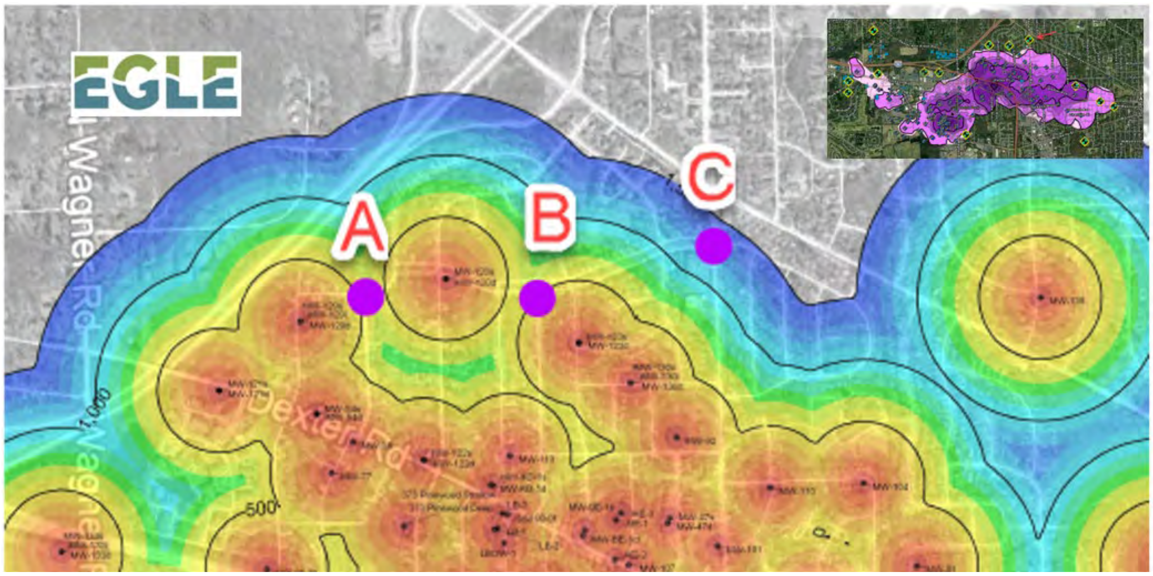


Figure 26. Map showing the distance to the closest well, new monitoring wells A, B and C locations with respect to the existing monitor well network.

56. Figure 27 depicts a cross section including the existing monitoring wells with the proposed monitoring wells. The sand and gravel are potential paths for the dioxane contaminated groundwater to move. The new wells are intended to intersect the sand and gravel if it exists in these locations and monitor the area for dioxane over time.

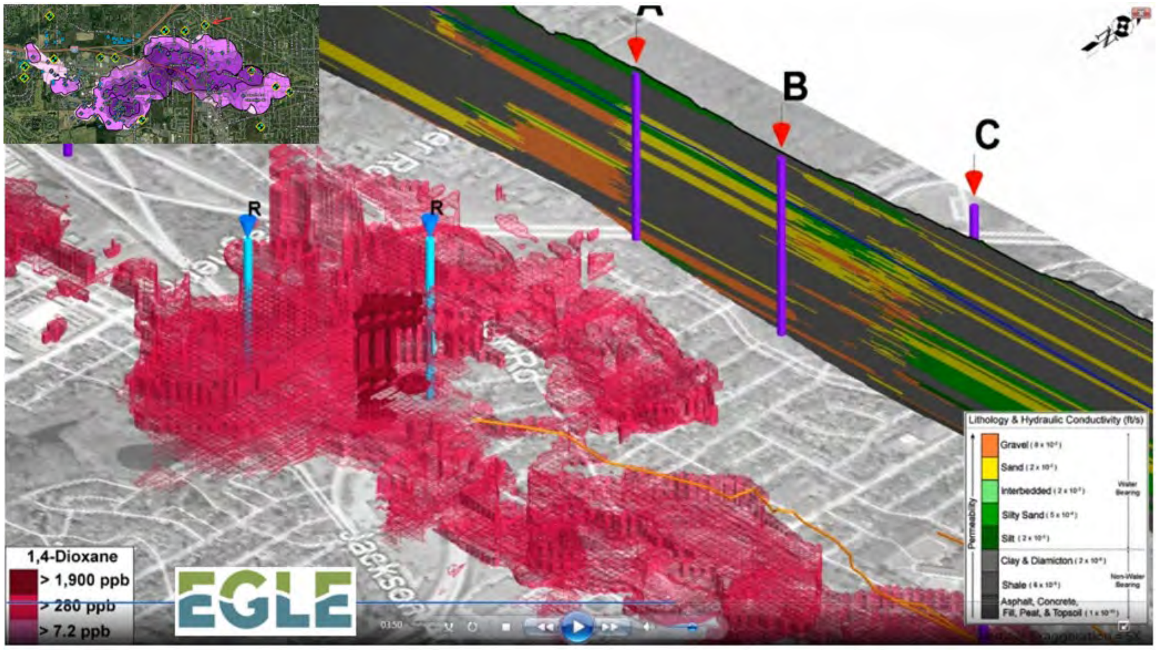


Figure 27. Proposed Monitor wells A, B, C locations and cross-section below. The red area is the area of the dioxane plume estimated above 280 ppb.

57. Proposed new monitoring wells A, B and C represent infilling between existing monitor wells along a northern line between the former Gelman facility and the northern Prohibition Zone, to monitor the extent of the dioxane plume and verify the dioxane plume is contained within the Proposed Prohibition Zone. These wells will provide more assurance that dioxane is not migrating to Barton Pond. The new well clusters along with existing well clusters represent new groundwater monitoring with wells separation at 500-700 feet and vertically monitoring up to three sand and gravel intervals for water quality and water elevations. These locations will be monitored quarterly by Gelman (four times per year). These locations could become the new sentinel wells triggered at 4.0 ug/L if the proposed 4th CJ is accepted. A

trigger of 4 ppb (below criterion of 7.2 ug/L) was included in the proposed 4th CJ. Sentinel Wells exceeding 4 ppb of dioxane will require Gelman to complete response actions and implement contingencies described in the proposed 4th CJ. The combination of new wells and lower triggers were supported by EGLE as measures to address the potential for dioxane to migrate towards Barton Pond, located approximately 2 miles from the Prohibition Zone.

58. MWs clusters 121, 129, 120, and 123 have been sampled by Gelman in over 60 sampling events, which reported between less than 1 ppb to 3 ppb. (There were spurious detections associated with laboratory errors that were not replicated.) EGLE prefers to rely on site-specific data collection over predictive models presenting a "worst case" simulation. Data verification must be demonstrated using appropriate field data. In this case, MWs clusters 120, 121, 123, 129, plus new MWs A, B and C (proposed 4th CJ), will be sampled to demonstrate compliance with the Prohibition Zone and verify dioxane is not migrating towards Baron Pond. Performance monitoring in monitoring wells vs modeling or a working hypothesis is the standard for measuring the actual behavior of the hydrogeologic system and demonstrating compliance with environmental statutes. This is consistent with the Risk Based Corrective Action (RBCA) process and ASTM guidelines state that "Predictive modeling is not to be used in the RBCA process as a substitute for site-specific verification data" (ASTM Standard E 1739-95

(2002), Appendix X3.4.3). At the compliance boundary, dioxane concentrations in groundwater should not reflect concentrations exceeding applicable compliance criteria. These Sentinel wells are located along and perpendicular to the potential migration path to Barton Pond and the northern Prohibition Zone boundary.

The need for Location D is driven by hydraulic dispersion. Dioxane moves through the aquifer as a discreet body, the dioxane plume moves laterally (expands in width) due to a phenomenon referred to as hydrodynamic dispersion. Figure 28 depicts the dioxane plume migration in the direction of the blue line pointed northeast and contour line estimating the location of the 7.2 ppb near the residential wells. The plume shown in plan view depicts the dioxane plume, however, the residential wells draw groundwater from above the elevation where the dioxane plume extent is estimated. The Location D will be useful to confirm the levels estimated by models.

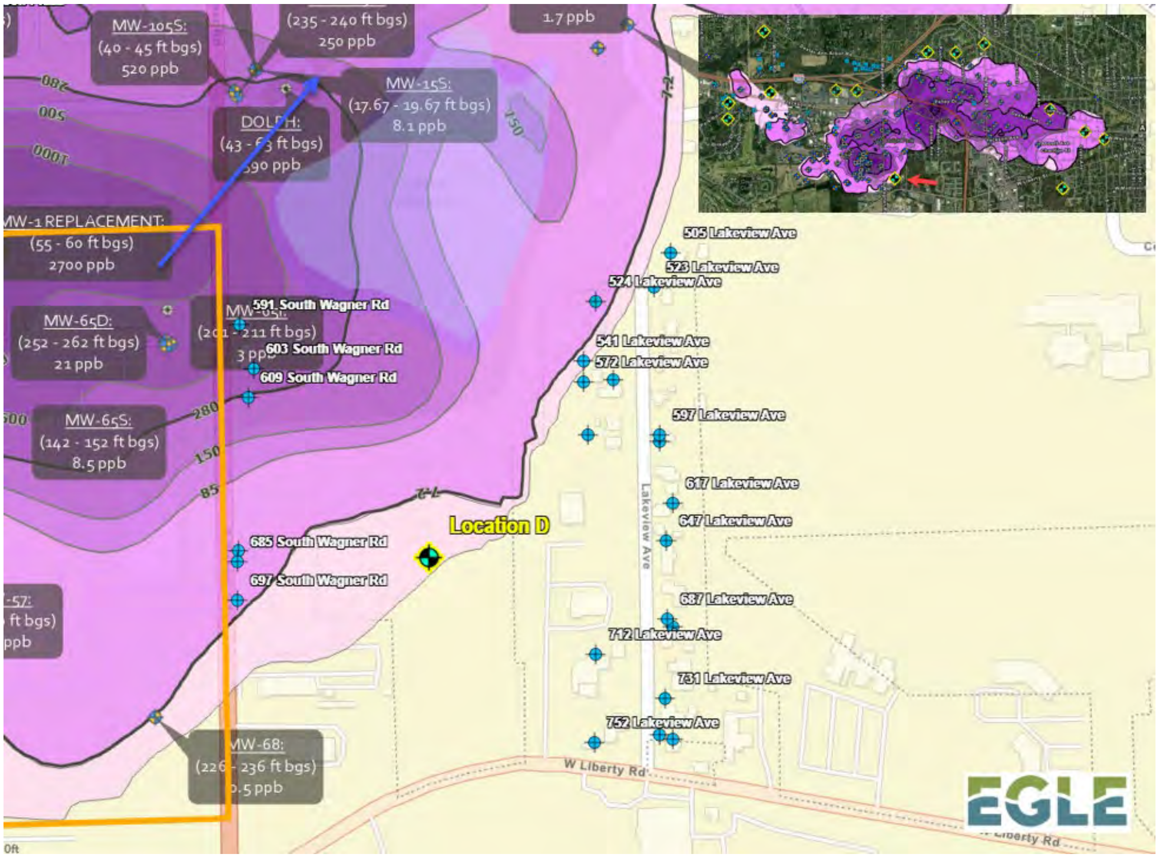


Figure 28. Plan view of the Dioxane Plume near the residential wells located along Lakeview Avenue. Blue arrow shows the direction of groundwater flow.

59. EGLE supports the installation of four additional monitoring wells E, F, G, and H in the Eastern Area to monitor dioxane in the Prohibition Zone. Monitoring well location E was located to monitor the hydraulic dispersion potential for the dioxane plume to expand laterally toward the south. Monitoring Well location E is approximately 1800 feet south of MW-112. The dioxane levels at MW-112 are increasing and currently above 7.2 ppb. Monitor well location E is anticipated to be utilized as a southern Sentential Well near the South Prohibition boundary. Figure 29 shows the location of E.

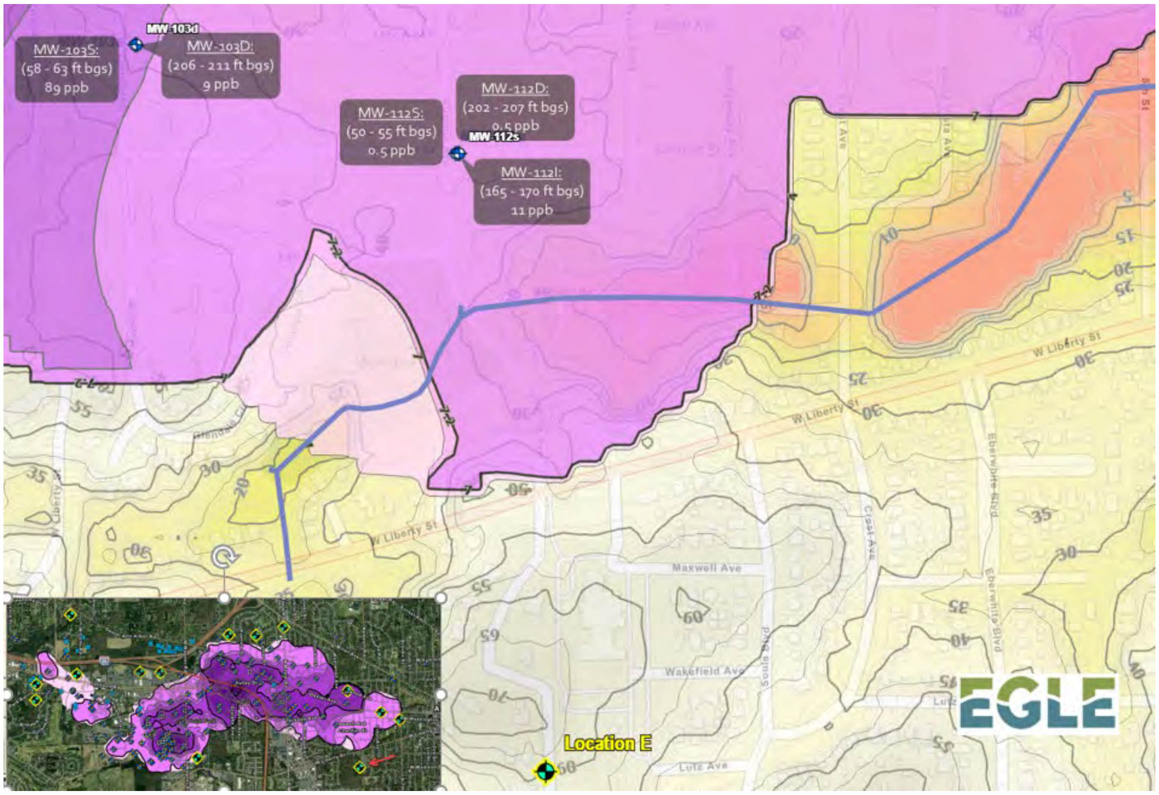


Figure 29. Location of proposed Monitor Well E. Also shown are thickness of glacial sediments to groundwater, the lower branch of the Allen Creek Drain storm sewer and the estimated location of the dioxane plume.

60. Proposed Locations F and G are dipicted in Figure 30. This area was selected to monitor the dioxane plume change in the Prohibition Zone. The dioxane plume is exhibiting a preference to align with the Allen Creek Drain and dioxane has been identifed in the Allen Creek Drain. EGLE is reviewing a Gelman work plan to investigate the Allen Creek Drain.

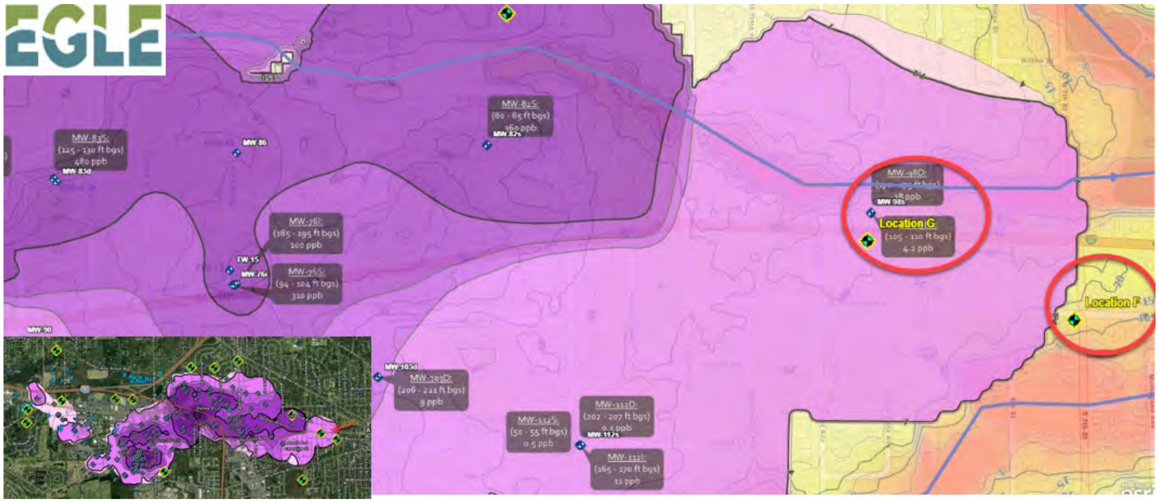


Figure 30. Proposed locations F and G.

61. EGLE supports installation of a monitoring well cluster at location H (Figure 31) for monitoring plume change in the Prohibition Zone. Location H was selected to be between the northern and middle Allen Creek Drain in an area north of MW-82.

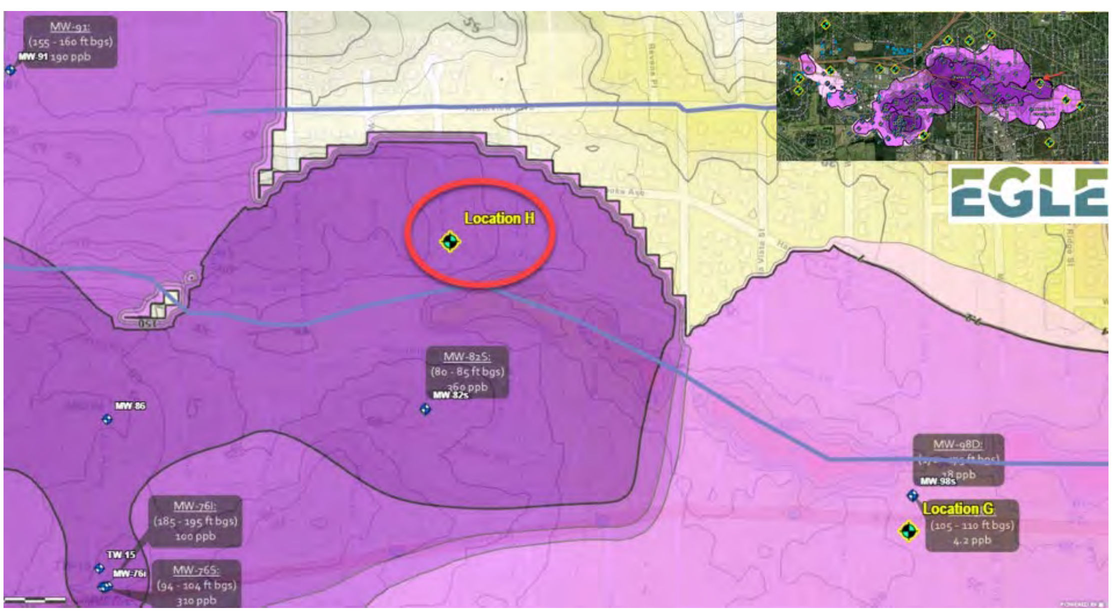


Figure 31. Proposed location H. The dioxane plume at a concentration exceeding

280 ppb is estimated to be located in the vicinty of Location H

62. EGLE supports installation of a monitoring well clusters at Locations I, J, K, L, M and N as deplicted in Figure 32. These locations are intended to address concerns of dioxane movement west and north and will be needed to establish compliance wells for the non-expansion objective for the Western Area. Locations I and J will be installed to test a suspected deep gravel unit that is not monitored, possible groundwater flow in this area and assess the lateral movement of dioxane to the north. Locations K, L, and M are located to monitor the lateral dispersion of the dioxane plume at locations between where the plume is estimated to be and residential wells. Location N is located along Honey Creek and positioned to assess the working hypothesis that the dioxane plume will continue to follow the path of Honey Creek.

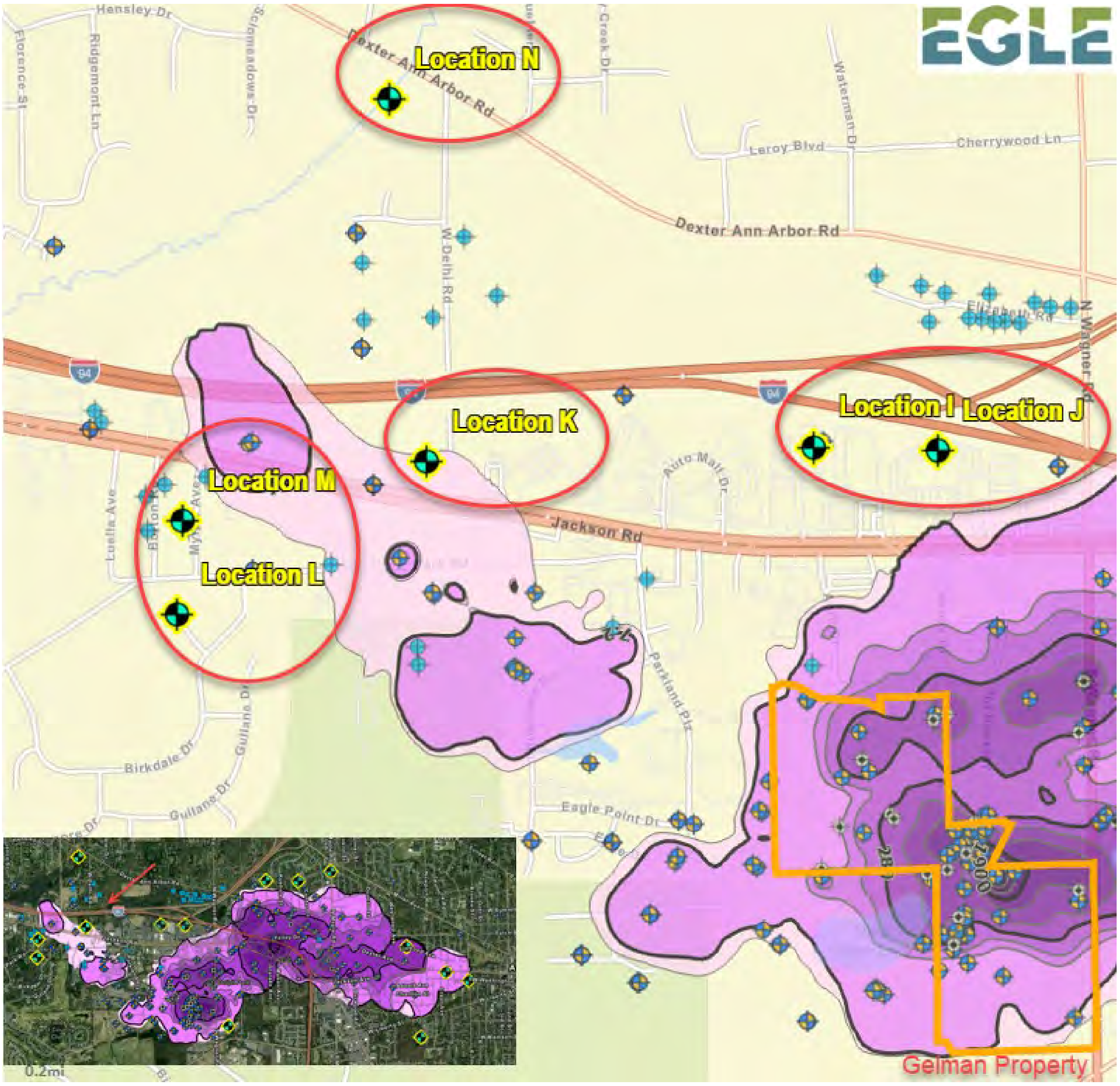


Figure 32. Locations of proposed monitoring wells I, J, K, L, M and N west of the Gelman Property.

63. EGLE supports the increased pumping proposed in the areas identified as Rose Well and Parklake Well. These areas have the most significant levels of dioxane estimated in the plume. Figure 33 depicts the locations of the Rose Well and the Parklake Well in the 2019 dioxane plume.

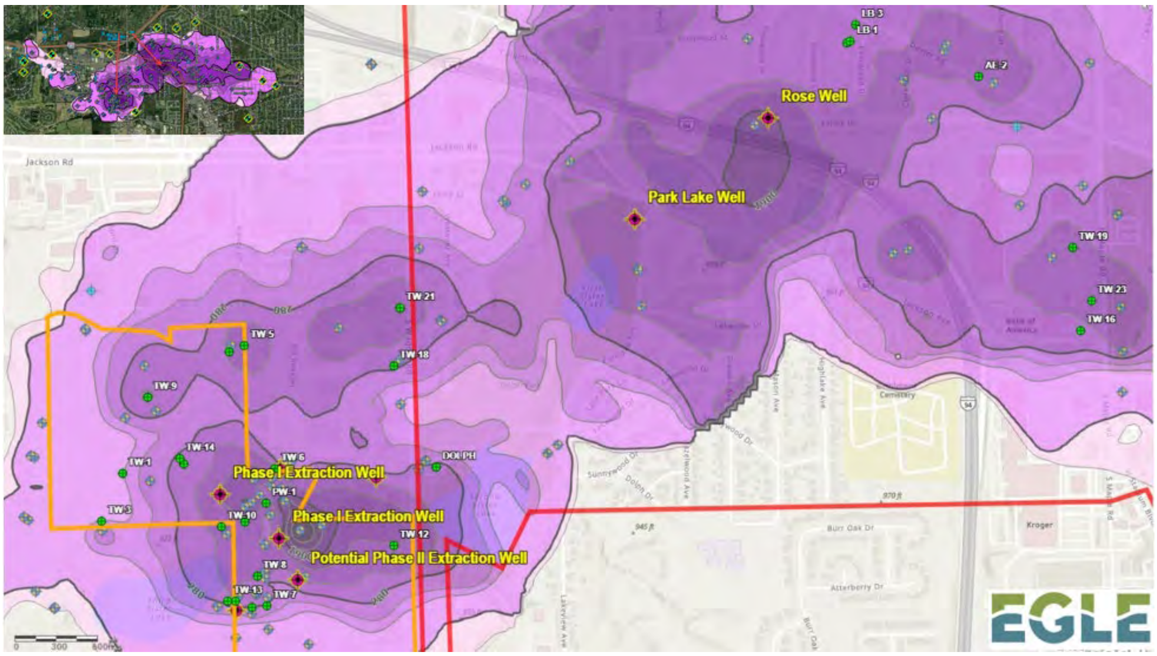


Figure 33. Locations of the Rose Well, Parklake Well and extraction well locations on the Gelman property.

Figure 34 depicts a cross section taken from the VCSM of the dioxane plume under the Gelman Property and in the vicinity of the Rose and Parklake wells. The darker shade of purple represents estimated levels greater than 500 ppb and the light purple represents estimated levels between 280 ppb and 500 ppb. The green lines represent the locations of the proposed extraction wells. These extraction wells will be installed at the depth that yields the greatest recovery of dioxane.

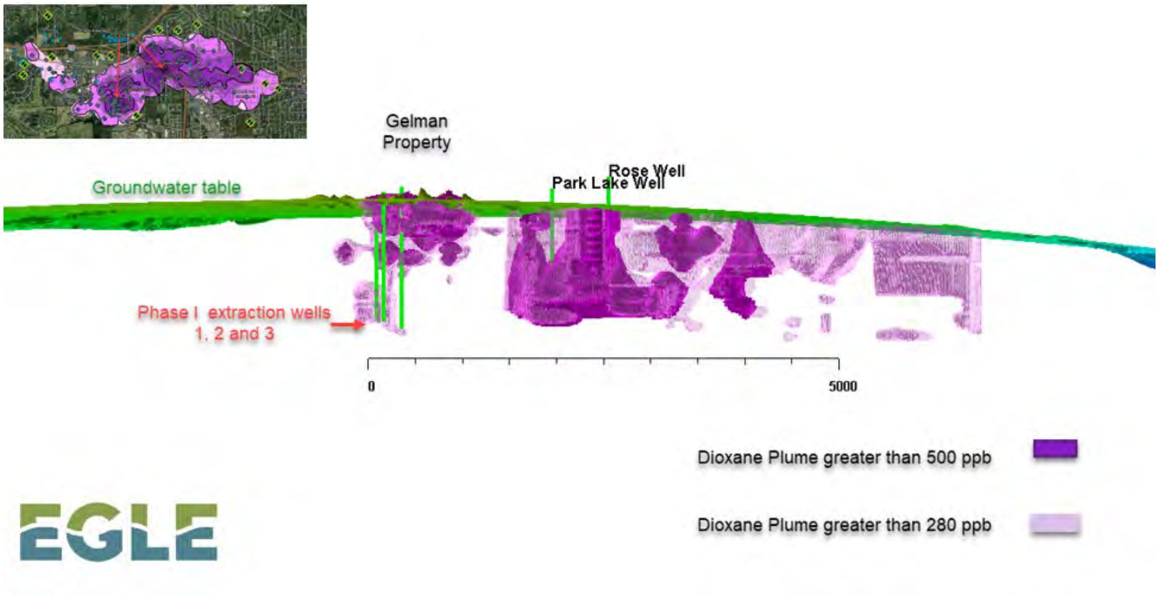


Figure 34. Vertical section looking north.

EGLE supports dioxane mass removal near Parklake. It was proposed to treat the extracted groundwater using a portable treatment system applying the same treatment process as used at the Gelman facility to mineralize the dioxane and discharge treated groundwater to First Sister Lake under a National Pollutant Discharge Elimination System (NPDES) permit. If Gelman is unable to obtain an NPDES permit, EGLE supports installing the Parklake extraction well with a lawful discharge of treated groundwater at another location.

64. In the proposed 4th CJ, Gelman agreed to install three groundwater extraction wells on the Gelman property with the plan to install three additional extraction wells to target removal of dioxane mass in the shallow groundwater. Figure 34 depicts the areas below the Gelman property that would be targeted for groundwater extraction. EGLE supports this because it

will reduce the potential hydraulic dispersion of dioxane above 7.2 ppb from reaching residential wells in the vicinity of proposed monitoring well D on Lakeview Drive. In addition, EGLE also believes the increased extraction of groundwater from the Gelman facility will reduce dioxane concentrations near Third Sister Lake and the Unnamed branch of Honey Creek. The proposed 4th CJ also requires Gelman to prepare work plans to conduct GSI investigation(s) for EGLE review comment and approval.

65. EGLE supports the heated Soil Vapor Extraction and phytoremediation proposed by Gelman. As with other remediation overseen by EGLE the proposed 4th CJ requires Gelman to prepare work plans for EGLE review, comment and approval for both activities. The details of Gelman's means and methods are better left to be decided in the work plan review vs the proposed 4th CJ.

66. The VCSM developed by the EGLE team supports the decisions in the proposed 4th CJ summarized in this report. The VCSM is useful for resolving misunderstandings. Figures 35 through 40 depict renderings of the Eastern Area/Prohibition Zone VCSM of the 2020 Gelman dioxane plume estimated to be greater than 280 ppb (purple) in Ann Arbor, Michigan.

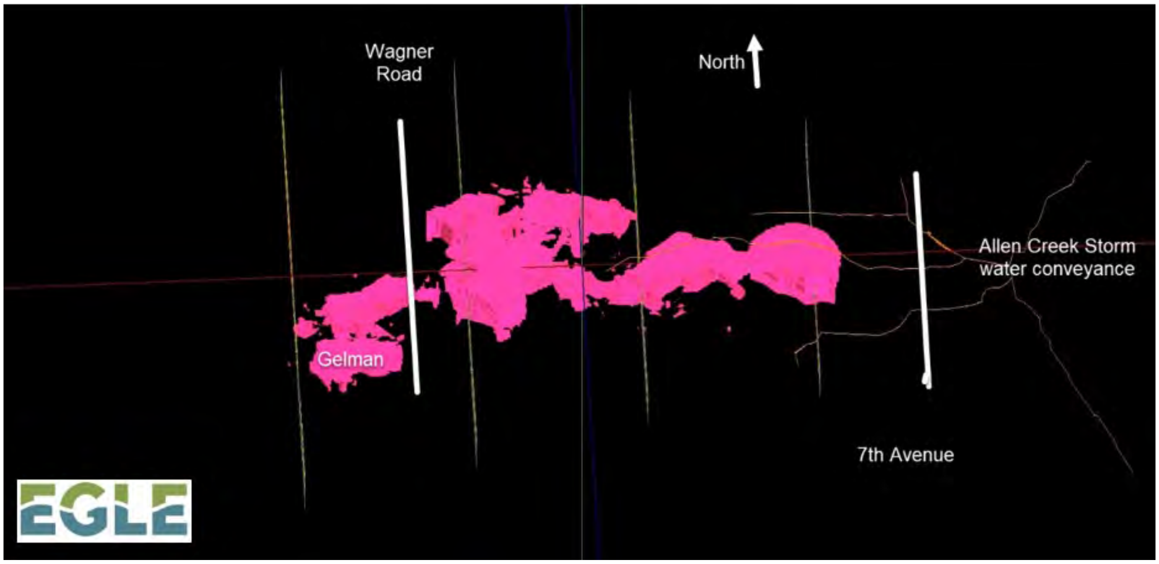


Figure 35. Looking down on the 2020 3D rendering of the dioxane plume estimated at greater than 280 ppb. Gelman, Wagner Road, 7th Avenue and Allen Creek Storm water conveyance were added for references.

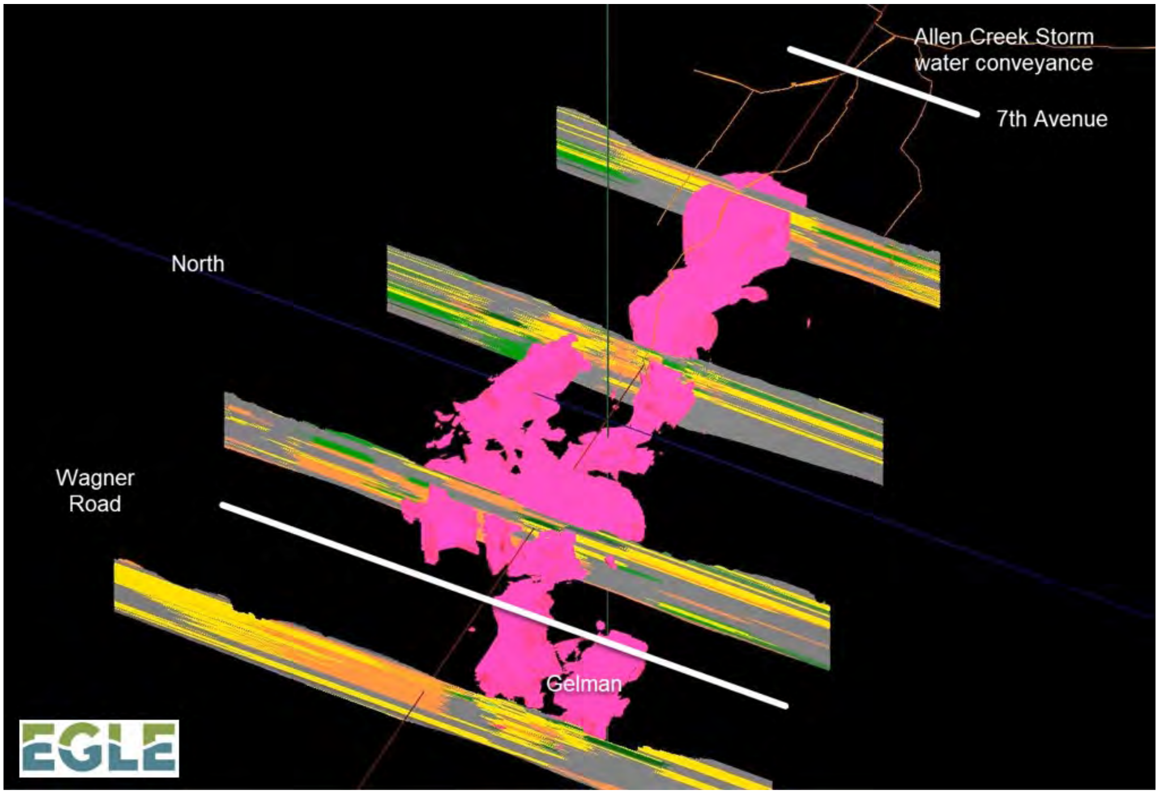


Figure 36. Looking East at the 2020 3D rendering of the dioxane plume with geology sections added to show relationship of sand and gravel depicted as yellow and orange with the dioxane plume estimated at greater than 280 ppb depicted as purple.

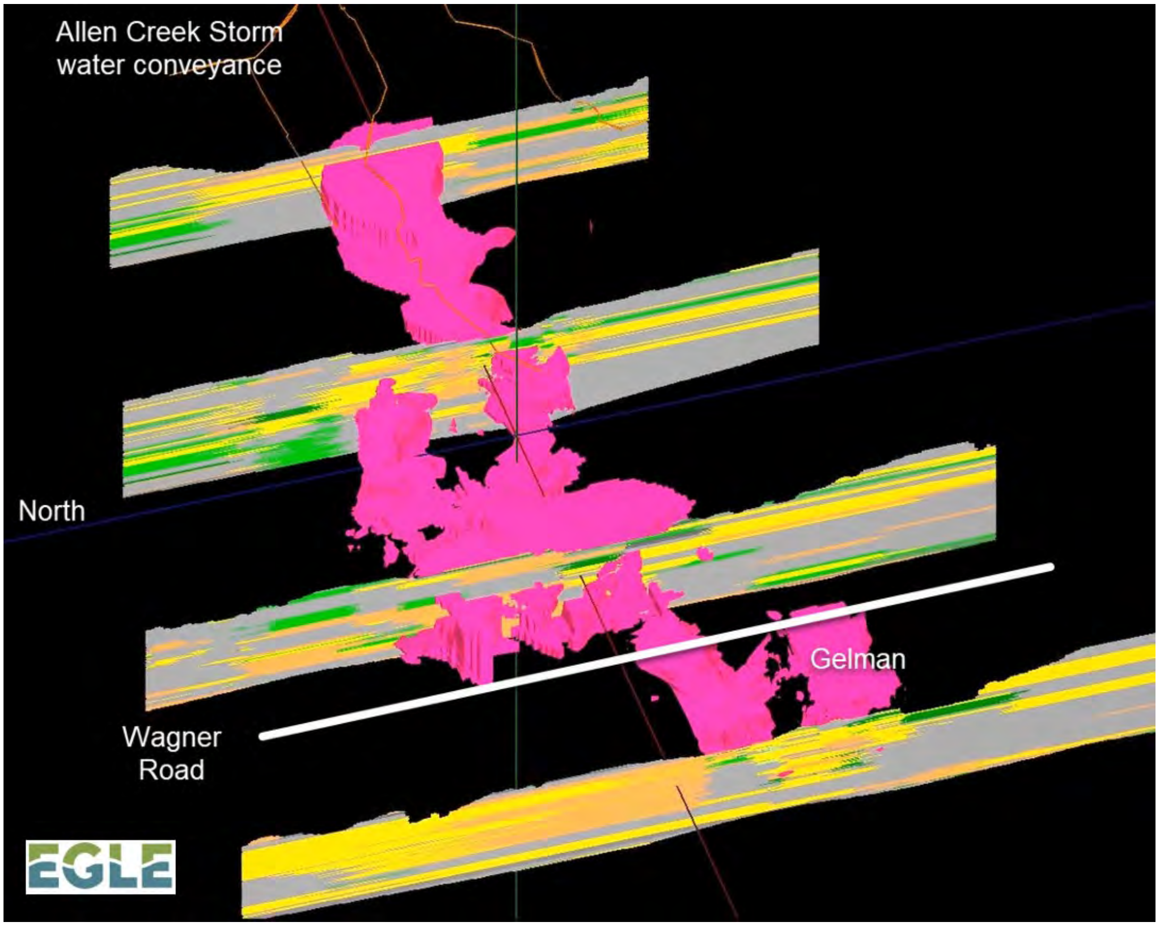


Figure 37. Looking East at 2020 3D dioxane plume, yellow and orange depict the sand and gravel while the grey depicts the clay.

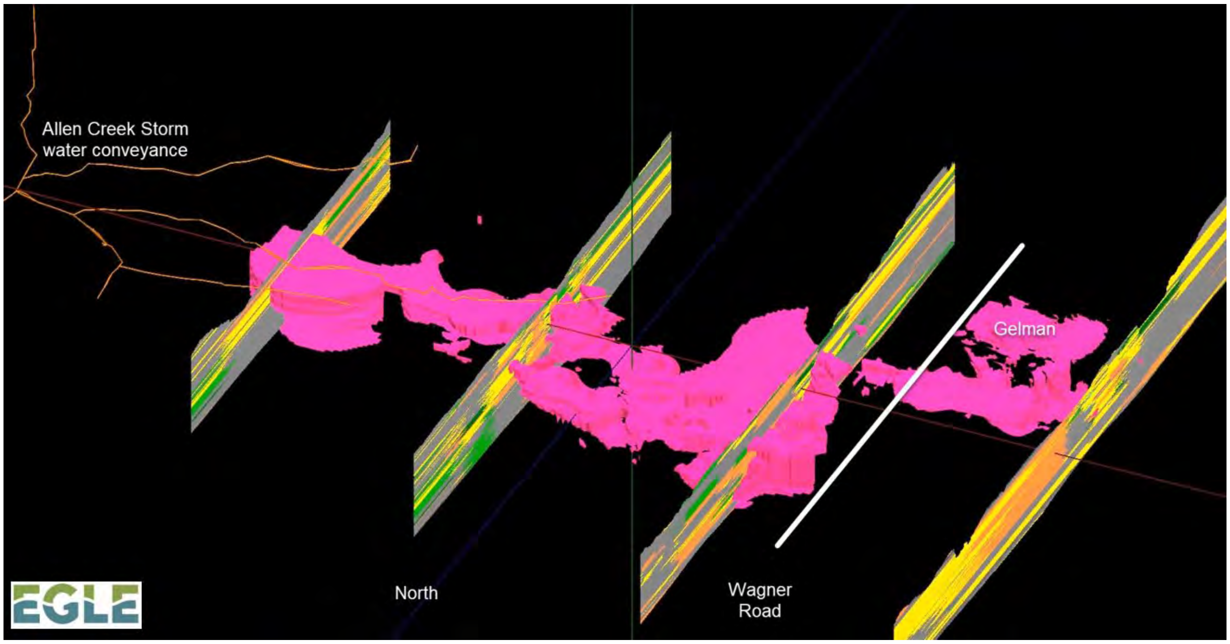


Figure 38. Looking south at 2020 3D dioxane plume

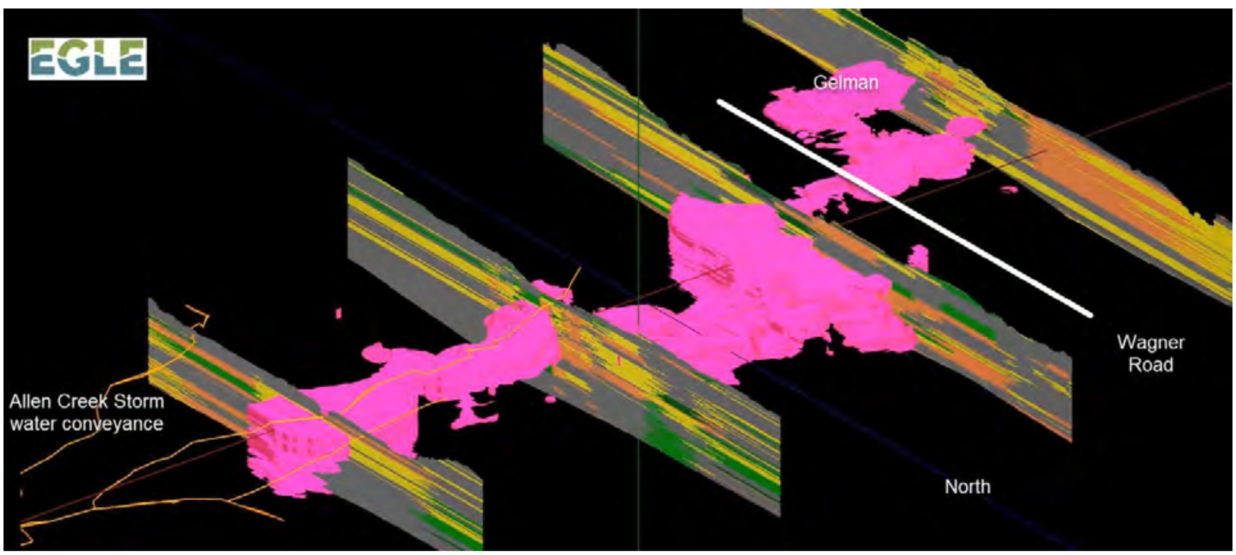


Figure 39. Looking Southwest at 2020 3D dioxane plume, the elevations of the Allen Creek branches were appoximated to depict the close association with the dioxane plume estimated to be greater than 280 ppb

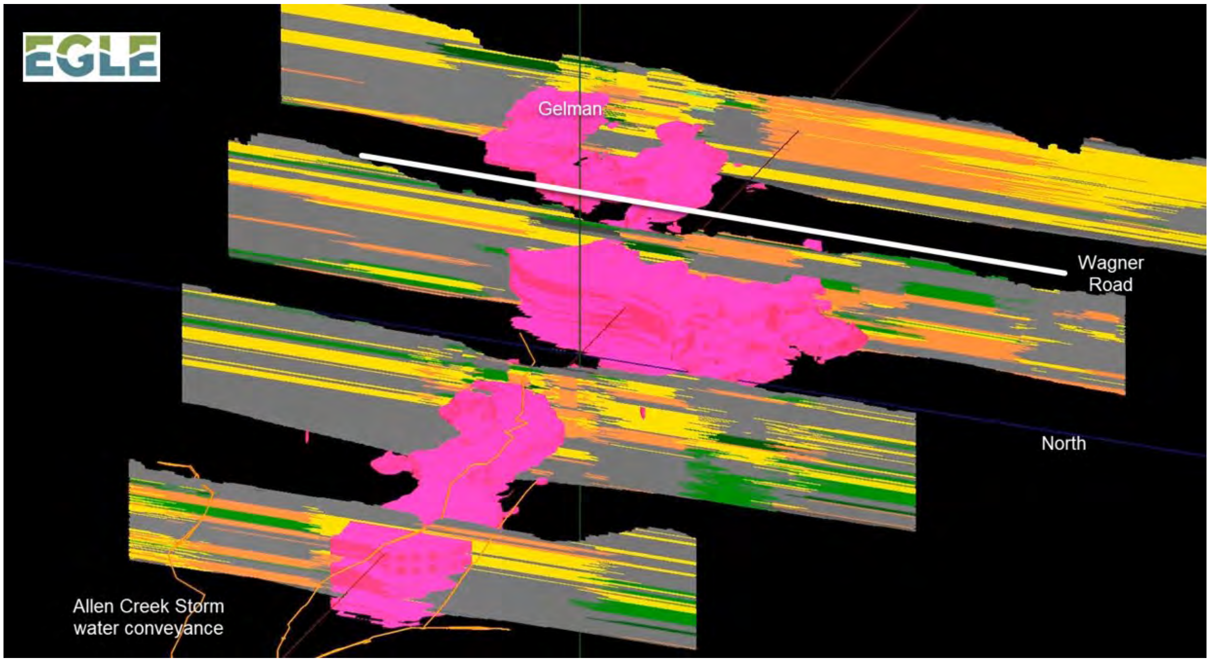


Figure 40. Looking West at the 2020 3D dioxane plume and geology

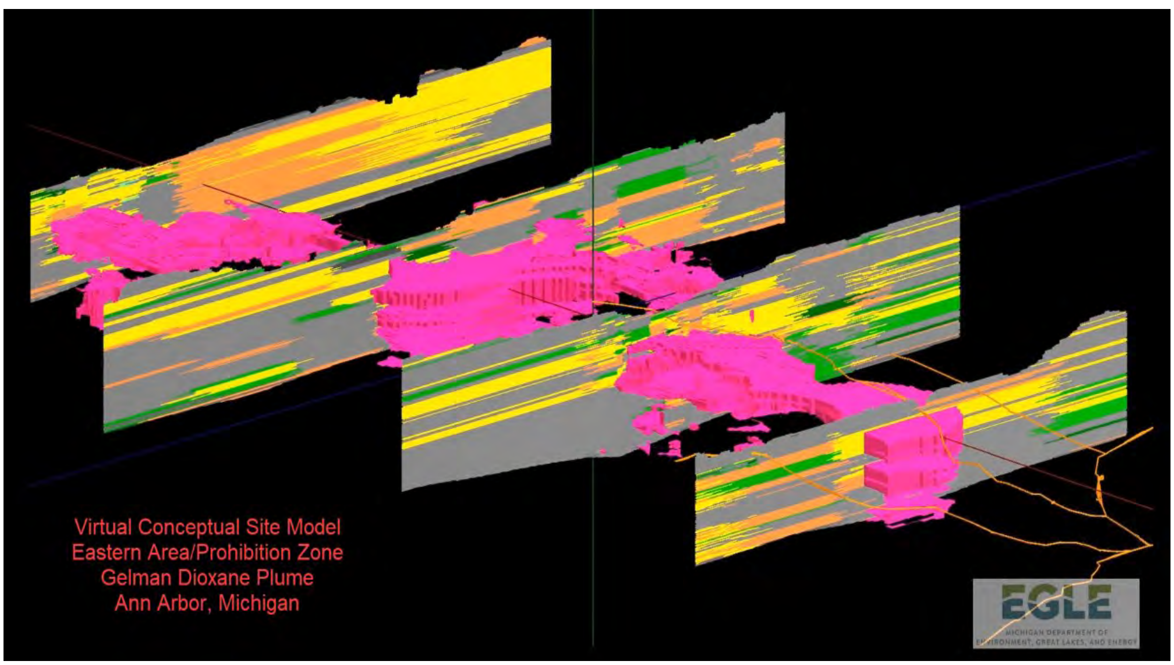


Figure 41. EGLE's 3D VCSM of the 2020 dioxane plume estimated to exceed 280 ppb is presented in pink along with the glacial geology. The Allen Creek storm sewer network is depicted in the lower right to explain a possible

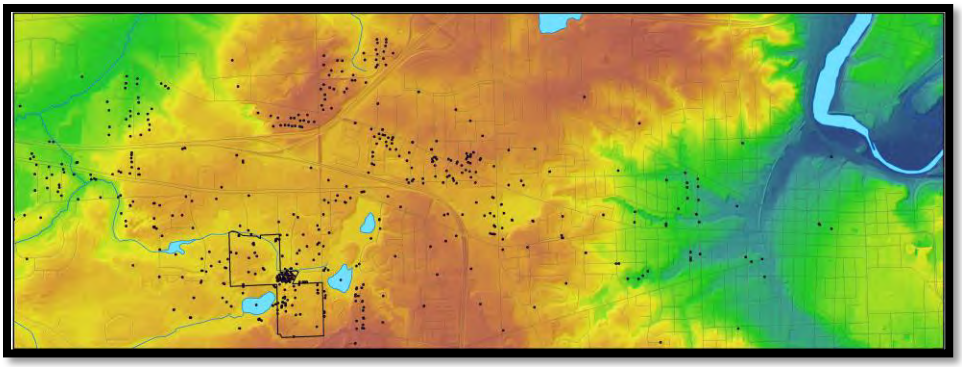
connection between the dioxane plume and the Allen Creek storm drain.

Attachment 1

Management Summary Report, RockWorks Project, April 1, 2020 by Mannik & Smith Group

DATA MANAGEMENT SUMMARY REPORT

ROCKWORKS PROJECT



APRIL 1, 2020

PREPARED FOR:
MICHIGAN DEPARTMENT OF ENVIRONMENT,
GREAT LAKES, AND ENERGY
REMEDIATION & REDEVELOPMENT DIVISION
JACKSON, MICHIGAN 49201

Mannik Smith GROUP

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<u>FIGURES</u>

<u>APPENDICES</u>

1.0 INTRODUCTION

The Mannik & Smith Group, Inc. (MSG) has been retained by the State of Michigan Department of Environment, Great Lakes, and Energy (EGLE) Remediation and Redevelopment Division (RRD) to incorporate data into a RockWorks project database and geographic information system (GIS) to allow for analysis and visualization of geologic and groundwater contaminant information. The RockWorks project consists of information from borehole logs totaling over 40,000 feet of drilling and over 24,000 separate analytical results covering several decades of work related to the 1,4–dioxane groundwater plume originating from Gelman Sciences, Inc. Site (EGLE Part 201 Facility ID 81000018).

The Site is located at 600 South Wagner Rd, Ann Arbor, Michigan 48103, in Scio Township approximately 2.75 miles west of downtown Ann Arbor, Michigan within the Huron River Watershed. *Figure 1, Project Location Map*, depicts the Site property boundary and the Project Area, which is the extent of the area modeled in the RockWorks project. The Project Area encompasses 1,4-dioxane groundwater contamination extending from the Site to the east underneath the City of Ann Arbor. Bore locations and additional Project Area features are depicted in *Figure 2, Project Features and Bore Locations.* Primary community concerns regarding the Site include potential contamination of the Ann Arbor municipal water supply (production wells and Barton Pond), potential contamination of private drinking water wells, potential contamination of Honey Creek and the Huron River, and exposure via shallow groundwater and vapor intrusion. A brief history of the Site is provided below and additional information can be found on EGLE's project website at https://www.michigan.gov/egle/0,9429,7-135-3311_4109_9846-71595--,00.html.

From 1966 to 1986, Gelman Sciences, Inc., now Pall Life Sciences (PLS), used 1,4-dioxane in the manufacture of medical filters. Various methods of disposal and waste handling during this period, including disposal in a waste pond, resulted in widespread groundwater contamination. In the fall of 1985, contamination was discovered in nearby private water supply wells. Beginning in 1986, investigations by PLS identified soil contamination on the Site and groundwater contamination extending off the property. A Consent Judgement entered in 1992 requires PLS to remediate affected groundwater with oversight conducted by RRD. Since 1997, PLS has been extracting and treating contaminated groundwater from shallow aquifers to meet the generic residential groundwater cleanup criterion for 1,4-dioxane, which at that time was 77 parts per billion (ppb) for groundwater. Treated water is discharge to an unnamed tributary to Honey Creek under a National Pollutant Discharge Elimination System (NPDES) permit. In 2001, it was discovered there was no confining layer of clay separating the shallower aquifers from a deeper aquifer (Unit E Aquifer) in an area west of the PLS property and the City of Ann Arbor shut down the city water supply well station at the corner of Montgomery Avenue and Bemidji Drive. A Unit E plume remedy was established by a Court Order entered in December 2004 and a Prohibition Zone (PZ) was established that prevents use of groundwater that is or may become contaminated with unacceptable levels of 1-4-dioxane by prohibiting certain uses of groundwater within the zone. In October 2016, the Michigan Department of Environmental Quality (MDEQ, now EGLE) found the residential drinking water cleanup criteria for 1,4-dioxane in groundwater was not protective of public health with respect to the drinking water ingestion pathway and was revised from 85 ppb to 7.2 ppb. Groundwater remediation and monitoring of the plume continues to present.

MSG's primary role on the project is to create and manage a RockWorks project database and GIS to assist EGLE with development of presentation material depicting Project Area geology and groundwater contamination. MSG retained the services of RockWare Inc. to model and produce visualizations in RockWorks, an integrated geological database, analysis, and visualization software developed by RockWare. MSG collated and consolidated data from numerous sources, reviewed the RockWorks model outputs, and modified the RockWorks project database as necessary in an iterative and collaborative fashion. RockWare produced various outputs from the model, including time-sequence animations, which are described in the *Gelman Chemical Site, Ann Arbor, Michigan 1,4-Dioxane Plume Migration Modeling & Visualization* report dated March, 2020 (RockWare, 2020). Additional output files from the RockWorks program were converted and integrated into a GIS.

This *Data Management Summary Report* summarizes the activities conducted between July 2019 and March 2020 in coordination with EGLE Jackson District (JAX) staff and RockWare staff to collate and consolidate data, develop modeling inputs, and to conduct quality control reviews of modeling outputs. To the extent possible, this work was done in general accordance with the EGLE *Guidance Document for Groundwater Modeling,* dated February 2014. It should be noted that the *Guidance Document for Groundwater Modeling* was prepared to provide guidance on the preparation and use of predictive groundwater flow models, not the lithologic and permeability models developed in this project. As a result, many aspects of the *Guidance Document for Groundwater Modeling* are not pertinent to this project.

2.0 OBJECTIVES AND SCOPE OF WORK

MSG developed project objectives and a scope of work in consultation with the State Project Manager (SPM) and District Geologist as identified in MSG's *RockWorks Site Work Plan*, dated July 2019, as augmented.

The primary objectives of the project were to:

1. Collate and consolidate datasets provided by EGLE into workable tables for import into a RockWorks project database.
2. Compile additional data specific to the Project Area for use in constraining and reviewing the RockWorks model.
3. Review and refine the RockWorks project database and associated outputs in both two dimensions (2D) and three dimensions (3D).

To fulfill the above project objectives, MSG completed the following scope of work:

1. Review data provided by EGLE.
2. Incorporate data into a Microsoft Access Relational Database Management System (RDBMS).
3. Develop tables formatted for import into a RockWorks project database.
4. Compile Project Area borehole logs and geologic cross sections.
5. Compile data for generation of three (3) model constraining surfaces (e.g., ground surface, maximum groundwater, and bedrock surface elevations).
6. Iterative quality control review of RockWorks model outputs and associated RockWorks project database.

MSG's work was done in conjunction with RockWare developing and refining the RockWorks project model. Details regarding RockWare's efforts can be found in the RockWare report (see RockWare, 2020). It should be noted that the work done on this project has been highly iterative with close coordination between MSG, EGLE, and RockWare.

3.0 DATA REVIEW

Data from several sources were provided to MSG by EGLE for review and integration into a RockWorks project database. Data were provided in several formats including a Microsoft Access (.mdb) database, Microsoft Excel (.xlsx) spreadsheets, and Adobe Portable Document Format (.pdf) files. RockWorks maintains all borehole data in an SQLite RDBMS known as the *'Borehole Manager'*, which utilizes database concepts as defined in the following excerpt from the RockWare Help Menu:

> Relational integrity: The database keeps track of records in a table that refer to records in other tables, such a stratigraphic unit for a borehole linking to the stratigraphy type table.
>
> - This prevents accidental deletions - a borehole cannot be deleted if there is data entered in any of its tables, at least not without the database asking you to confirm the deletion.
> - This also allows for data updates - if you rename a formation from "Aquifer-1" to "Upper-Aquifer", then all boreholes referencing that formation would be updated automatically.
>
> Data validation: Numerical values are checked and stored, preventing entry of alphabetic characters. Date fields (like Water Level Dates) are validated to be actual date/time values.
> (Source: https://help.RockWare.com/rockworks17/WebHelp/data_bh_database_overview.htm)

Database concepts such as *'Relational Integrity'* and *'Data Validation'* serve as fundamental requirements for utilizing data in the Borehole Manager. To ensure adherence to these fundamental requirements, data was assimilated into a

Microsoft Access RDBMS (.accdb) where database concepts could be applied and utilized. Data was then transformed and exported to spreadsheets to serve as the input files for the RockWorks project database. The following subsections provide an overview of data provided by EGLE, data standardization, and the development of a relational data structure.

3.1 Data Provided by EGLE

MSG conducted a comprehensive review of the data received from EGLE. The purpose of this task was to gain an understanding of the datasets and to identify data pertinent to the RockWorks modeling process. The content, formatting, and utility of provided source files are described as follows:

- EGLE Access Database through May 2019 - Analytical/Well Data (Received July 2019)
  Description: MS Access database with a custom user interface developed by PLS and now maintained by EGLE with new data being routinely provided by PLS.
  - File Name: *"DEQ_PLS_2018_DRH_WorkingCopy_CurrentThruMay2019Data.mdb".*
  - Contains 15 tables of data.
  - Contains Project Area data from January 1986 through May 31, 2019.
  - Total of 50,571 records.
  - Table(s) and associated field(s) of interest:
    i. Data Table: *'Well Name', '1,4-Dioxane Results (ppb)', 'Date Sampled', 'Reporting Limit', 'Static Reading'.*
    ii. Wells Table: *'Well Name', 'X CORD', 'Date Installed', 'Y CORD', 'Well Types', 'Boring Depth (Feet bgl)', 'Depth from TOC to bottom of screen (Feet)', 'TOC Elevation AMSL (Feet)', 'Bottom of Screen 1', 'Top of Screen 1', 'Screen Length (Feet)', 'Bottom of Screen 2', 'Top of Screen 2', 'Well Comments'.*

- EGLE RockWorks Excel - Bore/Well Data (Received July 2019)
  Description: Exported worksheets from a working version of a RockWorks project database developed by EGLE.
  - Filename: *"RW 17 July 9 2019 to Mannik.xlsx".*
  - Contains 33 sheets of data.
  - Contains Project Area data through February 2017.
  - Total of 37,725 records.
  - Table(s) and associated field(s) of interest:
    i. Location Table: *'Bore', 'Easting', 'Northing', 'Elevation', 'TotalDepth', 'CollarElevation', 'Comments'.*
    ii. Lithology Table: *'Bore', 'Depth1', 'Depth2', 'Keyword', 'Comment'.*
    iii. WellConstruction Table: *'Bore', 'Depth1', 'Depth2', 'Name', 'Comment'.*
    iv. Interval Table: *'Bore', 'Name', 'Depth1', 'Depth2', 'Value', 'Comment'.*
    v. TmInterval Table: *'Bore', 'Name', 'Depth1', 'Depth2', 'SampleDate', 'Value', 'Comment'.*
    vi. LithType Table: *'Name', 'GValue'.*

- Borehole Logs – (Received August 2019)
  Description: Combination of Project Area residential water supply and environmental borehole logs.
  - Files Provided:
    i. Four-hundred-thirty-seven (437) PDF files (.pdf).
       1. Included are 272 residential borehole logs from Wellogic.
    ii. Sixty-seven (67) DAT files (.dat).
    iii. Five (5) JPG files (.jpg).
    iv. One (1) Keyhole Markup language Zipped file (.kmz).
    v. One (1) Excel File (.xlsx).

- Cross Sections – (Received September 2019)
  Description: Project Area cross sections created by PLS.
  - Files Provided:
    - i. Thirty-three (33) PDF files (.pdf).
      1. Included are 32 cross sections and one (1) Master Cross Section location Map.

- Horizontal-to-Vertical Spectral Ratio (HVSR) Seismic Points – (Received September 2019)
  Description: Project Area seismic interpolation points (SIPs) for bedrock elevations.
  - Filename: *HVSR_W_ANN_ARBOR.pptx*
    - i. Two (2) Powerpoint Slides (.pptx).
      1. Included are 19 calibration readings and 29 exploration readings.

- Fleis and VandenBrink (F&V) *Shallow Groundwater Investigation Report*, dated October 2016 (Received November 2020):
  Description: Project Area investigation conducted by Fleis and VandenBrink.
  - Filename: *"deq-rrd-GS-GelmanShallowGWReport_538157_7.pdf".*
  - Contains 227 pages.
  - Contains Project Area data from investigation fieldwork conducted by F&V between August 8, 2016 and August 17, 2016.
  - Contains 26 borehole logs.
  - Contains 35 samples (including duplicate samples) with associated 1,4-dioxane analytical results.

- EGLE Access Database through December 2019 - Analytical Data (Received January 2020):
  Description: An updated version of the EGLE Access database containing PLS data described above appended with more recent analytical results. Downloaded from EGLE Gelman project website.
  - Filename: *"DEQ_PLS_2018_DRH_WorkingCopy_CurrentThruDec2019Data.mdb".*
  - Contains 15 tables of data.
  - Contains Project Area data through the December 31, 2019.
  - 1,008 additional records (ie. June 1, 2019, through December 31, 2019).

3.2 Data Standardization

A fundamental requirement for establishing a proper relational data structure is relational integrity. This is acquired through creating a common field with unique records known as the primary key through which tables are joined. The RockWorks program identifies the primary key as *'Borehole Name'*. Following the initial review process of the EGLE Access Database and EGLE RockWorks Excel worksheets, MSG determined that the bore/well fields contained naming inconsistencies (i.e. 752 Rose and 752 Rose Dr). In order to correct these inconsistencies and establish a primary key field, bore/well names were standardized for each bore/well location. In addition to correcting these inconsistencies, borehole original IDs were maintained in a new field so the records could be traced back to the original sources.

Data validation is another fundamental concept for relational data structures which controls that each field has one and only one data type. Example data types include *'short text'*, *'integer', 'double number'* and *'date/time'*. Data was standardized to conform to the data type of each intended field. For example, short text analytical results, such as "nd", were provided in the EGLE Access database but RockWorks requires analytical values to be numeric, so one-half the reporting limit value was used instead. Data validation rules also refers to whether or not an entry can be blank or 'null'. Records within numeric fields that cannot be null, such as northing, easting, and depth intervals, were replaced with the placeholder value of -9999 to allow for data entry. These values were excluded from the modeling algorithms. The benefit of adding the placeholder value to the database is that it allows for easy identification of records that may need to be updated as more information becomes available.

3.3 Development of a Relational Data Structure

Following the standardization process, data was incorporated into a Microsoft Access RDBMS. Queries with one-to-many relationships were leveraged for efficient identification of data discrepancies within and between data sources, including, but not limited to, duplicates, mismatched data types, non-numeric analytical values, 'null' sample dates, missing lithology, and missing screen intervals. Discrepancies were documented and presented to EGLE for feedback and revisions.

4.0 ROCKWORKS IMPORT TABLES

Following the comprehensive review of the available data described in Section 3, tables were created in Microsoft Access by populating information from the various sources and exporting to the following five (5) tables in the RockWorks input file format:

- Location
- WellConstruction
- Lithology
- TmInterval
- Water Level

Each table contained at a minimum the RockWorks standard fields required by the program for data input. Additional non-RockWorks standard fields were added for the purpose of tracking the original data source for individual records. After the initial model run and review, data were appended or revised as necessary and reloaded into the RockWorks project database. The following sub-sections describe the format and primary sources of the RockWorks input files.

4.1 Location Table

The Location input table contains spatial and depth information for each borehole. The field named *'Bore'* is the primary key which contains the standardized borehole name as described in Section 3.2. Referential integrity is maintained because associated records cannot be loaded into the system if a location is not defined. Furthermore, the primary key is required to be unique, which means there cannot be any ambiguous or many-to-many joins. The fields and data type of each field of the Location input table are shown below in Table 4.1.1.

Table 4.1.1
RockWorks Location Table

Field Name	Data Type	Description	Example Record
Bore	Short Text	Contains the Standardized Borehole Name	MW-135
Easting	Short Text	Referencing US State Plane 1983 (NAD83 Conus)	13284522.66
Northing	Short Text	Referencing US State Plane 1983 (NAD83 Conus)	289341.88
Elevation	Number	Ground surface elevation at boring XY location	964.5693
TotalDepth	Number	Total depth of the boring in feet	299
CollarElevation	Number	Elevation of top of casing	964.52
Edit_Date	Date	Contains data data was revised	8/13/2019
Edit_By	Short Text	Contains editor	1st import by MSG
Comments	Short Text	Comments	
Welltypes	Short Text	Contains well type	Monitoring Wells
Welltypes_orginal	Short Text	Contains well type original	Monitoring Wells
Note	Short Text	Note	
Xysource	Short Text	Source Dataset for XY	DEQ_PLS_2018_DRH_WorkingCopy_CurrentThruMay2019Data.mdb
Elevationsource	Short Text	Source Dataset for Elevation	SEMCOG 2019 LiDAR
Totaldepthsource	Short Text	Source Dataset for TotalDepth	DEQ_PLS_2018_DRH_WorkingCopy_CurrentThruMay2019Data.mdb
Collarelevationsource	Short Text	Source Dataset for CollarElevation	DEQ_PLS_2018_DRH_WorkingCopy_CurrentThruMay2019Data.mdb

Standard RockWorks Fields
Non-Standard RockWorks Fields

Each bore was assigned a value in the '*Well Types*' field which was initially sourced from the '*Well Types*' field located in the Wells table of the EGLE Access database. Locations were assigned to one of the following types:

- Extraction Wells
- Horizontal Wells
- Injection Wells
- Monitoring Wells
- Residential Wells
- Seismic Interpretation Point
- Surface Water
- Test Boring
- other

Locations identified as "Miscellaneous" were reassigned to the most appropriate category or "other" category. Locations identified as "Treatment System", or "Not Applicable" were not included. Locations without associated 1,4-dioxane results and lithology records were also excluded from being loaded into RockWorks.

All northings and eastings were entered as international feet referenced to the State Plane Coordinate System, Michigan South Zone (2113), NAD83 datum. The primary source for the coordinates was the EGLE Access database. These coordinate pairs were compared to the values provided in the EGLE RockWorks Excel Location table. A list of mismatching coordinate pairs were compiled in a spreadsheet and converted to a .kml format for viewing in Google Earth. Both formats were provided to EGLE for review and determination as to which coordinate pairs should be utilized in the RockWorks project database. Northing and easting values of -9999 were assigned for bores without coordinates that contained either a valid 1,4-dioxane or lithology record. Bores with assigned -9999 coordinate pairs were subsequently excluded from the model algorithms.

The *PLS May 2015 Monitoring Well Base Map* was downloaded from the EGLE project website as a PDF file, converted to an image file, georectifed using common reference points, and brought into a GIS. This layer was used during review for updating questionable coordinate values and to digitize bores that were lacking coordinates. For reference, the source of the coordinate pairs for each bore was recorded in the non-standard RockWorks field called *'XY Source'*. If a residential well was missing coordinates values, locations were typically not updated since the lithology data was typically not of the same quality as the environmental borehole logs produced by geologists.

Ground elevations were initially loaded using ground elevations as provided in the Wells table of the EGLE Access database. Ground elevations from the Southeastern Michigan Council of Governments (SEMCOG) LIDAR bare earth Digital Elevation Model (DEM) dated March, 2019 described in Section 5.3 were extracted at each location point and compared to the EGLE Access database value. A large number of discrepancies were identified resulting in a determination that DEM elevations should be utilized universally for each bore location.

Collar elevations, also known as top of casing (TOC), is the elevation of the top of the well casing from which the depth to static water is measured and used to calculate static groundwater elevations. Collar elevations were predominantly sourced from the EGLE Access database and supplemented by values provided in the EGLE RockWorks Excel Location table. For each bore location, differences between the LIDAR bare-earth DEM (SEMCOG, 2019) elevations and collar elevations were calculated in order to identify abnormal collar elevations (ie. greater than 4 feet above the ground and greater than 1 foot below ground). Bores with abnormal collar elevations were subsequently reviewed against the borehole log well construction diagram if available and revised accordingly.

4.2 WellConstruction Table

The WellConstruction table contains information including standardized borehole name, depth to top of screen interval, depth to bottom of screen interval, casing diameters, well types and associated comments. The format utilized for the WellConstruction table is outlined in Table 4.2.1:

Table 4.2.1
RockWorks WellConstruction Table

Field Name	Data Type	Description	Example Record
Bore	Short Text	Contains the Standardized Borehole Name	MW-94D
Bore Original	Short Text	Contains the Original Borehole Name	MW-94D
Offset	Number		0.5
Depth1	Number	Contains the top depth of a screen interval	215
Depth2	Number	Contains the bottom depth of a screen interval	220
Screen Interval Source	Short Text	Source Dataset for Screen Interval	RW 17 July 9 2019 to Mannik
Diameter1	Number	Contains diameter of casing	2
Diameter2	Number	Contains diameter of casing	2
Name	Short Text	Contains well type (ie. residential, extraction)	E
Comment	Short Text	Comment	MW-94D

Standard RockWorks Fields
Non-Standard RockWorks Files

Similar to the Location input table, non-standard RockWorks fields referencing the source of the information were added. The initial source for all well construction information were the EGLE RockWorks Excel worksheets. After the initial model run, review was conducted and the RockWorks project database inputs were revised per associated borehole log well construction diagrams if available.

4.3 Lithology Table

The Lithology table contains information including standardized borehole name, depth to top of lithology interval, depth to bottom of lithology interval, lithology keywords, and associated comments which are the fuller lithology description from the associated borehole log. The format utilized for the Lithology table is outlined in Table 4.3.1.

Table 4.3.1
RockWorks Lithology Table

Field Name	Data Type	Description	Example Record
Bore	Short Text	Contains the Standardized Borehole Name	MW-8s
Bore Original	Short Text	Contains the Original Borehole Name	MW-08S
Depth1	Number	Contains the top depth of a lithology interval as measured below ground surface (bgs).	16
Depth2	Number	Contains the bottom depth of a lithology interval as measured below ground surface (bgs).	23
Keyword	Short Text	Lithology keyword (ie. Sand, Diamicton). Converted to G-value and utilized in modeling algorithms.	Gravel
Comment	Short Text	Comment	Gravel, very fine to very coarse; Sand, med to very coarse; some Silt and Clay; saturated, brown

Standard RockWorks Fields
Non-Standard RockWorks Files

The lithology source for the initial model run was solely from the EGLE provided RockWorks Excel worksheet named "Lithology". After reviewing the cross sections generated from the model, a more in depth review of the input against the borehole logs was conducted resulting in an updated RockWorks project database. This review is described in greater detail within Section 6.

4.4 TmInterval Table

The TmInterval table within RockWorks stores time-based interval data, or specifically in this case 1,4-dioxane concentrations with the intervals being the screen depth interval of the sample and the time component being the sample date. The fields and format of the input table utilized is outlined in Table 4.4.1:

Table 4.4.1
RockWorks TmInterval Table

Field Name	Data Type	Description	Example Record
Bore	Short Text	Contains the Standardized Borehole/Well Name	MW-2d
Well Name Original	Short Text	Contains the Original Well Name	MW-2d
Well Types	Short Text	Contains well type	Monitoring Wells
Depth1	Number	Contains the combined top depth of screen interval	50.5
Depth2	Number	Contains the combined bottom depth of screen interval	53.5
Screen Interval Source	Short Text	Source dataset of screen interval	DEQ_PLS_2018_DRH_WorkingCopy_CurrentThruMay2019Data.mdb
Sample ID	Short Text	Sample ID .	67573
SampleDate	Date/Time	Date sample was collected	11/30/2015
Name	Short Text	Name of analytical parameter (ie. 1,4-Dioxane)	1-4 Dioxane
Value	Number	Standardized analytical value (ppb)	35
Original 1,4-Dioxane Results (ppb)	Short Text	Original analytical value (ppb)	35
Detected	Short Text	Yes/No detected field	Yes
Comments	Short Text	Comments	
Aquifer	Short Text	Aquifer name	C3

Standard RockWorks Fields
Non-Standard RockWorks Files

The initial source for 1,4-dioxane results was from the Data table located in the EGLE Access database. This table contained the following fields of note: '*Sample ID', 'Well Name', '1,4-Dioxane Results (ppb)', 'Date Sampled',* and *'Reporting Limit'.* The dataset was reduced by not including surface water or treatment system related sample results (for example, effluent samples) and all records with null (blank) 1,4-dioxane results or null sample dates.

Records from the '*1,4-Dioxane Results (ppb)*' field were used to populate the *'Value'* field in the RockWorks TmInterval input table with the associated standardized Bore name. Since the EGLE Access database stored the results in a text field, all entries with a non-numeric character needed to be converted to number format. Non-numeric values included the following: "nd", "NSP", less than symbol (<) followed by a number and "See Comments". Entries with "nd" were replaced with one half the value in the *'Report Limit'* field. It was determined that "NSP" was the code for "no sample" and was therefore excluded. Entries with "<" were updated by removing the "<" and multiplying the remaining number by one half. Entries with "See Comments" were reviewed further and ultimately excluded.

Values of *'Depth1'* and *'Depth2'* fields were populated by joining the standardized *'Bore'* field to the WellConstruction and Location tables and populating Depth1 by subtracting the well screen top depth from the ground surface elevation and Depth2 by subtracting the bottom well screen depth from the ground surface for each bore location.

Additional non-standard RockWorks fields were added for quality control purposes. Since the value entries were altered by changing from text to numeric, a text field was added to retain the original unaltered value. A yes/no field named *'Detected'* was also added indicating if the result was a positive detection or non-detected. The *'Sampleid'* field, which contains a unique record number for each sample in the EGLE Access database Data table, was also transferred into the RockWorks project database. The aquifer unit was populated from the Wells table of the EGLE Access database for reference but was not utilized in the modeling effort.

4.5 Water Level Table

The Water Level table contains fields including *'Borehole Name', 'Well Type', 'Sample Date', 'Static_Reading_from_TOC' and 'Aquifer'*. Sources include the EGLE Access database. The format used for the Water Level table is outlined in Table 4.5.1:

Table 4.5.1
RockWorks Water Level Table

Field Name	Data Type	Description	Example Record
Borehole Name	Short Text	Contains the Standardized Borehole/Well Name	MW-65d
Well Type	Short Text	Contains well type	MW-65d
Sample Date	Short Text	Date sample was collected	Monitoring Wells
Static_Reading_from_TOC	Number	Contains reading from top of casing	252
Aquifer	Number	Contains the combined bottom depth of screen interval	262

Standard RockWorks Fields

Because RockWorks requires a Depth to Top and Depth to Base be entered for each record, the value in the '*Static_Reading_from_TOC'* was used for both.

5.0 PROJECT AREA CHARACTERIZATION

The Project Area was characterized by compiling data from several different sources. Borehole logs and cross sections were provided to MSG by EGLE and subsequently reviewed to identify data pertinent to the modeling effort. Data was also compiled with the intention of creating three (3) constraining surfaces for different aspects of the model. The LIDAR bare-earth DEM (SEMCOG, 2019) was acquired for the purposes of defining the ground surface. Maximum groundwater elevations were compiled to create a surface for constraining the upper bounds of the 1,4-dioxane contaminant plume. Bedrock elevations were compiled to truncate the lower bounds of the model provided. Hydraulic conductivities were associated with lithologies for subsequent generation of a permeable/non-permeable model depicting potential groundwater pathways. The following subsections describe these processes within greater detail.

5.1 Compiling Borehole Logs

Files containing information related to Project Area geologic borehole logs and well construction diagrams were provided to MSG by EGLE. A total of 437 PDF files, 67 DAT files, five (5) JPG files, one (1) KMZ, and one (1) Excel file were provided. Included in these records were 272 residential water supply borehole logs from Wellogic. MSG organized files by extracting individual borehole logs contained in multi-log PDFs, renaming each file to match the log name, and removing duplicates. An additional 26 bore logs were obtained from the *Shallow Groundwater Investigation Report* (F&V, 2016) and saved to the file directory. Borehole logs were utilized for lithology data and analytical intervals, if available. For reference, see *Figure 3, Lithology and Plume Model Borehole Locations.*

5.2 Compiling Cross Sections

A total of 32 select cross sections produced by PLS consultants and published in various reports were provided to MSG by EGLE. A Master Cross Section Location Map was also provided as a PDF file for reference. The cross section location map was georectified in a GIS using common reference points, such as monitor well locations, as control points and the pertinent cross-sections lines were digitized for further reference. For reference, see *Figure 4, Cross Section Locations*.

5.3 SEMCOG 2019 Topographic LIDAR Data

In order to establish a RockWorks modeling ground surface, the LIDAR bare-earth DEM (SEMCOG, 2019) was utilized in RockWorks. MSG requested the March, 2019 LIDAR data for Washtenaw County directly from SEMCOG. In partnership with the State of Michigan, high density LIDAR data was captured in the spring or fall of 2017-2018, while no snow was on the ground, rivers were at or below normal levels, and which meets

United States Geological Survey (USGS) specifications for Quality Level 2 (QL2). SEMCOG then created a hydro-flattened bare earth DEM from the QL2 LIDAR data in 2500 x 2500 feet grids in IMG (.img) format with 2-foot cells. Grids covering the Project Area and just beyond were selected and mosaicked by MSG into a single GeoTIFF file retaining the original resolution and transferred to RockWare for incorporation into RockWorks. For reference, see *Figure 5, SEMCOG 2019 DEM and Ground Elevation Contours.*

5.4 Maximum Groundwater Elevation Surface

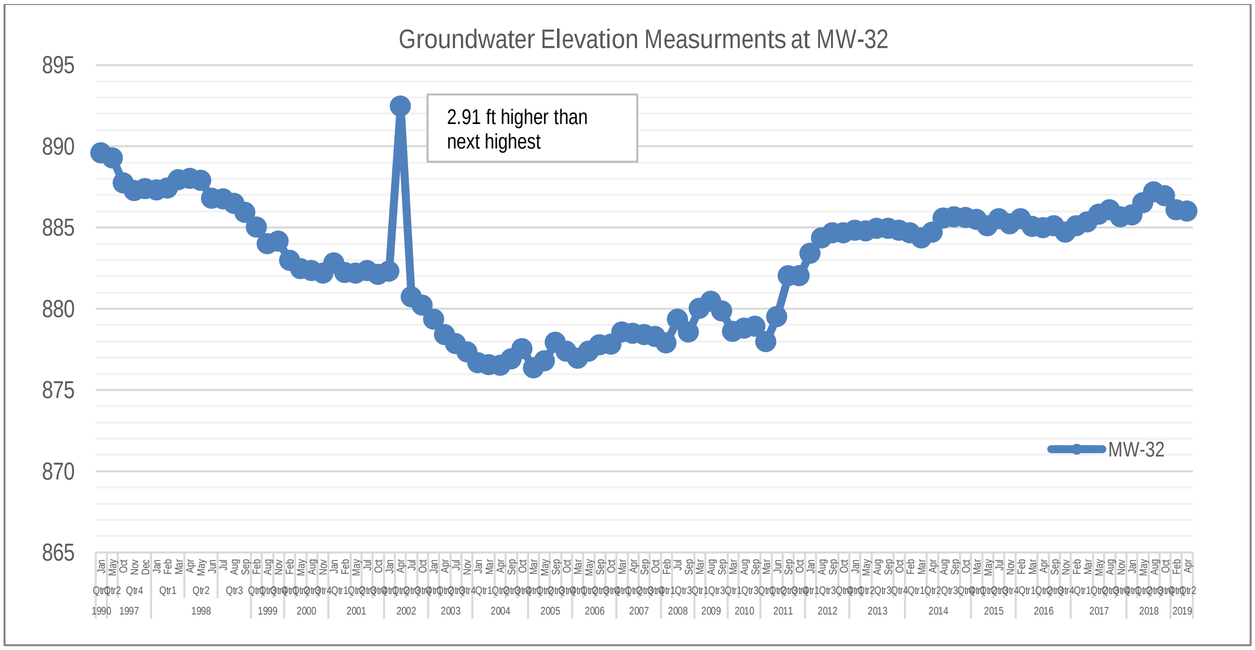
Maximum static water elevations from each well were compiled from each well location for the purpose of creating a constraining surface for the upper bound of the 1,4-dioxane contaminant plume. Groundwater elevations were calculated by subtracting the measured depth to static groundwater from the TOC elevation for each well. To ensure that anomalously high elevation data points were not included, the difference between the maximum water elevation and the second highest water elevation at each well was calculated. The differences ranged from 0 to 59.25 ft. Twenty-three (23) locations had differences of greater than 2 feet and are listed in Table 5.4.1.

Table 5.4.1
Maximum Groundwater Elevation Surface

Bore	Measurement Date	Groundwater Elevation (feet)	Well Type	Groundwater Elevation Difference to Next Highest Measurement
MW-68	5/16/2017	943.86	Monitoring Wells	59.25
MW-129d	3/31/2014	908.76	Monitoring Wells	34.27
AE-1	6/27/2002	899.79	Extraction Wells	32.3
MW-14d	9/1/1995	907.64	Monitoring Wells	27.53
MW-12d	7/2/2002	915.68	Monitoring Wells	25.4
LB-3	7/31/2013	895.28	Extraction Wells	25.22
MW-139s	12/22/2014	877.67	Monitoring Wells	18.74
TW-18	1/10/2006	873.14	Extraction Wells	18.53
MW-108d	11/26/2013	895.35	Monitoring Wells	17.86
MW-10d	6/22/1994	900.66	Monitoring Wells	13.43
MW-25s	1/7/2002	915.22	Monitoring Wells	11.59
MW-75	10/16/2018	896.73	Monitoring Wells	9.65
MW-21	9/17/1996	893.42	Monitoring Wells	8.77
AE-3	2/16/2009	869.25	Extraction Wells	7.8
MW-41d	5/26/1993	875.55	Monitoring Wells	5.79
MW-86	11/25/2003	858.96	Monitoring Wells	5.43
MW-KD-1d	3/14/2001	879.66	Monitoring Wells	4.81
MW-33	7/2/2002	892.08	Monitoring Wells	3.98
MW-64	5/21/2001	884.61	Monitoring Wells	3.81
MW-63i	4/2/2003	889.85	Monitoring Wells	3.46
MW-32	4/4/2002	892.47	Monitoring Wells	2.91
4401 Park East	1/19/2001	884.3	Residential Wells	2.7
MW-26	6/9/2011	908.84	Monitoring Wells	2.54

Time-series graphs were then plotted for each of the 23 wells for further review. An example is shown as Figure 5.4.1.

Figure 5.4.1
Groundwater Elevation Measurements at MW-32



MSG determined that all maximum readings from the 23 wells listed in Table 5.4.1 were anomalous and removed them as input into the surface generation. These readings were replaced by the next highest reading. MSG also determined that all measurements from extraction wells should be excluded as input for the surface generation due to their effects on the water table. It should also be noted that because this surface is being used as a boundary for the model and the measurements utilized span several decades, it should not be used for determination of groundwater flow direction. This surface can also be used as a representation for how close the water table and hence the 1,4-dioxane plume may be to the ground surface at a given location.

5.5 Bedrock Elevations

Bedrock elevations were compiled for the Project Area for the purpose of creating a constraining surface for the lower bound of the 1,4-dioxane contaminant plume. For the purposes of this model, bedrock shale was characterized as an impermeable confining layer from which the lower bounds of the model were truncated. Bedrock elevation data consists of top of shale elevations acquired from Project Area borehole logs and supplemented by EGLE HVSR data points.

Top of shale elevations were acquired from borehole logs that contained shale at their terminus. Elevations were calculated by subtracting total depth to shale from the ground surface elevation at that borehole. Maps containing HVSR data were provided to MSG by EGLE in the form of PowerPoint slides (.pptx). Maps were georeferenced utilizing calibration points with known borehole locations as control points. Exploratory points were subsequently digitized and given a unique identifier (ie. SIP-1 through SIP-29). Elevations to bedrock for each location were calculated by subtracting "Drift Thickness" as presented in "*HVSR_W_ANN_ARBOR.pptx*" from ground surface elevations derived from the LIDAR bare-earth DEM (SEMCOG, 2019).

5.6 Permeable/Non-Permeable Hydraulic Conductivity Cutoff Value

Hydraulic conductivities were established for each lithology included with the RockWorks import tables. These values were utilized in the generation of a Permeable/Non-Permeable model. Lithologies with assigned hydraulic conductivity values of greater than or equal to 0.00002 feet per second (ft/s) were defined as permeable (i.e., Gravel, Sand, Interbedded, Silty Sand, and Silt). Lithologies with assigned hydraulic conductivity values of less than 0.00002 ft/s were defined as impermeable (i.e., Clay, Diamicton, and Shale). It is important to note that assigning hydraulic conductivities to lithologies was not to model groundwater flow but rather to model potential groundwater pathways.

6.0 QUALITY CONTROL REVIEW OF ROCKWORKS DATASET

As one method of evaluating the RockWorks 3D lithology model, MSG conducted a 3-step assessment of the data and results using cross sections and original borehole logs. The first step was to compare borehole logs represented in the model's cross sections with the original borehole logs to ensure the lithologies were properly encoded. The second step was to review the correlations between boreholes developed by the model. The second step was generally done immediately after the first step during the review of each model cross section. The third step was to compare the model's cross sections with those developed by hand by previous consultants. Side by side comparison between model cross sections and hand-drawn cross sections may be viewed in *Appendix A, Cross Section Comparisons.*

6.1 Initial Review

To obtain cross sections for review, MSG requested RockWare to develop selected cross sections using the 3D Lithology solid model. Cross section locations were chosen based on the availability of hand-drawn cross sections prepared by previous consultants. Each model cross section was created using the same boreholes as the original hand-drawn cross section. In a few cases, additional boreholes were included in the model cross section because they were located on or adjacent to the line of the cross section. To simplify tracking, each model cross section was given the same name as the hand-drawn cross section, with the style and coloring allowing ready distinction between the two.

During the first step, MSG compared the lithology of each borehole log in the selected cross sections with the original borehole log. Discrepancies between the two logs were marked on a paper copy of the model cross section and recorded in a spreadsheet. Each entry in the spreadsheet was recorded by cross section and borehole and included a comment stating the specific issue and a check box for the general category of problem. The general categories of noted problems are summarized in Table 6.1.1.

Table 6.1.1
General Categories of Lithologic Discrepancies

Category	Description
Layers	An issue with individual layers (coding, interpretation of lithologic description, lens, etc.).
No Log	No boring log was available for comparison.
RockWorks Log Incorrect	Entire or a majority of the boring log in the model was incorrect.
Shale	The Coldwater Shale (bedrock) was not coded or correlated properly.
Correlation	Correlation between borings was incorrect or a differing lithology was immediately adjacent to a layer in the boring log.
Other	A discrepancy not covered by the categories above.

Typical *'Layers'* discrepancies included lithologic units that were miscoded in the RockWorks project database (e.g., a silt coded as a sand) and different terminologies between the borehole log and the model. The most common difference was a unit labeled as "till" on the borehole log being coded as "clay" instead of "diamicton". Except for such obvious differences, the lithologic description from the borehole log was entered "as-is" into the model database. As a result, Sand and Gravel units are distinguished as separate units even though the difference is often clearly due to the different descriptions between two geologists. Likewise, most of the clay and diamicton units on an individual cross section are likely the same.

The *'RockWorks Log Incorrect'* category covered cases where most or all of the model log differed from the borehole log. Typically, a borehole log was misnamed in the model.

During the first run of the model, correlations of "glacial" sediments below the top of the Coldwater Shale (bedrock) occurred. The *'Shale'* category primarily covered these instances. As described in the RockWare report and Section 5.5 above, a lower boundary surface was created at the top of the shale, which solved most of the *'Shale'* category problems.

The *'Correlation'* category covered odd correlations between boreholes or a differing lithology immediately adjacent to the borehole. The odd correlations were greatly reduced after the model layers were updated by correcting lithology keyword entries in the database and by changing the lithology model node spacing.

6.2 Lithology Keyword Standardization

Following an initial review of the lithology model output cross sections, it became apparent that lithology data within the datasets maintained numerous intricacies throughout. These intricacies appeared in the form of distinct transitions between input striplog lithology and interpolated lithology. As a result, a further comparison between RockWorks lithology input data and associated borehole logs was conducted beyond just those boreholes that appeared on cross sections. Additionally, unique lithologies were consolidated by lithology keywords as represented in Table 6.2.1.

Table 6.2.1
Keyword Naming Convention

Keyword	Unique Lithology Examples
Gravel	Sand and Gravel
Peat	PEAT/MARL: Organic Fibrous
Sand	GRAVELLY SAND: Sand, medium to coarse grained; Gravel; trace Clay stringers. Brown, very dense, wet.
Silt	CLAYEY SILT: Silt; Clay (20%); Sand, fine grained (30%); Gravel, fine (10%). Grayish brown, poorly sorted, stiff, dry.
	Sandy Silt: Silt (70%); Sand, fine grained (30%). Brown, well sorted, stiff, floury, dry.
	SILT WITH CLAY
Silty Sand	SANDY SILT: Silt (60%); Sand (30%) fine grained. Grayish brown with traces of clay, moist.
	SILTY SAND: Silt (60%); Sand, fine to coarse (60/20/20) (30%); Clay (10%); low plasticity, loose, organic matter, brown.
	SAND and SILT: fine sand, saturated, grayish brown, loose to medium dense. Upper - more sand; lower - more silt.
	SILTY, CLAYEY, SAND: Sand, fine to coarse (50/30/20) (30%), moderately sorted; Silt (40%); Clay (10%); moderate plasticity, organics, moist, green-gray. -Sand, fine to coarse (50/30/20) (60%), moderately sorted; Silt (30%); Clay (trace); wet, lt. gray.

Table 6.2.1
Keyword Naming Convention (cont.)

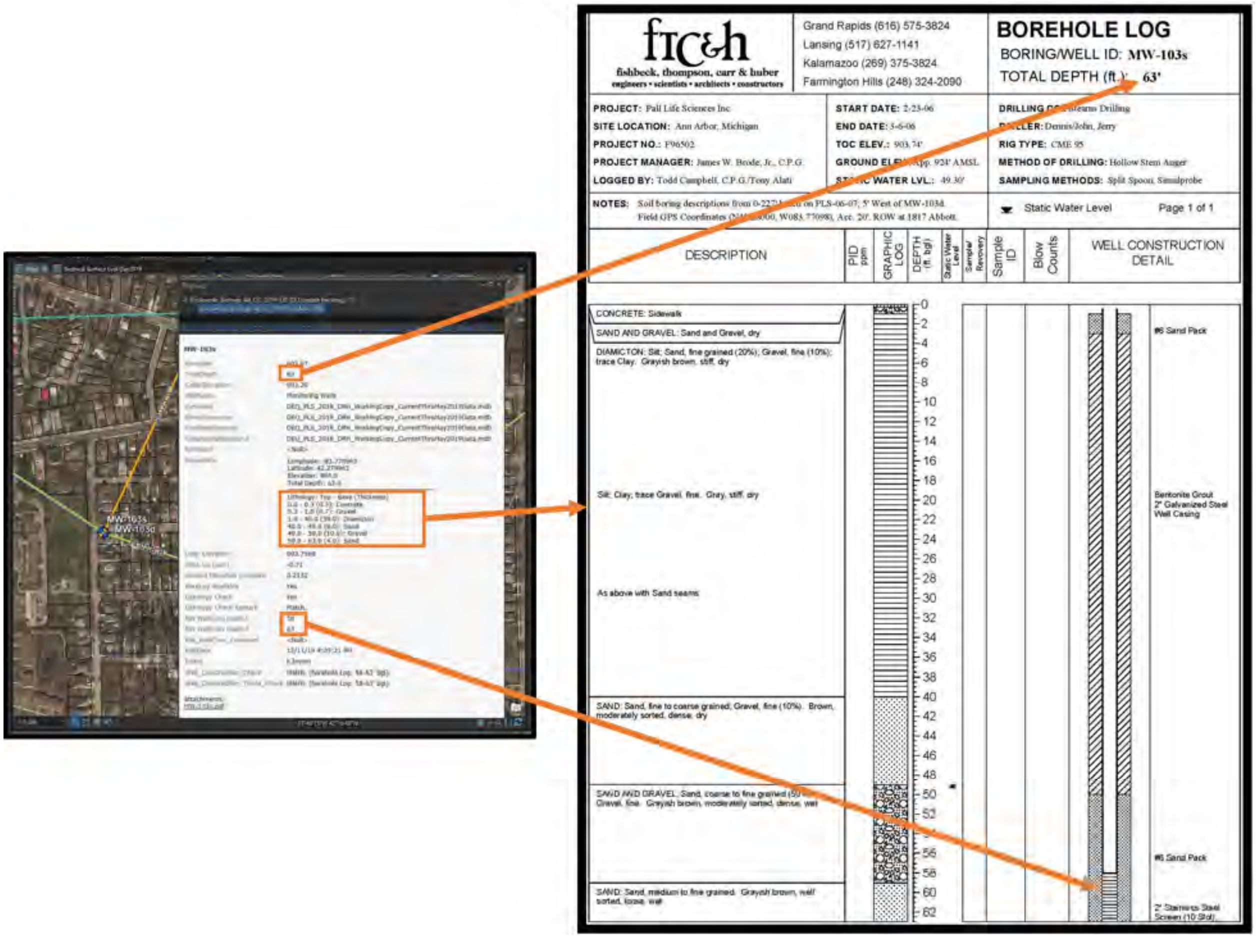
Keyword	Unique Lithology Examples
Clay	CLAY AND GRAVEL
	CLAYEY SAND: very fine grained sand, saturated, grey.
	Clay Sandy with Gravel. Brown
	CLAY AND SILT
	Clay; Silty; brown, soft
	SILTY CLAY W/ GRAVEL: low plasticity, poorly sorted gravel, stiff, slightly moist, grey, increasing sand & moisture content w/ depth.
	Clay Silt, Reddish brown, cohesive, pebbles/granules slow drilling to approximately 12' bgl. High drilling pressures from 21-22' bgl.
	Clay with Silt. Grayish Brown
	SAND AND CLAY
	SANDY CLAY TO CLAYEY SAND: Clay; Silt; Sand, fine to medium grained. Brown, dry.
	Clay; Silt; Sand, fine grained; Gravel, fine. Brown, stiff, dry.
	SANDY SILTY CLAY: Increasing Sand/Silt/Clay with Depth, Brown, Moist | SANDY SILTY CLAY: Brown, Moist to Saturated
	SILTY/CLAY matrix with abundant SAND (f-c), med. Gray, thick milkshake texture, coarsening at base.
	Silt with Clay
Diamicton	Clay Silt 20%;trace Sand medium to coarse dry,
	CLAY/SILT/SAND/GRAVEL, massive texture, brown.
	Diamicton, Silty Clay matrix, floating Sand Grains/Gravel.
	GRAVEL/SAND/SILT/CLAY
	Silty Clay matrix; fine to very coarse Sand fraction; some Gravel; light brown, hard, friable,
	Till; silty clay matrix, fine-very coarse and fraction and gravel, gray, hard, dry.

6.3 RockWorks Project Database Revisions

Efforts to revise the RockWorks project database were initially focused on correcting the errors that were identified from the cross-section review described in Section 6.1 and Section 6.2. First, boreholes that were present on the Gelman cross-sections but not present in the RockWorks project database were added. If available, corresponding borehole logs were referenced directly for lithology interval data to input into the RockWorks project database. If a borehole log was not available, lithology interval data was acquired by referencing the Gelman cross sections directly. Vertical scaling and lithology legends assisted with efficient transposition of the data. Missing borehole locations were supplemented using a digitized 2015 Fleis&Vandenbrink Site Map acquired from the file “deq-rrd-GS-PLSMWBaseMapMay2015_491423_7.pdf” which was downloaded from the EGLE’s project website. Elevations for the known borehole locations were supplemented using the LIDAR bare-earth DEM (March, 2019).

This was followed by a comprehensive review of all lithology keywords, lithology intervals, bore depths, and screen interval data to ensure all were properly entered. Data was exported out of the RockWorks project database and into a GIS, where a pop-up was configured to show the values in list-form when a bore was selected. Available borehole logs were also attached to this layer making reviewing the values side-by-side convenient as seen in Figure 6.3.1.

Figure 6.3.1
GIS Comparison of RockWorks Project Database and Borehole Logs



The reviewer was able to indicate locations that needed further review or changes. After changes were made in the RockWorks project database, the associated GIS layer was updated, and locations with changes were checked again until the process was complete.

6.4 Secondary Review

After the first review of the model cross sections was completed, the model database was corrected to the extent possible. No additional borehole logs were provided, so issues related to the *'No Log'* category could not be fixed. RockWare recreated the model cross sections using the updated model, including additional borehole logs when appropriate. Each updated model cross section was then rechecked and each comment evaluated as to whether it had been resolved. Qualitatively, the updated model cross sections were greatly improved over the originals.

The updated model cross sections were then compared to the hand-drawn cross sections. In several cases, the hand-drawn cross sections were based on natural gamma radiation logs where the rationale for the correlations was not obvious. In these cases, no comparisons were made.

When the hand-drawn cross sections were based on lithologies, comparisons with the updated model cross sections were done. Comparisons were rated on a qualitative scale because the hand-drawn and model cross sections were prepared for different purposes and so exact measurement of differences is not possible. The following rankings were used to describe the correspondence between the hand-drawn and model cross sections:

- Good – Lithologic correlations generally agree between the hand-drawn and model cross sections, subject to differences based on the different purposes.
- Fair – The general pattern of correlation generally agrees between the hand-drawn and model cross sections, but details and/or grouping of lithologies differ. Many of these differences dealt with correlations of thinner layers between boreholes.
- Poor – Little agreement between hand-drawn and model cross sections.

Some of the common differences between the hand-drawn and model cross sections are:

- Hand-drawn cross sections focused on aquifer and aquitard units.
- Hand-drawn cross sections are stylized (straight lines and sharp corners).
- Hand-drawn cross sections are generalized, with thinner layers often ignored.
- The vertical exaggeration for hand-drawn cross sections was approximately twice that of model cross sections, resulting in much thicker units.
- Layers within the upper portion of several hand-drawn cross sections were not correlated, sometimes being labeled "Undifferentiated".
- Model cross sections often had lithologic units appearing between boreholes based on the 3D nature of the model.

MSG qualitatively compared a total of 32 cross sections for differences between the hand-drawn and model cross sections. Four (4) hand-drawn cross sections were based on gamma logs and were therefore excluded from further review, leaving 28 cross sections for comparison. A total of 16 cross sections were rated as "Fair" for similarity and 12 cross sections were rated as "Good". No cross sections were rated "Poor" for similarity. Cross sections that compared as "Good" generally had a few of the common differences listed above. Cross sections that compared as "Fair" for similarity generally had more of the common differences or, in a few cases, a single larger difference in correlation. Given the different purposes of the hand-drawn and model cross sections, MSG believes the similarities between the cross sections are minor overall and the model cross sections are acceptable.

When differences in interpretation were identified, each cross section was examined in more detail to try to identify the cause(s) of the differences. Typical causes for differences include description of the individual units, lumping of similar lithologies, and generalization of the borehole logs (i.e., ignoring thinner lithologic units) in the hand-drawn cross sections. Another cause of discrepancies was the model correlating units within the "Undifferentiated" portion of hand-drawn cross sections with units below the "Undifferentiated" portion.

7.0 SUMMARY

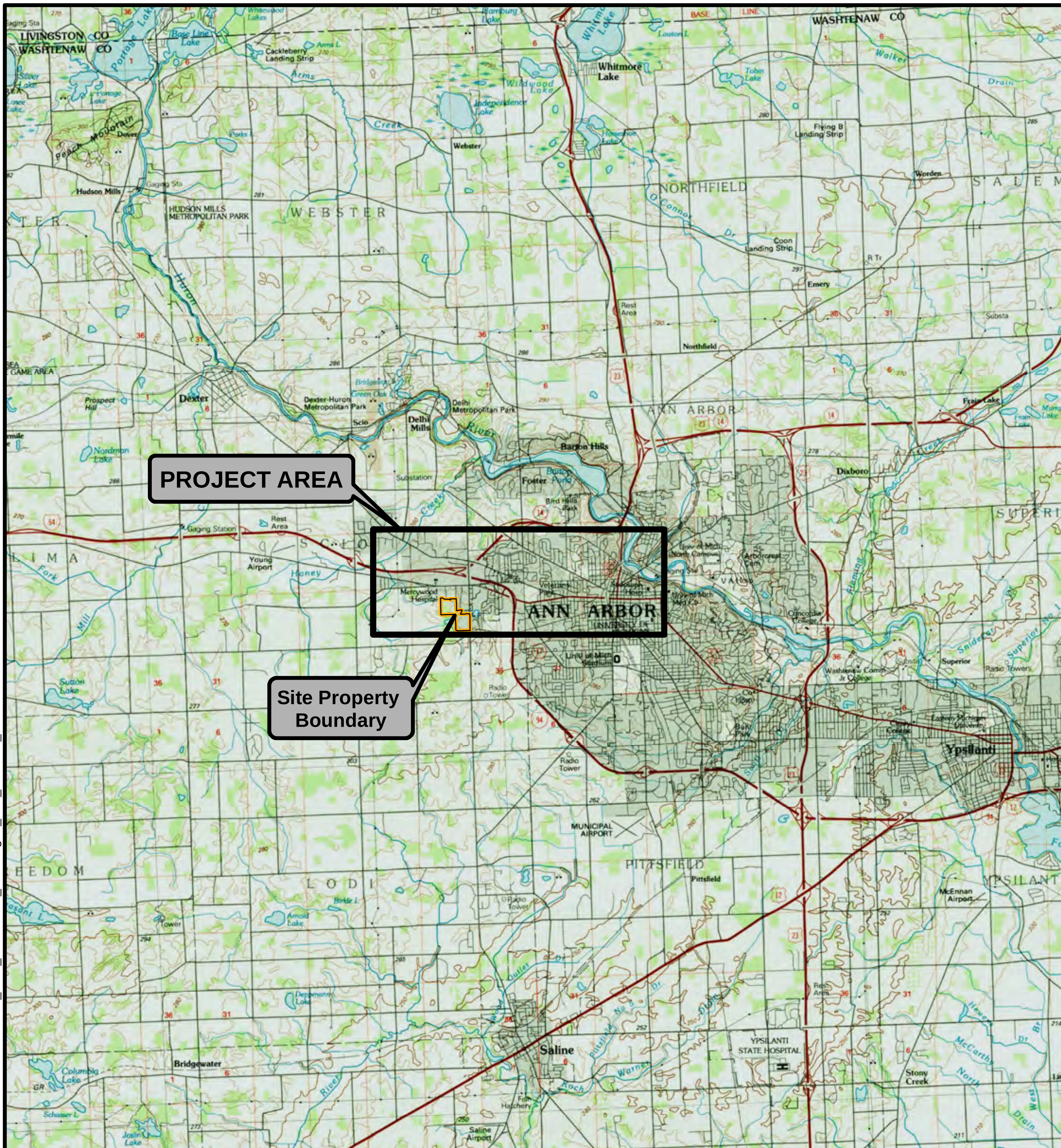
In order to fulfill the primary project objectives of collating data, constraining model inputs and reviewing the RockWorks project database and associated outputs, MSG completed the following:

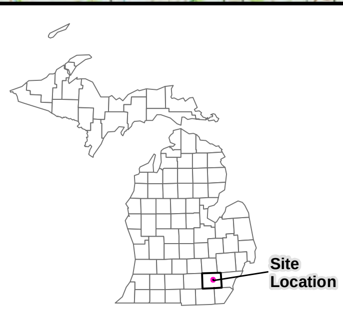
- Collated and consolidated data from EGLE and other sources for use in a RockWorks Project Area model.
- Standardized data and applied database concepts utilizing a Microsoft Access RDBMS.
- Created import tables for transfer into a RockWorks project database.
- Compiled data for the generation of three (3) model constraining surfaces.
- Iterative quality control review of the RockWorks models.

Data obtained from EGLE included a database (and update), Excel files, borehole logs, cross sections, HVSR seismic points, and an F&V report (F&V, 2016). A LIDAR bare-earth DEM (SEMCOG, 2019) was obtained from SEMCOG.

MSG standardized and incorporated data into a Microsoft Access RDBMS. MSG used the database to generate data input tables for development of the RockWorks model (see RockWare, 2020, for details of the modeling process). Model outputs were subjected to quality control review, including review of borehole logs and comparisons with hand-drawn cross sections prepared by PLS consultants. Refinements of the RockWorks model included changes to project node spacing and refinements to the three (3) bounding surfaces (ie. ground surface, highest groundwater elevation and top of bedrock). The use of a GIS facilitated additional visualization and quality control review of the data.

FIGURES





Legend

- RockWorks Project Area
- Gelman Sciences Inc. Property Boundary (now Pall Life Sciences)

Basemap Source: USGS 1:100,000-scale Quadrangle for Detroit, MI 1989

0 1.5 3 Miles
1:158,400

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FIGURE 1

PROJECT LOCATION MAP

Gelman Sciences Inc. Site
Washtenaw County, Scio Township, Michigan

DATE	DRAWN BY	DESIGNED BY	PROJECT NO.
04/01/20	KRB	KRB	EGLE0006

Date Saved: 04/01/20 2:46:19 PM Coordinate System: NAD 1983 StatePlane Michigan South FIPS 2113 Feet Intl
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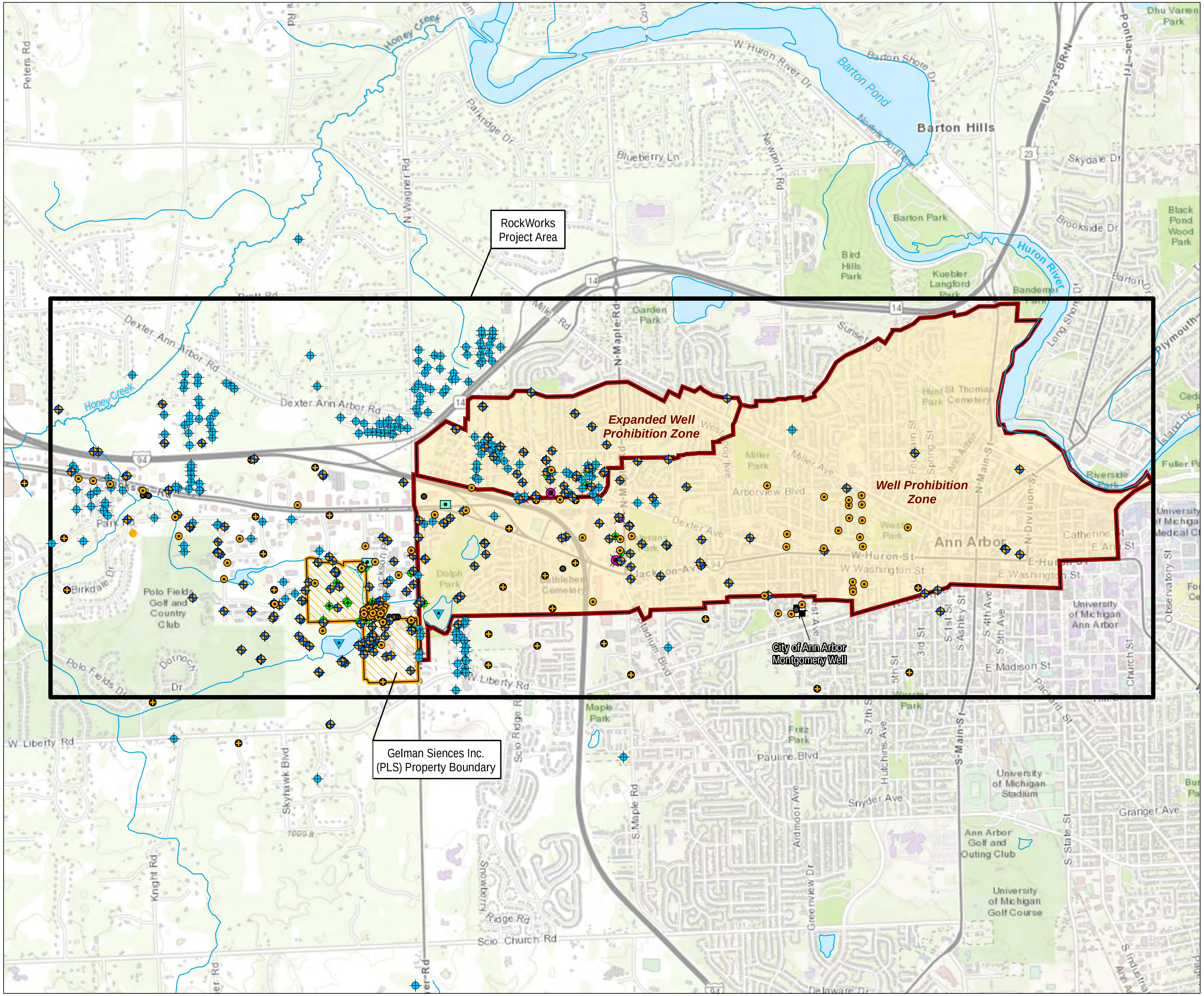

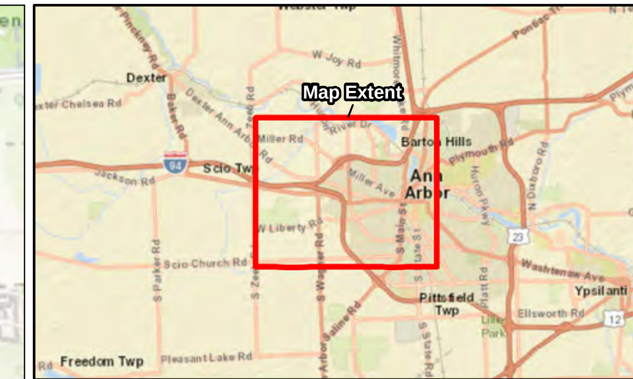

Bore - Well Type

- Monitoring Wells
- Residential Wells
- Test Boring
- Horizontal Wells
- Seismic Interpretation Point
- Extraction Wells
- Injection Wells
- Surface Water
- other
- Montgomery Well
- RockWorks Project Area
- Gelman Sciences Inc. Property Boundary (now Pall Life Sciences)
- Well Prohibition Zone
- Hydrography Line from Michigan Geographic Framework v17a

Basemap Source: ESRI World Topographic Map Service

0 2,400 4,800 Feet

1:28,800

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FIGURE 2

Project Features and Borehole Locations

Gelman Sciences Inc. Site
Washtenaw County, Scio Township, Michigan

DATE	DRAWN BY	DESIGNED BY	PROJECT NO.
04/01/20	KRB	KRB	EGLE0006

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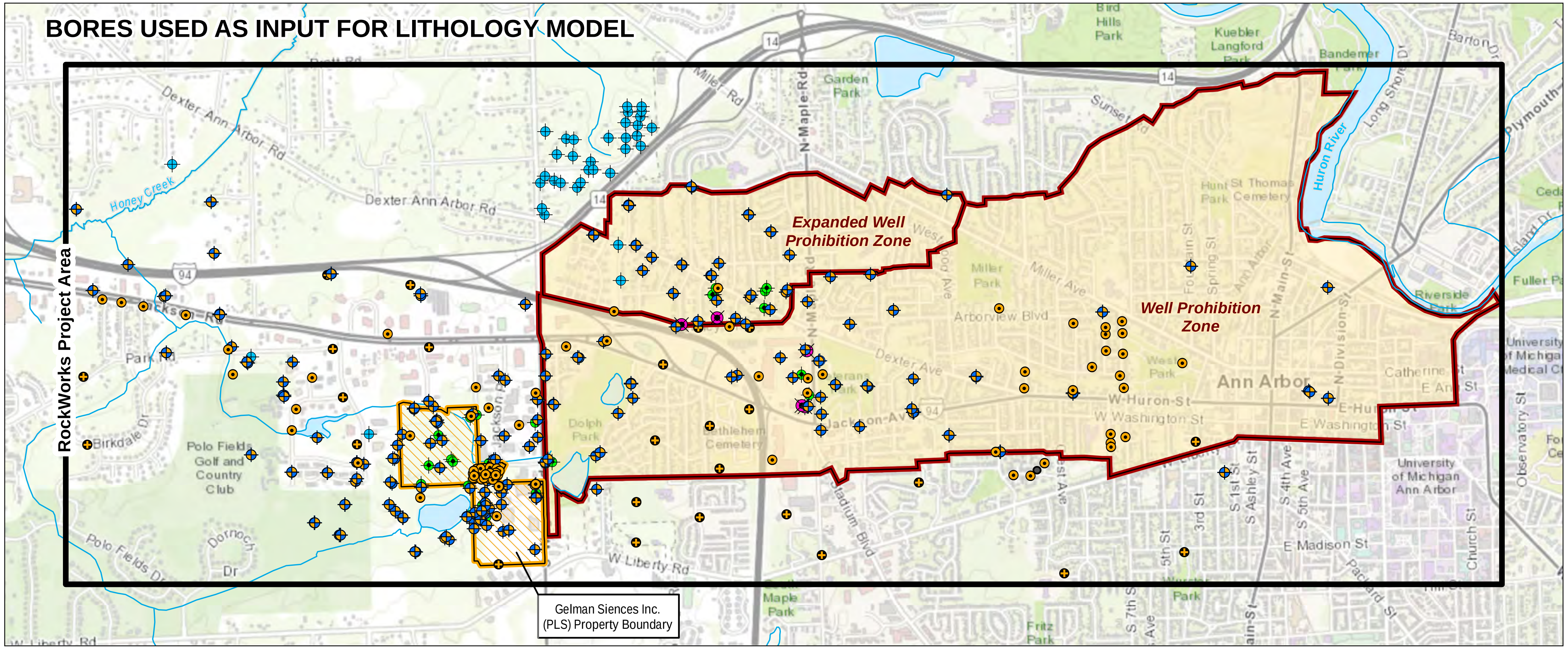

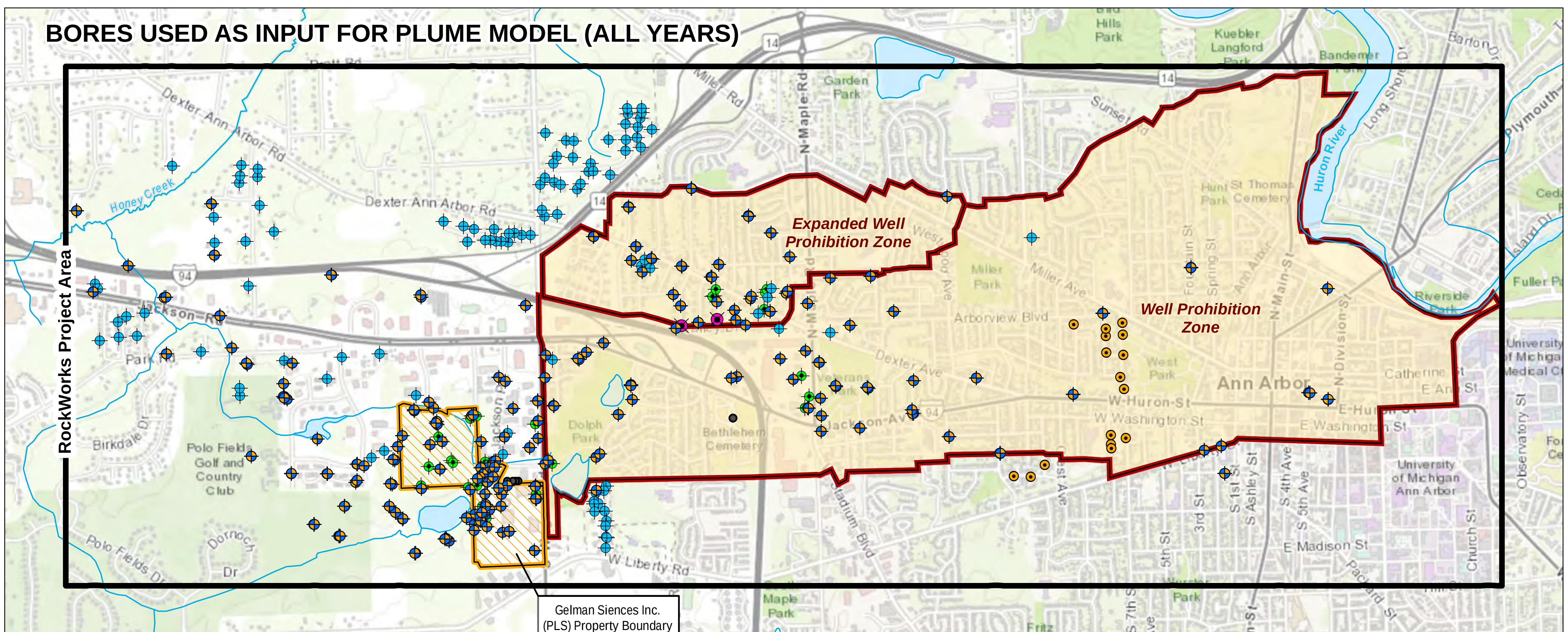

Bore - Well Type

- Monitoring Wells
- Residential Wells
- Test Boring
- Seismic Interpretation Point
- Extraction Wells
- Injection Wells
- other
- RockWorks Project Area
- Gelman Sciences Inc. Property Boundary (now Pall Life Sciences)
- Well Prohibition Zone
- Hydrography Line from Michigan Geographic Framework v17a

Basemap Source: ESRI World Topographic Map Service

0 2,400 4,800 Feet

1:28,800

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FIGURE 3

Lithology and Plume Model Borehole Locations

Gelman Sciences Inc. Site
Washtenaw County, Scio Township, Michigan

DATE	DRAWN BY	DESIGNED BY	PROJECT NO.
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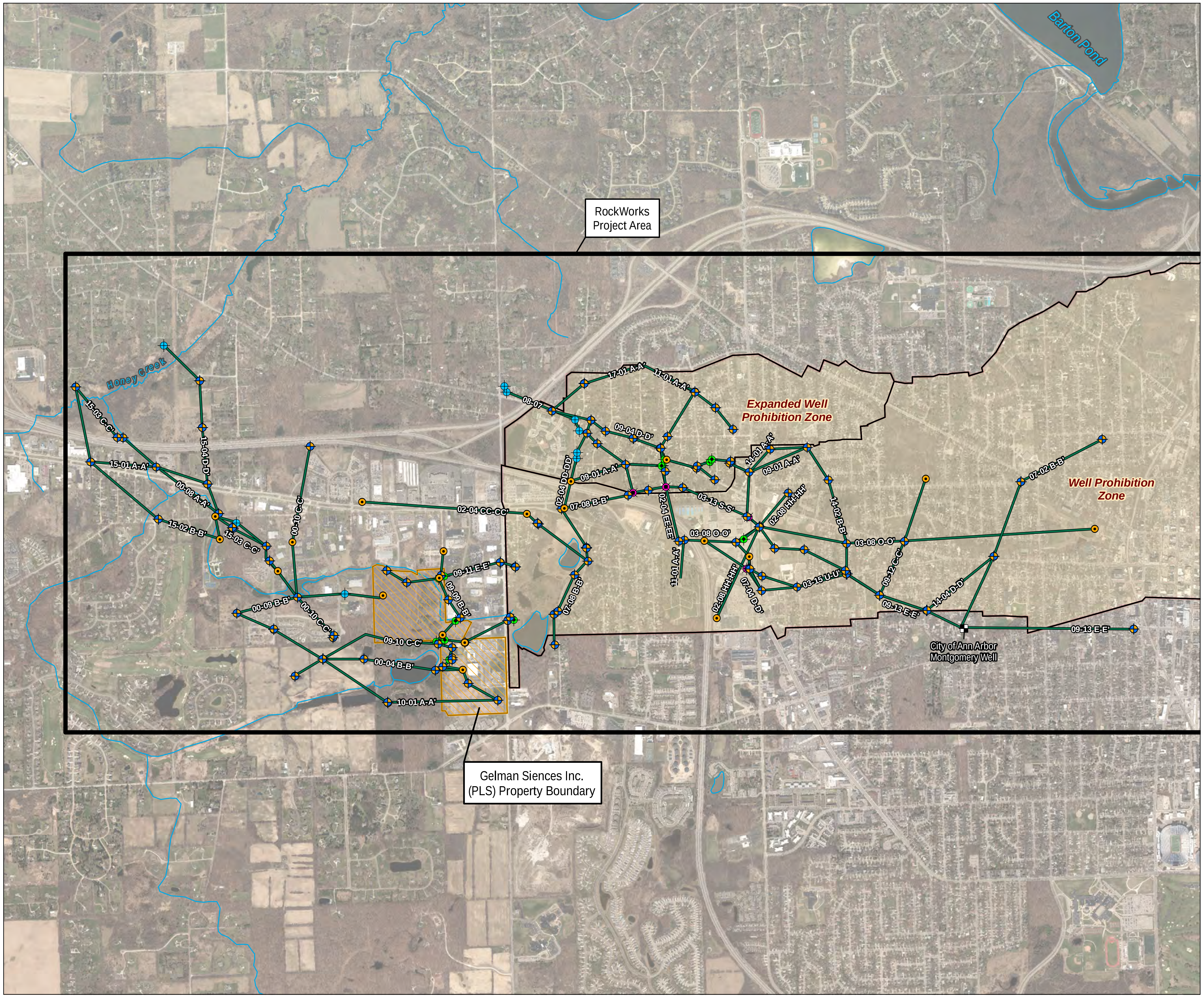

RockWorks Bore Used in Cross-Section

- Monitoring Wells
- Residential Wells
- Test Boring
- Extraction Wells
- Injection Wells
- Montgomery Well
- Cross Section Location
- RockWorks Project Area
- Gelman Sciences Inc. Property Boundary (now Pall Life Sciences)
- Hydrography Line from Michigan Geographic Framework v17a
- Well Prohibition Zone

Aerial Image Source: SEMCOG 2015

0 2,000 4,000 Feet

1:24,000

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FIGURE 4

Cross Section Locations

Gelman Sciences Inc. Site
Washtenaw County, Scio Township, Michigan

DATE	DRAWN BY	DESIGNED BY	PROJECT NO.
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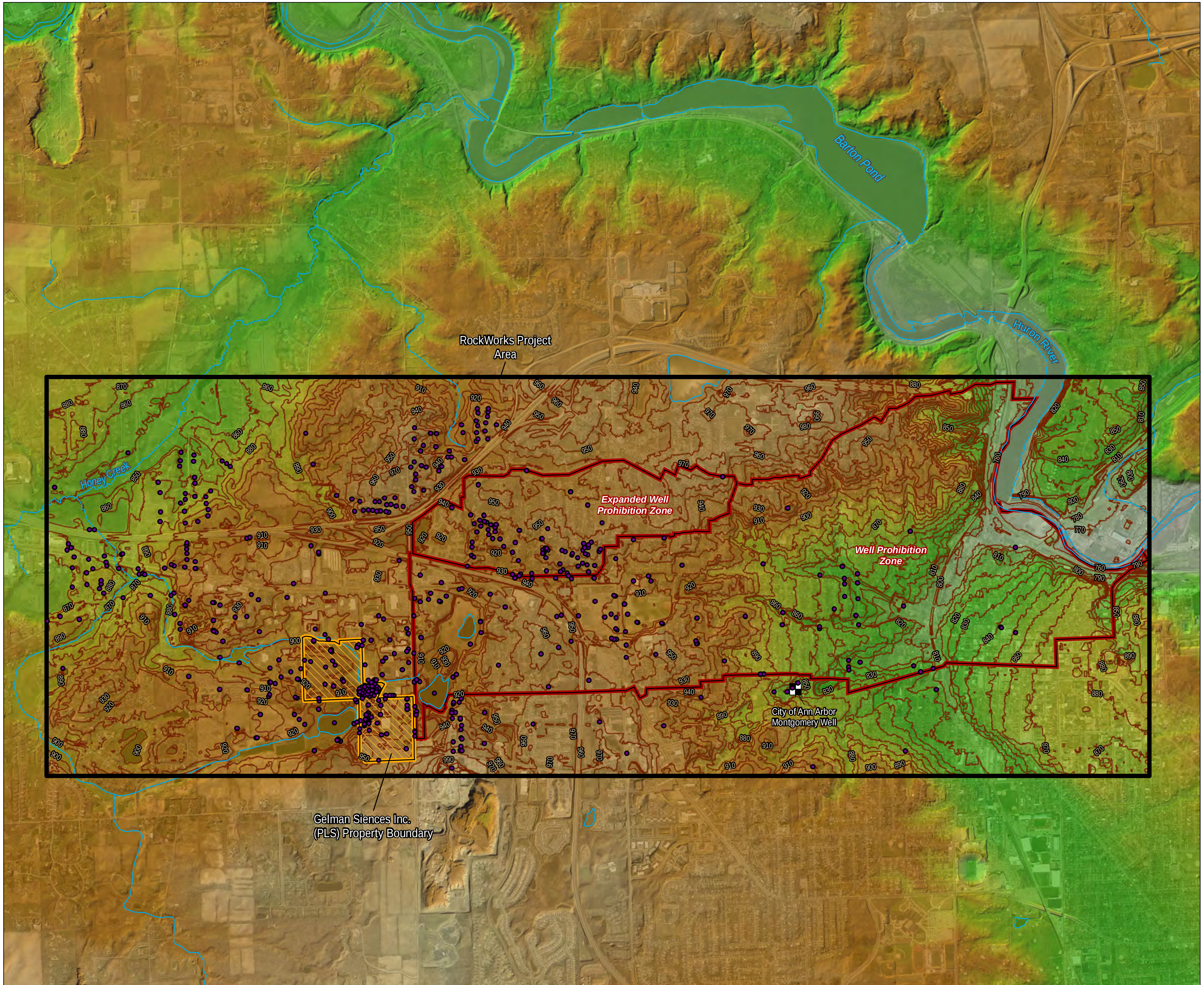

- RockWorks Bores
- Montgomery Well
- RockWorks Project Area
- Gelman Sciences Inc. Property Boundary (now Pall Life Sciences)
- Well Prohibition Zone
- 10 foot ground elevation contour from SEMCOG March 2019 LIDAR
- Hydrography Line from Michigan Geographic Framework v17a

SEMCOG March 2019 LIDAR Bare-Earth DEM

750 ft | 850 ft | 950 ft

Ground Elevation Feet Above Sea Level

Aerial Photograph Source: SEMCOG 2015

0 | 2,400 | 4,800 Feet

1:28,800

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FIGURE 5

SEMCOG 2019 DEM and Ground Elevation Contours

Gelman Sciences Inc. Site
Washtenaw County, Scio Township, Michigan

DATE	DRAWN BY	DESIGNED BY	PROJECT NO.
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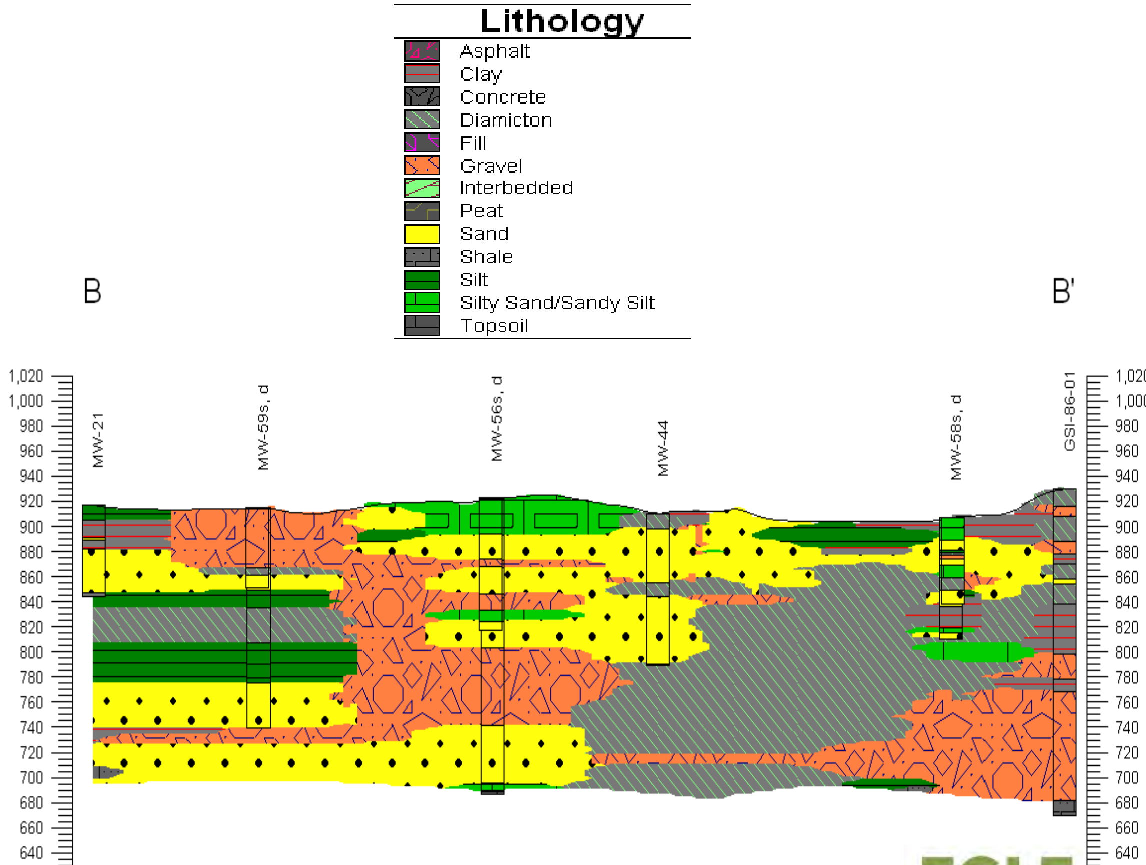
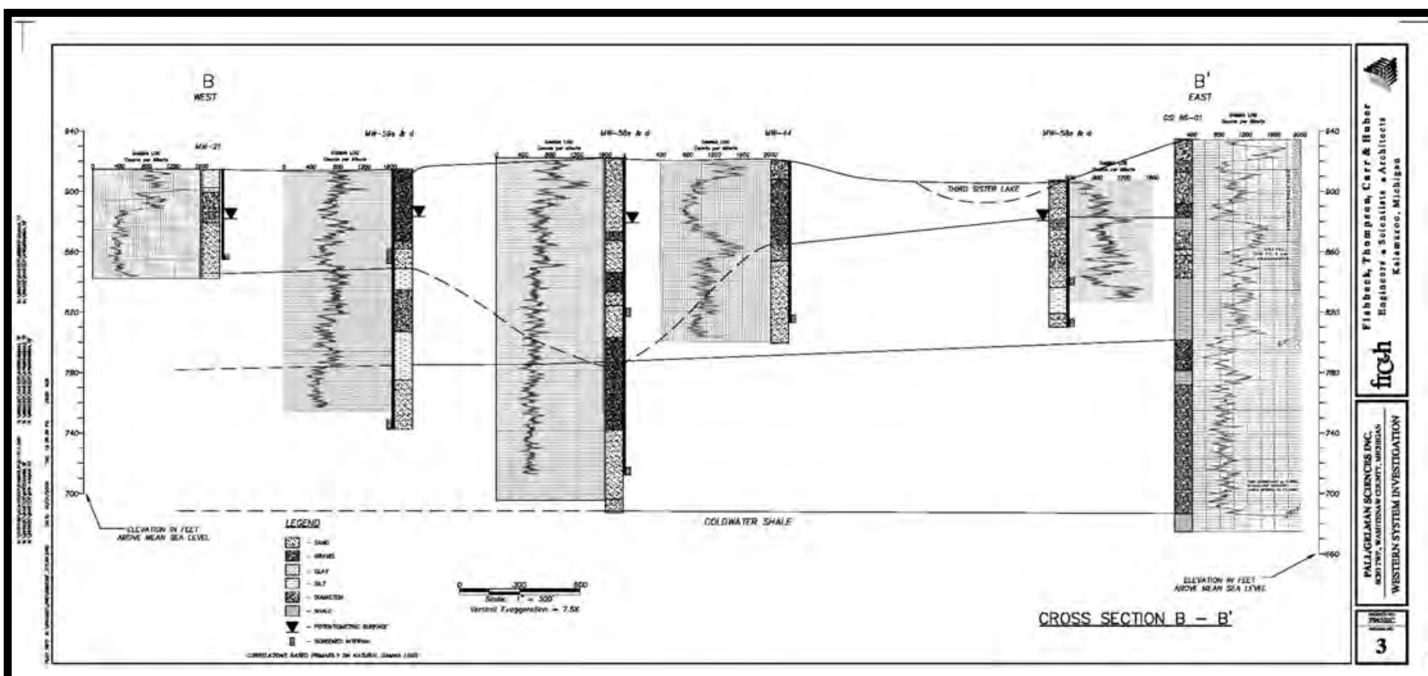
APPENDIX A
CROSS SECTION COMPARISONS

CROSS-SECTION 00-04 B-B' Comparison



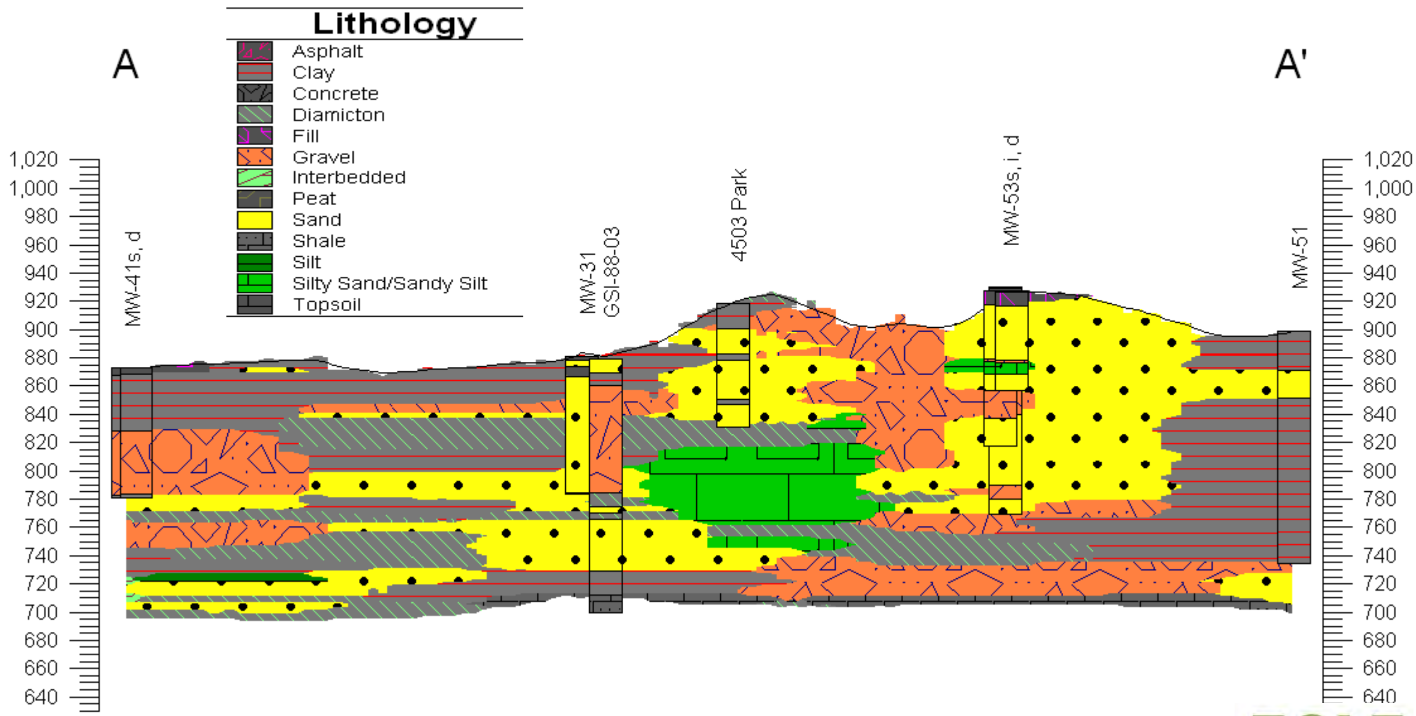
Cross-section exported December 2019

EGLE

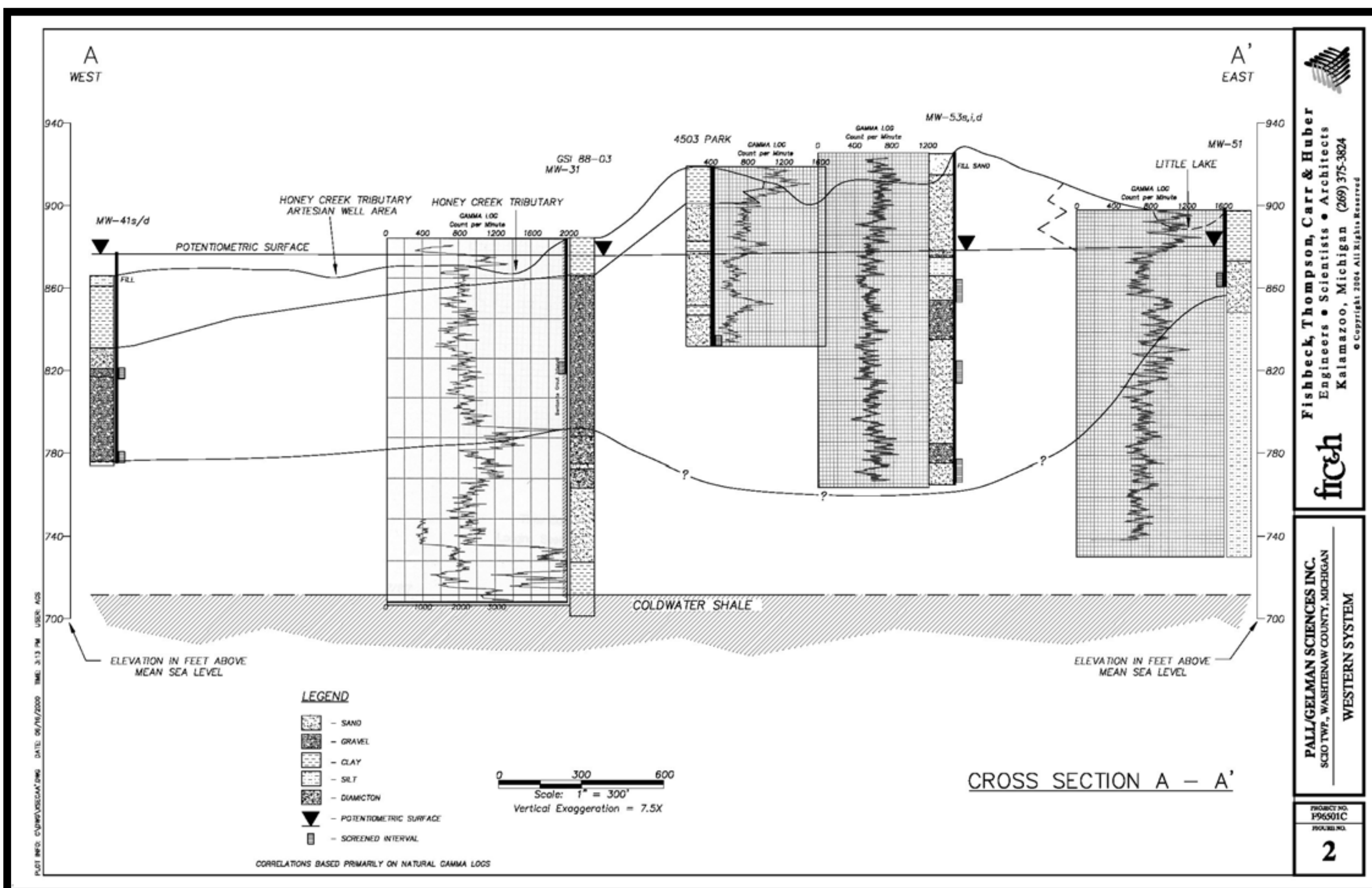


Cross-section from 00-04 B West MW-21 B' East
GSI 86-01.pdf

CROSS-SECTION 00-08 A-A' Comparison

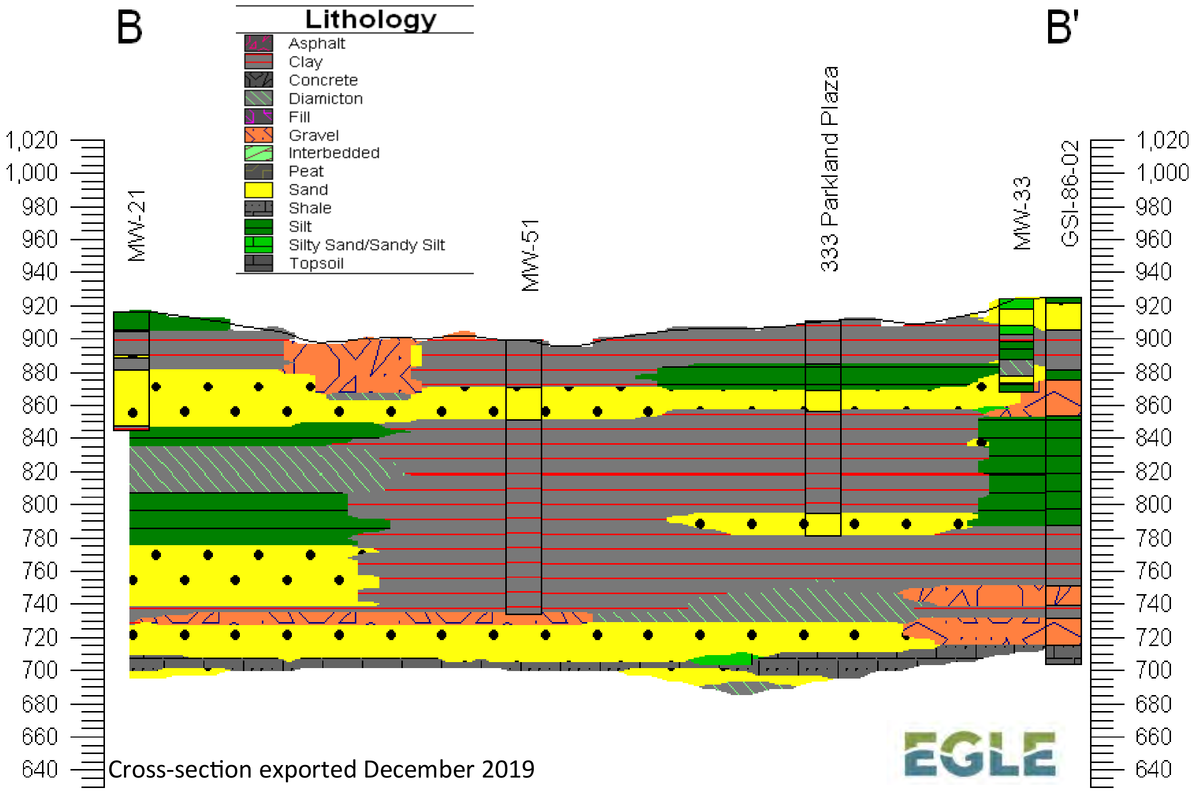


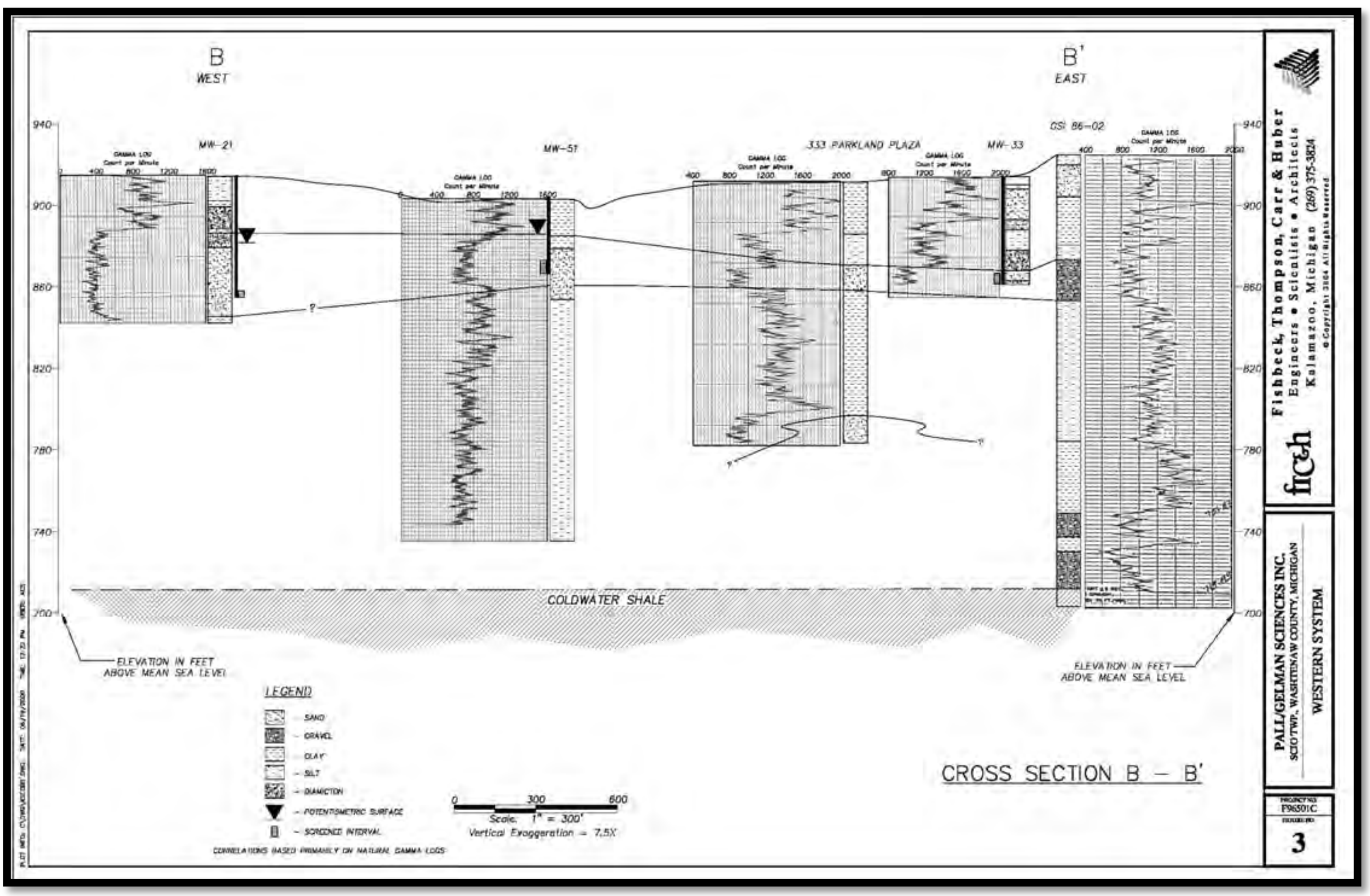
Cross-section exported December 2019



Cross-section from 00-08 A West MW-41sd A' East MW-51.pdf

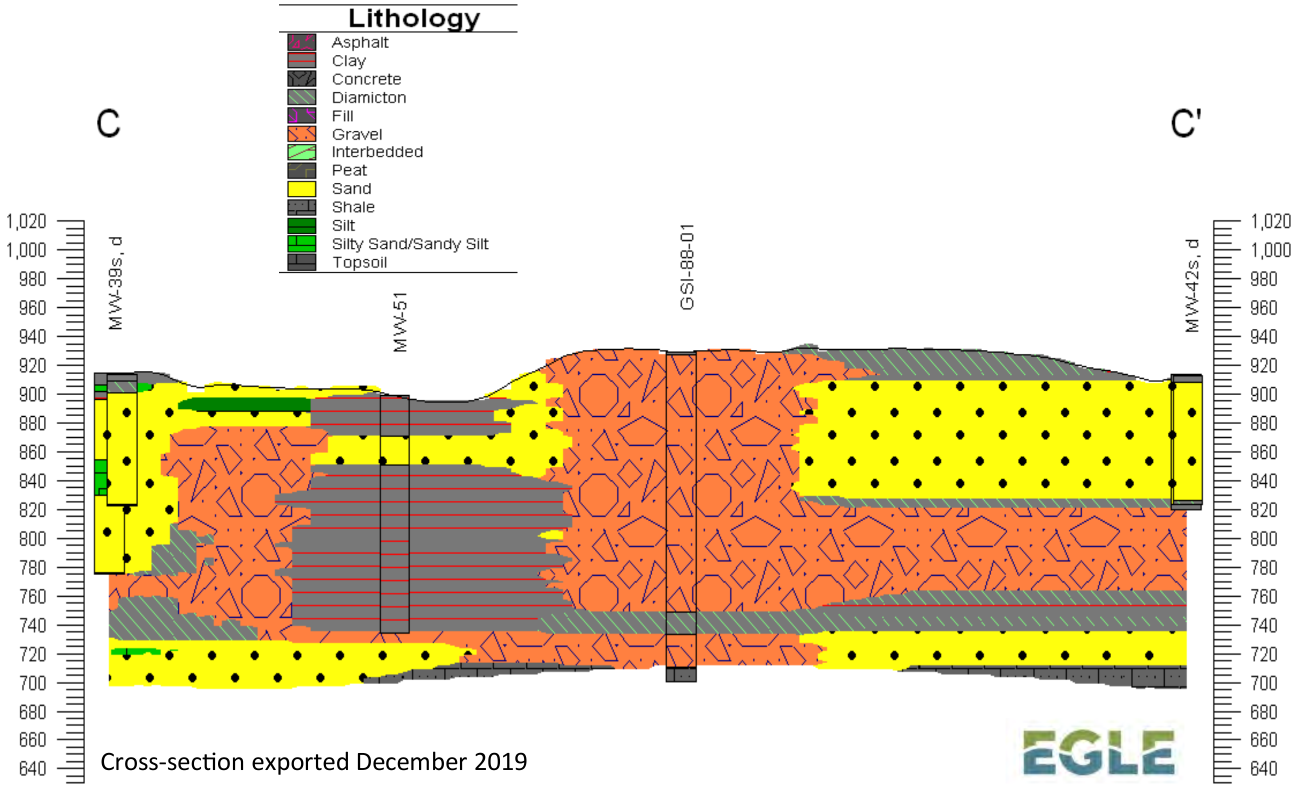
CROSS-SECTION 00-09 B-B' Comparison



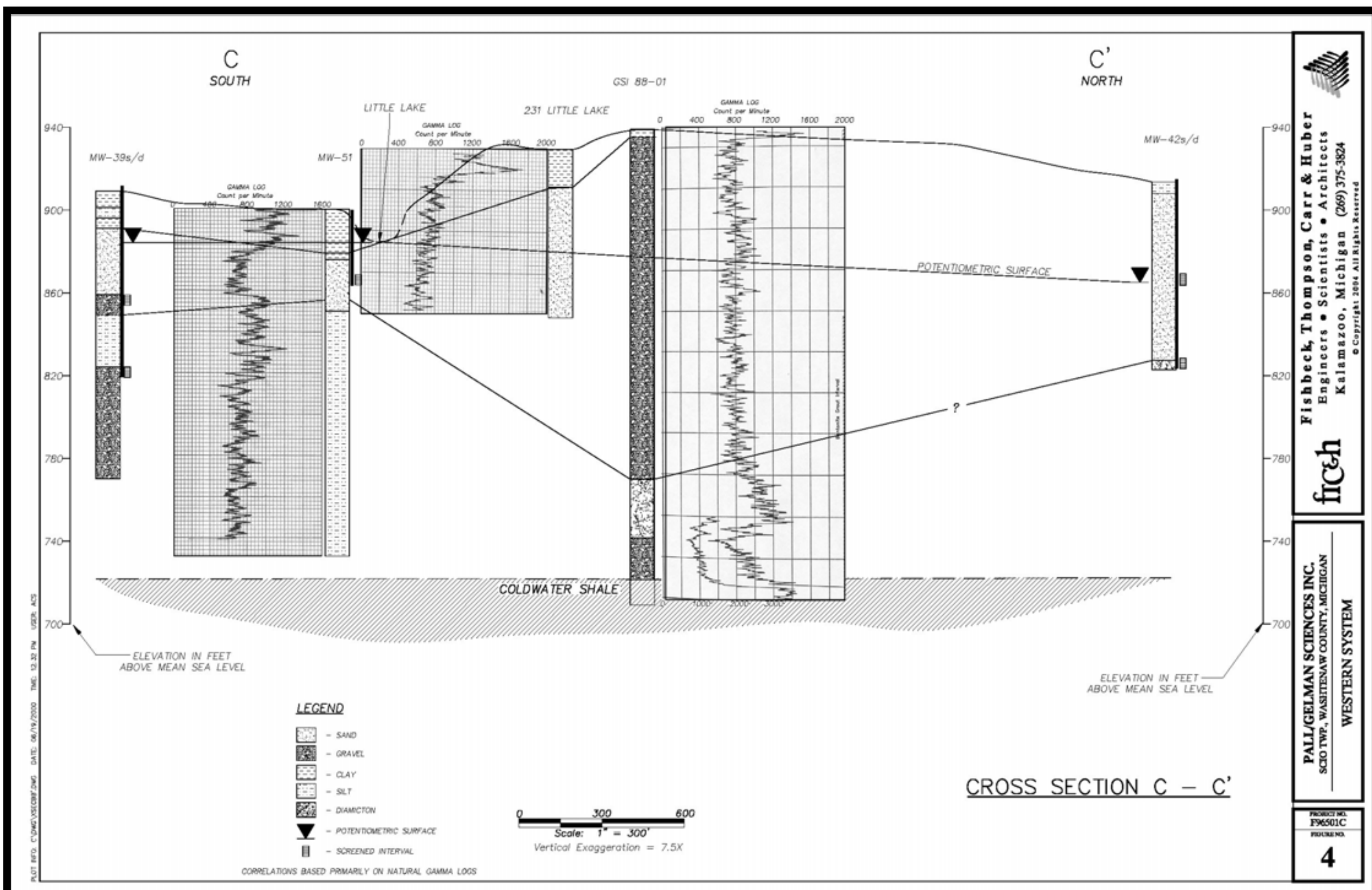


Cross-section from 00-09 B West MW-31 B' East GSI 86-02.pdf

CROSS-SECTION 00-10 C-C' Comparison

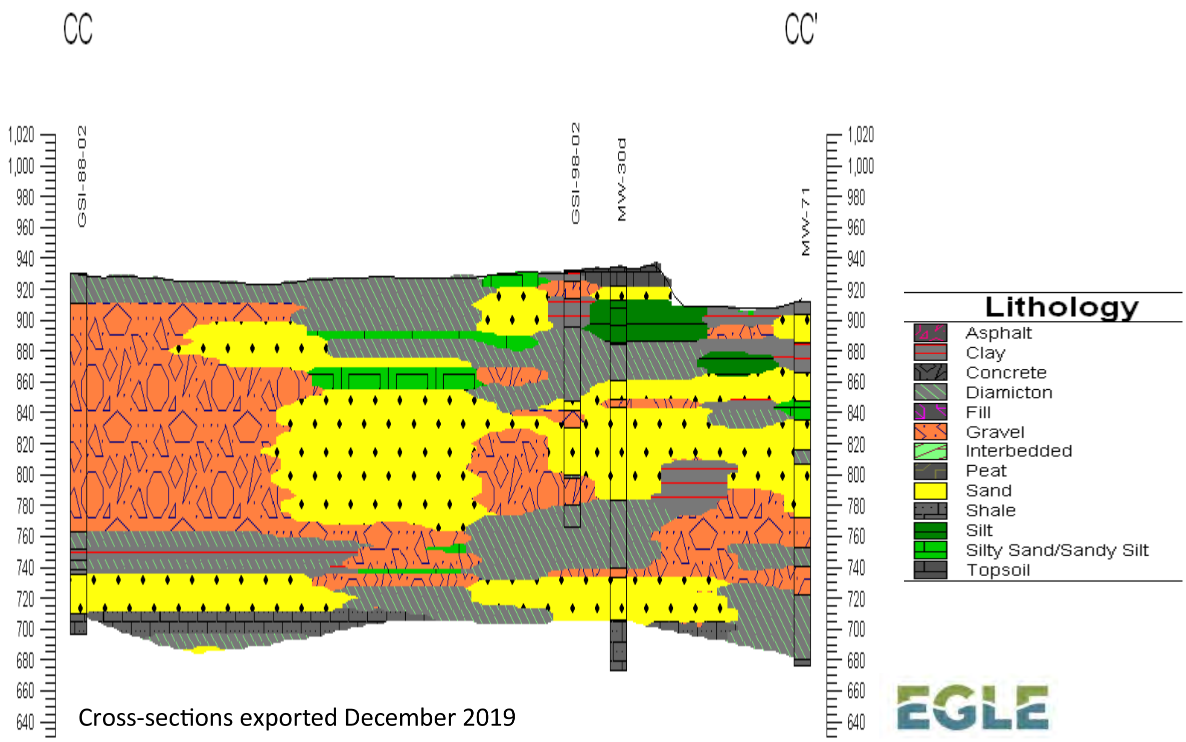


Cross-section exported December 2019

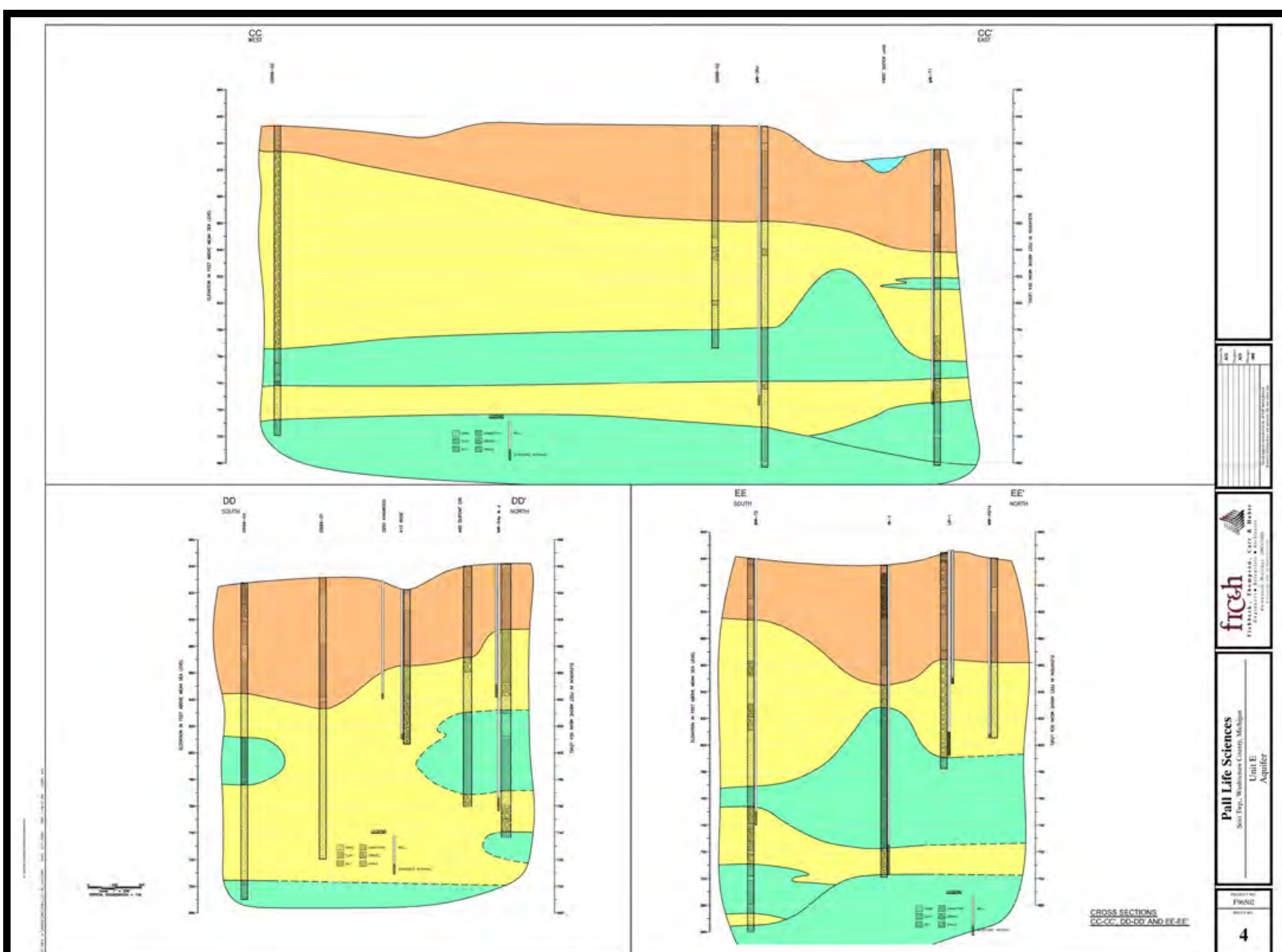


Cross-section from 00-10 C South MW-39sd C' North MW-42sd.pdf

CROSS-SECTION 02-04 CC-CC' Comparison

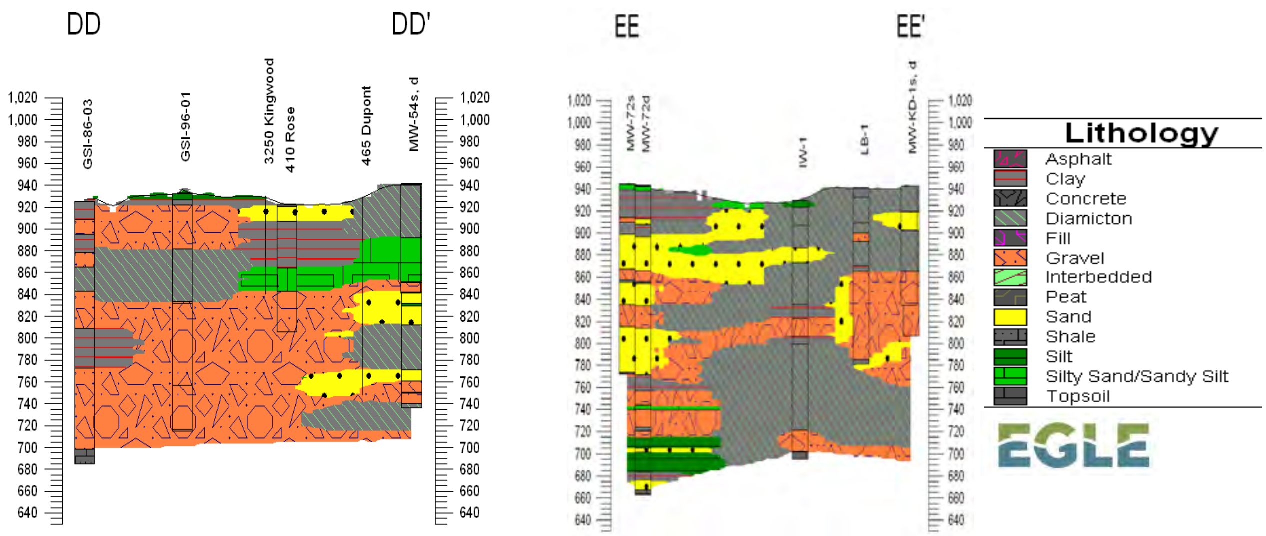


Cross-sections exported December 2019



Cross-section from 02-04 DD South GSI 86-03 DD' North MW-54sd (also shows 03 & 05).pdf

CROSS-SECTION 02-04 DD-DD' and EE-EE' Comparison



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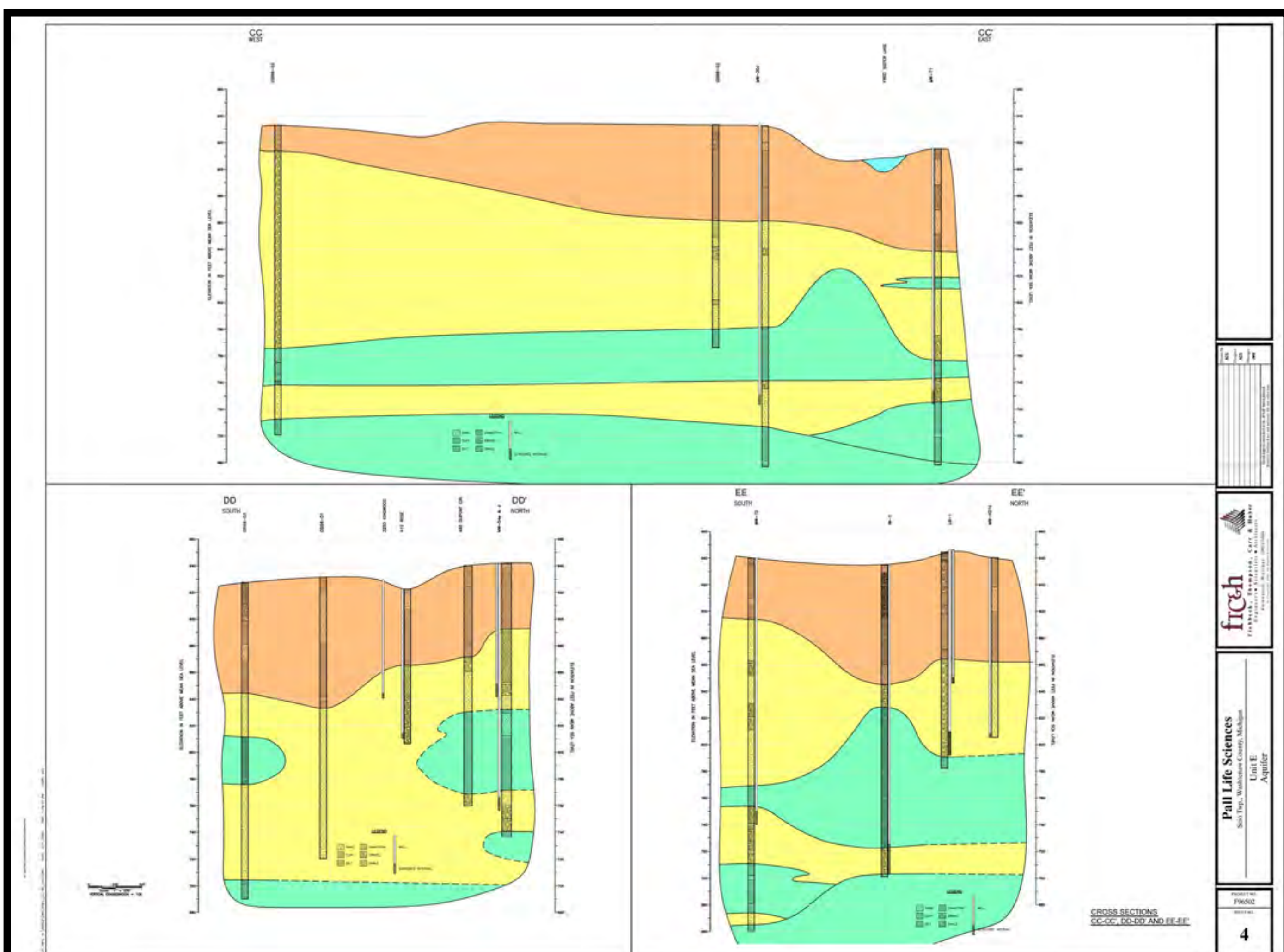
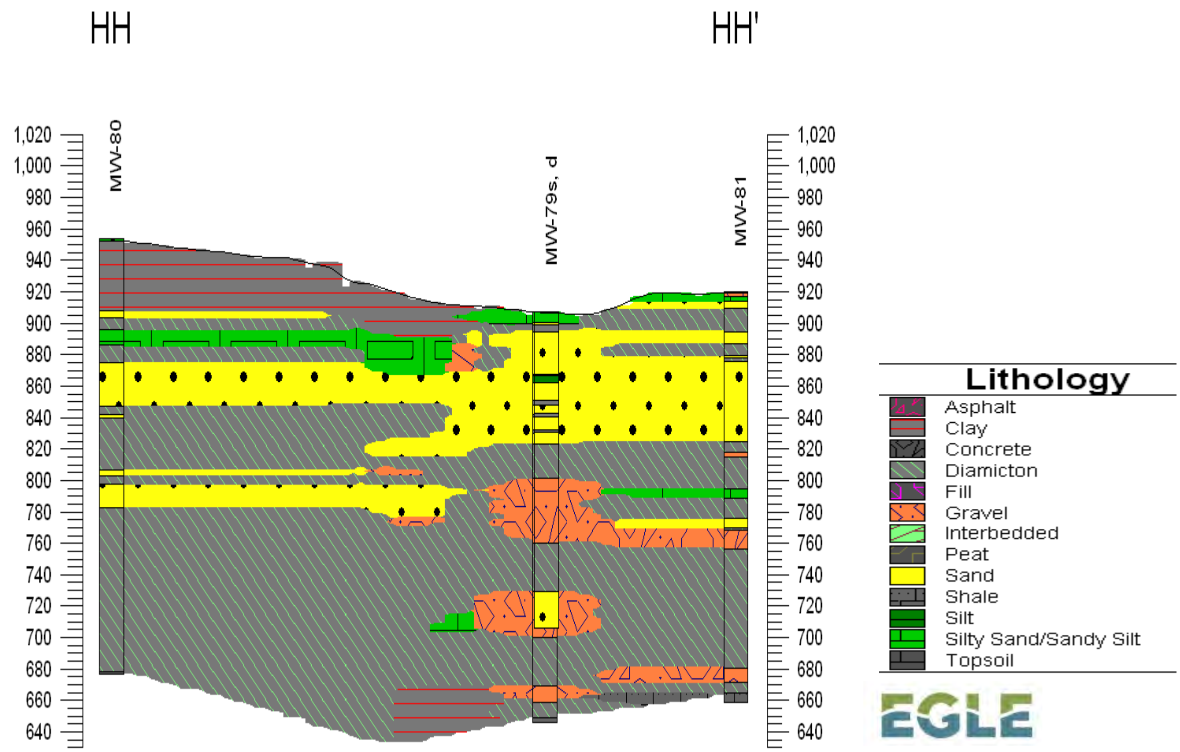


Cross-section from 02-04 DD South GSI 86-03 DD' North MW-54sd (also shows 03 & 05).pdf

CROSS-SECTION 02-08 HH-HH' Comparison



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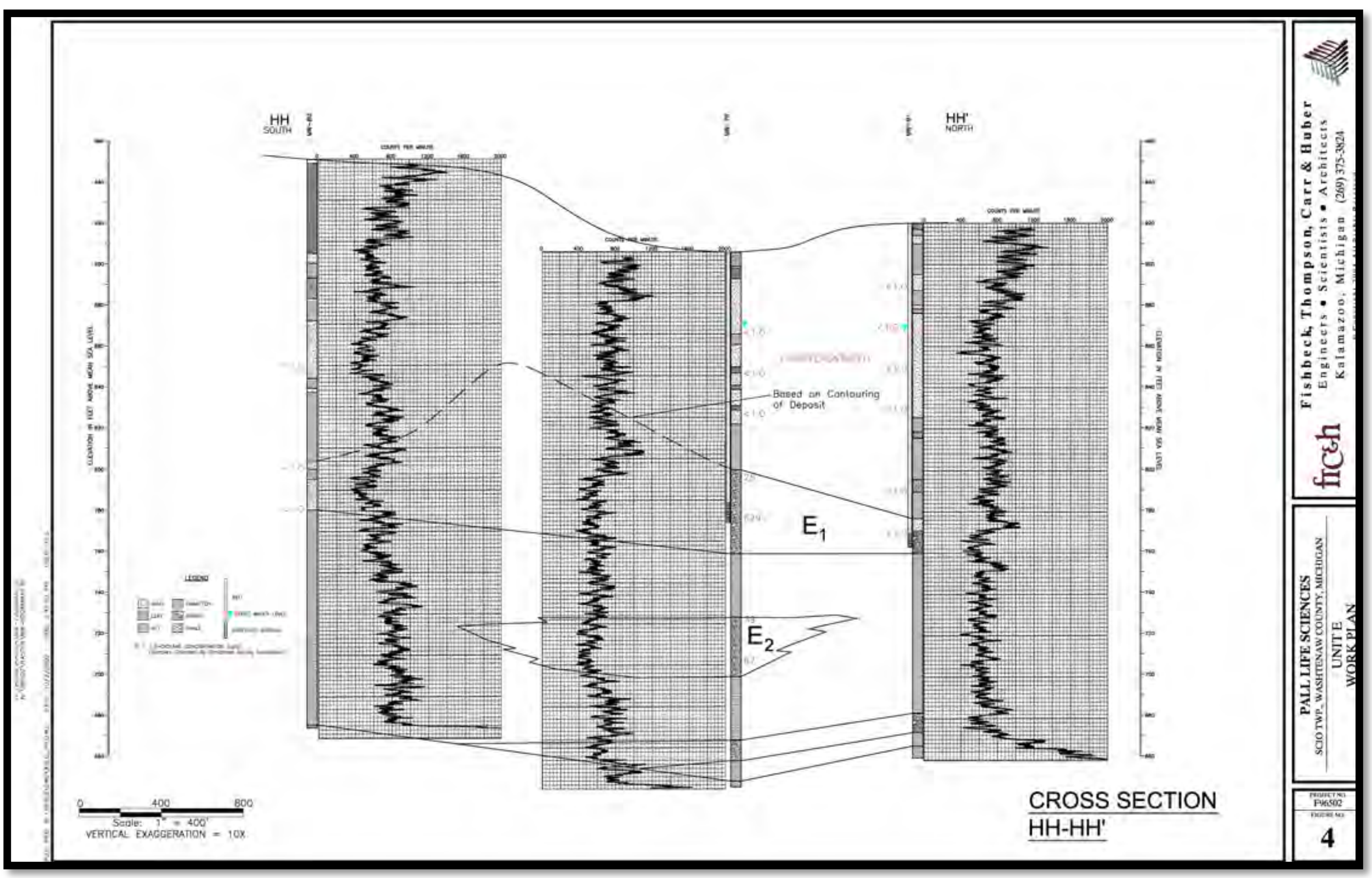
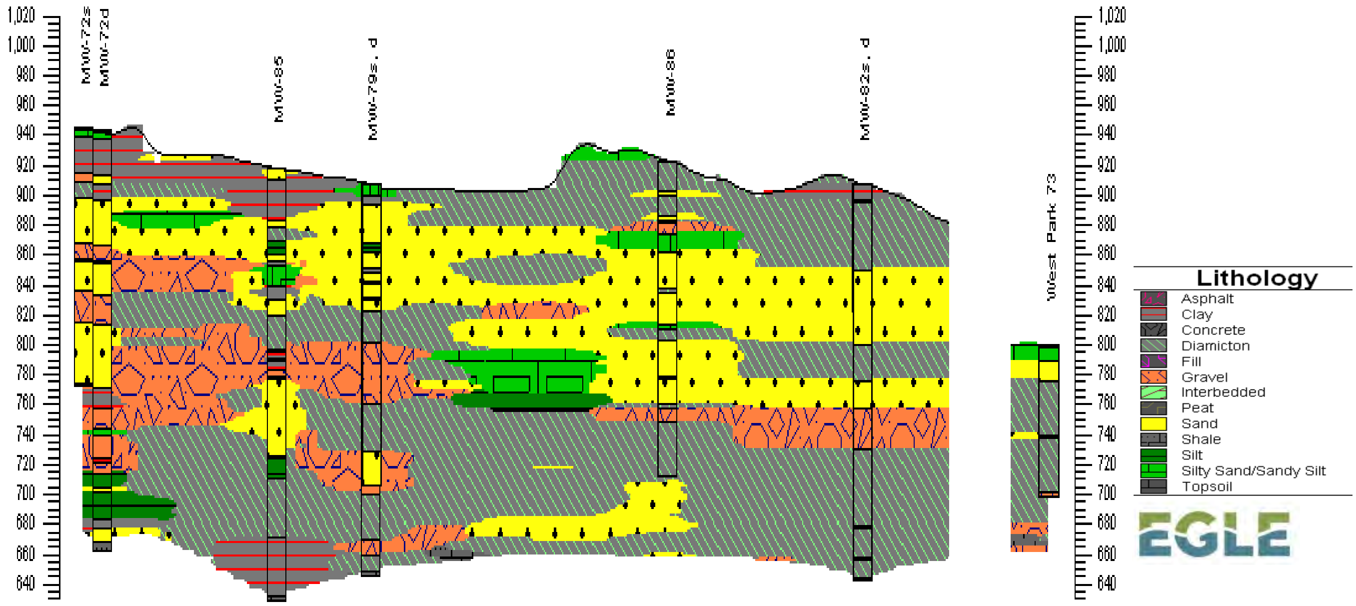


Cross-section from 02-08 HH South MW-80 HH' North MW-81.pdf

CROSS-SECTION 03-08 O-O’ Comparison



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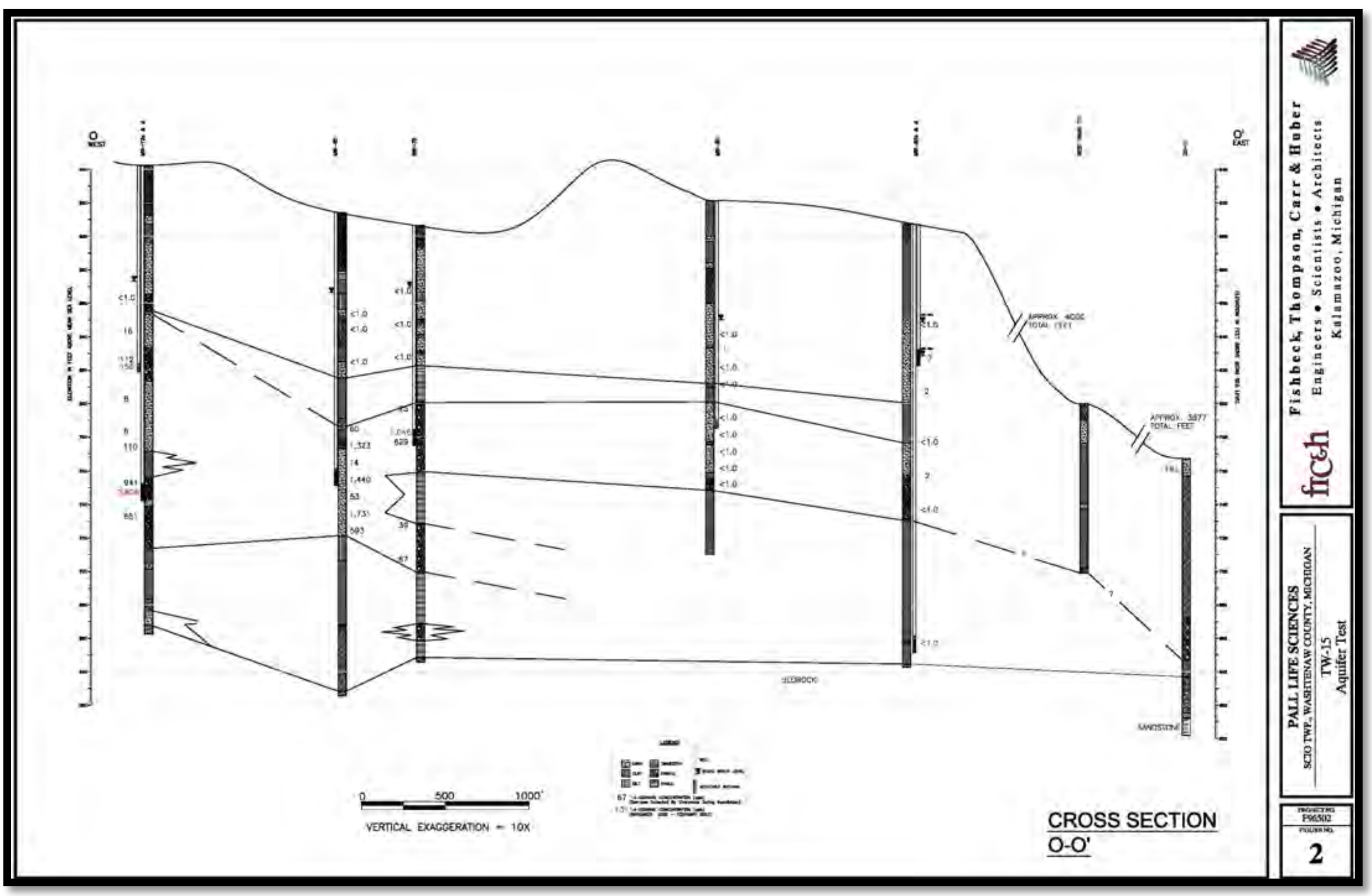

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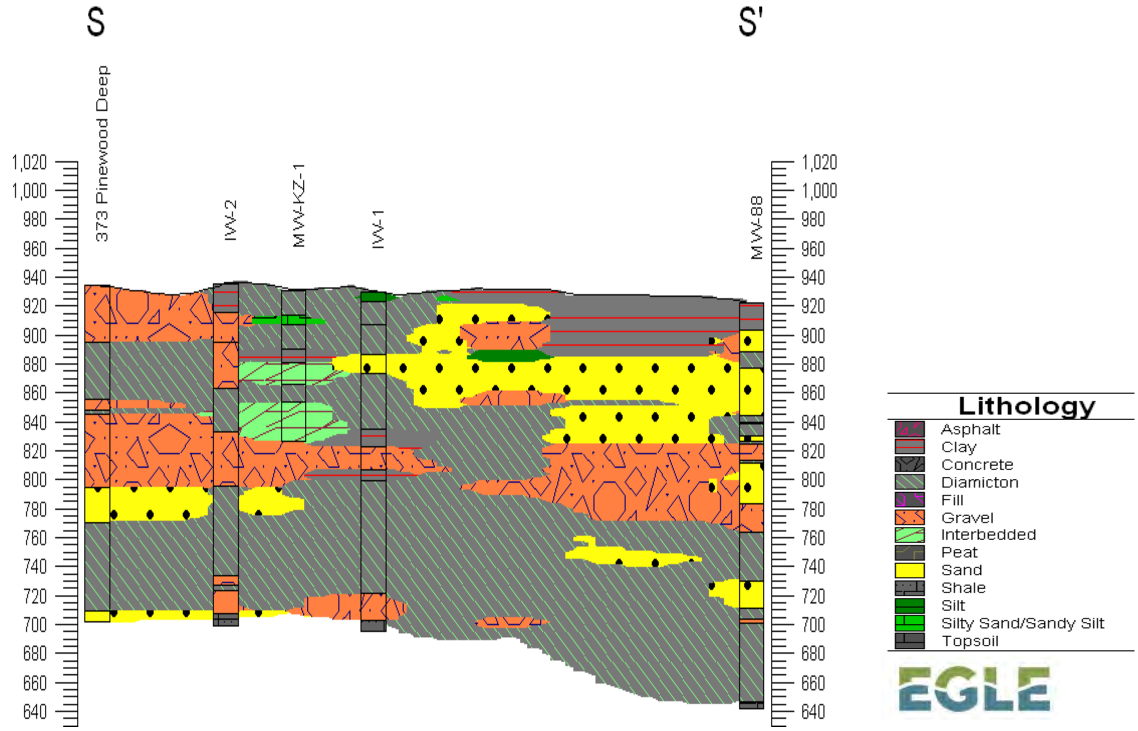
CROSS-SECTION 03-13 S-S' Comparison



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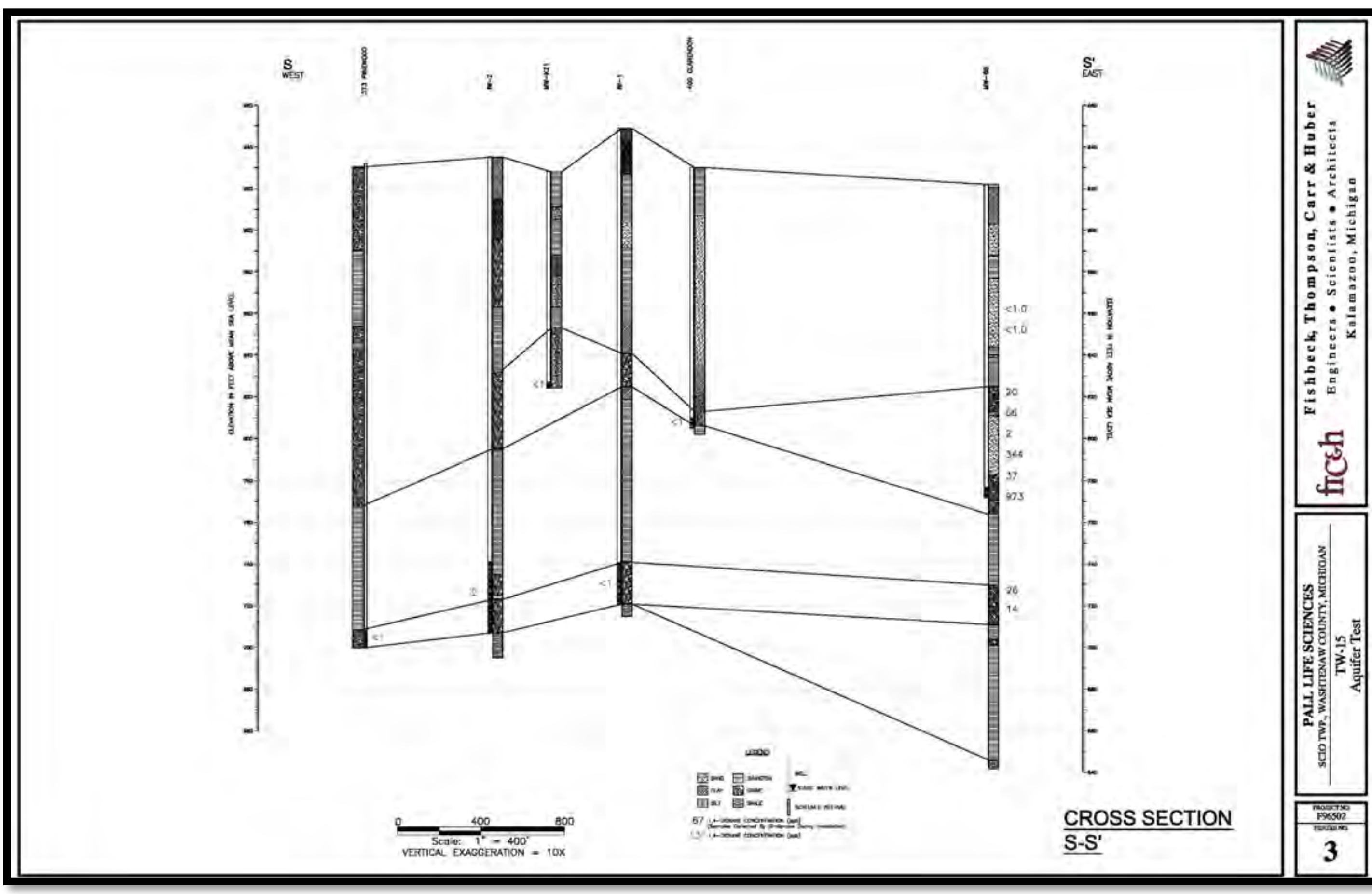
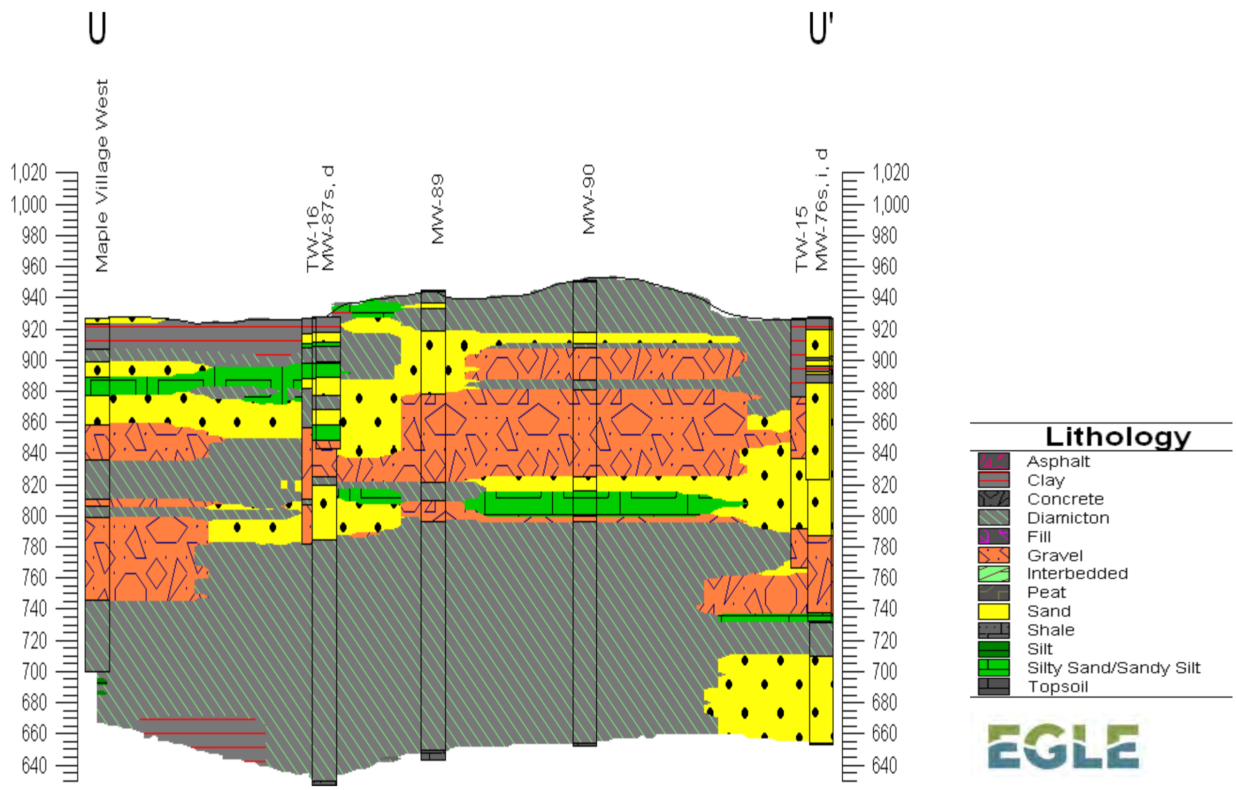


Cross-section from 03-13 S West 373 Pinewood S' East MW-88.pdf

CROSS-SECTION 03-15 U-U' Comparison



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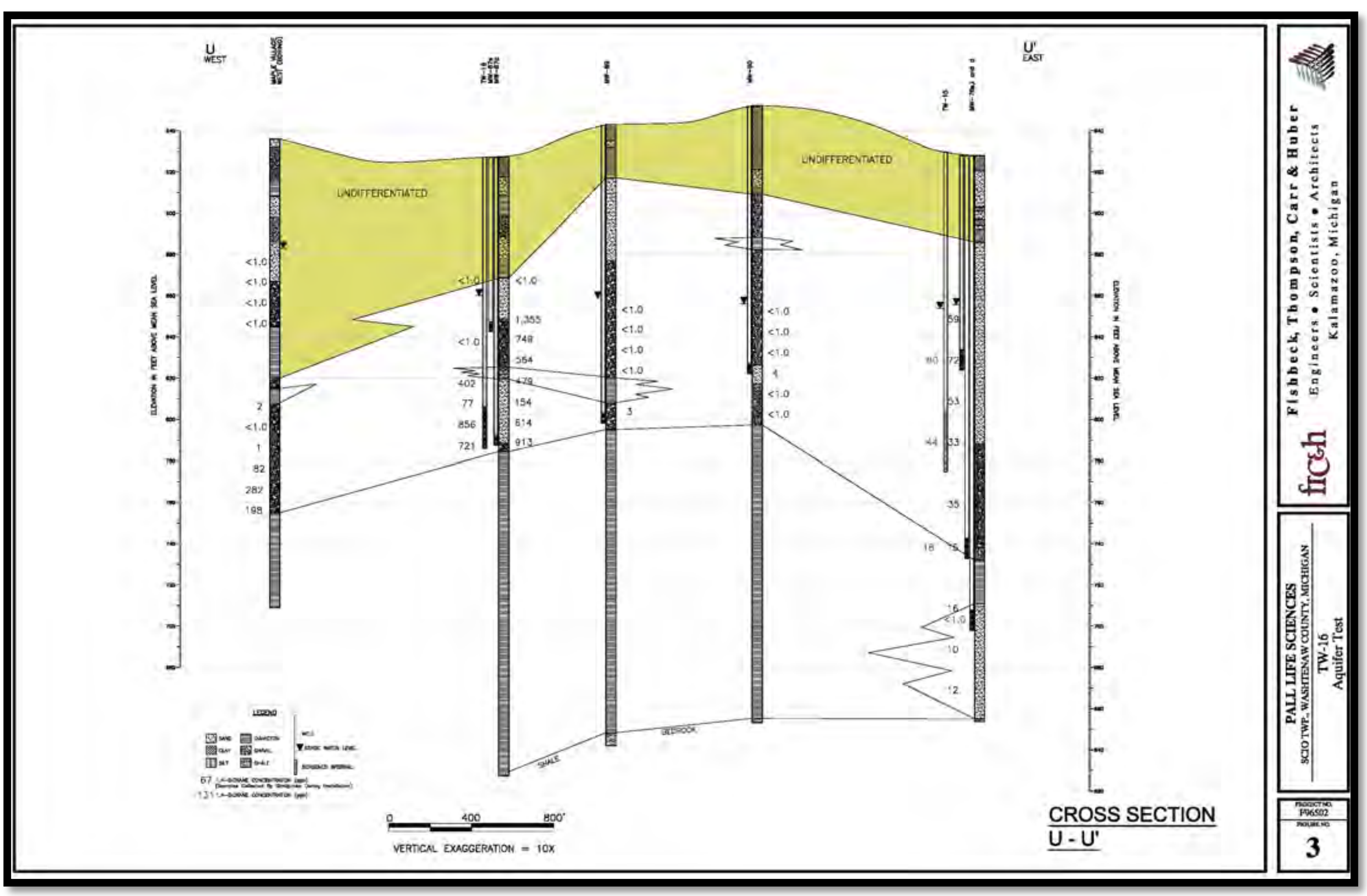
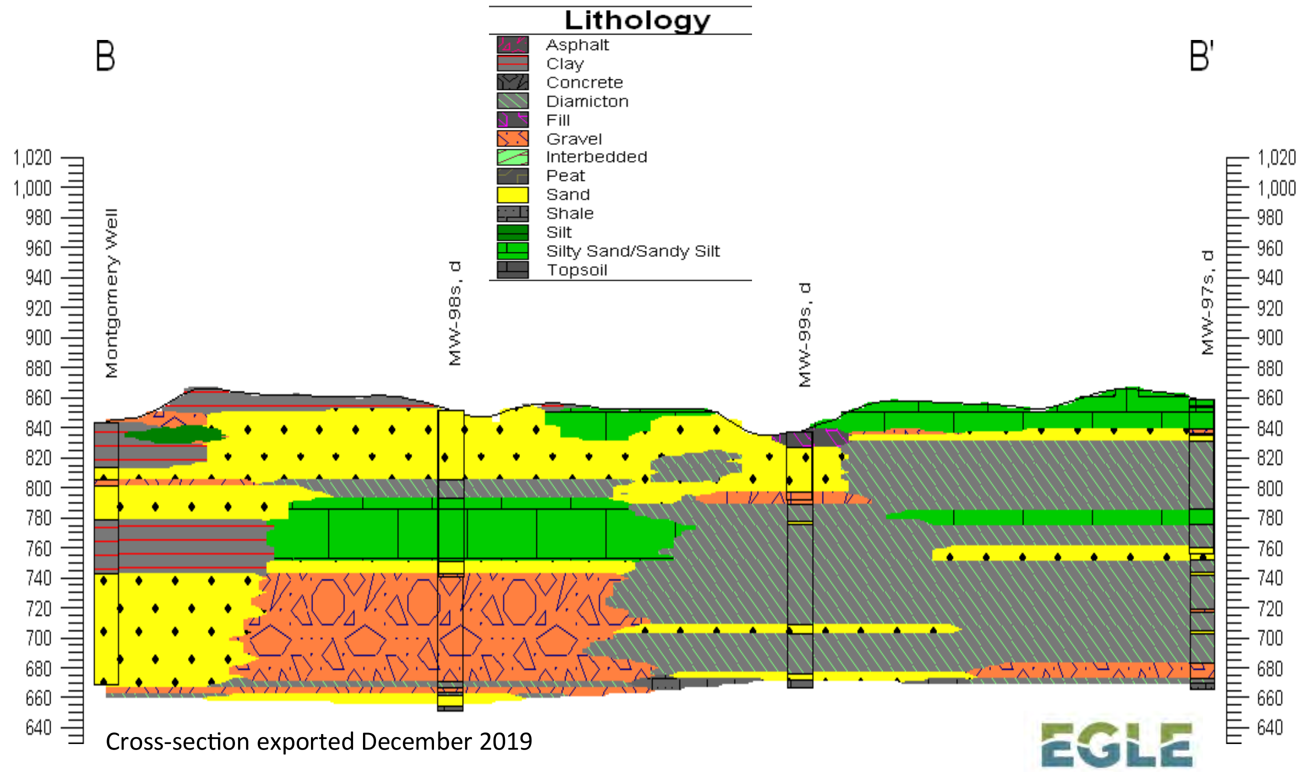


Cross-section from 03-15 U West Maple Village East U' East MW-76sid.pdf

CROSS-SECTION 07-02 B-B' Comparison



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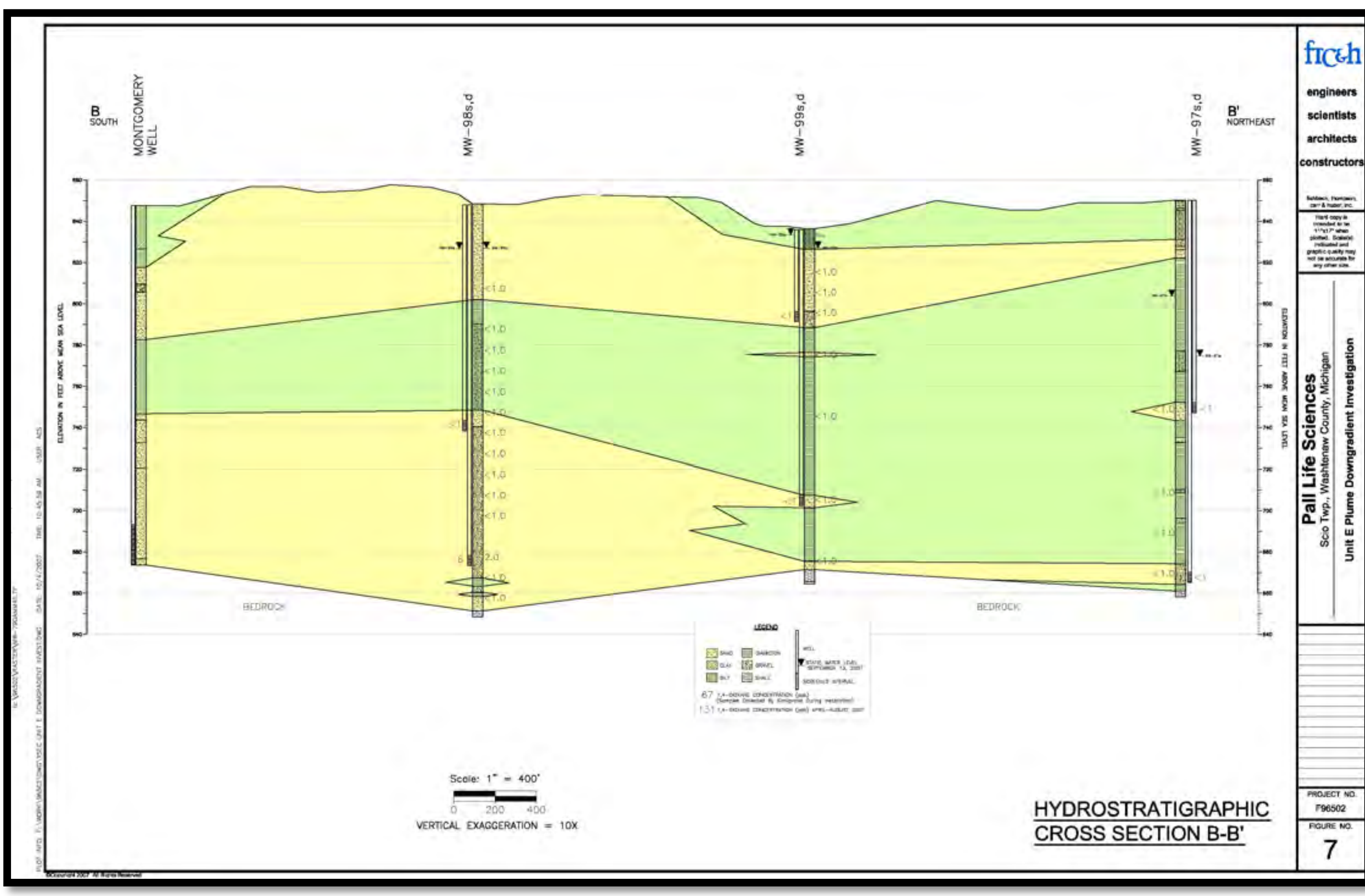
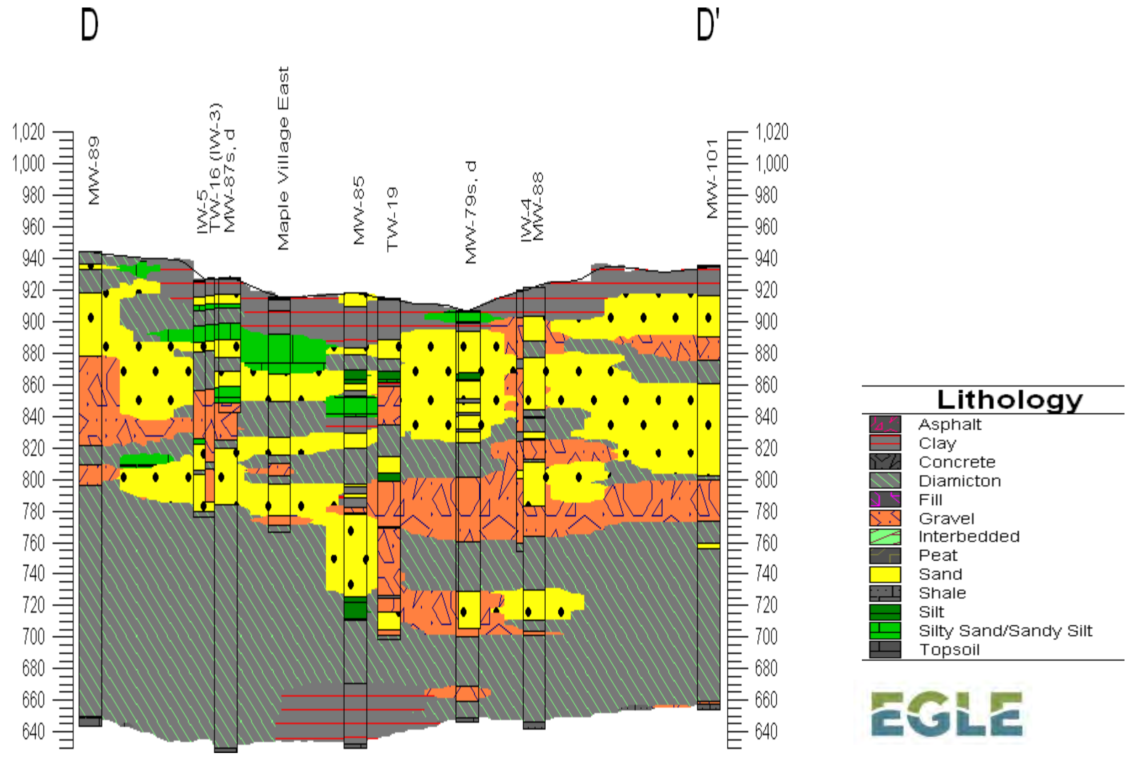


Cross-section from 07-02 B South Montgomery Well B' Northeast MW-97sd.pdf

CROSS-SECTION 07-04 D-D' Comparison



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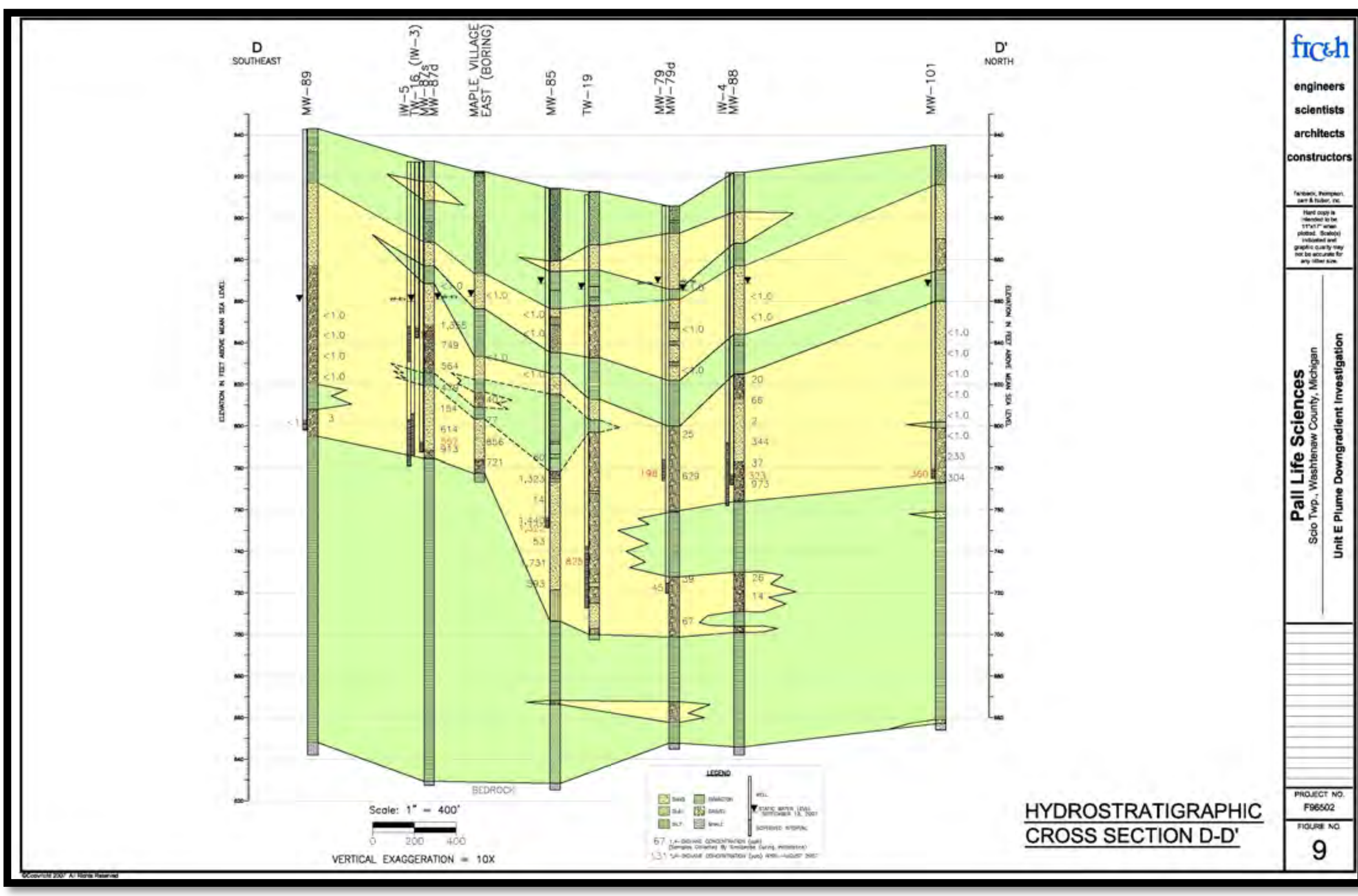
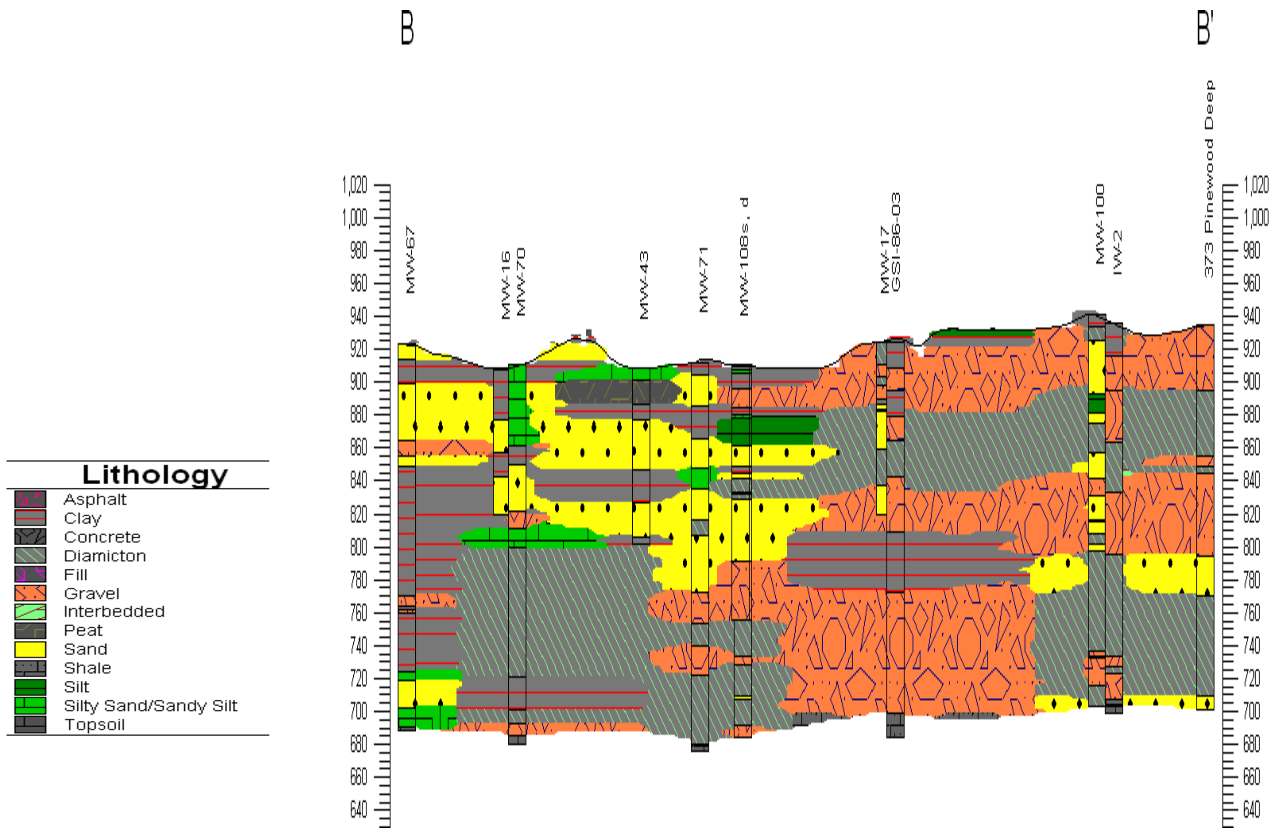


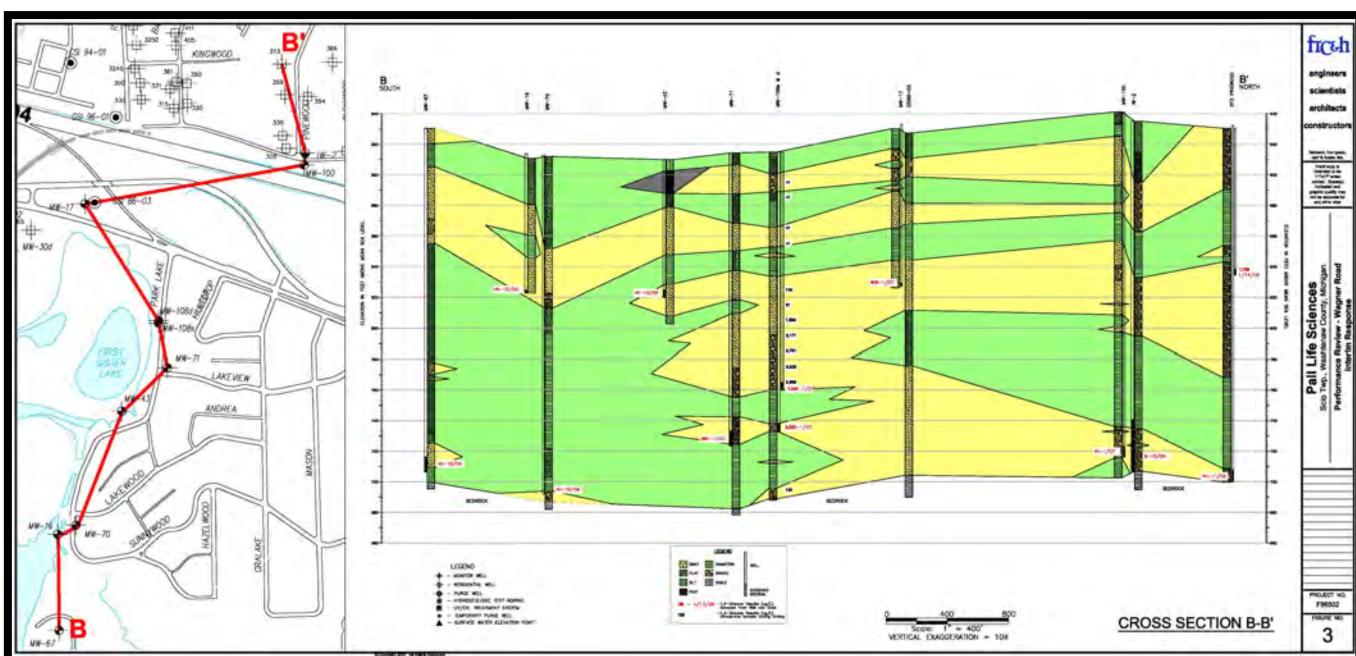
Cross-section from 07-04 D Southeast MW-89 D' North MW-101.pdf

CROSS-SECTION 07-08 B-B’ Comparison



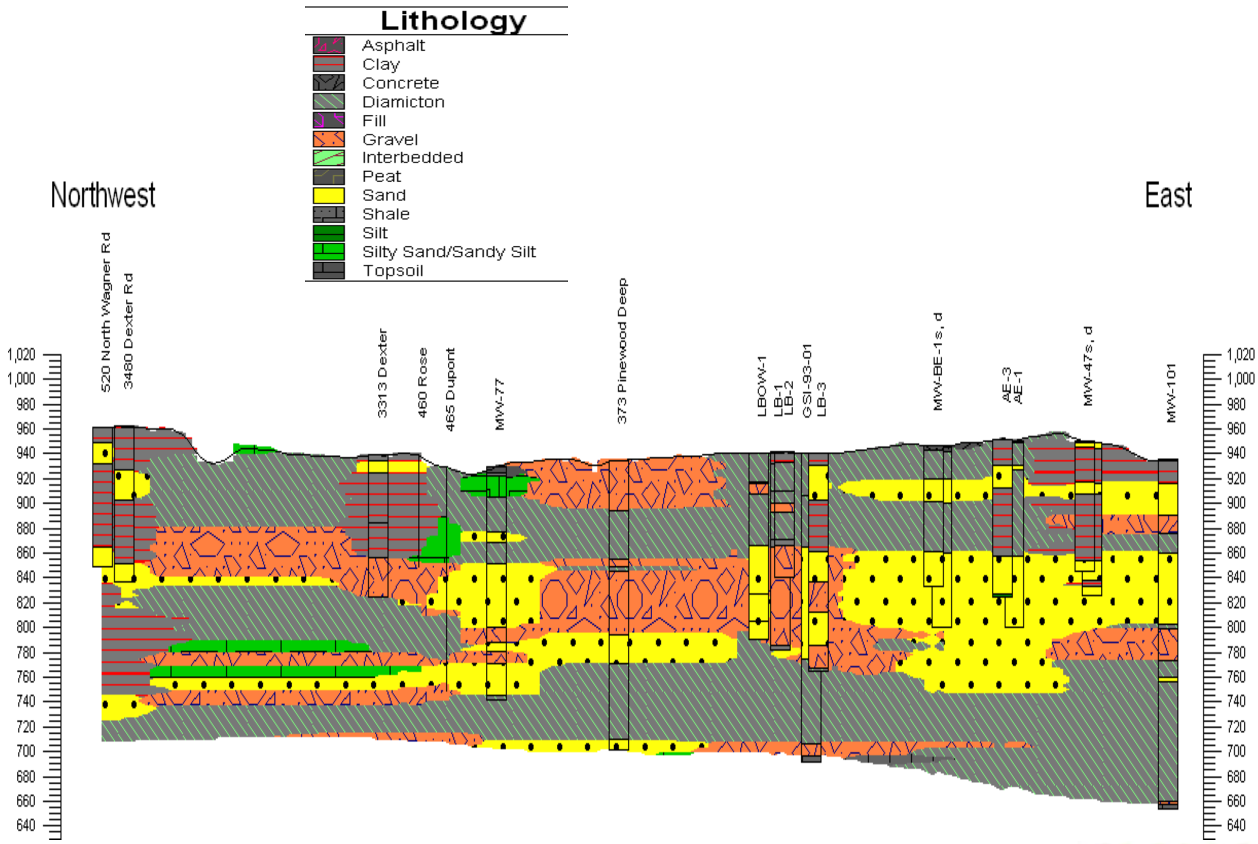
Cross-section exported December 2019

EGLE

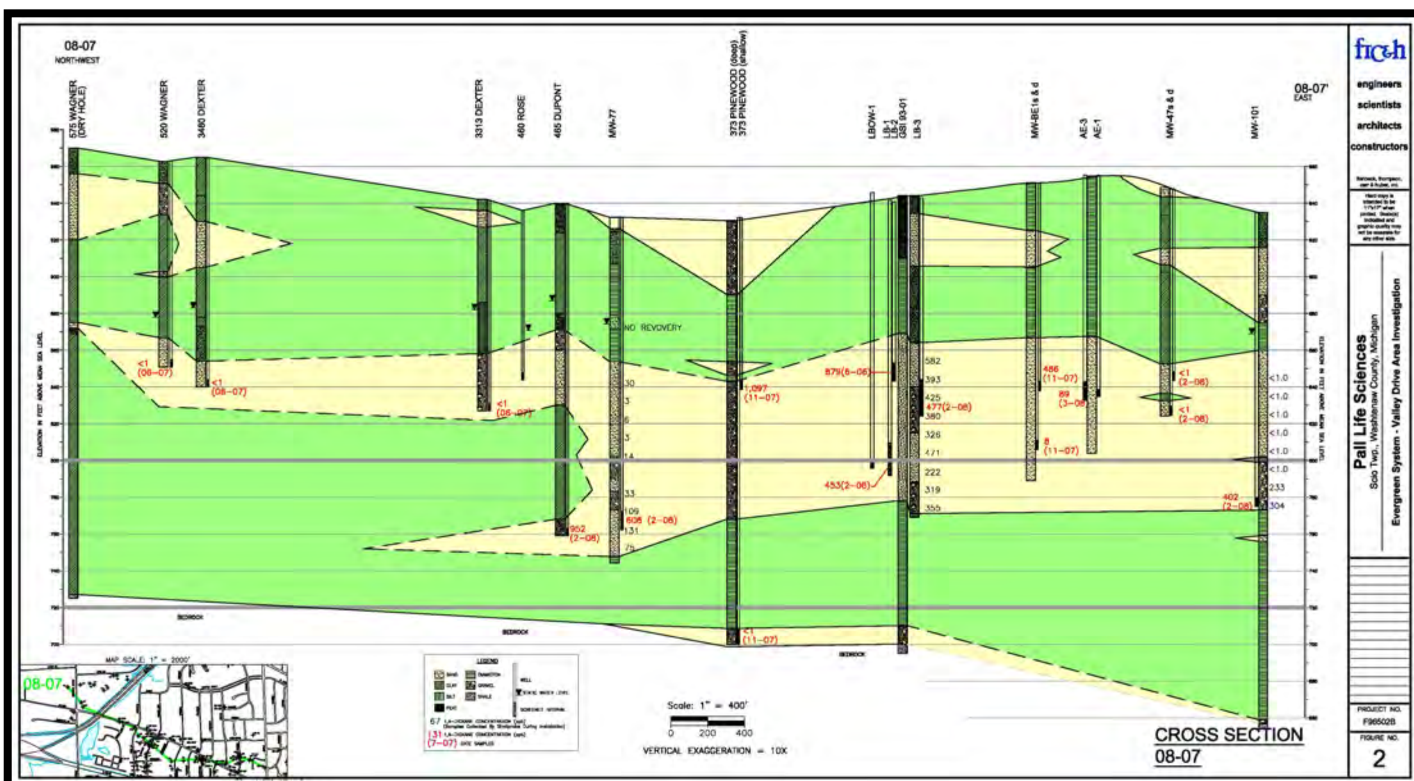


Cross-section from 07-08 B South MW-67 B' North 373 Pinewood.pdf

CROSS-SECTION 08-07 Northwest-East Comparison

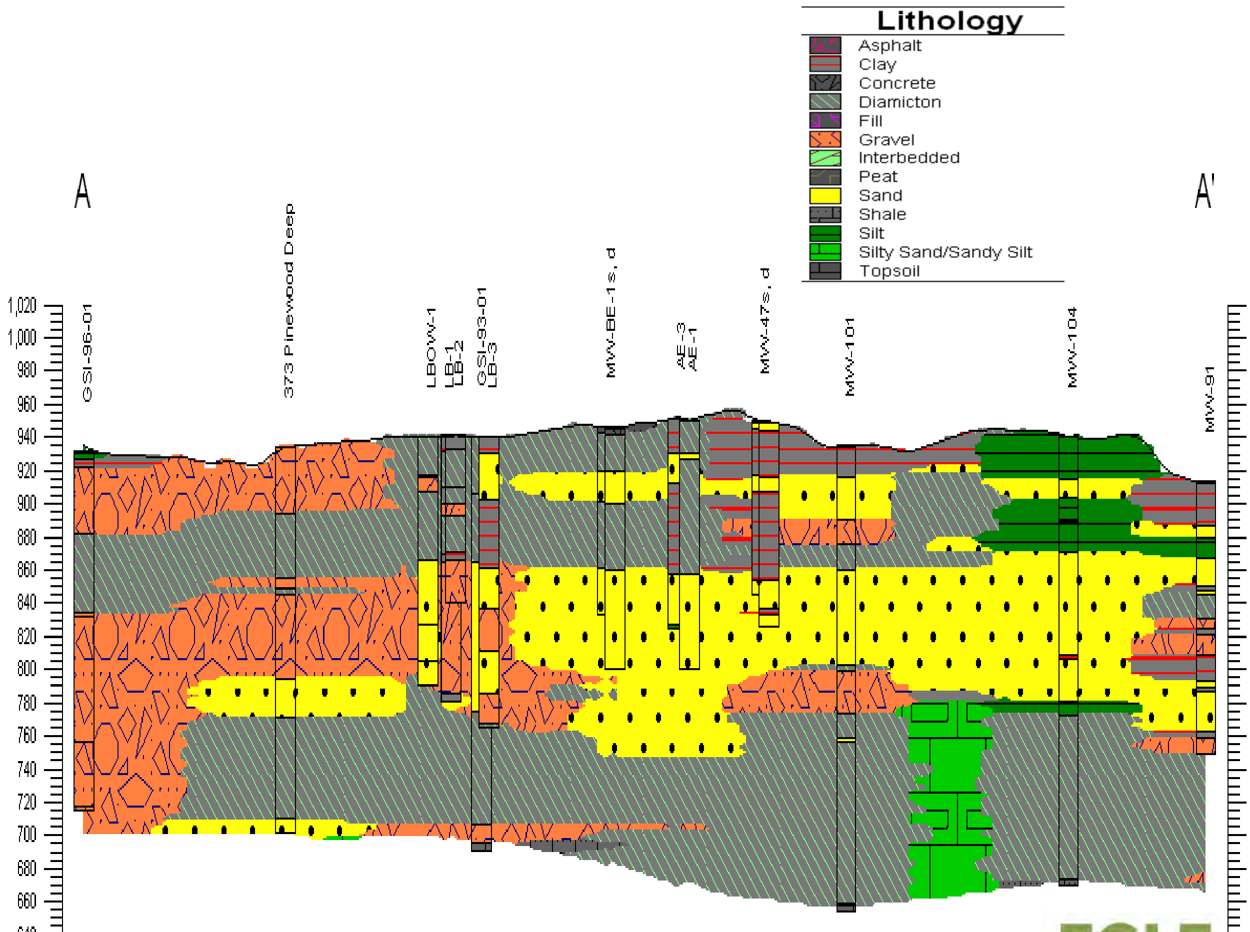


Cross-section exported December 2019



Cross-section from 08-07 (09) Northwest 575 Wagner East MW-101.pdf

CROSS-SECTION 09-01 A-A’ Comparison



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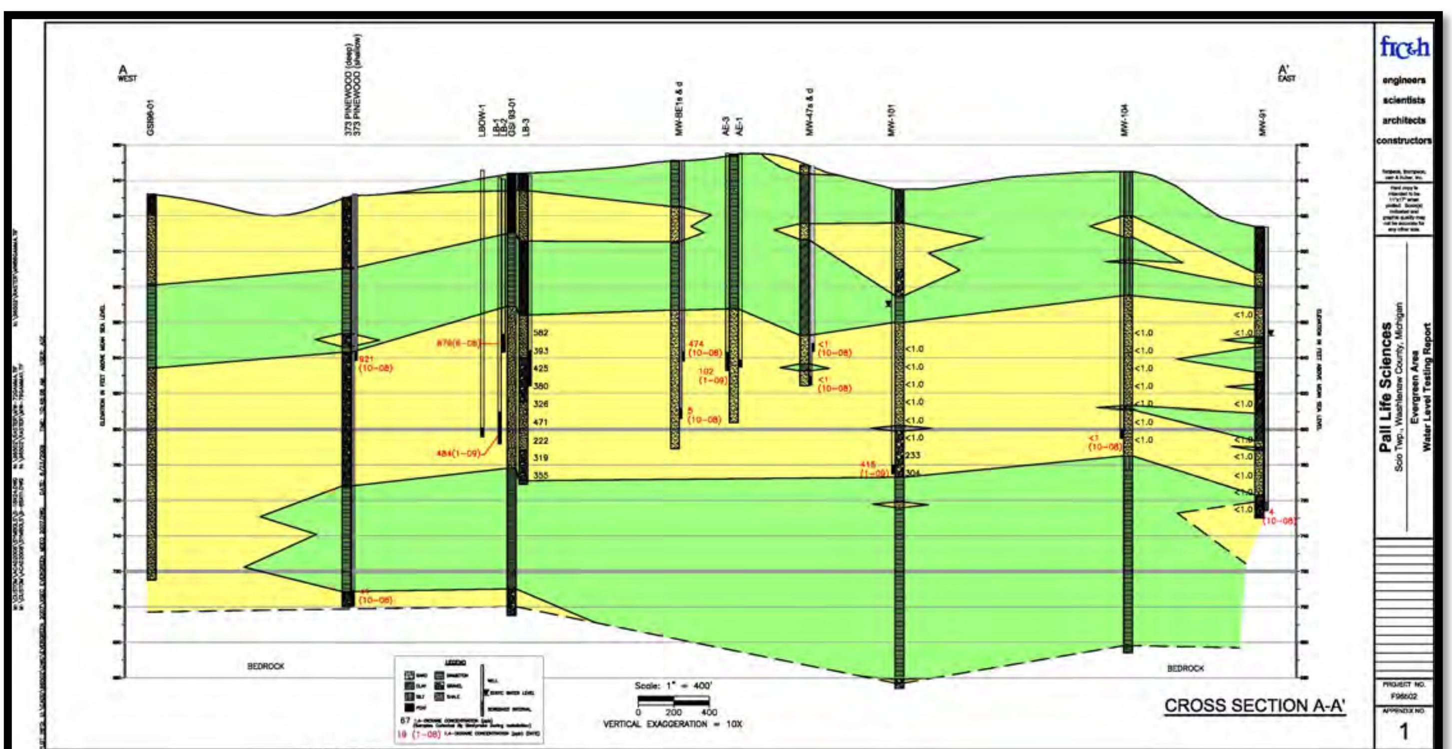
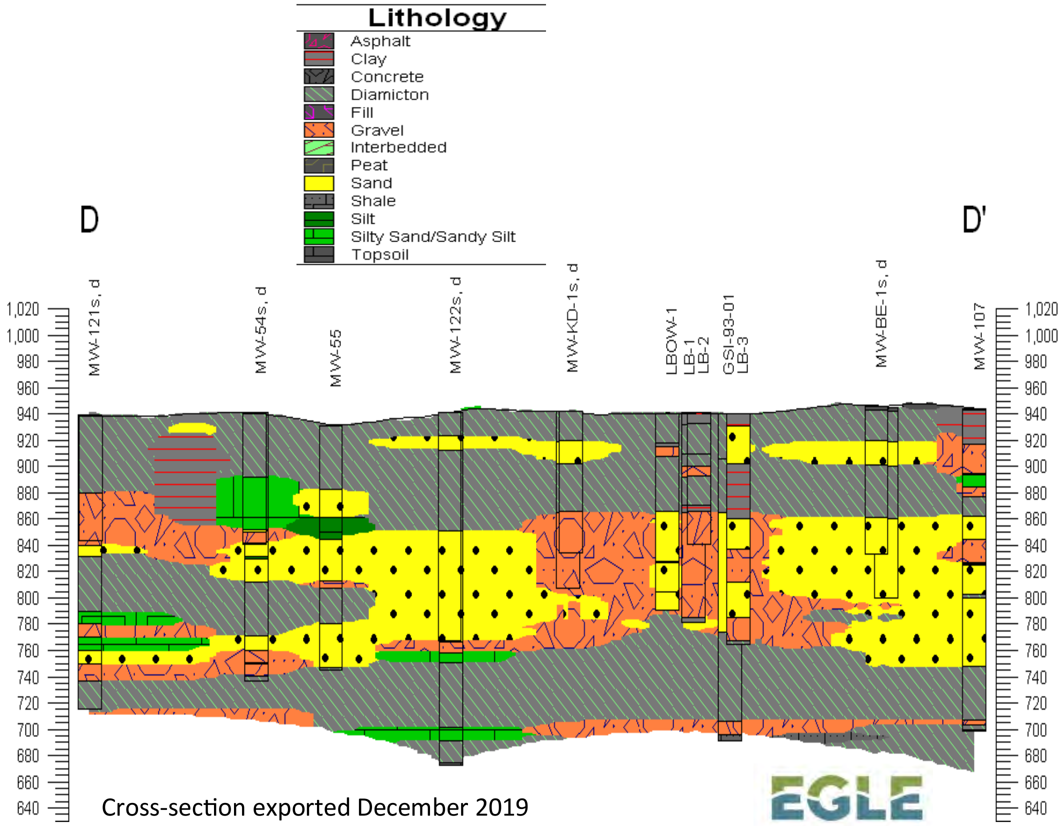


Cross-section from 09-01 A West GSI 96-01 A' East MW-91.pdf

CROSS-SECTION 09-04 D-D' Comparison



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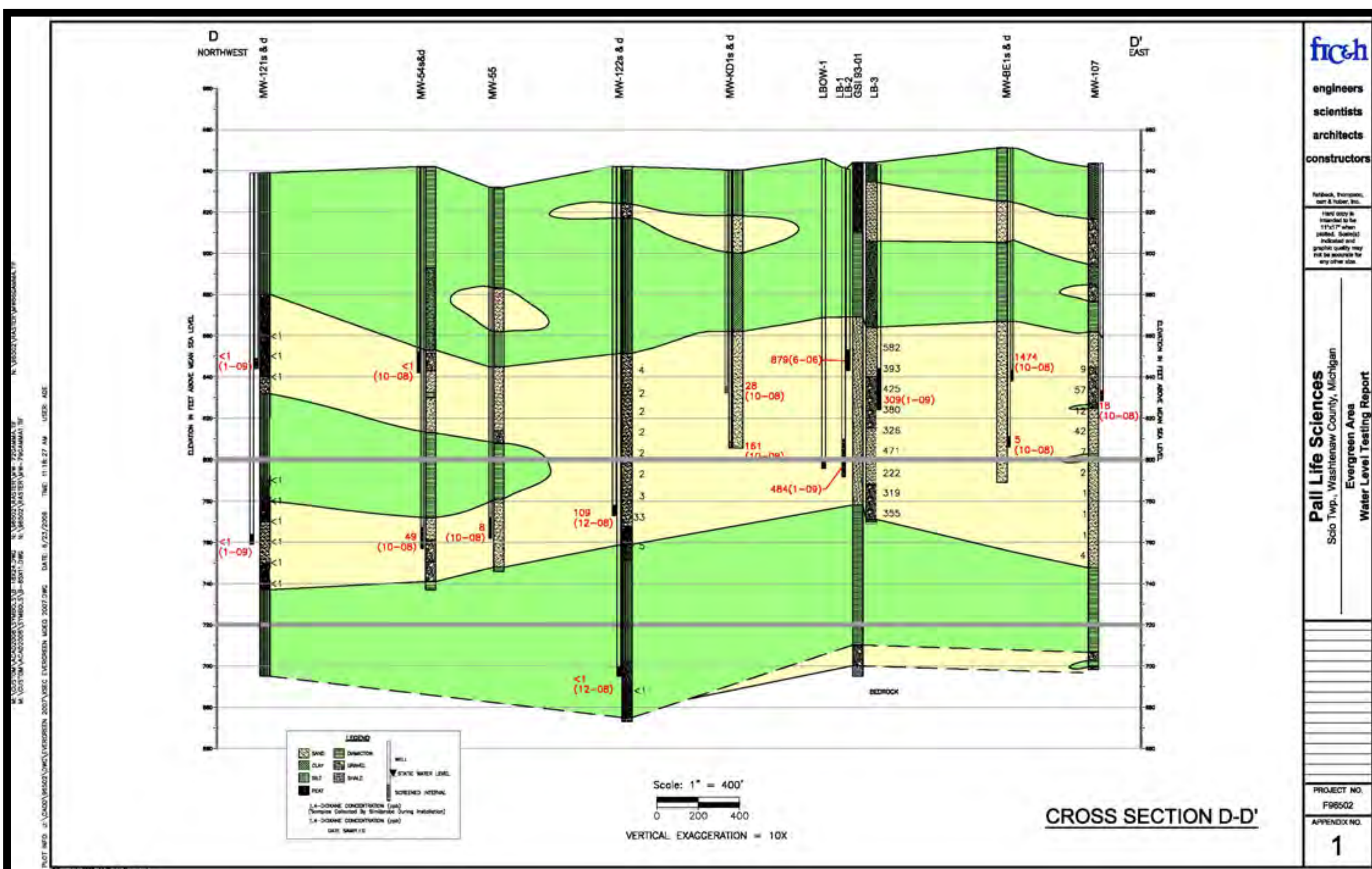
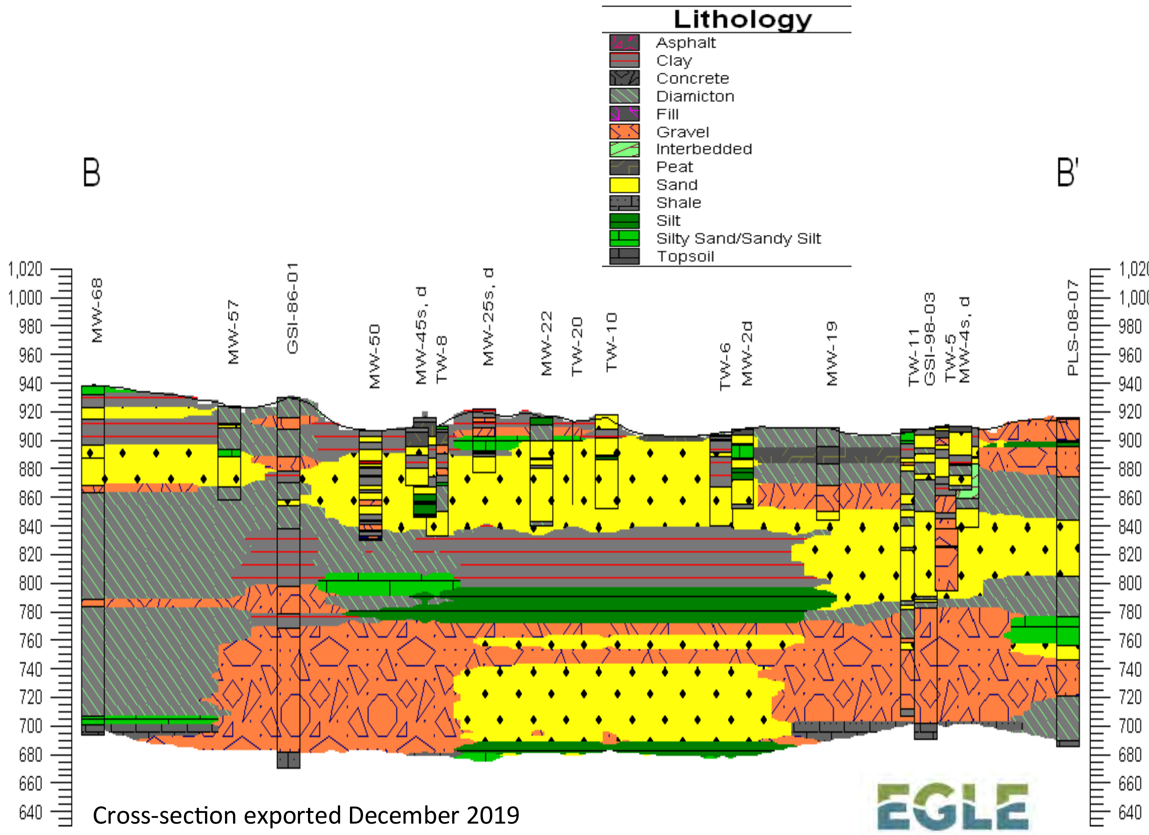


Cross-section from 09-04 D Northwest MW-121sd D' East MW-107.pdf

CROSS-SECTION 09-09 B-B' Comparison



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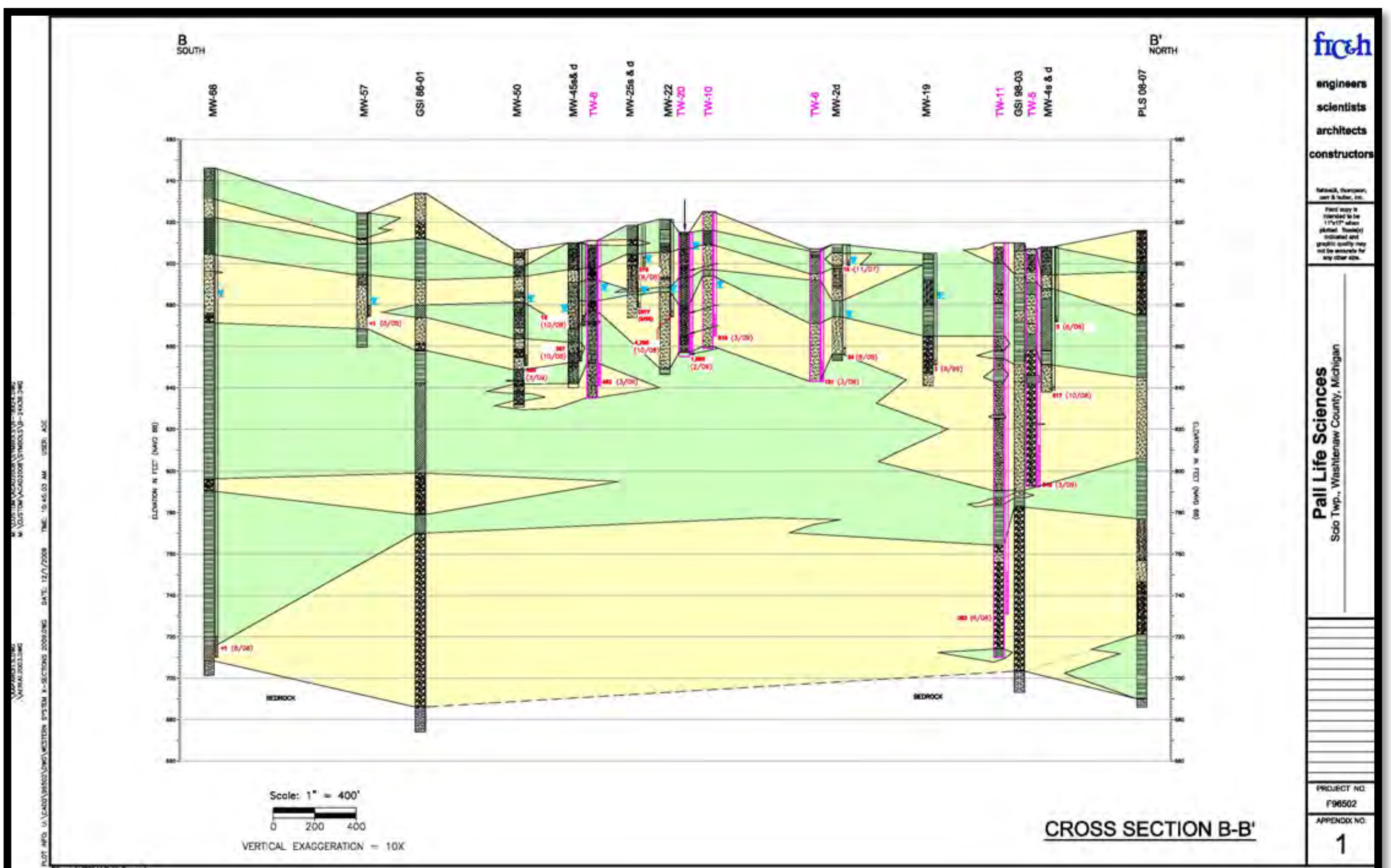
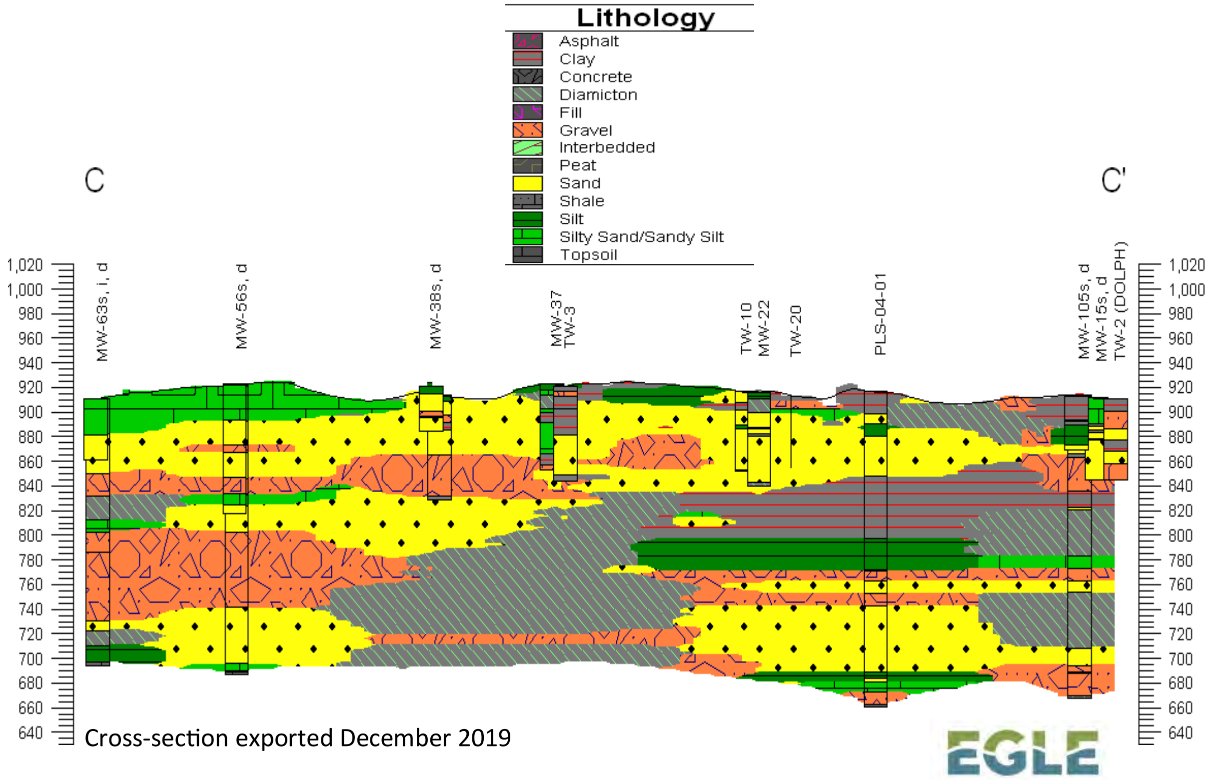
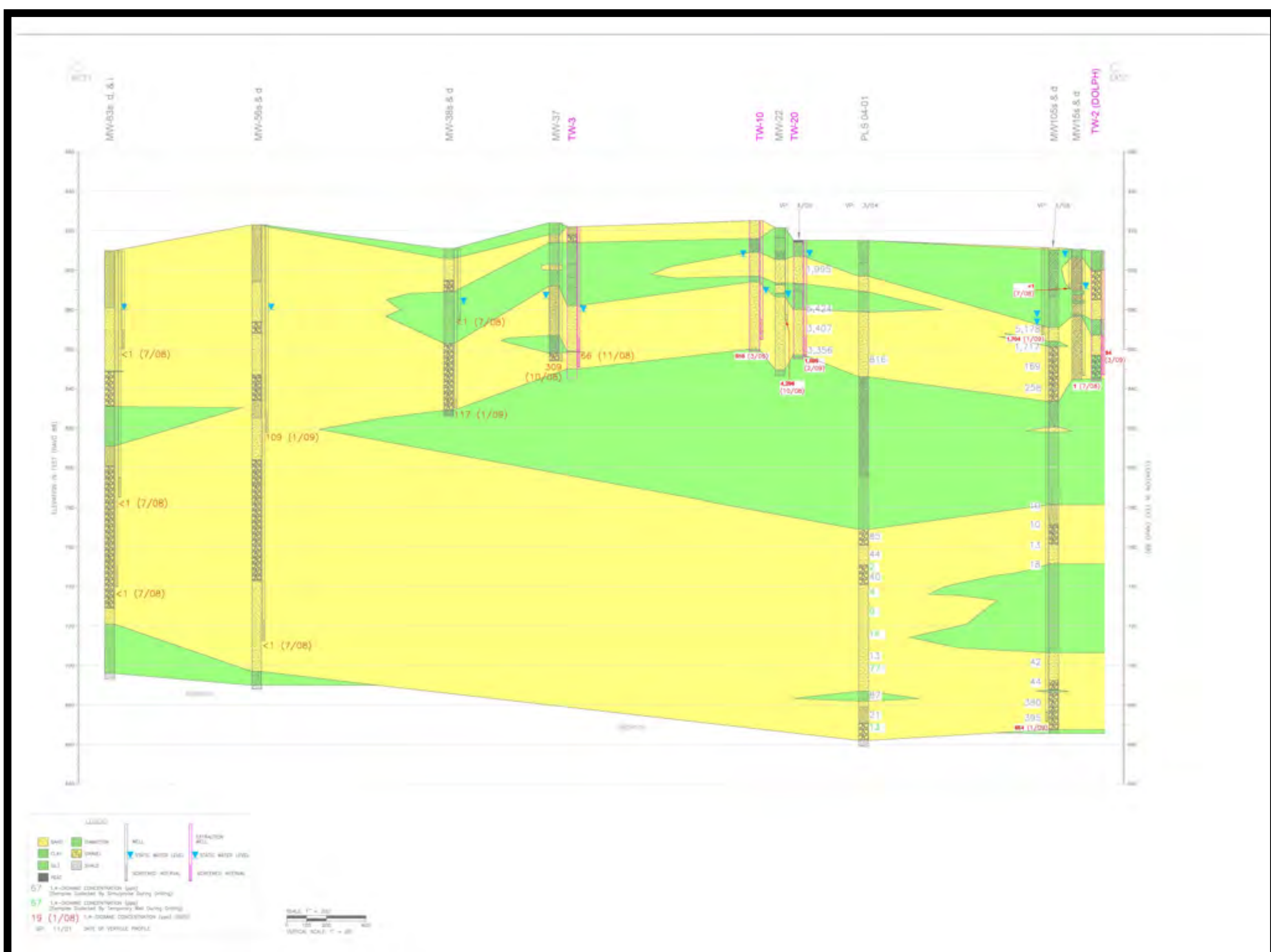


Cross-section from 09-09 B South MW-68 B' North PLS08-07.pdf

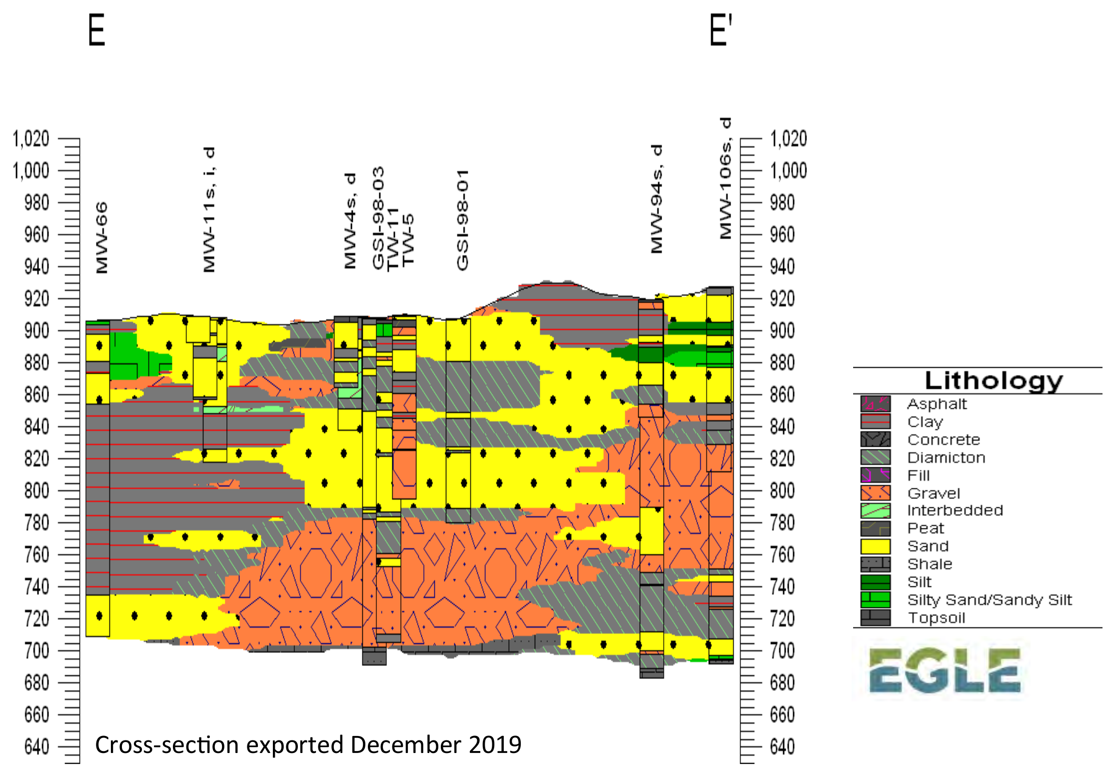
CROSS-SECTION 09-10 C-C' Comparison



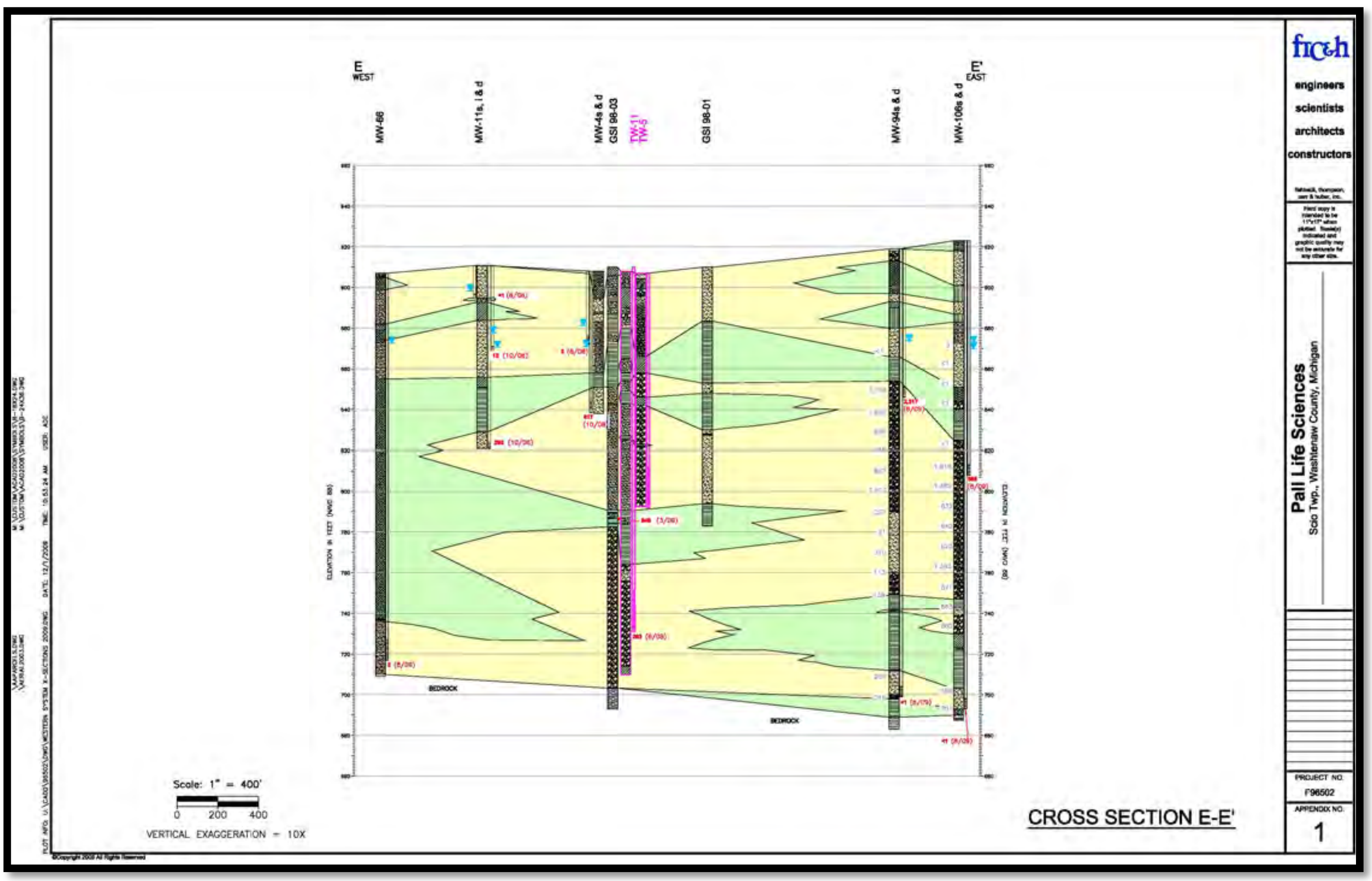


Cross-section from 09-10 C West MW-63sid C' East TW-2(Dolph) (with 1,4-D data).pdf

CROSS-SECTION 09-11 E-E' Comparison

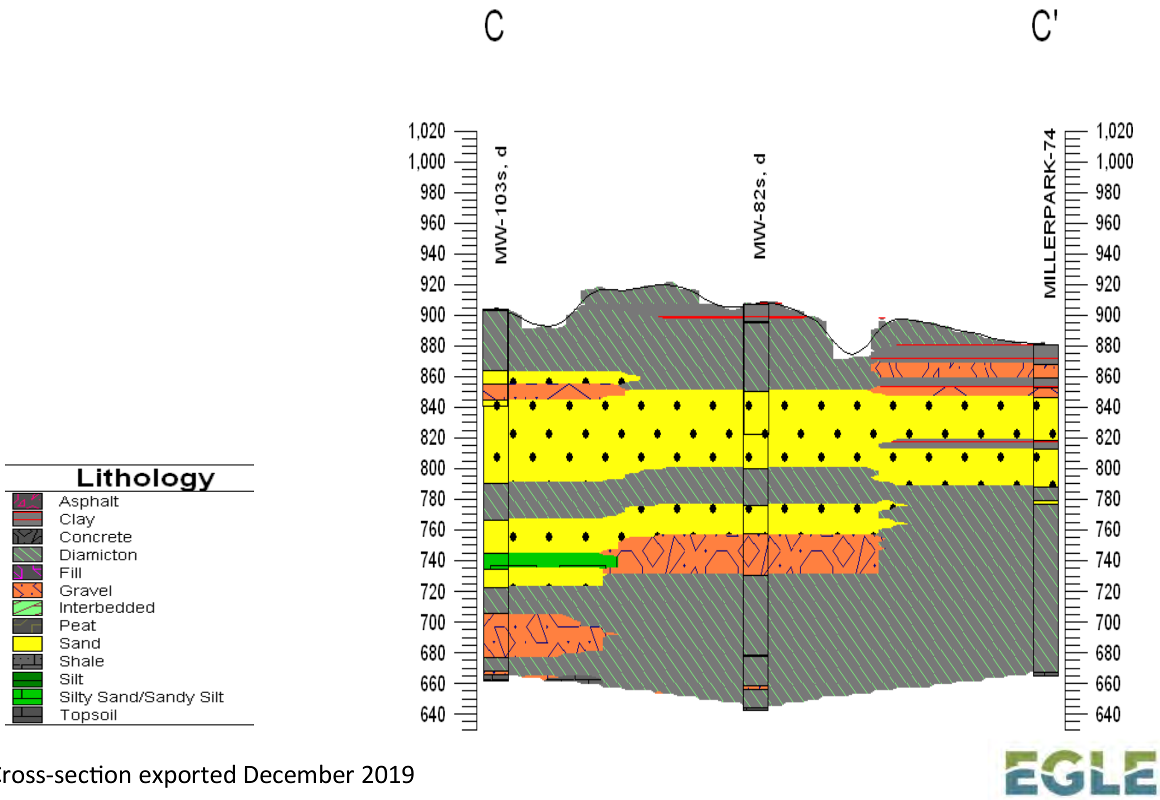


Cross-section exported December 2019



Cross-section from 09-11 E West MW-66 E' East MW-106sd.pdf

CROSS-SECTION 09-12 C-C' Comparison



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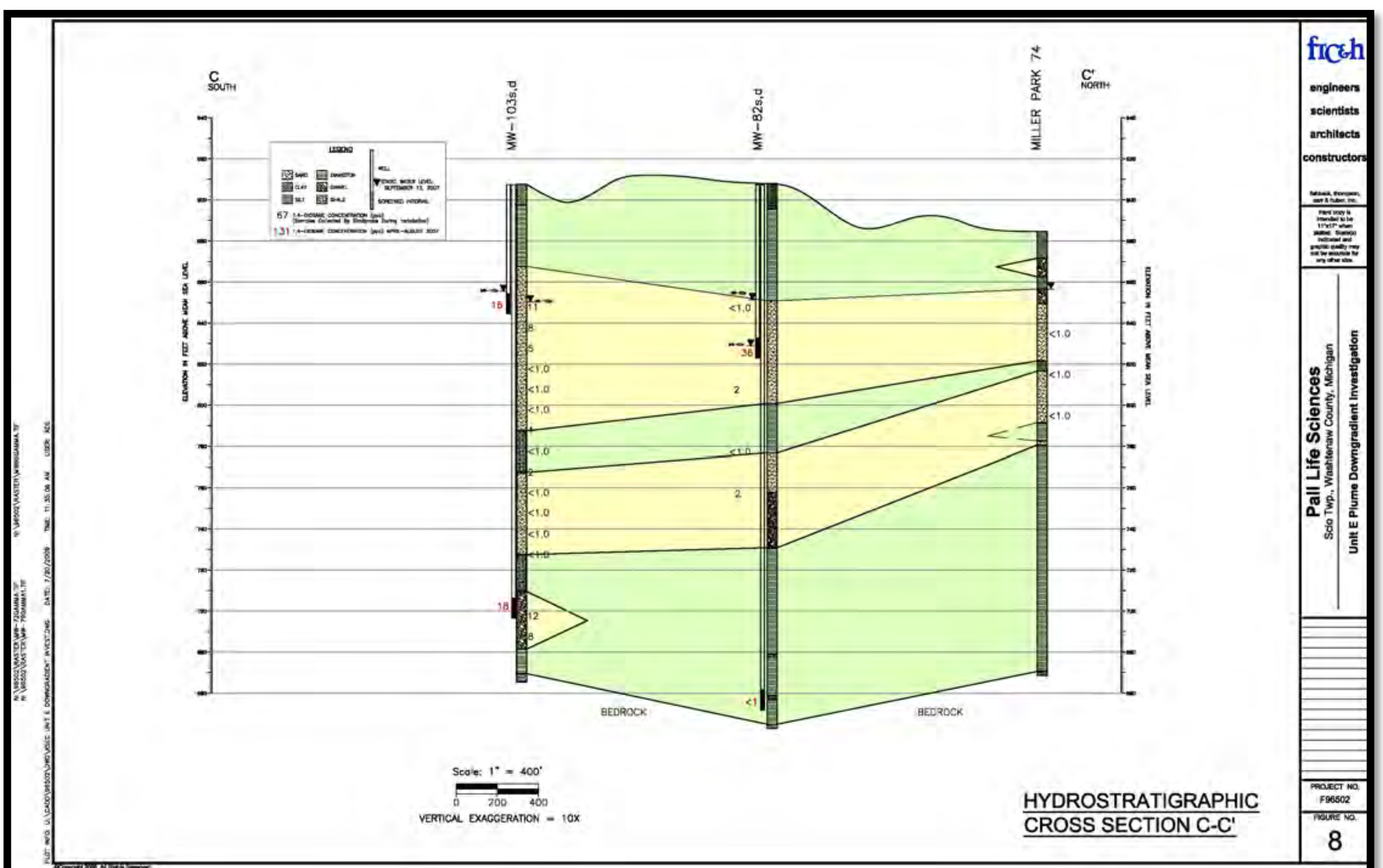
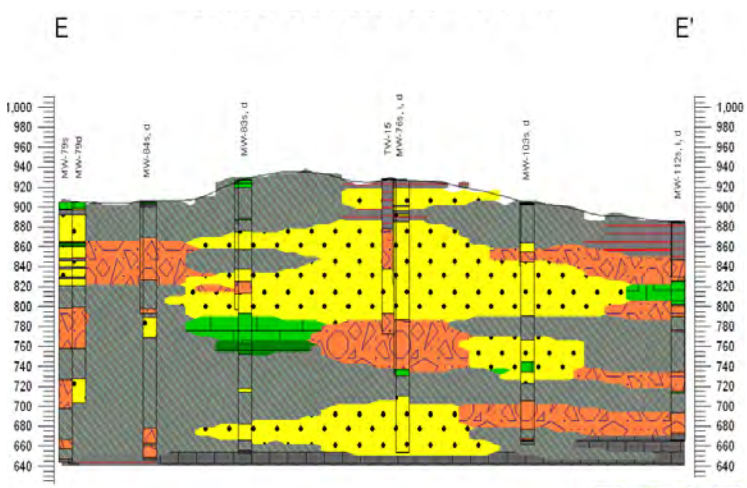
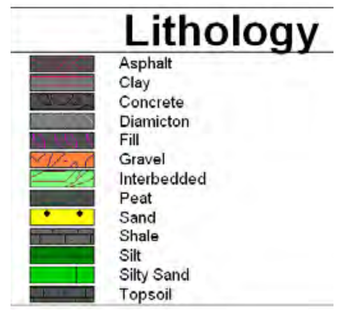


Cross-section from 09-12 C South MW-103sd C' North Miller Park 74.pdf

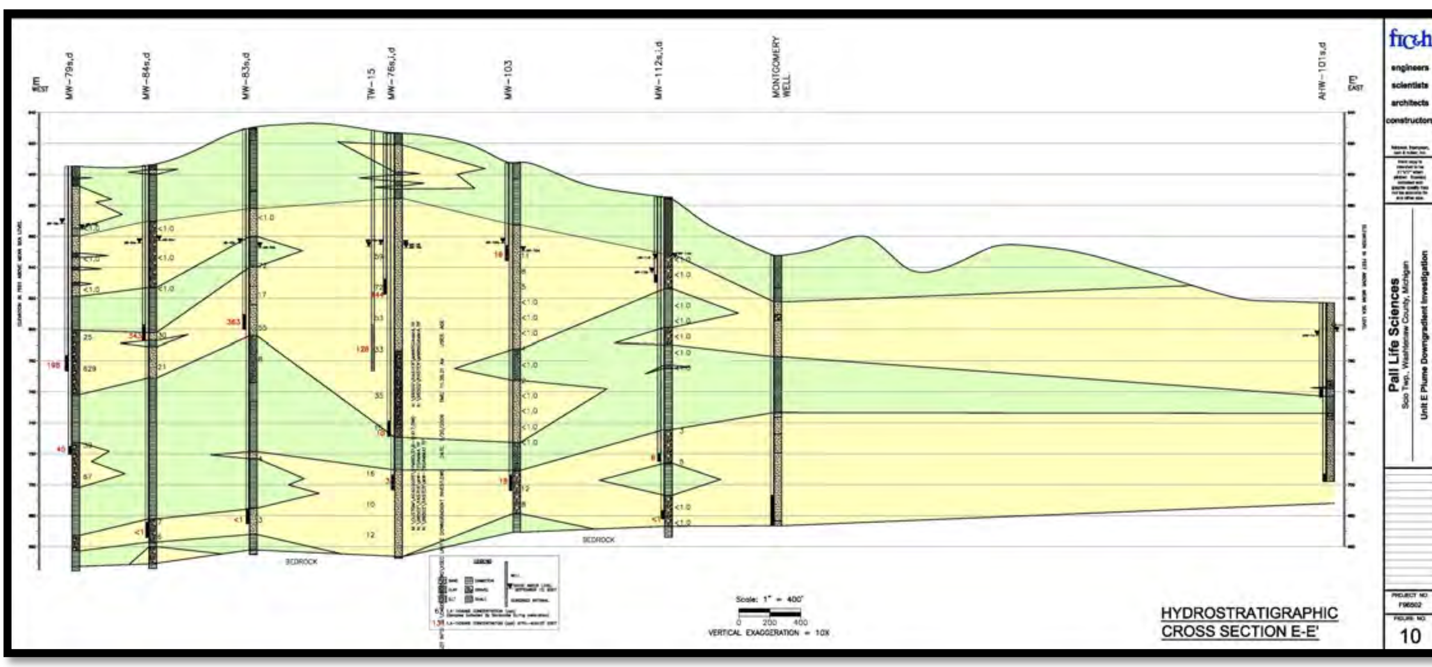
CROSS-SECTION 09-13 E-E' Comparison





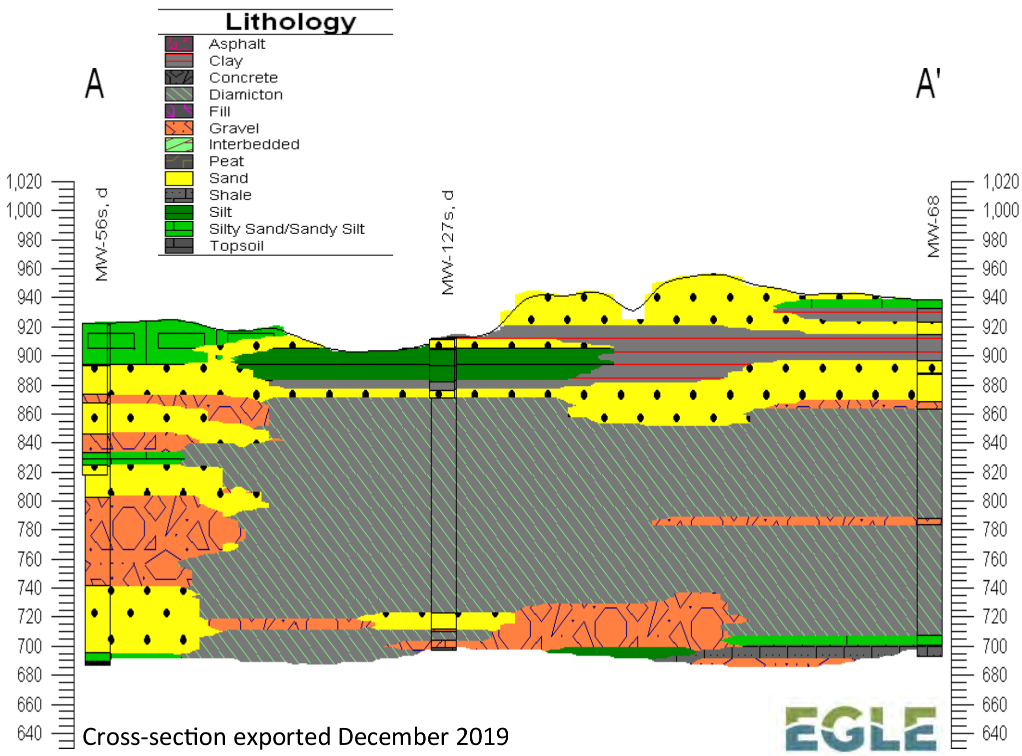
Cross-section exported October 2019

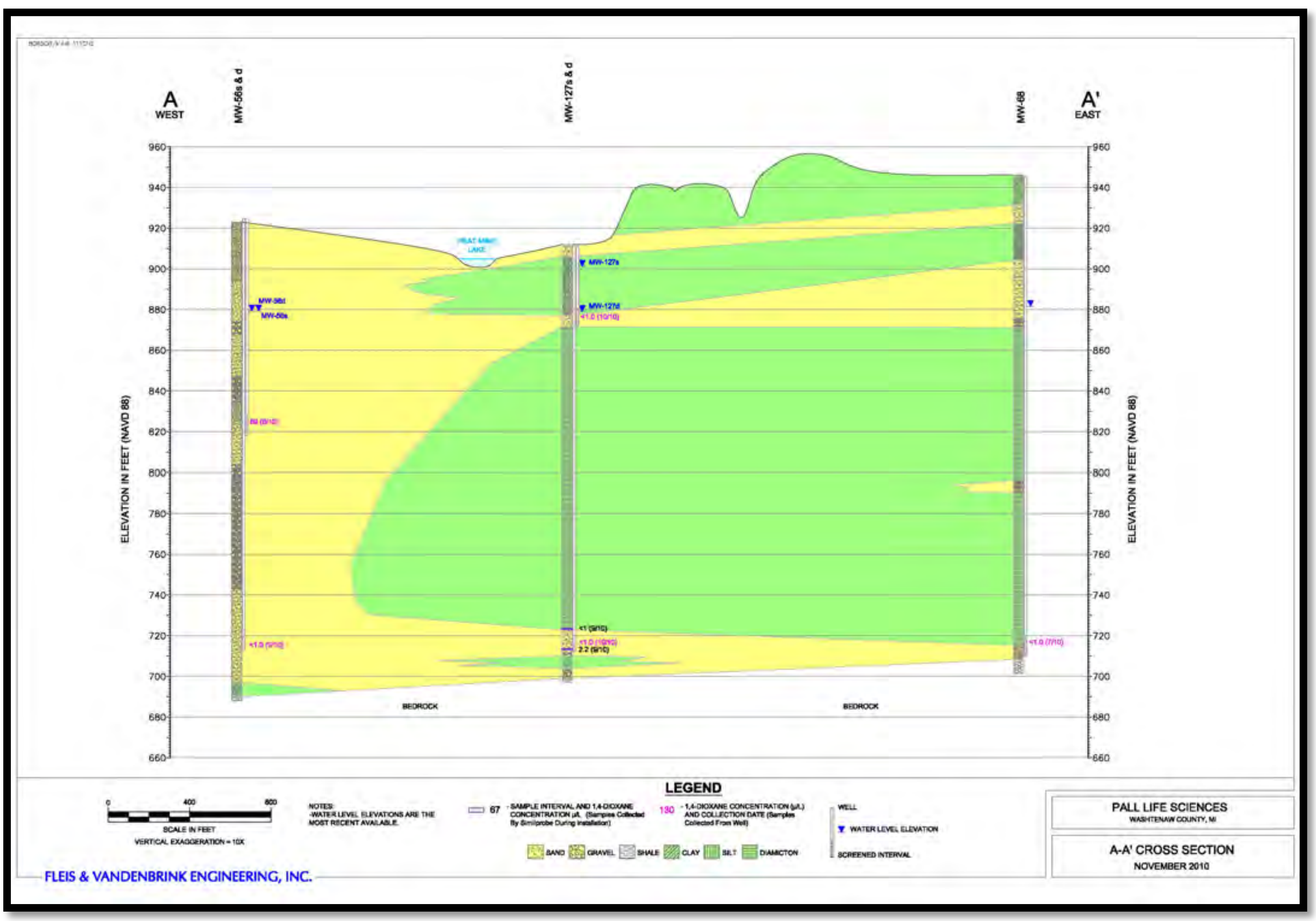
EGLE



Cross-section from 09-13 E West MW-79sd E' East AHW-101sd.pdf

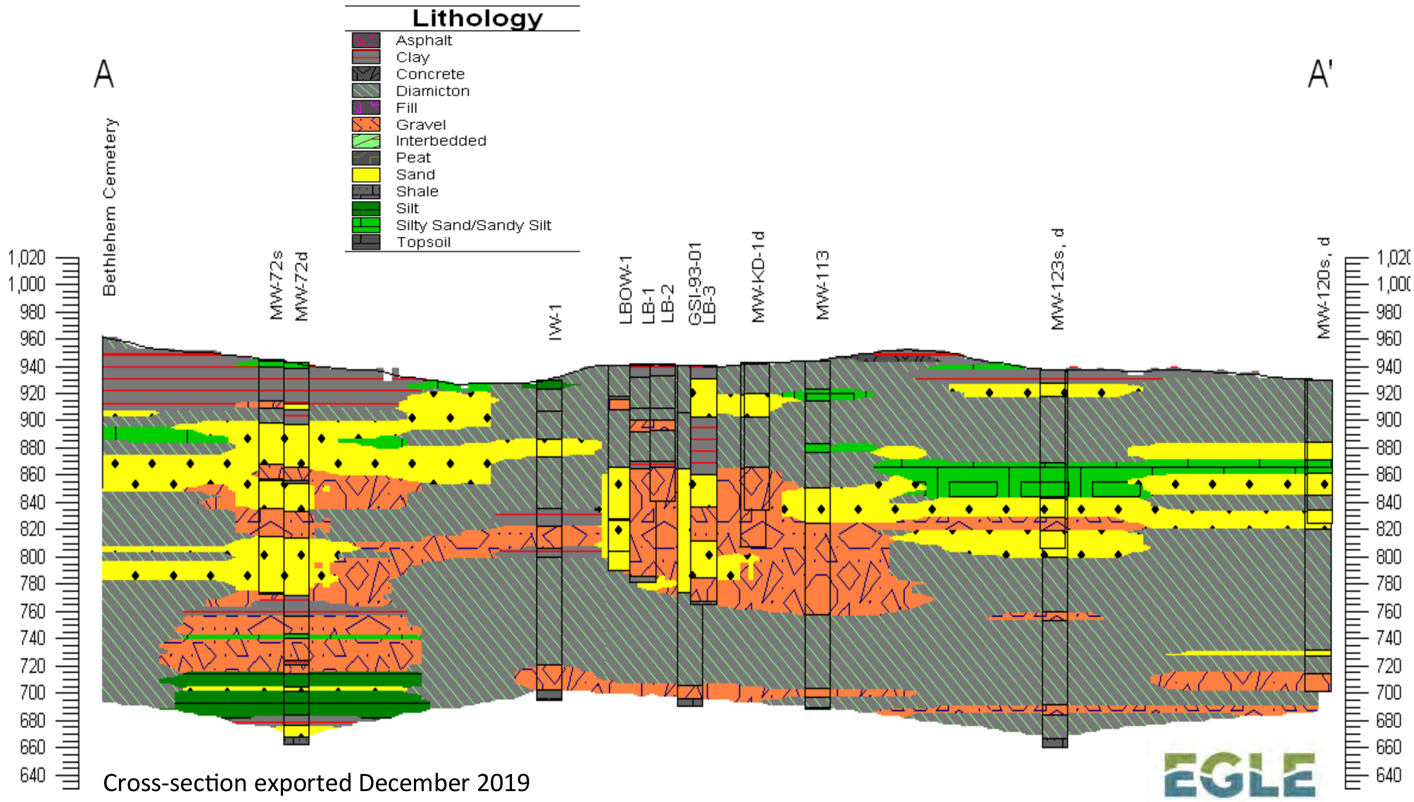
CROSS-SECTION 10-01 A-A' Comparison





Cross-section from 10-01 A West MW-56sd A' East MW-68.pdf

CROSS-SECTION 11-01 A-A' Comparison



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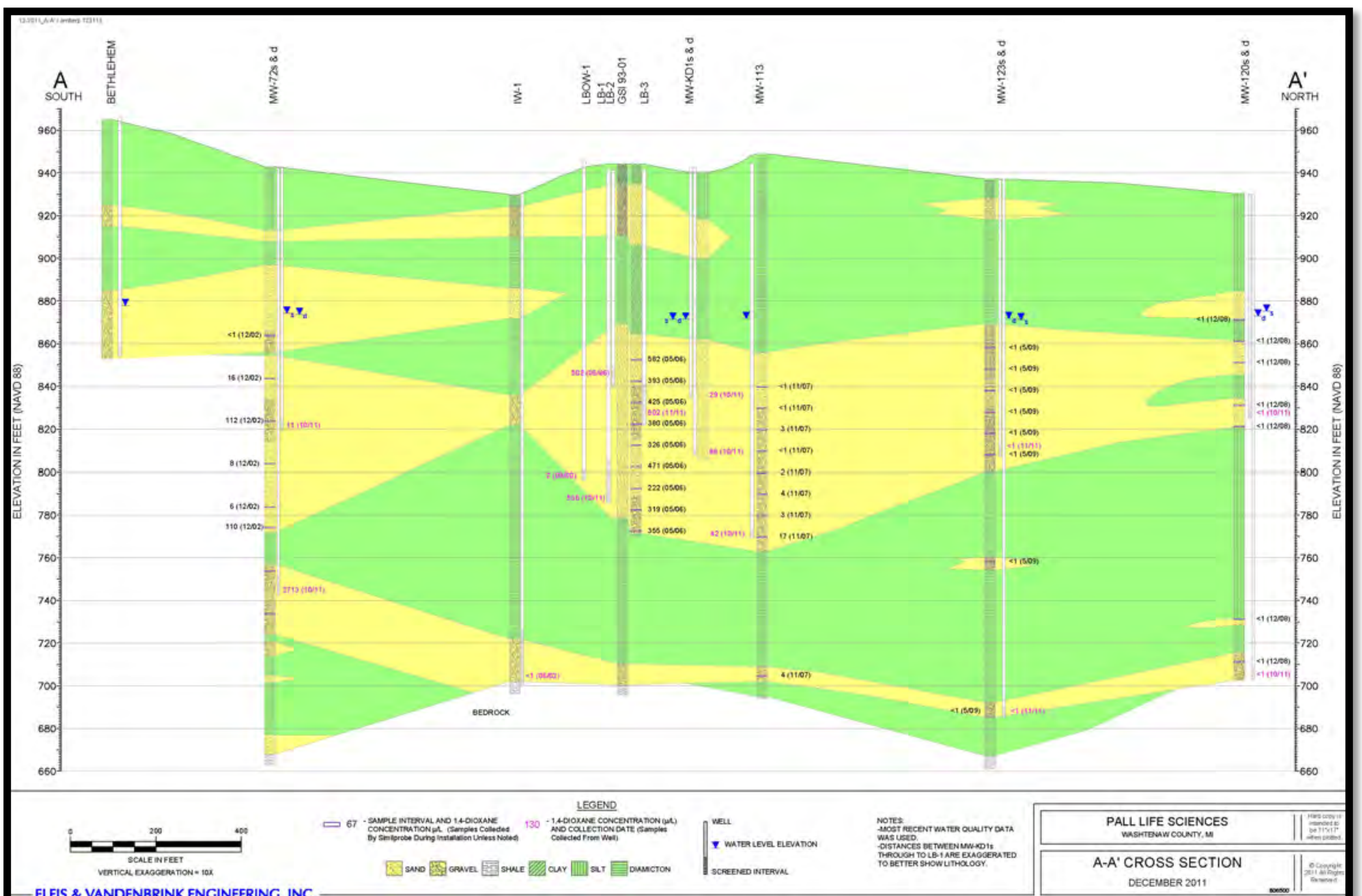
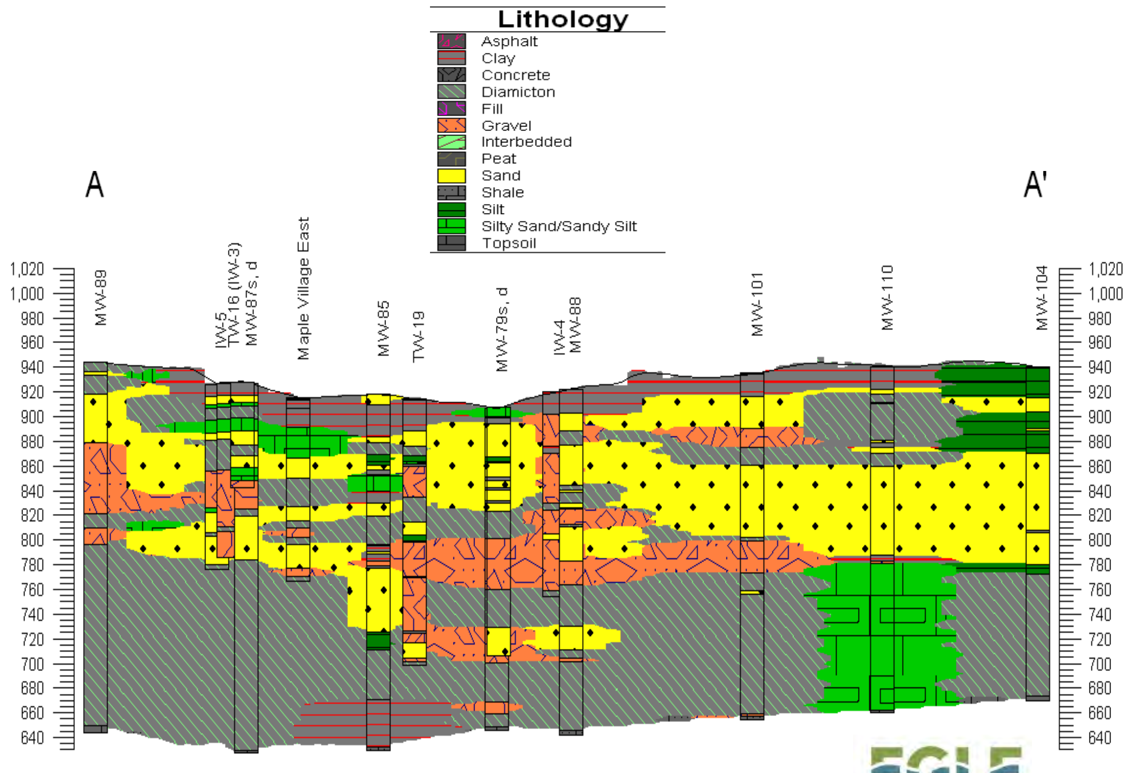
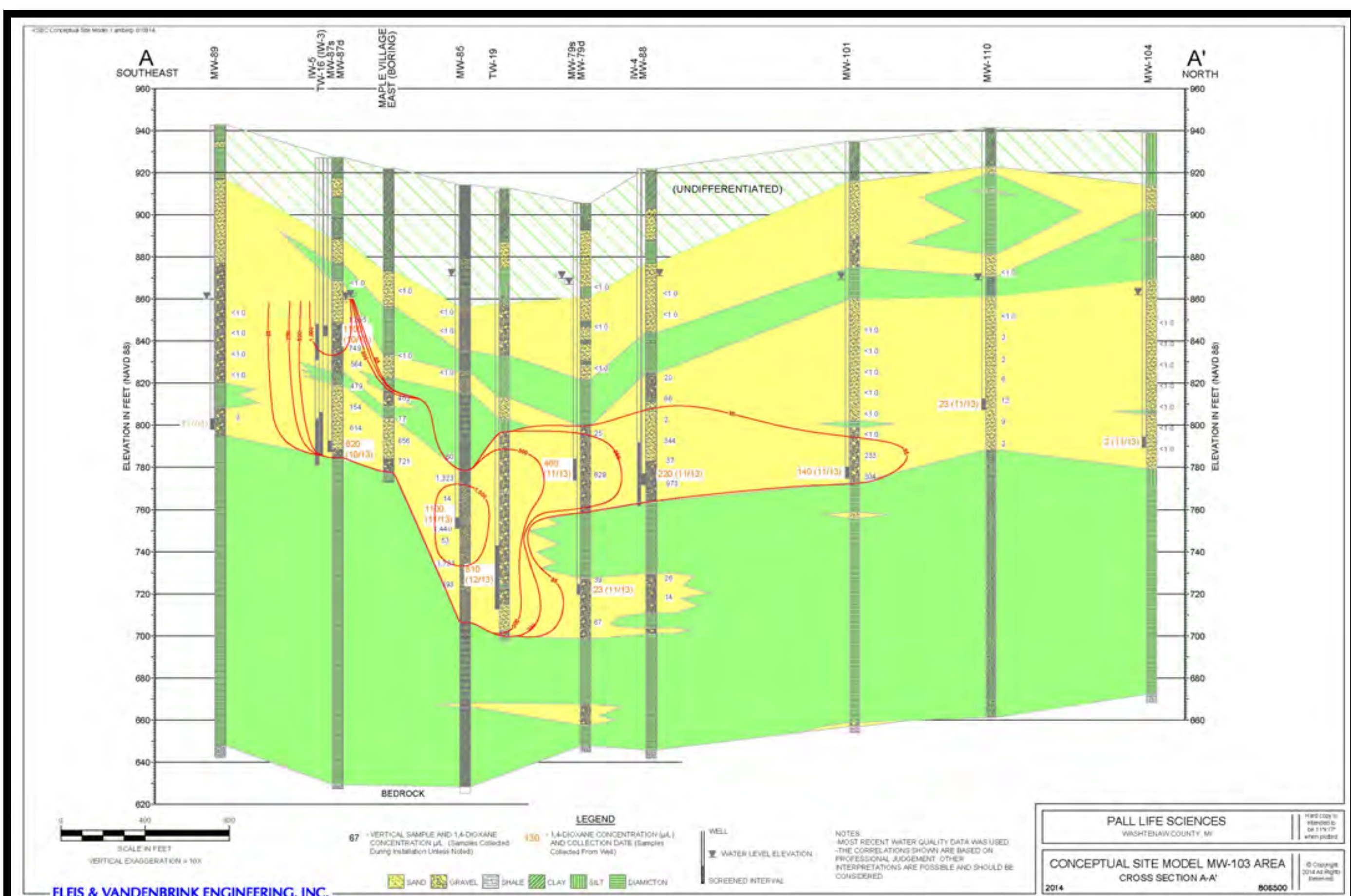


Cross-section from 11-01 A South Bethlehem A' North MW-120sd.pdf

CROSS-SECTION 14-01 A-A' Comparison

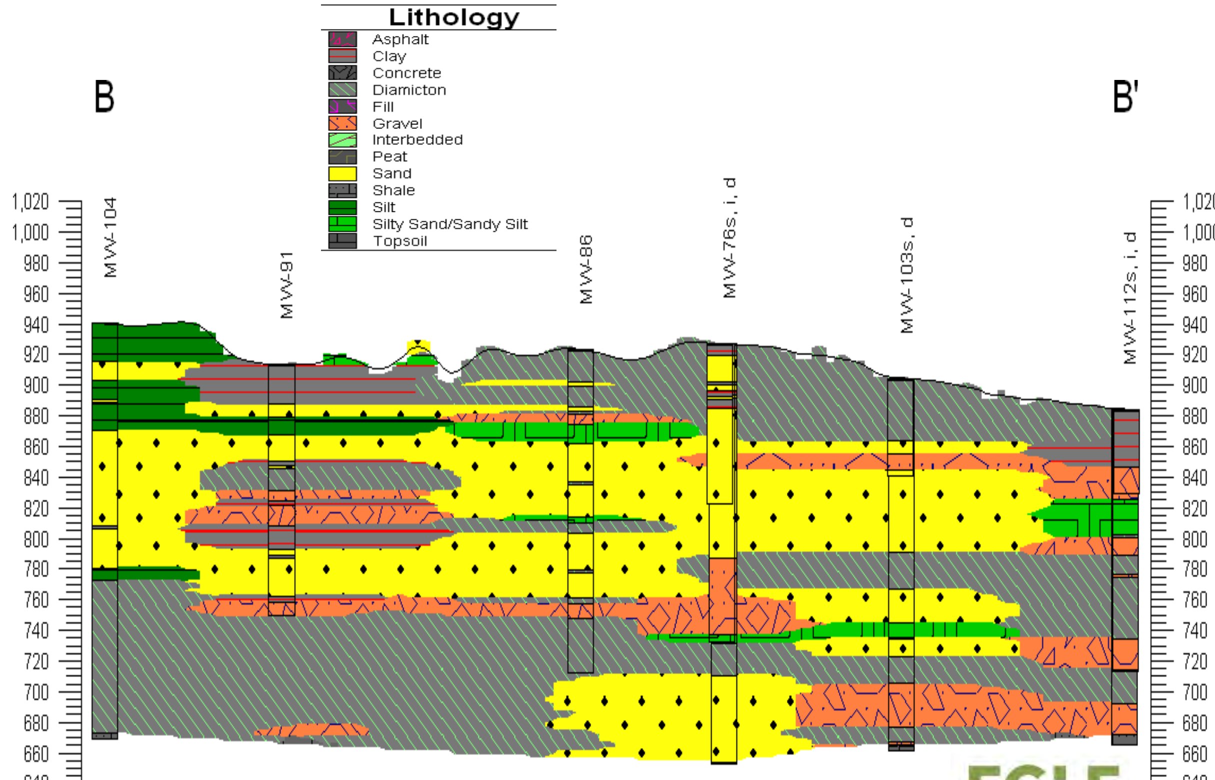


Cross-section exported December 2019



Cross-section from 14-01 A Southeast MW-89 A' North MW-104.pdf

CROSS-SECTION 14-02 B-B' Comparison



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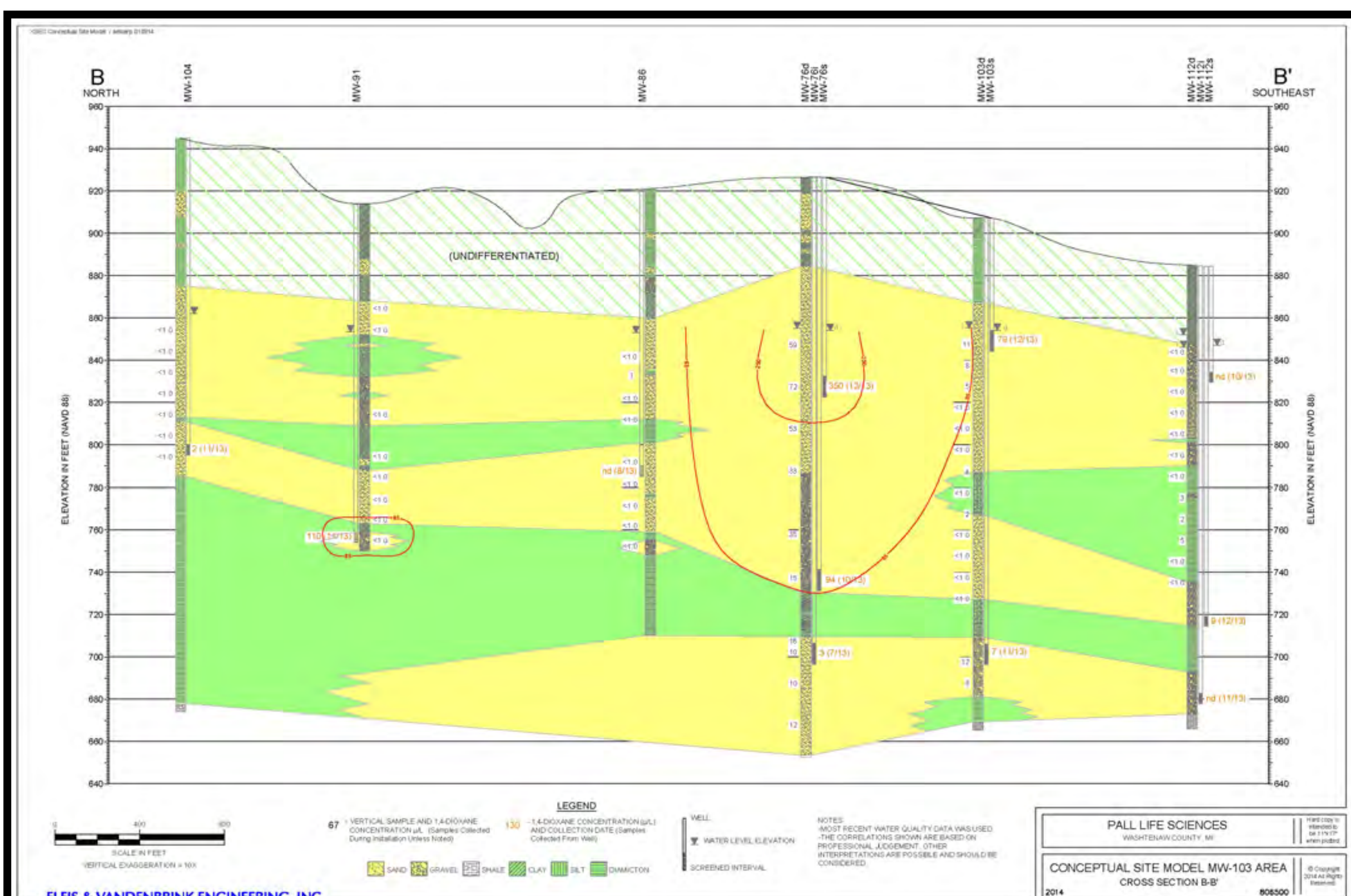
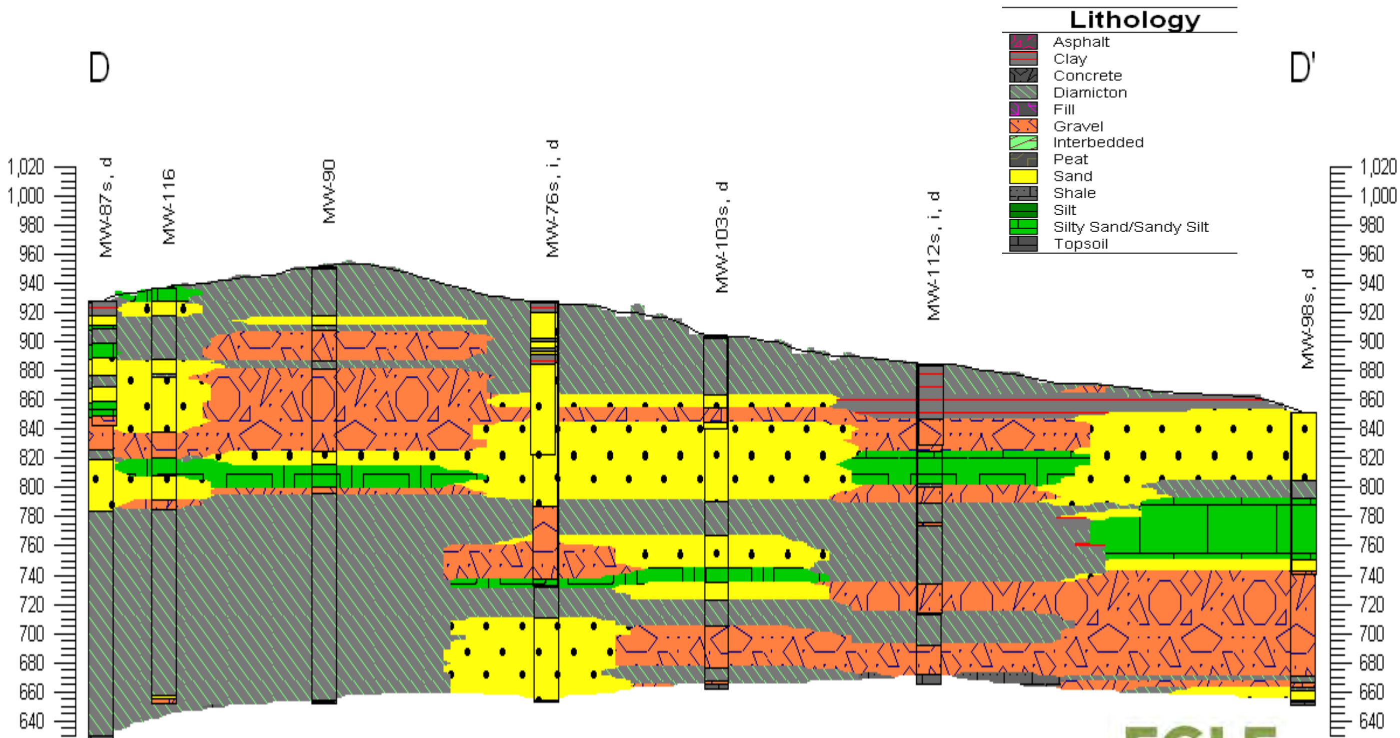


Cross-section from 14-02 B North MW-104 B' Southeast MW-112sid.pdf

CROSS-SECTION 14-04 D-D' Comparison



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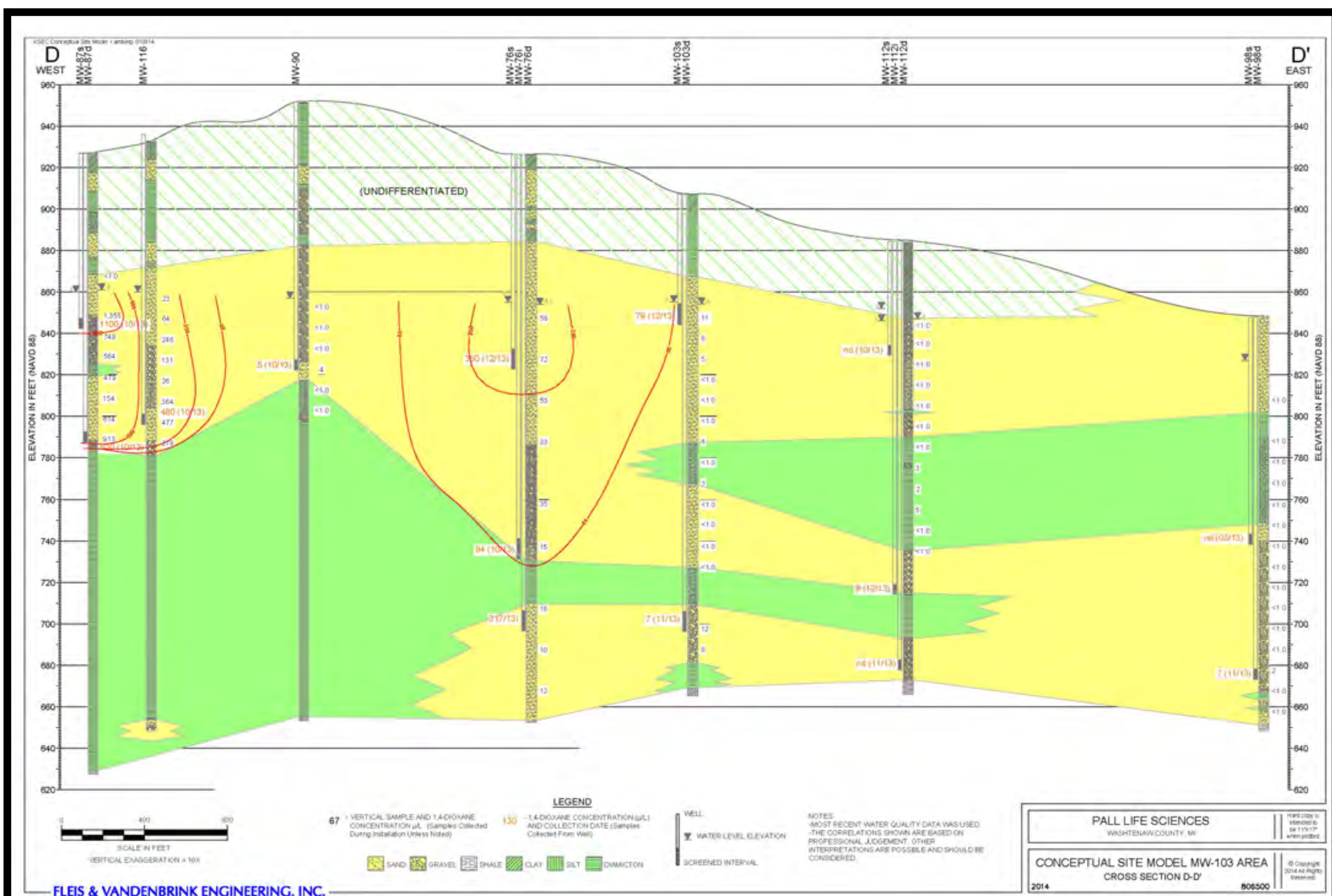
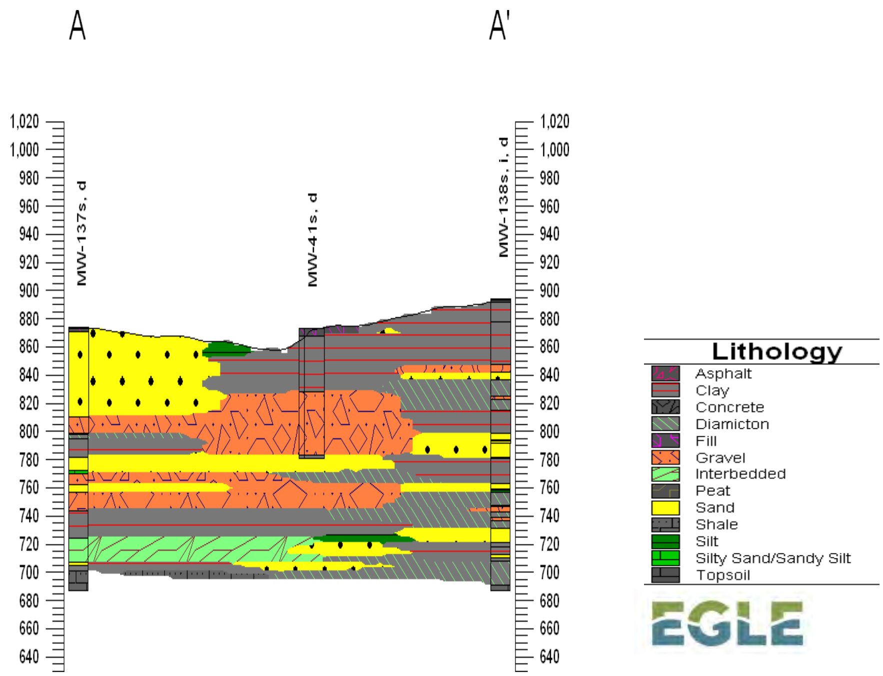


Cross-section from 14-04 D West MW-87sd D' East MW-98sd.pdf

CROSS-SECTION 15-01 A-A' Comparison



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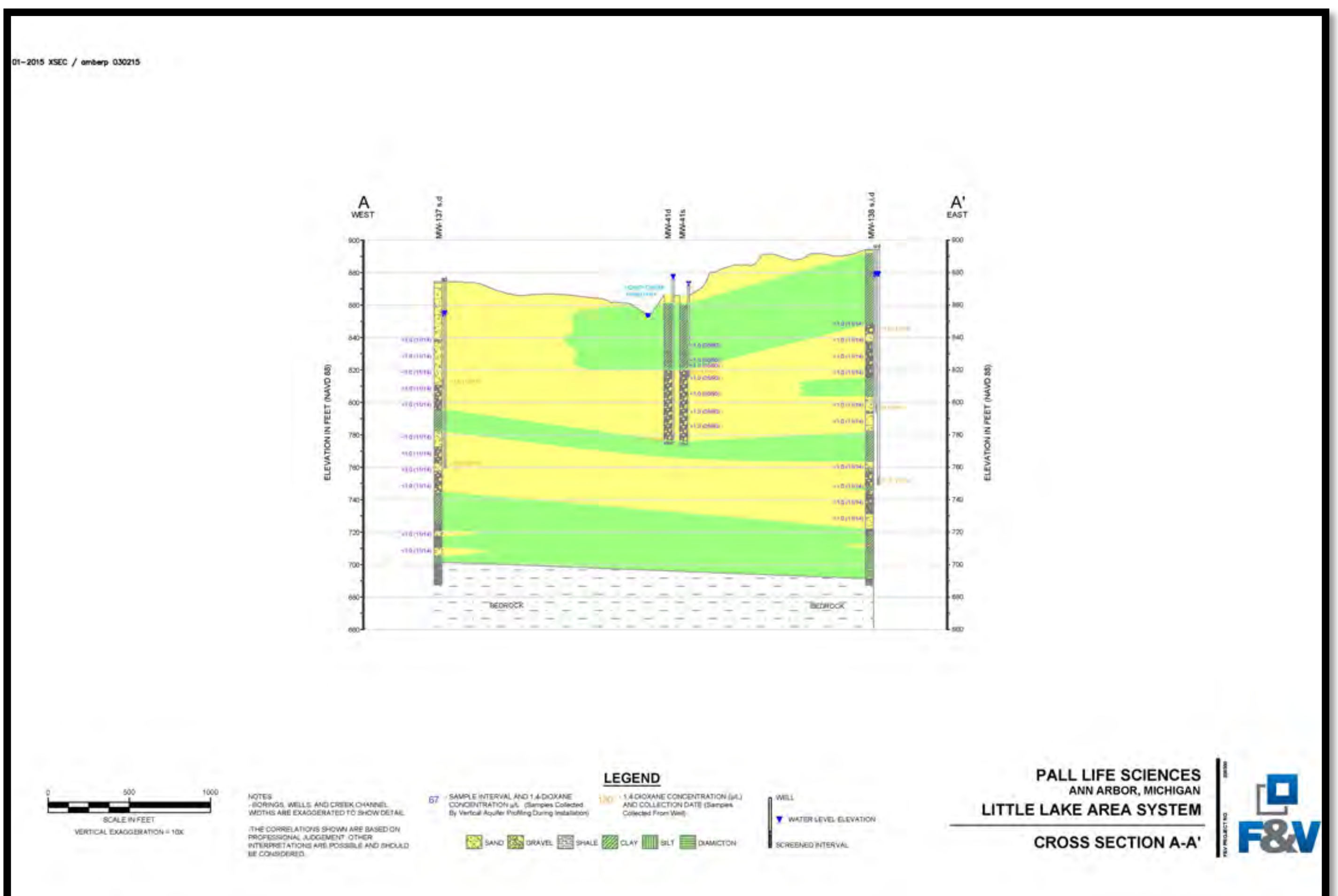
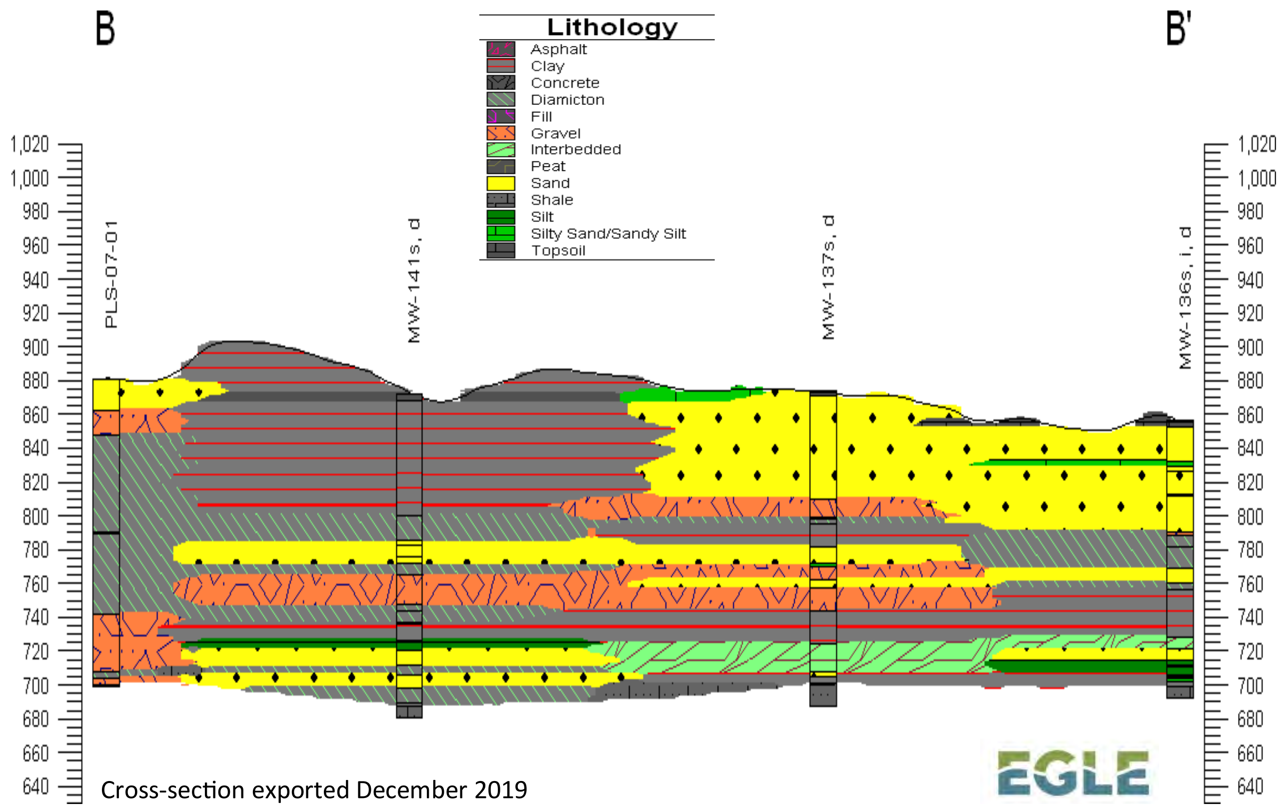


Cross-section from 15-01 A West MW-137sd _ A' East MW-138sid.pdf

CROSS-SECTION 15-02 B-B’ Comparison



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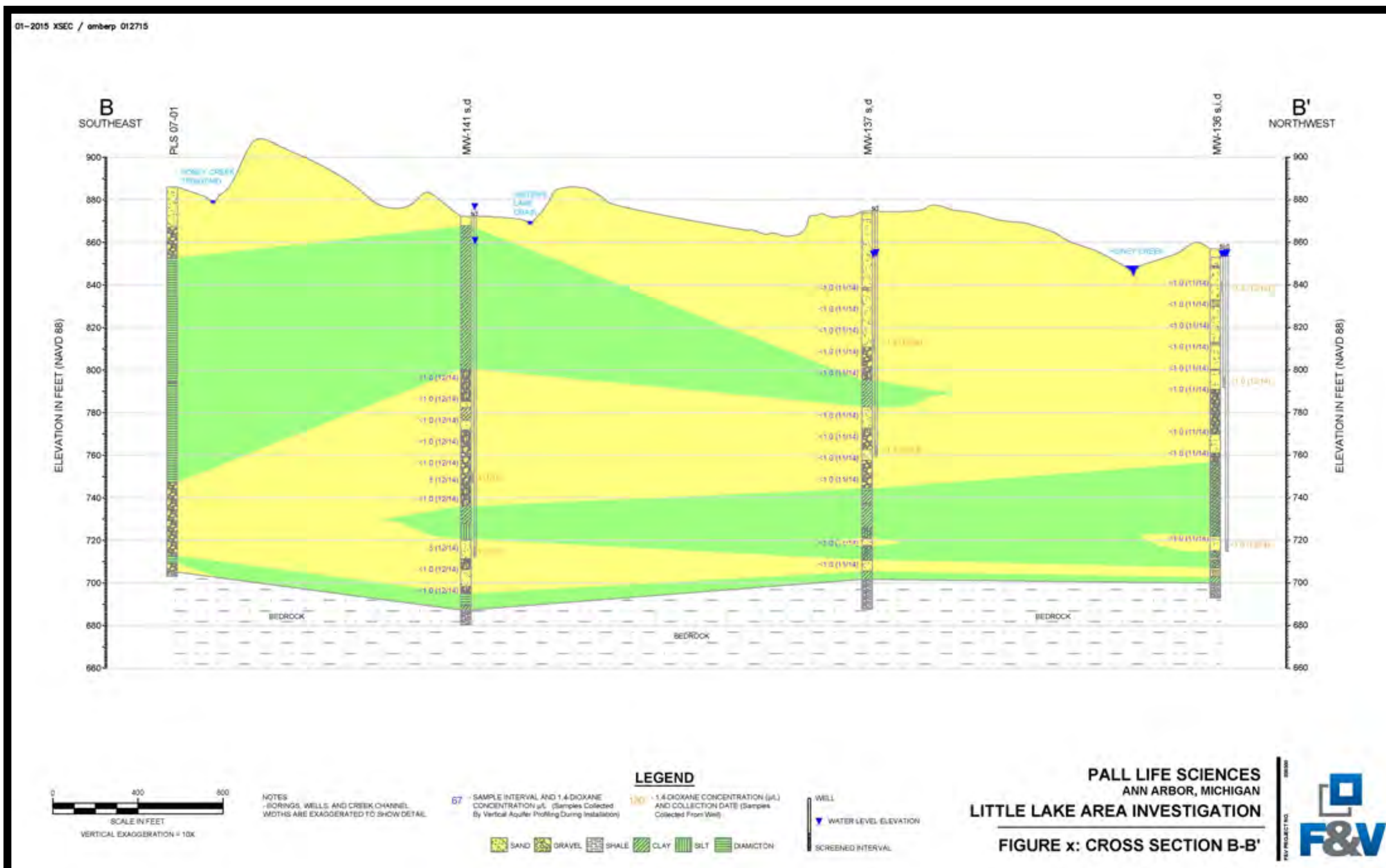
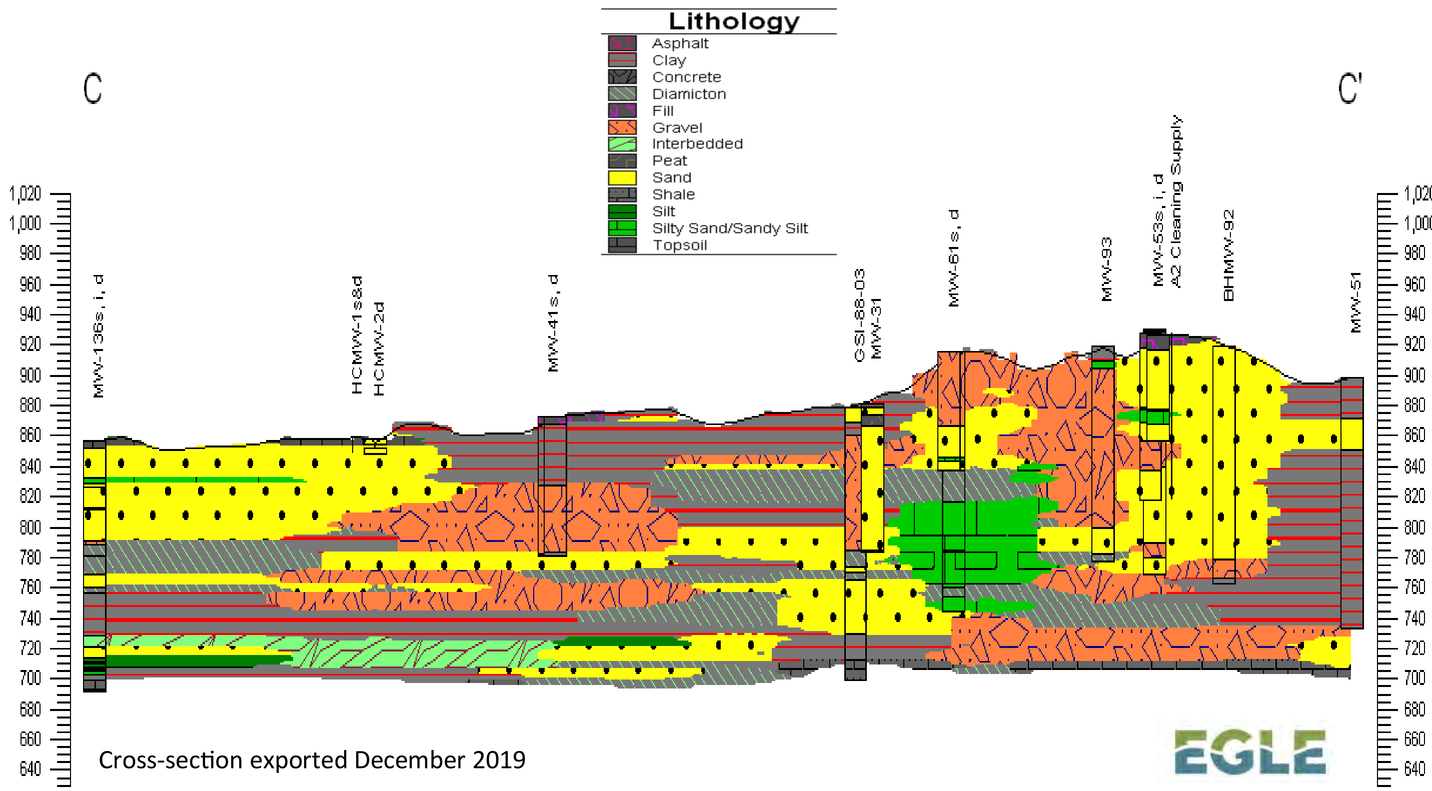


Cross-section from 15-02 B Southeast PLS 07-01 _ B' Northwest MW-136sid.pdf

CROSS-SECTION 15-03 C-C' Comparison



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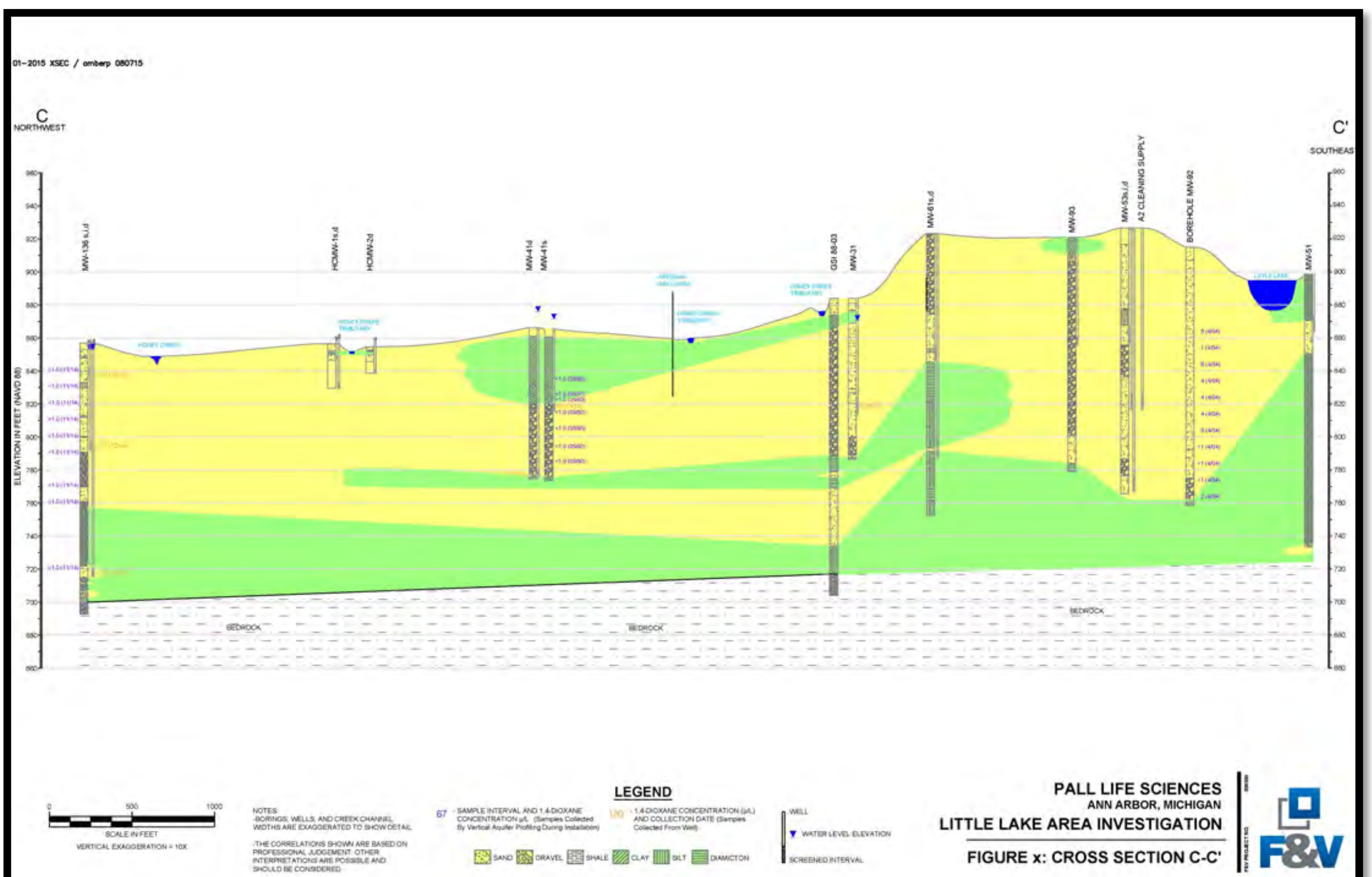
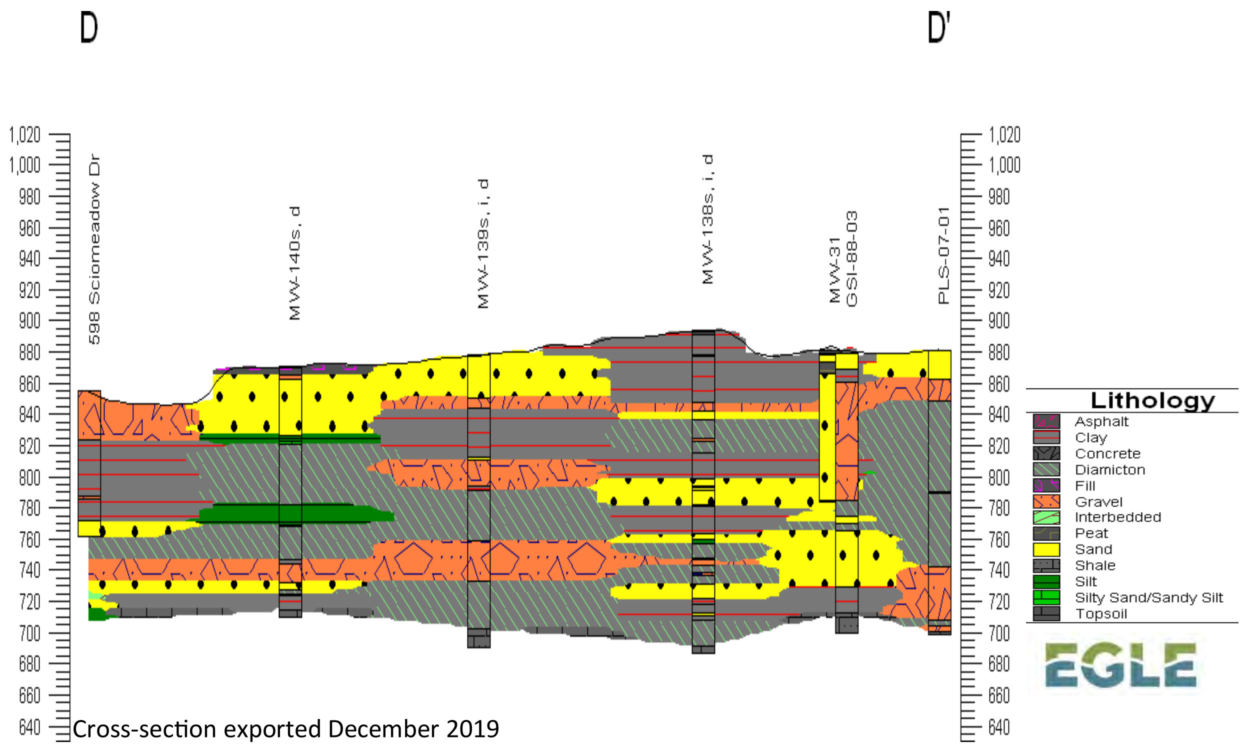


Cross-section from 15-03 C Northwest MW-136sid _ C' Southeast MW-51.pdf

CROSS-SECTION 15-04 D-D' Comparison



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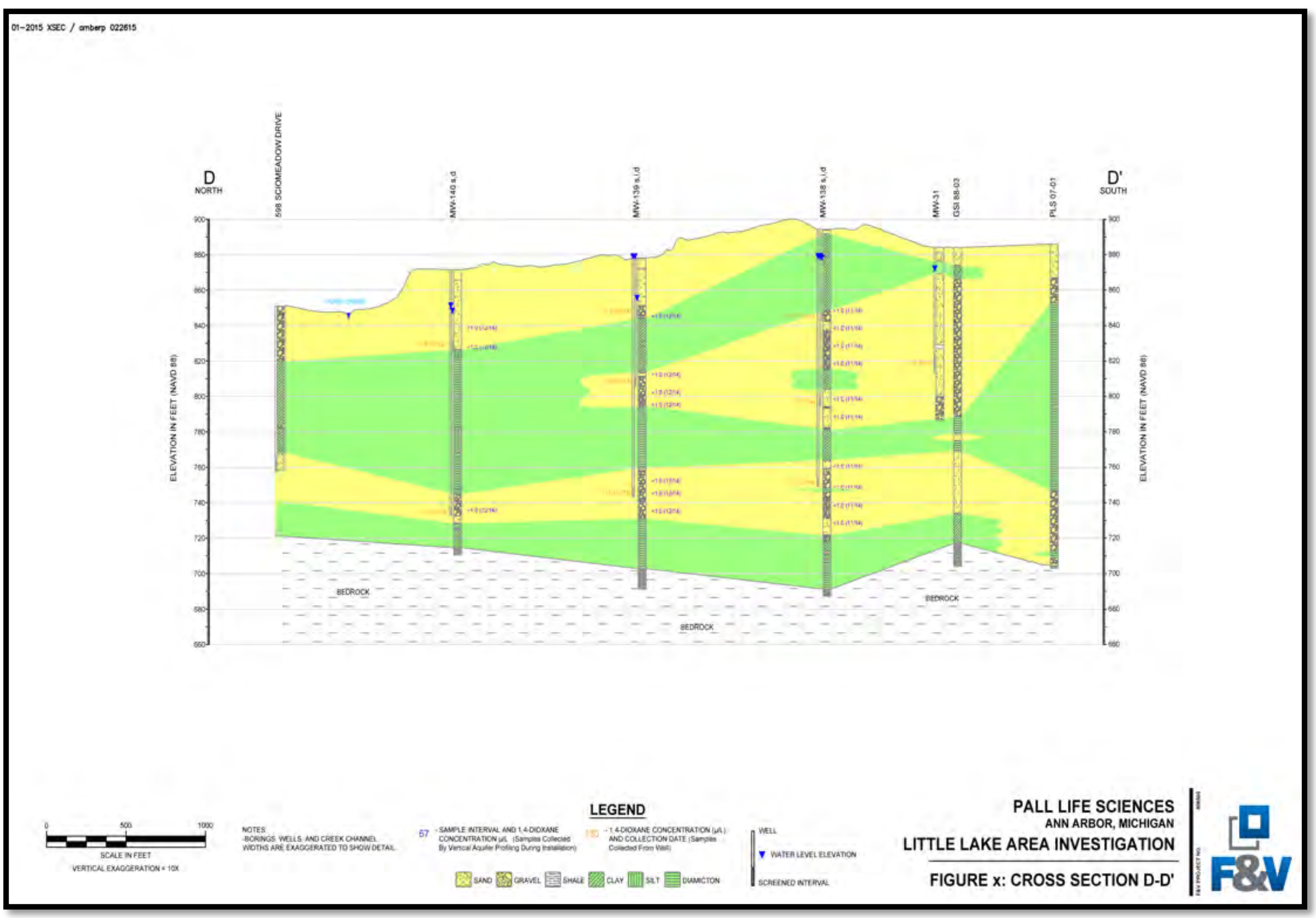
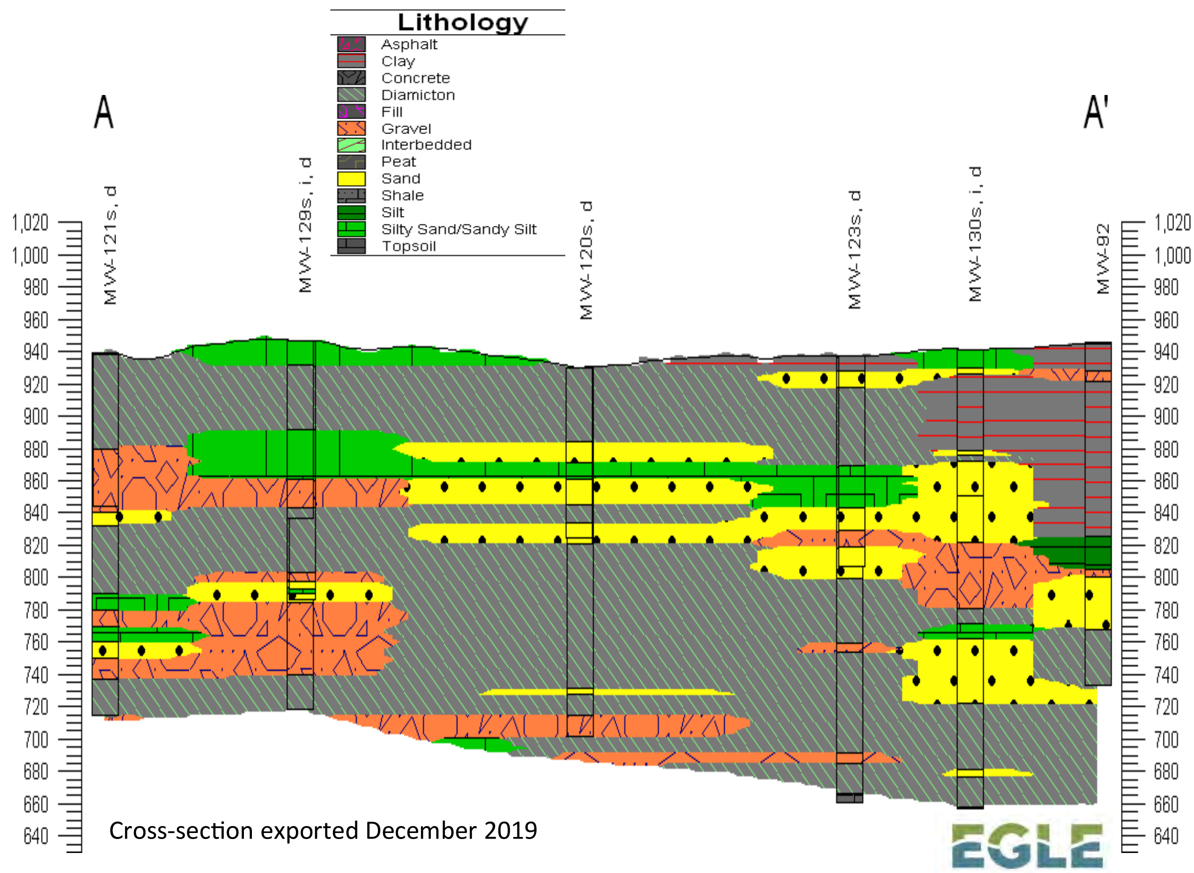
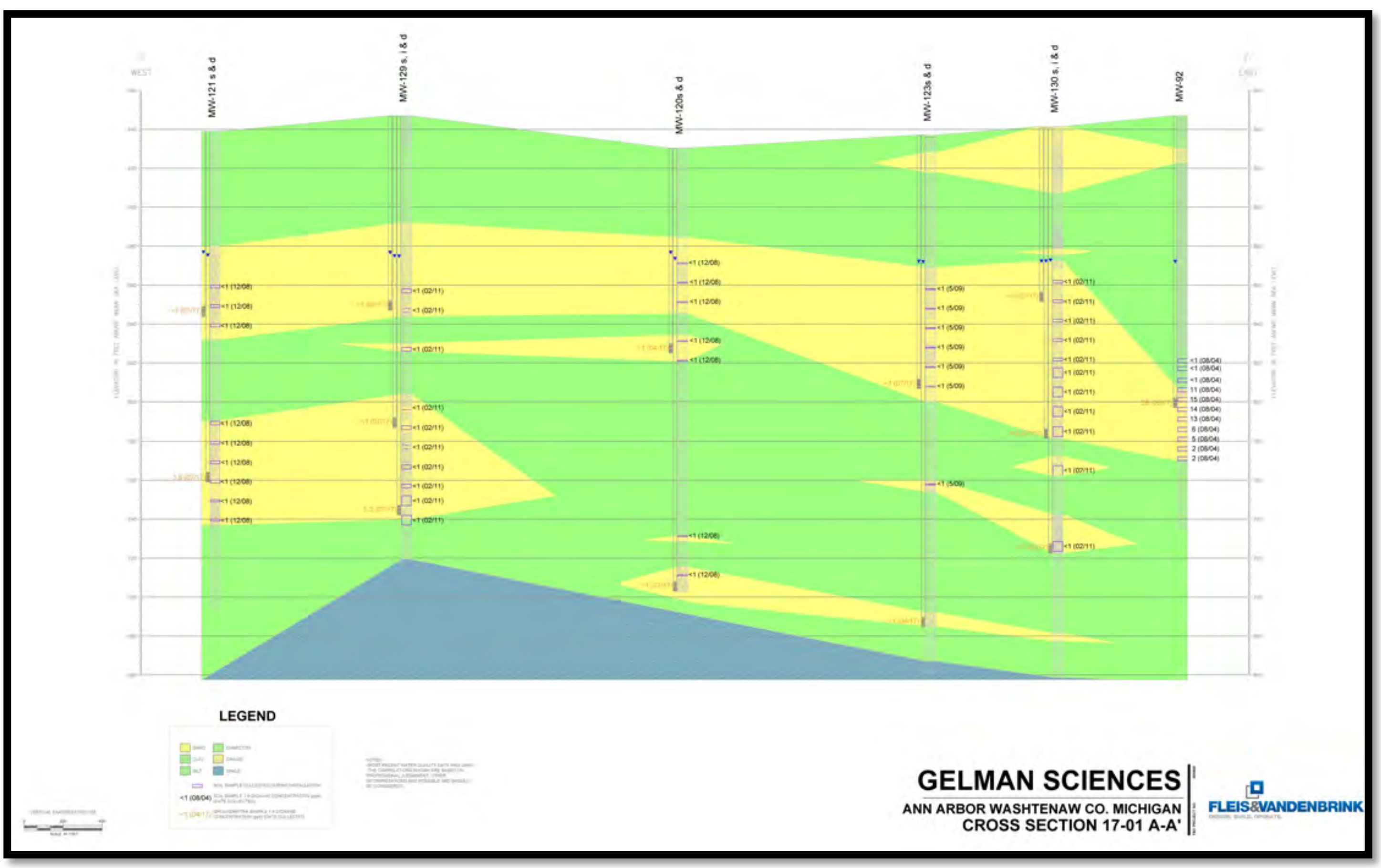


Cross-section from 15-04 D North 598 ScioMeadow Drive _ D' South PLS 07-01.pdf

CROSS-SECTION 17-01 A-A' Comparison





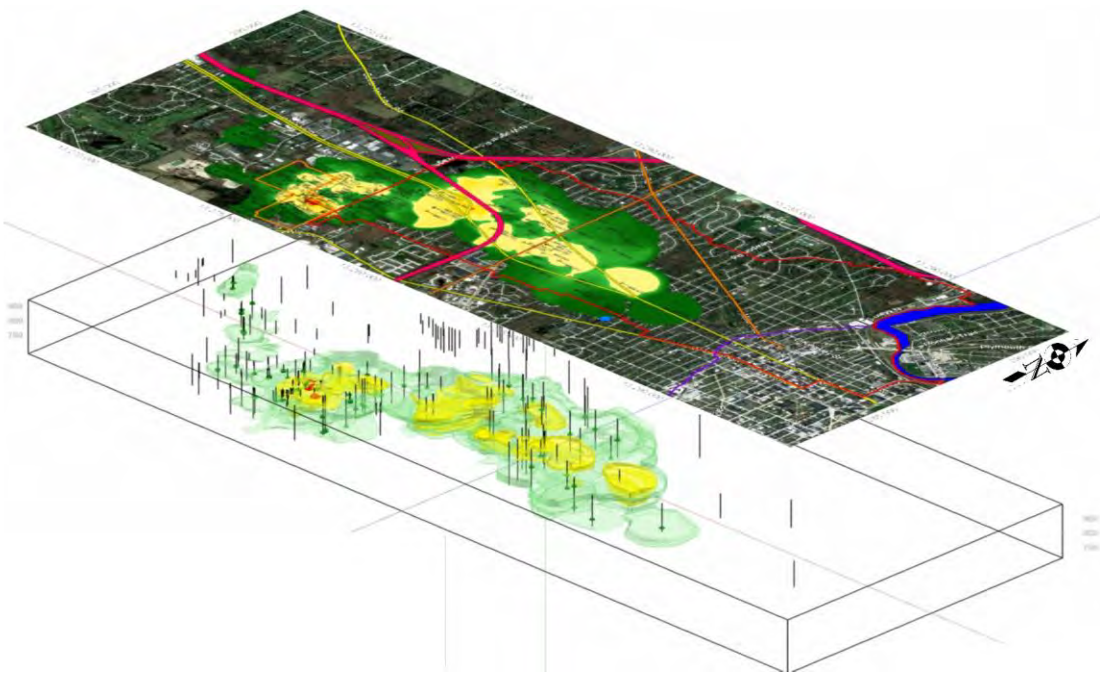
Cross-section from 17-01 A West MW-121sd A' East MW-92-Layout1.pdf

Attachment 2

Gelman Chemical Site Ann Arbor, Michigan 1,4-Dioxane Plume Migration Modeling and Visualization by James Reed, RockWare Incorporated, March 30, 2020

Gelman Chemical Site, Ann Arbor, Michigan
1,4-Dioxane Plume Migration Modeling & Visualization

James P. Reed
RockWare Incorporated
March 30th, 2020



Abstract

Starting in 2019, data from the Michigan Environment, Great Lakes and Energy (EGLE) public files relating to the Gelman contamination plume was consolidated into a RockWorks SQLite relational database. This data included lithologic, geochemical, well construction, and water level information from well logs, ground surface elevations, and interpreted bedrock contacts from seismic profiles. The data was used to create two-dimensional ground, bedrock, and maximum historical water level surface models and three-dimensional lithology, hydraulic conductivity, Boolean permeable/impermeable and annual 1,4-Dioxane geochemical models. Diagrams based on these models were then used to create maps and animations that depict the extent and concentrations of the 1,4-Dioxane groundwater contamination plume from 1986 to 2019.

Note: To look up an acronym or term within the report glossary, click on the blue underlined text.

Contents

Introduction

In August of 2019, RockWare began work on creating a series of computer models and time-lapse animations depicting 1,4-Dioxane groundwater contamination using publicly available data from the EGLE files collected over a 34-year period from 1986 to 2019. The source of the 1,4-Dioxane contamination is the former Gelman Manufacturing Facility located in Scio Township, approximately 2.75 miles west of downtown Ann Arbor, Michigan.

The work was performed under sub-contract to the Mannik Smith Group (MSG) as part of a larger project to support the Michigan Department of Environment, Great Lakes, and Energy (EGLE) with the development of an "outward facing" Internet site. When completed the Internet site will provide the public with an accurate spatial understanding of the Gelman contamination history as well as the current conditions via interactive maps and animations.

The numerical computer models used to produce the animations are based on data that was provided by EGLE and MSG. This data includes:

- a LIDAR-based DEM,
- lithologic and/or chemical data from 754 bores (monitoring wells, residential wells, treatment wells, and test borings),
- bedrock elevations inferred from seismic data and lithology logs, and
- hydraulic conductivities for the materials encountered within the boreholes.

The modeling process began with the interpolation of a lithologic block model in which the voxels measured 50′ x 50′ horizontally and 2′ vertically, extending 27,100′ in an east/west direction, 9,800′ in a north/south direction, and 342′ in height. This model was then converted to a Boolean Permeable/Impermeable (BPI) model based on representative hydraulic conductivities of the lithology types. The BPI model was additionally constrained by the following filters:

- an Upper Surface Filter based on the highest, historical (1986 to 2019) groundwater elevations,
- a Lower Surface Filter based on borehole observations and seismic interpretations, and
- an Enclosing Polygon Filter defined by a convex hull with a 500-foot buffer surrounding wells with lithology data.

A series of annual geochemical models were then interpolated based on the 1,4-Dioxane levels that were measured during that year. In cases where the same intervals were sampled on more than one occasion during a given year, the highest values were used.

The extent of each annual model were limited to polygons based on only the wells that were sampled during the associated year. It is important to note that these polygonal constraints may reduce the lateral extent of the plume, if wells sampled during a given year were not sampled during the succeeding year. As a consequence, the plume may appear to contract along portions of its perimeter during the transition from one year to the next. Nevertheless, the decision to use the polygon clipping has overridden these concerns based on the importance of constraining the models to the data extent and creating statistically defensible conclusions.

The annual geochemical models were then filtered, based on lithology, to eliminate any voxels within the areas deemed impermeable based on lithology. Finally, the solid models were converted to annual grid models, in which the cell values are based on the highest value within the corresponding column of voxels within the annual solid model.

The numerical models were rendered as maps and 3D diagrams for subsequent use within a variety of time-lapse animations. These animations include scrolling date annotations and reference maps designed to show the spatial, temporal and geochemical nature of the plume.

Reference Maps

A series of 14 reference maps were created and overlain on a satellite image for subsequent overlays with maps and three-dimensional diagrams (Figure 1). These maps highlight highways, selected roads, the Huron River, Downtown Ann Arbor, Allen Creek Drain, Montgomery Well, Gelman Property, and the Prohibition Zone. These maps were created as separate entities so that the features could be introduced on a one-at-a-time basis during the animations.

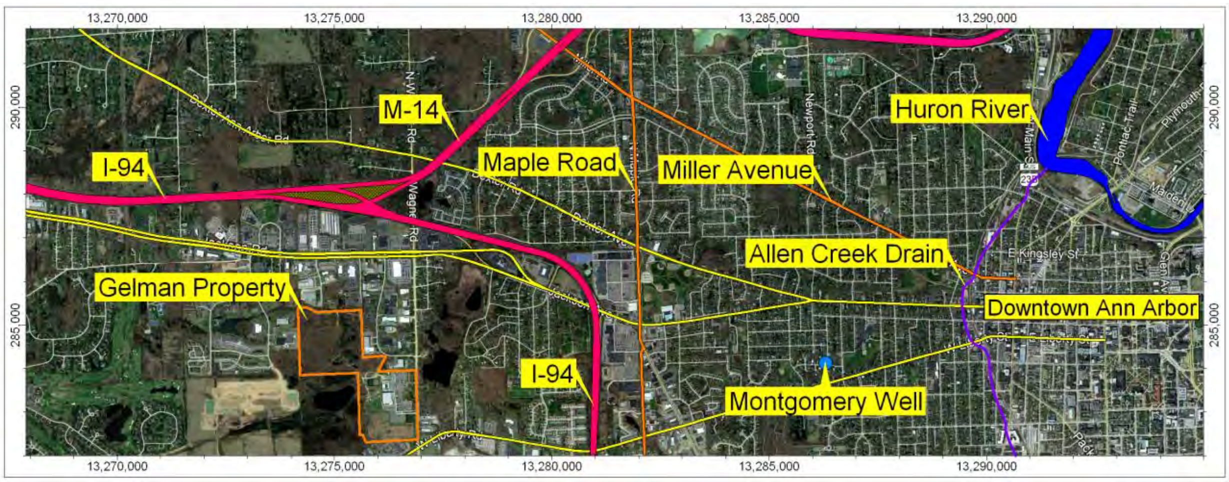


Figure 1. Composite Reference Map Example

Quality Control

Data provided by MSG was subjected to a variety of automated quality analyses including the following:

- Checking for boreholes in which the reported total drilled depth was less than the maximum depth for any of the data elements (e.g. lithology, water levels, geochemistry);
- Checking for boreholes whose collar coordinates were outside of the study area (e.g. wells with zero as the easting (X) or nothing (Y) coordinates);
- Lithology or geochemistry interval data in which the depth to top was greater than the depth to base (i.e. transposed depths); and
- Lithology types that were not defined within the lithology table.

Detailed reports listing these problems were submitted to and corrected by MSG in an iterative fashion until all known errors were eliminated.

In order to cross-check the RockWorks borehole database against the legacy data, 32 cross-sections were generated along the same traverses as hand-correlated cross-sections generated by Fleis & Vandenbrink Engineering in 2007 for Gelman Life Sciences (Figure 2). MSG used these comparisons to trace and correct discrepancies within the SQL database which was then re-submitted to RockWare for subsequent re-modeling.

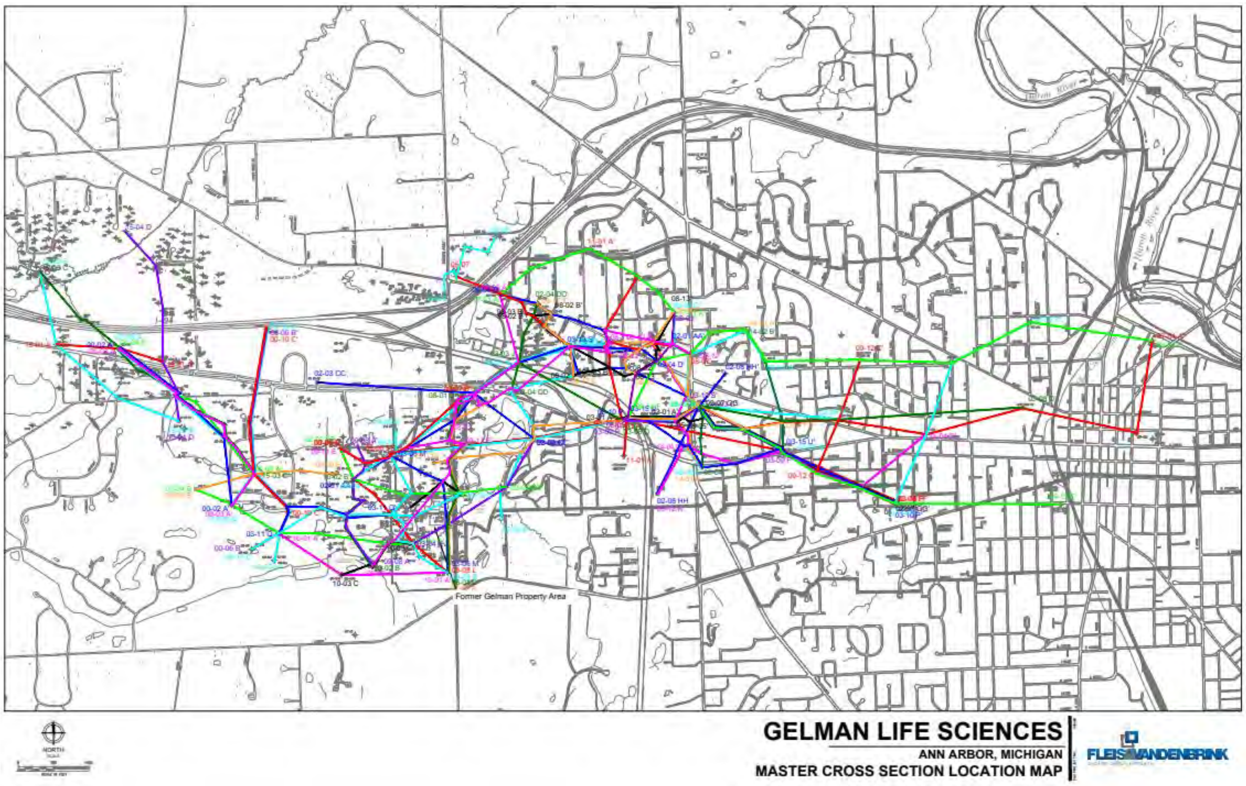


Figure 2. Fleis & Vandenbrink Cross-Section Index Map

These comparisons (Figure 3), performed by MSG, were focused on comparing the lithology within the striplogs, as opposed to the correlations.

During the comparisons of the RockWorks cross-sections with the Fleis & Vandenbrink diagrams, the lithology interpolation algorithm was adjusted to create a model that was the most geologically reasonable and accurate in regards to honoring the control points. The nuances of this algorithm are described within the portion of this report titled "Lithology Modeling."

Additional information about the QC process is available within a separate technical memo provided by MSG.

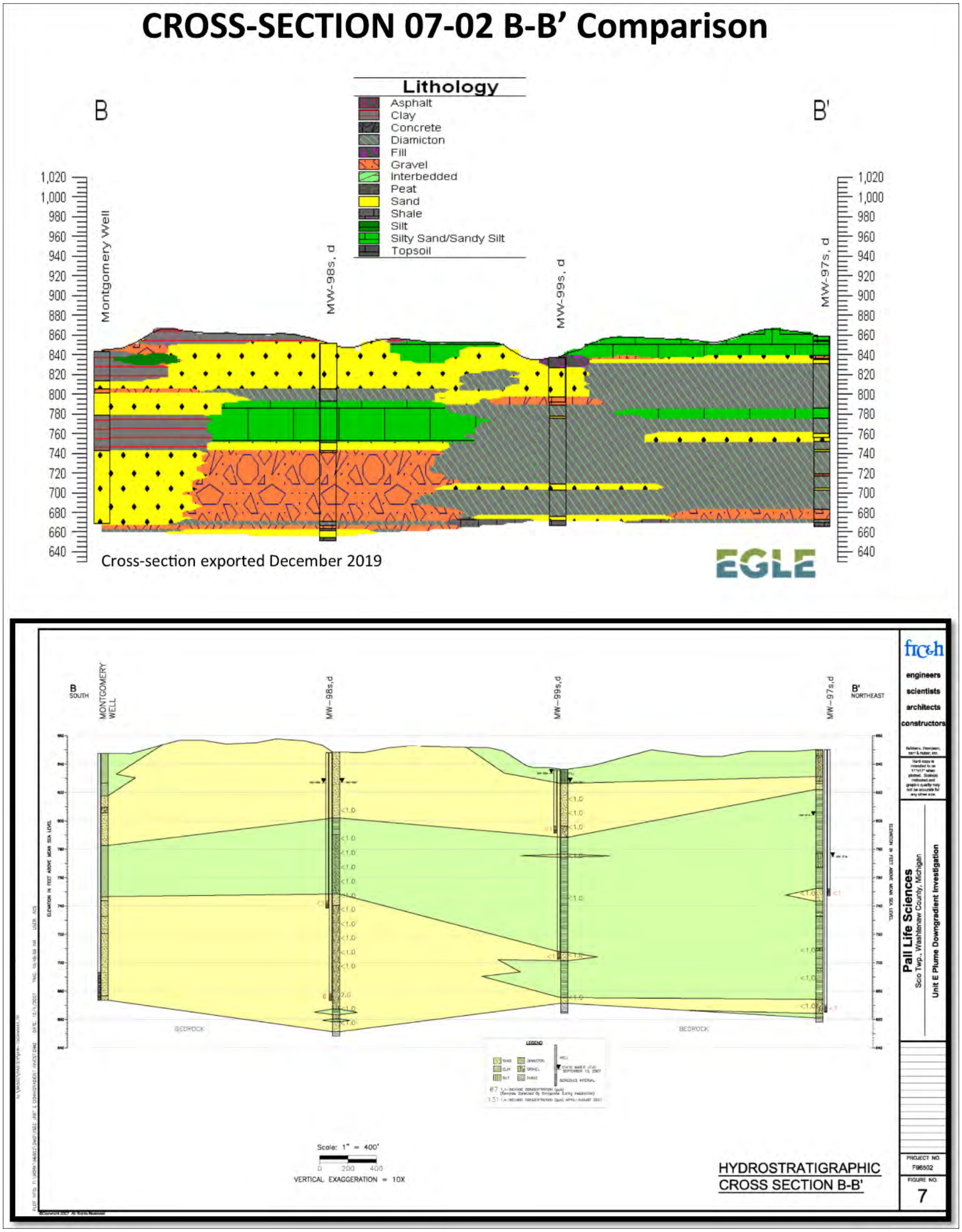
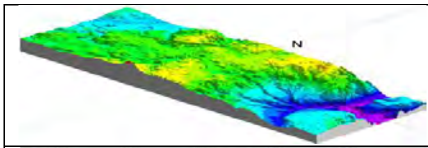
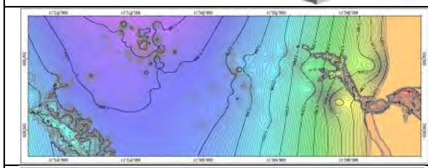
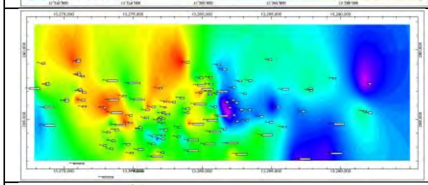
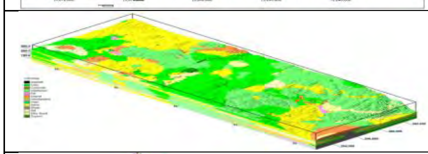
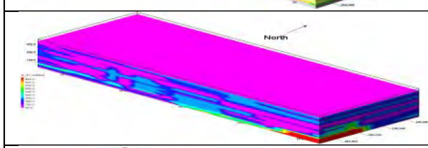
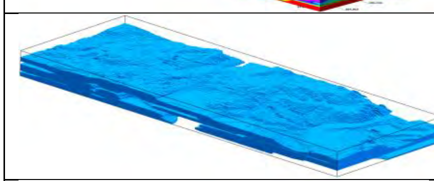
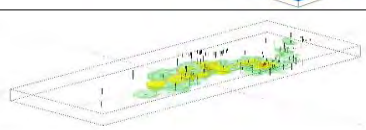


Figure 3. Example of Comparison Between RockWorks Section & Fleis & Vandenbrink Section

Numerical Modeling

Two types of models were created in order to produce the animations: grid models and solid models (Table 1).

Table 1. Summary of Grid & Solid Models

	**Ground Surface** Grid model representing surface elevations.
	**Maximum Historical Water Level Surface (MHWLS)** Grid model representing highest recorded static groundwater level measurements from 1986 to 2019.
	**Bedrock Surface** Grid model representing bedrock elevations.
	**Lithology** Solid model representing lithologic units.
	**Hydraulic Conductivity** Solid model representing hydraulic conductivities.
	**Boolean Permeable/Impermeable (BPI) Solid** Boolean solid model representing possible groundwater conduits (K≥0.00002).
	**Annual Geochemistry (Solids)** 34 solid models representing annual 1,4-Dioxane concentrations from 1986 to 2019.
	**Annual Geochemistry (Grids)** 34 grid models representing highest annual 1,4-Dioxane concentrations from 1986 to 2019.

Model Dimensions

All coordinates are based on the Michigan State Plane Coordinate System (feet) South Zone (2113), and all depths and elevations are expressed in feet. The dimensions of the models are summarized within Table 2.

Table 2. Model Dimensions & Statistics

<table>
<tr><th colspan="7">Model Dimensions</th></tr>
<tr><td colspan="2"></td><td>Minimum</td><td>Maximum</td><td>Spacing</td><td>Nodes</td><td>Range</td></tr>
<tr><td colspan="2">X (Easting)</td><td>13,267,900</td><td>13,295,000</td><td>50</td><td>543</td><td>27,100</td></tr>
<tr><td colspan="2">Y (Northing)</td><td>282,000</td><td>291,800</td><td>50</td><td>197</td><td>9,800</td></tr>
<tr><td colspan="2">Z (Elevation)</td><td>628</td><td>970</td><td>2</td><td>172</td><td>342</td></tr>
<tr><th colspan="7">Model Statistics</th></tr>
<tr><td rowspan="3">Grids</td><td>Nodes</td><td colspan="5">106,971</td></tr>
<tr><td>Cell Area</td><td colspan="5">2,500 Square Feet</td></tr>
<tr><td>Total Area</td><td colspan="5">267,427,500 Square Feet (9.6 Square Miles)</td></tr>
<tr><td rowspan="3">Solids</td><td>Nodes</td><td colspan="5">18,399,012</td></tr>
<tr><td>Voxel Volume</td><td colspan="5">5,000 Cubic Feet</td></tr>
<tr><td>Total Volume</td><td colspan="5">91,995,060,000 Cubic Feet (0.63 Cubic Miles)</td></tr>
</table>

The node spacings essentially determine the resolution of the model. For example, a horizontal node spacing of 500 feet means that the model will discriminate features that are 500 feet or greater in width. Conversely, features that are less than 500 feet in width may be completely omitted by the modeling.

The average minimum distance between the wells within the Project Area is 473 feet. Typically, the horizontal dimensions of solid model voxels are set to half of the average minimum distance between the wells, which in this case would be 236.5 feet. However, after careful consideration, it was decided to use a 50-foot spacing to provide a higher resolution that would accommodate areas with closely-spaced clustered wells. This minimizes the probability of two wells occupying the same voxel, thereby creating ambiguities and inaccurate 3D contours (isosurfaces). The downside of this decision was significantly longer processing times (22x longer), larger memory requirements (also 22x greater), and much larger file sizes.

The same considerations apply to the vertical node spacing (voxel height). Based on the higher vertical detail provided by the borehole logs, a voxel height of two feet was chosen. As such, the models essentially average data on a vertical 2-foot interval. Given the overall size of the Project Area, this dimension is considered to be very reasonable.

It should also be noted that smaller voxel heights improve the aesthetics of the lithologic cross sections by decreasing the pixelation associated with the solid model voxels.

The 50′ x 50′ x 2′ voxel dimensions were used for all solid modeling while 50′ x 50′ cell dimensions were used for all grid modeling.

Modeling Flowchart

The steps taken to produce the numerical models are illustrated within the flowchart (Figure 4) shown below.

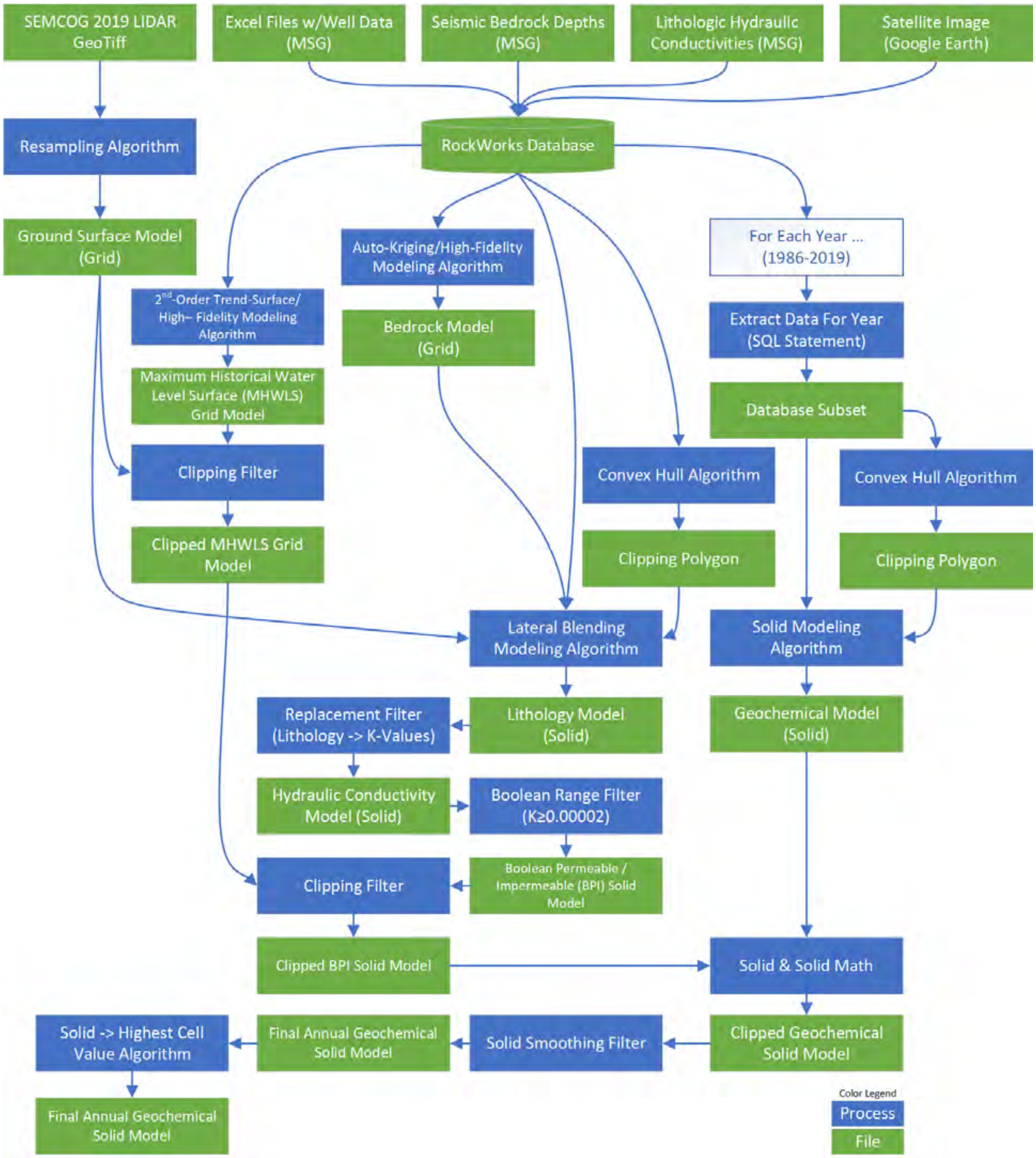


Figure 4. Modeling Flowchart

Ground Surface Grid Model

The uppermost constraining surface model was based on LIDAR data collected in March, of 2019 and provided by the Southeast Michigan Council of Governments (SEMCOG). This data was re-sampled to conform to the previously described model dimensions (Figure 5 and Figure 6).

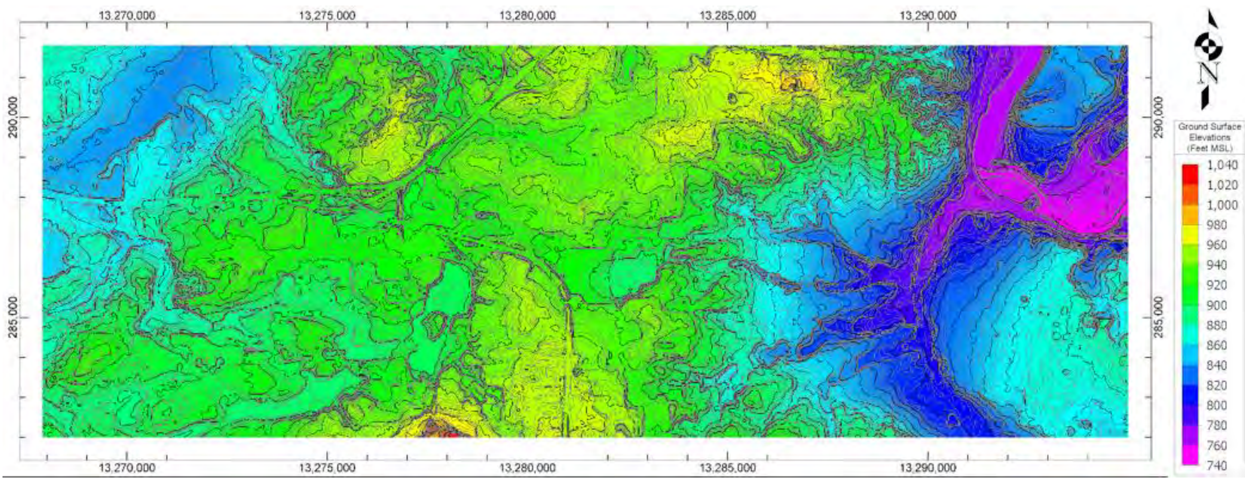


Figure 5. Ground Surface Model Based On March, 2019 LIDAR Data

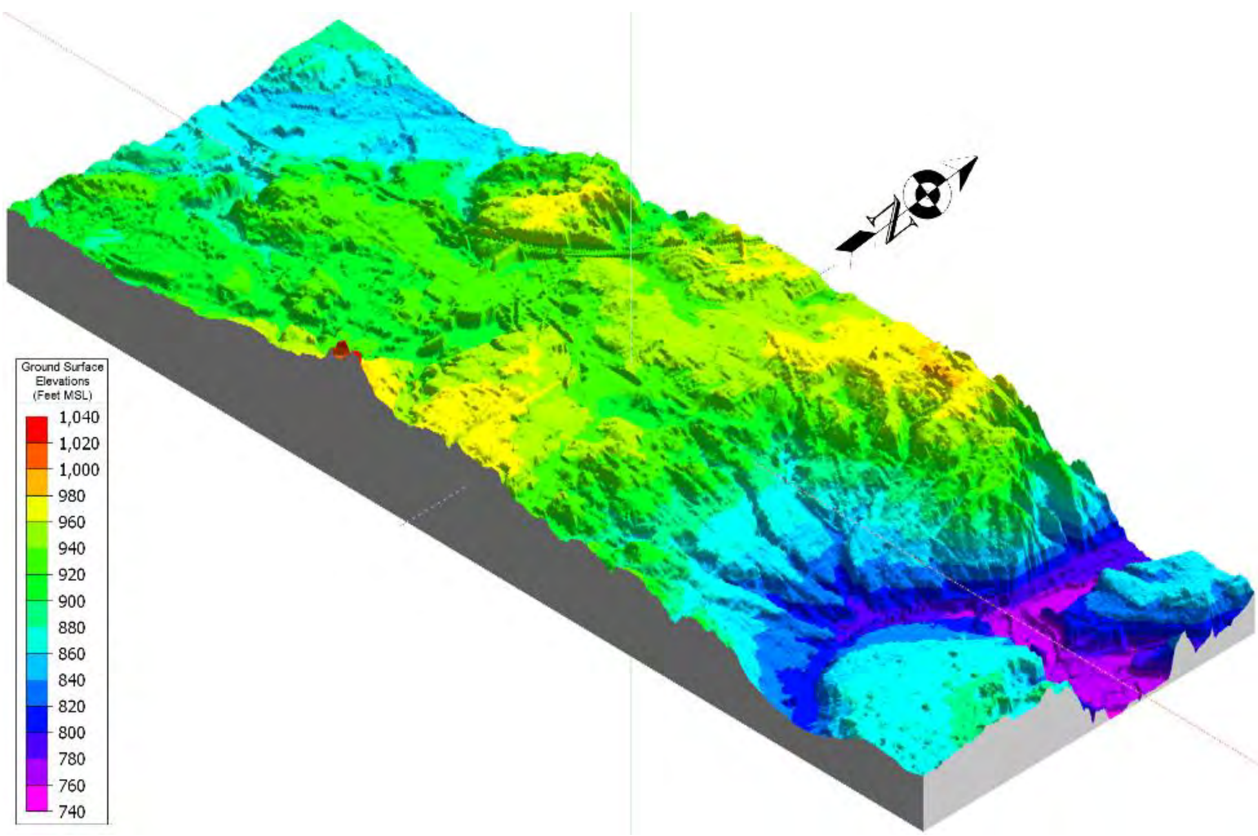


Figure 6. Three-Dimensional Display of Ground Surface Model - Vertical Exaggeration = 5x

Bedrock Surface Grid Model

The lowermost constraining surface model was based on a combination of lithologic data from the well logs and SIPs (Seismic Interpretation Points). These picks and interpretations were made by MSG. Unlike the maximum historical water levels, the bedrock surface morphology is very irregular and cannot be modeled with a polynomial trend surface. Instead, the bedrock grid modeling was performed with an auto-kriging/high-fidelity algorithm. This algorithm best fits a series of eight variograms to the data and then uses the variogram with the best correlation coefficient (least error) krig the data (Figure 7).

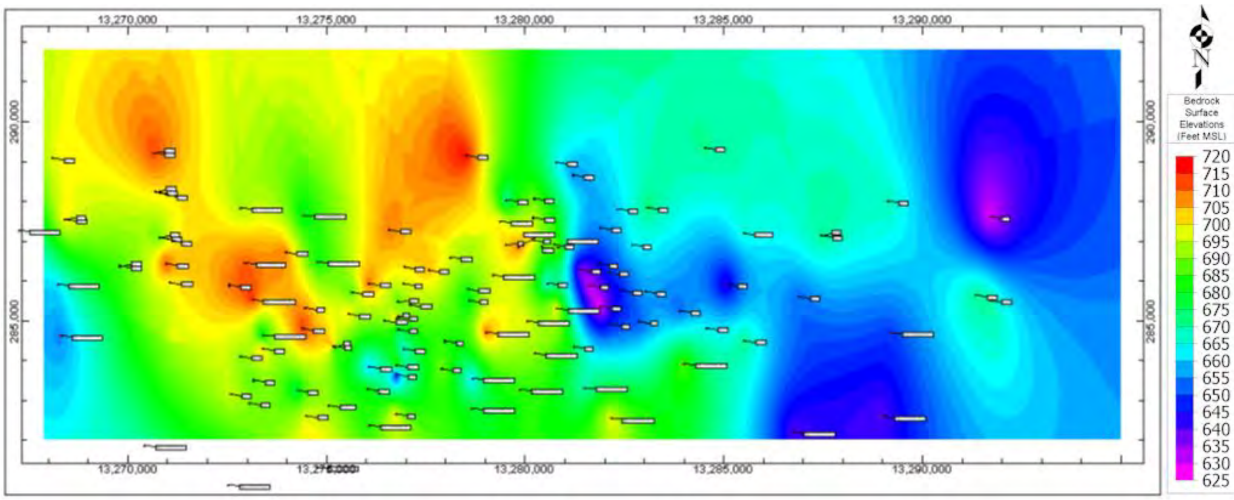


Figure 7. Bedrock Surface Model

Maximum Historical Water Level Surface Grid Model

The borehole database was filtered such that the maximum static groundwater elevation for each well utilizing all dates was computed. These points were then modeled with a 2^{nd}-order trend-surface polynomial/high-fidelity algorithm. This method essentially created a broad, anticlinal surface plunging to the north (Figure 8). A comparison was then made with the ground surface model to identify regions where the initial maximum potentiometric surface was equal to or above the ground surface (Figure 9). As would be expected, these regions corresponded with creeks, rivers, ponds, lakes, and swamps. The ground surface model was then used to truncate the Maximum Historical Water Level Surface (MHWLS) grid model for later use in constraining the hydraulic conductivity model (Figure 10).

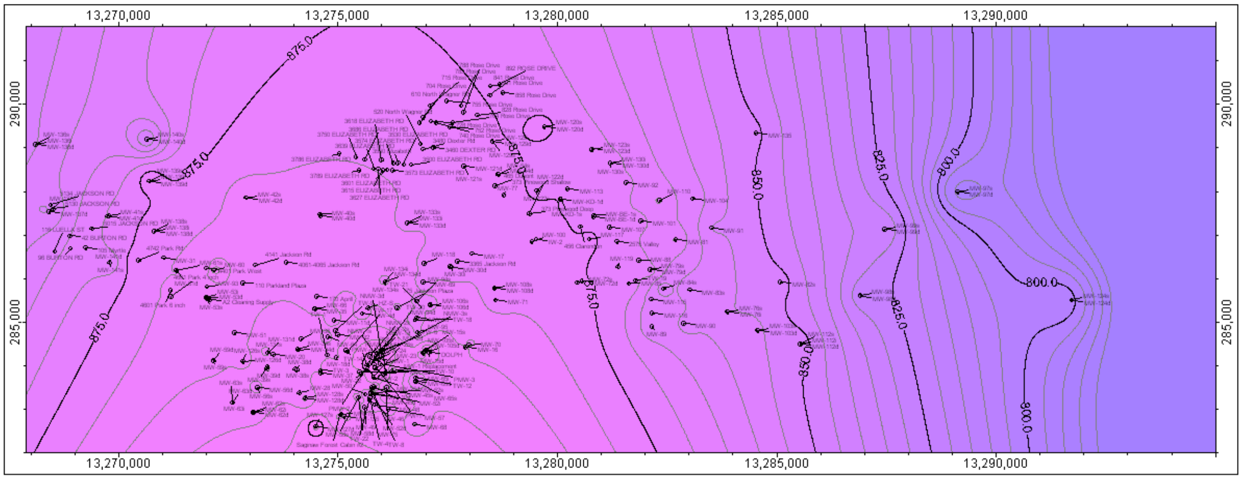


Figure 8. Maximum Historical Water Level Surface Model

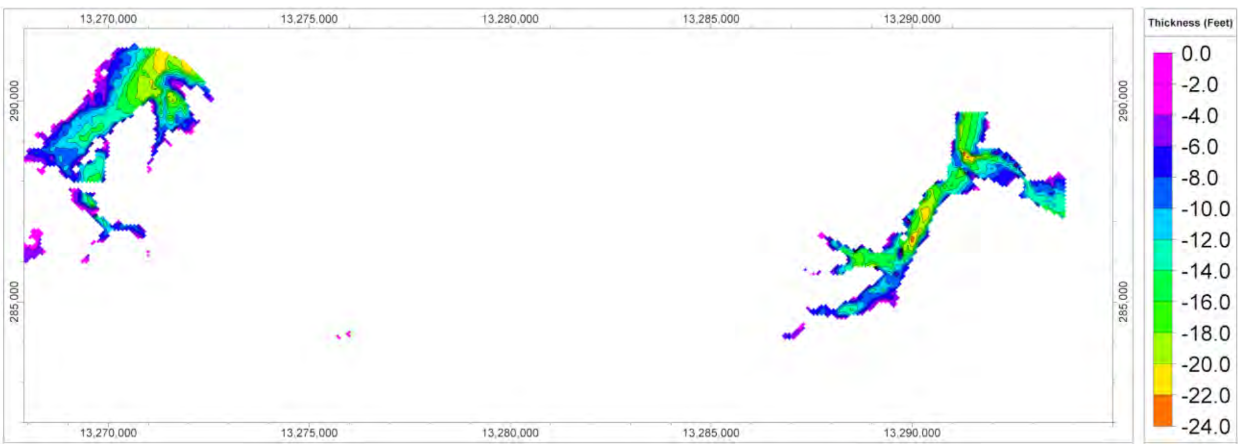


Figure 9. Areas Where Trend-Polynomial Extends Above Ground Surface

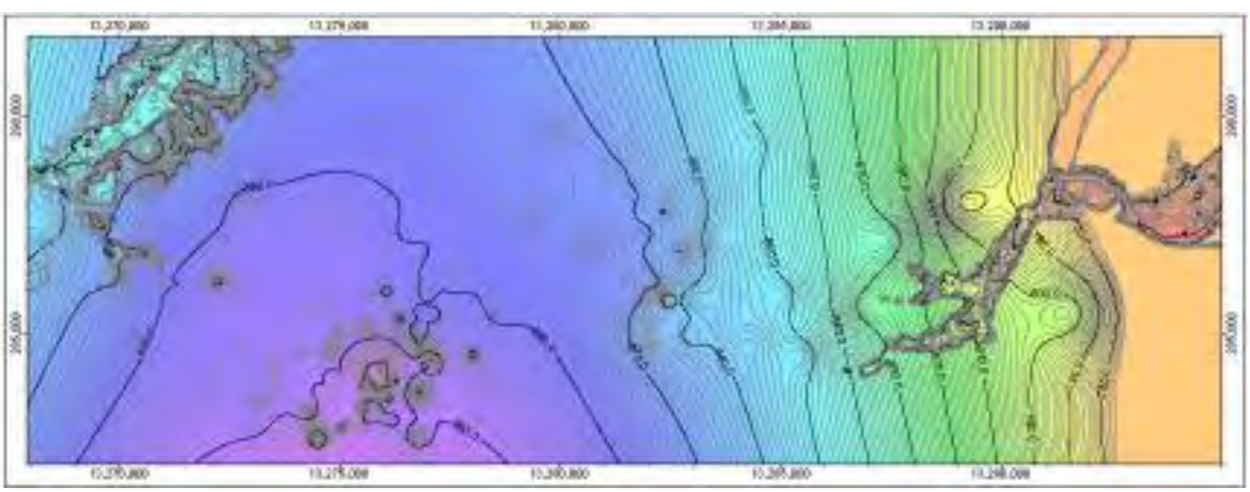


Figure 10. Maximum Historical Water Level Surface Elevation Model After Ground Surface Truncation

Lithology Modeling

The lithology model (Figure 11 & Figure 12) was interpolated by using all of the well data (no date filters) and a Lateral Blending algorithm with 2X smoothing. This model was vertically and horizontally clipped based on the following filters:

- Upper Constraining Surface: Ground Surface Model,
- Lower Constraining Surface: Bedrock Model, and
- Lateral Extent: ICH Polygon.

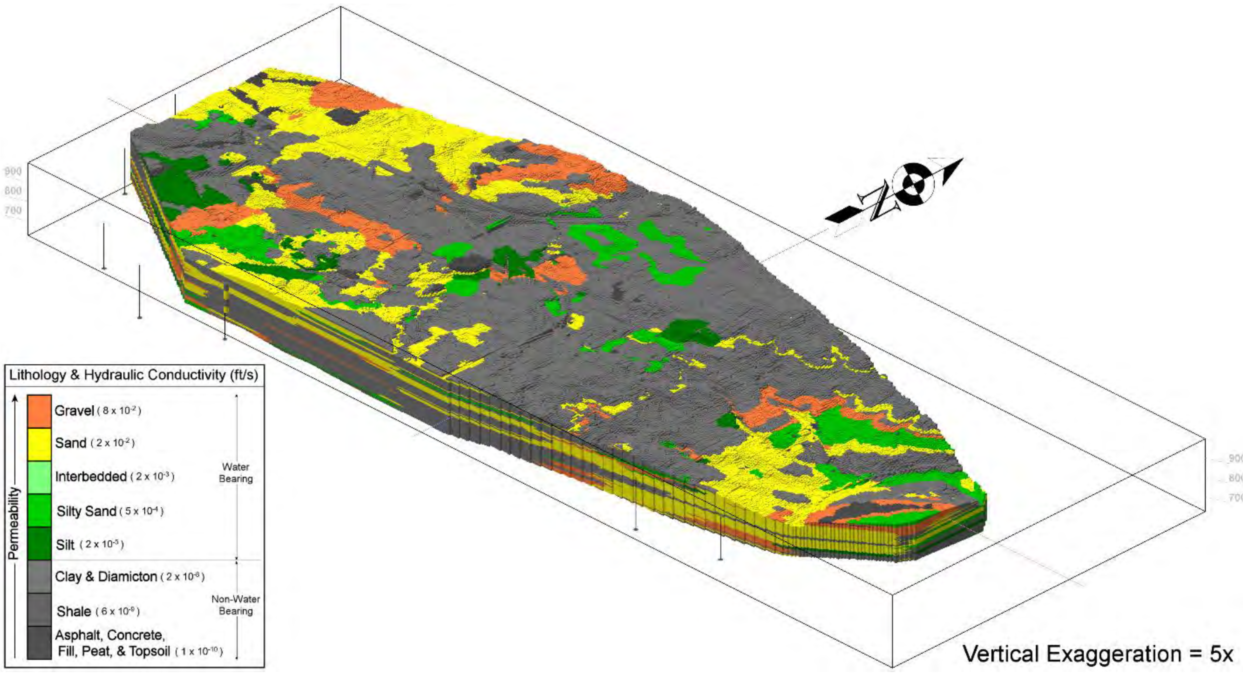


Figure 11. Lithology Model

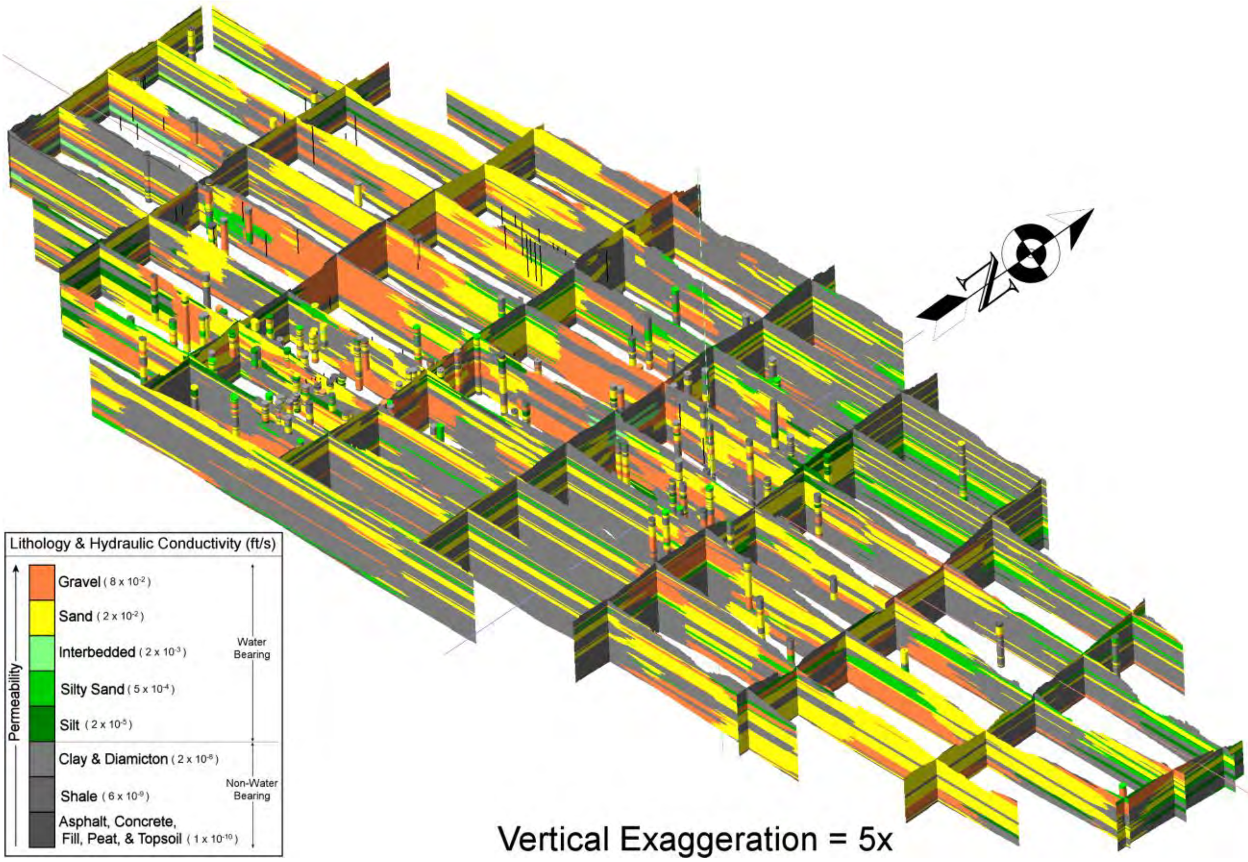


Figure 12. Lithology Model Fence Diagram

The Lateral Blending algorithm was chosen because when compared with the Lateral Extrusion algorithm (Figure 13), it produces a more geologically reasonable model. Specifically, Lateral Extrusion horizontally extends lithologic observations from each well to the midpoint with neighboring wells whereas Lateral Blending will horizontally extend the lithologic observations 1/3rd of the distance to a neighboring well and then randomly select the lithologies from the co-planar well intervals on either side (see Appendix 1. Lateral Blending Variability). This results in a transgressive/regressive appearance similar to hand-drawn sections while still honoring the observed lithologies.

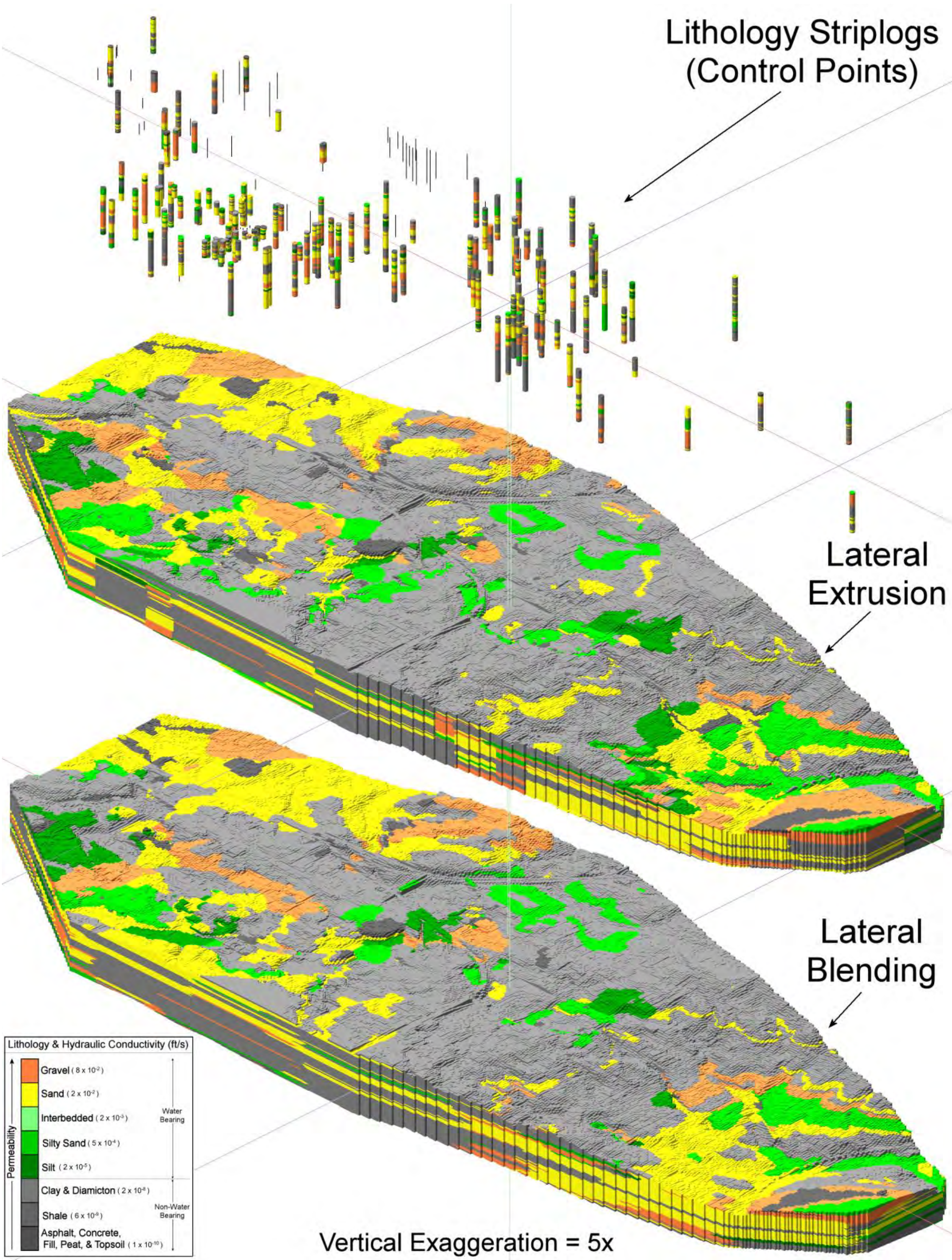


Figure 13. Lateral Extrusion Versus Lateral Blending Comparison

Hydraulic Conductivity Modeling

In order to determine possible pathways for the groundwater contaminant plume migration, the lithology model was converted to a hydraulic conductivity model by replacing the lithology node G-values with hydraulic conductivity values based on a replacement table provided by EGLE (Table 3).

Table 3. Lithology G-Values (Left) & Lithology-to-Hydraulic Conductivity Conversion Table (Right)

G-Value	Keyword	Pattern	Replacement	Comment
1.0	Asphalt		0.08	Gravel
300.0	Clay		0.02	Sand
2.0	Concrete		0.002	Interbedded
350.0	Diamicton		0.0005	Silty Sand
40.0	Fill		0.00002	Silt
100.0	Gravel		0.00000002	Clay
90.0	Interbedded		0.00000002	Diamicton
30.0	Peat		0.000000006	Shale
80.0	Sand		0.0000000001	Topsoil
990.0	Shale		0.0000000001	Concrete
250.0	Silt		0.0000000001	Fill
60.0	Silty Sand/Sandy Silt		0.0000000001	Asphalt
25.0	Topsoil		0.0000000001	Peat

The top of this model was subsequently clipped based on the MHWLS grid model based on the assumption that the contaminant is transported via groundwater. This step removes areas that are unlikely to ever be in contact with groundwater.

Permeable/Impermeable Modeling

The Hydraulic Conductivity model was then converted to a Boolean Permeable/Impermeable (BPI) model in which the conductivities less than 0.00002 (2.0×10^{-5}) feet per second were converted to 0.0 (False) while values equal to or greater than 0.00002 were converted to 1.0 (True). As shown by the lithology legend (Figure 14), node values are either 1.0 (True) or 0.0 (False).

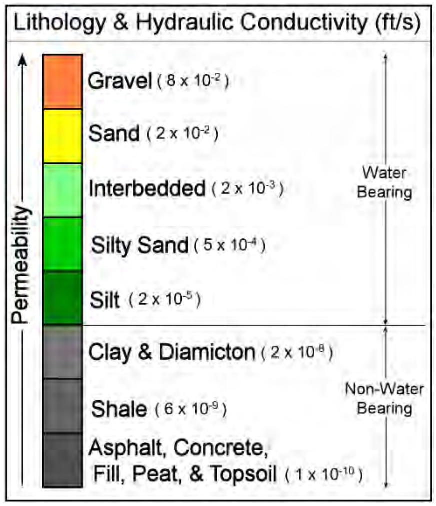


Figure 14. Lithology Legend Showing Associated Hydraulic Conductivity Values

Given the true/false nature of the BPI model (Figure 15), the voxels with a value of 1.0 (blue) define where it is possible for contaminants to be transported by groundwater. As shown within the lithology legend, a cutoff value of 0.00002 feet per second means that groundwater is not expected to flow through clay, diamicton, and shale. Furthermore, the asphalt, concrete, fill, peat, and topsoil may be disregarded because these materials lie well above the MHWLS.

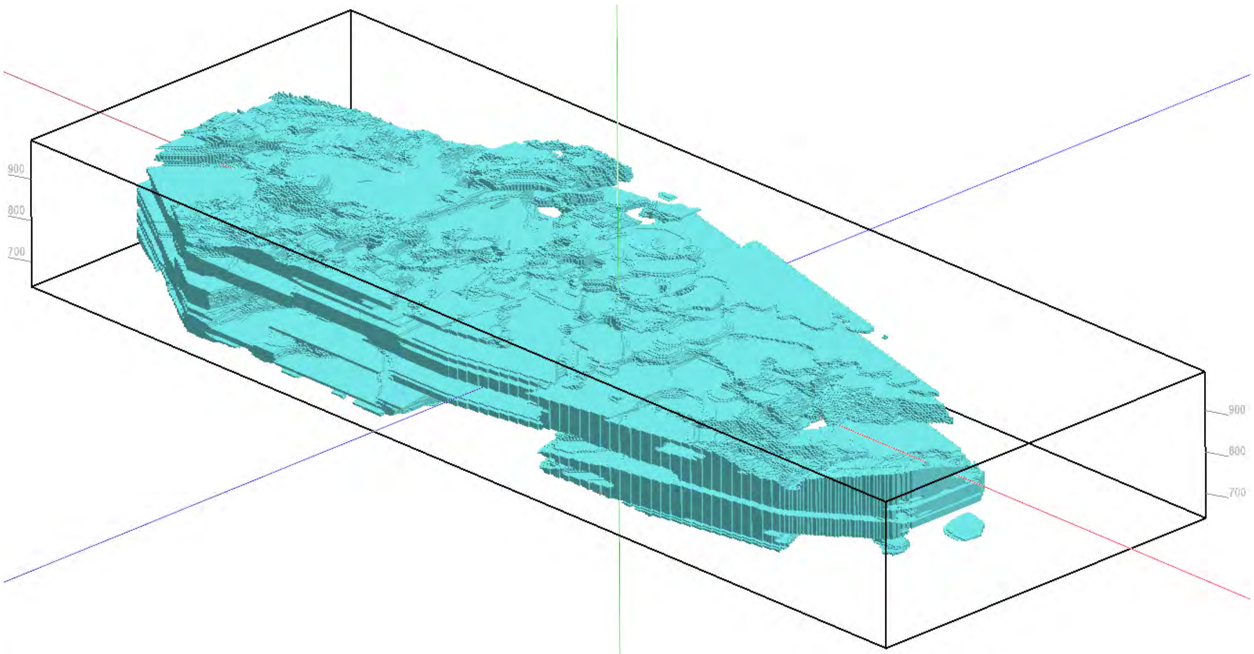


Figure 15. BPI Model Depicting Possible Groundwater Pathways (Blue = True, Empty = False) - Vertical Exaggeration = 8x

It should be noted that this strategy does not address chemical or electrochemical interactions between the contaminant and other materials (e.g. adsorption). Instead, it is designed to simply provide a spatial groundwater possible-pathways model that is used to delineate 1,4-Dioxane and to constrain the subsequent geochemical modeling.

Annual Geochemical Solid Models

Individual solid models were created for each year, from 1986 to 2019, by filtering out only the wells sampled during each year and interpolating the models using a Horizontally-Biased Inverse Distance Weighting (HBIDW) algorithm with Logarithmic/Exponentiating (L/E), and High-Fidelity (HiFi) conversions.

The lateral extent of each annual geochemical model were limited to a polygon defined by only the wells that were sampled during the associated year. These polygons were created by using an inflated convex hull algorithm.

Each annual model was then multiplied by the BPI model in order to confine the geochemistry to the groundwater pathways.

Finally, the models were rendered as semi-transparent color-coded shells depicting three cutoff levels (Figure 16 & Figure 17) for subsequent display within the animations. These cutoff levels are defined as follows:

- 7.2 ppb: EGLE Part 201 Residential Drinking Water Criteria,
- 280 ppb: EGLE Part 201 Groundwater, Surface Water, Surface Interface Criteria, and
- 1,900 ppb: Proposed Vapor Intrusion Screening Level.

Figure 16. Annual Geochemical Model Images Used Within Animations

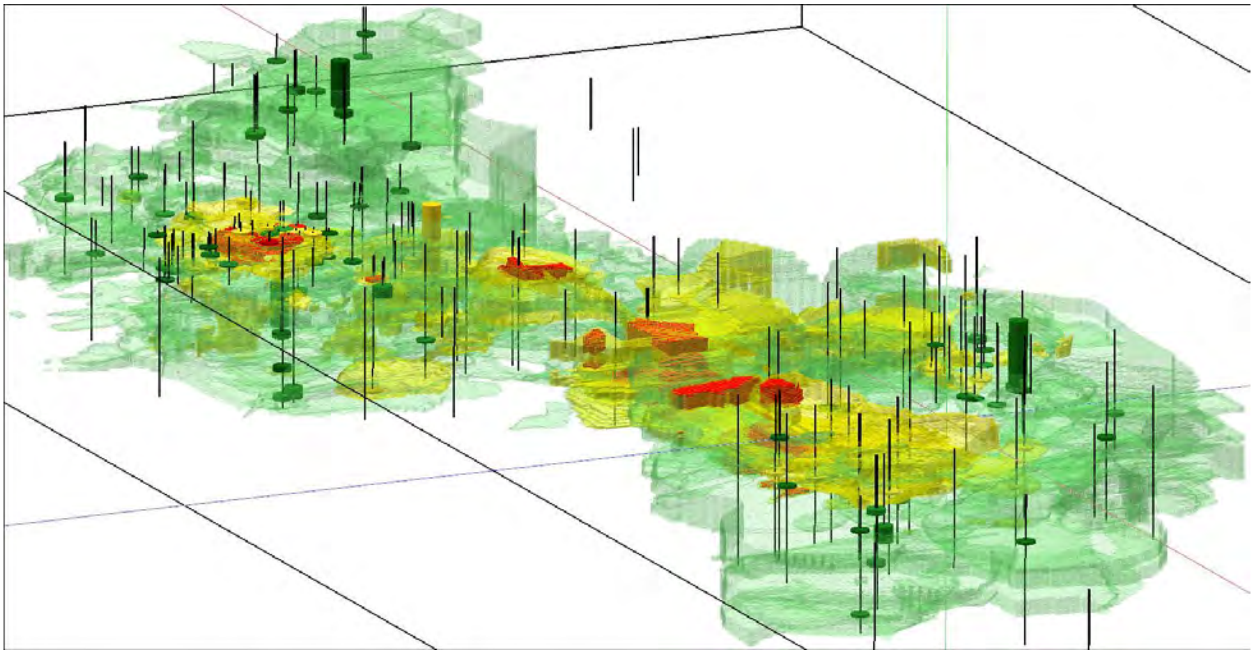


Figure 17. Enlargement Showing Portion of 2007 3D Plume Diagram

Final Comparison

A comparison of the 2019 Washtenaw County [1,4-Dioxane] and the 2019 EGLE Highest-Value [1,4-Dioxane] Map (Figure 18. 2019 Washtenaw vs 2019 EGLE Comparison) was created.

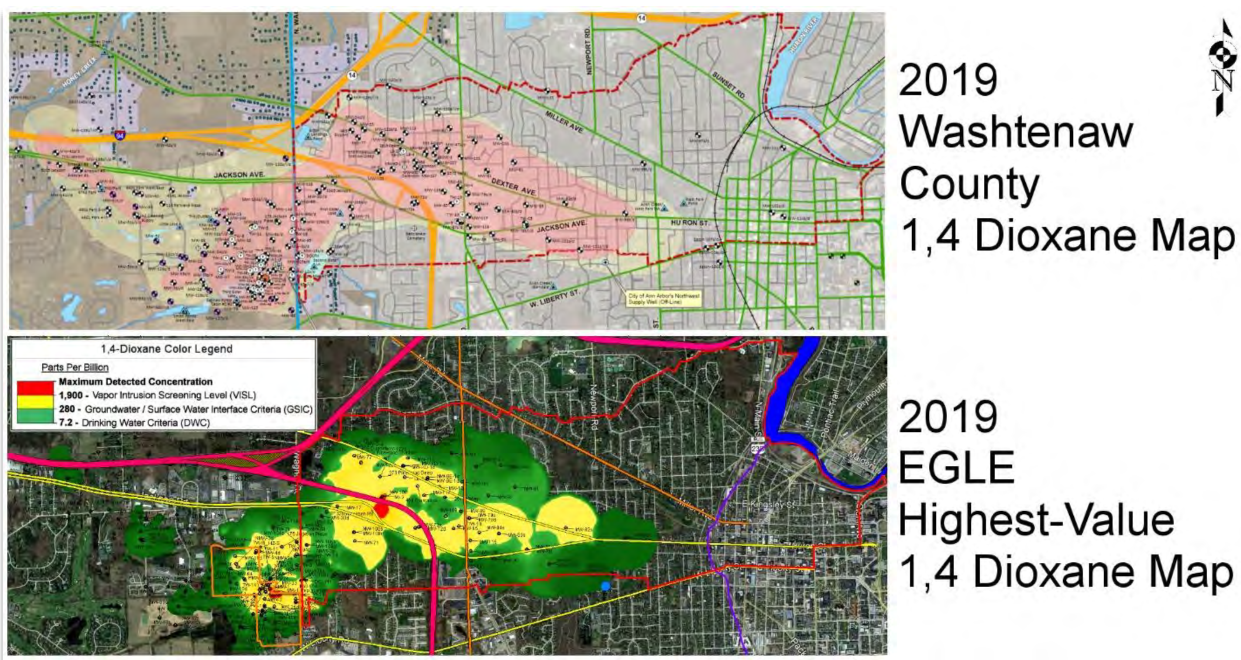


Figure 18. 2019 Washtenaw vs 2019 EGLE Comparison

Annual Geochemical Grid Models

The annual geochemical solid models were converted to grid models by setting the grid node values to the highest value within the corresponding solid model column. These grids were rendered as maps plotted on top of a reference image that includes the Gelman Site and the Prohibition Zone outlines for subsequent display within the animations (Figure 19 & Figure 20).

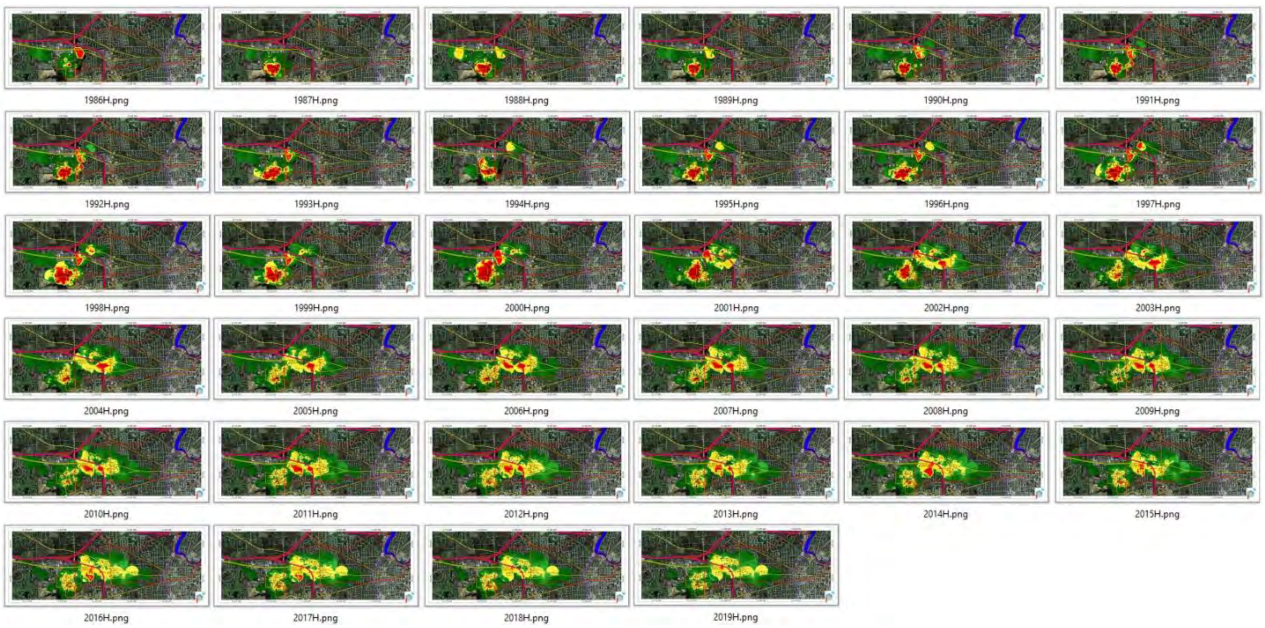


Figure 19. Annual Highest-Value Geochemical Map Images Used Within Animations

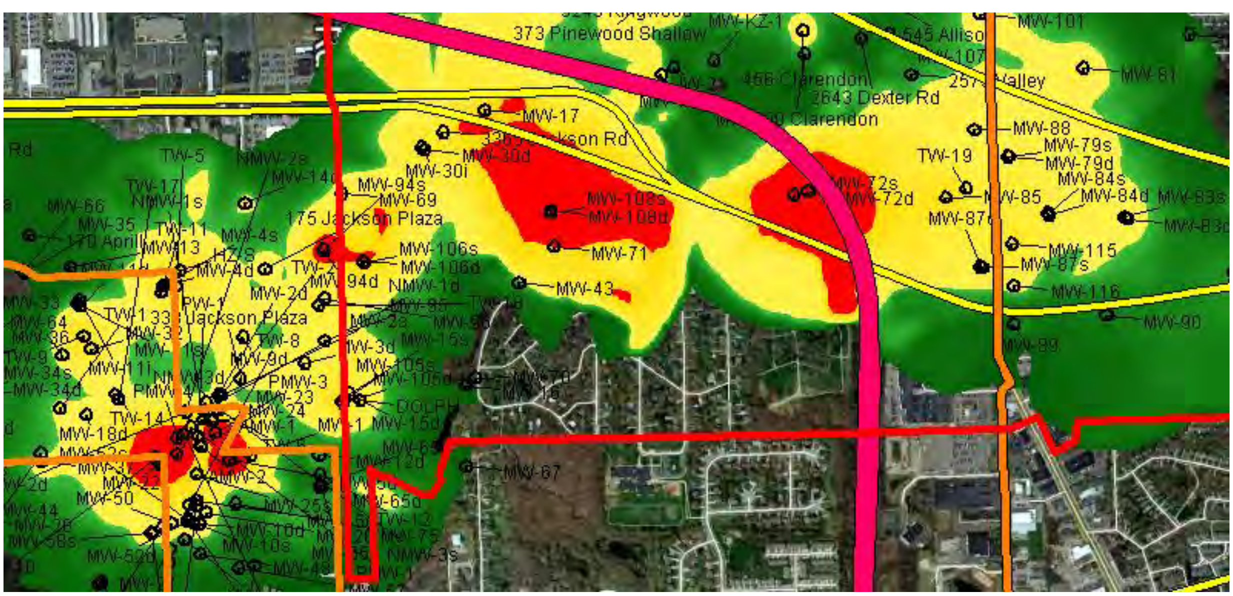


Figure 20. Enlargement Depicting Portion of 2007 Maximum-Value Map

Comparing Plume Volumetrics Over Time

To quantitatively evaluate the changes within the plume over time, the volume of 1,4-Dioxane for each of the cutoff thresholds (7.2 to 280, 280 to 1,900, and >1,900) was computed for each year, from 1986 to 2019. This data was then presented as a graph (Figure 21).

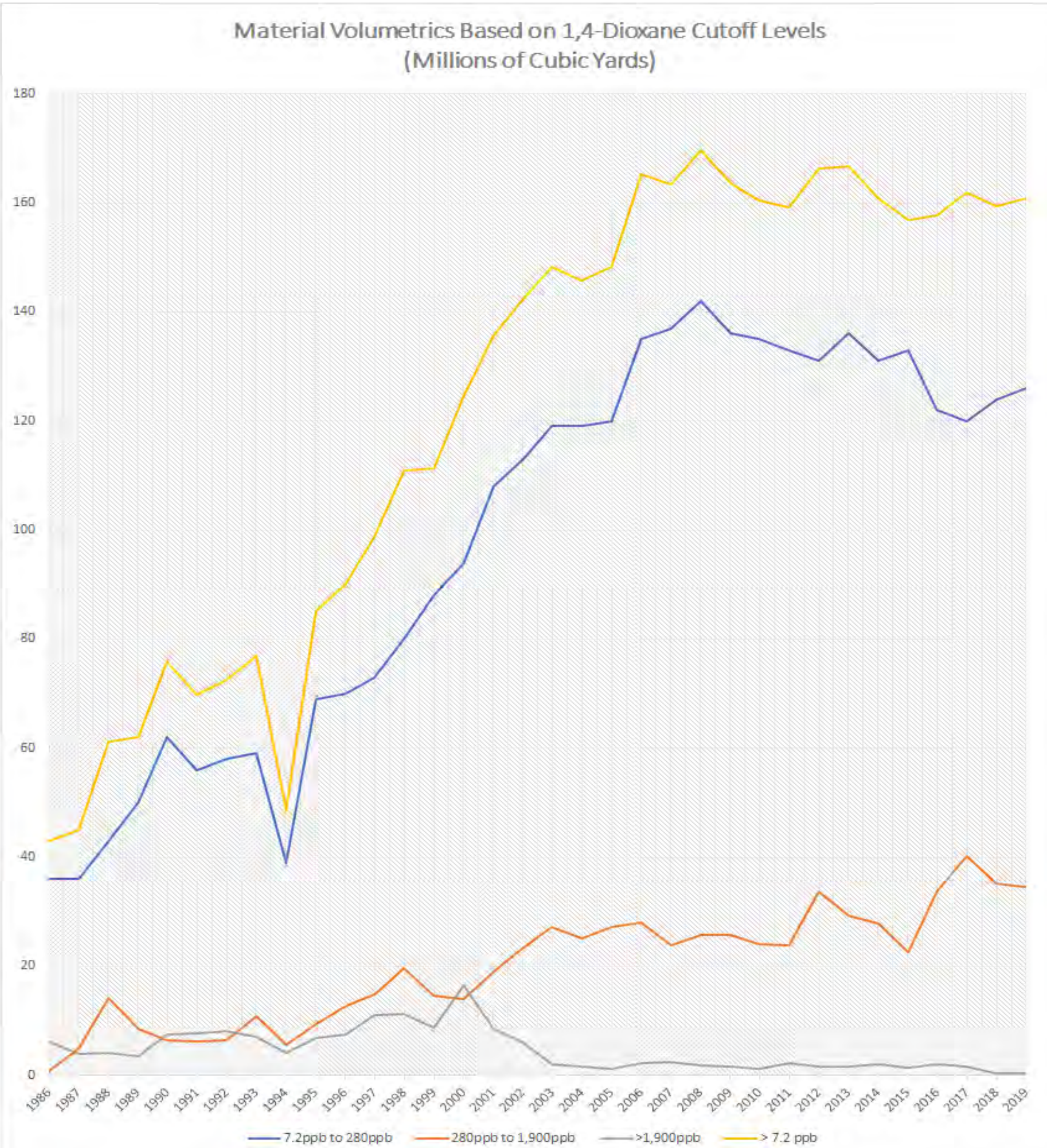


Figure 21. Material Volumetrics Based on 1,4-Dioxane Over Time

The volume of the plume peaked in 2008 with an areal extent of 1,343 acres (2.1 square miles) and shrank to 1,274 acres (2.0 square miles) by 2019. As reflected here, the volume of material with a contamination level greater than 1,900 ppb had decreased by 2003. Conversely, as shown in the chart, the volume of material with a contamination level between 280 and 1,900 ppb has steadily increased since 1986.

Depth Grids

In order to provide depth-to-contaminant information for any location within the project area, three grid models were created as described below.

Dioxane 7.2 Depth Model: Grid model in which the Z-values represent the depths (in feet) to the uppermost voxels within the 2019 1,4-Dioxane solid model with values greater than or equal to 7.2 ppb. A color-coded contour map depicting this grid is shown within Figure 22.

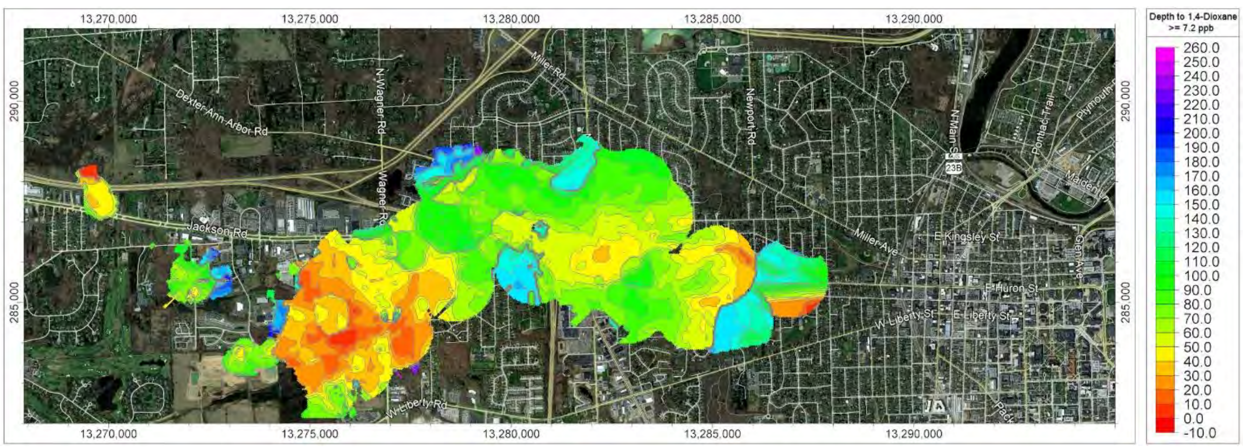


Figure 22. Depth to Shallowest 1,4 Dioxane >= 7.2ppb

Dioxane 1,900 Depth Model: Grid model in which the Z-values represent the depths (in feet) to the uppermost voxels within the 2019 1,4-Dioxane solid model with values greater than or equal to 1,900 ppb. A color-coded contour map depicting this grid is shown within Figure 23.

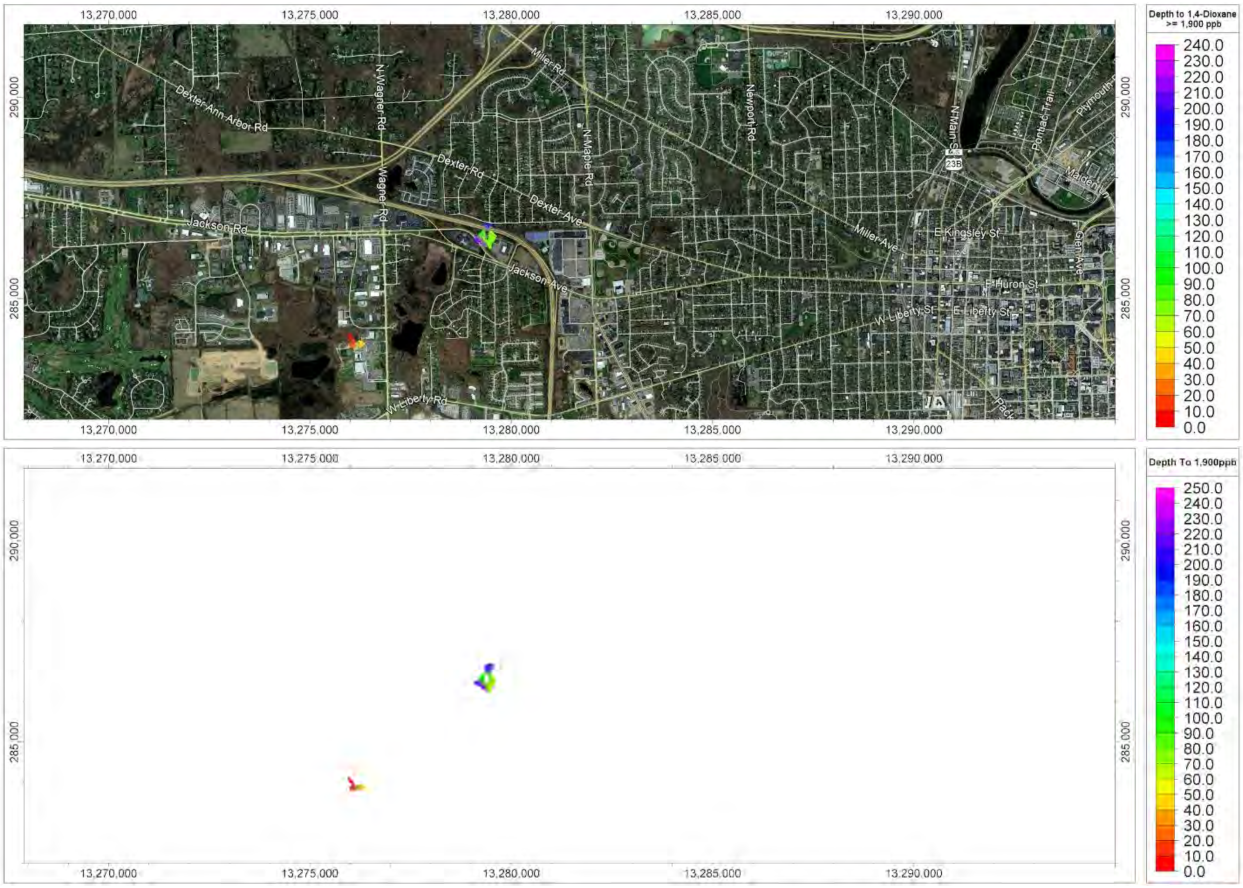


Figure 23. Depth to Shallowest 1,4-Dioxane > 1,900ppb (Upper map includes satellite image.)

Depth to Maximum 1,4-Dioxane Model: Grid model in which the Z-values represent the depths (in feet) to the highest G-Value within the 2019 1,4-Dioxane solid model. In cases where more than one voxel corresponding to the cell share the highest-value designation, the G-Value for the shallowest voxel was used. A color-coded contour map depicting this grid is shown within Figure 24

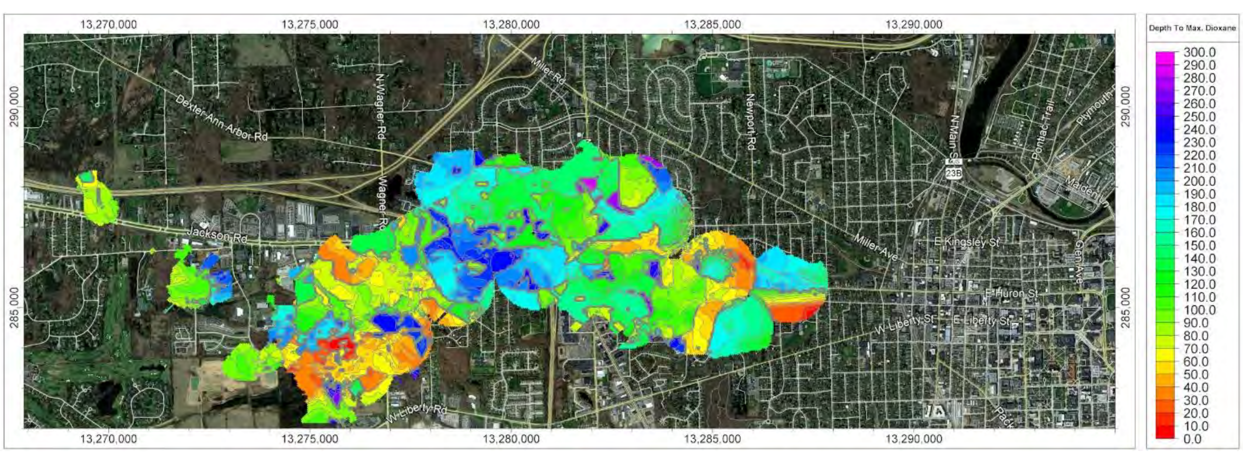


Figure 24. Depth to Maximum 1,4-Dioxane Contamination

The processes used to create these grids are shown within the flowchart shown below within Figure 25.

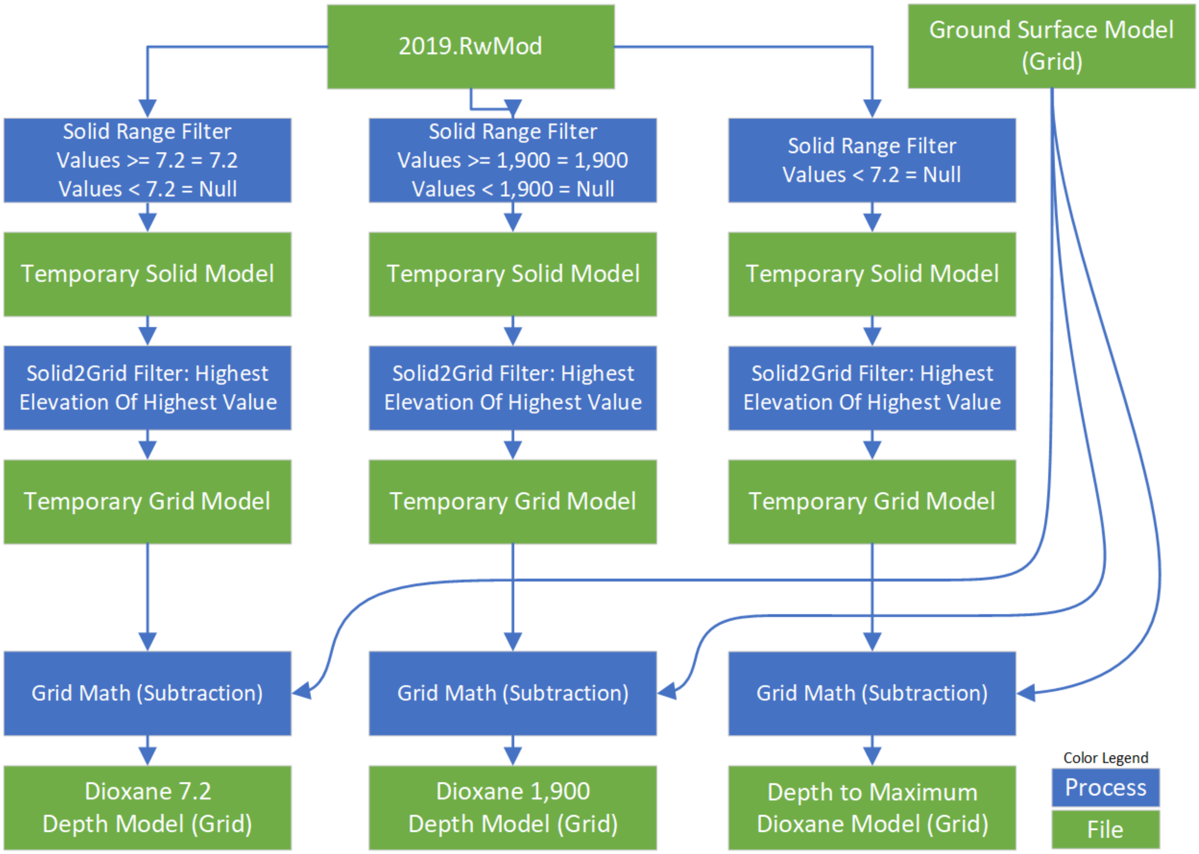


Figure 25. Processes Used to Create Grids

Animations

The images generated by the automation scripts were composited into animations, annotated, and then edited using a variety of commercial products such as PaintShop, Morpheus, Camtasia, Vegas, and FFmpeg. The steps taken to produce these animations are illustrated within the flowchart shown below (Figure 26).

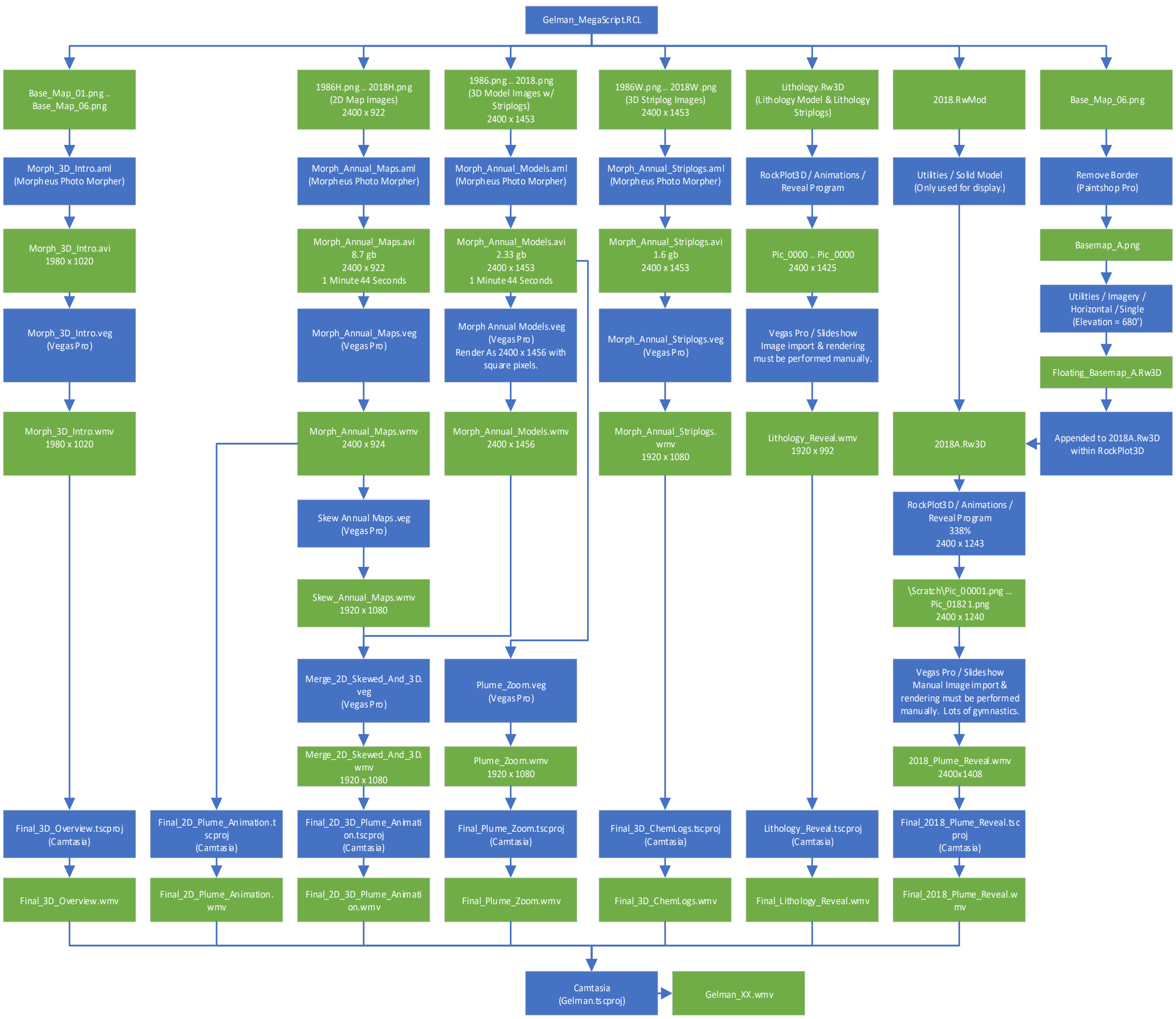


Figure 26. Animation Flowchart

Automation (Scripting) The Process

Creating the models, diagrams, and animations was an iterative process, meaning that as models and diagrams were created, errors within the data, methodology, and scripting became obvious. These errors were corrected and new models and diagrams were re-generated. This process was repeated until the models were deemed to be correct and accurately reflect the interpretations found in EGLE public files.

These iterations were streamlined by creating RCL scripts that bypass the RockWorks menus and allow for the easy re-generation of all the models and diagrams, including separate models each of the 34 years. In this way, if an error was corrected within the database or if new data is added to the database, all of the models and diagrams can be re-generated with a single command.

Appendix 1. Lateral Blending Variability

As previously described within the Lithology Modeling section of this report, the Lateral Blending algorithm horizontally extrudes the lithologies from the lithologic intervals defined within the wells. This extrusion extends to 1/3rd of the distance to the closest neighboring wells that also have lithology data. The undefined voxels that reside within the center 1/3rd region between the wells are defined by randomly selecting the co-planar lithologies from the surrounding wells.

For example, Figure 27 depicts two wells, named "Well-A" and "Well-B", separated by a distance of 90 feet. Both of these boreholes encountered alternating lithologies consisting of limestone and rhyolite. The voxels within 30 feet of each well are assigned a lithology based on the corresponding observed lithology within the associated well. The lithologies within the "Random Zone" are determined by randomly selecting a number between zero and 30 to serve as the demarcation point for extending the lithologies on either side.

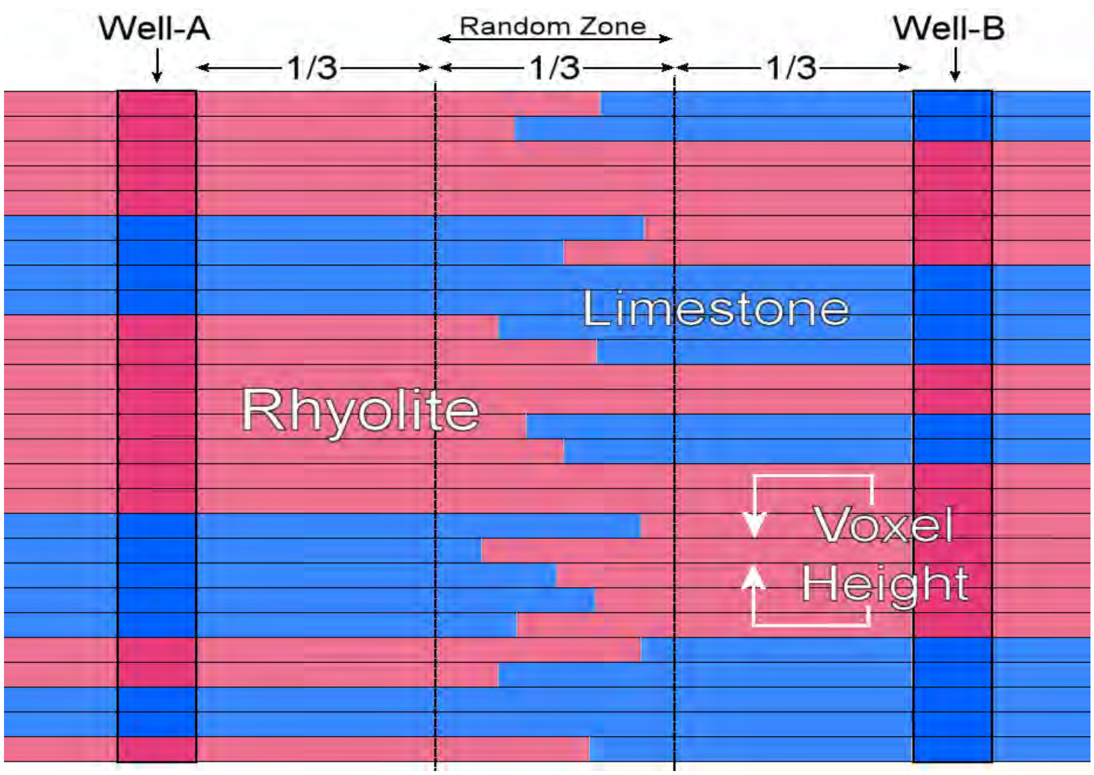


Figure 27. Simplified Lateral Blending Methodology

In order to quantify the variability produced by this process, five lithology models were created for the study area using the Lateral Blending algorithm with the same borehole data. The differences between the models are presented visually within Figure 28 and statistically within Table 4

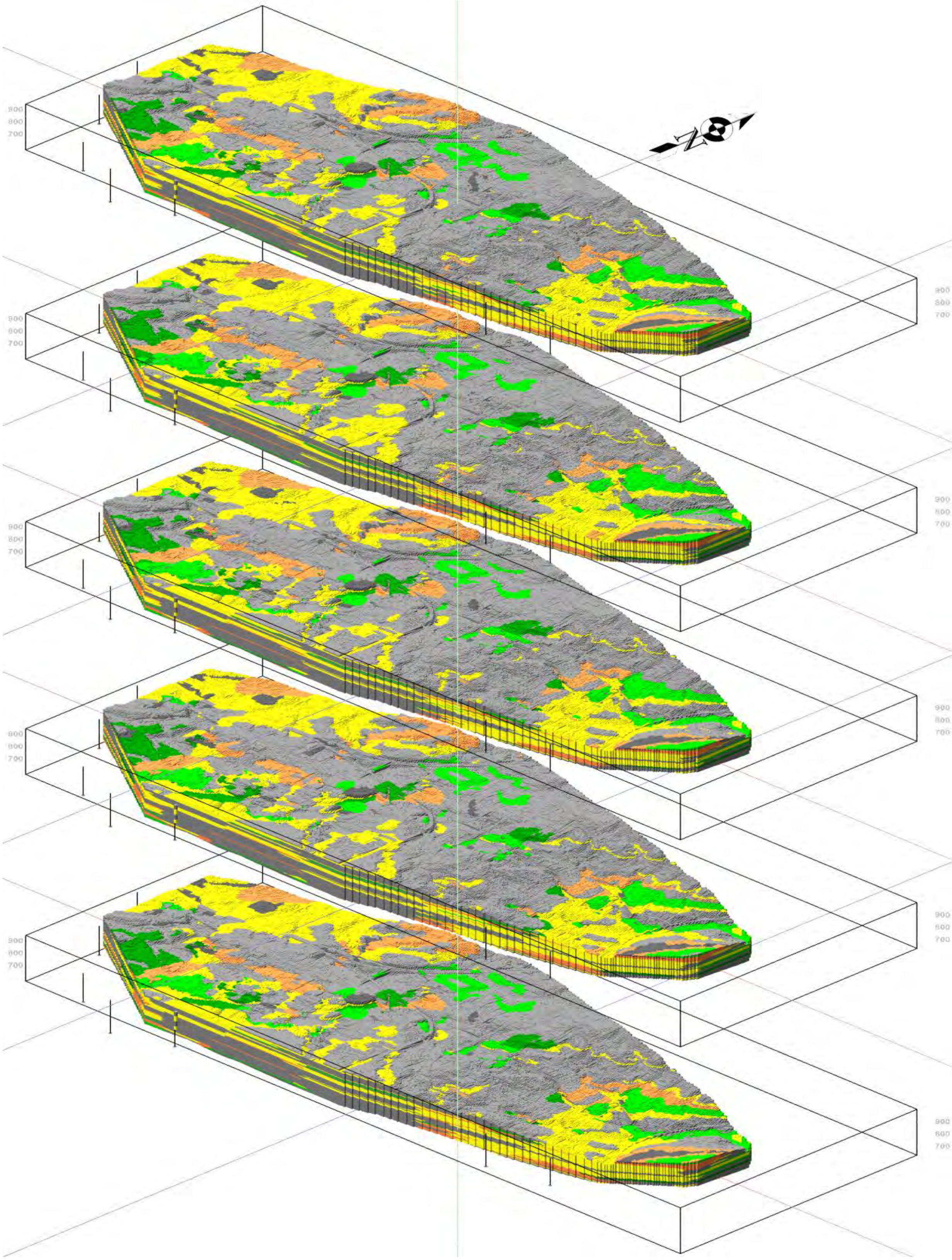


Figure 28. Five Lithology Models Created with Lateral Blending Algorithm

A visual comparison of the models (Figure 28) shows that in areas with dense well control, the differences between the models are too small to detect. Conversely, variations are noticeable within regions with sparse well control.

Table 4. Statistical Comparison of Five Lithology Models Created with Lateral Blending

	Model (1)									Standard
Lithology	1	2	3	4	5	Min	Max	Range	Mean	Deviation
Clay	1234401	1240906	1246566	1242624	1230799	1230799	1246566	15767	1239059	6371.8178
Concrete	243	387	316	66	579	66	579	513	318.2	188.42426
Diamicton	2867570	2860147	2852112	2865581	2868353	2852112	2868353	16241	2862753	6756.1674
Fill	5694	4727	6294	6133	5815	4727	6294	1567	5732.6	611.35121
Gravel	1149554	1145395	1138536	1124936	1148992	1124936	1149554	24618	1141483	10238.626
Inter-bedded	24556	25244	24329	23215	24764	23215	25244	2029	24421.6	754.33766
Peat	5114	5321	5561	5993	4842	4842	5993	1151	5366.2	439.10671
Sand	2103807	2115500	2094355	2114689	2105341	2094355	2115500	21145	2106738	8715.9638
Shale	112373	109964	121547	116864	122038	109964	122038	12074	116557	5385.3787
Silt	175610	180645	181168	173855	170137	170137	181168	11031	176283	4664.0031
Silty Sand / Sandy Silt	388893	379208	397001	393507	385631	379208	397001	17793	388848	6918.4247
Topsoil	8227	8598	8257	8579	8751	8227	8751	524	8482.4	229.60575
Sum	8076042	8076042	8076042	8076042	8076042		Min Range	513		
							Max Range	24618		
							Range of Range	24105		
(1) Number of voxels assigned to lithologies.							Variability	0.2985		

The statistical comparison (Table 4) indicates that there is a 0.3% variability between the models, meaning that the models can vary by as much as 0.3%. This number was determined by counting the number of voxels for each lithotype and computing the range for the five models. The range of these ranges was then divided by the total number of defined voxels and multiplied by 100 to define the variability.

It should be noted that the variability relates inversely with the voxel dimensions. If the voxels are larger, the variability will increase exponentially. The very low variability (0.3%) associated with the model generated for this report justifies the increased processing time associated with higher resolution models.

The following terms are defined in the context of how they were used within this Project. Other software and disciplines may have completely different meanings for these terms.

1,4-Dioxane: "… likely human carcinogen and has been found in groundwater at sites throughout the United States. The physical and chemical properties and behavior of 1,4-Dioxane create challenges for its characterization and treatment. It is highly mobile and does not readily biodegrade in the environment." – USEPA Technical Fact Sheet. Also referred to as simply "Dioxane."

Algorithm: A computer process used to calculate, estimate, or interpolate Node values within a Grid or Solid.

Allen Creek Drain: Underground storm drain sewer system. Converted from an open creek to an underground pipe in 1926.

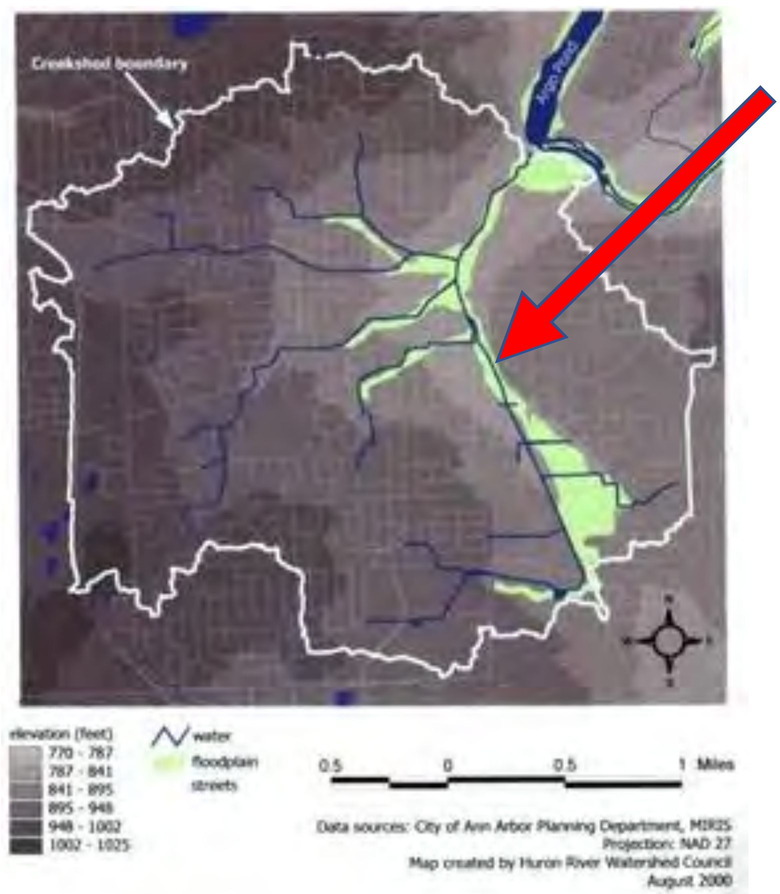


Figure 29. Allen Creek Drain System & Watershed
Source: https://localwiki.org/ann-arbor/Allen_Creek

Animation: Video (avi, mp4, wmv), animated GIF, or Google Earth movie.

Anticline: A fold within a surface in which both sides dip away from the axial plane (Figure 30).

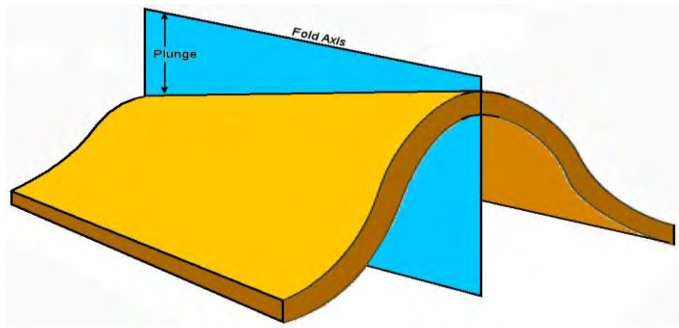


Figure 30. Plunging Anticline

Auto-Kriging: Modeling algorithm that automatically computes the optimal spoke-spacing and tolerance, distance-increment and tolerance, and maximum distance based on point-to-point statistics. A series of eight variograms (exponential, gaussian, linear, and spherical with and without nugget) are then best fit to the observed directional variograms. This algorithm then selects the variogram with the best correlation coefficient (least error) and uses that variogram to krig the data. This kriging process is essentially a form of directionally-weighted averaging.

Bedrock: Materials below the glacial sediments that are considered to be impermeable. Although this term is more typically associated with crystalline rocks, the preferable term of "basement" is not used in order to avoid confusion with the basements below a residence or office building given the local concerns over 1,4-Dioxane contamination migrating into dwellings.

Boolean & Boolean Models: In the context of grids and solids, a "Boolean" model consists of only two possible values: 0.0, meaning "false" and 1.0, meaning "true". If a non-Boolean model (e.g. geochemistry) is multiplied, on a voxel-by-voxel basis with a Boolean model, any geochemistry that corresponds with a false Boolean voxel will be set to zero while any voxel that corresponds with a true Boolean voxel will be left as-is.

Boolean Permeable/Impermeable (BPI) Model: A Boolean solid created by filtering the Permeability model such that all nodes with a value less than less than 0.00002 (2.0×10^{-5}) feet per second were converted to 0.0 (False) while values equal to or greater than 0.00002 were converted to 1.0 (True).

Cell: Element within a grid model. Grids are made up of cells. The value assigned to a cell is referred to as the node value or the Z-value. A cell is analogous to a pixel within a digital image while a grid is analogous to a digital image.

Cell Value: See node value.

Clipping: When used in reference to a grid model, clipping removes cells. When used in reference to a solid model, clipping removes voxels. This removal is accomplished by setting the cell or voxel values to a null value (-1.0e27). The RockWorks software is configured to treat null values as absent rather than zero.

Contamination Plume: Visual representation of a space in water or soil containing pollutants released from a point source of contamination.

Control Point: An observation such as a geochemical sample within a borehole. Grid and Solid Models are created by interpolating cells and voxels between control points.

DEM: Acronym for "Digital Elevation Model". A digital representation of surface topography consisting of regularly-spaced points sampled as a grid model.

G-Value: The value assigned to a voxel.

Gelman: The Gelman Manufacturing Facility discharged 1,4-Dioxane solvent from their medical filter manufacturing facility 3.5 miles west of Ann Arbor, Michigan between the 1960's and the 1980's. Gelman Sciences Corporation. was acquired by the Pall Corporation in 1997.

Grid Cell: See Cell**.**

Grid Model: Data structure used to model data that has two independent variables (X and Y) and one dependent variable (Z). For any given XY coordinate there can only be one Z value (e.g. elevation). Examples of data that can be modeled with grids include surface topography, surface geochemistry, and formation thicknesses. Grids model XYZ data by assigning an interpolated value to imaginary cells (nodes) within the grid based on the surrounding control points (Figure 31). There are many different gridding methods (algorithms), for performing these estimations, each of which has its own strengths and limitations. There is no universal algorithm that is applicable to all types of geologic data. Also referred to as just "Grid."

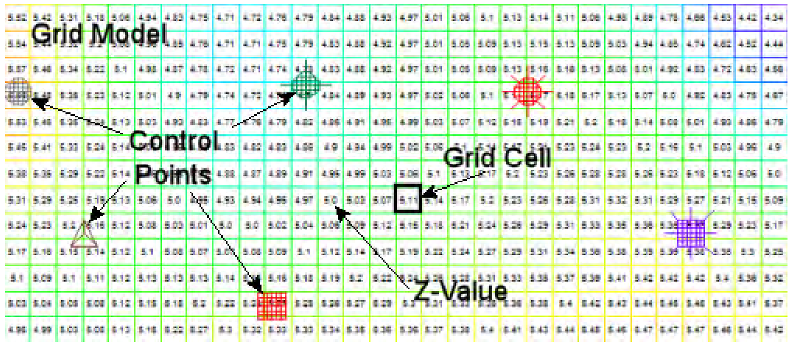


Figure 31. Grid Model Terminology

A Grid Model is not a diagram. Instead it is just a list of numbers that define the XY coordinates and Z-Value for each cell.

Grid Modeling: The process of creating a Grid Model by interpolating the Z-Values (aka nodes or cell values) based on irregularly-spaced control points. Also referred to as "Gridding."

Grid Resampling: A process in which grid nodes are converted to control points and then used to interpolate cell values for a new grid with different cell dimensions. The interpolation is performed by using an inverse-distance weighting algorithm.

Horizontally-Biased Inverse Distance Weighting (HBIDW): This interpolation algorithm is based on a three-dimensional inverse-distance weighting interpolation in which the weighting factor varies with the inclination of a control point relative to the voxel that is being estimated. The influence of a co-planar point will be based on its inverse distance squared whereas a point that is directly above or below the voxel will have an influence based on the inverse distance to a power of five. The weighting factor for all other points will range between 2 and 5 as scaled to their relative inclination. The net result is a modeling algorithm that horizontally biases the influence of the control points.

High-Fidelity (HiFi) Post Processing: A process in which cells or voxels that contain control points are replaced with the control point values in order to honor the data. This process is applied after the initial model has been created, hence the "high-fidelity" nomenclature. If a cell or voxel contains more than one control point, an IDW (Inverse Distance Weighting) algorithm relative to the cell or voxel midpoint is used to estimate the new value. Adjacent cells or voxels that do not contain control points are smoothed to minimize the "bullseye" effect when the new value is significantly different that the original value.

Hydraulic Conductivity: The ease with which a fluid (usually water) can move through pore spaces or fractures. Symbolically represented as "K."

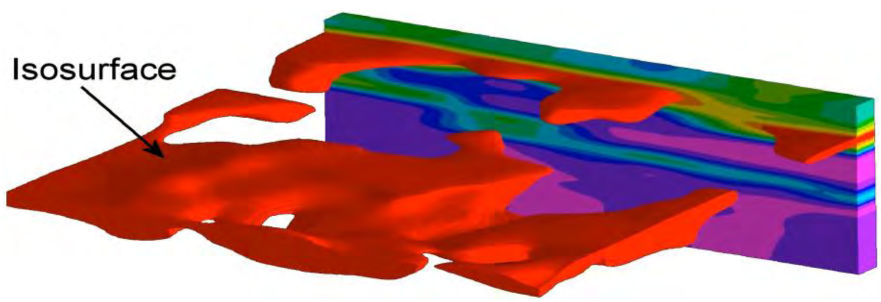
Impermeable: Soil or rock that does not allow a fluid to pass through it.

Inflated Convex Hull (ICH): The shape created by fitting a convex polygon to peripheral control points. This process is analogous to stretching a rubber band around all of the points. The algorithm can also be used to expand (inflate) this perimeter a specified distance outward. Specifying a conservative distance (e.g. ½ Average Minimum Distance Between Control Points) for the inflation will eliminate abrupt and unrealistic terminations against the convex hull (Figure 32).

Figure 32. Inflated Convex Hull

Interpolation: The estimation of an intermediate value into a grid or solid by evaluating the surrounding known values based on an estimation algorithm.

Isosurface: A three-dimensional contour analogous to a skin that conforms to the extent of a given plume concentration.



K: Symbolic representation of hydraulic conductivity. Expressed in feet per second.

Lateral Blending: As with Lateral Extrusion, the Lateral Blending algorithm does not attempt to create transitional gradations between the control points. Instead, Lateral Blending will laterally extend observations from each well one-third of the distance to the neighboring wells. The lithology within the center third is randomly selected from the borehole lithologies on either side resulting in a transgressive/regressive appearance similar to hand-drawn sections while still honoring the observed lithologies.

The primary difference between Lateral Blending and Lateral Extrusion is that the former method produces more aesthetically pleasing (in a geologically sense) correlations.

Lateral Extrusion: Unlike most of the other estimation algorithms, Lateral Extrusion and Lateral Blending do not attempt to create transitional gradations between the control points. Instead, Lateral Extrusion will laterally extend lithologic observations from each well to the midpoint with the neighboring wells. This creates a discrete model in which the lithotypes do not blend from one type to the other (e.g. rhyolite will not grade into limestone). This algorithm has proven to be well suited for modeling laterally discontinuous units that are too complex for stratigraphic correlations (e.g. glacial deposits west of Ann Arbor, Michigan).

Legacy Data: Data presented within previous reports.

LIDAR: Acronym for “Light Imaging, Detection and Ranging.” A surveying method in which a laser is used to measure the distances between the camera and millions of points on the ground. These distances are used to create a digital 3D model of the ground surface.

Lithology: Type of material including concrete, asphalt, soil, sand, gravel, clay, and rocks.

Lithology Model: Solid model in which the numeric voxel values represent the types of material conceptually contained within each voxel.

Lithology Table: Table within the SQL database that defines lithologic terms and their associated patterns, colors, and G-Values. These G-Values define the numbers that are used to represent the associated lithologic terms within the numeric solid models.

Logarithmic/Exponentiating (L/E) Conversion: Before a model is created, all of the control point values are converted to their natural logarithm equivalents. Once the model has been created, the voxel values are converted back to the original range of values by exponentiating the node values. These steps diminish the overwhelming influence of anomalously high and anomalously low values upon the weighting. A useful analogy involves the gravity equation (the basis for this algorithm) which states that gravitational force upon an object varies inversely with the distance squared multiplied by the mass of the object. A neighboring point with tremendous mass (e.g. a star) will overwhelm the weighted averaging thereby rendering the influence of other nearby objects (e.g. a spacecraft) to be insignificant. The logarithm/exponentiating conversion diminishes the mass of the star when computing its influence and effectively allows us to see both the forest and the trees.

Mannik Smith Group (MSG): Engineering and environmental firm with offices throughout Ohio and Michigan. RockWare is a subcontractor to Mannik Smith. Web site: https://manniksmithgroup.com/

Maximum Historical Water Level Surface (MHWLS) Model: An interpolated surface (grid) model based on the maximum water level elevations observed within all of the boreholes from 1986 to 2019.

Mean Sea Level (MSL): Elevation relative to the average global sea level datum.

Michigan Department of Environment, Great Lakes, and Energy (EGLE): State agency charged with protecting Michigan's environment and public health by managing air, water, land, and energy resources. Formerly known as the "Michigan DEQ". Web site: https://www.michigan.gov/egle/0,9429,7-135-3311_4109_9846-71595--,00.html

Model: Either a grid model or a solid model.

Modeling: The process of interpolating node values for a grid model or a solid model.

Montgomery Well: Ann Arbor municipal water well decommissioned in 2001 after 1-2 ppb of 1,4-Dioxane was detected during a routine sampling.

Node: The midpoint of a cell or voxel.

Node Value: The numeric value assigned to the Node within a grid model or a solid model. When used in regards to a Grid Model, the Node Value is also referred to as the Cell Value or the Z-Value.

Node Spacing: Horizontal or vertical distance between nodes. The Node Spacing essentially determines the resolution of the model. For example, a horizontal Node Spacing of 500 feet means that the model will discriminate features that are 500 feet or greater in width. Conversely, features that are less than 500 feet in width may be completely omitted by the modeling. In a grid, the Node Spacing is the same as the cell width. In a solid, the horizontal node spacing is the same as the voxel width while the vertical node spacing is the same as the voxel height.

Node Value: Number assigned to a cell (Z-value) or a voxel (G-value).

Permeability: The capability of a porous rock or sediment to permit the flow of fluids through its pore spaces.

Pixelation: Blocky, Lego-like, appearance caused by rendering diagrams based on grid or solid models at an enlarged scale.

Potentiometric Surface: In the context of this report, the Potentiometric Surface is defined as an imaginary surface that is based on the maximum water table elevations for all wells from 1986 to 2019. Given the ambiguities with other related terms (e.g. Piezometric, Water Table), this report refers to this surface as the Maximum Historical Water Level Surface (MHWLS).

PPB: Parts per billion (1/1,000,000,000).

Prohibition Zone: Region of the Gelman 1,4-Dioxane plume deemed off-limits for water well usage or construction in 2007. Web site: https://www.michigan.gov/documents/deq/rrd-GS-PLSPZFactSheet-3-15-07_190336_7.pdf

Project Area: 27,100' east/west by 9,800' north/south by 342' deep parallelepiped (3D rectangle) considered to be effected by 1,4-Dioxane contamination associated with the former Gelman Manufacturing Facility located in Scio Township, approximately 2.75 miles west of downtown Ann Arbor, Michigan.

RockWare Inc.: Geological software development, resale, and consulting company based in Golden, Colorado. Subcontractor to Mannik Smith Group. Web site: www.rockware.com.

RockWorks: Integrated geological database, analysis, and visualization software developed by RockWare, Inc. Web site: https://www.rockware.com/product/rockworks/

RockWorks Command Language (RCL) Scripts: Batch-processing language that bypass the RockWorks menus and allow for the automated re-generation of all the models and diagrams. RCL Scripts are stored within generic ASCII (American Standard Code for Information Interchange) text files that can be viewed and edited within a simple text editor (e.g. Windows NotePad). RCL scripts consist of blocks of parameters definitions (menu settings) followed by a command that executes the associated sub-program. The example displayed below, shows how a solid model is truncated by an overlying grid model.

```
: Truncate BPI Model Above MHWLS
:-------------------------------
DEFINE: SOLID_G_FILTER_1 INPUT_SOLID      BPI.RwMod
DEFINE: SOLID_G_FILTER_1 INPUT_GRID       MHWLS.RwGrd
DEFINE: SOLID_G_FILTER_1 OUTPUT_FILE      BPI.RwMod
DEFINE: SOLID_G_FILTER_1 OPERATION        1
DEFINE: SOLID_G_FILTER_1 UPPER_MULTIPLIER 0.0
DEFINE: SOLID_G_FILTER_1 LOWER_MULTIPLIER 1.0
DEFINE: MODEL_DISPLAY    INCLUDE_DIAGRAM  False
EXECUTE: solid_gfilter_1
```

Solid Model: Data structure used to model data that has three independent variables (X, Y, and Z) and one dependent variable (G). For any given XYZ coordinate there can be only one G value (e.g. 1,4-Dioxane). Examples of data that can be modeled with solids include geochemistry, geophysical data, and ore grades. The three-dimensional cells within a solid are termed "voxels", and just like grid cells, the center of a voxel is called a "node" (Figure 33). Also referred to a "Block Model" or "Solid."

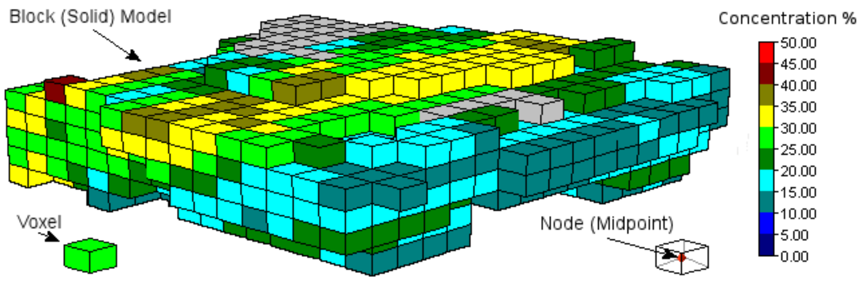


Figure 33. Solid Model Terminology

By way of analogy, a digital picture (essentially a grid), cannot be used to model a deformed onion in three dimensions whereas a 3D radiological CT scan (essentially a solid) can. A digital image is essentially a grid made up of pixels (pixel elements) whereas a 3D CT is a solid, made up of voxels (volumetric elements).

A Solid Model is not a diagram. Instead, it is just a list of numbers that define the XYZ coordinates and G-Value for each Voxel.

Solid Modeling: The process of creating a solid model by interpolating the G-values for voxels based on irregularly-spaced control points. Also referred to as "Block Modeling."

Southeast Michigan Council of Governments (SEMCOG): Association of Michigan state agencies that supports local planning through its technical, data, and intergovernmental resources. Web site: https://www.semcog.org/

SQLite: Relational Database Management System (RDBMS). Reportedly the most widely used RDBMS in the world.

Trend-Surface Polynomial Algorithm: This method best-fits a polynomial equation to the points. A first-order surface is a plane, a second-order surface has one flexural axis, a third-order surface has two flexural axes, and so on. Second-order trend-surface polynomials have proven to be a very useful tool for modeling potentiometric surfaces because the water levels have reached a state of equilibrium that lacks the crenulations and perturbations that other algorithms, such as Kriging, are designed to enhance.

Vertical Exaggeration: Ratio of vertical scale relative to horizontal scale within cross-sections and 3D diagrams. For example, if the Vertical Exaggeration equals 5x then features are being vertically stretched to five times the horizontal scale. Vertical Exaggeration is used to highlight features that would otherwise be obscured if the vertical scale equals the horizontal scale.

Voxel: Volumetric element within a solid model. Solids are made up of voxels. The value assigned to a Voxel is referred to as the Node Value or the G-Value.

Voxel Value: The value assigned to a voxel. See Node Value.

Z-Value: The value assigned to a cell. See Node Value.

Signature Page

Signed:

James P. Reed
RockWare Incorporated
March 30th, 2020

Attachment 3

EGLE GROUNDWATER MODELING TAPs REVIEW TEAM APPROVAL & TRACKING FORM, February 23, 2021

GROUNDWATER MODELING TAPs REVIEW TEAM
APPROVAL & TRACKING FORM

Groundwater Modeling Peer Review Date: February 23, 2021

Site Name: Gelman Sciences

Address: 600 South Wagner Road, Ann Arbor, MI 48106

County: Washtenaw

ID: 81000018

Project Manager: Dan Hamel

Presenters: Kevin Lund (MMD), Jim Reed (Rockworks) and Kevin Brown The Mannik & Smith Group, Inc. (MSG)

District Peer Review Completed: No

Purpose of Presentation (Question(s) before In Situ Peer Review):

The JAX district are sharing the results of its primary objectives to collate and consolidate Gelman geology and water chemistry datasets into workable tables for import into a RockWorks project database for an interactive virtual conceptual site model.

EGLE, Rockworks and MSG will present how the data was used to prepare the Gelman CSM into both two dimensions (2D) and three dimensions (3D) geology and geochemistry models that are integrated and presented on the Arc GIS platform.
Questions

- Critical review of the process to prepare the data for Rockworks and GIS.
- Critical review of how the geology model was developed and validated.
- Critical review of how the geology model was used to constrain the Dioxane in groundwater model
- Critical review of how arithmetical operations performed on the grid node Z-values in two existing grid files are used to create a new grid file.
- In the GIS platform, using zonal statistics on grid files created in rockworks to present parcel information on the depth to groundwater, depth to Dioxane and any other risk-based concern.
- Did the JAX District meet its goal to establish an accurate spatial understanding of the Gelman groundwater contamination history as well as the current conditions via interactive maps that may be made public on the GIS platform?

Attachments & Reports Used in Developing the Conclusions and/or Recommendations:

2020-03-30 Rockware final Gelman Summary Report (44 pages)

2020-04-01 MSG Data Management Summary Report. (58 Pages)

Site History / Details:

Beginning in 1963, Gelman manufactured membrane filtration material and related products for the pharmaceutical, microelectronics, and pollution testing industries. Between 1966 and May 1986, 1,4-dioxane was used for cellulose triacetate filter production and cleaning process lines. Process waste water, including 1,4-dioxane, tetrahydrofuran, and acetone was managed on site in ponds, by spray irrigation, and in a deep underground injection well.

In 1969, the estimated volume of process waste water discharged to Former Ponds 1 and 2 was 50,000 gallons per day. In 1977, Gelman received a National Pollutant Discharge Elimination System (NPDES) permit from the Michigan Water Resources Commission to discharge up to 44,000 gallons per day of process waste water and non-contact cooling water to the ground and groundwater by spray irrigation, Permit No. M00337. Between October 1983 and October 1984, about 9 million gallons of process waste water was disposed of in the underground injection well and 2.6 million gallons was disposed of by spray irrigation.

In 1985, sampling conducted by the Washtenaw County Health Department revealed the presence of 1,4-dioxane in private drinking water wells in the vicinity of the Gelman property. Between 1987 and 1994, Gelman utilized a single water supply well near the Gelman property as an extraction well to remove 1,4-dioxane from the aquifer. This untreated water was discharged into the on-site deep injection well. Gelman also provided bottled water to a number of area residents and businesses where wells had become contaminated and paid for the extension of municipal water supplies for these areas.

In 1992, Gelman and the Michigan Natural Resources Commission, the Michigan Water Resources Commission, and MDNR entered into a consent judgement requiring Gelman to conduct groundwater remediation, including design, installation, operation, and maintenance of groundwater pump and treat systems, and to conduct a soil investigation and subsequent remediation.

In 1996, Gelman and the Michigan Natural Resources Commission, the Michigan Water Resources Commission, and MDNR entered an amendment to the 1992 consent judgement. The consent judgement amendment named the Michigan Department of Environmental Quality (MDEQ) as the successor to MDNR. The consent judgement amendment also revised the definition of contaminated groundwater to mean 1,4-

dioxane in groundwater at a concentration more than 77 µg/L and contaminated soil to mean 1,4-dioxane concentrations in excess of 1,500 micrograms per kilogram.

In 1999, Gelman and the Michigan Natural Resources Commission, the Michigan Water Resources Commission, and MDEQ entered into a second amendment to the 1992 consent judgement. This second amendment conditionally approved storm drain discharge and pumping of the treated or untreated groundwater through an underground pipeline to the groundwater treatment system at the Gelman site.

In 2000, a court opinion and remediation enforcement order required that Gelman submit a detailed plan, with monthly benchmarks, to reduce the 1,4-dioxane in all affected water supplies below legally acceptable levels within a maximum period of five years. The order also required installation of monitoring wells, an additional ultraviolet treatment unit, and an increased pumping rate of certain purge wells.

In 2004, a court opinion and order required Gelman to remediate contamination in the Unit E aquifer. The order indicates that the leading edge of the 1,4-dioxane groundwater plume is more than 2 miles from the Gelman site. The order required an investigation and installation of extraction wells in the Unit E aquifer to remove 1,4-dioxane, as well as other actions.

In 2011, the third amendment to the consent judgement designated the “Eastern Area” as the area located east of Wagner Road and the areas encompassed by the Prohibition Zone and expanded the Prohibition Zone. The “Western Area” was designated as the area west of Wagner Road, except the Little Lake Area System. The Eastern, Western, and Little Lake Areas replaced all previously designated areas associated with the site. The third amendment also modified the remedial objective for the Western Area of the Gelman site from a requirement to completely remediate 1,4-dioxane at concentrations exceeding 85 µg/L to a no-expansion cleanup objective. Gelman is now required to prevent the horizontal extent of the groundwater contamination in the Western Area from expanding. However, continued migration of the groundwater contamination into the Prohibition Zone or Expanded Prohibition Zone is not considered expansion and is allowed. The third amendment to the consent judgement also expanded the groundwater use Prohibition Zone located east of Wagner Road, which was established by the 2005 order prohibiting groundwater use.

The Washtenaw County Public Health Department (WCPHD) and MDEQ have continued sampling residential and business water supply wells within and around the leading edges of the 1,4-dioxane groundwater contamination plume. WCPHD and MDEQ annually review which water supply wells should be sampled. For 2017, 54 water supply wells were sampled, in 2016, 104 wells sampled, 1,4-dioxane was detected at only two locations at concentrations at or just above 0.001 mg/L.

Current remediation activities performed by Gelman include operation of 11 groundwater extraction wells at the Gelman site and elsewhere in Scio Township and the City of Ann Arbor. Gelman is currently pumping 500 gallons per minute of contaminated groundwater from the extraction wells and piping the water to the Gelman facility for treatment using ozone and hydrogen peroxide.

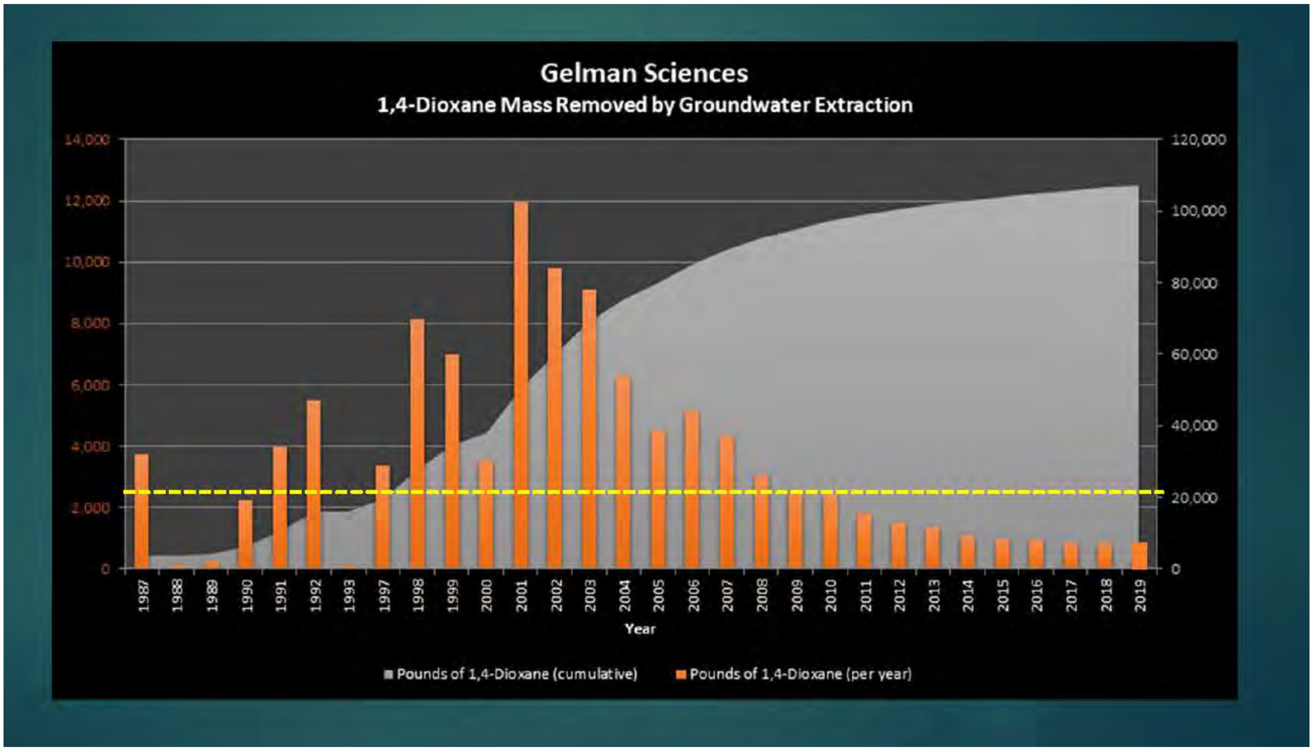
GROUNDWATER MIGRATION PATHWAY

Five glacial depositional units have been identified in the site vicinity. Unit A is the uppermost unit and consists of 7 to 91 feet of interbedded silty sands and lacustrine clays. Unit B is directly below Unit A and consists of 0 to 28 feet of lacustrine clay with varying amounts of silt. Unit C is immediately below Unit B and consists of fine to very coarse sands and gravels with varying minor amounts of interstitial silts and clays. Unit C varies between 15 and 40 feet in thickness and is a source of groundwater for industrial and domestic purposes. Unit D lies beneath Unit C and consists of 7 to 90 feet of silty clay till or clay. Below Unit D is Unit E. Unit E is composed of fine to very coarse sands and gravels and is a source of groundwater for local wells. Unit E directly overlies bedrock. Units C and D have been further divided into subunits, including the C1, C2, C3, D0, D1, D2, and D3. Based on the 1987 and 1988 Phase II and Phase III Hydrogeologic Investigations, Unit C3, Unit D0, Unit D2 and Unit E are considered aquifers, while Units B, C2, D1, and D3 act as aquitards separating the aquifers. Interconnection between all glacial deposits has been established based on the presence of 1,4-dioxane contamination detected extensively in the deepest Unit E aquifer. Beneath the surficial glacial depositional units lies Coldwater Shale bedrock comprised of blue gray shale.

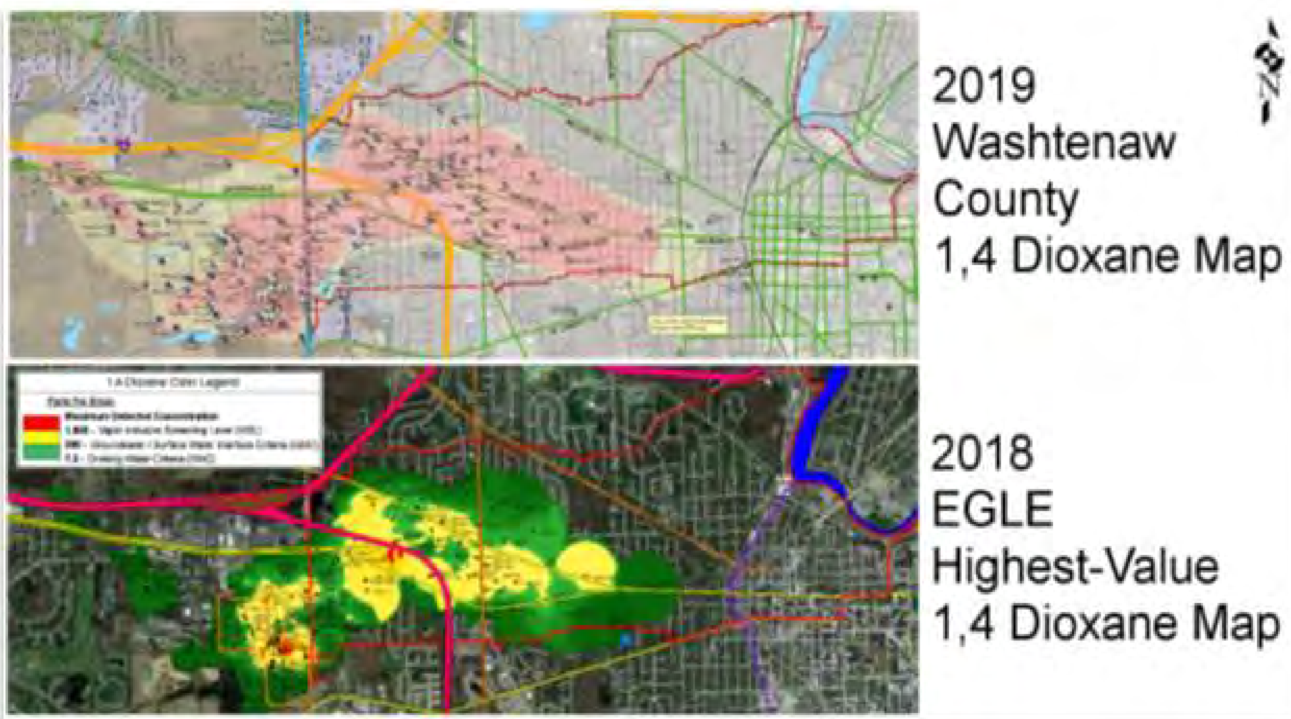
According to Washtenaw County drinking water well location information obtained from the Michigan Geographic Data Library and additional information provided by MDEQ, 1,773 private drinking water wells are located within a 4-mile radius of the Gelman site. The City of Ann Arbor maintains two drinking water intakes on the Huron River at Barton Pond along the 15-mile TDL. Potable water obtained from the surface water intakes provide about 80 percent of the municipal water supply. The City of Ann Arbor provides drinking water to about 125,000 people; therefore, the surface water intakes provide drinking water to about 100,000 people. Approximately, 124 private water supply wells have been closed as a result of groundwater contamination attributable to the Gelman site. The City of Ann Arbor’s Montgomery Wellfield is not currently in use because of 1,4 dioxane detections and its location adjacent to the Gelman Prohibition Zone.

Groundwater Extraction

Gelman has been pumping since 1987. Over that time 8 billion gallons of groundwater have been extracted, treated and discharged under an NPDES permit. The chart below summarizes some specifics regarding the mass of 1,4-Dioxane recovered, approximately 110,000 pounds.



The map below is the public facing document available on-line and most used to describe the current site conditions and an example of the plume represented by the work with Rockworks.



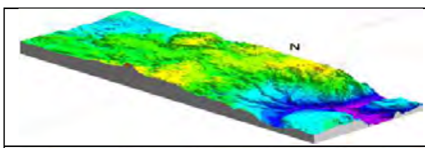
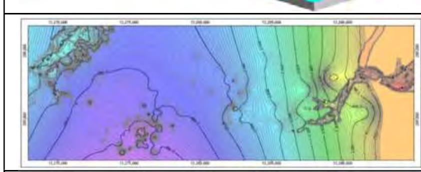
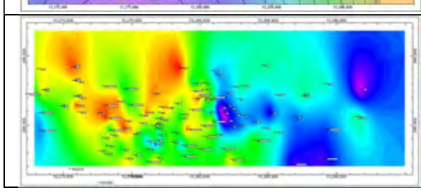
To tell the story and evaluate the horizontal and lateral extent of 1,4-Dioxane EGLE Remediation and Redevelopment Division (RRD) retained RockWare Incorporated and The Mannik & Smith Group, Inc. (MSG) to incorporate the Gelman data into a RockWorks project database and geographic information system (GIS) to allow for analysis and visualization of geologic and groundwater contaminant information. The RockWorks project consists of information from borehole logs totaling over 40,000 feet of drilling and over 24,000 separate analytical results covering several decades of work related to the 1,4–dioxane groundwater plume originating from Gelman Sciences, Inc. Site.

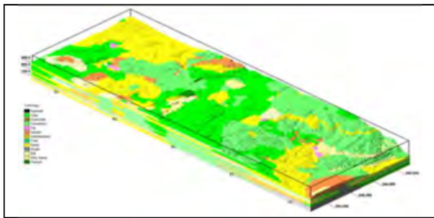
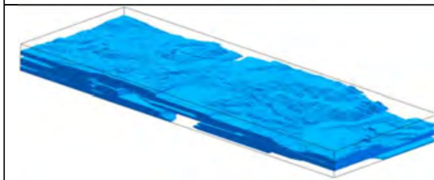
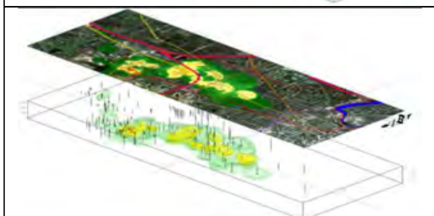
EGLE oversaw the lithologic, geochemical, and water level information from well logs, ground surface elevations, and interpreted bedrock contacts from seismic profiles used to create two-dimensional ground, bedrock, and potentiometric surface models and three-dimensional lithology, and annual 1,4-Dioxane geochemical models. This work was done to establish an accurate spatial understanding of the Gelman contamination history as well as the current conditions via interactive maps.

MSG brought the data into a Microsoft Access RDBMS (.accdb) so that database concepts could be applied and utilized. Data was then transformed and exported to spreadsheets to serve as the input files for the RockWorks project database. MSG working with EGLE, established a data standardization, and the development of a relational data structure.

Rockware prepared for EGLE grid models. (Table 1).

Table 1. Summary of Grid & Solid Models

	**Ground Surface** Grid model representing surface elevations.
	**Potentiometric Surface** Grid model representing highest recorded water table elevations.
	**Bedrock Surface** Grid model representing bedrock elevations.

	**Lithology** Solid model representing lithologic units.
	**Permeability** Boolean solid model representing possible groundwater conduits.
	**Annual Geochemistry (Solids)** 33 solid models representing annual 1,4-Dioxane concentrations from 1986 to 2018.
	**Annual Geochemistry (Grids)** 33 grid models representing highest annual 1,4-Dioxane concentrations from 1986 to 2018.

and solid models (Figure 11/12. Lithology Model and Fence Diagram

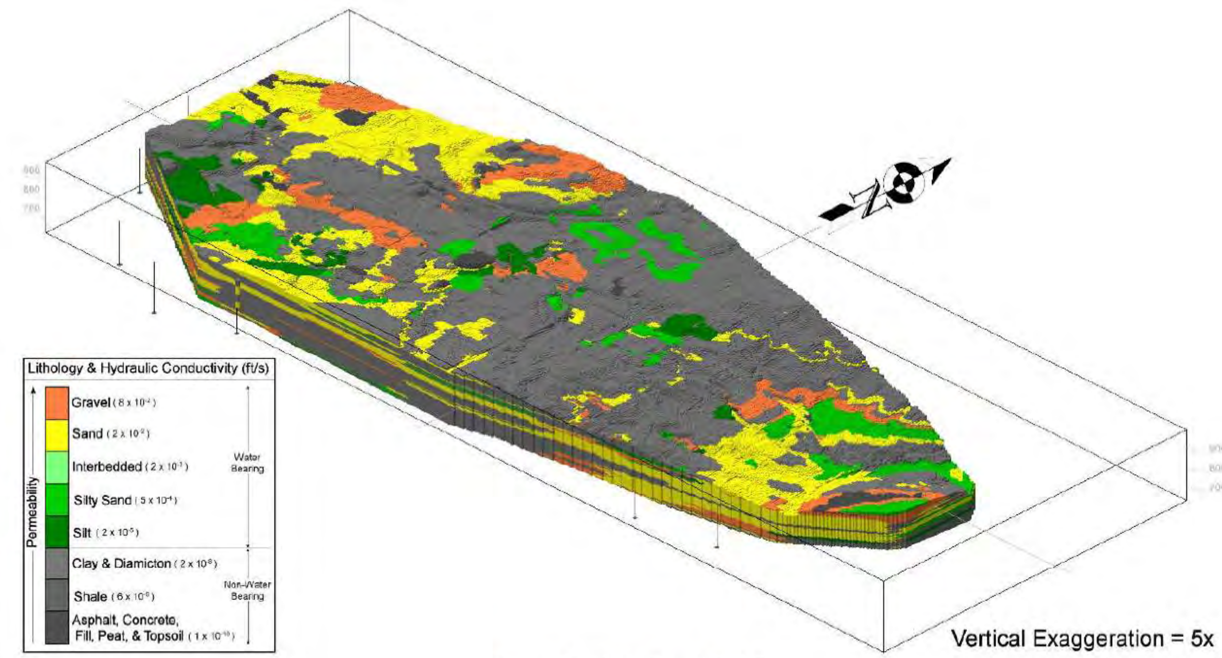


Figure 11. Lithology Model

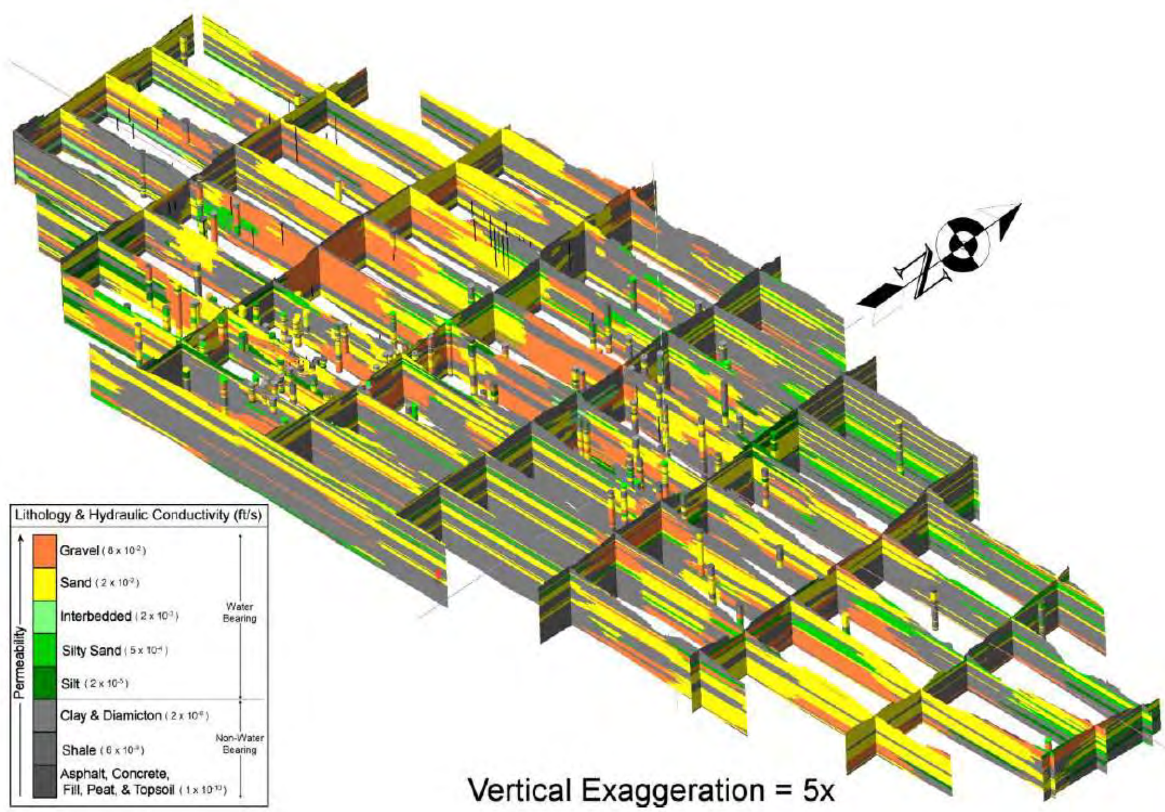


Figure 12. Lithology Model Fence Diagram

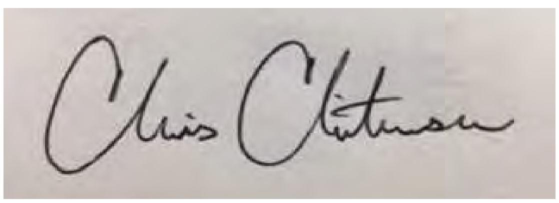
These grids, models and how these graphics are described in the attached reports and will be summarized to the Modeling TAPS by Rockware and MSG modelers.

Groundwater Model Review Conclusions, Reasoning, and Follow-up Recommendations:

The static model of lithology/geology is appropriate used as a part of the conceptual site model. The TAPS team appreciate the attention paid to validate or compare the computer-generated geology model to the cross sections drawn by geologists. The reasoning and strategy to create a flow-no flow model using the geology model making the sand and gravel as flow areas and clay as no flow areas was appropriate. Creating an upper boundary using the maximum water level was appropriate to limit the dioxane plume. Mapping the bedrock elevation was appropriate to set a vertical no flow to limit the vertical extent of Dioxane plume. The strategy to limit the dioxane groundwater contamination to the flow areas using the geology model, groundwater table model, and bedrock model are science based and describe the extent of Dioxane in the Gelman Plume.

The creation of grid files that depict the areas where groundwater is nearest the ground surface, depth to contamination, and dioxane trend increases and decreases may be used as a virtual conceptual site model to evaluate VIAP and GSI. Utilizing the zonal statistic application in ArcGIS to answer questions homeowners are asking about depth to dioxane contamination and groundwater under their home is a useful tool for EGLE and Washtenaw County Health staff to be able to answer those questions.

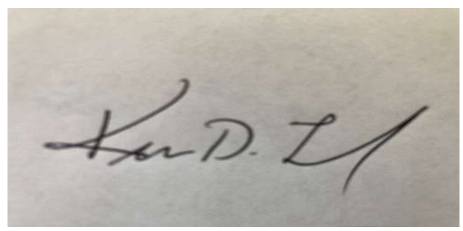
The TAPs team agree, the District has established an accurate spatial understanding of the Gelman groundwater contamination using the static models. The development of the static models along with the data validation and adequate calibration are an example of sound science. These static models will be a useful tool for EGLE to explain the Dioxane history as well as the current conditions via interactive maps that should be made public on the EGLE GIS platform.



March 17, 2021

Christen Christensen/Date:

Lead GW Modeling TAPS



March 17, 2021

Kevin Lund/ Date:

MMD TAPs representative