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A Division of GZA

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December 11, 2017
File No. 16.0062335.30

Ms. Abigail Hendershott
Acting District Supervisor – Remediation and Redevelopment Division
Michigan Department of Environmental Quality
350 Ottawa Avenue NW #10
Grand Rapids, MI 49503

Re: Susceptibility of Wells Along the Rogue River to Impacts from the Former Wolverine Tannery, 123 Main Street, Rockford, Michigan

Dear Ms. Hendershott:

On behalf of Wolverine World Wide, Inc. (Wolverine), Rose & Westra, a Division of GZA GeoEnvironmental, Inc. (R&W/GZA), prepared this Technical Memorandum (Memo) for the Michigan Department of Environmental Quality (MDEQ) in response to its interest about the potential for groundwater venting from the Former Wolverine Tannery property in Rockford, Michigan (Tannery Site) to affect supply wells located along the Rogue River. MDEQ requested Wolverine consider proposing a sampling plan for residential wells downgradient of the Tannery Site along the Rogue River south of Rockford that would alleviate its concerns and confirm that downgradient wells along the river are not at risk. See Figure 1 for the evaluation area.

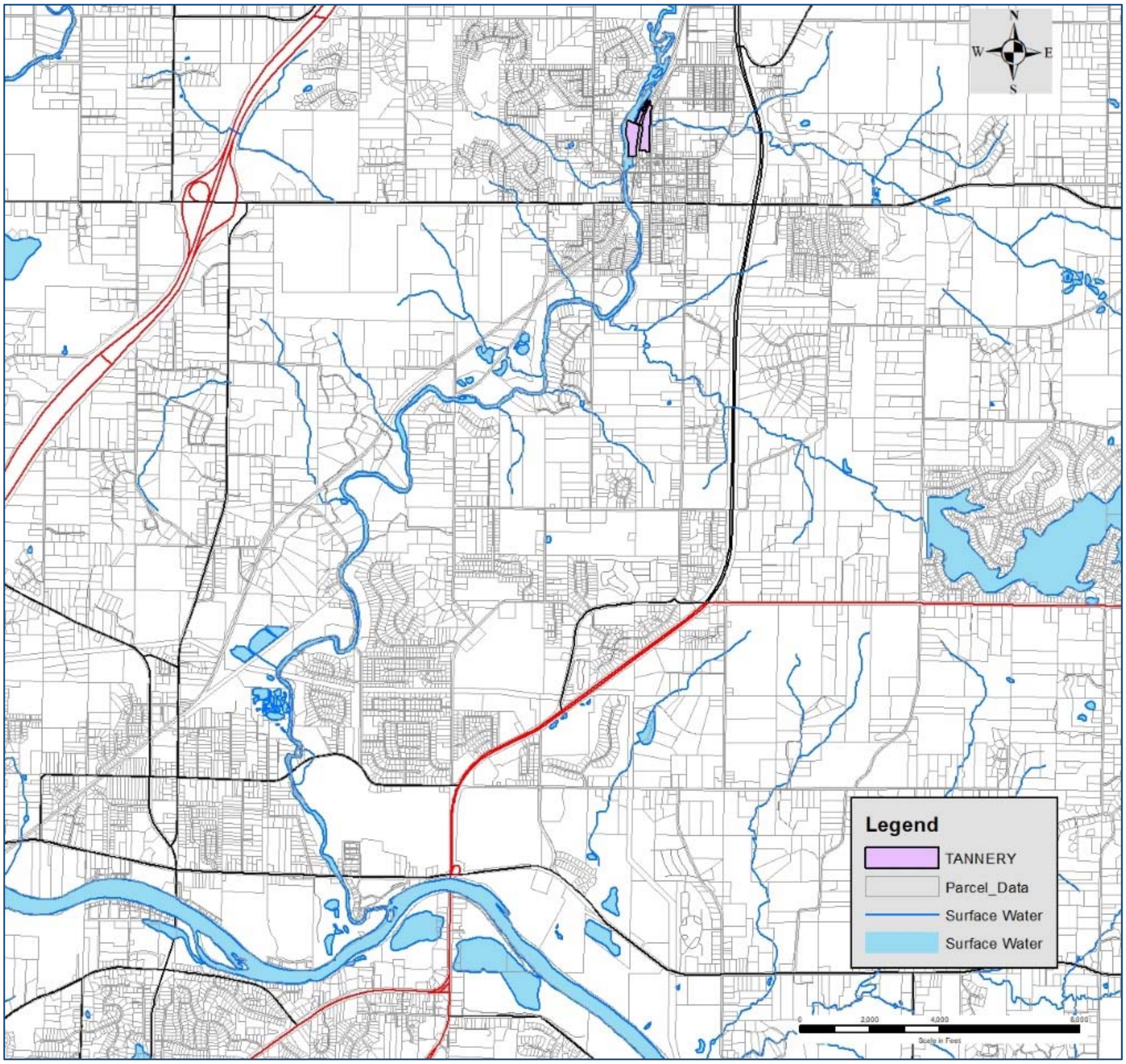

Figure 1 - Evaluation Area

TECHNICAL APPROACH

To consider the possibilities of the Rogue River and its underlying alluvial deposits conveying PFAS from the Tannery Site to water wells along the Rogue River, R&W/GZA closely considered the key Conceptual Site Model (CSM) elements in the riparian setting including:

1. The geologic setting including the glacial depositional history and the general consistency of deposits along the Rogue River from the former tannery to its confluence with the Grand River;
2. The groundwater flow regime, especially the consistency of recharge and discharge zones throughout the area of interest; and,

3. The groundwater/surface water interaction, especially two locations and conditions under which conventional groundwater flow patterns could be disrupted by anthropogenic and/or naturally occurring conditions. Such conditions include:
    a. altered groundwater movement induced by dams or impoundments;
    b. seasonal bank storage during high river stages when groundwater flow direction can be temporarily reversed;
    c. historic river channels which could represent preferential flow paths close the Rogue River. The likelihood elevated head conditions could induce reversed flow through bank storage or other groundwater underflow conditions which could cause result in groundwater migrating out of the river basin and toward wells flanking the river;

The relevant regional geologic and hydrologic conditions were also previously described as part of the preliminary CSM described in the Remedial Investigation Work Plans (RIWPs) for the Tannery Site and the House Street Site.

With our key observations presented, R&W/GZA presents discrete areas for further evaluation due to these localized conditions. We believe that the evaluation of these discrete areas, once implemented, will provide the confidence needed to understand the susceptibility of water wells along the Rogue River. The following sections provide our assessment of these key CSM elements and how they contribute to addressing the current concern expressed by the MDEQ.

GEOLOGIC CONDITIONS AND DEPOSITIONAL HISTORY ALONG THE ROGUE RIVER

Our review of the glacial depositional history based on published research, our detailed review of well logs throughout the area of interest, and construction of two cross sections flanking the 6.4-mile Rogue River reach and 10 transections crossing the river valley indicate the following relevant geologic conditions:

1. The Glacial Rouge River, the earliest and westernmost of the tributary glacial streams to the Glacial Grand River Valley (GRV), formed a major outwash channel that drained from the interlobate area lying <u>toward the north</u> of Rockford into Glacial Muskegon lake.
2. Between Rockford and the GRV to the south, an area of finer grained end-moraine deposits and glacial lake bottom sediments dominate the geology.
3. The significance of this depositional environment is major deep bolder zones or bouldery gravel zones that may represent highly hydraulically conductive deposits are not likely to extend between Rockford and the Rogue River's confluence with the Grand River.
4. Twelve cross sections flanking and crossing the Rogue River confirm the presence of fine textured deposits associated with the mapped morainal deposits dominating in the northern portion of the area of interest, but coarsening toward the south as it approaches the primary GRV channel.

The detailed evaluation conducted of these conditions by R&W/GZA are presented in Attachment A of this Memorandum.

In R&W/GZA's opinion, these conditions aid in limiting the focus of evaluating PFAS migration in the Rogue River valley to shallower alluvial deposits related to recent depositional activities associated and does not show evidence highly conductive sand/gravel/boulder deposits would exist in the deeper sections of the Rogue River valley between Rockford and the Grand River confluence.

GROUNDWATER FLOW REGIME ALONG THE ROGUE RIVER

An important feature of the Rogue River is its direct connection with the groundwater systems and its presence as a significant groundwater discharge zone. The River exists in a classic unconfined flow regime formed by groundwater recharge zones in the elevated terrain flanking the river system and converging to the river as the discharge zone. The groundwater head contours for the groundwater system feeding the river is provided in Attachment B. The hydraulic gradients on both sides of the river (toward the river) were also calculated and compared. This evaluation was supplemented by a review of Rogue River baseflow comparisons along the entire area of interest to confirm the Rogue River is a continually "gaining stream" as groundwater discharges to the river along the entire reach. This evaluation resulted in the following key observations:

1. The groundwater flow configuration of the watershed confirms relatively symmetric; consistent flow and uniform gradients converge on the Rogue River. It is important to note the surface topography on each side of the river rises to similar elevations and characterized by similar geologic deposits both of which aid in establishing a relatively uniform converging flow pattern.
2. Streamflow data from the USGS Gaging Station indicates the Rogue River is a gaining stream, and groundwater contributes approximately 80% of the total streamflow.
3. The above conditions set up the Rogue River to be the regional discharge "line sink" for nearly all the recharge that enters the watershed. As further presented in Attachment B, hydraulic heads are the deciding factor to determine groundwater flow direction. If the groundwater elevations are higher than the river elevation, groundwater will discharge to the surface water.
4. An important feature is that the groundwater hydraulic gradients near the Rogue River are relatively steep (0.01 to 0.08) compared to typical hydraulic gradients in sand and gravel aquifers. The steeper gradient results in more consistent flow toward its discharge point at the river that will reduce the significance of groundwater flow reversals that could temporarily occur from elevated river stage following snow melt or other flooding periods.
5. The migration of PFAS is driven primarily by advective groundwater movement. Therefore, understanding groundwater movement is the key to tracking PFAS migration.
6. Given this established groundwater flow regime and transport characteristics, PFAS in groundwater flanking the Rogue River will move in subsurface alluvial deposits and ultimately discharge to the Rogue River. Because groundwater converges from both sides, the migrating plume will vent to the river through its associated course-grained deposits. These conditions do not support migration to the other side of the river in subsurface deposits.
7. Once PFAS is within groundwater in underlying alluvial deposits and the river, the possibility of excursions outside the river is extremely unlikely, as PFAS moves conservatively with bulk groundwater movement.

ADDITIONAL SURFACE WATER AND GROUNDWATER INTERACTION CONSIDERATIONS AND PROPOSED AREAS FOR FURTHER EVALUATION

In consideration of the geologic and groundwater flow setting of the area of interest as presented above, in R&W/GZA's opinion, PFAS migration out of the Rogue River or its underlying alluvial deposits could be categorized as highly anomalous. However, close consideration was still given to the combination of atypical surface water and groundwater interactions that could be reasonably theorized as possible resulting in PFAS migrating out of the river flow system and toward water supply wells flanking the river. Given the body of evidence reviewed, we provide the following anomalous conditions within the area of interest that resulted in the identification of focus areas along the Rogue River where these anomalous conditions could be further evaluated.

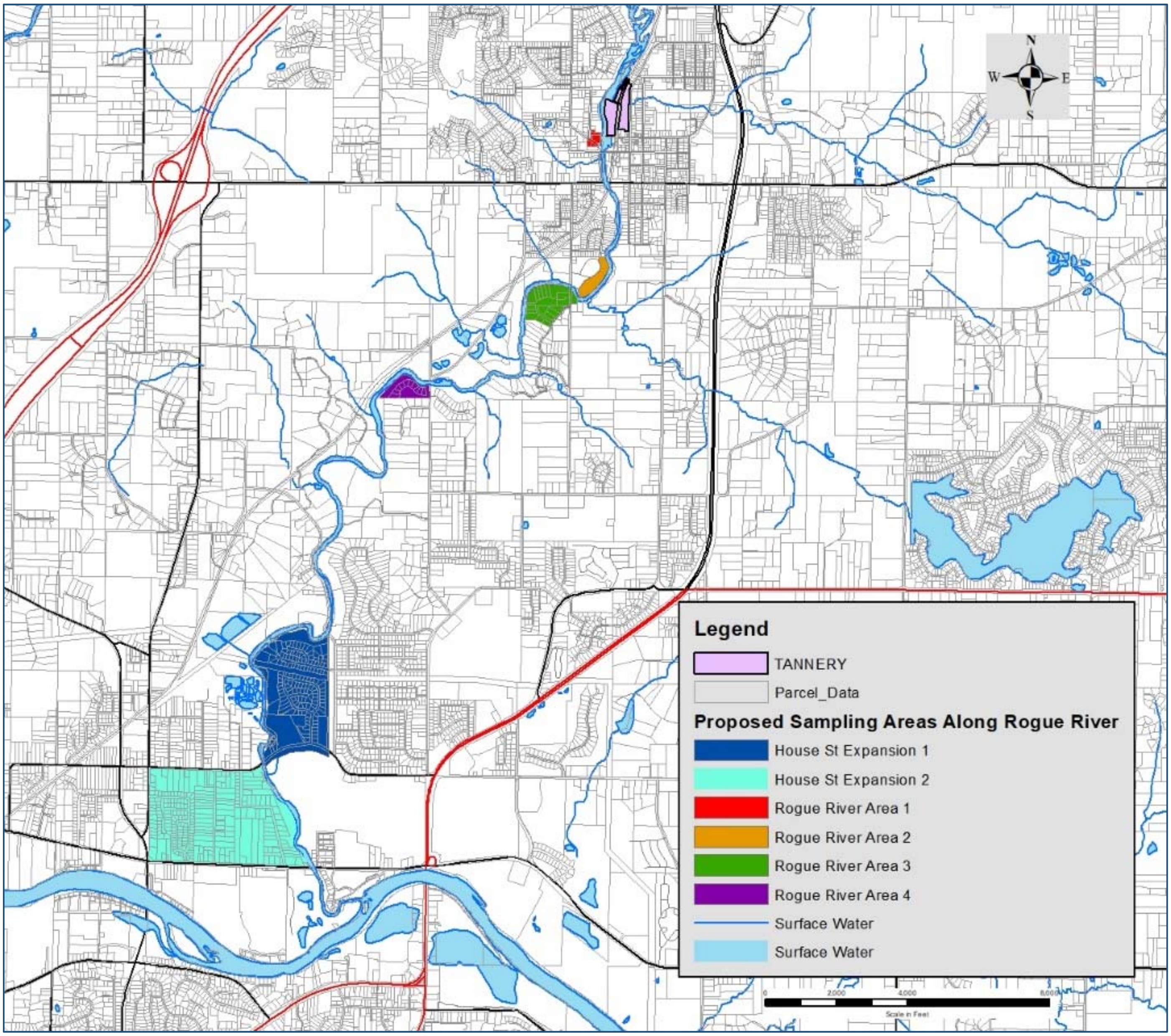

Figure 2- Proposed Water Well Sampling Areas

<u>Condition 1 – Surface water and Groundwater Flow Patterns Affected by a Dam</u>

The Rockford Dam on the Rogue River impounds water and enhances hydraulic gradient around the dam. It can be theorized that groundwater venting to the river immediately above the dam has the potential to migrate around the feature though porous media flanking the dam. Under this condition, it appears that the most likely movement by PFAS-affected groundwater would be on the east of the dam; however, this area has municipal water and does have residential wells. It appears less likely, but perhaps possible, for groundwater containing PFAS to migrate around the dam to the west, and as this area is not on municipal water. Therefore, to further evaluate this condition, we have proposed Rogue River Sampling (RRS) Area 1, as shown on the attached Figure 2, consisting of six properties.

Condition 2 – Subsurface Groundwater Flow Patterns Interrupted by River Meanders

Under some alluvial conditions where horizontal gradients are low associated with meandering rivers, it has been shown shallow groundwater that would typically discharge to the surface water will "short cut" a sharp meander bend mainly through historical, hydraulically conductive subsurface stream channels. Therefore, groundwater is moving parallel to the river rather than discharging. Even though the Rogue River gradient is relatively high for this condition to occur, given that several sharp meanders occur along the 6.4-mile river reach, and residential development has occurred in relative proximity to the river in some areas further evaluation in these focus areas is proposed. We have selected three downgradient areas RRS Areas 2 through 4 which enable this condition to be evaluated and potentially ruled out as a concern. Area 2 contains 11 residences; Area 3 contains 17 residences; and Area 4 contains 10 residences.

In addition, another two areas, one east of the Rogue River and another west of the Rogue River, have been proposed as part of House Street Site investigation expansion (See Figure 2), will also provide useful information related to the susceptibility of the water wells along the Rogue River.

In conclusion, the evaluation of the four areas described above and the two House Street expansion areas provides an assessment of conditions, which we believe, have the greatest, albeit small, potential for PFAS behavior in groundwater to be anomalous and result in a condition where a closely located water supply well could be affected. Evaluation of these focus areas while examining these potential anomalies, will also provide MDEQ a cross section of water well quality in the area of interest.

We hope you find this evaluation responsive to your requests and present concerns. We look forward to talking through these concepts during our upcoming meetings and discussions. Should you have any questions, please feel free to contact us. On behalf of Wolverine, we appreciate your assistance and collaboration in this present endeavor.

Very truly yours,

Rose & Westra, a Division of GZA GeoEnvironmental, Inc.

Jiangeng (Jim) Cai, P.E.
Senior Consultant

Mark Westra
Associate Principal

John C. Osborne, P.G.
Consultant Reviewer/Senior Vice President

Attachments: Attachment A, Evaluation of Geologic Conditions and Depositional History along Rogue River
Attachment B, Evaluation of Groundwater Flow and Hydrologic Conditions along the Rogue River
Bibliography

LIST OF TABLES

LIST OF FIGURES

Attachment A

EVALUATION OF GEOLOGIC CONDITIONS AND DEPOSITIONAL HISTORY ALONG ROGUE RIVER

A. EVALUATION OF GEOLOGIC CONDITIONS AND DEPOSITIONAL HISTORY ALONG ROGUE RIVER

The glacial geology along the Rogue River was influenced by the Grand River Valley (GRV), through which the lower Grand River flows. Significantly larger than the modern floodplain, the GRV begins near the town of Maple Rapids, MI where it extends west to Grand Haven, MI. Previous research has suggested that the GRV was formed, since the last glacial maximum (LGM), by glacial outwash travelling from the Huron Basin to Glacial Lake Chicago (in the Lake Michigan Basin). The existence of a pre-glacial valley underlying the GRV has been theorized by previous studies (Bretz, 1952). Bretz suggested that the GRV was cut when it served as the main outlet for glacial meltwater in the Huron and Erie Basins during the Late Wisconsinan glacial period (Bretz, 1952). This valley is characterized in most regions by the presence of broad valley floors, deeply incised ravines, and relict flood terraces; (Bretz, 1952).

Glacial Grand River was supplied by branch streams from both north and south whose course were determined by the successive land-laid moraines built during the glacial retreat. All the branch streams built valley trains leading to the GRV. Of significance to this evaluation, the Glacial Rouge River, the earliest and westernmost of the tributary glacial streams, formed a major outwash channel that drained from the interlobate area lying toward the north into Glacial Muskegon Lake. Between Rockford and the GRV to the south, an area of end-moraine deposits and glacial lake bottom sediments were laid. Further upstream, Rogue River flows on a valley train for many miles upstream from Rockford with a gradient of four feet a mile but crosses the morainal deposits immediately north of the Plainfield terrace in a narrow valley from one hundred to two hundred feet deep, along which it drops forty feet in two and one-half miles. See Figure 3-Glacial Features of a Portion of South-Central Michigan (Clipped) (Bretz, 1952). The significance of this depositional environment is that major deep bolder zones or bouldery gravel zones that may represent highly hydraulically conductive deposits are not likely to extend between Rockford and the Rogue River's confluence with the Grand River.

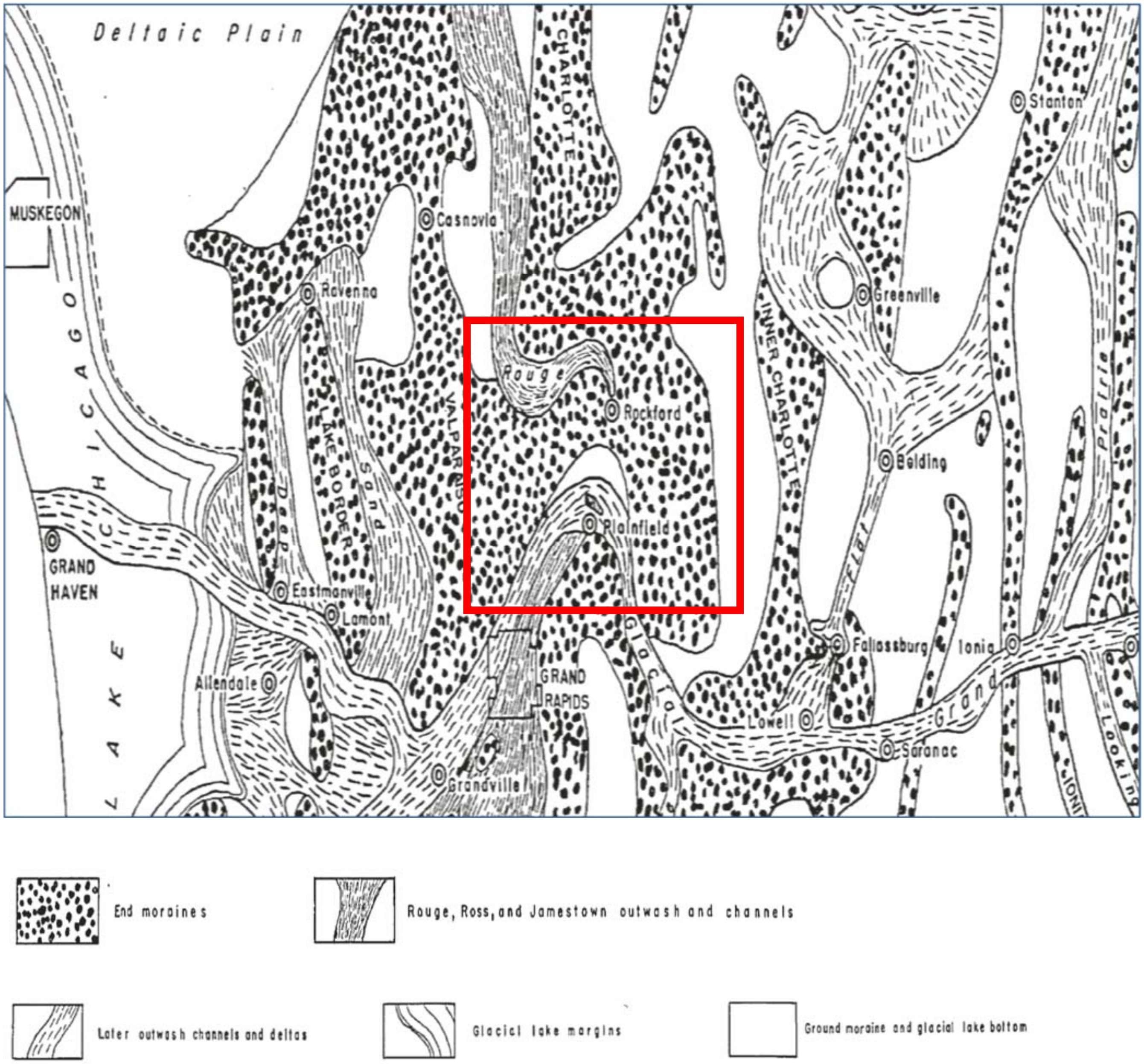

Figure 3-Glacial Features of a Portion of South-Central Michigan (Clipped) (Bretz, 1952)

Further shallow geologic conditions are provided based on the Michigan Glacial Land systems (Groundwater Inventory and Mapping Project, 2005), downloaded from the Michigan Geographic Data Library (MGDL)[1], which display the near-surface glacial land systems along the Rogue River is shown in Figure 4- Glacial Land System Near the Rogue River.

[1] https://www.mcgi.state.mi.us/mgdl/

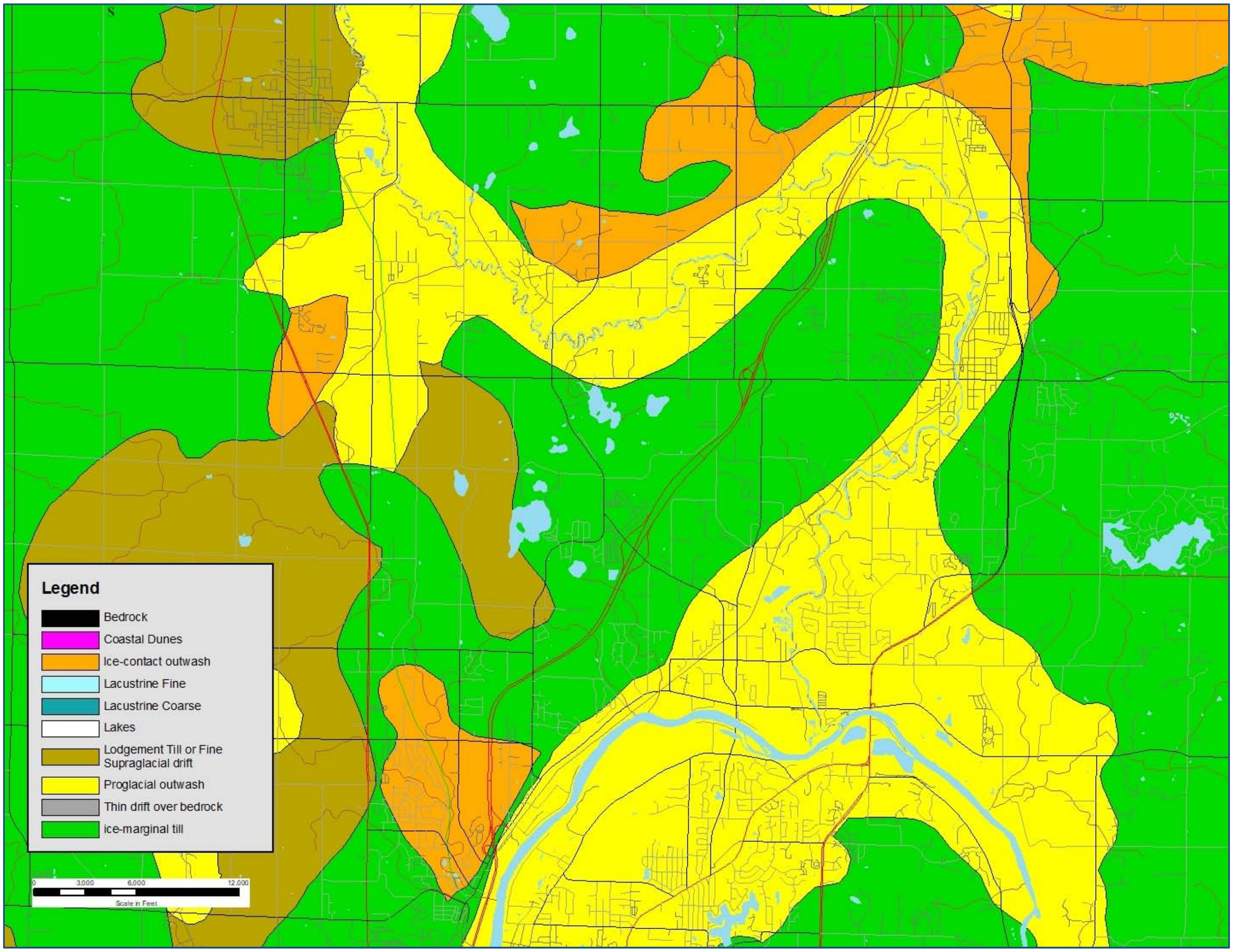

Figure 4- Glacial Land System Near the Rogue River

As shown in Figure 4- Glacial Land System Near the Rogue River, proglacial outwash train is present along the Rogue River; ice-contact outwash channel is present north of the City of Rockford. Moraines are present either side of the Rogue River until the "wide" near the Grand River.

To gain more specific confirmation of the geologic conditions in the area of interest, the Wellogic-Statewide Wells GIS Data for Kent County **Invalid source specified.** was downloaded from the MGDL. To simplify the soil descriptions in the well logs, primary lithology was classified in the Wellogic GIS data file as follows:

AQ = aquifer material	MAQ = marginal aquifer material
CM = confining material	PCM = partially confining material

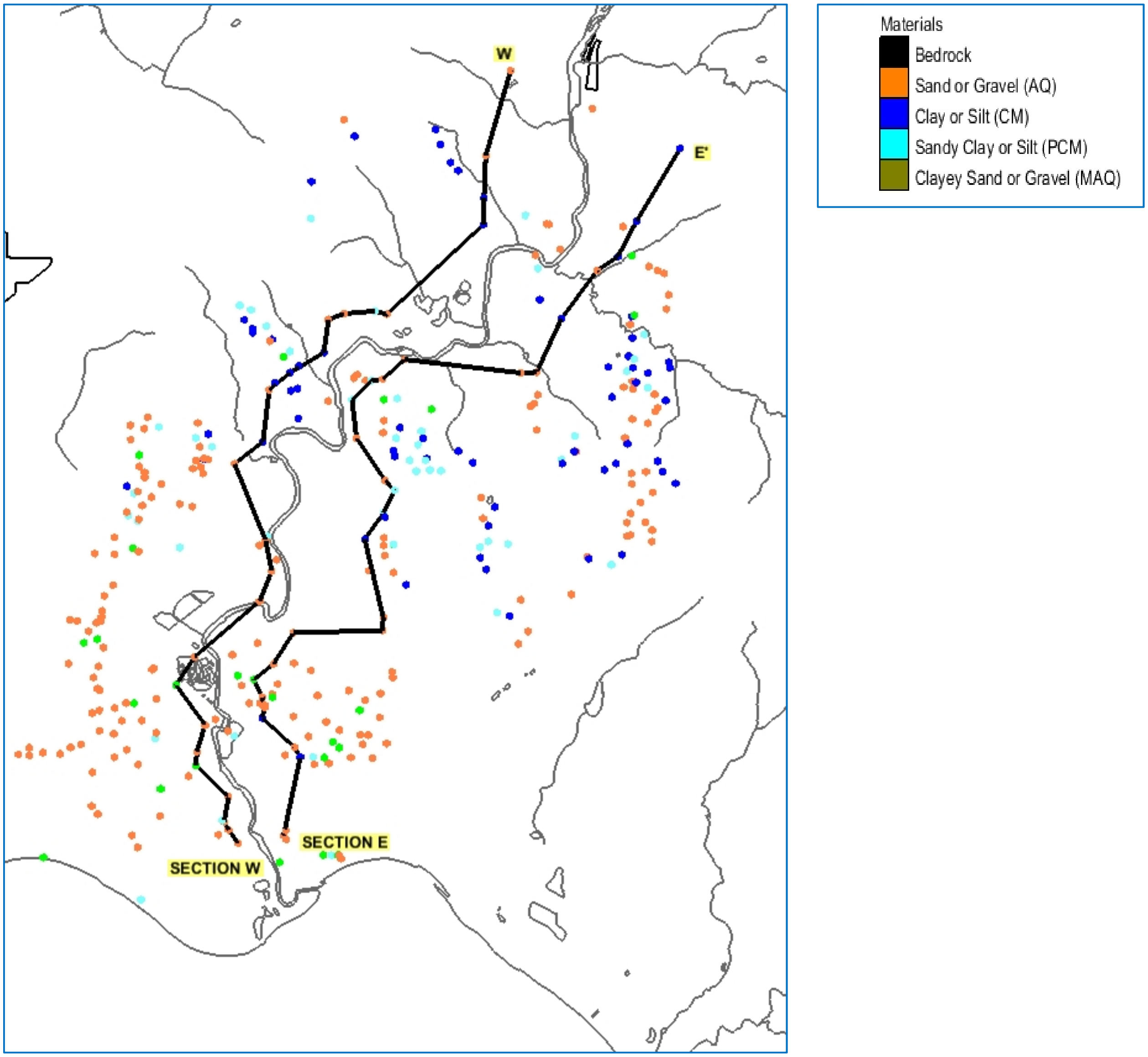

Figure 5 - South to North Cross Section Locations

Two cross sections through several boreholes from the south (near the Grand River) to the north (near the Tannery Site) were created as shown in Figure 5 - South to North Cross Section Locations (the borehole colors symbolize the soil materials of the borehole top layers), and the cross section is shown in the following figures.

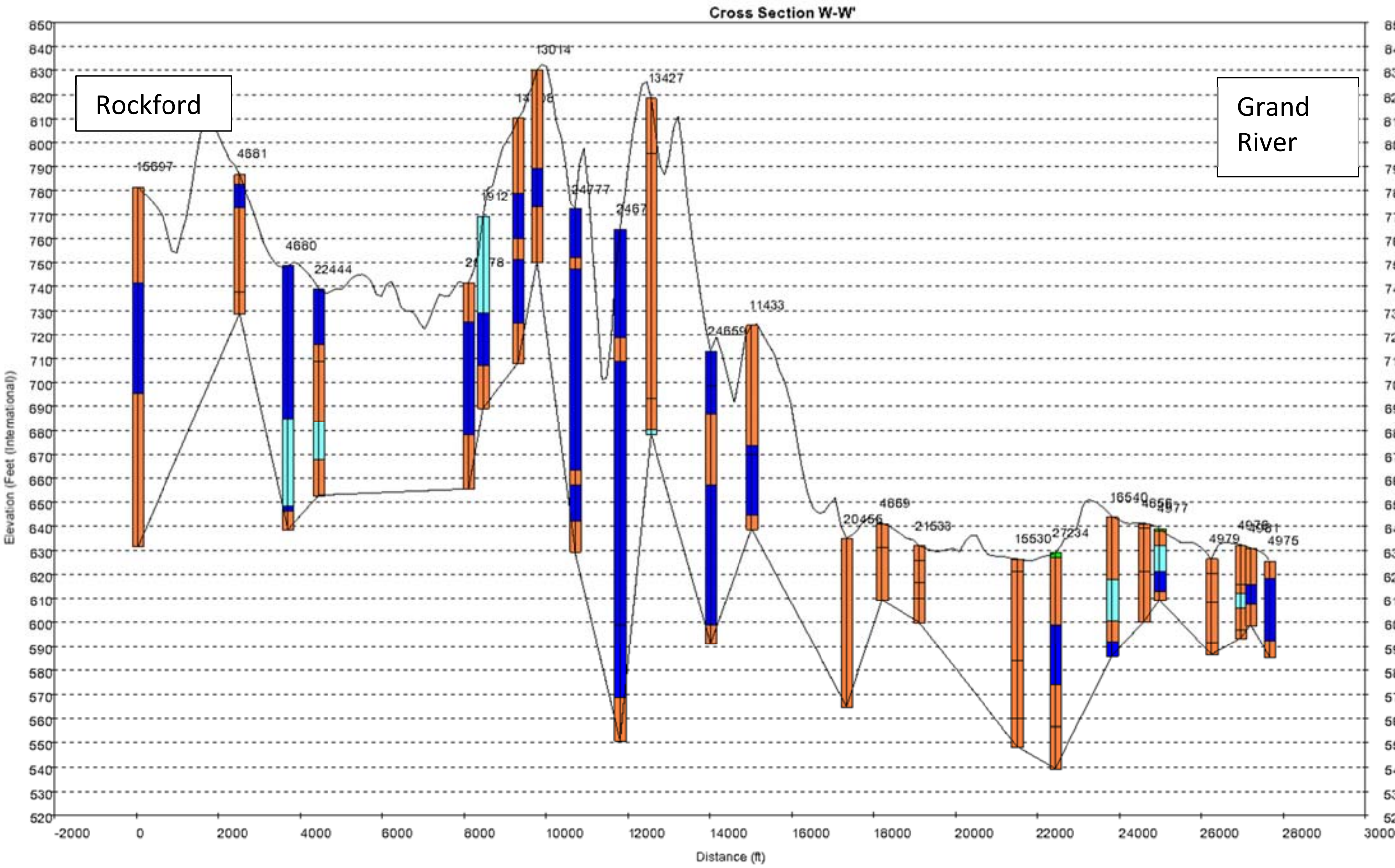

Figure 6- Cross Section West of the Rogue River, From Rockford to the Grand River

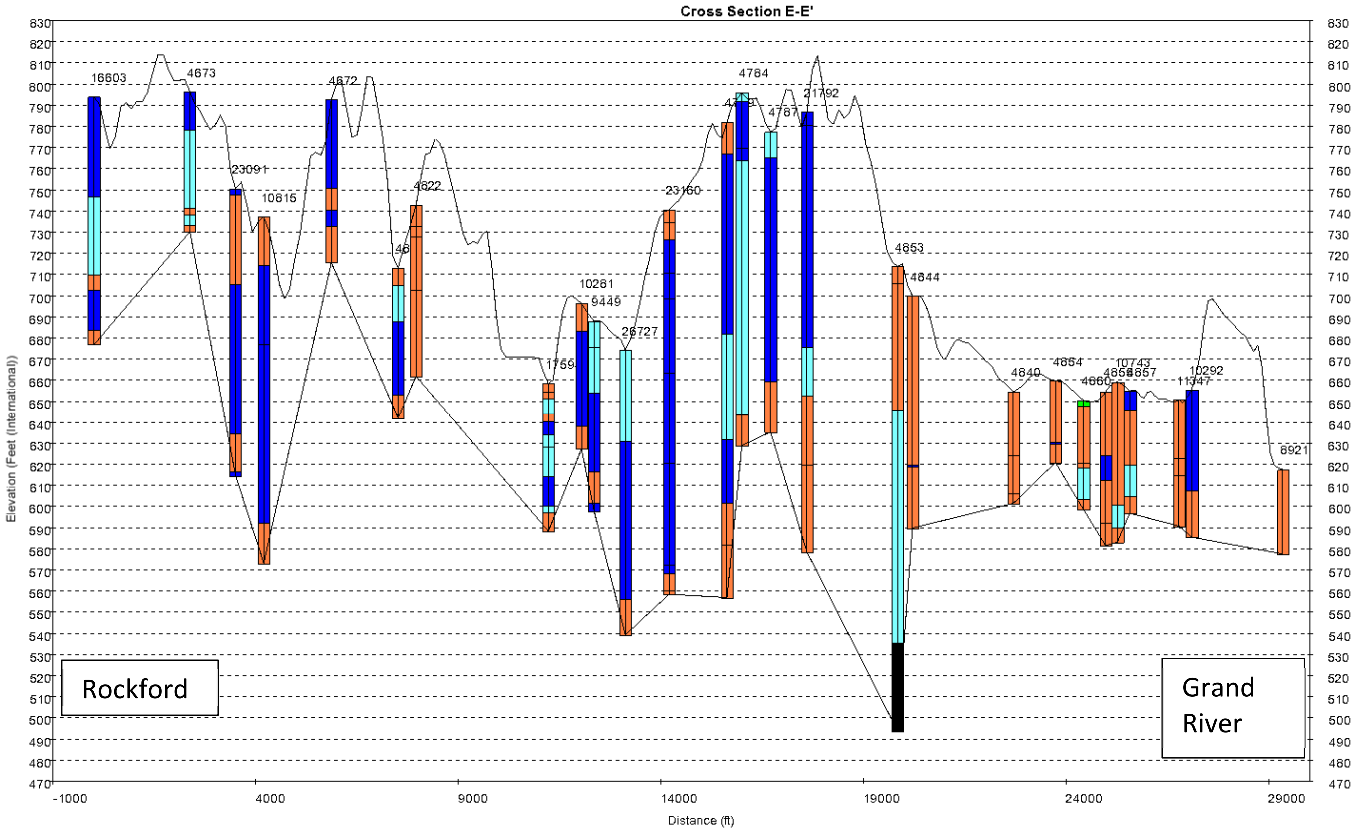

Figure 7 - Cross Section East of the Rogue River

As shown in the above figures, fine-grained soils are present either side of the Rogue River from the City of Rockford to Plainfield Township area; and a sharp drop in topology is observed near Plainfield Township, after which the soil profiles primarily consist of coarse-grained materials.

Additional cross-sections cut across the Rogue River are present in Attachment A. In general, the observations from the water well logs are consistent with the geomorphic description along the Rogue River by Bretz (Bretz, 1952).

Additional cross sections cut across the Rogue River are shown below.

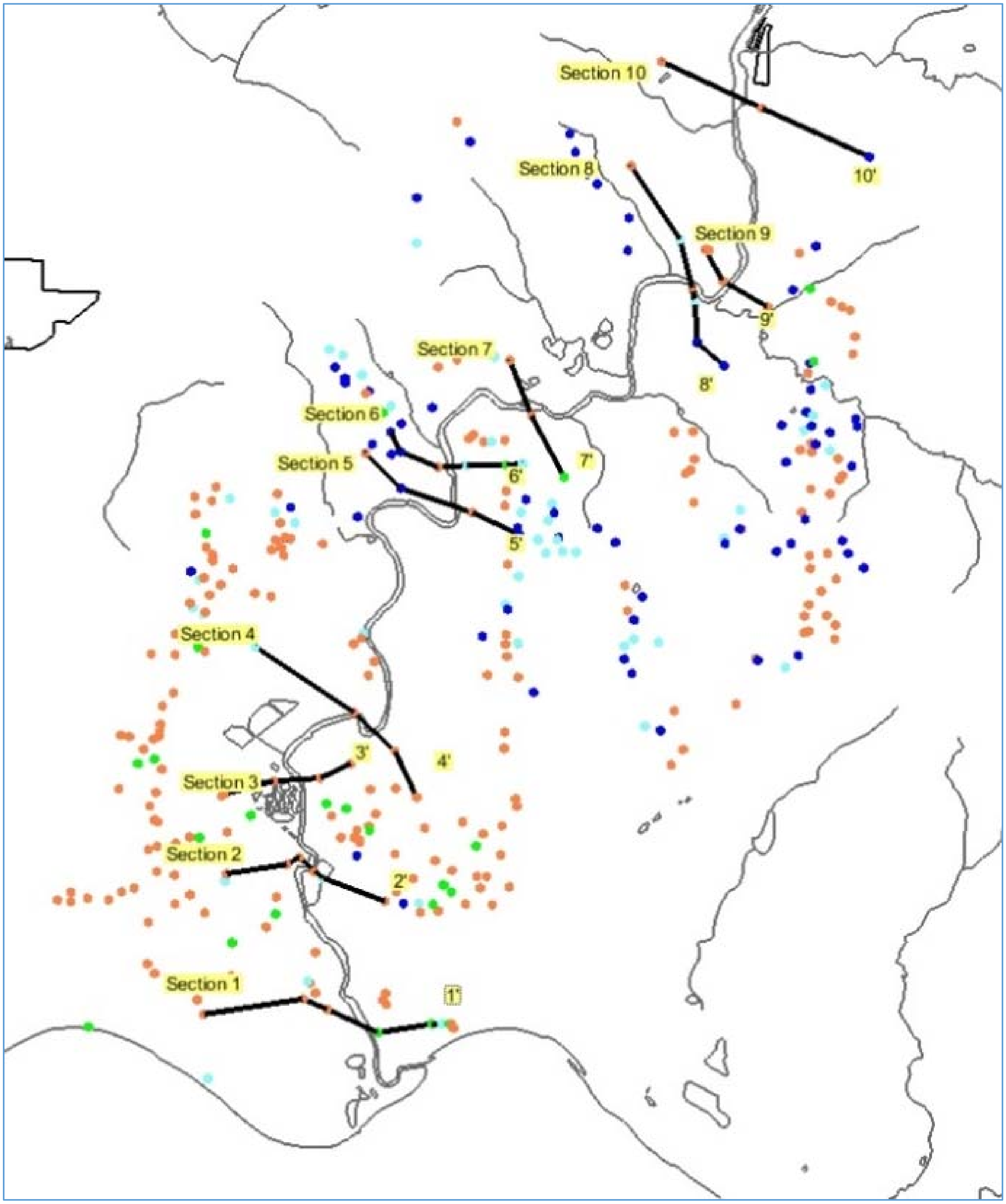

Figure 8 – West to East Cross Section Locations

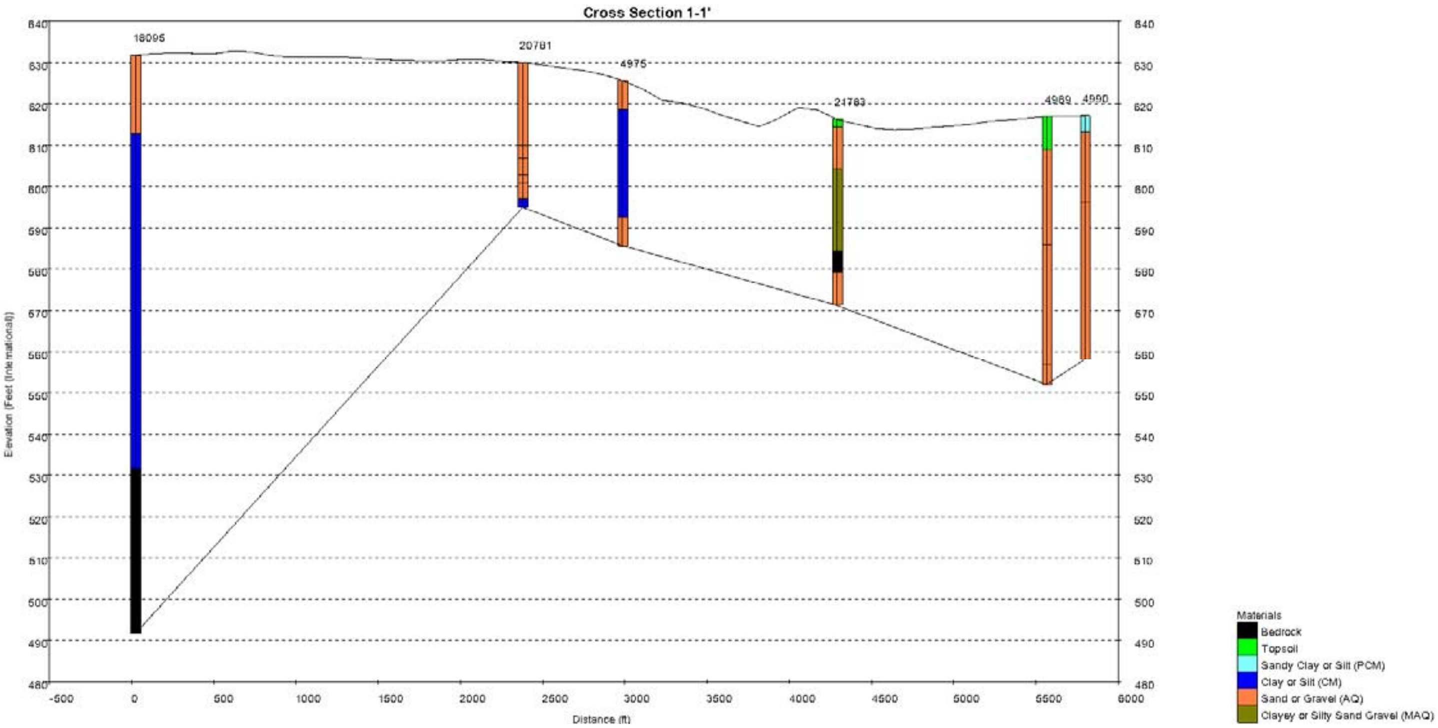

Figure 9 - Cross Section 1

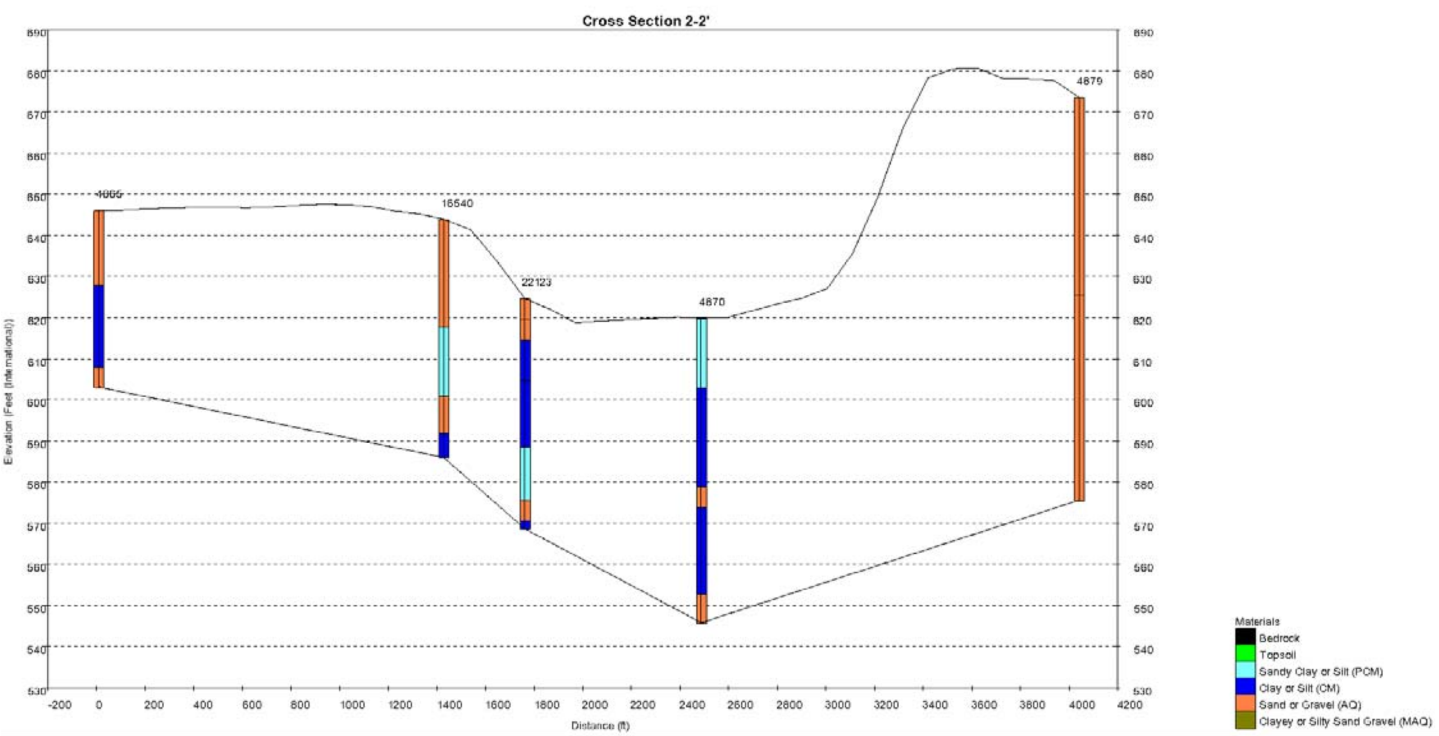

Figure 10 - Cross Section 2

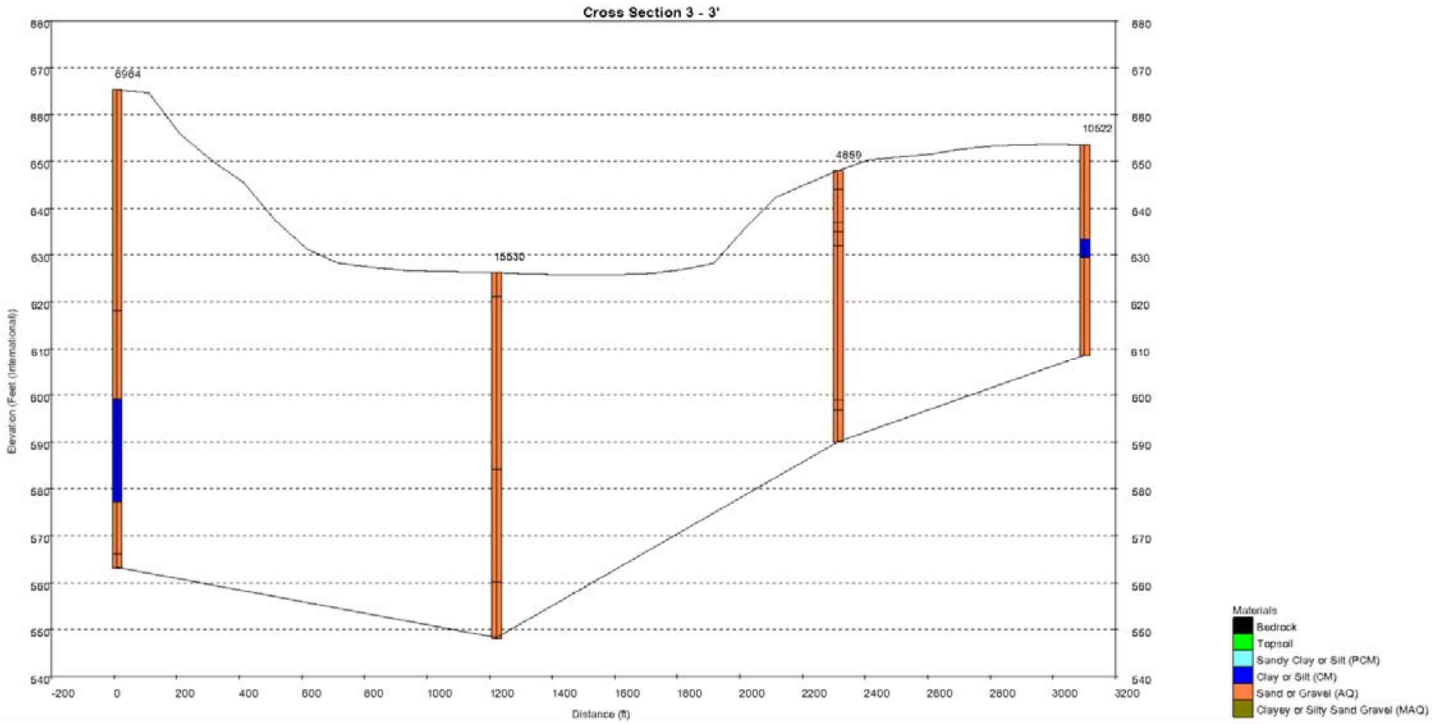

Figure 11 - Cross Section 3

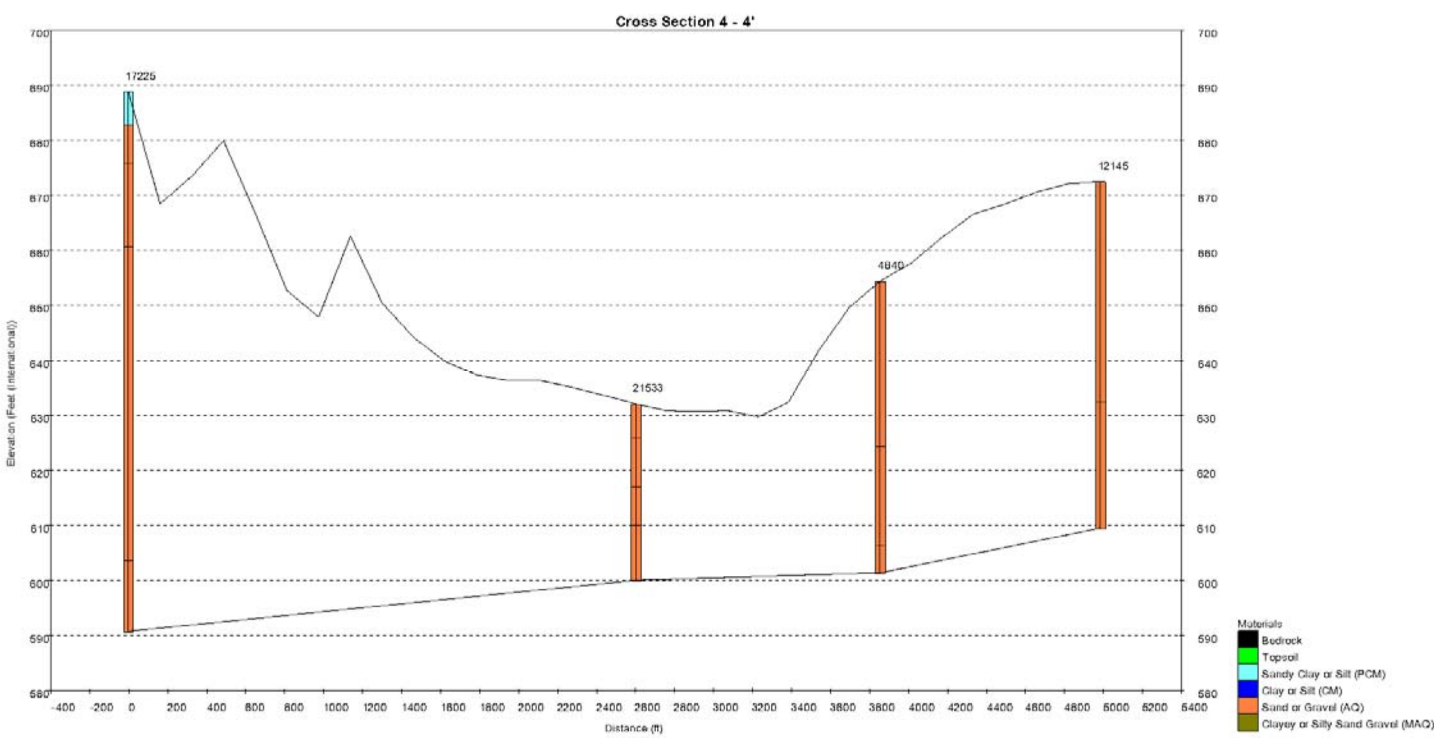

Figure 12 - Cross Section 4

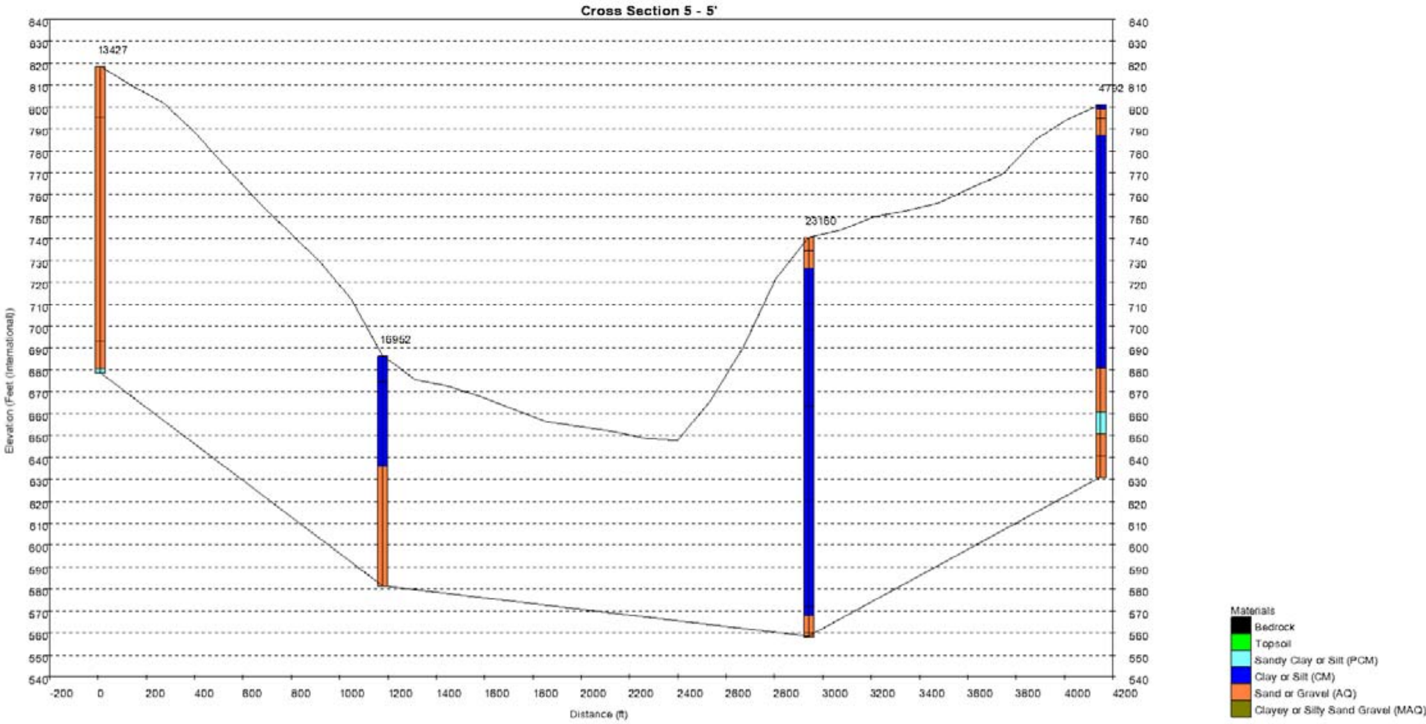

Figure 13 - Cross Section 5

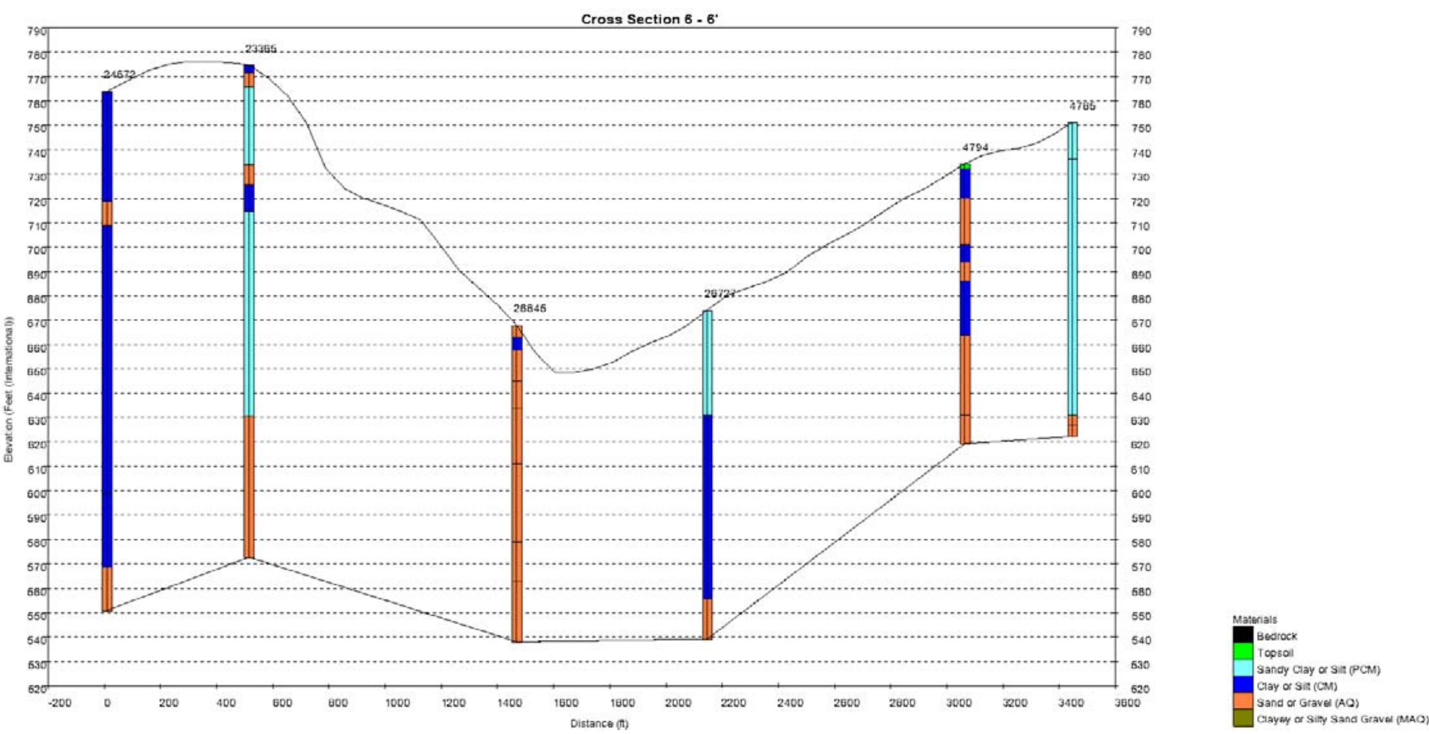

Figure 14 - Cross Section 6

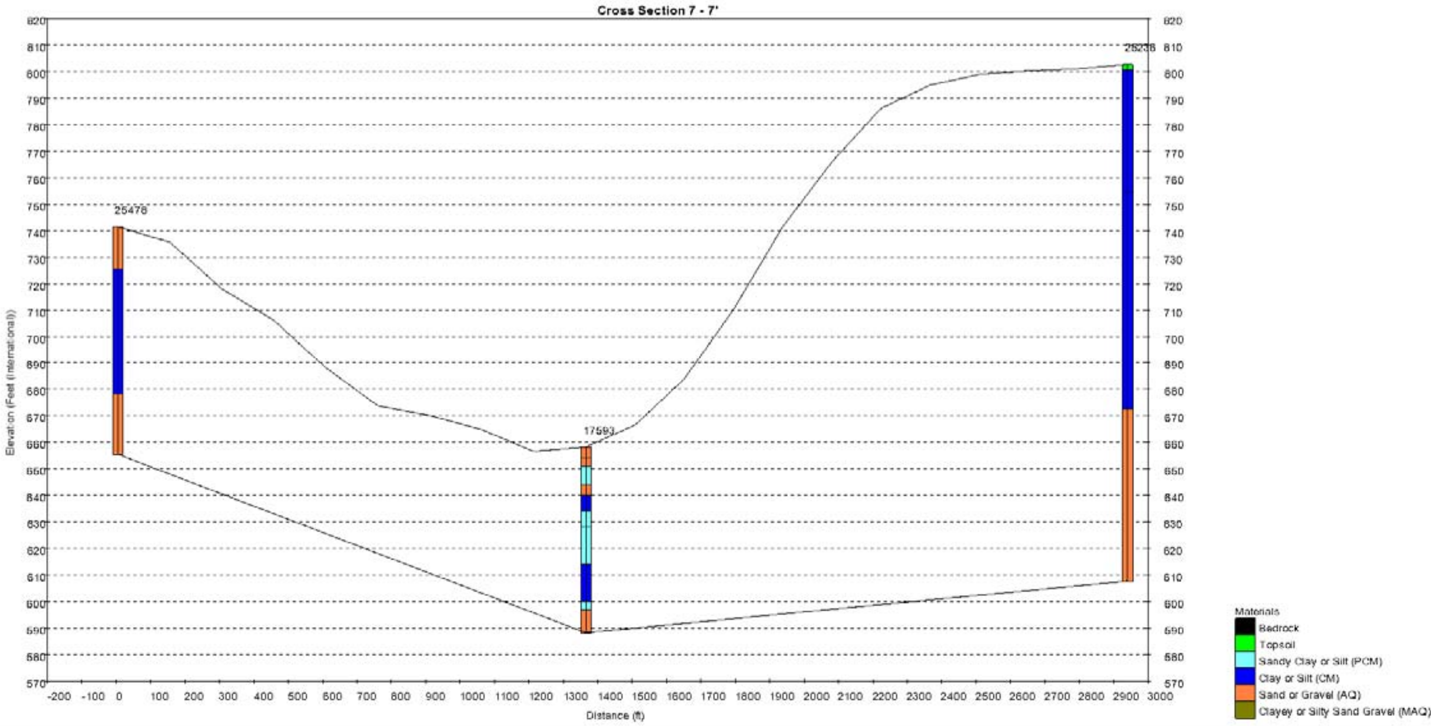

Figure 15 - Cross Section 7

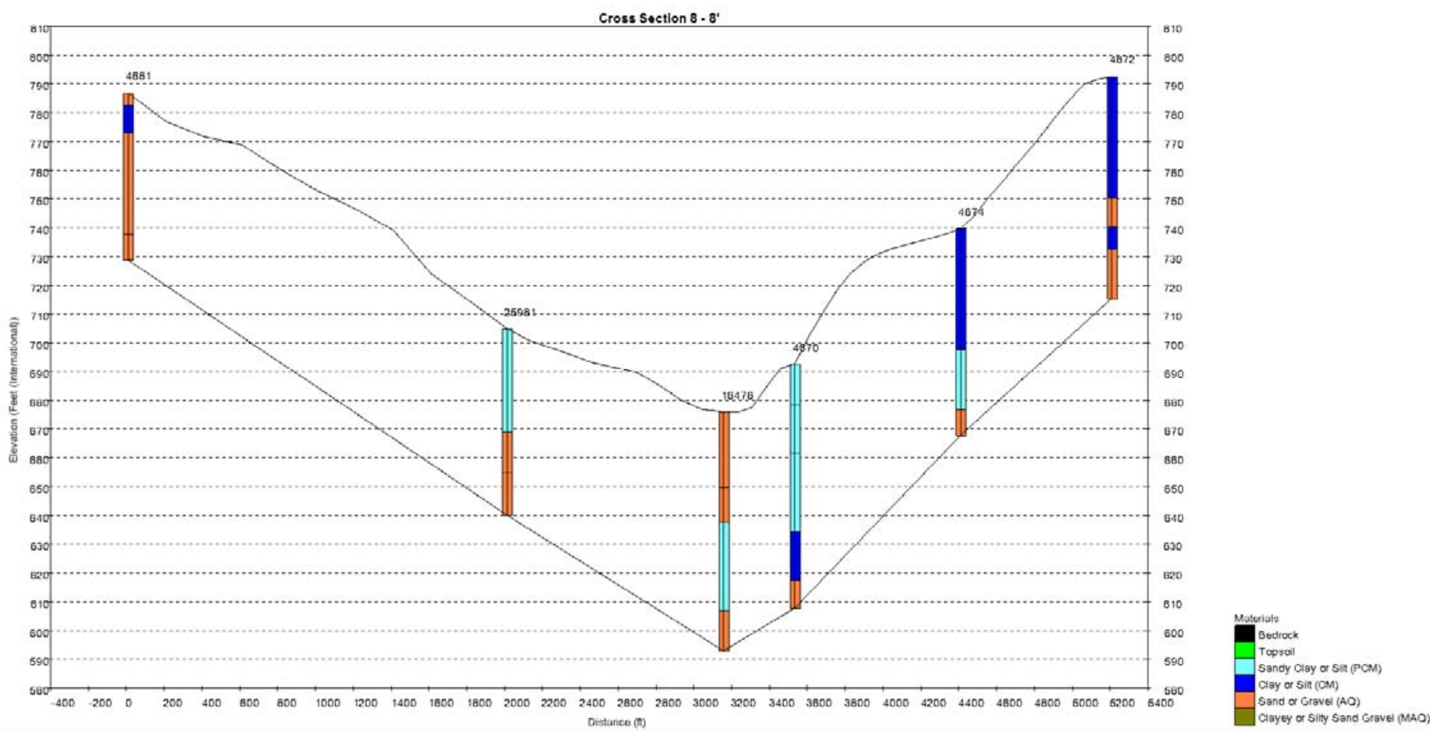

Figure 16 - Cross Section 8

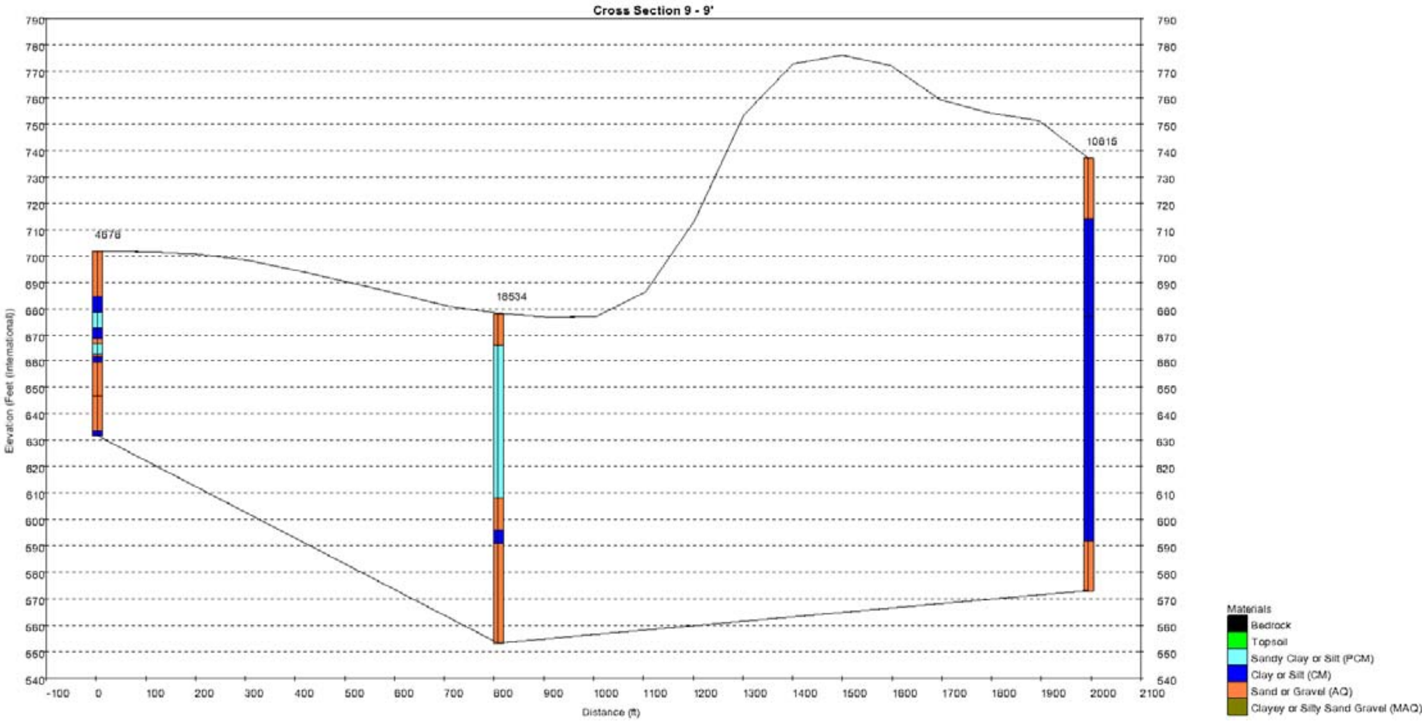

Figure 17 - Cross Section 9

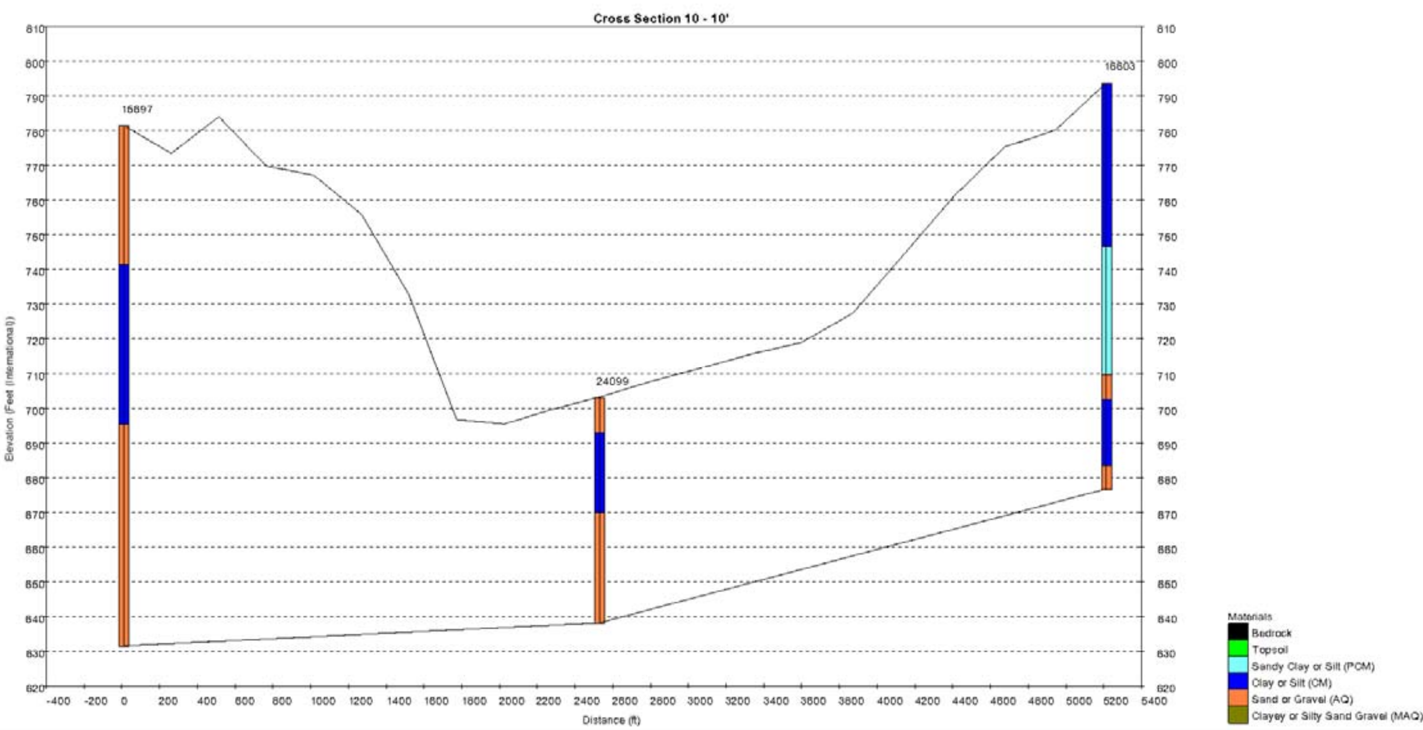

Figure 18 - Cross Section 10

Attachment B

EVALUATION OF GROUNDWATER FLOW AND
HYROLOGIC CONDITIONS ALONG THE ROGUE RIVER

B. EVALUATION OF GROUNDWATER FLOW AND HYDROLOGIC CONDITIONS ALONG THE ROGUE RIVER HYDROLOGY

Streamflow data at the USGS Gaging Station No. 04118500, located at Rockford, Michigan, the discharge point of sub-basin HUC 405006040110, from 1989 to 2016, were downloaded and reviewed with the use of USGS Groundwater Toolbox software. The gaging station measures the flow for the sub-basin, HUC 405006040110, and all the upstream sub-basins, representing a drainage area of approximately 234 square miles according to the USGS record. Monthly baseflow rates were estimated and plotted with the yield in Figure 19 - Monthly Baseflow Rates from 1989 to 2016. The yield represents the percentage of the total streamflow contributed by groundwater. In addition, the average, minimum and maximum monthly baseflow rates for each month of the year from 1989 to 2016 are also summarized in Table 1.

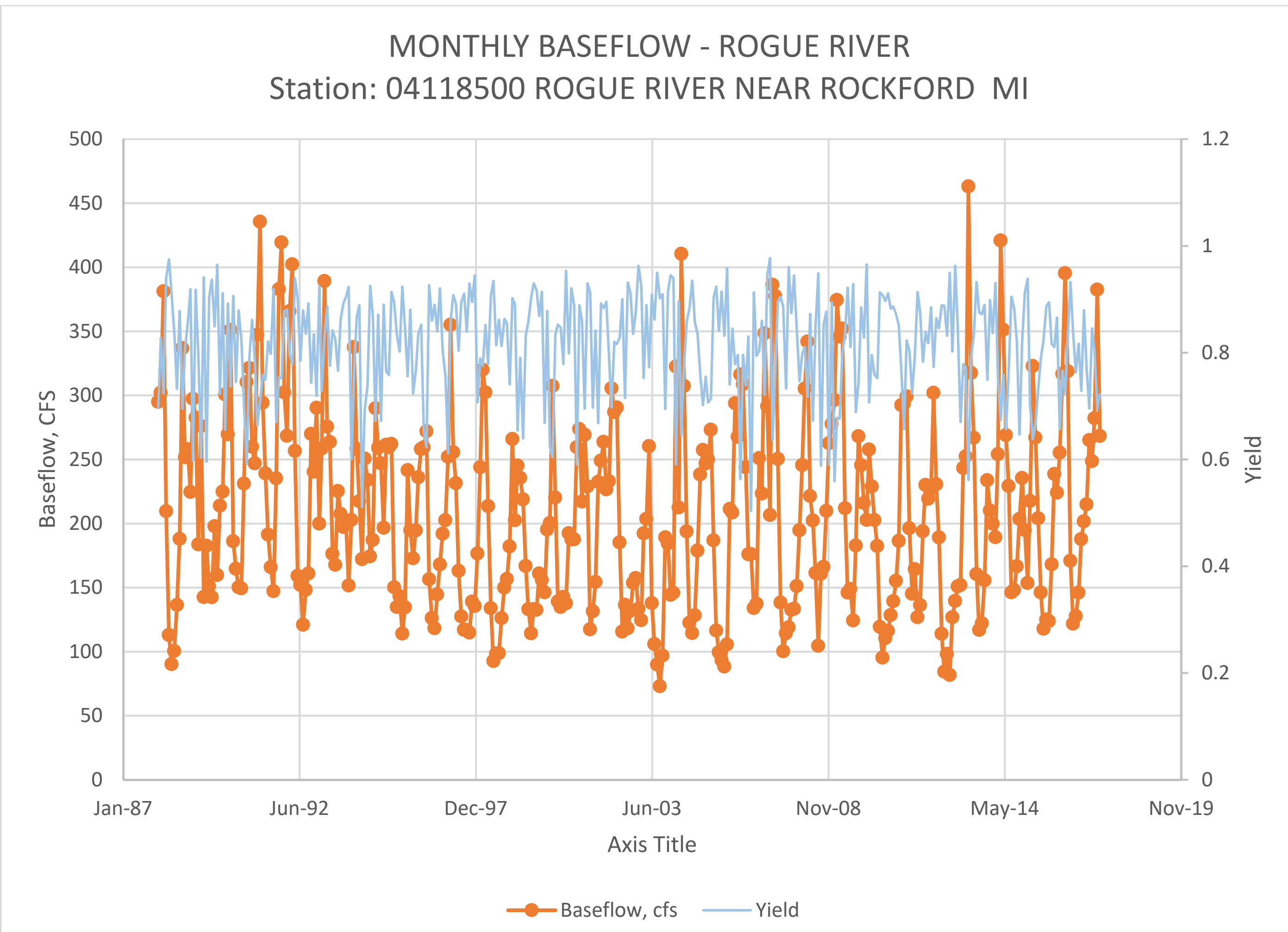

Figure 19 - Monthly Baseflow Rates from 1989 to 2016

Table 1 - Monthly Baseflow Rate Statistics From 1989 to 2016

Month	Average Baseflow, cfs	Minimum Baseflow, cfs	Maximum Baseflow, cfs
1	215.4	133.4	302.3
2	223.1	124.5	296.4
3	289.3	192.2	386.3
4	308.1	200.4	463.1
5	266.5	183.8	410.4
6	195.7	113.0	307.4
7	145.1	84.3	250.6
8	131.6	89.8	234.0
9	130.6	73.0	225.4
10	158.1	96.9	250.9
11	210.1	128.5	382.8
12	219.3	135.7	419.3

From 1989 to 2016, the monthly baseflow ranges from approximately 73 to 463 cubic feet per second (CFS) as shown in *Figure 20 - Base Flow Rates for the Rogue River*. For the relatively dry months, July to October, the average monthly baseflow range from 130 to 158 cfs, indicating that groundwater discharges to the Rogue River year-around. The average yield from 1989 to 2016 is approximately 81 percent, indicating that in average 81 percent of the total streamflow was contributed by groundwater.

Based on the Base Flow of Michigan Streams geographic information system (GIS) data ((Groundwater Inventory and Mapping Project, 2005), the estimated base flow rates for the Rogue River from the City of Rockford to the Grand River are reviewed. The GIS data provided yield and cumulative base flow for each segment, which includes upstream baseflow rates. For each of the five segments of the Rogue River, labeled as RR Segment No. 1 through 5 in *Figure 20 - Base Flow Rates for the Rogue River*, the base flow rate attributed to groundwater discharging directly to the Rogue River (labelled as Q_b_seg) was estimated by deducting the upstream baseflow rate and tributary baseflow rates from the total base flow at that segment. The following table provides a summary of the groundwater discharging rates to each segment:

Table 2 - Groundwater Discharge Rates to Rogue River Segments

Segment No.	Groundwater Discharge Rates to the Rogue River Segment (Q_b_seg), CFS	Groundwater Discharge Rates to the Rogue River Segment (Q_b_seg), gallon per minute (GPM)
1	0.78	350.22
2	1.33	597.17
3	1.44	646.56
4	0.97	435.53
5	7.3	3277.7

The length of Segment 5 is approximately the same as the sum of Segment 1 through 5, but the groundwater discharge rate to Segment 5, 7.3 CFS, is more than that of Segment 1 through 4, which is approximately 4.5 CFS. It is likely because

Segment 5 is within the "wide" of the GRV channel lying at the junction of the Rogue River and the Grand River, where the soil consists of primarily more permeable, coarse-grained outwash sand and gravel, as shown in Figure 4- Glacial Land System Near the Rogue River, while Segments 1 through 4 of the Rogue River cross through the relatively less permeable moraines. Regardless the permeability of soil, however, the groundwater discharge rates summarized in the above table further indicates that groundwater discharges to the Rogue River at these segments.

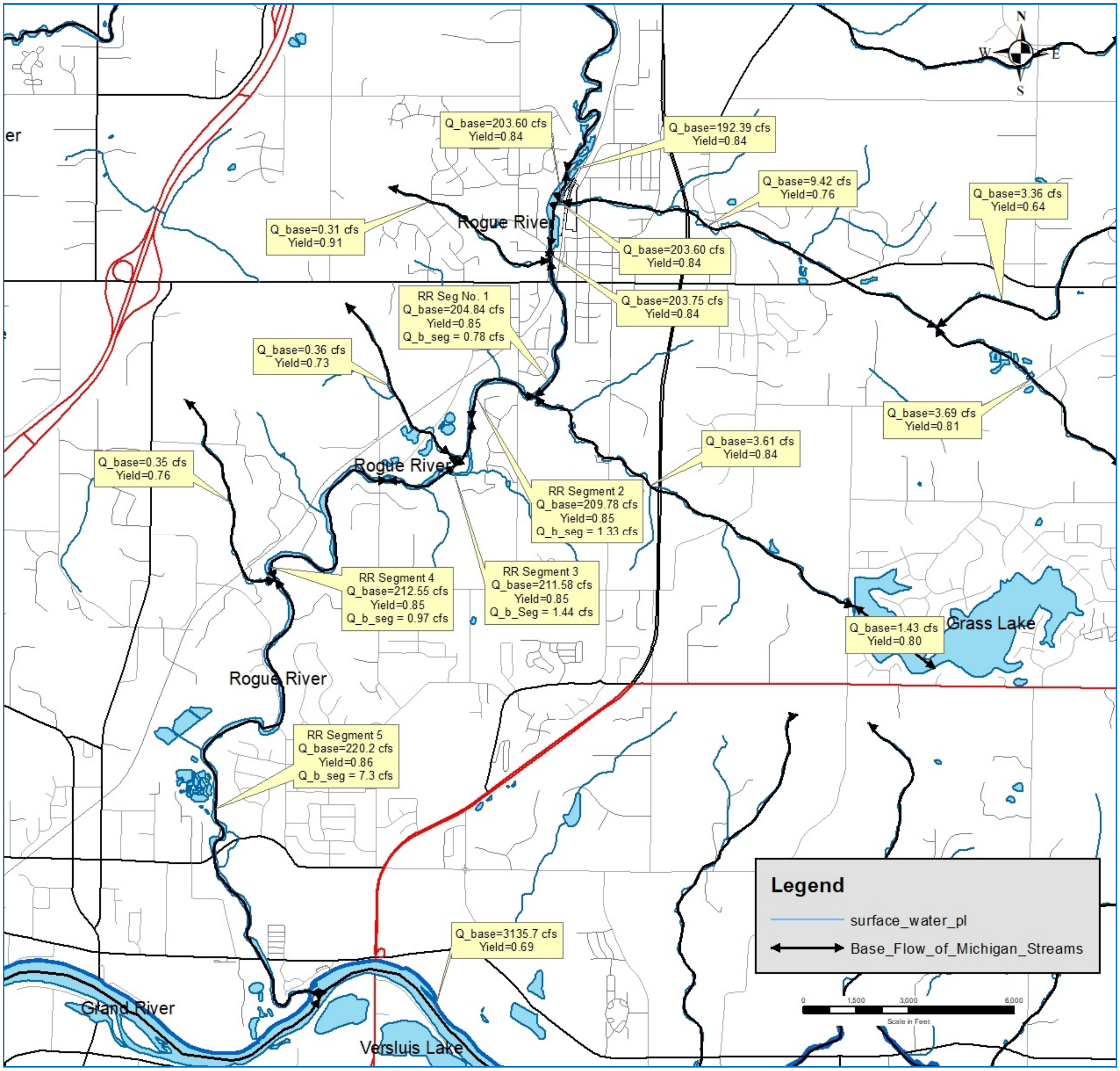

Figure 20 - Base Flow Rates for the Rogue River

HYDROGEOLOGY

Based on the groundwater contour GIS data for Kent County (Groundwater Inventory and Mapping Project, 2005), groundwater contours along the Rogue River is plotted in the following figure.

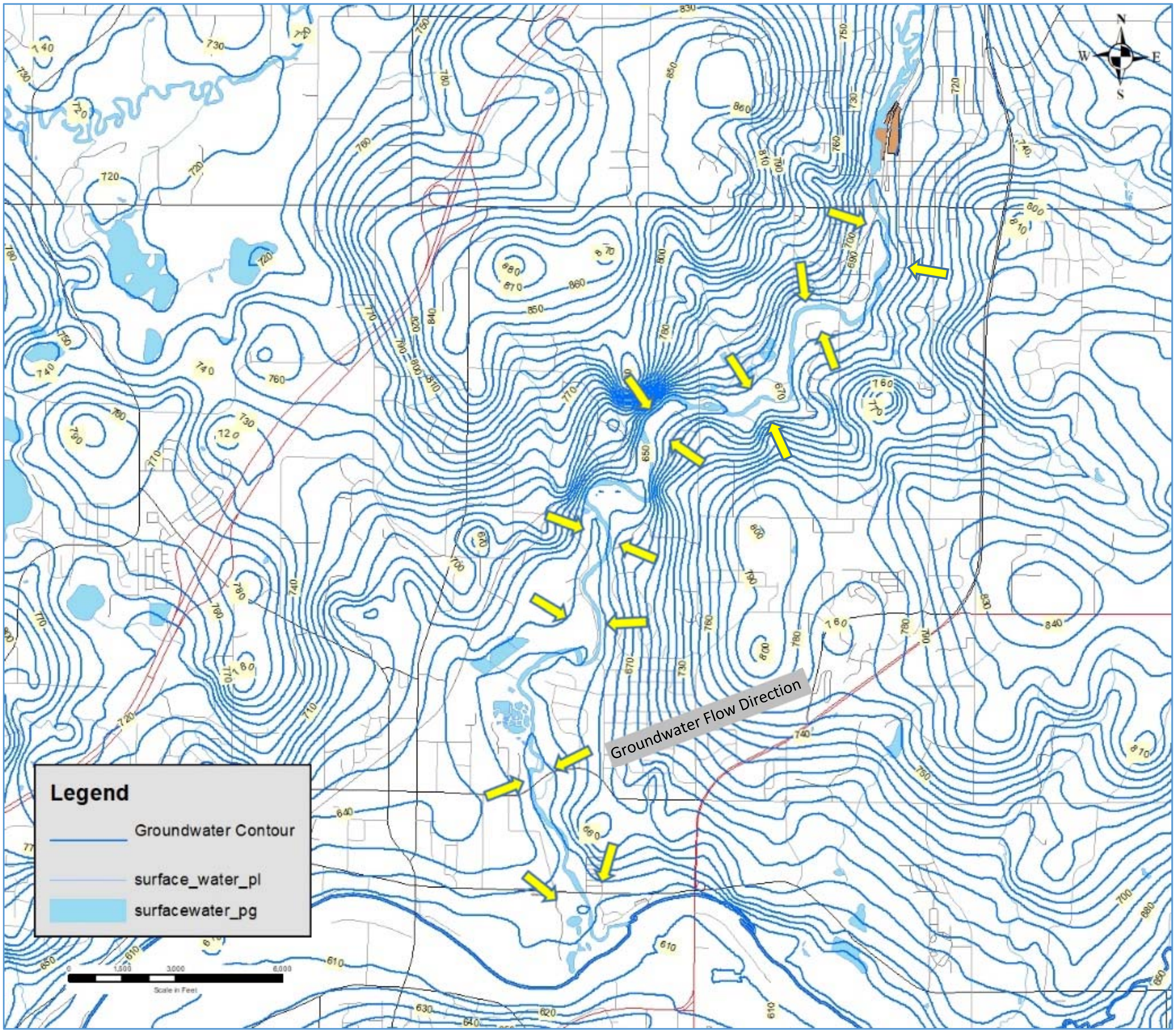

Figure 21- Groundwater Contours and Flow Directions Near the Rogue River, Interval: 10 Feet.

The above figure indicates that the surface water elevation drops from 690 ft immediately south of the Tannery Site to approximately 670 ft near the Childsdale Avenue bridge, from 670 ft there to 640 ft to the unnamed stream crossing Roguewood Drive where Segment 4 from Figure 20 - Base Flow Rates for the Rogue River is, from 640 ft to 610 ft to the Grand River. Consistent with the description regarding sharp water elevation drop as the Rogue River passes through

Plainfield (Bretz, 1952), the water elevation drop in Segment 4, from Childsdale Avenue Bridge to the unnamed stream crossing Roguewood Drive is the most steep as compared to the other segments.

Based on the groundwater contours, groundwater hydraulic gradients either side of the Rogue River are estimated below:

Table 3 - Groundwater Hydraulic Gradient West and East of the Rogue River

Segment Description	**Groundwater Hydraulic Gradient West of the Rogue River**	**Groundwater Hydraulic Gradient East of the Rogue River**
Segment 1 to 3 (From Tannery Site to Childsdale Avenue Bridge)	0.030 – 0.062	0.021 - 0.045
Segment 4 (From Childsdale Avenue Bridge to Unnamed Stream crossing Roguewood Drive)	0.037 - 0.060	0.020 - 0.08
Segment 5 (From Unnamed Stream crossing Roguewood Drive to the Grand River)	0.011 - 0.023	0.016 - 0.036

The groundwater contours indicate groundwater from both side of the Rogue River discharges to the Rogue River. In general, groundwater hydraulic gradient near the Rogue River are relatively steep as compared to typical hydraulic gradient in sand and gravel aquifers. Groundwater hydraulic gradient from the unnamed Stream crossing Roguewood Drive to the Grand River are relatively flat as compared to the upstream segments.

Groundwater flow patterns or hydraulic gradient are affected locally near some of the meanders. As shown in the figure below, some localized areas are identified as potential areas where surface water in the Rogue River may cut through groundwater (red arrows).

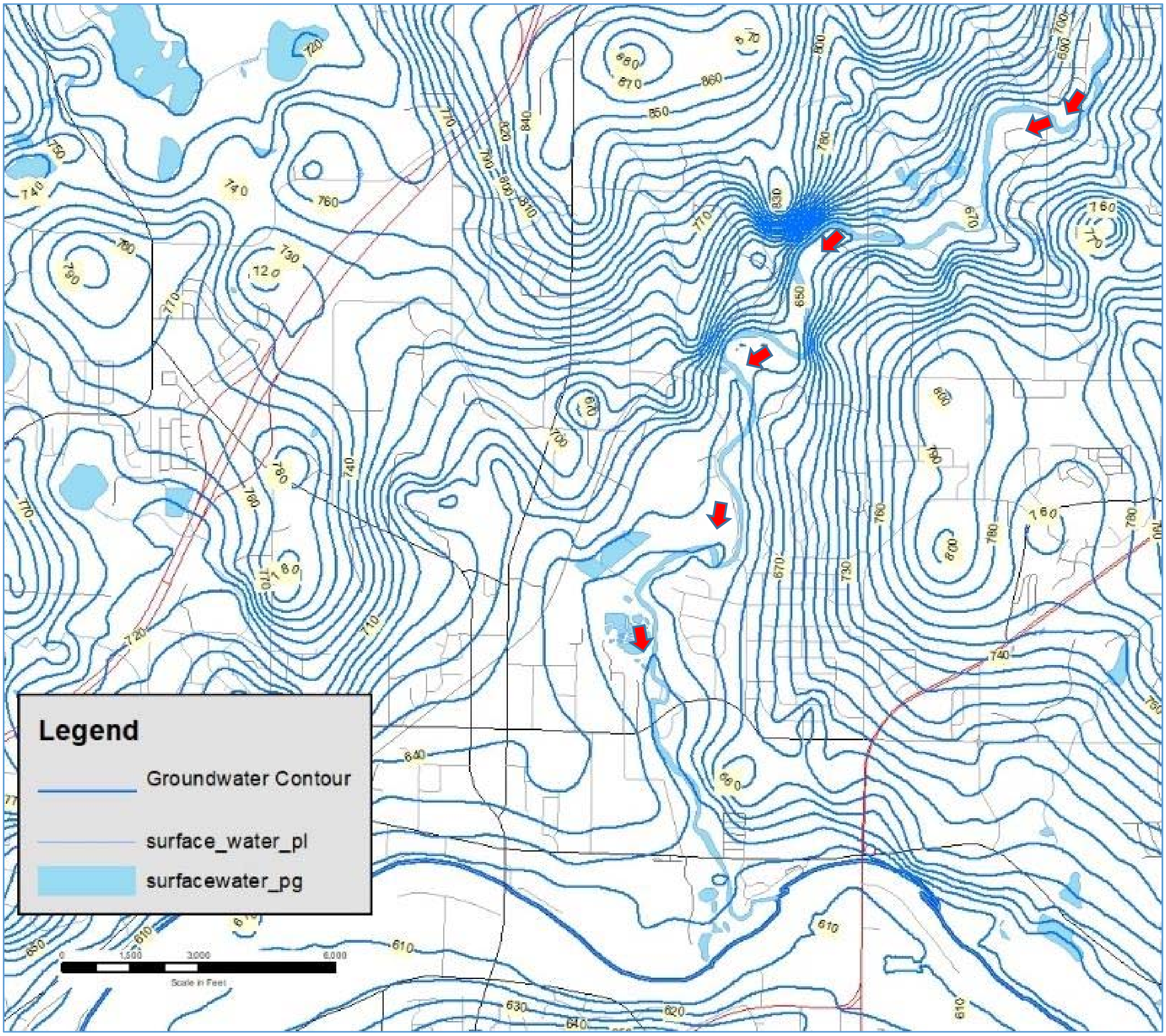

Figure 22 - Surface Water - Groundwater Exchange Near Some of the Meanders

Overall, the groundwater contours indicate groundwater flows to the Roger River because higher groundwater elevations lead to the Rogue River. As shown in the figure below (Winter, Harvey, Franke, & Alley, 1998), hydraulic heads are the deciding factor to determine groundwater flow direction. If the groundwater elevations are higher than the river elevation, groundwater is expected to discharge to the surface water.

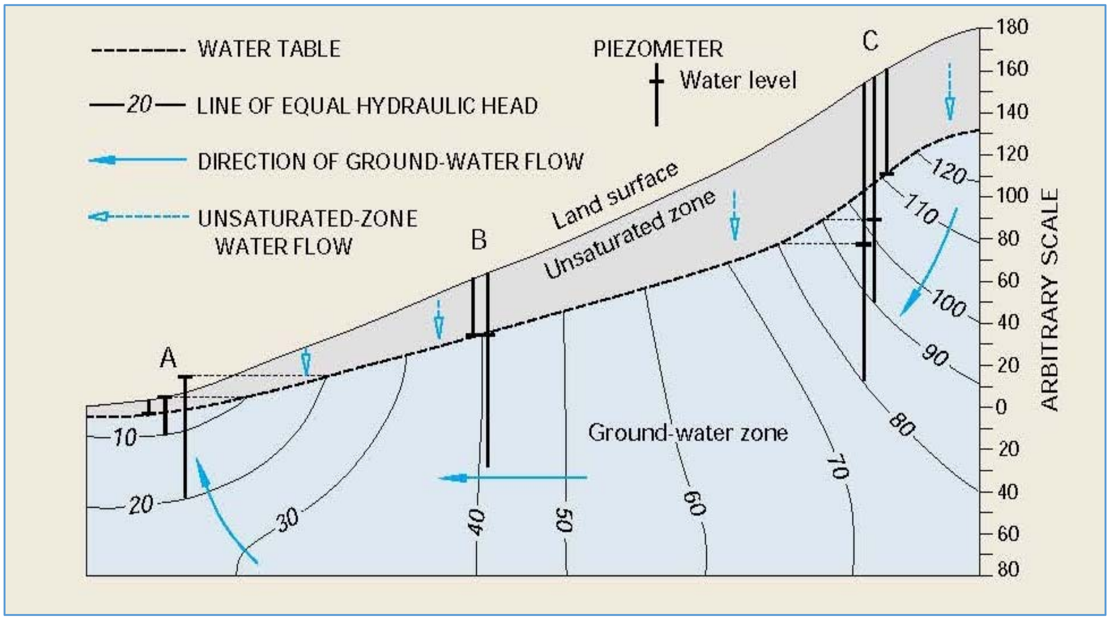

Figure 23- Conceptual Diagram for Groundwater Discharge to Surface Water (Winter, Harvey, Franke, & Alley, 1998)

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