Appendix B.4:
Water Use Technical Memorandum

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Technical Memorandum

Task 7.8 – Water Use

Zavoral Property Mine and Reclamation Project

AECOM

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AECOM
161 Cheshire Lane, Suite 500
Minneapolis, MN 55441
www.aecom.com

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1.0 Executive Summary

The Tiller Corporation, Inc. (Tiller) proposes to operate a sand and gravel mine on the site of a dormant, unreclaimed gravel mine in the City of Scandia, Washington County, Minnesota. The 114-acre site (Zavoral Site or Site) is located along St. Croix Trail North (State Trunk Highway [TH] 95) near its intersection with TH 97. Tiller proposes to mine and reclaim 64 acres of the 114-acre site, predominately on portions of the Zavoral Site that were previously disturbed by mining. An 9-acre area that has not been previously mined is included in the proposed mining area. Tiller is also proposing to restore approximately 4 acres of the previously mined area located within the St. Croix National Scenic Riverway and USA Scenic Easement Area.

This technical memorandum presents the evaluations completed for Task 7.8 – Water Use for the Project. It identifies potential environmental impacts related to the Project alternatives and identifies measures that could avoid, minimize, or mitigate for these potential impacts. This work was conducted as part of the Environmental Impact Statement (EIS) process to be completed under Minn. R. 4410. The following alternatives are included in the EIS analysis.

- Alternative 1 – Tiller's Preferred Alternative. Mining and reclamation would occur over a 5 to 10-year period.
- Alternative 2 – No Build Alternative.
- Alternative 3 – Reduced Timeframe. Mining and reclamation would occur over an up to 5-year period.

The following were the study goals for the Water Use Task:

- Identify construction details for the Zavoral Site Well using existing records; Compile and review information about wells and groundwater production in the area around the Zavoral Site.
- Quantify the potential water use under each of the Alternatives, and diurnal (daily) or seasonal variation in water use.
- Design and conduct aquifer test.
- Identify the potential impacts of pumping from the Zavoral Site Well on groundwater resources and local wells in the project area, under each of the alternatives.
- Identify the potential impacts of project-related water use on groundwater-dependent resources such as bluff springs, Zavoral Creek (trout stream), seepage swamps and any unique water-dependent ecosystems, under each of the alternatives.

The following are key findings of the water use assessment:

- The Zavoral Site Well is cased to a depth of 245 feet and finished as a multi-aquifer open hole. The well is open to the Franconia-Ironton-Galesville and the Mount Simon aquifers.

- Ninety-one wells (89 private/residential and 2 public/commercial) were identified within 1.5 miles of the Zavoral Site Well. Only 14 of the 91 wells identified are completed at elevations equal to or greater than the top elevation of the open section of the Zavoral Site Well. The remaining 77 wells are completed at shallower elevations and are not likely to be impacted by water use from the Zavoral Site Well.

- Wells west of the Zavoral Site Well were constructed in shallower aquifers than the Zavoral Site Well.

- Wells north and south of the Zavoral Site Well were constructed in the Franconia-Ironton-Galesville aquifer, the same aquifer as the upper portion of the Zavoral Site Well but none of the wells intercepted the Mt. Simon aquifer, which the Zavoral Site Well also intercepts.

- The limit of groundwater production from the Zavoral Site Well specified for Alternatives 1 and 3 (Alternative 2 specifies no pumping from that well) is 10,000 gallons per day and 1,000,000 per year. Pumping would be seasonal, spring through fall, and only on weekdays.

- The aquifer test confirmed that wells completed in the shallow aquifer were not measurable influenced by pumping the Zavoral Site Well because of the St. Lawrence Formation aquitard, which restricts the flow of groundwater between the shallow and deeper aquifers.

- Pumping of the Zavoral Site Well at the maximum daily production, 10,000 gallon per day, would result in minimal drawdown to wells completed in the Franconia-Ironton-Galesville aquifer.

- No measurable reductions in water levels were identified in Zavoral Creek, Middle Creek or Spring Box Creek during the aquifer test. Water for these creeks appear to be provided primarily from the shallow aquifers.

- The St. Croix River discharge was not measurably impacted by pumping the Zavoral Site Well.

No additional mitigation measures were identified for the proposed water use since no significant impacts were identified.

2.0 Project Background

AECOM is completing tasks to analyze the potential for environmental impacts, and identify measures to mitigate potential impacts for the identified alternatives related to the Zavoral Property Mining and Reclamation Project. This work is part of the EIS process to be completed under Minn. R. 4410. This technical memorandum presents the analysis and evaluation completed for Task 7.8 - Water Use.

The alternatives to be addressed in the EIS are summarized below. This Water Use Technical Memorandum addresses primarily Alternatives 1 and 3 and discusses the differences between the alternatives with regard to water use and the potential associated impacts. Alternative 2 does not include water use.

2.1 Alternative 1—Applicant's Preferred Alternative

The Project area includes 114 acres of which previous mining activity had disturbed approximately 55 acres. The proposed Project would involve mining and restoration of 64 acres located predominately on the previously disturbed portions of the Zavoral Site. The active mining area would include mining to an average depth of about 15 feet, and expanding the limits of mining by about 8 acres. In addition, Tiller is proposing to restore approximately 4 acres of the previously-mined area located within the St. Croix National Scenic Riverway and USA Scenic Easement Area.

Tiller Corporation is proposing the following activities at the Zavoral Site:

- Clearing and grubbing the site of vegetation, as necessary.
- Removal of overburden from areas to be mined, and stockpiling the material on the site for potential future use in reclamation.
- Excavation of raw aggregate materials.
- Transporting mined aggregate materials (pit-run, add-rock); the majority of which would likely be delivered to the Scandia Mine near Manning Avenue and 225th Street for use in material produced at that site.
- Pumping water from the existing well at the Zavoral Site (Zavoral Site Well) to be used for dust suppression. Pumping would be no more than 10,000 gallons per day and no more than 1,000,000 gallons per year. The Well would be pumped at a 1,200 gallons per minute (gpm) rate, or at a lower pumping rate, for a few minutes a couple of times a day.
- Potential fuel storage and storage of related materials such as oil, anti-freeze, grease, and hydraulic fluid.
- Reclamation activities, including grading, placing topsoil, and seeding.

Mining operations would be conducted on a seasonal basis, typically from April through mid-November. The Zavoral Site is proposed to be mined and reclaimed in phases, with the duration of the project expected to be up to 10 years under this alternative.

Site reclamation would proceed as areas of mining are completed. The reclamation plan proposes that perimeter areas be sloped and the interior areas backfilled and graded to reclamation grades. Topsoil or other organic material would be applied to these areas and vegetation established to reduce erosion. The analysis of the Zavoral Site carried out as part of the EAW resulted in the recommendation that the previously-mined area within the St. Croix Riverway be restored during the first phase of mining operations at the site. Tiller's letter to the City (April 7, 2009) proposed revising the reclamation and phasing plan to include reclamation of the area within the St. Croix Riverway and scenic easement areas during the first years of operation. This technical memorandum therefore evaluates the Project area that includes reclamation of the St. Croix National Scenic Riverway and USA Scenic Easement Area during the first 5 years of mining operations on the Zavoral Site.

Raw aggregate material mined at the Zavoral Site would be transported to the Scandia Mine (Mine) for processing. Processing of aggregate materials is currently occurring at the Scandia Mine for materials mined at that site and materials that are transported to the Site from other locations. Tiller has indicated that the materials transported from the Zavoral Site would replace the materials from Franconia, Minnesota and the Osceola, Wisconsin, area.

2.2 Alternative 2--No-Build Alternative

The No-Build Alternative is described in the EIS. The No-Build Alternative addresses the potential impacts, outcomes, constraints, benefits, disadvantages, and economics if the existing land uses on the Zavoral and Scandia sites were to continue. The description will be based on the existing and allowed use of the site for Agricultural and Rural Residential purposes, and will make projections or forecasts based on this use, to identify the No-Build Alternative effects and impacts. The No-Build Alternative does not include the Reclamation Activities on previously mined areas that are included in Alternative 1.

2.3 Alternative 3—Mining and Reclamation Activities—Evaluate Reduced Time Frame for Mining Activities

This Alternative will focus on the impacts of the proposed activities if the overall time frame for mining at the Zavoral Site is up to 5 years rather than up to 10 years, as proposed in the Preferred Alternative. Water use for Alternative 3 is the same as Alternative 1. The volume of water used is not based on the volume of material mined. The same maximum volume of water per day and per year would be use under both Alternatives 1 and 3.

3.0 Study Goals

The following were the study goals for the Water Use Task:

1. Identify construction details for the Zavoral Site Well using existing records; Compile and review information about wells and groundwater production in the area around the Zavoral Site.

2. Quantify the potential water use under each of the Alternatives, and diurnal (daily) or seasonal variation in water use.

3. Design and conduct an aquifer test.

4. Identify the potential impacts of pumping from the Zavoral Site Well on groundwater resources and local wells in the project area, under each of the alternatives.

5. Identify the potential impacts of project-related water use on groundwater-dependent resources such as bluff springs, Zavoral Creek (trout stream), seepage swamps and any unique water-dependent ecosystems, under each of the alternatives.

4.0 Methodology

4.1 Goal 1 – Zavoral Site Well and Area Wells

Information about the wells at and around the Zavoral Site was obtained from the Minnesota County Well Index (CWI) Database (http://www.health.state.mn.us/divs/eh/cwi/ - the on-line database does not include information about public wells – that information was obtained directly from the Minnesota Department of Health.

4.2 Goal 2 – Potential Water Use

The limit of groundwater production from the Zavoral Site Well is established under Alternatives 1 and 3 (Alternative 2 specifies no pumping from that well). Diurnal and seasonal variation in water use from the Zavoral Site Well can only be estimated considering temperature and precipitation patterns and Tillers anticipated production schedules.

Materials removed from the Zavoral Site would be transported to the Scandia Mine for processing. This would include any washing of the materials that may be required. Water use from the existing permitted well at the Scandia Mine was assumed to be similar to the production in the past as the material from the Zavoral Site would replace material currently being sourced from other sites.

4.3 Goal 3 - Design and Conduct Aquifer Test

Aquifer Test Design

The existing Zavoral Site Well was identified as a source of groundwater for the Zavoral Site's mining operations. Available well record (CWI) shows that the Zavoral Site Well is cased to a depth of 245 feet and is completed as an open hole in two deep aquifer systems, the Franconia-Ironton-Galesville aquifer and the deeper Mt. Simon aquifer, to a total depth of 648 feet.

The aquifer test was proposed to evaluate the potential effect of pumping groundwater from the Zavoral Site Well upon groundwater resources and groundwater dependent resources of the area at and around the Zavoral Site.

The aquifer test design activities included a simulated lowering of water levels in aquifer around the Zavoral Site Well as a result of a ten minute long pumping at 1,200 gpm (ten minutes is longer that the maximum anticipated length of pumping) using a numerical computer program, PT1, presented by Walton (1989). The program input parameters were set based on the Zavoral Site Well's construction diagram available from the CWI and estimates of hydraulic properties of aquifers penetrated by the Zavoral Site Well, based on available regional data (Runkel et al., 2003).

The results of the simulation performed by AECOM indicated that, after ten minutes of pumping, water levels may drop by 0.2 feet at a distance of 670 feet from the Well. Based on the simulation, no drawdown would be observed at a distance of 1,682 feet.

The results of this simulation, however, were based on several assumptions and, for that reason, the simulation results were associated with considerable uncertainties. Consequently, AECOM proposed an aquifer test with water levels monitored in the three closest representative wells and at four surface water monitoring points around the Zavoral Site.

Water level measurements during the aquifer test provide direct evidence of the effect of pumping from the Zavoral Site Well upon the surrounding environment. The data generated allows a better characterization of the groundwater system and the interaction between groundwater and surface water at the Zavoral Site. The aquifer test pumped several times more water than the maximum daily water production of 10,000 gallons per day. Pumping would only occur during seasonal mining operations.

The final list of the wells included in the aquifer test monitoring network (Figure 1) is shown below. A cross section of the wells including elevations and depths, aquifers and aquitards are shown in Figure 2.

- Zavoral Cabin Well (No Minnesota Unique Number) located about 1,300 feet east of the Zavoral Site Well. The Zavoral Cabin Well was measured (on May 24, 2010) to be 240 feet deep and, therefore, is completed in the Franconia-Ironton-Galesville formation. It is representative of other wells close to the St. Croix River and it is the closest well to the Zavoral Site Well. Slug testing of this four inch diameter well conducted on May 24, 2010 (using a three inch diameter stainless steel slug) revealed that water level in the well completely recovered within several minutes of the

aquifer test. The measured water level in the well was measured on June 29, 2010 to be 37.5 feet above the St. Croix River stage. This steep upward gradient indicates a strong discharge of groundwater occurs from the Franconia-Ironton-Galesville aquifer into the River.

- Trails End Well (Minnesota Unique Number 00263147) (Trails End Well) is located about 1,700 feet west of the Zavoral Site Well. Measurements conducted by AECOM staff on May 24, 2010 determined that this four inch diameter well is 139 feet deep. Slug testing (conducted with the use of a three inch diameter stainless steel slug) revealed that water level in the well completely recovered within seconds of the aquifer test. The well is shallower than the other nearby wells and is likely completed in sand and gravel deposits above the bedrock. Consequently, it was concluded that this well is not sufficiently representative of the nearby wells located west of the Zavoral Site. As a result the Magnuson Well, described below, was added to the list of monitoring wells. In addition to aquifer test monitoring, water levels in the Trails End Well were measured using an electronic water level meter (Level Troll) which captured the water level once every fifteen minutes for thirty seven days, from May 25 through June 30, to collect long-term background water level data.
- Magnuson Well (Minnesota Unique Number 00154397), owned by Mr. Roger Magnuson, is located about 1,900 feet west-northwest of the Zavoral Site Well. This 232 feet deep well is completed in the Jordan Sandstone formation and is representative of many other nearby wells located west, southwest, and northwest of the Zavoral Site and further away from St. Croix River.

Water levels were not monitored in the Zavoral Site Well itself because the well does not have an access port for water level monitoring equipment when a pump is in place. However, measuring the water level in the Zavoral Site Well is not required to address potential impacts from pumping that well.

In addition to monitoring water levels in nearby wells, AECOM completed measurements in the creeks near the Zavoral Site at the following four locations:

- Zavoral Creek at the culvert (near the Zavoral cabin). This monitoring point was located a few feet up-stream from the monitoring station installed by the Watershed District for long term monitoring.
- Zavoral Creek near Crystal Springs, located about 1,100 feet northwest and up-stream of the Zavoral Creek culvert (on the property of Gregory Page).
- Unnamed creek designated as Middle Creek located about 400 feet south-southeast of the Zavoral Creek culvert. This creek is the next creek south of Zavoral Creek.
- Unnamed creek designated as Spring Box Creek is located at the north end of a culvert below Quint Avenue North, west of railroad tracks, a short distance down-gradient from spring box, and about 2,800 feet south of the Zavoral Creek culvert.

The purpose of this surface water monitoring was to document if pumping the Zavoral Site Well would result in detectable changes in water levels in the nearby creeks. Water levels were measured once every fifteen minutes for the monitoring period.

There is one permitted high capacity well within the three-mile radius around the Zavoral Site Well - Abrahamson Nurseries Well (MnDNR Permit: 2007-0195, MN Unique Well No. 00 733013). Since the permit for the Abrahamson well allows pumping at a rate of up to 420 gpm, pumping from that well could interfere with the planned aquifer test. Therefore, the City of Scandia contacted the owners of the Abrahamson Nurseries Well and requested that they not pump the well during the planned aquifer test.

The water pumped from the Zavoral Site Well during the aquifer test was piped to an on-site, depression south of the well, to prevent excessive runoff, sediment transport, and erosion. The water level in the depression (Discharge Pond) was monitored periodically during the aquifer test to assess infiltration rates.

Since the rate of water flow (discharge) and water levels in the creeks directly respond to precipitation caused surface runoff, the aquifer test was scheduled, as much as possible, during a dry, precipitation free, period of time.

Aquifer Test Execution

The aquifer test started at 9:00AM, June 29, 2010. After 4 hours and 20 minutes of pumping the pump failed (1:20PM) and could not be restarted. The calculated average pumping rate was 664 gpm. The total volume of water pumped was 172,600 gallons, or more than 17 times the maximum amount of water the Tiller would use daily during its seasonal operations of the Zavoral Site.

Water level measurements in the monitoring wells and at surface water monitoring points were conducted using transducers, Micro-Diver Sensors, Mini Baro-Diver Sensor, and other equipment, and recorded once every two minutes. This water level monitoring was initiated a day before commencement of the test, June 28, 2010, and continued until the morning of the next day after the aquifer test, June 30, 2010.

Water levels were measured at the four surface water monitoring points once every five minutes. This monitoring was initiated in the afternoon of June 28, 2010, the day before the aquifer test, and was completed in the afternoon of July 2, 2010.

A staff gage was installed in the middle of the Discharge Pond south of the Zavoral Site Well where the water pumped from the well was discharged. Water level at the staff gage was observed and recorded a total of five times – three times on the day of the aquifer test (June 29), one time the next day (June 30) and a final time on July 2, 2010.

The St. Croix River stage was measured four times at a benchmark point established near the Zavoral cabin – one day before the aquifer test day (June 28), two times on the day of the aquifer test (June 29) and a final time on June 30, 2010.

All of the monitoring points (three wells, four surface water monitoring points, Discharge Pond staff gage and the St. Croix River at Zavoral cabin benchmark point) were surveyed to allow calculation of water level elevations to mean sea level (msl).

4.4 Goal 4 – Potential Impacts of Pumping from Zavoral Site Well

The potential impacts of pumping the Zavoral Site Well on groundwater resources and local wells in the Project area were evaluated by analyzing water level data collected from monitoring wells during the aquifer test and by estimating the groundwater balance for the site (see discussion in Section 4.5).

4.5 Goal 5 – Potential Impacts on Groundwater-dependent Resources

The potential impacts of project-related water use on groundwater-dependent resources were evaluated by analyzing water level data collected from the surface water monitoring points, and additional data collected by AECOM or other parties: discharge data for St. Croix River (USGS) and Zavoral Creek (Washington Conservation District – WCD), precipitation data (USGS and WCD) and groundwater balance estimations.

St. Croix Discharge Data

The St. Croix River's average daily discharge data was obtained from the USGS website for a gaging station USGS 05340500 St. Croix River at St. Croix Falls, Wisconsin, located about 14 miles upriver from the Zavoral Site (http://wi.waterdata.usgs.gov/nwis/uv?site_no=05340500).

Zavoral Creek Water Discharge Measurements

On December 7, 2009, AECOM staff measured discharge from Zavoral Creek at two points:

- Culvert under the gravel road near the discharge of Zavoral Creek to St. Croix River
- Waterfall in the upper reaches of Zavoral Creek – this is the first waterfall along the Creek after it emerges from the upper rock cliff in the Zavoral Creek ravine (Crystal Springs).

On June 29 (7:55AM) and June 30 (10:10AM), 2010, AECOM staff measured discharge of Zavoral Creek at the culvert for the second time (the same point that was measured on December 7, 2009).

Discharge measurements at the culvert were conducted using two independent methods:

- Measurements of the time it takes a floater to travel through the length of culvert and the measurement of a maximum depth of water at the bottom of the down-gradient site of the culvert (Floater Method);
- Measurements of the time needed to fill-up a 5-gallon bucket (Bucket Method).

Floater Method Measurements and Calculations

The area of flow was obtained using a formula for calculating the area of circular segment (see equation below).

$$A = \left(\frac{R^2}{2}\right) \cdot (\theta - \sin(\theta))$$

Where:

A - area of the circular segment

θ - angle at the center of a circle for the triangle with arms extending from the center of the circle to the ends of a chord

The θ angle can be calculated using the following formula:

$$\theta = 2 \cdot \arccos\left(\frac{d}{R}\right)$$

Where:

R - radius of the circle (culvert in our case – 21" or 1.75 ft)

d - difference between R and height of the segment (in our case maximum depth of water in culvert)

The floaters used on December 7, 2009 were placed 20 inches below the up-gradient end of the culvert, below debris that was present in the culvert. The floaters' travel distance (to the outfall on the other end of culvert) was 210 inches or 17.5 feet. During the June 2010 measurements, the debris was removed, and the floaters were placed at the up-gradient end of the culvert and traveled a distance of 230 inches or 19.2 feet.

Bucket Measurements

Creek discharge was estimated by measuring the time it took to fill-up a 5-gallon bucket placed under the outfall of the culvert.

Measuring Discharge at the Upstream Waterfall

Discharge at the waterfall in the upper reach of Zavoral Creek was measured using a 5-gallon bucket.

Precipitation Data

Daily precipitation data were obtained for two gaging stations for a period of time from May 25 through July 2, 2010:

- Forest Lake gauging station located about 10 miles west of the Zavoral Site;
- Swedish Flag Creek gauging station located a few miles south of the Zavoral Site that is operated by the WCD.

Estimating Groundwater Fluxes Across the Zavoral Site

The rate of groundwater flow across the Zavoral Site was estimated by using the databases of the Metropolitan Area Groundwater Model (the Metro Model) (Minnesota Pollution Control Agency's website: http://www.pca.state.mn.us/index.php/water/water-types-and-programs/groundwater/groundwater-data-and-programs/metropolitan-area-groundwater-model.html?menuid=&missing=0&redirect=1). The report for the "Metro Model - Northeast Province" provides the groundwater discharge to St. Croix River simulated by the calibrated model for layers 1, 2 and 3 (representing Glacial Drift, St. Peter Sandstone and Prairie du Chien – Jordan aquifers, respectively). The report for the "Metro Model – Lower Aquifer Model" provides the groundwater discharge to St. Croix River simulated by the calibrated model for layers 4 and 5 (representing Franconia-Ironton-Galesville and Mt. Simon- Hinckley aquifers, respectively). The model reports provide the values of average discharge in units of m^3/day/m (cubic meters of discharge per day per one meter of St. Croix River's length).

It was assumed that groundwater discharge into St. Croix River at Zavoral Site is reasonably well represented by average discharge along the entire run of St. Croix River simulated by the Metro Model. Groundwater discharge into the River across the Zavoral Site was calculated by multiplying the average values of discharge (as presented in the Metro Model report) by 600 meters (1800 feet) of the Zavoral Site's width measured parallel to the River.

5.0 Findings

5.1 Goal 1 – Zavoral Site Well and Area Wells

Zavoral Site Well

According to well log provided in the CWI database, the 648 feet deep Zavoral Site Well, MN Unique Number 00210498, is cased to a depth of 245 feet and finished as a multi-aquifer open hole. According to Tiller's survey the top of the casing is at 866.1 feet MSL, the bottom of the Well is at an elevation of 218.1 feet msl.

Wells around the Zavoral Site

Ninety one wells are listed in the CWI database within a 1.5 mile radius around the Zavoral Site Well – 89 of these wells are private/residential wells and 2 of them are public/commercial wells.

Only 14 of these 91 wells are completed at depths such that the bottom of the well is at an elevation below the elevation of the top of the open section of the Zavoral Site Well. This was the group of wells initially considered for inclusion in the monitoring network for the aquifer test, as such wells are likely completed in the same aquifer as the Zavoral Site Well. Since the geologic strata (and associated aquifers) dip slightly toward the west-southwest, it is likely that wells with bottoms above the top of the open section of the Zavoral Site Well are completed in different/shallower aquifers than the Zavoral Site Well.

The wells completed in shallower aquifers are not as likely to be affected by pumping from the Zavoral Site Well. This is because the St. Lawrence Formation separating the Franconia-Ironton-Galesville Aquifer (the highest among the aquifers tapped by the Zavoral Site Well) and the next shallower aquifer, the Jordan Sandstone, is acting as an aquitard. An aquitard is a geological unit of low permeability that restricts movement of water between aquifers. A cross section of the three wells included in the aquifer test including elevations and depths, aquifers and aquitards are shown in Figure 2.

The difference between water levels measured in wells completed in the Franconia-Ironton-Galesville and the Jordan aquifers (MGS, 1990) illustrate a relative hydraulic separation between these two aquifer systems. On a regional scale, water levels measured in the Jordan aquifer wells are higher than water levels measured in the Franconia-Ironton-Galesville Aquifer. However, it was recommended that representative wells completed in shallower aquifers should also be included in the monitoring network. The St. Lawrence Formation near the St. Croix River valley is present under a "shallow bedrock condition" (Runkel et al., 2003) and, therefore, is more prone to the presence of systematic fractures. Such fractures, if present, may render the St. Lawrence Formation less effective as an aquitard and may provide for hydraulic connection between deeper and shallower aquifers.

All of the 14 deep wells within a 1.5 mile radius around the Zavoral Site Well are completed in the Franconia-Ironton-Galesville Aquifer – the same aquifer system that is intercepted by the Zavoral Site Well. However, none of these wells are completed in the deeper Mt. Simon Aquifer, the lower aquifer intercepted by the Zavoral Site Well.

All these 14 wells are located either north or south of the Zavoral Site Well, close to the St. Croix River. The St. Croix River valley constitutes a regional groundwater discharge area and the river acts as a boundary to groundwater flow. Consequently, after the aquifer test was initiated, changes in water levels in deep aquifers (tapped by the well) close to the river were expected to be smaller compared to changes in water level further away from the river. This is because some level of hydraulic connection between the aquifers and the River is to be expected. Consequently. the evolving cone-of-depression is likely to either trigger recharge into the aquifer from the river or cause a decrease in groundwater discharge into the river.

No deep wells were identified west of the Zavoral Site Well (away from the St. Croix River), within the 1.5 mile radius. One likely explanation is that contractors installing wells further from the river valley drill to the shallowest usable aquifer and not deeper. Further away from the St. Croix River the first usable aquifers encountered are Drift and/or Prairie du Chien – Jordan aquifers – these aquifers are shallower than the Franconia Aquifer. In contrast, the first aquifer encountered when drilling within the St. Croix River valley, or close to it, is the Franconia Aquifer.

5.2 Goal 2 – Potential Water Use

The limit of groundwater production from the Zavoral Site Well specified for Alternatives 1 and 3 (Alternative 2 specifies no pumping from that well) is 10,000 gallons per day and 1,000,000 per year. The daily limit would likely be approached only on dry days during the seasonal mining operations. Since groundwater would be pumped to control dust, no pumping would be necessary during rainy days. In addition, no pumping would be taking place during weekends.

5.3 Goal 3 - Design and Conduct Aquifer Test

The discussion of the aquifer test is provided in Section 4.3.

5.4 Goal 4 – Potential Impacts of Pumping from Zavoral Site Well

The Zavoral Site Well was pumped for 4 hours and 20 minutes during an aquifer test. This is much longer than the approximately 15 minutes at 660 gallons per minute needed to produce up to 10,000 gallons per day for dust control. Thus, draw-downs (lowering of water levels in monitoring wells) measured toward the end of aquifer test were much larger than draw-downs expected to be produced during the mine operations.

A drawdown of 0.25 feet was measured in the Zavoral Cabin Well (a 240-foot deep well completed in the Franconia Aquifer located approximately 1,300 feet away from the Zavoral Site Well) after the first 15 minutes of the aquifer test, that was conducted at a rate of approximately 660 gallons per minute. This represents 1/800th of the total water column present in that well. After four hours of pumping, the drawdown was 3.5 feet, which represents less than 1/50th of the total water column in that well (Figure 1). The other two Franconia wells closest to the Zavoral Site are the Paul Bowlin well (MN Unique Number 609546 completed to a depth of 110 ft) and the Joe Fitzpatrick well (MN Unique Number 151789 completed to a depth of 175 feet), which are located about 2,000 and 2,500 feet away from the Zavoral Site Well, respectively. The bottoms of all two wells are at similar elevations as the bottom of Zavoral Cabin Well. The Zavoral Cabin Well is located much closer to the Zavoral Site Well than the other two wells, while other Franconia wells in the area are located at still greater distances. Consequently, draw-downs caused in those wells by pumping Zavoral Site Well are expected to be less than observed in Zavoral Cabin Well. The presence of St. Croix River near the Zavoral Site is likely to limit the extent of cone of depression around the Zavoral Site Well during pumping. Thus, draw-downs along the River are likely to decrease away from the pumping well at a rate faster than would be the case if the River was not present.

No aquifer test related draw-downs were observed in the other two monitored wells (see Figure 1):

- Trails End Well (Minnesota Unique Number 00263147) is located about 1,700 feet west of the Zavoral Site Well; and
- Magnuson Well (owned by Mr. Roger Magnuson, Minnesota Unique Number 00154397), located about 1,900 feet west-northwest of the Zavoral Site Well.

The lack of drawdown in those wells indicates that the St. Lawrence Formation, which is separating the shallow aquifers (Drift and Prairie du Chien – Jordan) and the Franconia-Ironton-Galesville Aquifer, acts as an effective aquitard.

5.5 Goal 5 – Potential Impacts on Groundwater-dependent Resources

Monitoring Water Levels in Creeks

Collected data shows that in late June/early July of 2010 (a period of time around the aquifer test), water levels fluctuated in the monitored creeks within a few centimeters. As Figure 3 demonstrates, changes in stage in all the monitored creeks were highly synchronous, with water levels rising following the aquifer test.

St. Croix Discharge Data

According to the USGS data, the St. Croix River's average daily discharge at St. Croix, Wisconsin on the day of aquifer test (June 29, 2010) was 5,770 cubic feet per second (cfs) (USGS 05340500 St. Croix River at St. Croix Falls, Wisconsin, about 14 miles upriver from the Zavoral Site.

This river discharge is about 3,900 times larger than the average pumping rate during the test (1.47 cfs). The record of average daily discharge rates shows a distinct decreasing trend - on June 24, 2010 the discharge was 7,310 cfs and from that day on, the average daily discharge kept decreasing every day to a value of 3,340 cfs on July 5, 2010. This decreasing trend coincides with the declining stage as captured by the very limited number of stage measurements taken on the River below the Zavoral Cabin during the days before and after the aquifer test.

Zavoral Creek Water Discharge Measurements

Floater Method Measurements

The following are the results of "floater method" measurements are following:

Date	Measurements (Number of)	Water depth of Water in Culvert	Floater travel Time	Calculated Q
12/07/2009	6	0.109 ft	4.44 sec	157 gpm (0.35 cfs)
6/29/2010	5	0.125 ft	4.75 sec	197 gpm (0.44 cfs)
6/30/2010	5	0.125 ft	4.72 sec.	181 gpm (0.41 cfs)

The calculated discharges (Q) were adjusted because surface velocities are typically higher than mean or average velocities. The equation$V_{mean} = k\ V_{surface}$ defines this adjustment where k is a coefficient that generally ranges from 0.8 for rough beds to 0.9 for smooth beds (0.85 is a commonly used value – see: Stream Discharge using the Float Method

http://www.fs.fed.us/ARMdata/PDFfiles/floatmethod.doc).

With the k coefficient (= 0.85) adjusted discharges are:

Date	**Calculated Discharge**
12/07/2009	134 gpm (0.30 cfs)
6/29/2010	168 gpm (0.37 cfs)
6/30/2010	154 gpm (0.34 cfs)

On December 7, 2009 the Zavoral Creek water entered the culvert at higher velocity than the velocity at which it was leaving it. That was because of the presence of a "mini-waterfall" at the entrance to the culvert. Consequently, the floaters (table tennis balls were used as floaters) placed just below the entrance point to the culvert assumed a speed that was likely somewhat higher than the average velocity of water in the culvert – the floaters were accelerated below the fall and there was not enough friction to slow them to the velocity of water near the outlet of culvert. Thus, the floater measurements made on December 7, 2009, likely overestimate the actual flow rate.

Bucket Measurements

The following are the results of "the bucket fill-up time" measurements:

Date	**Number of Measurements**	**Average fill-up time**	**Calculated Q**
12/07/2009	9	2.80 sec.	107 gpm (0.24 cfs)
6/29/2010	8	2.69 sec.	112 gpm (0.25 cfs)
6/30/2010	8	2.39 sec.	126 gpm (0.28 cfs)

Since, during each of the measuring events it was estimated that the bucket was capturing only about 90% of the flow, the result obtained by the "bucket fill-up time" were multiplied by a factor of 1 over 0.9. The resulting discharge rates are:

Date	Calculated Discharge
12/07/2009	119 gpm (0.27 cfs)
6/29/2010	124 gpm (0.28 cfs)
6/30/2010	140 gpm (0.31 cfs)

Measuring Discharge at the Upstream Waterfall

Discharge at the waterfall in the upper reach of Zavoral Creek was measured using a 5-gallon bucket. This measurement was very approximate as the bucket was capturing only about 1/3rd of the water falling. It took 65 seconds to fill-up the bucket. The calculated discharge rate was 14 gpm (or 0.03 cfs). This represents about 10 percent of flow measured at the culvert downstream. Such significant measured increase of flow in the downstream direction along the Creek demonstrates that

the Creek is fed by groundwater seeps (Black ash swamp seepage subtype wetland) emerging at numerous places from the bluffs along the Creek in the ravine. Many of the seeps were easily visible on December 7, 2009, as they were marked by ice covers. The observed ice covers were starting at the top of the outcropping bedrock. None of them were starting in the middle of outcropping bedrock face, except the uppermost waterfall that emerges from the middle of the rock face – Crystal Springs. These observations indicate that much of the water in the Creek represents shallow groundwater migrating at the top of bedrock strata.

Estimated Discharge in Middle Creek

No discharge measurements were carried out for Middle Creek. However, during several site visits to the Zavoral Site AECOM staff estimated that discharge of Middle Creek (below the point where the two of its branches merge) is similar to discharge from Zavoral Creek.

Summary and Discussion

Given that the "float method" is a very approximate method, the results obtained by the "bucket fill-up time" method are judged to be more reliable because it is a direct measurement method.

The lower discharge values for December 7, 2009, compared to the June 2010 measurements are consistent with the fact that the December measurement was made at the end of a dry period. The June 2010 measurements were made a few days after a significant storm. Recharge caused by this storm likely caused an increase in shallow groundwater levels observed in the Trail's End Well located about 3,000 feet west of the culvert at Zavoral Creek.

The discharge measured on December 7, 2009 likely represents almost entirely base flow – all water flowing in the Creek was groundwater (defined as water below regional water table) that discharged directly to the Creek, or discharged to ground surface a short distance before reaching the Creek. During several days preceding the measurements, temperatures were consistently well below freezing point. Such weather conditions practically eliminate overland flow.

It is important to point out that discharge measured in June 2010 also represents mostly base flow, with a possibility of some contribution from a delayed discharge of interflow (water migrating horizontally or close to horizontally below ground surface but above the regional water table). The upper portion of the Zavoral Creek ravine, above Crystal Springs, was dry. The variations in discharge are likely caused by varying levels of shallow groundwater which is apparently a predominant source of water flowing into Zavoral Creek, except during and after significant precipitation events and periods of snow melt.

Although AECOM did not conduct quantitative measurements of water discharge in Zavoral Creek during the September 1, 2009 site visit, the discharge observed at that time was notably lower that on December 7, 2009. This is likely because September of 2009 was a dry period, while precipitation events took place during several weeks prior to December 7, 2009 and before the onset of below freezing point temperatures. Such precipitation events likely resulted in a groundwater recharge. Such recharge likely elevated shallow groundwater levels and, consequently, increased seeping rates along the ravine bluffs of Zavoral Creek.

Monitoring Water Level in the on-site, Depression South of the Zavoral Site Well

The monitoring of water level in the on-site, depression south of the Zavoral Site Well indicates that the pumped water was seeping through the bottom of the depression at a relatively constant and slow rate – approximately 15 gpm.

Precipitation Data

Daily precipitation data obtained for two gaging stations (Forest Lake gauging station located about 10 miles west of the Zavoral Site and Swedish Flag Creek gauging station located a few miles south of the Zavoral Site) showed a somewhat different pattern of precipitation for a period of time from May 25 through July 2, 2010 (Figure 4). During that period of 39 days, Forest Lake station recorded 19 days with precipitation (maximum daily precipitation of 35 mm on June 27, 2010), while Swedish Creek station recorded 20 days with precipitation (maximum daily precipitation of 23 mm on June 25, 2010). Inspection of Figure 4 reveals that precipitation at Swedish Creek often varies from precipitation recorded at Forest Lake.

Estimating Groundwater Fluxes Across the Zavoral Site

Table 1 presents a summary of groundwater and surface water balance and flow rate calculations. The top portion of the table presents the results of Zavoral Creek discharge measurements. The average discharge is calculated to be 134 gpm, or 730 m^3/day, or 0.30 cfs.

The middle portion of that table presents the rates of groundwater discharge into St. Croix River as simulated by the Metro Model – Northwestern Province for layers 1, 2 and 3, and Lower Aquifer Model for layers 4 and 5. The discharge is presented in units of m^3per day per meter of St. Croix River and m^3per day per the width of Zavoral Site along the River. The simulated daily discharges from each model layer representing different aquifers are compared to the maximum daily groundwater production from the Zavoral Site Well (in the rightmost column of the table). Thus, it is calculated that the maximum daily groundwater production from the Zavoral Site Well represents about 0.70 percent of groundwater moving through the Zavoral Site and discharging to the River.

The lower portion of the table presents the results of various surface water/groundwater mass balance calculations that are useful for evaluation of the Zavoral Site conditions. These calculations show that the maximum daily groundwater production from the Zavoral Site Well represents about 2.6 percent of an average combined discharge from the Zavoral and Middle Creeks

6.0 Impact Analysis

6.1 Goal 4 – Potential Impacts of Pumping from Zavoral Site Well

The June 29, 2010 aquifer test of the Zavoral Site Well pumped at an average rate of 664 gpm. Pumping at that rate would produce 10,000 gallons (the daily limit of groundwater production) in approximately 15 minutes. During the test, after 15 minutes of pumping, water level in the Zavoral Cabin Well dropped 0.25 feet. This drop represents 1/800th of the total water column present in that well. Even if the water level does not completely recover in a day, the cumulative draw down over a number of days is likely to be negligible. Inspection of Figure 1 shows that the water level mostly recovered within 24 hours after the completion of a 4 hour and 20 minute aquifer test – this test pumped 17 times more water than the 10,000 gallons daily limit (to be observed during Zavoral Mine operations) and produced a 3.5 foot draw down, which represents less than 1/50th of the total water column in the Zavoral Cabin Well.

The Zavoral Cabin Well is the closest well to the Zavoral Site Well among the Franconia Aquifer wells in the area. Draw-downs in other wells in the area would most likely be smaller than in the Zavoral Cabin Well. Water levels measured in other monitored wells, Trail's End and Magnuson, did not respond to pumping from the Zavoral Site Well. During the aquifer test, water level in the Magnuson Well was increasing, instead of decreasing, while water level in the Trail's End Well was apparently responding to factors not related to pumping the Zavoral Site Well. Hydrographs presented on Figure 1 indicate that the shallow aquifers (in which the wells further away from the St. Croix River wells are completed) are not well connected to the Franconia Aquifer (in which the Zavoral Site Well is completed).

Inspection of the contents of Figure 4 illustrates that the daily water level fluctuations in the Trail's End Well (on the order of close to one foot) are loosely correlated with precipitation pattern and respond to some other factors that are not identified. These other factors might be diurnal cycle of evapotranspiration affecting water levels of the shallow aquifer, or daily cycle of pumping from other nearby shallow wells.

Groundwater balance estimations summarized in Table 1 indicate that pumping the Zavoral Site Well at a daily limit of 10,000 gallons represents about 0.7 percent of groundwater flow rate across the Zavoral Site.

The data and calculations presented in this report clearly indicate that pumping from the Zavoral Site Well at a daily limit of 10,000 gallons would only minimally affect groundwater resources around the Zavoral Site and that any potential impacts are likely to be insignificant.

6.2 Goal 5 – Potential Impacts on Groundwater-dependent Resources

Surface water monitoring conducted in late June through the beginning of July 2010, at several points documented water level fluctuations on the order of a few centimeters. As Figure 3 illustrates, water levels were increasing on the day of aquifer test, June 29, throughout the day. No discernable change in that increasing trend could be linked to pumping from the Zavoral Site Well. The increase was possibly a delayed effect of a significant precipitation event recorded at the Forest Lake gauging station two days before the aquifer test (Figure 4).

Groundwater level data indicate that the shallow aquifers (Drift and Prairie du Chien – Jordan) are likely not well hydraulically connected with the deeper Franconia aquifer in which the Zavoral Site Well is completed (see Figure 1). If the creeks were fed mainly by groundwater discharge from the deep aquifer, pumping from the Zavoral Site Well should have lowered water level in the creeks. However, water levels in the creek were increasing.

Measurements of discharge from Zavoral Creek indicate that this Creek is fed mainly by groundwater discharge from shallow aquifers (see discussion in Section 5.5). However, since the pumped Franconia aquifer is not well hydraulically connected to the shallow aquifers, pumping from the Zavoral Site Well should not have caused lowering of water levels in the creeks – and that is what was observed.

Increasing of water levels in the creeks on the day of aquifer test linked to infiltration from the Discharge Pond (into which the water pumped from the Zavoral Site Well was discharged) was also considered. As Figure 5 illustrates, water level in that Pond was systematically dropping after the aquifer test. However three observations can be enumerated which indicate that infiltration of water through the bottom of the Discharge Pond was not causing increase in water levels in the creeks:

- First, it has been estimated that the rate of water infiltration through the bottom of the Discharge Pond was about 15 gpm – this is about 5% of the combined discharge from the Zavoral and Middle Creeks, which are the closest creeks to the Pond.
- The trend of water level increase in the creeks started before the aquifer test started.
- And finally, water level increases were similar in different creeks, regardless of the distance to the Pond, especially in a distant Spring Box Creek considered a background monitoring point.

The data collected near the Zavoral Cabin indicate that the St. Croix River's stage decreased about 0.2 feet during the aquifer test (see Figure 6). The following discussion evaluates the likelihood that such stage drop might have been caused by pumping from the Zavoral Site Well.

According to the USGS data, the St. Croix River's average daily discharge at St. Croix, Wisconsin on the day of aquifer test (June 29, 2010) was 5,770 cfs (USGS Gaging Station 05340500 St. Croix River at St. Croix Falls, Wisconsin, Located about 14 miles upriver from the Zavoral Site).

This river discharge is about 3,900 times larger than the average pumping rate during the test (1.47 cfs). The record of average daily discharge rates shows a distinct decreasing trend - on June 24, 2010 the discharge was 7,310 cfs and from that day on, the average daily discharge kept decreasing every day to a value of 3,340 cfs on July 5, 2010. This decreasing trend coincides with the declining stage as captured by the very limited number of stage measurements taken on the River below the Zavoral Cabin during the days before and after the aquifer test.

The River stage dropped by about 0.2 of a foot during the aquifer test . Assuming average depth of the River of about ten feet, the drop of 0.2 of a foot represents 1/50th of the River's depth. If we compare this ratio to the ratio of the River's discharge vs. pumping rate, 1/3900th, it is clear that, even if the Zavoral Site Well were pumping water directly from the River, the drop in River stage should have been about 78 times smaller than the measured drop – about 0.003 of a foot (Table 2).

But the much higher water level in the Zavoral Cabin Well compared to the River stage indicates that the pumped aquifers (Franconia and Mt. Simon-Hinkely) are separated from the River by aquitards that diminish interaction between these deep aquifers and the River.

Just prior to the initiation of the aquifer test, water level in the Zavoral Cabin Well was measured to be 37.55 feet higher than the River stage. At the end of the test that difference dropped to 34.05 feet. This large water level difference indicates a strong upward gradient that is driving groundwater discharge into the River. That upward gradient was only slightly decreased as a result of the aquifer test.

The estimated discharge from the deeper aquifers, in which the Zavoral Site Well is completed, to the River is about 850 m^3/day or about 0.33 cfs (see Table 1). That discharge only slightly declined as a result of a small decrease in the vertical upward gradient caused by a long pumping from the Zavoral Site Well. Thus, the groundwater discharge from the deeper aquifers to the River across the Zavoral Site is a very minor contributor to the River's discharge. The River's discharge would not have changed in any measurable way, even if the aquifer discharge to the River was stopped altogether, as a result of aquifer test. For that to occur, the water level measured in the Zavoral Cabin Well at the end of aquifer test would have to be the same as the River stage (and the difference between the River stage and water level in that well changed only 9.3%.

Finally, even if the four hour and twenty minute pumping from the Zavoral Site Well had by any chance resulted in measurable water level impacts, these would not occur with the planned up-to-15 minute long pumping that is limited by a 10,000 gpm daily limit.

The results of these calculations allow a conclusion that the June 29, 2010 aquifer test could not have affected the flow of water in the River in any significant way.

The collected data and the presented above discussion lead to a conclusion that pumping up to 10,000 gpd from the Zavoral Site Well would not have a significant impact the groundwater-dependent resources at and around the Zavoral Site in any significant way.

7.0 Potential Mitigation

No mitigation measures are proposed because no anticipated significant impacts are expected to occur due to the proposed groundwater pumping. The following monitoring to be funded by Tiller is recommended.

- Tiller should keep records of when the Zavoral Site Well is pumped, and provide these to the City for groundwater monitoring activities. This should document both the daily use and total annual pumped volume from the Zavoral Site Well. The daily total should not exceed 10,000 gallons at a maximum pumping rate of 1,200 gpm. The total annual pumping should not exceed 1mgy.
- The WCD monitoring point installed for the pump test and collection of baseline data in Zavoral Creek should be monitored during the lifetime of the Project.
- The Black ash seepage subtype wetland boundary mapped by CCES (CCES January 2010) established the baseline boundary of the seep along Zavoral ravine. This should be monitored during the life of the Project.

8.0 References

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Tables

Table 1 - Water Balance Calculations

Measured Zavoral Creek Discharge			
	Q		
Baseflow measurements:	gpm	m^3/day	cfs
Date			
November 2003 (baseflow) [1]	153	832	0.34
November 2003 (bamkfull) [1]	1831	9982	4.08
December 7, 2009 (AECOM measurement)	119	649	0.27
June 29, 2010 (AECOM measurement)	124	676	0.28
June 30, 2010 (AECOM measurement)	140	763	0.31
Average (bankfull data event not included in calculation):	**134**	**730**	**0.30**

Daily discharge limit for Zavoral Site Well:	10000	gallons per day
	37.85	m^3/day
	5%	% disccharge from Zavoral Creek in Dec 2009
Width of Zavoral Site:	600	m

Metro Model - Northeast Province			
Simulated discharge to St. Croix River	Q		
	m^3/day/m	m^3/day/Zavoral Site	Q Zavoral Well / GW Discharge
Layer 1	3.91	2346	2%
Layer 2	1	600	6%
Layer 3	2.62	1572	2%
Tot. Layers 1, 2 and 3	7.53	4518	**0.84%**
Metro Model - Lower Aquifer Model			
Simulated discharge to St. Croix River	Q		
	m^3/day/m	m^3/day/Zavoral Site	
Layer 4	0.69	414	9%
Layer 5	0.73	438	9%
Tot. Layers 4 & 5	1.42	852	**4.44%**
Discharge from all Layers 1 through 5:	**8.95**	**5370**	**0.70%**

Estimated Q from both Zavoral and Middle Creeks:	**1460**	**m^3/day**
Maximum daily discharge from Zavoral site well vs. daily discharge from both Zavoral and Middle Creeks:	**2.6%**	
Groundwater use per household in City of Scandia:	**274**	**gpd/household**
Lawn sprinkling use per houshold in City of Scandia:	**206**	**gpd/household**
Total water use per household in City of Scandia:	**480**	**gpd/household**
Maximum daily groundwater production from Zavoral Site Well vs water use per household:	**21**	**households**

Notes:

[1] - Source for 2003 data: Lower St. Croix River Spring Creek Stewardship Plan (2003)

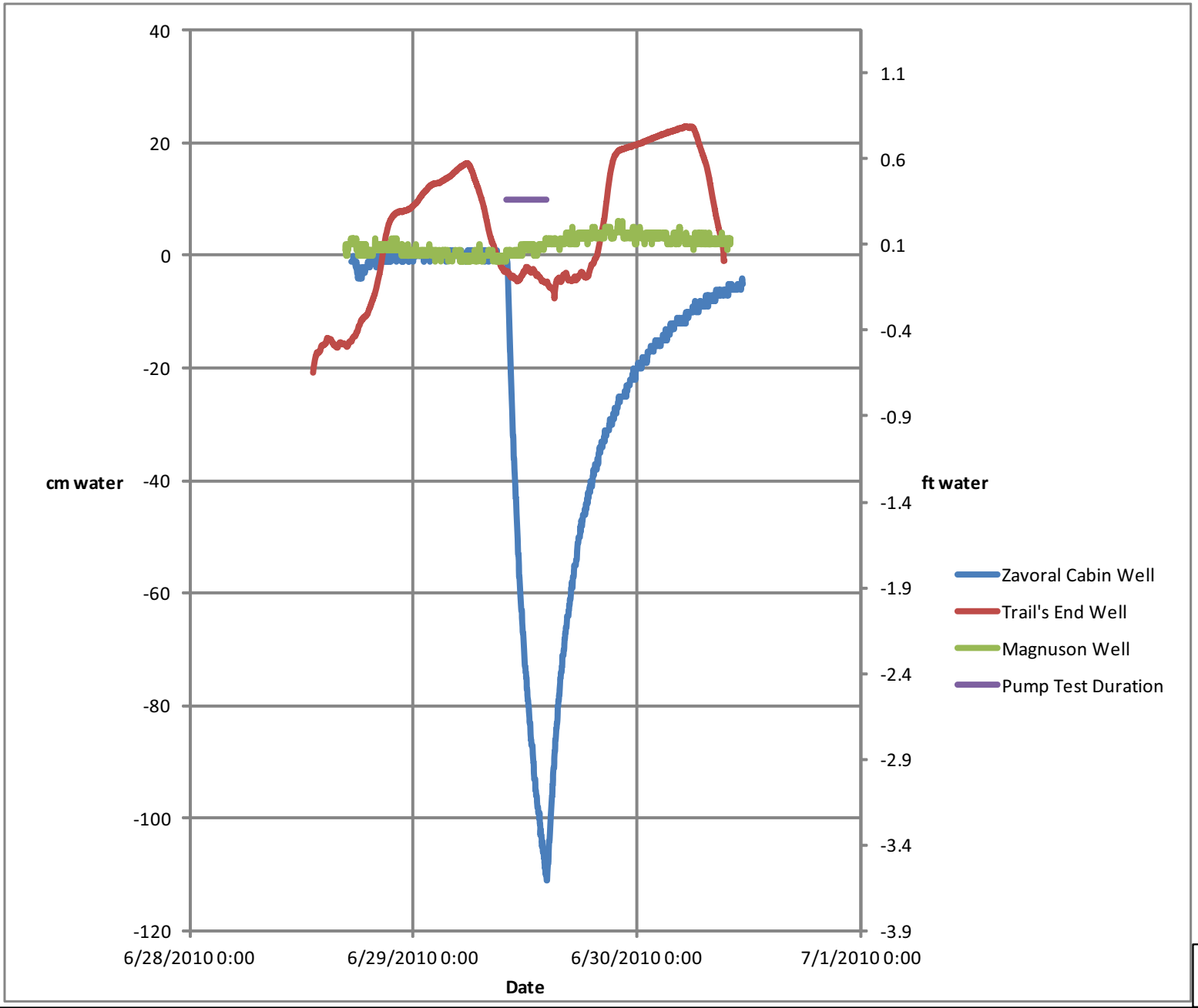
Table 2 - Comparison of St. Croix River and Zavoral Site Well Discharges

St. Croix River flow on a day of pump test [1]:	5,770	cfs
	2,590,038	gpm
Zavoral Pump Test Rate:	1.47	cfs
Zavoral Pump Test Rate:	660	gpm
Ratio of Zavoral Site Well's and St. Croix River's Discharges	0.03%	(Q Well / Q River) x 100
If the River is 10 ft deep pumping Zavoral Site Well would decrease the River's depth by:	0.003	ft
Drop in river stage observed during pump test	0.2	ft
The observed drop in River stage during pump test is:	78	times larger than what pumping Zavoral Site Well could cause

Notes:

[1] - Discharge reported for USGS 05340500 ST. CROIX RIVER AT ST. CROIX FALLS, WI, for June 29, 2010

Figures



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Prepared By:

AECOM

Prepared For:

SCANDIA minnesota

ZAVORAL MINING AND RECLAMATION PROJECT
SCANDIA, MINNESOTA

FIGURE 1
HYDROGRAPH OF ALL MONITORING WELLS

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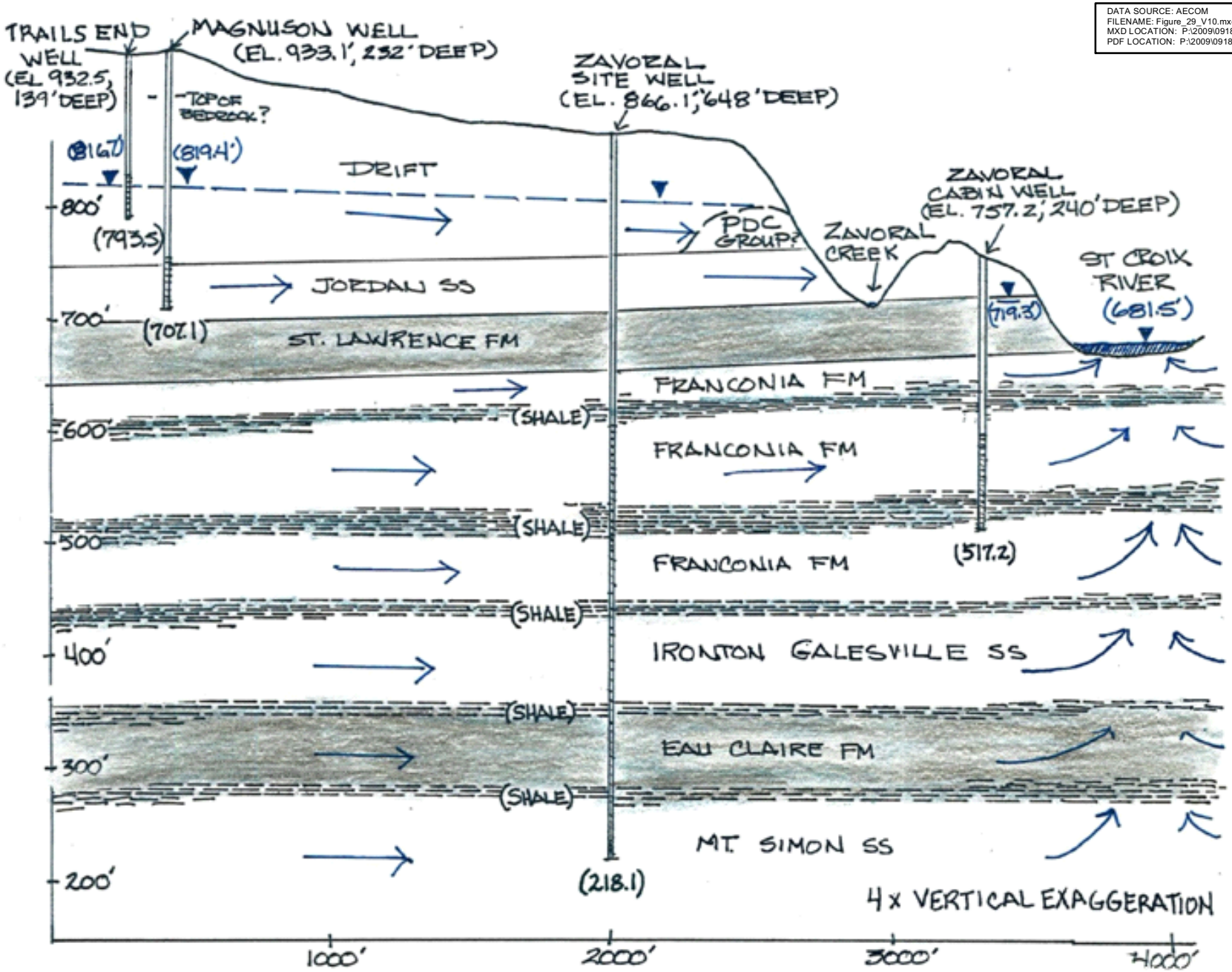

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FIGURE 2
AREA SCHEMATIC CROSS-SECTION

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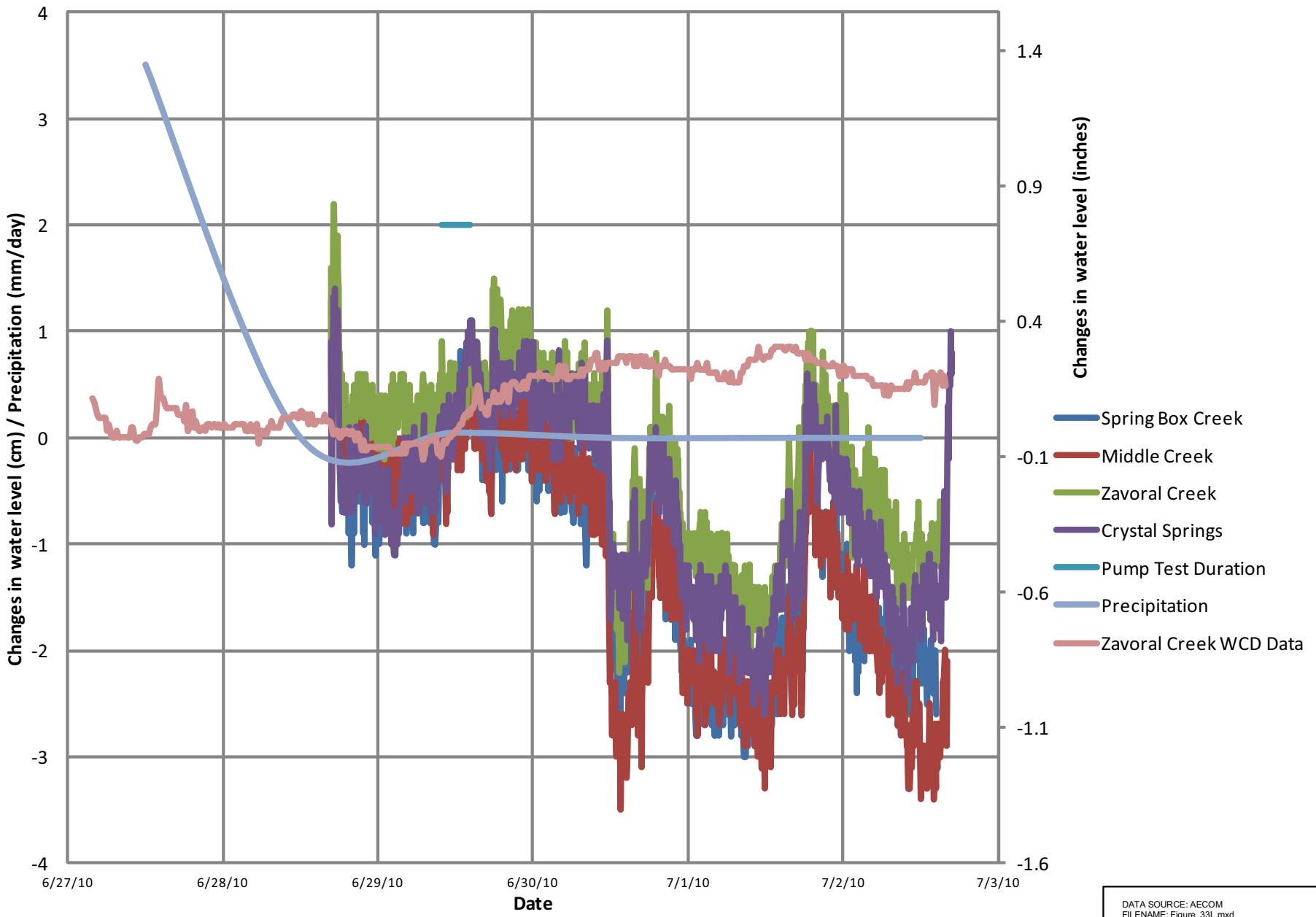

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FIGURE 3
WATER LEVEL CHANGES AT ALL SURFACE WATER POINTS

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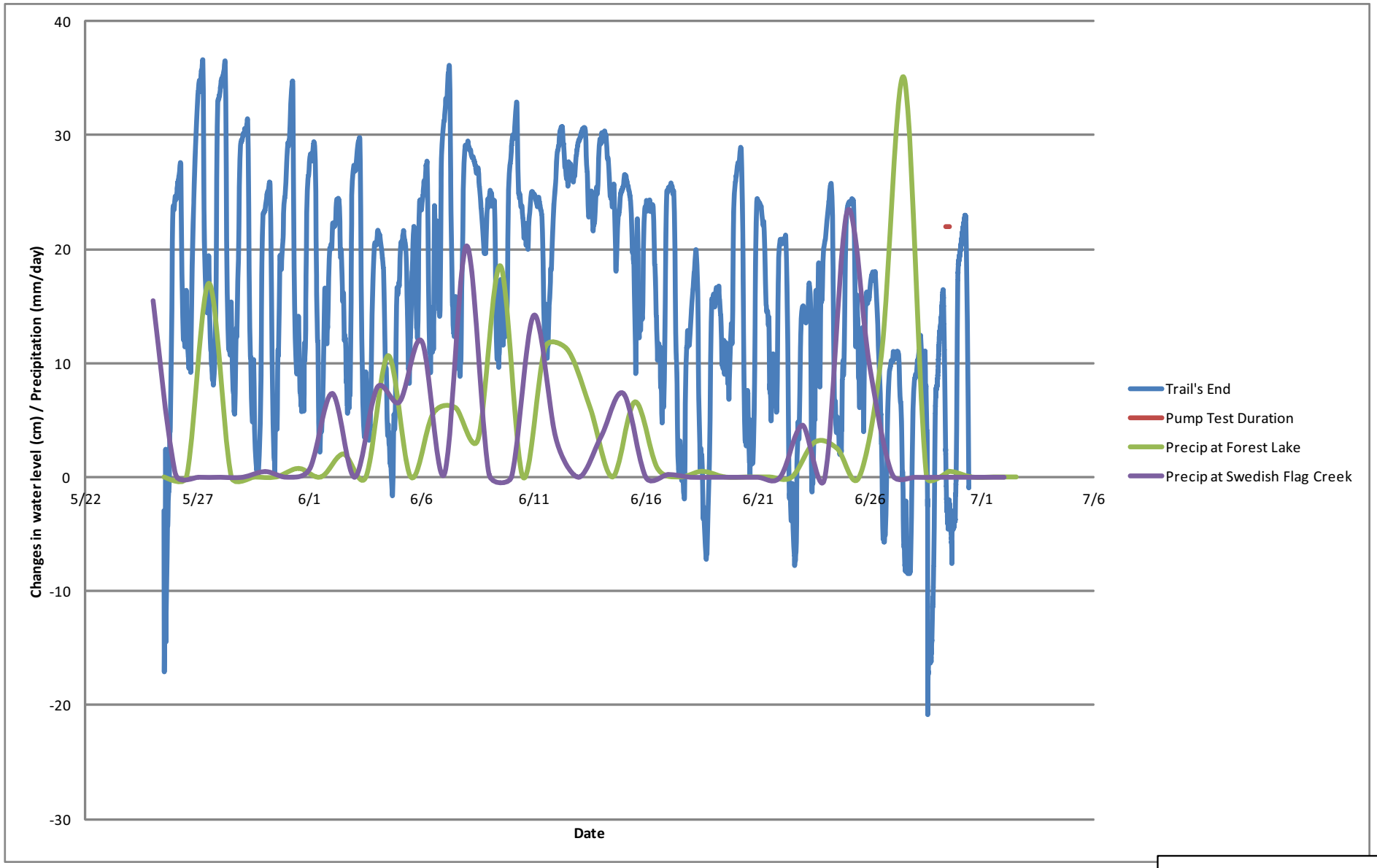

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FIGURE 4
HYDROGRAPH OF TRAILS END WELL VS. PRECIPITATION

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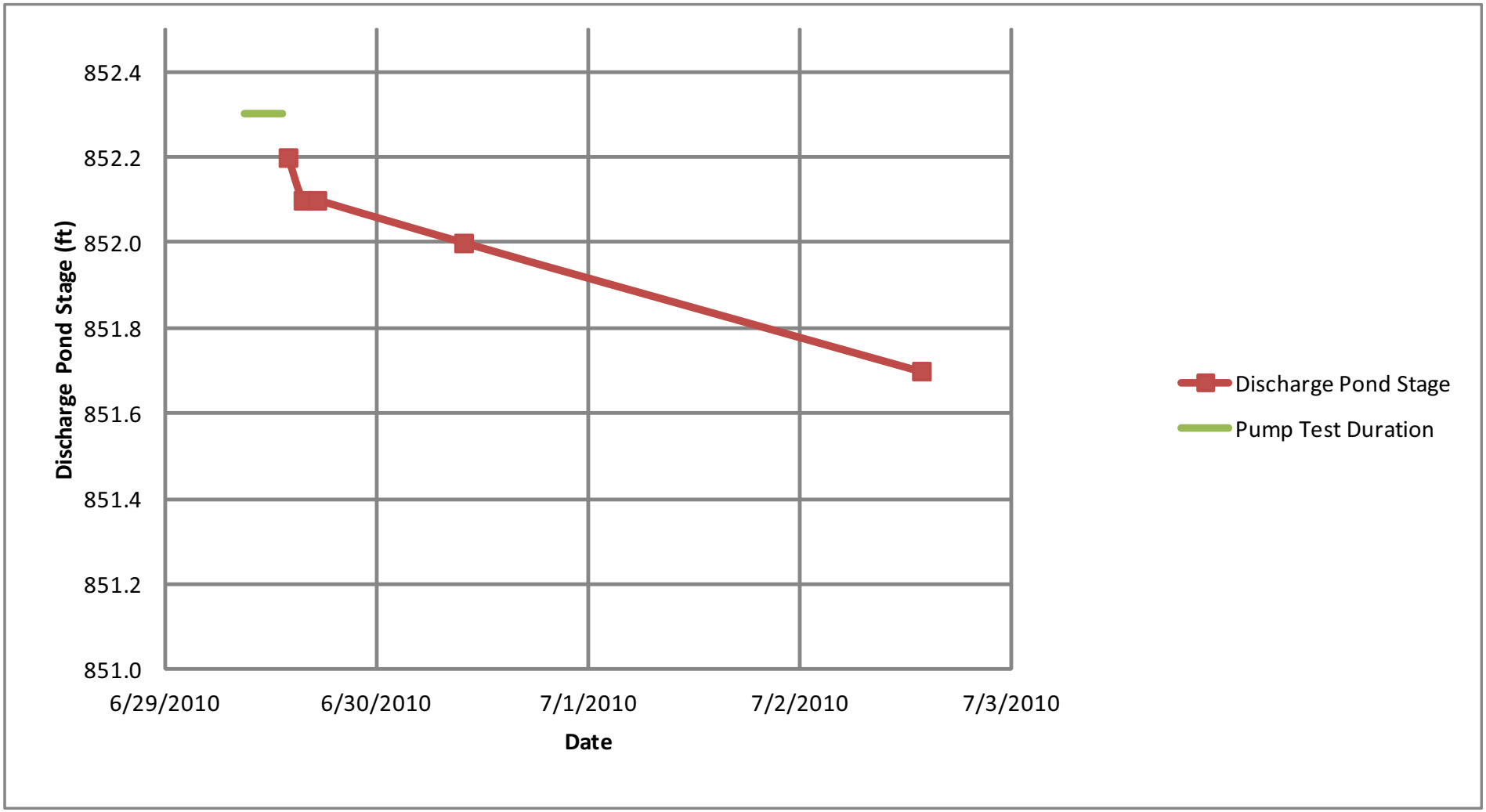

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FIGURE 5
DISCHARGE POND STAGE

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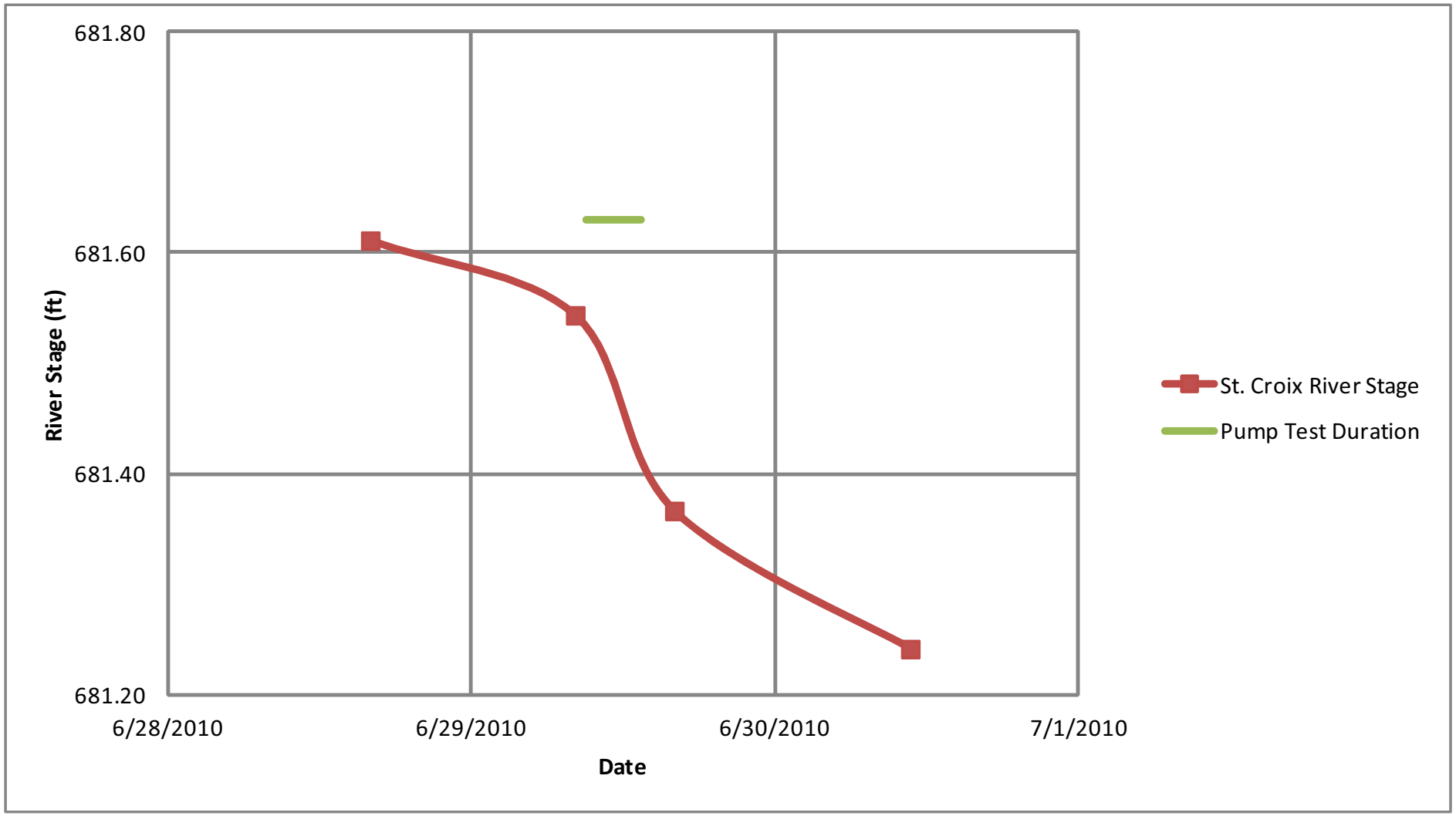

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Prepared For: SCANDIA minnesota

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FIGURE 6
ST. CROIX RIVER STAGE
NEAR ZAVORAL CABIN

Feb. 2012

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