Phase I Feasibility Analysis: Use of Coagulant for Phosphorus Treatment at Starkweather Creek, Madison WI

Prepared for
City of Madison
Madison, WI

March 31, 2016

Revised December 10, 2018

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[Project 147143]

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The Brown and Caldwell project team members include:

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- Jeff Herr; Senior Technical Advisor
- Caroline Burger; Project Manager, Modeling Task Leader
- Kelly Mattfield; Sr. Engineer; FEMA Modeling Task Leader
- Mike Wegner; Sr. Engineer; Design Task Leader
- Erin Holloway; Administrative Assistant/Editor

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Table of Contents

List of Figures

List of Tables

List of Abbreviations

ACH	Aluminum Chlorohydrate
Al	Aluminum
BC	Brown and Caldwell
cfs	cubic feet per second (~ 450 gallons per minute)
CMP	Corrugated Metal Pipe
FEMA	Federal Emergency Management Administration
gpm	gallons per minute
LA	Load Allocation
LOMR	Letter of Map Revision
MS4	Municipal Separate Storm Sewer System
PAH	Polyaluminum Chloride
TMDL	Total Maximum Daily Load
TP	Total Phosphorus
TSS	Total Suspended Solids
USACE	United Stated Army Corps of Engineers
USGS	United States Geologic Survey
WDNR	Wisconsin Department of Natural Resources
WLA	Waste Load Allocation
WPDES	Wisconsin Pollutant Discharge Elimination System

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Section 1

Introduction

1.1 Project Purpose

The City of Madison (City), Wisconsin is a MS4 Phase I stormwater permittee. As of February, 2016, the permit is under revision by the Wisconsin Department of Natural Resources (WDNR) to include more specific requirements, including a numeric target for annual total phosphorus (TP) and total suspended solids (TSS) load reductions from the City's MS4 system. The proposed pollutant load reductions are based on the Rock River TMDL (WDNR, 2011). On a citywide basis, the targeted TP reduction is approximately 50 percent based on current land use and management conditions. Technologies beyond traditional stormwater management measures will likely be required to achieve the targeted TP reductions. This is especially true when stormwater treatment life cycle costs are considered.

The purpose of this project is to evaluate the practicality and cost effectiveness of coagulant treatment of stormwater to achieve enhanced TP reduction. Coagulant treatment of wastewater has been in use for many decades, and the use of coagulants for stormwater treatment has been applied in the southeastern US since the late 1980s (Herr, 2009). The use of this technology in northern climates is relatively untested.

Coagulant treatment involves adding a reactive flocculent to water to form precipitates which trap phosphorus and other pollutants. The addition of chemical coagulants, such as liquid aluminum compounds, to stormwater forms precipitates of aluminum hydroxide and aluminum phosphate. Particulate pollutants including suspended solids, particulate phosphorus and bacteria are trapped within an aluminum hydroxide precipitate. Also dissolved phosphorus by reaction is bound within an aluminum phosphate precipitate. When the precipitate (floc) is allowed to settle, the pollutants remain bound and unavailable to the water environment.

If the City concludes that coagulant treatment is feasible and cost effective at the project site, the City intends to move forward with design and implementation.

1.2 Project Concept

The coagulant stormwater treatment concept consists of the following primary components:

1. Divert wet-weather flows from an urban stream off-line for treatment while maintaining a minimum "baseflow" in the stream at all times
2. Add a coagulant to the diverted water on a flow-proportionate at an offline location.
3. Allow thorough mixing of the coagulant with the diverted water
4. Allow the precipitates or floc (containing phosphorus, sediment and other pollutants) to settle out in an offline pond
5. Return the treated water to the stream

1.3 Project Site and Study Area

1.3.1 Watershed Description

The project site and study area encompasses nearly all of the East Branch of the Starkweather Creek watershed. The watershed is located on the east side of the City of Madison and includes portions of the City of Madison and the Town of Blooming Grove (see Figure 1-1). The contributing watershed at the project site is approximately 5,500 acres; a breakdown of the watershed's land use is provided in Table 1-1.

Table 1-1. East Fork Starkweather Creek Watershed Land Use; Starkweather Creek Phosphorus Treatment Phase I Study

Land Use	Area (acres)	Percent
Commercial	699	13
Industrial	318	6
Institutional / Government	104	2
Residential	1,126	20
Transportation / Utilities	1,125	20
Parks & Recreation	399	7
Agricultural	645	12
Open Space & Water	1,099	20
Total	**5,515**	**100**

The drainage system within the watershed includes a mix of storm sewers and open-channel drainage-ways. These drainage systems discharge to the East Branch of Starkweather Creek at numerous locations. The East Branch meets the West Branch of Starkweather Creek approximately 0.6 miles downstream of the proposed project site (see Section 1.3.2) to create the main branch of Starkweather Creek which ultimately discharges into Lake Monona.

1.3.2 Project Site Description

The project site under consideration for the coagulant treatment system is shown on Figure 1-2. The land is currently privately owned, and is the site of a former sand and gravel quarry. This location was identified by City staff based on the following factors:

1. The drainage area to the site encompasses 5,415 acres with an urban / rural land use mix
2. There is existing open space available for the construction of the treatment system
3. There is an existing quarry pond which has the potential to serve as a floc settling basin
4. Preliminary public acceptance of the project's location

The potential project location also presents several constraints and challenges including: existing mapped floodway/floodplain dominating the site; relatively low hydraulic head in the channel; and the indication of wetlands at the site.

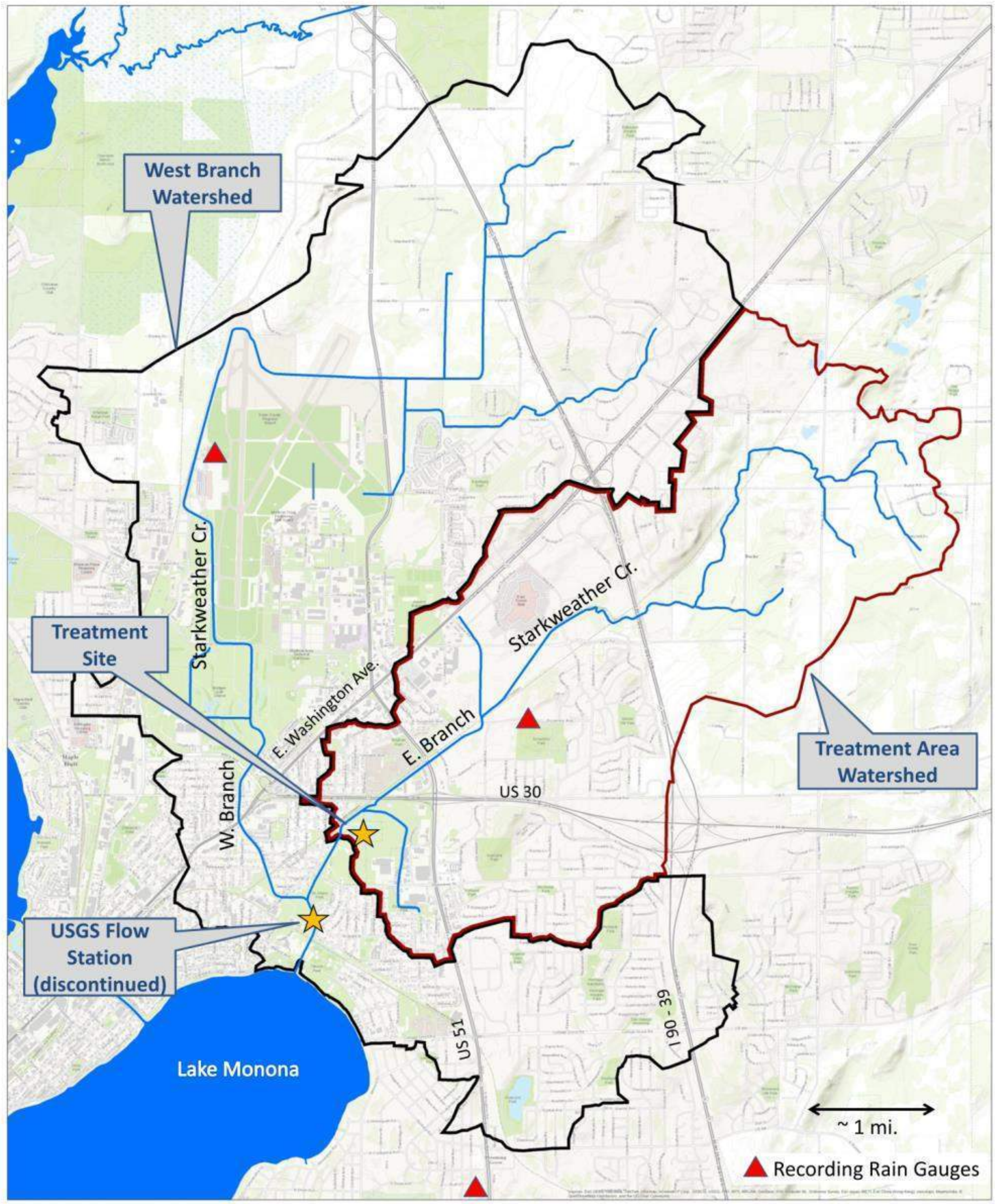

Figure 1-1. Location of East Branch Starkweather Creek Watershed, Madison, WI;
Starkweather Creek Phosphorus Treatment Phase I Study

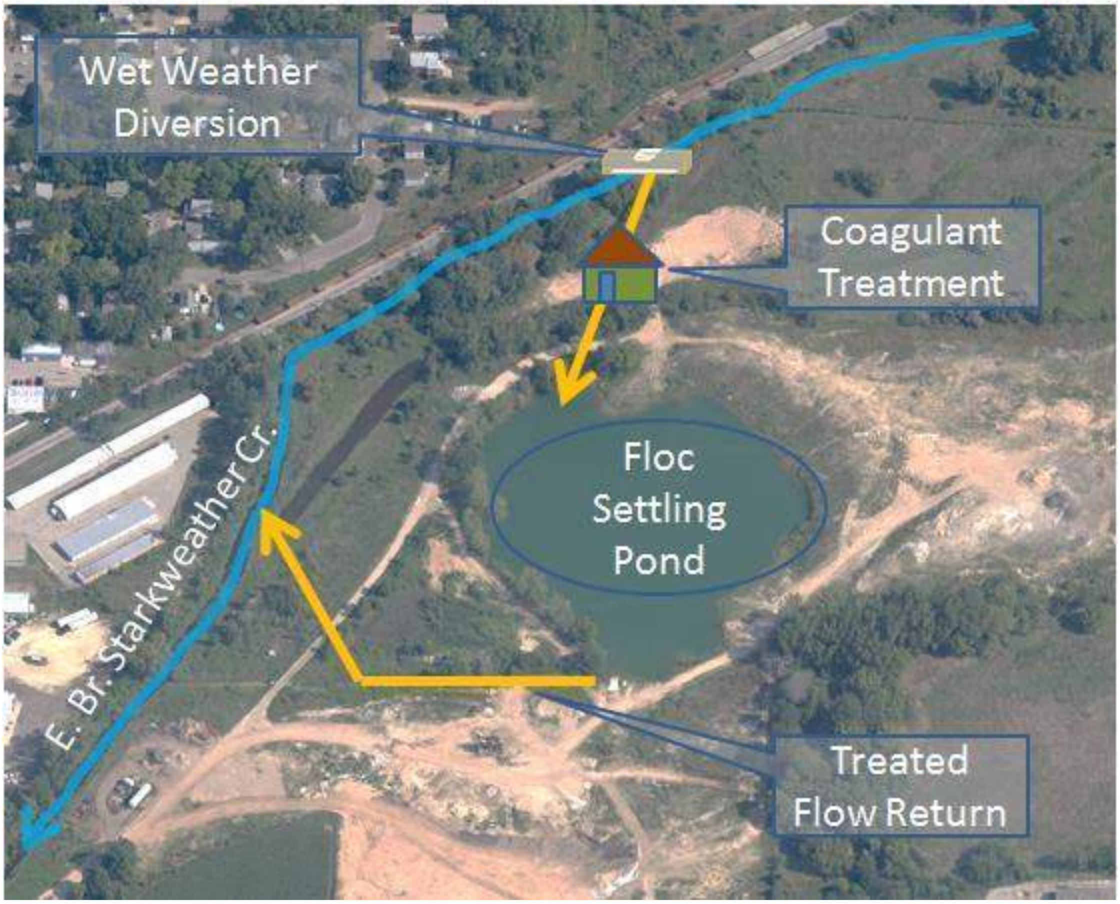

Figure 1-2. Project Site with Treatment Features

Starkweather Creek Phosphorus Treatment Phase I Study

1.4 Phase I Feasibility Study Tasks

The main tasks conducted under Phase I of the project are summarized below. Subsequent sections of this document provide a more detailed description of the methodology, results, and conclusions of each task.

1.4.1 Task 1: Project Site Floodplain Re-Mapping

The existing Federal Emergency Management Agency (FEMA) maps (Dane County, Wisconsin National Flood Insurance Program Flood Insurance Rate Map, September 17, 2014) show floodplain and floodway boundaries within the project site. The FEMA maps were developed with topographic, land use, and channel information available at the time of the mapping. A Letter of Map Revision (LOMR) was prepared for the project site incorporating updated information including:

1. Detailed one foot topographic survey of the project site conducted by the City of Madison in 2014
2. The addition of an abandoned railroad culvert on the project site that was not included in the previous floodplain modeling
3. A reconstructed bridge crossing at Milwaukee Street (reconstructed in 2015)

A description of the floodplain re-mapping process conducted during Phase I is provided in Section 2.

1.4.2 Task 2: Coagulant Jar Testing and Quarry Pond Monitoring

To better understand the effectiveness of coagulant treatment to remove phosphorus from wet weather discharges in Starkweather Creek, six rounds of wet weather sample collection and jar testing were conducted in 2015. The testing evaluated five different coagulant compounds at different concentrations of Aluminum (Al).

The methodology and results of the coagulant testing conducted under this study are included in Section 3.

1.4.3 Task 3: Watershed Hydrologic and Hydraulic Watershed Modeling

The watershed and drainage system contributing runoff to the project site was modeled. The purpose of the modeling was to assess predicted peak flow and runoff volume to the project site under a series of design rain events, and under continuous simulation of ten years of locally measured rainfall. The modeling results were used to estimate: 1) runoff flowrate and volume at the project site for treatment purposes, and 2) residence time of the existing quarry pond (for floc settling purposes) under various flowrate conditions.

Section 4 includes the methodology, assumptions, results, and limitations of the computer modeling conducted under this study. Also included in Section 4 are estimates of the annual runoff volume that could be treated and the corresponding annual TP load reductions.

1.4.4 Task 4: Feasibility Level Design of Treatment System

The final task conducted under Phase I included the preparation of design concepts for the flow diversion structure, conveyance channel, coagulant treatment system, settling basin, equipment/instrumentation, and the pond inlet/outlet structures. This task also included developing planning level cost estimates for construction of the treatment system.

Section 4 reports the assumptions, limitations, conceptual design, and planning level cost estimates for the proposed project.

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Section 2

Project Site Floodplain Remapping

2.1 Overview

The existing floodplain and floodway information at the project site is from the Dane County, Wisconsin National Flood Insurance Program Flood Insurance Rate Map (dated September 17, 2014). Updating the floodplain / floodway map was important because the proposed project would likely require construction within the currently designated floodway and floodplain. If the project is implemented, no structures will be allowed in the floodway, and land disturbing activities must meet local, state, and national floodplain requirements.

2.2 Letter of Map Revision

The City of Madison (City) submitted a Letter of Map Revision (LOMR) to the Wisconsin Department of Natural Resources (WDNR) in September 2015 prepared by Brown and Caldwell (BC). The LOMR requested an update to the floodplain mapping of a portion of the East Branch of Starkweather Creek adjacent to the proposed project site. The revisions to the effective modeling and mapping incorporated several updates including:

1. A field survey of the proposed project area was conducted in May 2014 to update topographic data. HEC-RAS cross sections (River Stations 1079 through 4271) within the project area were updated using the May 2014 data.
2. A culvert crossing the East Branch of Starkweather Creek (located adjacent to the proposed project site and not included in the previous Effective Model) was added at river station 3682.
3. The Milwaukee Street Bridge over Starkweather Creek (just downstream of the proposed project area) was reconstructed in 2015. The geometry data for the reconstructed bridge and the cross sections just upstream and downstream of the bridge were updated (River Stations 966 through 1029) and incorporated into the HEC-RAS model.

2.3 Floodplain Mapping Conclusions

A Corrected Effective Model (incorporating the new topography and the existing culvert near the project site) and a Post Project Conditions Model (adding the Milwaukee Street Bridge reconstruction) were developed incorporating the updates described above. The water surface elevations in the Corrected Effective Model increase between 0.11 and 0.24 feet as compared to the Effective Model due to the updates. The Post Project Conditions Model indicates the water surface elevations decrease at all locations when compared to the Corrected Effective Model. Across most of the project area the floodway and floodplain decrease in width, due to the updates to the model. There are a few areas with minor increases in floodway and floodplain width.

Most importantly, the existing quarry pond is no longer within the mapped floodway.

The remapped floodplain and floodway also show where project construction must be avoided or will require future modeling should grading or structures be necessary within the floodplain. Based on the remapping effort there would appear to be adequate areas to implement the coagulant treatment structures without impacting the newly remapped floodplain or floodway.

Figure 2-1 shows the revised mapping as submitted in the LOMR request.

The City received a letter of approval from the WDNR on December 3, 2015. Following the receipt of the letter, the LOMR was then submitted to the Federal Emergency Management Agency (FEMA). FEMA sent a Summary of Additional Data Required letter on dated January 19, 2016. The requested data was sent to FEMA in February. As of the drafting of this report, FEMA has not provided a letter of approval.

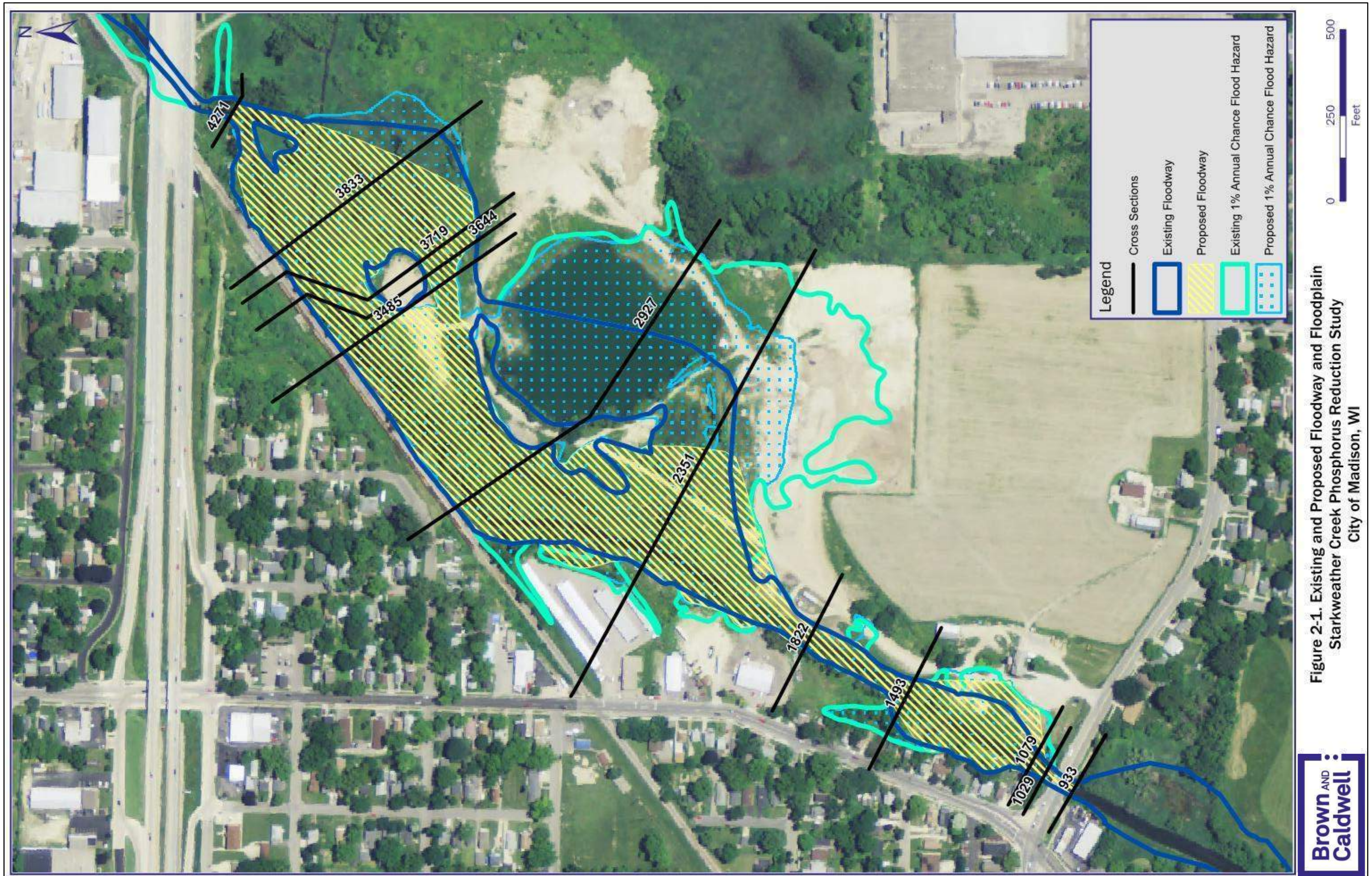

Figure 2-1. Existing and Proposed Floodway and Floodplain

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Section 3

Coagulant Jar Testing and Quarry Monitoring

3.1 Coagulant Treatment Background

There is evidence that aluminum compounds have been used since Roman times for the removal of turbidity and other impurities from surface water and drinking water. In the modern era, aluminum coagulants are still being used to remove impurities from drinking water sources and wastewater. A wide range of aluminum coagulants are used in wastewater treatment processes to remove TP, Organic Phosphorus (OP) and other pollutants. Today there are dozens of aluminum coagulants used throughout the U.S. The most common forms include aluminum sulfate, polyaluminum chloride, sodium aluminate, and aluminum chlorohydrate. Aluminum sulfate in liquid form (alum) is probably the most commonly used aluminum coagulant due to its purity, availability and relatively low cost.

In 1970, granular aluminum sulfate was mixed with lake water and applied to the surface of Horseshoe Lake in Wisconsin to reduce the concentration of phosphorus in the water column. This is the first recorded surface application of a coagulant to a lake in the United States. Due to the beneficial effects on water quality, alum and other coagulants are now routinely applied to the surface of lakes as a lake management tool. The surface application of coagulants removes phosphorus in the water column and bind phosphorus in lake bottom sediments to reduce algae growth and improve surface water quality.

The first known use of a coagulant to treat a non-point source discharge was at Lake Ella in Tallahassee, FL. Stormwater runoff was the primary source of TP to this shallow, hypereutrophic lake. Coagulant treatment of stormwater was selected because of limited space adjacent to the lake to construct traditional stormwater treatment best management practices (BMPs). After extensive jar testing with aluminum sulfate and other coagulants, along with pre-construction testing of lake surface water quality, sediment quality, and benthic macroinvertebrate sampling, a coagulant stormwater treatment system was designed and constructed in 1987. The system, which has now been in operation for over 25 years, includes water flow meters to continuously measure the flow of water through six stormwater outfalls. The project resulted in immediate and substantial improvement in lake water quality. Extensive post construction testing was performed on lake surface water quality, sediment quality, and benthic macroinvertebrates. Improvements were observed in all areas evaluated.

Since Lake Ella, over 30 coagulant treatment systems have been constructed to reduce the concentration of TP and other pollutants in non-point source discharges and improve surface water quality.

The use of offline systems with floc settling ponds began in the mid-1990s. Current systems use offline settling ponds almost exclusively and have evolved to include automated floc removal systems and floc dewatering systems. Coagulant treatment has also been combined with other treatment train components including sedimentation basins and constructed wetlands to minimize coagulant use.

Aluminum coagulants are commonly selected over ferric (iron) coagulants due to aluminum's high ionic charge and small crystalline radius. These characteristics combine to create a level of reactivity greater than any other soluble metal. Another benefit is the quality of aluminum coagulants and their availability. Aluminum coagulants are manufactured using quality raw materials with minimal impurities, are approved for drinking water treatment, and are used extensively throughout the U.S. daily to treat surface drinking water sources for potable use. Aluminum precipitates are also very stable with minimum aluminum solubility in the pH range of natural surface waters (6-8 s.u.) Ferric coagulants are often manufactured using lower quality materials and ferric precipitates have minimum solubilities at a water pH lower than typical for natural surface waters. Aluminum precipitates are also stable with changes in water reduction-oxidation potential (related to water dissolved oxygen concentration) whereas ferric precipitates can dissolve under reduced conditions (low DO).

The addition of aluminum based coagulants to stormwater creates precipitates which remove pollutants by two primary mechanisms. The removal of suspended solids, particulate phosphorus, heavy metals, and bacteria occurs primarily by enmeshment and adsorption onto aluminum hydroxide precipitate per the following reaction:

$$Al^{+3} + 6H_2O \rightarrow Al(OH)_{3(s)} + 3H_3O^+$$

The aluminum hydroxide precipitate, $Al(OH)_3$, is a gelatinous floc which attracts and adsorbs colloidal particles onto the growing floc, thus purifying the water. The removal of additional dissolved phosphorus is achieved by the direct formation of aluminum phosphate according to the following reaction:

$$Al^{+3} + HnPO_4^{n-3} \rightarrow AlPO_{4(s)} + nH^+$$

These reactions occur very quickly and are generally complete in less than 30 to 45 seconds. Therefore, after 45 seconds of contact between coagulant and water, the coagulant no longer exists, and only the resulting aluminum hydroxide and aluminum phosphate are present in the treated water. For use in stormwater treatment projects, this reaction occurs in an enclosed concrete rapid mix tank, so that it is not possible for the coagulant to enter the environment. The solubility of dissolved aluminum in the treated water is primarily regulated by water pH. Since the addition of many aluminum coagulants slightly reduce water pH, and the minimum solubility of aluminum is in the 6-7 s.u. pH range, the dissolved aluminum concentration in treated water is often less than the raw water.

Aluminum precipitates once formed are exceptionally stable and do not dissolve due to changes in pH or redox potential in natural waters. Therefore pollutants such as TP trapped by the precipitates are not released into soils or groundwater. As the floc ages at the bottom of the settling pond, even more stable complexes form, eventually forming gibbsite. Gibbsite is an important ore of aluminum and is one of three phases that make up the rock bauxite. Bauxite is the primary source of raw aluminum.

The floc which is formed as a result of the coagulation process settles to the bottom of the wet settling pond and will remain there until removed. Because TP and other pollutants contained in the floc are tightly bound, under natural conditions these pollutants will not be released from the floc into the environment. Floc will continue to accumulate in the bottom of the settling pond and will increase in depth above the bottom of the pond until the floc is removed. Periodically, the accumulated wet floc will be removed from the bottom of the settling pond. Although the dredging effort will slightly disturb the floc, the aged floc will not release bound pollutants. Instead, any disturbed floc will resettle to the pond bottom. Freshly formed floc is typically 98 to 99 percent water.

As additional floc depth accumulates it will consolidate to some extent but will still be on the order of 95 to 98 percent water until dried.

3.2 Field Sampling Procedure

Coagulant performance for phosphorus removal is dependent on the specific chemical and physical characteristics of the water being treated. For this reason wet weather discharges in Starkweather Creek were collected during a series of runoff events and tested in a laboratory to evaluate the phosphorus control performance of various coagulants.

Between April and October 2015 six (6) runoff events were sampled at a location about 3,300 feet downstream of the proposed flow diversion (on the East Branch of Starkweather Creek). The intent was to characterize Starkweather Creek water quality during spring, summer, and fall runoff periods and to test the performance of various coagulants under these conditions.

The following field sampling procedure was used:

1. Consult three real-time recording rain gauges near the watershed to verify that a rain event occurred within the watershed. (NOAA gauge at Dane County Regional Airport and two United States Geologic Survey (USGS) gauges – one within the watershed and one just south of the watershed)
2. Collect Equal Width Increment water samples (USGS 2006) from the creek at the O.B. Sherry Park footbridge.
3. Capture adequate volume of stream water for testing three (3) coagulants at multiple doses during each event (this required three 10-liter containers)
4. Deliver water samples to the Wisconsin State Laboratory of Hygiene (WSLH) located on Agricultural Drive in Madison for testing and laboratory analysis.

Three 10-liter containers were filled over 1 – 1 ½ hours of sampling. The water samples were generally delivered to the lab within 30 minutes of sampling completion. Because of the low hydraulic gradient of the stream, and watershed size and land use, significant changes in water quality were not expected over this time period. This assumption appears to be valid based on the consistent raw water laboratory results.

Field sampling dates and the corresponding total rain event depth and duration (based on the USGS rain gauge located at Sycamore Park) are summarized in Table 3-1

Table 3-1. Starkweather Creek Rainfall Sampling Events
Starkweather Creek Phosphorus Treatment Phase I Study

Field Sample Date	Corresponding Rainfall (USGS Sycamore Park, Madison, WI)
April 8, 2015	1.22-inches over 7 hrs.
May 4, 2015	0.36-inches over 4 hrs.
May 27, 2015	0.34-inches over 5.5 hrs.
June 12, 2015	1.65-inches over 21 hrs.
July 29, 2015	0.94-inches over 3.5 hrs.
October 28, 2015	0.33-inches over 10 hrs.

Field procedures also included recording: weather conditions; visual water quality; water stage at a fixed point on the foot bridge; and other observations. The field sheets and rain event measurements corresponding to each sampling event are included in Appendix B.

3.3 Coagulant Analysis Lab Procedure

Aluminum (Al), ferric (Fe), and polymer-based coagulants are three types of compounds commonly used to remove phosphorus and other pollutants. Aluminum-based coagulants have been used extensively in stormwater and lake applications, particularly in Florida and Georgia (Herr 2009). Based on discussions with the City and prior experience, it was determined that the following coagulants would be tested for this project:

- Aluminum Sulfate (Alum – AH 1100*; 4.4 percent Al by weight)
- Polyaluminum Chloride (PAC - AH 2192*; 7.6 percent Al)
- Polyaluminum Chloride (PAC - AH 4137*; 9.0 percent Al)
- Polyaluminum Chloride (PAC - AH 5507*; 5.6 percent Al)
- Aluminum Chlorohydrate (ACH - AH 3507*; 12.6 percent Al)

*chemical coagulants provided by Hawkins Inc. Roseville, MN

The complete analytical parameter list included:

- pH
- Temperature
- TP
- Dissolved Phosphorus
- TSS
- Alkalinity
- Sulfate
- Total Aluminum
- Dissolved Aluminum
- Chloride
- Conductivity

Once at the laboratory, the raw water samples were split (using a churn splitter) for coagulant testing. For each coagulant to be tested, the raw water sample was split into four jars representing:

- Raw water (no coagulant)
- Coagulant added at three different doses (to achieve a pre-determined lower, medium and higher aluminum concentration)

A diagram of the sample splitting process conducted at the laboratory is shown on Figure 3-1 below.

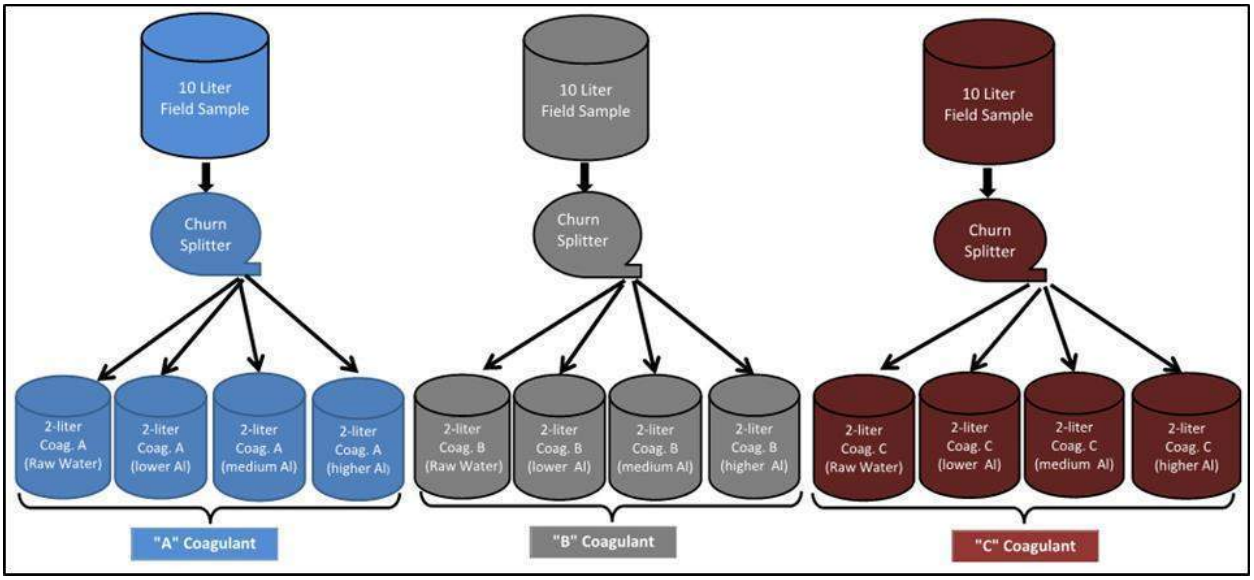

Figure 3-1. Schematic of Starkweather Creek project sample splitting and coagulant testing process

Starkweather Creek Phosphorus Treatment Phase I Study

After the raw water samples were split into individual jars a series of analyses were conducted as summarized in Table 3-2. Initially the selected coagulant dose was added to each jar and rapid mixed for one minute. The sample was allowed to settle in the lab and measurements were performed at one minute, 1.5 hours, 3 hours, and 24 hours after rapid mixing. After 24 hours the supernatant (water at the top of each of the coagulant jars) was carefully siphoned off for laboratory analysis. Some settling of solids occurred in the untreated sample (raw water) after 24 hours, and supernatant was also siphoned from the top layer of this jar. After 24 hours of settling, a series of laboratory analyses were conducted as summarized in Table 3-2. In the first four rounds of testing multiple raw water samples were collected and analyzed. In the last two rounds only one raw water sample was analyzed since the same raw water was used for each coagulant test. Figure 3-2 shows example settling (after 24 hours) from the first round of sampling.

Table 3-2. Starkweather Creek Project Laboratory Testing Parameters
Starkweather Creek Phosphorus Treatment Phase I Study

	Raw Water Sample (No Coagulant)				Each Coagulant Treated Sample				
Before Adding Coagulant	pH	Conductivity	Temperature	Alkalinity	pH	Temperature			
	Total P	Dissolved P	TSS	Sulfate					
	Total Al	Dissolved Al	Chloride						
1 Minute After Adding Coagulant			---		pH	Temperature	Photo		
1.5 Hours After Adding Coagulant			---		Photo	measure floc depth			
3 Hours After Adding Coagulant			---		pH	Temperature	Photo	measure floc depth	
24 Hours After Adding Coagulant	pH	Conductivity	Temperature	Alkalinity	pH	Conductivity	Temperature	Alkalinity	measure floc depth
	Total P	Dissolved P	TSS	Sulfate	Total P.	Dissolved P	TSS	Sulfate	
	Total Al	Dissolved Al	Chloride		Total Al	Dissolved Al	Chloride	Photo	

Figure 3-2. Jar Test April 9, 2015 at 11:40 am (24 hour settling time). Polyaluminum Chloride (AH 4137; 8.96% Al);

Starkweather Creek Phosphorus Treatment Phase I Study

After removal of the supernatant from the coagulant jars for lab analysis, the remaining water was removed to the top of the floc layer. The floc from each jar was poured into a 100 ml graduated cylinder to evaluate floc production and consolidation over time. The floc depth was measured over time to assess the compaction of the floc. Figure 3-3 shows an example of initial floc production at different coagulant doses. Generally, the higher the initial dose of aluminum, the larger the floc volume. Individual measurements of floc volumes are provided in Appendix A.

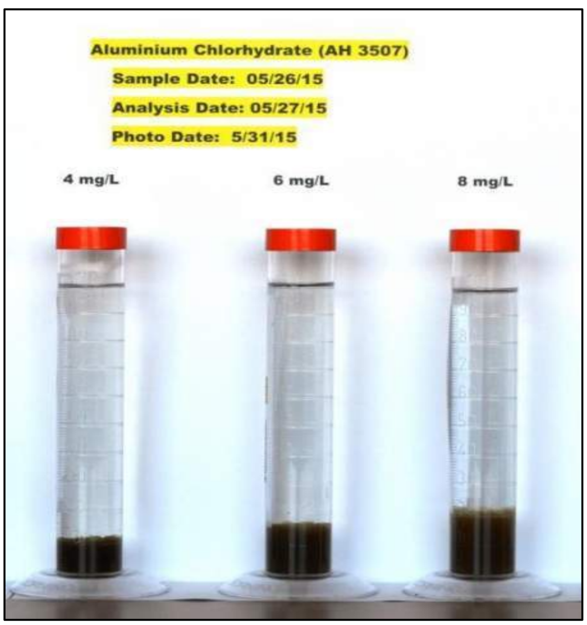

Figure 3-3. Example initial floc volume production – Aluminum Chlorohydrate from 5/26/15 sample; doses in mg Aluminum per liter. (floc volumes approximately 10 mls., 15 mls., and 20 mls. from 1.75 L samples)

Starkweather Creek Phosphorus Treatment Phase I Study

3.4 Coagulant Testing Lab Results

Table 3-3 provides a summary of coagulant testing results for TP, Dissolved Phosphorus (DP), and TSS. The results of all the parameters analyzed are included in Appendix A.

The performance of the three primary coagulants (in terms of TP reduction) is summarized in Table 3-4 and Figure 3-4. It should be noted that the TP reduction for the raw (untreated) samples ranged from 12 percent to 55 percent with an average of 32 percent (see table 3-3). The TP reduction observed in the untreated samples was strictly from the settling process over 24 hours.

Table 3-3. Summary of Starkweather Creek Project Coagulant Testing Results for TP, DP, and TSS
Starkweather Creek Phosphorus Treatment Phase I Study

Sample Date	Coagulant	Total P (mg/L)		% Change from Raw @ 0 hr. (%)	Diss. Total P (mg/L)		% Change from Raw @ 0 hr. (%)	TSS (mg/L)		% Change from Raw @ 0 hr. (%)
		0 hrs.	+ 24 hrs.		0 hrs.	+ 24 hrs.		0 hrs.	+ 24 hrs.	
Round 1	Aqua Hawk 1100 - Alum, 4.4% Aluminum									
4-8-2015	Raw Sample A	0.289	0.130	55%	0.128	0.087	32%	83	15	82%
4-8-2015	3 mg/L Al		0.024	92%		0.007	94%		3.8	95%
4-8-2015	6 mg/L Al		0.018	94%		0.006	95%		2.6	97%
4-8-2015	9 mg/L Al		0.014	95%		0.006	95%		2.4	97%
	Aqua Hawk 3507 - ACH, 12.59% Aluminum									
4-8-2015	Raw Sample B	0.255	0.136	47%	0.103	0.088	15%	69	10	86%
4-8-2015	3 mg/L Al		0.027	89%		0.012	88%		ND	98%
4-8-2015	6 mg/L Al		0.014	94%		0.007	93%		ND	98%
4-8-2015	9 mg/L Al		0.012	95%		0.008	93%		2.8	96%
	Aqua Hawk 4137 - PAC (Mid Basicity), 8.96% Aluminum									
4-8-2015	Raw Sample C	0.251	0.143	43%	0.109	0.101	7%	64.5	11.7	82%
4-8-2015	3 mg/L Al		0.057	77%		0.008	93%		8.33	87%
4-8-2015	6 mg/L Al		0.018	93%		0.006	94%		ND	98%
4-8-2015	9 mg/L Al		0.011	95%		0.006	94%		ND	98%
Round 2	Aqua Hawk 1100 - Alum, 4.4% Aluminum									
5-4-2015	Raw Sample A	0.141	0.119	16%	0.094	0.024	74%	16.7	8	52%
5-4-2015	3 mg/L Al		0.122	13%		0.007	93%		19.7	-18%
5-4-2015	6 mg/L Al		0.022	85%		0.006	93%		5.67	66%

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Table 3-3. Summary of Starkweather Creek Project Coagulant Testing Results for TP, DP, and TSS Starkweather Creek Phosphorus Treatment Phase I Study										
Sample Date	Coagulant	Total P (mg/L)		% Change from Raw @ 0 hr. (%)	Diss. Total P (mg/L)		% Change from Raw @ 0 hr. (%)	TSS (mg/L)		% Change from Raw @ 0 hr. (%)
		0 hrs.	+ 24 hrs.		0 hrs.	+ 24 hrs.		0 hrs.	+ 24 hrs.	
5-4-2015	9 mg/L Al		0.017	88%		0.007	93%		ND	93%
	Aqua Hawk 2192 - PAC (Low Basicity), 7.56% Aluminum									
5-4-2015	Raw Sample B	0.127	0.103	19%	0.097	0.075	22%	15	7.33	51%
5-4-2015	3 mg/L Al		0.125	2%		0.007	93%		21	-40%
5-4-2015	6 mg/L Al		0.021	83%		0.007	93%		5.33	64%
5-4-2015	9 mg/L Al		0.014	89%		0.007	93%		ND	92%
	Aqua Hawk 5507 - PAC (Mid Basicity), 5.6% Aluminum									
5-4-2015	Raw Sample C	0.134	0.114	15%	0.097	0.030	69%	15.5	7	55%
5-4-2015	3 mg/L Al		0.053	60%		0.008	92%		ND	92%
5-4-2015	6 mg/L Al		0.019	86%		0.007	93%		4.25	73%
5-4-2015	9 mg/L Al		0.014	90%		0.006	94%		ND	92%
Round 3	Aqua Hawk 1100 - Alum, 4.4% Aluminum									
5-27-2015	Raw Sample A	0.176	0.143	19%	0.072	0.079	-9%	8.25	4.4	47%
5-27-2015	4 mg/L Al		0.038	78%		0.009	87%		4.8	42%
5-27-2015	6 mg/L Al		0.028	84%		0.008	89%		4.2	49%
5-27-2015	8 mg/L Al		0.026	85%		0.007	90%		3.4	59%
	Aqua Hawk 3507 - ACH, 12.59% Aluminum									
5-27-2015	Raw Sample B	0.197	0.152	23%	0.082	0.088	-7%	8	4.75	41%
5-27-2015	4 mg/L Al		0.037	81%		0.011	86%		4	50%

Table 3-3. Summary of Starkweather Creek Project Coagulant Testing Results for TP, DP, and TSS Starkweather Creek Phosphorus Treatment Phase I Study										
Sample Date	Coagulant	Total P (mg/L)		% Change from Raw @ 0 hr. (%)	Diss. Total P (mg/L)		% Change from Raw @ 0 hr. (%)	TSS (mg/L)		% Change from Raw @ 0 hr. (%)
		0 hrs.	+ 24 hrs.		0 hrs.	+ 24 hrs.		0 hrs.	+ 24 hrs.	
5-27-2015	6 mg/L Al		0.024	88%		0.008	90%		3.25	59%
5-27-2015	8 mg/L Al		0.020	90%		0.007	91%		3.25	59%
	Aqua Hawk 4137 - PAC (Mid Basicity), 8.96% Aluminum									
5-27-2015	Raw Sample C	0.197	0.154	22%	0.093	0.094	-2%	8	3.5	56%
5-27-2015	4 mg/L Al		0.030	85%		0.012	87%		2.75	66%
5-27-2015	6 mg/L Al		0.024	88%		0.009	90%		3	63%
5-27-2015	8 mg/L Al		0.027	86%		0.008	92%		4	50%
Round 4	Aqua Hawk 1100 - Alum, 4.4% Aluminum									
6-12-2015	Raw Sample A	0.198	0.111	44%	0.073	0.073	1%	37.7	3.67	90%
6-12-2015	4 mg/L Al		0.019	91%		ND	97%		ND	97%
6-12-2015	6 mg/L Al		0.018	91%		ND	97%		ND	97%
6-12-2015	8 mg/L Al		0.022	89%		ND	97%		3.75	90%
	Aqua Hawk 3507 - ACH, 12.59% Aluminum									
6-12-2015	Raw Sample B	0.194	0.109	44%	0.080	0.079	1%	42.7	2.5	94%
6-12-2015	4 mg/L Al		0.014	93%		0.006	92%		ND	97%
6-12-2015	6 mg/L Al		0.016	92%		ND	97%		ND	97%
6-12-2015	8 mg/L Al		0.023	88%		ND	97%		5	88%
	Aqua Hawk 4137 - PAC (Mid Basicity), 8.96% Aluminum									
6-12-2015	Raw Sample C	0.203	0.111	45%	0.077	0.075	2%	37	3.5	91%

Table 3-3. Summary of Starkweather Creek Project Coagulant Testing Results for TP, DP, and TSS Starkweather Creek Phosphorus Treatment Phase I Study										
Sample Date	Coagulant	Total P (mg/L)		% Change from Raw @ 0 hr. (%)	Diss. Total P (mg/L)		% Change from Raw @ 0 hr. (%)	TSS (mg/L)		% Change from Raw @ 0 hr. (%)
		0 hrs.	+ 24 hrs.		0 hrs.	+ 24 hrs.		0 hrs.	+ 24 hrs.	
6-12-2015	4 mg/L Al		0.015	93%		ND	97%		ND	97%
6-12-2015	6 mg/L Al		0.012	94%		ND	97%		ND	97%
6-12-2015	8 mg/L Al		0.013	94%		ND	97%		ND	97%
Round 5	Aqua Hawk 1100 - Alum, 4.4% Aluminum									
7-29-2015	Raw Sample	0.225	0.132	41%	0.084	0.084	0%	52.7	15.5	71%
7-29-2015	4 mg/L Al		0.027	88%		ND	97%		2.75	95%
7-29-2015	6 mg/L Al		0.023	90%		ND	97%		ND	98%
	Aqua Hawk 3507 - ACH, 12.59% Aluminum									
7-29-2015	Raw Sample	0.225	0.132	41%	0.084	0.084	0%	52.7	15.5	71%
7-29-2015	4 mg/L Al		0.023	90%		ND	97%		2.75	95%
7-29-2015	6 mg/L Al		0.020	91%		ND	97%		3.75	93%
	Aqua Hawk 4137 - PAC (Mid Basicity), 8.96% Aluminum									
7-29-2015	Raw Sample	0.225	0.132	41%	0.084	0.084	0%	52.7	15.5	71%
7-29-2015	4 mg/L Al		0.026	89%		ND	97%		3.33	94%
7-29-2015	6 mg/L Al		0.019	91%		ND	97%		ND	98%
Round 6	Aqua Hawk 3507 - ACH, 12.59% Aluminum									
10-28-2015	Raw Sample	0.217	0.192	12%	0.155	0.147	5%	25	6	76%

Table 3-3. Summary of Starkweather Creek Project Coagulant Testing Results for TP, DP, and TSS
Starkweather Creek Phosphorus Treatment Phase I Study

Sample Date	Coagulant	Total P (mg/L)		% Change from Raw @ 0 hr. (%)	Diss. Total P (mg/L)		% Change from Raw @ 0 hr. (%)	TSS (mg/L)		% Change from Raw @ 0 hr. (%)
		0 hrs.	+ 24 hrs.		0 hrs.	+ 24 hrs.		0 hrs.	+ 24 hrs.	
10-28-2015	4 mg/L Al		0.023	90%		0.005	97%		3.67	85%
10-28-2015	6 mg/L Al		0.015	93%		ND	98%		3.33	87%
	Aqua Hawk 3507 - ACH, 12.59% Aluminum (Cold)									
10-28-2015	Raw Sample	0.217	0.192	12%	0.155	0.147	5%	25	6	76%
10-28-2015	4 mg/L Al		0.034	90%		0.010	93%		3.33	87%
10-28-2015	6 mg/L Al		0.024	93%		ND	98%		2.4	90%
	Aqua Hawk 4137 - PAC (Mid Basicity), 8.96% Aluminum									
10-28-2015	Raw Sample	0.217	0.192	12%	0.155	0.147	5%	25	6	76%
10-28-2015	4 mg/L Al		0.021	90%		ND	98%		3.67	85%
10-28-2015	6 mg/L Al		0.016	93%		ND	98%		ND	95%

ND = No Detect (less than lab analytical detection limit)

Table 3-4. Comparison of Coagulant Performance for TP Reduction (%) Starkweather Creek Phosphorus Treatment Phase I Study						
	Aqua Hawk 1100 - Alum, 4.4% Aluminum		Aqua Hawk 3507 - ACH, 12.59% Aluminum		Aqua Hawk 4137 - PAC (Mid Basicity), 8.96% Aluminum	
Sample Date	Al Dose (mg/L)	% TP Reduction	Al Dose (mg/L)	% TP Reduction	Al Dose (mg/L)	% TP Reduction
4-8-2015	3	92%	3	89%	3	77%
5-4-2015	3	13%				
5-27-2015	4	78%	4	81%	4	85%
6-12-2015	4	91%	4	93%	4	93%
7-29-2015	4	88%	4	90%	4	89%
10-28-2015			4	90%	4	90%
10-28-2015			4	84%		
4-8-2015	6	94%	6	94%	6	93%
5-4-2015	6	85%				
5-27-2015	6	84%	6	88%	6	88%
6-12-2015	6	91%	6	92%	6	94%
7-29-2015	6	90%	6	91%	6	91%
10-28-2015			6	93%	6	93%
10-28-2015			6	89%		
5-27-2015	8	85%	8	90%	8	86%
6-12-2015	8	89%	8	88%	8	94%
4-8-2015	9	95%	9	95%	9	95%
5-4-2015	9	88%				

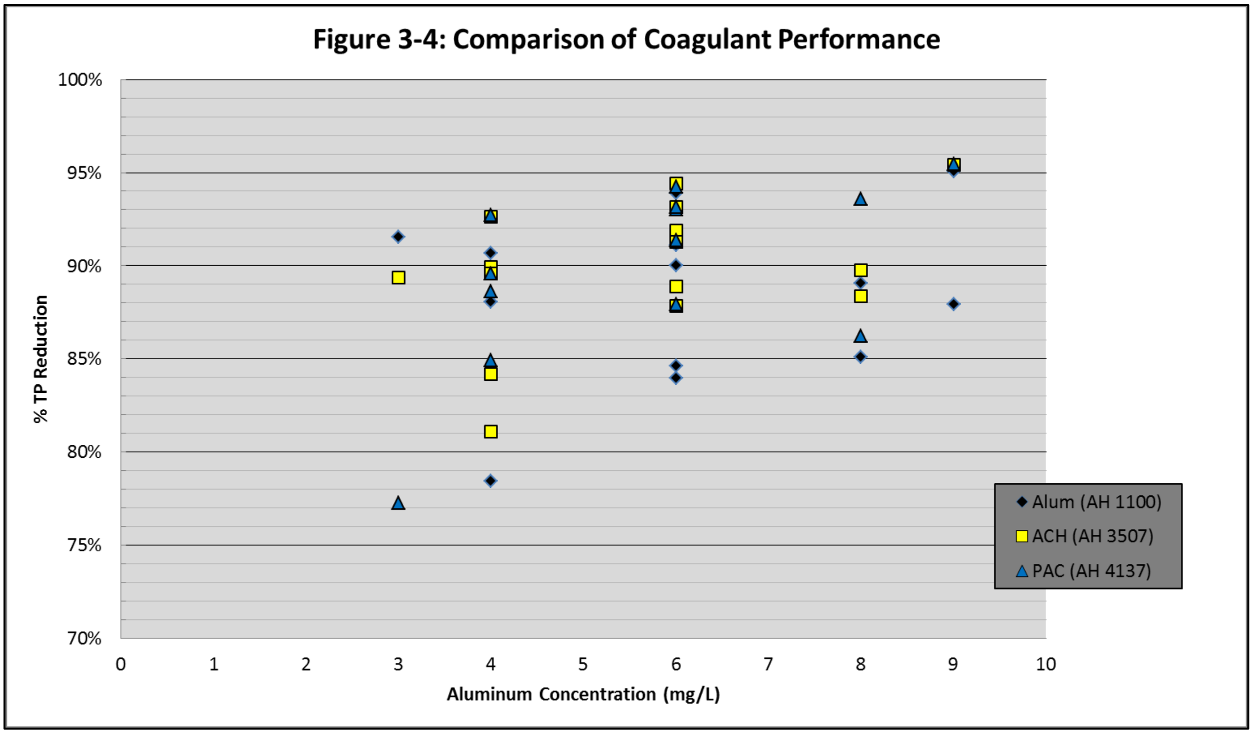

Figure 3-4. Comparison of Coagulant Performance

Starkweather Creek Phosphorus Treatment Phase I Study

**not shown on chart is the 5/4/15 Alum TP reduction of 13.1%*

3.5 Coagulant Results Discussion

The following is a summary of observations from the coagulant jar testing results:

1. The raw water quality characteristics varied from each event as expected due to seasonal watershed conditions, time between rain events, rainfall intensity and total depth, and other factors.
2. The raw water quality during the sample collection period for each event appears to be reasonably consistent. For example, on the 4/8/15 sampling date, the TSS concentrations from the three 10-liter containers collected over a 1.5 hour time period were 83, 69, and 64 mg/L.
3. For most coagulants, the pH dropped slightly with the addition of the coagulants (comparing the "0 time pH" with the "1 minute pH" levels). This pH change was most evident with Alum, and less evident with the other coagulants. Alkalinity levels appear adequate to buffer significant decreases in pH from the coagulants.
4. Substantial reduction of TP and DP occurred with most of the coagulants tested at the various aluminum concentrations (exceptions to this are noted in point 5 below). For the 4/8/15 sampling event, the TP reduction was near or above 90 percent (when compared to the raw water TP concentration) for all coagulants and aluminum concentrations except for the 3 mg/L aluminum concentration of PAC 4237 (which was at 77 percent TP reduction).
5. Low to very low TP reductions were noted for the 5/4/15 samples for the 3 mg/L Al concentration for each coagulant. (2- 60 percent). The TSS and TP concentrations of these samples were also relatively low. It appears that the lower aluminum concentration (3 mg/L) was not adequate for effective TP removal. During this same test, the higher Al concentrations (6 mg/L and 9 mg/L) achieved good TP and DP removals. (80–90+ percent). The 3 mg/L Al concentration level was discontinued for subsequent sampling events.

6. The sampling conducted on October 28, 2015 included a procedure that kept a duplicate ACH treated sample cold (4° C) throughout the 24 hour settling period. The purpose of this approach was to simulate the early spring or late fall condition of cold water treatment. The coagulant (ACH) treated water had similar TP reductions with both room temperature and cold water samples.

3.6 Recommended Coagulant

After reviewing all coagulant performance results and analytical data, the recommended coagulant for the Starkweather project is ACH at a dose of 4 to 5 mg/L. The justification for this recommendation is as follows:

1. ACH provided comparable TP reduction with other coagulants tested at similar Al doses.
2. The post treatment dissolved Al concentration in the water was equal to, or less than the raw water Al over six tests. Post treatment total Al was less than the raw water in two of six results; about the same in one of six results, and greater in three of six results.
3. ACH has a lower freezing temperature (19 F) compared to the other coagulants.
4. ACH retains its effectiveness in colder raw water.
5. ACH contains no sulfates. Alum contains sulfates and may be of concern because of potential to cause mercury release from the lake sediments.
6. ACH results showed a negligible change in chloride. PAC includes chlorides and resulted in an increase.
7. The ACH product tested requires less volume of chemical because of higher Al concentration. Thus, smaller equipment and storage requirements for the treatment system.
8. Results from the ACH samples showed no change in pH.
9. Estimated ACH costs per year are the lowest of the coagulants tested (see Appendix E for details on costs comparisons)

3.7 Quarry Pond Monitoring

3.7.1 Scope and Results

In addition to coagulant testing, water quality in the existing quarry pond was monitored on May 12, and June 29, 2015. The purpose of the monitoring was to obtain information on the pond’s dissolved oxygen / temperature profile with water depth in the spring and summer periods. During each trip several (DO/Temperature) profiles were measured at various locations within the pond. Pond water pH was also measured during the June 29 event. Sampling was specifically targeted at the deepest area of the pond. The deepest part of the pond was measured at 50 feet near the central area (see Figure 3-7). The profiles obtained from the deepest location in the pond are shown on Figures 3-5 and 3-6 for the May and June sampling respectively. During the June visit, the City also collected pond bathymetric information; the results of that survey are shown on Figure 3-7.

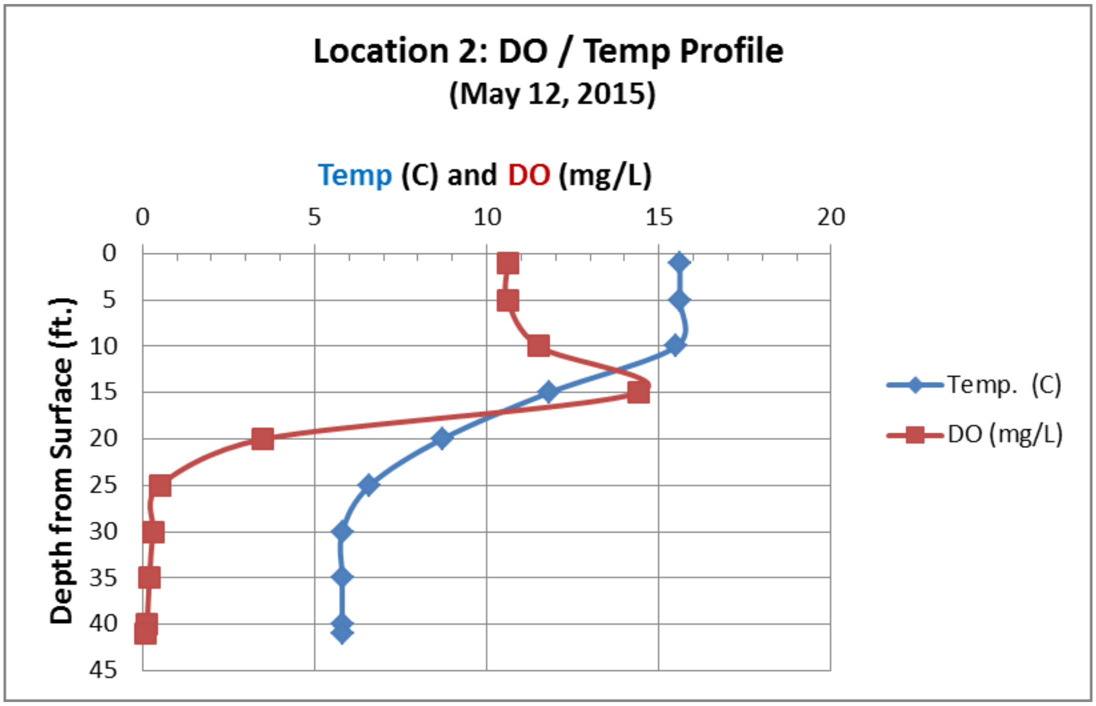

Figure 3-5. DO/Temperature Profile at Quarry Pond (5/12/15)

Starkweather Creek Phosphorus Treatment Phase I Study

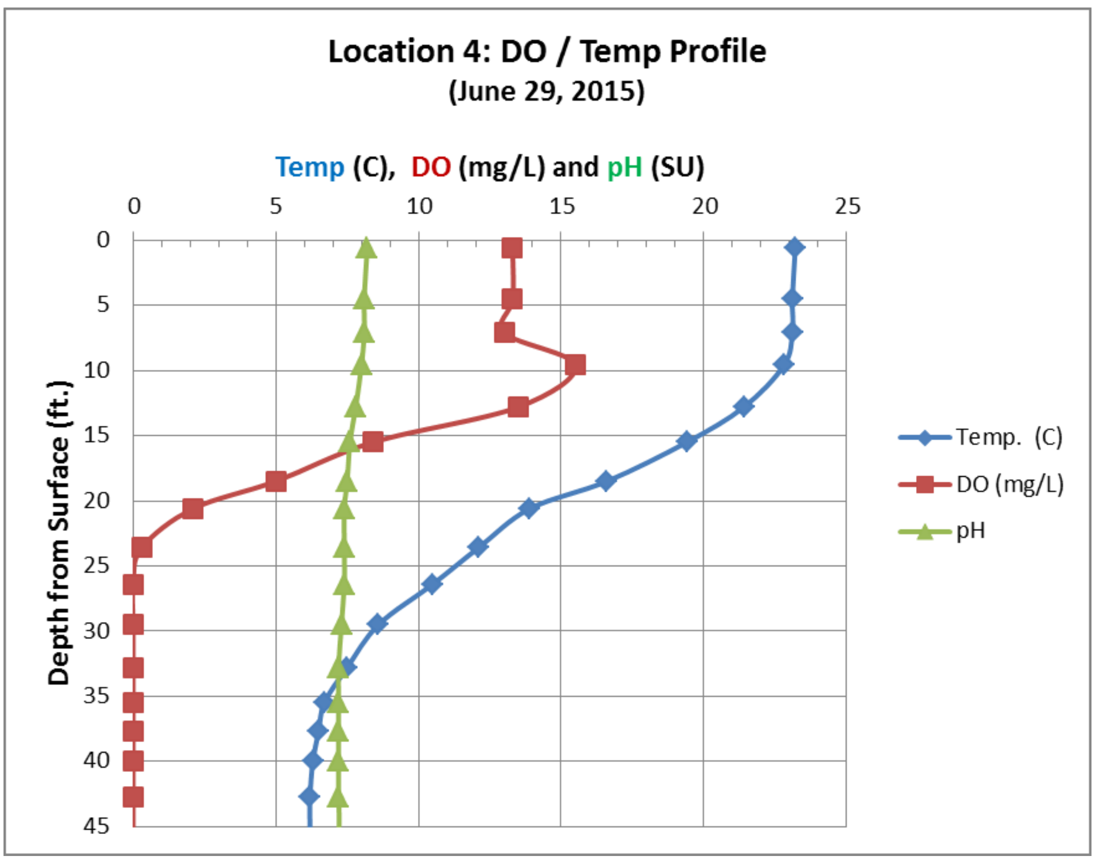

Figure 3-6. DO/Temperature / pH Profile at Quarry Pond (6/29/15)

Starkweather Creek Phosphorus Treatment Phase I Study

3.7.2 Quarry Pond Monitoring Discussion and Conclusions

The pond showed thermal stratification on both monitoring dates. In both May and June the thermocline was located generally between 10 and 20 feet of water depth. In June the surface water had warmed to 23° C (compared to 16° C in May). Also on both sampling dates the DO showed in increase in the thermocline zone. This is commonly due to an algae layer located just above the colder, dense layer of deeper water. In both May and June the DO concentration approached 0 mg/L at about 20 – 25 feet of water depth. Anoxic conditions exist below this water depth.

In June, pH measurements were also taken. The pH ranged from 8.2 s.u. at the surface to 6.9 s.u. at the bottom. A lower pH is often associated with low dissolved oxygen conditions in the deeper layers of a water body.

Secchi disk readings were also obtained at several locations during both dates. The Secchi disk depth varied from 12 – 13 feet in May and 6.0 – 6.5 feet in June. Visual observations indicated that the presence of additional algae in June could account for the lower water clarity.

The quarry pond monitoring provides the following guidance for future project design:

1. The anoxic conditions in the deeper areas of pond may promote the release of phosphorus from the newly settled floc.
2. Grading the pond bottom for a maximum depth of 20 feet will help to reduce the potential for anoxic conditions.
3. Also, grading the pond for a maximum depth of 20 feet will aid in the floc removal process because the depth of pumping will be reduced.

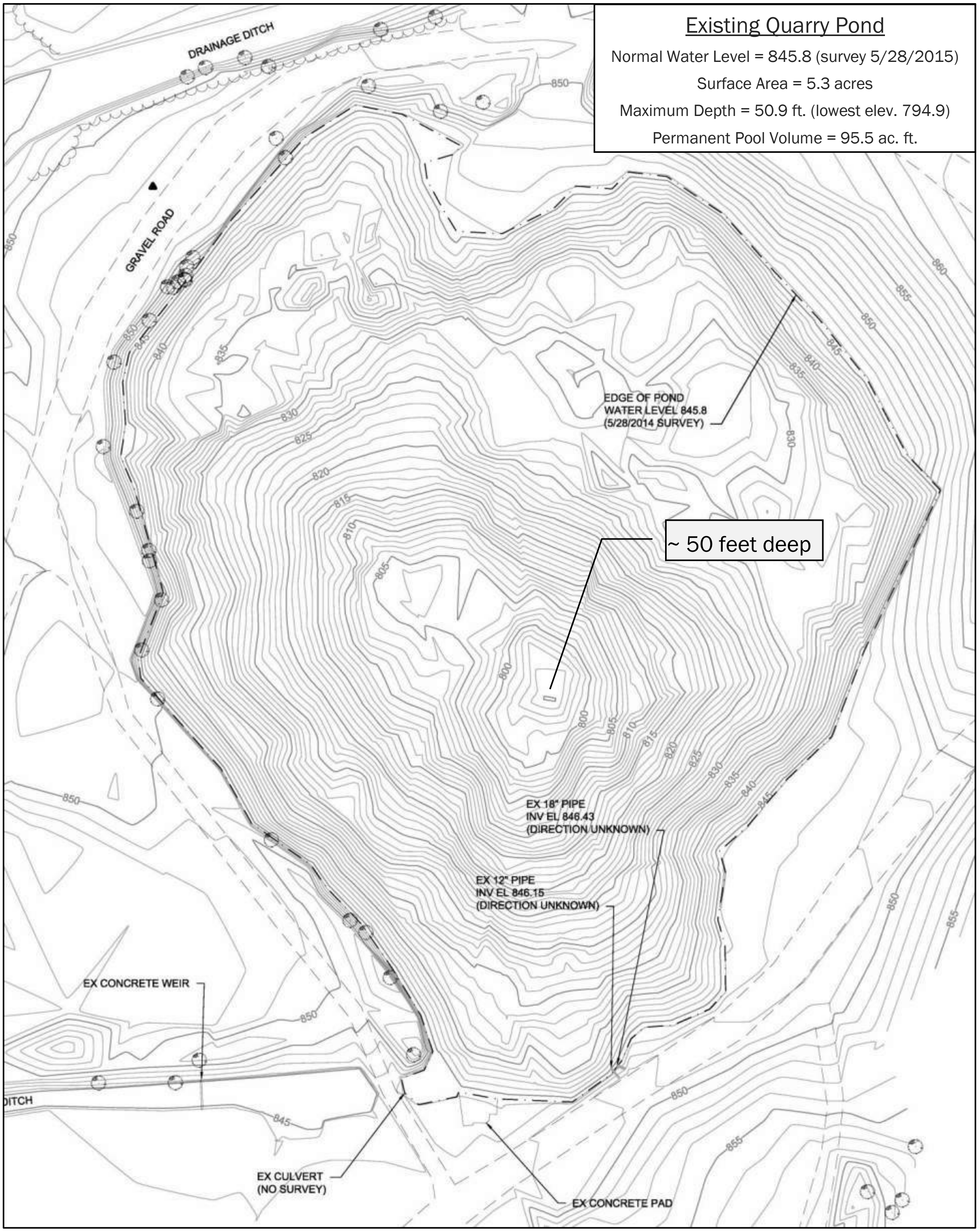

Figure 3-7. Current Quarry Pond Bathymetric Survey Results

(data collected by the City of Madison on June 29, 2015);

Starkweather Creek Phosphorus Treatment Phase I Study

Section 4

Hydrologic and Hydraulic Modeling

4.1 Introduction

4.1.1 Purpose of this Task

This task was divided into two phases:

1. **Watershed Existing Conditions Hydrologic and Hydraulic Modeling**: Both design storm and continuous simulation rainfall modeling was conducted on the East Branch of Starkweather Creek watershed to a point just below the project area (the Milwaukee Street bridge). The design storm modeling provided peak flow information utilized in traditional stormwater treatment system design in Wisconsin. The watershed continuous simulation modeling provided estimates of the potential annual treatable runoff volume delivered to the system. The modeling also provided a basis of comparison to evaluate the hydraulic effects the proposed treatment system will have on the existing channel.
2. **Treatment System Hydrologic and Hydraulic Modeling**: The treatment system modeling utilized the same continuous rainfall files as the watershed modeling. Treatment system modeling was used to estimate the diversion pipe size and slope, pond residence time, and pond outlet pumping rates.

A detailed discussion regarding the modeling inputs and results is provided in this section.

4.1.2 Study Area

The East Branch of Starkweather Creek watershed is located on the east side of the City. It is within both the City of Madison and the Town of Blooming Grove. The watershed is approximately 5,500 acres and is shown on Figure 1-1. The watershed contains a variety of land uses including commercial, industrial, and residential. There are also significant areas of agricultural land within the watershed. The drainage system within the watershed includes a mix of storm sewers and open-channels. The municipal drainage system discharges to the East Branch of Starkweather Creek. This branch meets the West Branch of Starkweather Creek approximately 2,100 feet downstream of the project area to create the main branch of Starkweather Creek which ultimately discharges to Lake Monona.

4.1.3 Data Sources for Watershed Conditions

The City provided the watershed data for the modeling including subbasin delineations, parcels, impervious area, land use, topography, and data for the stormwater conveyance system. For portions of the watershed outside of the City, land use files from Dane County were used. Unless noted below, the accuracy of data obtained from the City and County was not verified by BC.

The City data included 39 subbasins for the project watershed. After review of the subbasin boundaries, revisions were made based on the available stormwater conveyance system and topographic data. This resulted in a total of 32 subbasins for the project watershed. Appendix D contains a table showing acres for the original City of Madison subbasins and the revised project subbasins. Figure 4-1 shows the project area and subbasins.

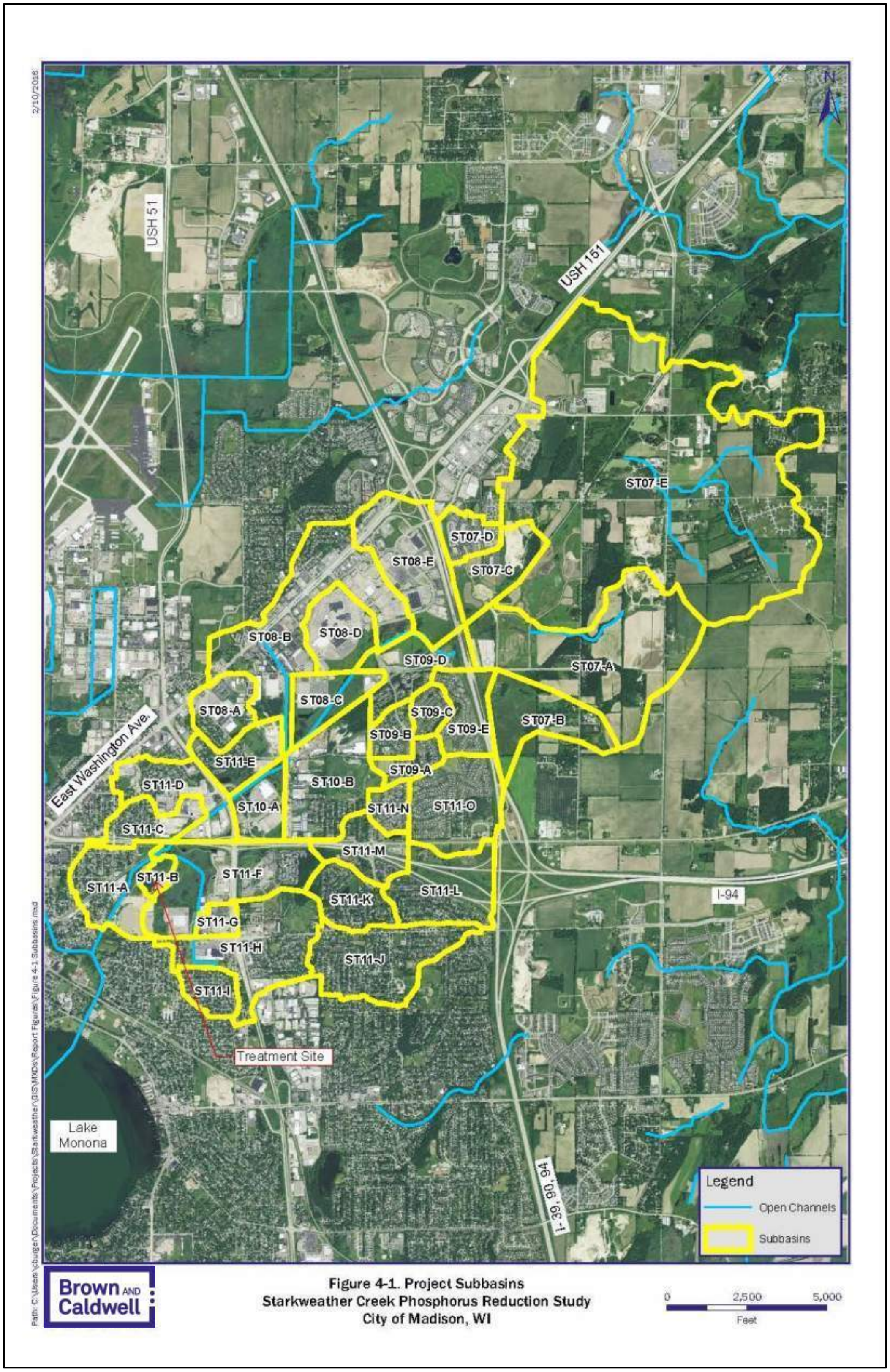

Figure 4-1. Project Area Watershed and Subbasin Delineations;

Starkweather Creek Phosphorus Treatment Phase I Study.

4.1.4 Model Selection

Two software packages were utilized for the hydrologic / hydraulic modeling effort. The first was XP-SWMM™ and the second was PC-SWMM™ Both software packages are proprietary versions of the public domain software: EPA SWMM. Both proprietary versions use the same algorithms as EPA SWMM.

Initial model construction and design storm modeling was conducted in XP-SWMM™ . Because of the local team's knowledge of XP-SWMM, this allowed for very efficient model construction. As the project progressed to continuous simulation modeling and the use of real-time controls (to operate the treatment system components), the project model was converted to PC-SWMM™. This conversion was made to take advantage of BC experts in continuous simulation modeling and the use of PC-SWMM™'s real-time controls.

Once the conversion was complete, XP-SWMM and PC-SWMM results were compared. Calculated runoff volumes from the two models for each subbasin showed good comparisons. Appendix D contains tables showing the comparisons of the two models.

4.2 Watershed Existing Conditions Modeling

4.2.1 Design Storm Event Modeling

This section describes the methodology and approach to each of the modeling analyses.

Precipitation: The 1-, 2-, 5-, 10-, and 100-year, 24 hour storm events were modeled. The City uses the MSE4 (Midwest/South East states) rainfall distribution with the NOAA Atlas 14 rainfall depths for design storm modeling. The rainfall depths are shown in Table 4-1.

Table 4-1. Design Storm Precipitation Depths
City of Madison, WI
Starkweather Creek Phosphorus Treatment Phase I Study

Frequency (24 hour duration)	Rainfall Depth (inches)
1-year	2.49
2-year	2.84
5-year	3.47
10-year	4.09
100-year	6.66

Hydrologic Factors: For design storm modeling, the MSE4 rainfall distribution is used in conjunction with a time of concentration and curve number. A time of concentration and curve number were calculated for each subbasin within the project area.

- Time of Concentration – Flow paths for each subbasin were delineated in ArcGIS using the provided topographic and storm sewer data. A line representing the typical flow path to the inlet location in the model within the subbasin was drawn. Sections of the flow path were identified as "sheet flow", "shallow concentrated flow", or "channel flow". The equations published in TR-55, Urban Hydrology for Small Watersheds, were used to calculate the time of concentration for each subbasin.

- Curve Number – A weighted curve number for each subbasin was calculated using pervious and impervious data and the hydrologic soil group. Several pieces of data were used for these calculations. They are as follows:
  - Percent impervious for the City parcels
  - Right-of-Way (ROW) percent impervious for ROW areas inside the City
  - County land use for areas outside the City
  - Hydrologic Soil Groups from the National Resources Conservation Service (NRCS)

Table 4-2 shows the curve number used for the pervious areas as defined in TR-55, "Urban Hydrology for Small Watersheds". Impervious areas were assigned a curve number of 98. Table 4-3 shows the hydrologic factors as assigned to each subbasin.

Table 4-2. Pervious Curve Numbers
Starkweather Creek Phosphorus Treatment Phase I Study

HSG	Urban Turf	Agricultural - Row Crop	Agricultural - Non-Row Crop	Woodland
A	39	64	60	36
A/D	80	85	84	79
B	61	75	72	60
B/D	80	85	84	79
C	74	82	80	73
C/D	80	85	84	79
D	80	85	84	79

Table 4-3. Subbasin Area, Curve Number, and Time of Concentration
Starkweather Creek Phosphorus Treatment Phase I Study

Subbasin	Area (ac)	Composite CN	Tc (min)
ST07-A	452.96	66	56
ST07-B	148.38	68	27
ST07-C	105.07	66	32
ST07-D	52.73	81	12
ST07-E	1,555.83	69	100
ST08-A	81.96	84	21
ST08-B	347.10	86	23
ST08-C	89.60	85	51
ST08-D	104.45	90	8
ST08-E	209.95	80	8
ST09-A	42.07	76	19

Table 4-3. Subbasin Area, Curve Number, and Time of Concentration Starkweather Creek Phosphorus Treatment Phase I Study			
Subbasin	Area (ac)	Composite CN	Tc (min)
ST09-B	44.84	76	22
ST09-C	36.46	80	14
ST09-D	113.92	71	13
ST09-E	94.39	77	13
ST10-A	75.89	86	27
ST10-B	211.00	79	30
ST11-A	131.85	78	19
ST11-B	20.52	64	11
ST11-C	76.84	84	22
ST11-D	130.40	84	21
ST11-E	86.40	70	40
ST11-F	236.00	81	17
ST11-G	26.49	92	9
ST11-H	220.33	78	24
ST11-I	52.32	80	29
ST11-J	202.17	73	21
ST11-K	92.21	74	24
ST11-L	164.02	72	28
ST11-M	90.81	76	13
ST11-N	39.95	79	23
ST11-O	176.92	78	16

4.2.2 Continuous Simulation

Precipitation: The USGS provided a 20 year data set of one-hour time-step precipitation recorded at the NOAA station located at the Dane County Regional Airport. The Dane County Regional Airport is the closest location with long-term continuous rainfall data. It is approximately 2.5 miles (straight line) from the center of the project watershed. From the 20 year record, a ten-year period was selected for the continuous simulation modeling.

Annual rainfall data from Water Years 1994 through 2013 were reviewed to select the most representative continuous 10 year period. Water years 2002 through 2011 were chosen as the ten-year period for the continuous simulation modeling. These water years were chosen because, on average, they were the closest to the overall average annual rainfall depth. Also, this period of time contained good representation of high and low rain years. Table 4-4 shows the annual rainfall depth for the 20 year period and the selected ten-year period for modeling purposes.

Table 4-4. Water Year Annual Rainfall Depth*
Starkweather Creek Phosphorus Treatment Phase I Study

Water Year (Oct.-Sept.)	Annual Rainfall Depth (in.)	+ / - from 20-yr. Average (%)	
1994-1995	29.9	-15%	
1995-1996	34.5	-2%	
1996-1997	30.3	-14%	
1997-1998	38.2	+9%	
1998-1999	34.4	-2%	
1999-2000	39.2	+11%	
2000-2001	37.2	+6%	
2001-2002	27.8	-21%	Selected H&H Modeling Period
2002-2003	24.4	-31%	
2003-2004	44.3	+26%	
2004-2005	25.8	-27%	
2005-2006	35.4	0%	
2006-2007	43.5	+24%	
2007-2008	44.5	+26%	
2008-2009	37.0	+5%	
2009-2010	41.3	+17%	
2010-2011	28.5	-19%	
2011-2012	25.2	-28%	
2012-2013	47.7	+36%	
2013-2014	35.4	0%	
1994 - 2013 Average:	35.2		
Modeled Period Average:	35.2	0.0%	

** NOAA rain station located at Dane County Regional Airport*

Hydrologic Factors: Curve number hydrology is not appropriate for continuous simulation modeling; therefore SWMM Runoff hydrology was used for the continuous simulation analysis.

The SWMM runoff parameters were calculated for each subbasin. The methodology used for calculating the parameters is summarized below.

- Percent Impervious – The data used to calculate the curve numbers in Section 2.2.2 was also used to calculate the percent impervious. The total impervious area for each subbasin was summed and then divided by the total subbasin area.

- Slope – The same flow path used to calculate the time of concentration was used to calculate the slope. Elevations at the upstream and downstream ends of the line were calculated based on the City's topographic data and the slope was calculated.
- Width – The width was calculated by dividing the subbasin area by the length of the flow path created to determine the subbasin slope.

Table 4-5 shows the area, percent impervious, slope, and width for each subbasin.

Table 4-5. Subbasin Area, Percent Impervious, Width, and Slope
Starkweather Creek Phosphorus Treatment Phase I Study

Subbasin	Area (ac)	% Impervious (%)	Width (ft.)	Slope (ft./ft.)
ST07-A	452.96	11%	2,897	0.025
ST07-B	148.38	6%	2,193	0.052
ST07-C	105.07	9%	1,591	0.044
ST07-D	52.73	55%	1,233	0.046
ST07-E	1,555.83	9%	7,203	0.014
ST08-A	81.96	58%	1,782	0.014
ST08-B	347.10	56%	2,084	0.018
ST08-C	89.60	32%	1,869	0.006
ST08-D	104.45	73%	1,939	0.011
ST08-E	209.95	53%	2,782	0.018
ST09-A	42.07	28%	699	0.027
ST09-B	44.84	35%	988	0.010
ST09-C	36.46	30%	902	0.025
ST09-D	113.92	26%	2,131	0.034
ST09-E	94.39	29%	1,979	0.045
ST10-A	75.89	42%	1,447	0.007
ST10-B	211.00	35%	3,525	0.030
ST11-A	131.85	38%	2,912	0.019
ST11-B	20.52	25%	1,487	0.008
ST11-C	76.84	53%	1,380	0.014
ST11-D	130.40	56%	1,770	0.014
ST11-E	86.40	32%	1,193	0.014
ST11-F	236.00	34%	2,052	0.028
ST11-G	26.49	79%	1,070	0.014
ST11-H	220.33	42%	7,641	0.016
ST11-I	52.32	35%	1,230	0.006

Table 4-5. Subbasin Area, Percent Impervious, Width, and Slope
Starkweather Creek Phosphorus Treatment Phase I Study

Subbasin	Area (ac)	% Impervious (%)	Width (ft.)	Slope (ft./ft.)
ST11-J	202.17	32%	2,242	0.018
ST11-K	92.21	27%	2,134	0.010
ST11-L	164.02	27%	2,011	0.022
ST11-M	90.81	41%	2,108	0.020
ST11-N	39.95	48%	880	0.008
ST11-O	176.92	30%	1,775	0.021

Evapotranspiration: Continuous simulation modeling incorporates evapotranspiration in the modeling process. Average monthly evapotranspiration values were referenced from the Water Environment Research Federation (WERF) 2011 publication “Stormwater Non-Potable Beneficial Uses and Effects on Urban Infrastructure”. Values for site 158 (the closest site to the project area) were used. Table 4-6 displays the evapotranspiration rates used in the modeling.

Table 4-6. Monthly Evapotranspiration Rates*
Starkweather Creek Phosphorus Treatment Phase I Study

Month	Rate (in./month)
January	0.90
February	1.12
March	2.48
April	4.50
May	6.82
June	7.20
July	8.06
August	6.82
September	5.40
October	3.72
November	2.10
December	0.93

Source: WERF 2011

Infiltration: SWMM Runoff hydrology does not incorporate an inherent infiltration factor like curve number hydrology does; therefore infiltration parameters are required as a separate model input. Two different infiltration methodologies were evaluated in the modeling process: 1) Horton infiltration and 2) Green-Ampt infiltration. Horton Infiltration methodology uses an empirical formula that sets the infiltration at an initial constant rate, and the rate decreases exponentially with time. After some time the soil saturation level reaches a value and the rate of infiltration levels off to a constant rate. Green-Ampt infiltration is a function of the soil suction head, porosity, hydraulic conductivity and time. As water infiltrates, the wetting front moves down into dry soil. Once the soil is saturated, or if the rainfall intensity exceeds the hydraulic conductivity, water ponds at the surface and can become runoff.

Infiltration input parameters were developed for the land use and soil conditions in the watershed area. Table 4-7 displays the infiltration parameters used in the analysis.

Table 4-7. Infiltration Parameters For Each Methodology
Starkweather Creek Phosphorus Treatment Phase I Study

Factor	Horton	Green-Ampt
Depression Storage		
Impervious	0.075	0.075
Pervious	0.15	0.15
Manning's n		
Impervious	0.013	0.013
Pervious	0.24	0.24
Zero Detention (%)	0	0
Maximum Infiltration Rate (in/hr.)	6	NA
Minimum Infiltration Rate (in/hr.)	0.2	NA
Decay Rate of Infiltration (1/hrs.)	0.001250	
Maximum Infiltration Volume	0	NA
Regeneration	0.01	NA
Average Capillary Suction	NA	8
Initial Moisture Deficit	NA	0.31
Saturated Hydraulic Conductivity	NA	0.13

A complete continuous simulation was run using each of the infiltration methodologies. The results of each run were then used to develop a range of runoff volumes that could be treated at a given flow rate. The approach to develop the range of volumes is discussed and presented in Section 4.2.3.

Hydraulic Factors: The hydraulic portion of the model represents the storm sewers, culverts, bridges, open channels, and detention basins that comprise the drainage system within the East Branch of the Starkweather Creek watershed. The hydraulic input parameters required by the model vary depending on the different parts of the drainage system. The source data used to compile the hydraulic model input data is summarized below.

- **Public Storm Sewers**: The information for the storm sewer included in the model was referenced from the storm sewer data provided by the City. In some areas, the City data uses a local datum. Per conversations with City staff, the factor used to convert from the local datum to NAVD88 is 845.6 feet. The major public storm sewers necessary to hydraulically connect the 39 delineated subbasins were incorporated into the model.
- **Private Storm Sewers**: Private storm sewers were not included in the analysis.
- **Open Channels**: The data for the East Branch of Starkweather Creek was imported from the HEC-RAS model used in the LOMR development. The data for the other open channels included

in the model were derived from the City of Madison storm sewer system data and the City of Madison topographic data.

- **Bridges**: The data for the bridges in the project area were imported from the HEC-RAS model used in the LOMR development.
- **Culverts**: The data for the culverts in the project area were either imported from the HEC-RAS model used in the LOMR development or referenced from the City storm sewer system data.
- **Detention Basins**: Several public and private detention basins exist within the project area. However, the majority of the detention basins serve single-site developments and were not included in the model. Autumn Lake is the only detention basin included in the model. Data for Autumn Lake was referenced from the Stormwater Management Plan created for the development served by Autumn Lake.
- **Overland Flow**: The drainage route for overland flow that occurs due to the storm sewer system surcharging or overtopping the channels was defined using the topographic data provided by the City.
- **Tailwater Conditions**: The average of the target summer minimum and maximum Lake Monona water surface elevation (844.95 feet) was used for the fixed backwater (tailwater). The data is available through the Dane County Land and Water Resources Department.

Model hydraulic input data, including invert elevations, length, slope, size, and type of link are included in Appendix D.

4.2.3 Watershed Model Results - Design Storm and Continuous Simulation

The model was executed for each of the design storms and the continuous ten years of rainfall data. Tables 4-8 and 4-9 summarize the results for each of the model analyses. The results are referenced from the model link just downstream of the proposed diversion location.

Table 4.8. Design Storm Event Model Results
Starkweather Creek Phosphorus Treatment Phase I Study

Storm Reoccurrence Interval (24-hour duration)	Rainfall Depth (in.)	Peak Flow Rate (cfs)	Runoff Volume (ac. ft.)
1 - yr.	2.49	268	554
2 - yr.	2.84	313	741
5 - yr.	3.47	421	1,114
10 - yr.	4.09	591	1,517
100 - yr.	6.66	1,378	3,413

Table 4.9. Continuous Simulation Results: Comparing Green-Ampt Infiltration to Horton Infiltration Starkweather Creek Phosphorus Treatment Phase I Study							
Water Year	Total Rainfall Depth	Green-Ampt Infiltration		Horton Infiltration		% Difference	
		Total Runoff Volume	Largest Peak Flow Modeled	Total Runoff Volume	Largest Peak Flow Modeled	Total Runoff Volume	Largest Peak Flow Modeled
(Oct. - Sept.)	(in)	(ac-ft.)	(cfs)	(ac-ft)	(cfs)		
2002	26.87	2,946	259	2,320	238	21%	8%
2003	23.73	2,669	316	1,955	254	27%	20%
2004	44.09	6,428	599	4,488	346	30%	42%
2005	25.6	2,999	317	2,192	226	27%	29%
2006	34.22	4,117	339	3,062	282	26%	17%
2007	43.24	6,940	991	4,758	642	31%	35%
2008	44.53	6,835	1023	4,738	540	31%	47%
2009	36.98	5,079	965	3,757	647	26%	33%
2010	40.91	5,651	661	4,126	428	27%	35%
2011	28.49	3,219	360	2,440	273	24%	24%
Average:	34.87	4,688		3,384		27%	29%

The continuous simulation model runs using the Green Ampt infiltration function consistently generated greater annual runoff volumes and peak flows compared to the Horton Infiltration method. There is no measured data to compare the modeled results. It was decided to use the Horton infiltration function so that the estimates of watershed runoff volumes would be conservative and thus the predicted phosphorus load reductions would be achievable.

Estimating Treatment Diversion Flow Rate: Not all of the wet weather flow volume in the East Branch Starkweather Creek may be diverted and treated. There are several limiting factors:

1. The WDNR will require a minimum baseflow to be maintained in the channel at all times with only the wet weather flows diverted for treatment. It should be noted that the existing “baseflow” at the project site is difficult to define. The targeted summer water surface elevation for Lake Monona is a minimum of 844.7 feet and a maximum of 845.2 feet. The channel bottom elevation near the proposed treatment diversion location varies from approximately 841 to 842 feet. This means that there may be approximately 3.5 feet of water depth in the channel with no “base flow”. Due to this condition, rather than maintain a minimum “baseflow” in the creek, a minimum water surface elevation will be targeted to be maintained in the creek. The purpose of the minimum water surface elevation is to protect habitat and maintain aquatic organism passage.
2. The maximum flow rate that can be diverted and treated is dependent on the existing drainage system, the proposed diversion hydraulics, and the quarry pond residence time relative to the flow rate. Adequate residence time must be provided in the pond to allow for proper floc settling.

Using the results of the model for the 10 year rainfall simulation, a series of plots were produced indicating the percent of runoff volume from the high, low, and average rainfall years that can be diverted and treated at varying peak flow diversion rates.

The results of this analysis are provided in Figure 4-2 and Table 4-10. From the graph it can be seen that at a peak flow diversion rate of 100 cfs, approximately 73 percent of the average annual discharge volume from the watershed could be diverted during the ten-year modeling period.

This analysis was conducted to provide a “starting point” for selection of a treatment flow rate and estimating potential annual treatment volumes and TP load reduction. More detailed modelling and refining of a conceptual diversion structure and treatment system is explained in Section 4.3.

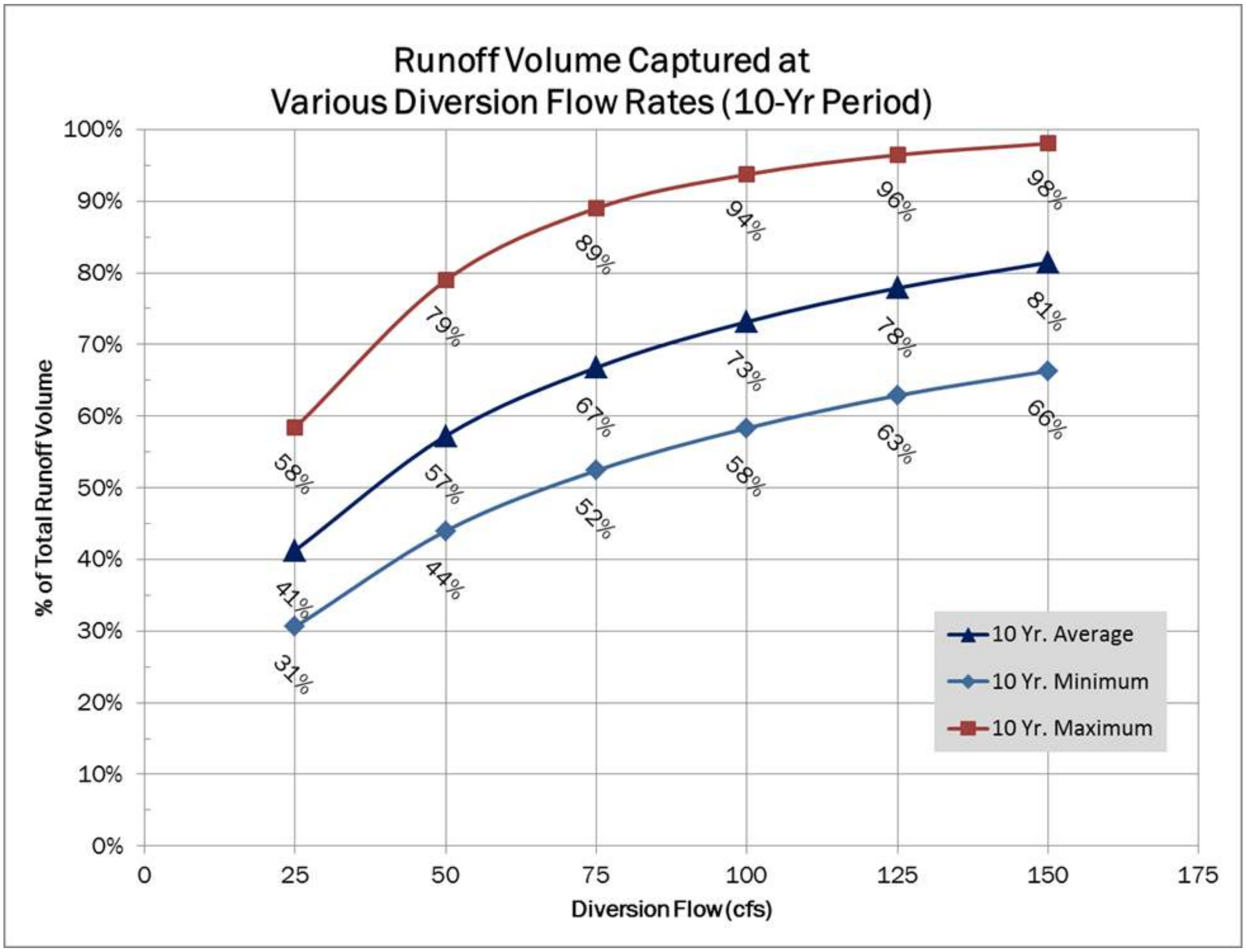

Figure 4-2. Diversion Rate Versus Percent of Total Runoff Volume (over the 10 year modeling period)

Starkweather Creek Phosphorus Treatment Phase I Study.

Table 4-10. Results of Peak Diversion Flow Rate versus Potential Annual Runoff Volume Treatment
Starkweather Creek Phosphorus Treatment Phase I Study

Water Year	Total Rainfall	Total Runoff Volume	Largest Peak Flow	Peak Diversion Flow Rate and Corresponding Annual Runoff Volume Treated											
				25 cfs		50 cfs		75 cfs		100 cfs		125 cfs		150 cfs	
(Oct. - Sept.)	(in)	(ac-ft.)	(cfs)	(ac-ft.)	(%)	(ac-ft.)	(%)	(ac-ft.)	(%)	(ac-ft.)	(%)	(ac-ft.)	(%)	(ac-ft.)	(%)
2001-2002	26.87	3,074	257	1,794	58%	2,427	79%	2,736	89%	2,881	94%	2,965	96%	3,014	98%
2002-2003	23.73	2,846	307	1,470	52%	1,943	68%	2,216	78%	2,397	84%	2,526	89%	2,627	92%
2003-2004	44.09	6,625	612	2,218	33%	3,244	49%	3,911	59%	4,393	66%	4,773	72%	5,080	77%
2004-2005	25.60	3,055	309	1,727	57%	2,278	75%	2,546	83%	2,725	89%	2,851	93%	2,932	96%
2005-2006	34.22	4,311	344	2,093	49%	2,859	66%	3,292	76%	3,567	83%	3,753	87%	3,891	90%
2006-2007	43.24	7,154	1,029	2,188	31%	3,146	44%	3,749	52%	4,172	58%	4,498	63%	4,743	66%
2007-2008	44.53	7,015	1,008	2,296	33%	3,290	47%	3,945	56%	4,410	63%	4,766	68%	5,056	72%
2008-2009	36.98	5,241	950	2,093	40%	2,824	54%	3,273	62%	3,602	69%	3,855	74%	4,059	77%
2009-2010	40.91	5,568	709	2,252	40%	3,231	58%	3,810	68%	4,197	75%	4,481	80%	4,697	84%
2010-2011	28.49	3,325	358	1,762	53%	2,360	71%	2,715	82%	2,933	88%	3,078	93%	3,165	95%
Average:	34.87	4,821	588	1,989	41%	2,760	57%	3,219	67%	3,528	73%	3,755	78%	3,926	81%
Minimum	23.73	2,846	257	1,470	31%	1,943	44%	2,216	52%	2,397	58%	2,526	63%	2,627	66%
Maximum	44.53	7,154	1,029	2,296	58%	3,290	79%	3,945	89%	4,410	94%	4,773	96%	5,080	98%

4.2.4 Watershed Existing Conditions Modeling Results and Discussion

As a result of this analysis it is estimated that an average of 3,400 to 4,700 acre feet of runoff are generated annually from the watershed to the project site. During the 10-year rainfall simulation the annual runoff volume ranged from 2,000 to 7,000 acre feet. These volumes, when combined with mean runoff TP concentration provide a range of annual TP loading that may be delivered to the treatment site.

From discussions with the City, and based on the measured wet weather in-stream TP concentrations, a system that treats an average water volume of 3,500 acre feet per year is anticipated to meet the City's desired benefit / cost criteria. The modeling results show that over 3,500 acre feet of runoff can be delivered to the treatment system on an average annual basis with a peak flow rate diversion of approximately 100 cfs. These average annual treatment volume and peak diversion flow rates are used for the project throughout the remainder of this report.

The treatment system modeling is described in Section 4.3.

4.3 Treatment System Modeling

4.3.1 Treatment System Components

Conceptually, the creek diversion and water conveyance features include:

1. An inlet / diversion structure located just upstream of the three existing CMP culverts at the abandoned railroad crossing. The City requested that the conceptual design assume that the existing crossing remains in place and 2 of the 3 culverts are reconstructed.
2. A retractable weir structure in the 2 reconstructed culverts in the channel.
3. An operable gate on the diversion inlet to control flow into the system.
4. A conveyance pipe from the diversion inlet to the existing quarry pond.
5. A lift station to pump treated wet weather flows back to Starkweather Creek.

These components are conceptually shown on Figure 4-3. Additional details on these features are provided in Section 5 of this report. The treatment system model was configured to include the following elements:

1. A gate at the inlet pipe that can open to allow flow into the treatment system and close when runoff is not occurring.
2. A retractable weir at the upstream opening of the reconstructed culverts to prevent backflow in the channel when the inlet gate is open and retract during non-runoff periods.
3. A conveyance pipe sized to carry the necessary flow rate and volume to the treatment system.
4. The wet pond to allow for floc settling.
5. An outlet pump station to pump treated water from the pond back to Starkweather Creek.

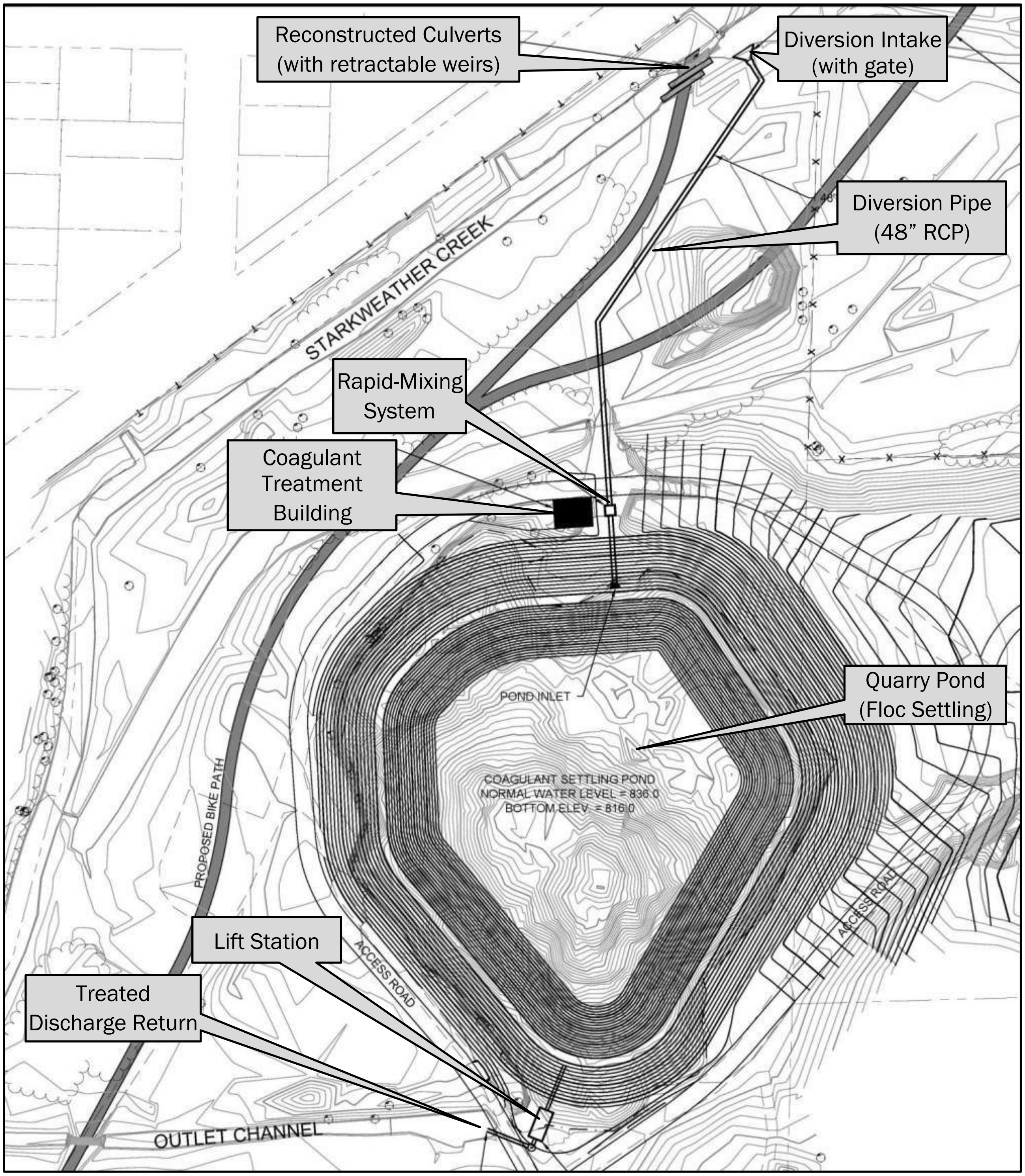

Figure 4-3. Conceptual Components of Treatment System;

Starkweather Creek Phosphorus Treatment Phase I Study.

4.3.2 Treatment System Modeled Component Assumptions and Conditions

The following modifications were made to the existing conditions watershed model to evaluate the proposed treatment system:

1. A rectangular gate at the entrance of the diversion pipe. The gate will open at the start of each rain event and close two (2) hours after the end of each rain event.
2. If the quarry pond elevation is greater than the channel elevation (at the diversion), the diversion gate will close. (This will prevent treated quarry water from back flowing into the channel.)
3. A pipe or box culvert to convey the water from the inlet to the quarry pond.
4. The quarry pond's normal water surface elevation will be pumped down to provide a positive hydraulic slope to the inlet culvert, improve treatment volume storage, and prevent backflow to the channel. This will be accomplished with a lift station at the pond outlet.
5. Regrading of the quarry pond to provide optimal storage and residence time.
6. The quarry pond outlet lift station discharge rate will be determined to treat the selected peak diversion flow rate while maintaining an acceptable pond residence time of at least 6 hours.
7. The quarry pond lift station operation ("on / off") will be determined based on the pond water surface elevation.
8. An operable weir may be located across Starkweather Creek on the upstream side of the existing railroad culverts. The weir may be needed to reduce backwater flow into the treatment system from the downstream channel. Whenever the diversion gate is open for the treatment process, the retractable weirs will be in the "up" position to enhance flow diversion and minimize backwater effects.

A schematic of the weir structure and culverts is provided in Figure 4-4. A schematic of the treatment system is provided in Section 6.

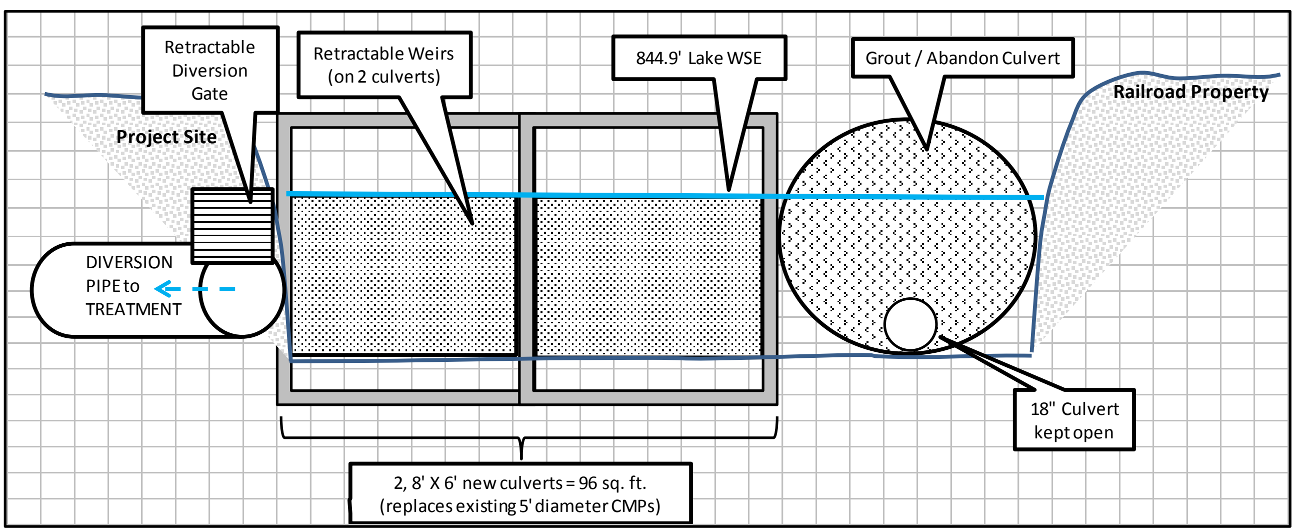

Figure 4-4. Schematic of Diversion and Weir (view looking downstream)

Starkweather Creek Phosphorus Treatment Phase I Study.

4.3.3 Treatment System Modeling Results

Approximately 80 combinations of potential treatment system components were modeled to optimize the system configuration and achieve treatment of 3,000 acre feet of runoff volume per year. The model was run for the following time periods representing dry, median, and wet rainfall years.

1. Water Year 2003 (24.4 inches)
2. Water Year 2006 (35.4 inches)
3. Water Year 2008 (44.5 inches)

The modeling period for each year was March 12 - December 2 to represent the rain runoff period. It was assumed that the treatment system would not be activated during the winter period because frozen pond conditions would prevent floc settling.

Factors that were varied in the model runs include:

- Size of gate opening
- Gate open/close conditions
- Conveyance culvert size and slope
- Pond normal water surface elevation
- Pond outlet pump rate
- Pond outlet pump on/off conditions
- Analysis period / Water Years
- Pond stage/storage

Based on the modeling analysis, a set of design criteria and conditions were determined to achieve the treatment of 3,000 acre feet of annual runoff volume (under the 2006 Water Year precipitation). Table 4-11 summarizes the design criteria and conditions.

Table 4-11. Treatment System Design Criteria and Conditions
Starkweather Creek Phosphorus Treatment Phase I Study

Factor	Criteria / Condition*
Lake Tailwater Elevation	844.5 feet
Diversion Gate Opening	Size: 4 ft. x 4 ft. Gate Open: at start of rain event Gate Close: 2 hours after end of rain event
Diversion Culvert	Length: 645 ft. Size: 48 inch diameter Slope: 0.5% Upstream Invert: 841 ft. Downstream Invert: 839 ft.
Pond Outlet Lift Station:	Pump Rate: 25 cfs Pump on: Pond WSE 837 Pump off: Pond WSE 836
Pond	Maximum Water Surface Elevation: 847 feet Normal Water Surface Elevation: 836 Maximum Water Surface Area: 6.04 acres Normal Water Surface Area: 4.31 acres Pond Maximum Storage: 57 acre feet Maximum Pond Depth: 20 ft. below Normal WSE (elevation 816 ft.)
Channel Weir:	Weir Up Elevation: 844.9 ft. Weir Down Elevation: channel bottom Weir Up: at diversion gate open Weir Down: at diversion gate close

**Note: These conditions are preliminary and subject to revision during final design.*

Incorporating the conditions summarized in Table 4-11 into the model, the annual treatment volumes can be estimated for the selected rainfall conditions as summarized in Table 4-12.

Table 4-12. Treatment System Capacity Model Results Starkweather Creek Phosphorus Treatment Phase I Study			
Analysis Period	Annual Rainfall Depth	Peak Flow Rate into Pond	Total Annual Volume into Pond
(Water Year)	(inches)	(cfs)	(acre feet)
Water Year 2003	24.4	110	2,521
Water Year 2006	35.4	111	3,448
Water Year 2008	44.5	109	3,517

As shown on Table 4-12, the configured treatment system, as modeled, would treat approximately 3,500 acre feet of water in the WY 2006 rainfall condition. This value is greater than the predicted annual runoff from the watershed. As discussed in Section 4.2.3, the summer operating level of Lake Monona is at an elevation approximately 3.5 feet above the channel bottom at the diversion site. The current invert of the proposed gate is 842.5, which is 0.5 feet above the channel bottom and below normal lake level. This means that when the gate opens, the initial water inflow will be a mix of runoff water and standing water in the channel. Thus, over a year's time there will be approximately 500 acre feet of treated water that is not from the watershed's runoff. This "extra" water still has high phosphorus levels, and removal of this phosphorus will benefit Lake Monona.

4.3.4 Results of Pond Residence Time Analysis

The treatment system model was also used to analyze the pond residence time over the range of expected flow rates and water surface elevations. The pond residence time is important so that there is adequate time for floc (with pollutants) to settle so that the floc (and pollutants) remain in the pond. The equation for calculating residence time is the flow rate divided by the volume of water the pond. The model tracks the inlet flow rate and pond water surface elevation (and associated water volume) for each time step (1 minute). The residence time was calculated for each time step in each storm event during the 2005 - 2006 Water Year. Figure 4-5 summarizes the results of this analysis and shows that for over 99 percent of the runoff period, the pond's residence time exceeds 6.5 hours.

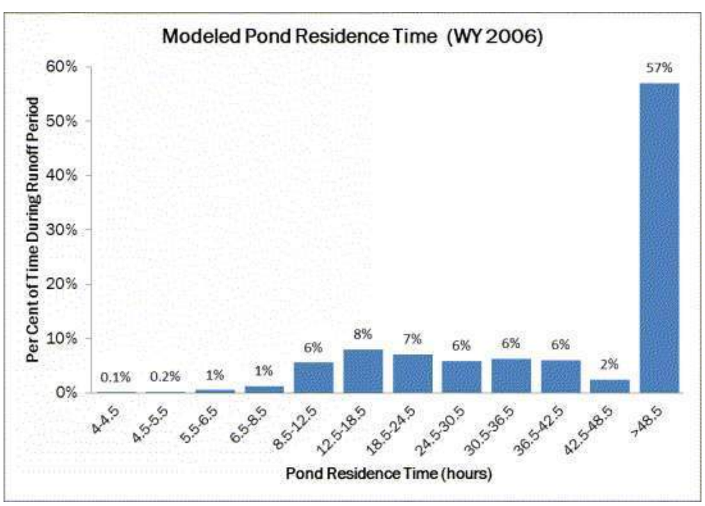

Figure 4-5. Analysis of Pond Residence Time (WY 2006)

Starkweather Creek Phosphorus Treatment Phase I Study.

Section 5

Potential Phosphorus Treatment Performance

5.1 Introduction

Four factors were evaluated to estimate the potential annual mass TP load reduction at the project site:

1. The annual stream flow and runoff volume at the project site
2. The minimum and maximum flow rate that could be treated by the system
3. The average TP concentration in the raw treated water
4. The potential TP load reduction from coagulant treatment

The method used to evaluate each factor is explained below.

5.2 Annual Stream Flow and Runoff Volume

5.2.1 Measured Flow

Downstream from the project site is a USGS gauging station that monitored flow in Water Year 2009 – 2010. The station is located on the main channel of Starkweather Creek (below the confluence of the West and East Branch. However USGS personnel reported that the measurements were very problematic because of the tailwater effect from Lake Monona, and other factors which made the site a poor location for flow gauging. After discussing the data from this station, it was decided not to use the information in the evaluation of this project.

5.2.2 Modeled Wet Weather Flow Rate and Volume

Annual wet weather flow rates and volume in the East Branch of Starkweather Creek at the project site were based on the model results (see Section 4). The continuous simulation runoff model utilized measured rainfall over a ten year period (Water Year 2001/02 through 2010/11) from the NOAA station located at Dane County Regional Airport. The modeling analysis included surface runoff to the drainage system. Channel dry weather baseflow is not considered in the model. Thus, the model results are an estimate of the total potential stormwater runoff volume at the proposed treatment location. The modeled annual stormwater runoff volumes are summarized in Table 4-9.

As previously discussed the target peak water diversion rate is approximately 100 cfs and the average annual treatment volume is 3,500 acre feet. The total water volume treated will vary from year to year depending on rainfall patterns.

5.3 Selecting Raw Water Total Phosphorus Concentration for Load Calculations

The concentrations of pollutants (sediment, phosphorus, heavy metals, bacteria, etc.) fluctuate significantly in a given surface water system over time. Many factors including seasonal variations in land and vegetation conditions, precipitation, water temperature, and cultural conditions can change the pollution concentrations in a water body. The target pollutant for the coagulant treatment system is TP, and the concentration of this element varies in the creek throughout the year and at different flow regimes.

TP concentrations measured in the East Branch of Starkweather Creek during the six 2015 monitoring events were used to estimate average annual TP load. (See Section 3.2 for details on the stream sampling task). The reasons for using this data source are summarized below:

1. The monitoring for this project reflects water quality conditions under the most recent watershed conditions and takes into account the current land use and level of stormwater management in the watershed.
2. The monitoring was conducted using the Equal Width Increment (EWI) approach as defined in USGS protocols. Under the EWI monitoring approach the water sample is integrated over the entire cross section (stream width and depth) to better represent the mean stream water quality. Obtaining a sample from a single point characterizes the conditions of the stream at single point in the cross section.
3. The monitoring was purposely conducted during high flow (runoff) periods. The water quality is reflective of stormwater runoff conditions, and avoids base flow conditions.

Table 5-1 provides the TP monitoring results used for load calculations. An average raw water TP concentration of 0.205 mg/L will be used to estimate the annual TP load from stormwater runoff in the watershed.

Table 5-1. Total Phosphorus Monitoring Results
Starkweather Creek Phosphorus Treatment Phase I Study

Date	Total Phosphorus (mg/L)
4-8-2015	0.265*
5-4-2015	0.134*
5-27-2015	0.190*
6-12-2015	0.198*
7-29-2015	0.225
10-28-2015	0.217
Average	0.205

** average of 3 raw samples*

5.4 Coagulant Performance – TP Reduction

Figure 3-4 shows the percent TP removal from the various coagulants at different Al concentrations. Using the coagulant Aluminum Chlorohydrate (ACH) at an Al concentration of 5 mg/L would provide an estimated 89 percent TP reduction. The justification for selecting ACH as the coagulant of choice was previously explained in Section 3.

For purposes of analyzing the system's TP removal performance and cost effectiveness, a conservative 85 percent TP load reduction is used in the remaining sections of the report.

5.5 Estimating the Coagulant Treatment System TP Load Reduction

The potential TP load reduction from the treatment system was estimated using the factors described in Sections 5.2 – 5.4. The average annual values based on the modeled treatment system conditions is summarized in Table 5-2.

Table 5-2. Estimated Annual TP Removal from Coagulant Treatment System
Starkweather Creek Phosphorus Treatment Phase I Study

Factor	Value
Annual Target Treatment Volume	3,500 ac. ft.
Average TP Concentration	0.205 mg/L
Average Annual TP Load to be Treated:	1,951 lbs./yr.
Coagulant Effectiveness (percent reduction of TP)	85%
Target Annual TP Load Reduction:	1,658 lbs./yr.

Under the Rock River TMDL Waste Load Allocation, the City of Madison MS4 system annual TP load reduction target is approximately 16,000 lbs. The Starkweather Creek coagulant treatment system has the potential to achieve approximately 10 percent of the City's Rock River TMDL total TP load reduction requirement.

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Section 6

Feasibility Design Components

6.1 Conceptual Plan Drawings

Conceptual drawings were prepared for the coagulant treatment system using the information collected during this study and experience from similar projects. The basic site design components are provided in the following list:

1. Modifications to the existing abandoned railroad culverts and diversion structure in Starkweather Creek.
2. Inlet structure and gate for the diversion system.
3. Conveyance culvert from Starkweather Creek to the quarry pond.
4. Quarry pond re-grading / modifications.
5. Site grading and improvements for the access road, snow dump area, and access to the treatment building
6. Quarry pond outlet lift station
7. Building for the treatment equipment, monitoring equipment, coagulant storage, and controls.

Preliminary drawings of these primary project features are provided on Figures 6-1 through 6-4. The treatment system configuration will likely change as additional information is developed during the detailed design phase of work.

6.2 Description of Treatment System Components

The project treatment train includes the following primary unit processes:

1. Coagulation –rapid mix basin
2. Settling pond
3. Water flow rate measurement
4. Coagulant injection system
5. Coagulant storage and equipment enclosure
6. Floc removal and dewatering
7. Floc disposal

A brief description of each project unit process is provided in the following sections.

6.2.1 Coagulant Addition and Rapid Mix

The diverted water flowing in the 48" pipe will discharge into a rapid mixing system where coagulant will be added. The mixing will take place upstream from the settling pond. Water flow rate through the 48" pipe will be continuously monitored by measuring both depth and velocity of flow and recorded. Because water flow rate measurement is essential to the treatment system operation and effectiveness, two (duplicate) operable water flow meters will likely be installed. Water flow rate will be converted to a milliamp (mA) signal and sent to the coagulant feed pump controller. The coagulant feed pump will automatically inject the proper dose of coagulant (4-5 mg Al/L) based on measured water flow rate. A mechanical rapid mixer or "flash-mixer" will be used to thoroughly mix the water with the coagulant. Intense rapid mixing for 10 seconds is sufficient for complete mixing of the coagulant with the raw water and floc formation.

6.2.2 Settling Pond

After the coagulant has been added to the water and rapid mixed the flow will enter the settling pond. The settling pond will provide time for floc to settle to the bottom of the pond while the treated effluent will be pumped from the pond or discharge via gravity to the outflow structure and channel.

The required settling time for complete floc settling in an off-line coagulant treatment system is typically in the 3 to 6 hour range. During this study a minimum residence time of 6 hours was used for design at the selected peak diversion water flow rate of 100 cfs. The required wet pool volume to provide 6 hours of residence time is 50 acre-feet (at a water flow rate of 100 cfs). To minimize the potential for anoxic conditions on the pond bottom and to allow for easy floc removal from the bottom of the pond, the pond normal water depth will be limited to less than 20 feet. This will require regrading of the pond bottom in some areas.

Additional pond volume is needed for floc storage. Based on the modeling described in Section 4, during treatment of 100 cfs of water, the minimum water volume in the settling pond is 57 ac-ft. Depending on the final configuration of the settling pond, flow barriers will likely be needed to maximize residence time and minimize short circuiting in the pond.

6.2.3 Coagulant Injection System

Key components of the coagulant treatment system are the coagulant feed pumps and pump control system. The coagulant feed pump will inject the proper amount of coagulant based on information received from the pump programmable logic controller (PLC). The PLC receives information from the water flow meter. The same coagulant dose will be maintained regardless of water flow rate. The PLC is programmable and provides a great deal of flexibility in the operation of the system.

The PLC will receive the 4 to 20 mA signal from the water flow meter and control the coagulant feed pump motor based on the influent water flow rate. At a peak design water flow rate of 100 cfs and an ACH dose of 5 mg Al/L, the peak ACH feed rate would be approximately 1.4 gallons per minute (gpm). The system will be designed to treat all diverted flows up to 100 cfs. Because it is not possible to treat water flow rates from1 to 100 cfs with a single pump, two coagulant feed pumps will be needed. A smaller pump will be used for lower water flow rates and a larger pump will be used to treat higher water flow rates. To enhance the reliability of the system, a second backup coagulant feed pump and control panel will be considered and discussed with the city during final design. With the redundancy provided by a backup feed pump, the system can continue to operate if either the primary pump or the control panel is inoperable for any reason. A coagulant flow meter will be used to meter the volume of coagulant added to the raw water for treatment.

6.2.4 Coagulant Storage and Equipment Building

The treatment of 3,500 acre-feet of water at an ACH dose of 5 mg Al/L will require about 33,800 gallons of ACH in an average rainfall year. At a maximum ACH pumping rate 1.4 gpm, the maximum daily pumping rate is about 2,000 gallons per day. The preliminary design includes two 5,000 gallon coagulant storage tanks. This will provide about 5 days of coagulant at the maximum pumping rate. Coagulants are delivered in tanker trucks with a capacity of approximately 4,500 gallons.

Fiberglass Reinforced Plastic (FRP) tanks are preferred for coagulant storage although high density polyethylene (HDPE) tanks are less expensive. Secondary containment is accomplished by using a double wall tank with interstitial wall monitoring. The tank storage area will need to be heated to prevent freezing of the coagulant.

The coagulant feed pumps and control panel, coagulant flow meter and piping, water flow metering electronics, and coagulant storage tanks should be placed within a building. The preliminary design includes a split face block building with metal or shingle roof. The floor will need to be designed to handle the weight of the full chemical storage tanks; aluminum coagulants weigh approximately 11 pounds per gallon. The building will need electricity and portable eyewash / shower station. As currently proposed, the building would not have potable water supply or sanitary sewer service. The building size and opinion of cost includes a storage tank area, a pump room, and electrical room, and a small office area. The pump station and the rapid mixer will require 230/460V 3-phase power to the project site.

6.2.5 Floc Handling

During the treatment process, floc will gradually build up on the bottom of the settling pond and must be removed to maintain sufficient pond volume and required residence time. Therefore, a key component of the overall project design is a clear approach to manage the accumulated floc. Based on the jar testing conducted during the study, the estimated average annual consolidated wet floc volume is approximately 3,760,000 gallons (18,600 cu. yds.) per year (the “average” runoff year was the 2006 WY).

The wet floc can either be dredged and pumped to the existing sanitary sewer system or dredged and pumped on site for dewatering and sent off-site for disposal. Pumping wet floc to the sanitary sewer system is easier because there is no required floc dewatering or disposal of the dewatered floc. In some places the local government performs the dredging while in other cities a contractor is hired to dredge the wet floc. For purposes of cost estimating, it was assumed that the sanitary sewer floc disposal approach would not be available. As discussed below, a drying area using dewatering bags (“Geotubes®” is one product) would be the approach used by the City.

The current floc dewatering approach would use a portable hydraulic dredge to pump accumulated wet floc from the bottom of the settling pond to geotextile dewatering bags commonly used for sediment dewatering. A manually driven dredge would be used and this dredge could be trailered and used to remove sediment from other stormwater ponds within the city.

As shown on Figure 6-1, a municipal snow storage area is proposed as part of the project. The snow storage area will consist of a hard-pack gravel pad approximately 2 acres in size. This area provides a good location for the dewatering bags and dewatering operation during the non-winter months. It will likely be necessary to add a polymer to the wet floc before entering the dewatering bags to aid the dewatering process. The dewatering area would be graded such that the supernatant (water seeping from the geotextile bags) would flow back to the settling pond. Once the wet floc has dewatered, the geotextile bags are cut open, and the dewatered floc is loaded into trucks. The geotextile bags are only used once. At this time, it is the City’s intent to truck the dewatered floc to the county landfill. The project opinion of probable construction cost includes the cost of the dredge and associated piping, fittings, and valves. The annual O&M cost includes the geotextile bags, polymer, the cost of trucking the dewatered floc to the landfill, and labor for dredging and dewatering the wet floc.

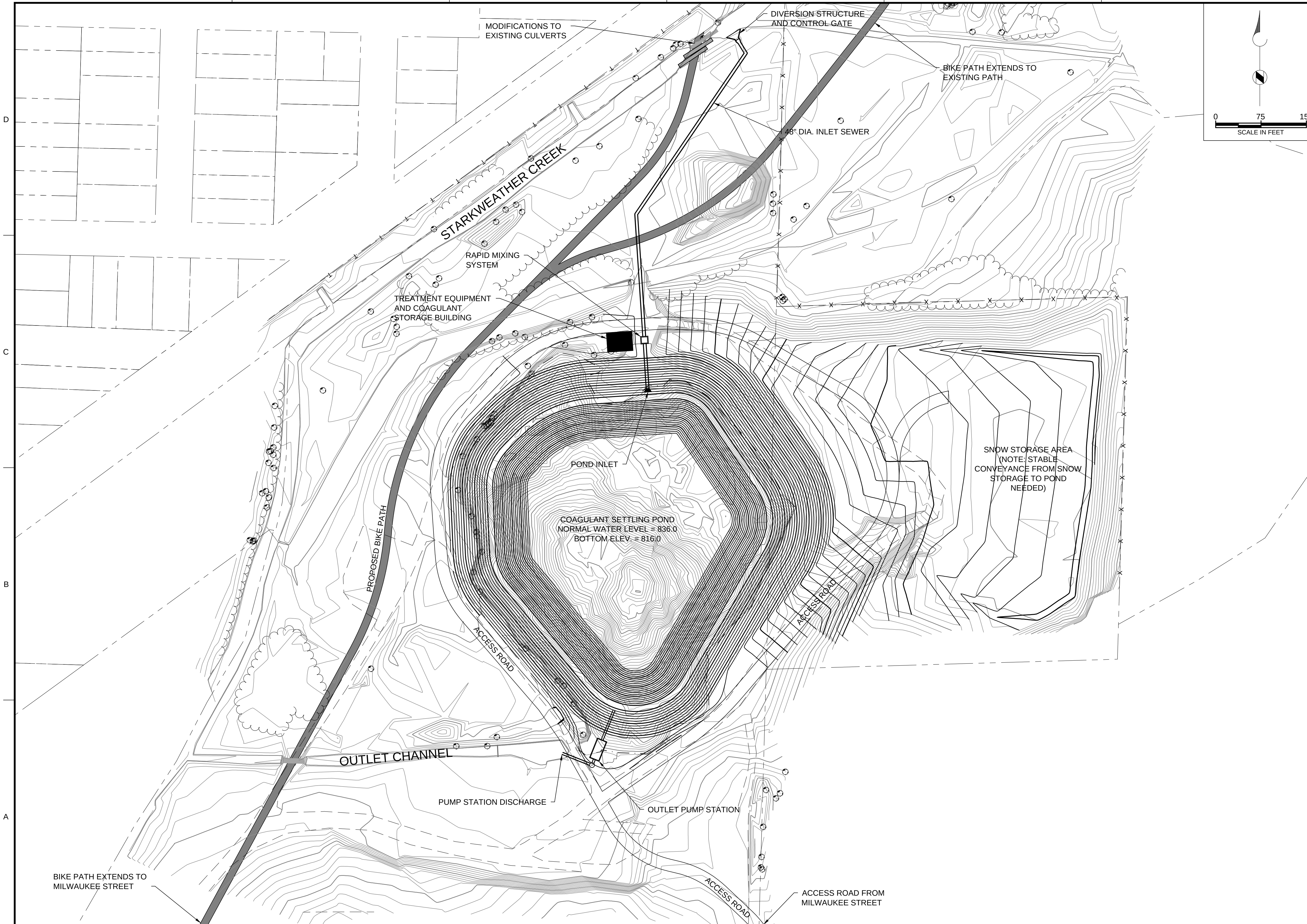
Once the floc is dewatered, there are multiple potential beneficial uses. One option is to use the dewatered floc for agricultural non-point source best management practices (BMP) augmentation and MS4 treatment BMP augmentation. Dewatered floc applied to phosphorus enriched soils can bind available phosphorus reducing leaching of phosphorus from soils to surface waters. Dewatered floc can be used to amend the soils in constructed wetlands during maintenance to bind phosphorus and minimize release during reflooding. Potential dewatered floc beneficial uses will be evaluated and refined during the project’s final design phase.

6.2.6 Remote Monitoring and Operation and Maintenance

Remote monitoring and control of the system is proposed to allow operations staff to observe the operation of the system and adjust settings from a remote location. Web cameras to view key system components are also being considered. The purpose of remote monitoring is to reduce unnecessary trips to the site, make minor operational adjustments, as well as alert offsite personnel if coagulant shipments need to be scheduled or if there are system concerns that need to be addressed. Proposed remote monitoring elements typically include:

1. System power on/off
2. Building access
3. Coagulant storage tank(s) volume
4. Flow meter water depth, velocity, and flow rate
5. Totalized water flow
6. Coagulant feed pump run
7. Coagulant feed rate
8. Totalized coagulant pumped
9. Chemical feed pump alarm
10. Mixer run
11. Automated/operable gate position

An operation and maintenance (O&M) manual will be prepared for the facility during final design along with fill-in-the-blank observation forms to be completed during each visit by operations staff. Training will be provided for City personnel operating the system. Although the coagulant treatment system operates automatically, visits should be performed at least two to three times each week. Simple system testing should be performed to ensure the operable system components are working properly. Personnel should also record key system information. Periodic servicing of the coagulant feed pumps is required along with occasional system repairs. Required spare parts will be kept on site. The operators will also need to dredge the wet floc from the settling pond and transfer the wet floc to the sanitary sewer or drying area. If the floc is dewatered, the operators will also need to dispose of the dewatered material.



Brown AND Caldwell

CONCEPTUAL DESIGN NOT FOR CONSTRUCTION

CITY OF MADISON WISCONSIN

STARKWEATHER CREEK COAGULANT TREATMENT SYSTEM - PHASE I
CITY OF MADISON
WISCONSIN

REVISIONS

REV	DATE	DESCRIPTION

LINE IS 2 INCHES AT FULL SIZE

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APPROVED:

FILENAME
1_OVERVIEW_PROPPOND.DWG
BC PROJECT NUMBER
147143
CLIENT PROJECT NUMBER

PROPOSED PROJECT OVERVIEW

DRAWING NUMBER
FIGURE 6-1

SHEET NUMBER
OF

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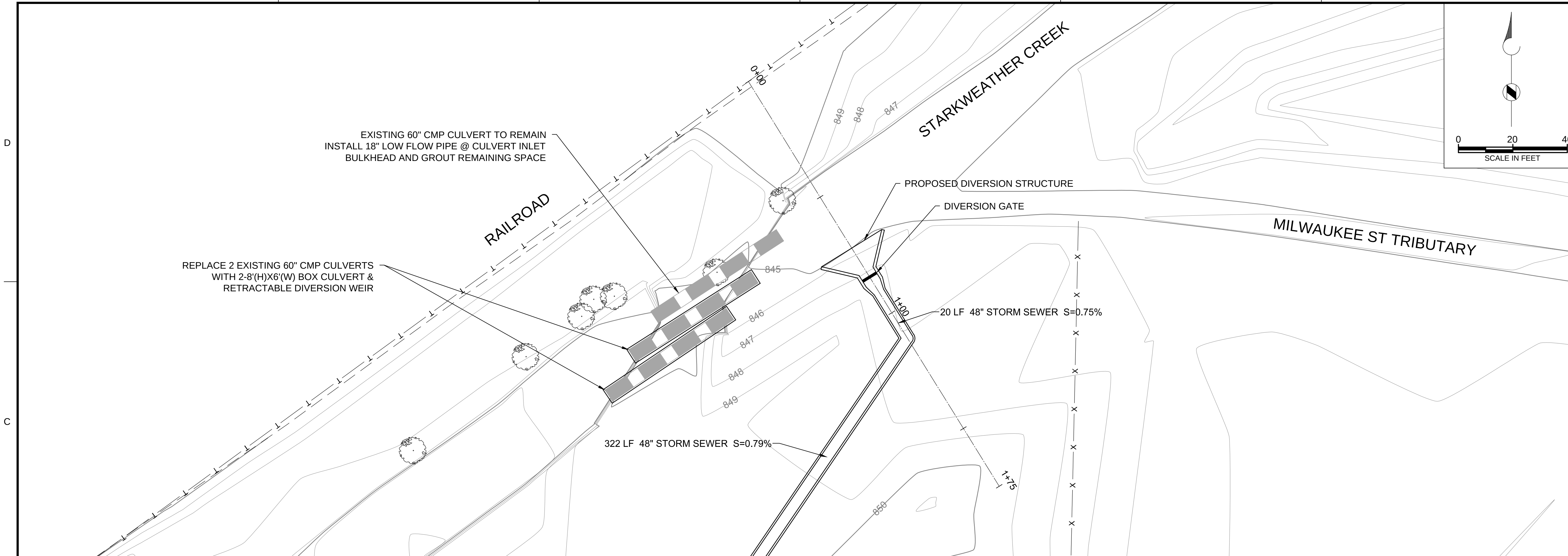

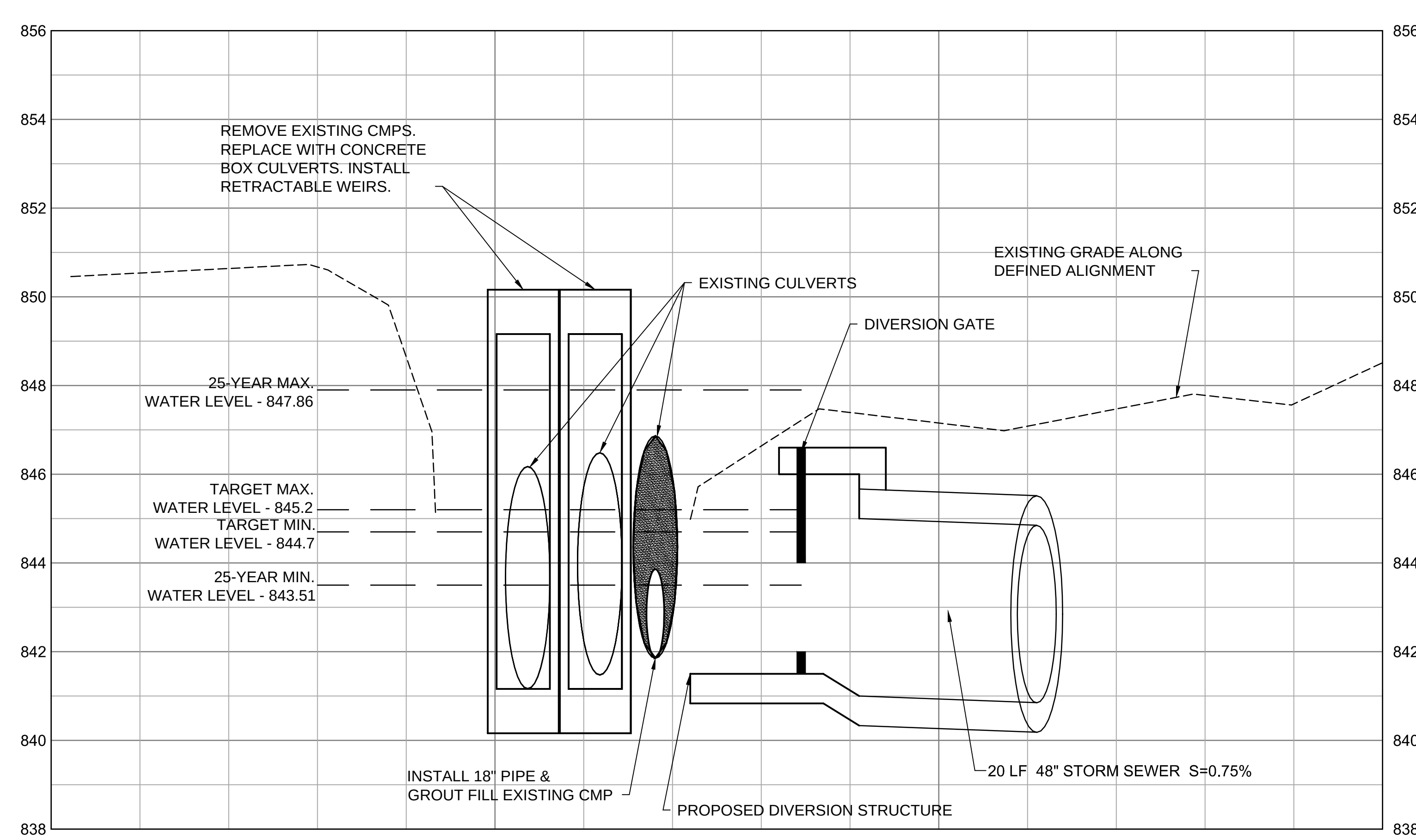

Brown AND Caldwell

CONCEPTUAL DESIGN NOT FOR CONSTRUCTION

CITY OF MADISON WISCONSIN

STARKWEATHER CREEK COAGULANT TREATMENT SYSTEM - PHASE I
CITY OF MADISON
WISCONSIN

REVISIONS

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147143
CLIENT PROJECT NUMBER

INLET STRUCTURE LAYOUT

DRAWING NUMBER
FIGURE 6-2

SHEET NUMBER
OF

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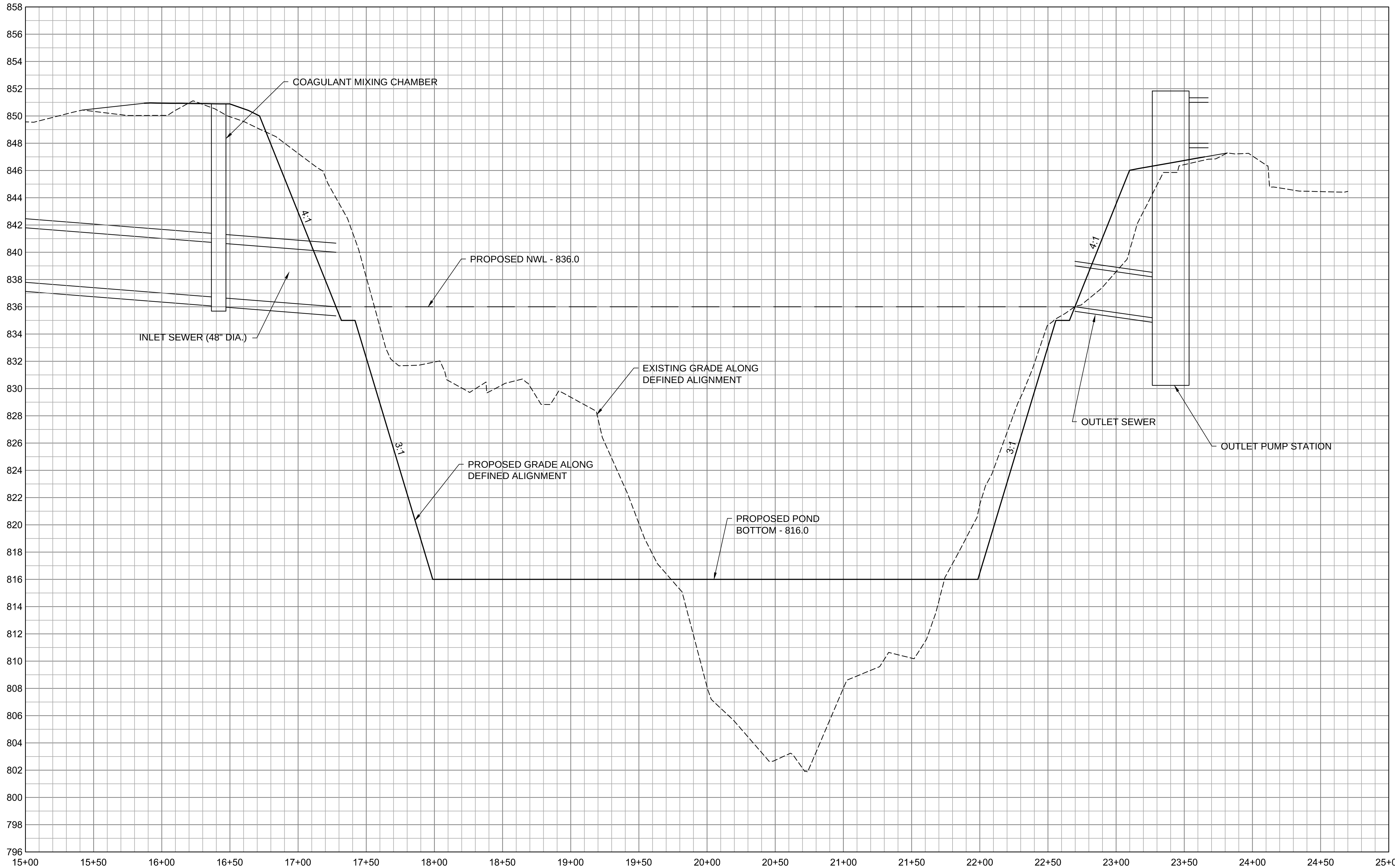

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CITY OF MADISON WISCONSIN

STARKWEATHER CREEK COAGULANT TREARMENT SYSTEM - PHASE I
CITY OF MADISON
WISCONSIN

REVISIONS

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FILENAME 3_POND_XSEC.DWG
BC PROJECT NUMBER 147143
CLIENT PROJECT NUMBER

POND CROSS SECTION

DRAWING NUMBER
FIGURE 6-3

SHEET NUMBER
OF

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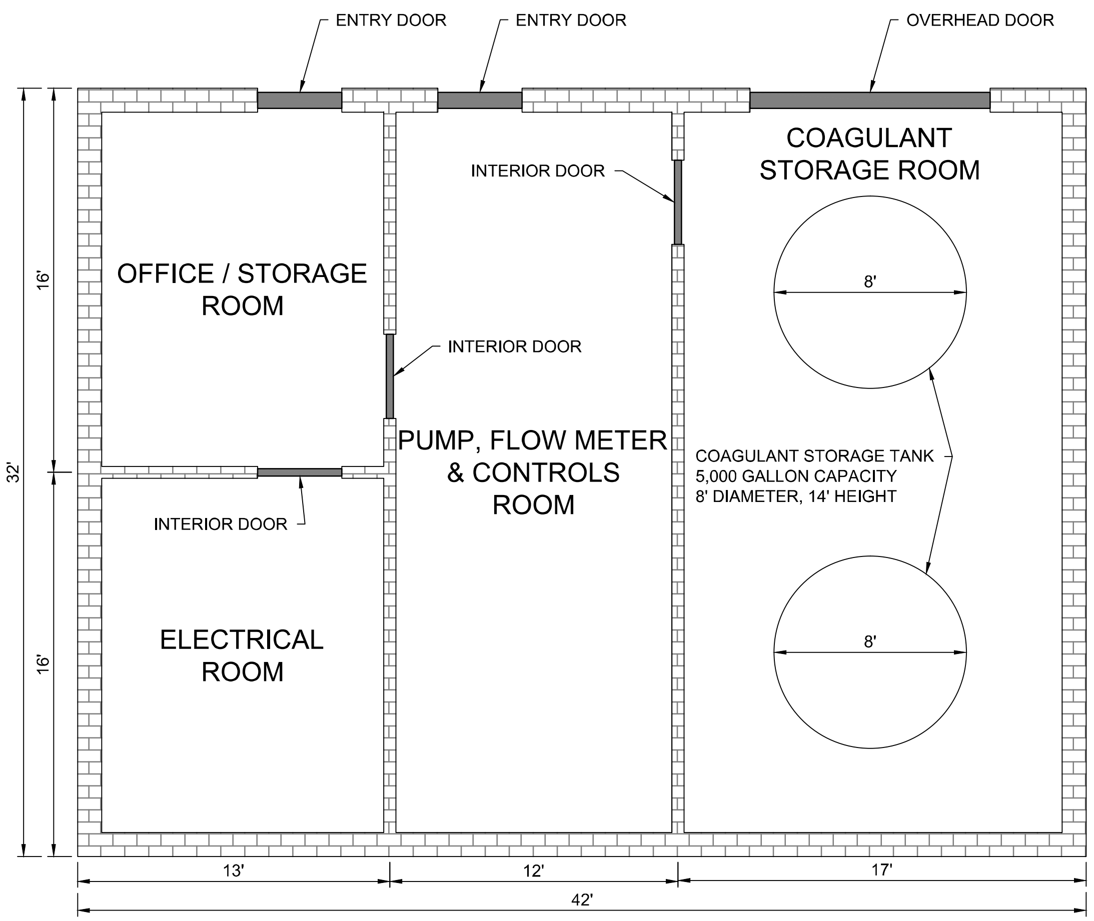

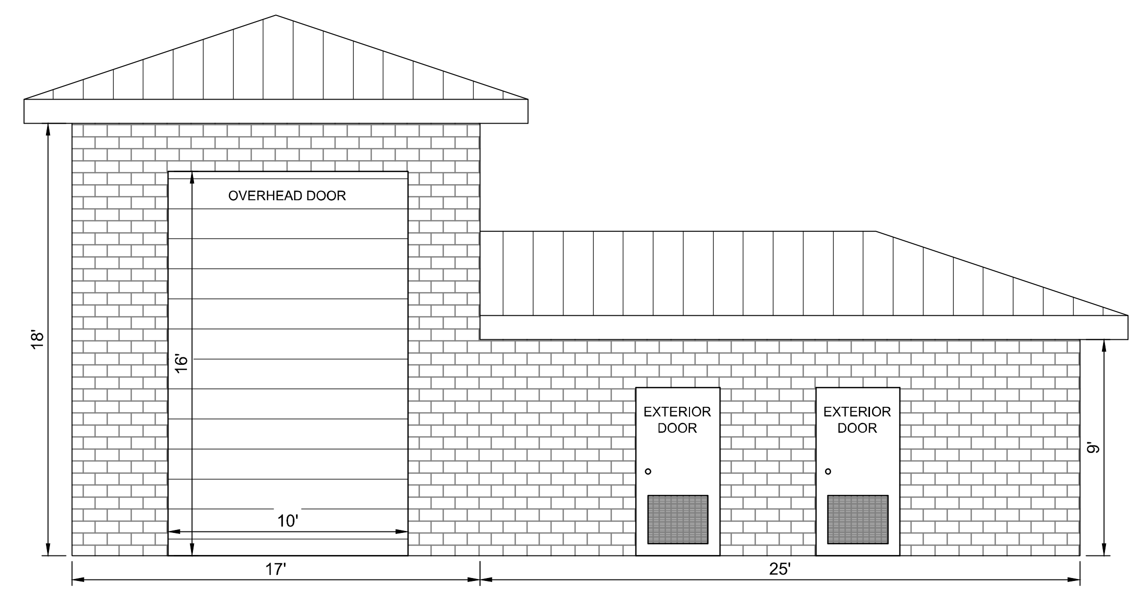

Brown AND Caldwell

CONCEPTUAL DESIGN NOT FOR CONSTRUCTION

CITY OF MADISON WISCONSIN

STARKWEATHER CREEK COAGULANT TREARMENT SYSTEM - PHASE I
CITY OF MADISON
WISCONSIN

REVISIONS

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BC PROJECT NUMBER
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CLIENT PROJECT NUMBER

TREATMENT EQUIPMENT AND COAGULANT STORAGE BUILDING

DRAWING NUMBER
FIGURE 6-4
SHEET NUMBER
OF

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6.3 Project Cost Estimates

Based on available information, and the conceptual drawings, cost estimates were developed for:

1. Site Work and Conveyance System (site grading, storm sewers, pond grading, lift station, access road, etc.),
2. Treatment System (housing, equipment, controls, etc.), and
3. Annual Operations and Maintenance

Unit cost estimates were based on several sources including:

1. For work of similar nature (site work, excavation, storm sewers), contractor bid tabs from other Wisconsin municipalities were evaluated.
2. The City of Madison provided unit cost rates for components that the City had information on.
3. Vendor estimates were provided for certain components such as the diversion gate and movable weir, and other equipment.
4. Costs for treatment system equipment, instruments, and other components of the actual treatment process were obtained from similar treatment systems in other states.

It is understood that at this stage of the project, quantities and unit costs are best estimates from current information. In subsequent stages the design will be refined and more accurate quantities and costs will be determined. Also, better unit cost values will be obtained because there will be a better understanding of the type of soil at the site, specific groundwater and bedrock conditions, and more specific product details will be known. The cost estimates presented in this section will be modified at later stages of the project.

Table 6-1 provides a summary of the capital and non-capital cost estimates for the project. A more detailed breakdown of the cost estimate line items is provided in Appendix D.

Table 6-1. Starkweather Creek Project Cost Estimates Starkweather Creek Phosphorus Treatment Phase I Study	
Construction Costs	
Site Work and Conveyance	$2,280,000
Coagulant Treatment System	$1,201,500
Construction Contingency (30%)	$1,044,450
Construction Sub-Total	$4,525,950
Design and CRS (20%)	$905,190
Cost Escalation from 2016 (3%) (assume construction in 2017)	$135,779
Total Construction Estimate	**$5,566,919**
Annual Operation and Maintenance	
Labor (weekly maintenance, inspections, monitoring, floc removal)	$30,900
Coagulant Purchase	$158,500
Non-capital (equipment, supplies, lab, material, etc.)	$85,580
Equipment Renewal (5%/year)	$17,500
Annual O&M Subtotal	$292,480
Annual O&M Contingency (20%)	$58,496
Total Annual O&M Estimate:	**$350,976**
20 Year Life Cycle cost ($/ lb. Total Phosphorus Removal)	
TP removal over 20 years (1,685 lbs./yr.)	33,160
Capital Costs:	$5,566,919
O&M Costs over 20 years:	$7,019,520
$/lb. Phosphorus removal (over 20 year period):	$379.57

Section 7

Conclusions and Next Steps

7.1 Conclusions

This feasibility level analysis addressed many of the questions related to the implementation an off-line coagulant treatment system at the project site. The results are summarized as follows:

1. The floodway and floodplain remapping indicates that the conceptual system could be constructed on the project site and meet FEMA requirements.
2. The tested coagulants were very effective for removing phosphorus in Starkweather Creek wet weather discharges. An average annual 85 percent TP load reduction (from raw water sample) could be expected.
3. With the diversion and treatment of discharges up to 100 cfs approximately 3,500 acre feet of runoff could be treated by the system during an average rainfall year.
4. With the diversion and treatment of discharges up to 100 cfs the predicted annual phosphorus load reduction on an average rainfall year is 1,658 pounds per year.
5. The planning level opinion of probable construction cost, including a 30 percent contingency, is approximately $5,566,919. The planning level average annual O&M cost, including a 20 percent contingency, is $350,976. The 20 year life cycle cost on a “pound of TP removal” basis is approximately $379.57/lb. TP removal.
6. There are multiple regulatory issues to address during the final design of this project. The project will involve work within a navigable waterway, work near or within a mapped floodplain, potential for wetland impacts, and discharge of treated water to Waters of the State. These issues will require close coordination with Federal, State, County, and City agencies.

7.2 Next Steps

There are many issues to be address for the proposed project to be implemented. In addition to the technical and engineering components, regulatory compliance and public acceptance also need to be addressed. Below is a list of key work items identified for the final design and permitting phase of the project.

1. Subsurface Investigations at the Project Site.
    a. Geotechnical: Testing to determine site soil and groundwater characteristics and environmental conditions.
    b. Groundwater Assessment/Modeling: Groundwater flow direction and rates will influence the proposed drawdown of the pond and the need for groundwater dewatering to maintain a normal pond water surface elevation at 836 feet. The current normal pond water surface elevation is approximately 846 feet.
2. Wetland Field Investigations.

    Field delineation and characterization of jurisdictional wetlands in accordance with WDNR and USACE protocols. In addition, the City is interested in possibly using portions of the treated pond discharge for wetland restoration of the park lands east of the project site. A wetland restoration will likely be prepared.

3. Government Permitting

   A variety of permits will be required for the project to proceed to implementation. Based on the current system, permits identified at this time include:

   a. WDNR Chapter 30, WPDES, and Wetlands
   b. USACE: Chapter 404 for work within a navigable waterway.
   c. Dane County: Erosion Control and Stormwater Management
   d. City of Madison Land Disturbance

4. Hydrologic and Hydraulic Modeling Refinement

   Addition modeling will be conducted to optimize system design and performance.

5. Final Design of Site and System Components

   Items that will be conducted under this task include:

   a. Survey of channel area and extended project site (road access, snow dump area etc.)
   b. Construction Documents (Civil, Electrical, Mechanical, Structural, Architectural)
      i. Plans
      ii. Technical Specifications
      iii. Bid documents
      iv. Opinion of Probable Construction Cost and Estimated Annual O&M Costs

6. Design of a Monitoring System
7. Bidding and Construction Phase Assistance
8. System Startup

   This task may include operator training and development of an O&M Manual

9. Public Information and Involvement

   The project is located along a popular waterway and next to a City natural area and park. There will be interest from the public to make sure the project integrates with other public uses of the resources in the area.

10. FEMA re-mapping to reflect updated project site conditions.
11. Depending upon ultimate decisions on floc disposal, analytical testing the floc may be required. Dewatering test may also be required.

This list in not all encompassing and additional items will likely be identified during the next phase of the project.

Section 8

Limitations

This document was prepared solely for the City of Madison, WI, in accordance with professional standards at the time the services were performed and in accordance with the contract between the City of Madison and Brown and Caldwell dated January 5, 2015. This document is governed by the specific scope of work authorized by the City of Madison; it is not intended to be relied upon by any other party except for regulatory authorities contemplated by the scope of work. We have relied on information or instructions provided by the City of Madison and other parties and, unless otherwise expressly indicated, have made no independent investigation as to the validity, completeness, or accuracy of such information.

This document sets forth the results of certain services performed by Brown and Caldwell with respect to the property or facilities described therein (the Property). The City of Madison, WI recognizes and acknowledges that these services were designed and performed within various limitations, including budget and time constraints. These services were not designed or intended to determine the existence and nature of all possible environmental risks (which term shall include the presence or suspected or potential presence of any hazardous waste or hazardous substance, as defined under any applicable law or regulation, or any other actual or potential environmental problems or liabilities) affecting the Property. The nature of environmental risks is such that no amount of additional inspection and testing could determine as a matter of certainty that all environmental risks affecting the Property had been identified. Accordingly, THIS DOCUMENT DOES NOT PURPORT TO DESCRIBE ALL ENVIRONMENTAL RISKS AFFECTING THE PROPERTY, NOR WILL ANY ADDITIONAL TESTING OR INSPECTION RECOMMENDED OR OTHERWISE REFERRED TO IN THIS DOCUMENT NECESSARILY IDENTIFY ALL ENVIRONMENTAL RISKS AFFECTING THE PROPERTY.

Further, Brown and Caldwell makes no warranties, express or implied, with respect to this document, except for those, if any, contained in the agreement pursuant to which the document was prepared.

All data, drawings, documents, or information contained this report have been prepared exclusively for the person or entity to whom it was addressed and may not be relied upon by any other person or entity without the prior written consent of Brown and Caldwell unless otherwise provided by the Agreement pursuant to which these services were provided.

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Section 9

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USDA, Natural Resources and Conservation Service, June, 1986; Urban Hydrology for Small Watersheds TR-55.

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Appendix A: Detailed Results of Coagulant Testing

1. Analytical Lab Results from all Field Samples

2. Individual Floc Volume Measurements.

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Table A-1. Analytical Lab Results from all Field Samples

Starkweather Creek, Madison WI
Coagulant Treatment Results (April - October, 2015)

Sample	Parameter:	pH (SU)				Temperature (C)				Total P (mg/L)		Reduction	Diss. Total P (mg/L)		Reduction	TSS (mg/L)		Reduction	Alkalinity (mg/L)		Reduction	Sulphate (mg/L)		Reduction	Total Al (ug/L)		Reduction	Diss. Al (ug/L)		Reduction	Chloride (mg/L)		Reduction	Conductivity (uS/cm)		Reduction
Date	Time:	0	+ 1 min.	+3.0 hrs.	+ 24 hrs.	0	+ 1 min.	+3.0 hrs.	+ 24 hrs.	0	+ 24 hrs.	from Raw @ 0 hr. (%)	0	+ 24 hrs.	from Raw @ 0 hr. (%)	0	+ 24 hrs.	from Raw @ 0 hr. (%)	0	+ 24 hrs.	from Raw @ 0 hr. (%)	0	+ 24 hrs.	from Raw @ 0 hr. (%)	0	+ 24 hrs.	from Raw @ 0 hr. (%)	0	+ 24 hrs.	from Raw @ 0 hr. (%)	0	+ 24 hrs.	from Raw @ 0 hr. (%)	0	+ 24 hrs.	from Raw @ 0 hr. (%)
	Aqua Hawk 1100 - Alum, 4.4% Aluminum																																			
4-8-2015	Raw Sample A	6.48		7.05	7.54	10.2		19.2	22.1	0.289	0.13	55.0%	0.128	0.0867	32.3%	83	15	81.9%	13.9	53.7	-286.3%	10.4	10.7	-2.9%	1490	317	78.7%	62.8	54.9	12.6%	150	110	26.7%	537	478	11.0%
4-8-2015	3 mg/L Al		7.42	6.98	7.05		13.2	18.5	22.2		0.0244	91.6%		0.00719	94.4%		3.8	95.4%		42.6	-206.5%		24.5	-135.6%		307	79.4%		27.7	55.9%		110	26.7%		492	8.4%
4-8-2015	6 mg/L Al		6.44	6.9	6.74		12.8	18.8	22.1		0.0176	93.9%		0.00599	95.3%		2.6	96.9%		30.2	-117.3%		38.1	-266.3%		378	74.6%		15.9	74.7%		110	26.7%		502	6.5%
4-8-2015	9 mg/L Al		6.26	6.62	6.52		13	18.9	22.1		0.0143	95.1%		0.00581	95.5%		2.4	97.1%		18.1	-30.2%		53.3	-412.5%		418	71.9%		18.3	70.9%		110	26.7%		513	4.5%
	Aqua Hawk 3507 - ACH, 12.59% Aluminum																																			
4-8-2015	Raw Sample B	6.53		7.08	7.23	10.3		19.3	22	0.255	0.136	46.7%	0.103	0.0879	14.7%	69	10	85.5%	56.2	54.9	2.3%	11.4	11.4	0.0%	1250	336	73.1%	82.7	79.4	4.0%	113	113	0.0%	493	492	0.2%
4-8-2015	3 mg/L Al		6.59	7.17	7.27		11.8	18.8	22.1		0.0271	89.4%		0.0124	88.0%		ND	98.3%		54	3.9%		10.2	10.5%		227	81.8%		ND	94.0%		114	-0.9%		499	-1.2%
4-8-2015	6 mg/L Al		6.81	7.17	7.25		11.7	18.8	22.1		0.0142	94.4%		0.0068	93.4%		ND	98.3%		52.7	6.2%		10.2	10.5%		320	74.4%		10.4	87.4%		116	-2.7%		499	-1.2%
4-8-2015	9 mg/L Al		6.83	7.16	7.30		11.8	19	22.1		0.0117	95.4%		0.00758	92.6%		2.8	95.9%		50.7	9.8%		9.16	19.6%		410	67.2%		ND	94.0%		118	-4.4%		498	-1.0%
	Aqua Hawk 4137 - PAC (Mid Basicity), 8.96% Aluminum																																			
4-8-2015	Raw Sample C	6.68		7.28	7.28	10.4		19.4	22.2	0.251	0.143	43.0%	0.109	0.101	7.3%	64.5	11.7	81.9%	58.3	#N/A	#N/A	11.4	10.5	7.9%	1170	405	65.4%	66.8	41	38.6%	117	180	-53.8%	511	776	-51.9%
4-8-2015	3 mg/L Al		6.7	7.26	7.12		13.3	19.2	22.2		0.0571	77.3%		0.00796	92.7%		8.33	87.1%		50.9	12.7%		10.6	7.0%		1010	13.7%		54	19.2%		123	-5.1%		519	-1.6%
4-8-2015	6 mg/L Al		6.75	7.09	7.24		13.7	19.2	22.2		0.0175	93.0%		0.00628	94.2%		ND	98.1%		41.8	28.3%		10.7	6.1%		376	67.9%		26.4	60.5%		130	-11.1%		529	-3.5%
4-8-2015	9 mg/L Al		6.61	6.84	6.78		13.1	19.4	22.2		0.0114	95.5%		0.00631	94.2%		ND	98.1%		35.3	39.5%		9.17	19.6%		339	71.0%		17.7	73.5%		135	-15.4%		532	-4.1%
	Aqua Hawk 1100 - Alum, 4.4% Aluminum																																			
5-4-2015	Raw Sample A	7.04		7.15	6.76	18.6		21.9	22.7	0.141	0.119	15.6%	0.0944	0.0244	74.2%	16.7	8	52.1%	101	99	2.0%	14.2	14.1	0.7%	180	141	21.7%	23.1	15.9	31.2%	93	93.6	-0.6%	513	515	-0.4%
5-4-2015	3 mg/L Al		6.99	7.24	6.91		19.2	21.9	22.6		0.122	13.5%		0.00693	92.7%		19.7	-18.0%		89.7	11.2%		27.4	-93.0%		2190	-1116.7%		47.2	-104.3%		91.5	1.6%		527	-2.7%
5-4-2015	6 mg/L Al		6.81	7.21	6.79		19.3	21.8	22.7		0.0217	84.6%		0.00636	93.3%		5.67	66.0%		73.6	27.1%		42.2	-197.2%		321	-78.3%		29.7	-28.6%		91	2.2%		528	-2.9%
5-4-2015	9 mg/L Al		6.62	7.07	6.64		19.4	21.8	22.7		0.017	87.9%		0.00696	92.6%		ND	92.8%		61.1	39.5%		56.1	-295.1%		334	-85.6%		26.7	-15.6%		91.3	1.8%		537	-4.7%
	Aqua Hawk 2192 - PAC (Low Basicity), 7.56% Aluminum																																			
5-4-2015	Raw Sample B	7.12		7.22	7.05	18.3		21.8	22.7	0.127	0.103	18.9%	0.0972	0.0754	22.4%	15	7.33	51.1%	96.9	97.9	-1.0%	13.8	13.9	-0.7%	216	135	37.5%	22.3	73.3	-228.7%	84.4	84	0.5%	479	483	-0.8%
5-4-2015	3 mg/L Al		7.01	7.29	7.00		19.3	21.7	22.7		0.125	1.6%		0.00714	92.7%		21	-40.0%		88	9.2%		13	5.8%		2660	-1131.5%		44.7	-100.4%		91.8	-8.8%		491	-2.5%
5-4-2015	6 mg/L Al		6.89	7.25	6.91		19.3	21.6	22.7		0.0211	83.4%		0.00684	93.0%		5.33	64.5%		75	22.6%		12.1	12.3%		335	-55.1%		34.2	-53.4%		102	-20.9%		502	-4.8%
5-4-2015	9 mg/L Al		6.71	7.10	6.71		19.3	21.6	22.7		0.0139	89.1%		0.00652	93.3%		ND	92.0%		63	35.0%		12.2	11.6%		315	-45.8%		27.2	-22.0%		112	-32.7%		514	-7.3%
	Aqua Hawk 5507 - PAC (Mid Basicity), 5.6% Aluminum																																			
5-4-2015	Raw Sample C	7.09		7.3	7.08	18.4		22	22.8	0.134	0.114	14.9%	0.0968	0.0301	68.9%	15.5	7	54.8%	93.7	94.9	-1.3%	12.9	12.6	2.3%	185	137	25.9%	24.3	15.8	35.0%	79.7	78.6	1.4%	459	463	-0.9%
5-4-2015	3 mg/L Al		7.11	7.37	7.05		19.3	21.9	22.8		0.0532	60.3%		0.00766	92.1%		ND	92.3%		87.5	6.6%		11.6	10.1%		818	-342.2%		48.1	-97.9%		84.5	-6.0%		470	-2.4%
5-4-2015	6 mg/L Al		7.07	7.32	7		19.4	21.9	22.7		0.0194	85.5%		0.00672	93.1%		4.25	72.6%		80.3	14.3%		12.2	5.4%		314	-69.7%		45.1	-85.6%		90.9	-14.1%		472	-2.8%
5-4-2015	9 mg/L Al		6.95	7.29	6.95		19.5	22	22.7		0.0136	89.9%		0.00598	93.8%		ND	92.3%		73.2	21.9%		11.6	10.1%		309	-67.0%		34.5	-42.0%		97.2	-22.0%		485	-5.7%
	Aqua Hawk 1100 - Alum, 4.4% Aluminum																		(NOTE: 5-27-15 Alkalinity corrected)*																	
5-27-2015	Raw Sample A	7.58		7.54	7.62	8.3		18.2	23.2	0.176	0.143	18.8%	0.0723	0.0791	-9.4%	8.25	4.4	46.7%	208	204	1.9%	20.7	20.3	1.9%	94.9	55.8	41.2%	11.3	13.6	-20.4%	144	145	-0.7%	890	886	0.4%
5-27-2015	4 mg/L Al		7.26	7.32	7.27		9.6	18.2	23.2		0.038	78.4%		0.00914	87.4%		4.8	41.8%		186	10.6%		38	-83.6%		550	-479.6%		141	-1147.8%		145	-0.7%		890	0.0%
5-27-2015	6 mg/L Al		7.15	7.17	7.13		9.8	18.4	23.2		0.0282	84.0%		0.00801	88.9%		4.2	49.1%		177	14.9%		46.4	-124.2%		490	-416.3%		57.4	-408.0%		145	-0.7%		894	-0.4%
5-27-2015	8 mg/L Al		7.05	7.15	7.02		10.3	18.6	23.3		0.0262	85.1%		0.0069	90.5%		3.4	58.8%		167	19.7%		57.5	-177.8%		565	-495.4%		135	-1094.7%		146	-1.4%		893	-0.3%
	Aqua Hawk 3507 - ACH, 12.59% Aluminum																		(NOTE: 5-27-15 Alkalinity corrected)*																	
5-27-2015	Raw Sample B	7.67		7.62	7.59	7.5		18.3	23.4	0.197	0.152	22.8%	0.0822	0.0881	-7.2%	8	4.75	40.6%	199	197	1.0%	18.5	19.5	-5.4%	86.6	43.2	50.1%	16.6	12.9	22.3%	146	146	0.0%	867	864	0.3%
5-27-2015	4 mg/L Al		7.64	7.62	7.60		9.2	18.3	23.5		0.0373	81.1%		0.0113	86.3%		4	50.0%		196	1.5%		17.8	3.8%		438	-405.8%		17.3	-4.2%		149	-2.1%		870	-0.3%
5-27-2015	6 mg/L Al		7.64	7.59	7.61		9	18.3	23.5		0.024	87.8%		0.00847	89.7%		3.25	59.4%		194	2.5%		18	2.7%		410	-373.4%		16.9	-1.8%		149	-2.1%		862	0.6%
5-27-2015	8 mg/L Al		7.63	7.56	7.58		9.3	18.7	23.5		0.0202	89.7%		0.00722	91.2%		3.25	59.4%		192	3.5%		17.3	6.5%		496	-472.7%		15.6	6.0%		148	-1.4%		862	0.6%
	Aqua Hawk 4137 - PAC (Mid Basicity), 8.96% Aluminum																		(NOTE: 5-27-15 Alkalinity corrected)*																	
5-27-2015	Raw Sample C	7.72		7.62	7.67	9.5		18.7	23.8	0.197	0.154	21.8%	0.0925	0.0942	-1.8%	8	3.5	56.3%	199	199	0.0%	19.6	18.4	6.1%	69.7	54.7	21.5%	12.7	13	-2.4%	146	145	0.7%	868	866	0.2%
5-27-2015	4 mg/L Al		7.43	7.47	7.39		10.9	18.7	23.7		0.0297	84.9%		0.0122	86.8%		2.75	65.6%		186	6.5%		17.5	10.7%		354	-407.9%		93.8	-638.6%		154	-5.5%		881	-1.5%
5-27-2015	6 mg/L Al		7.32	7.35	7.29		11.1	18.6	23.7		0.0238	87.9%		0.00909	90.2%		3	62.5%		180	9.5%		17.3	11.7%		448	-542.8%		73.7	-480.3%		160	-9.6%		883	-1.7%
5-27-2015	8 mg/L Al		7.28	7.32	7.25		11.3	18.6	23.7		0.0271	86.2%		0.00817	91.6%		4	50.0%		178	10.6%		18.3	6.6%		517	-641.8%		97.9	-670.9%		162	-11.0%		882	-1.6%

Brown AND Caldwell

Table A-1. Analytical Lab Results from all Field Samples

Starkweather Creek, Madison WI

Coagulant Treatment Results (April - October, 2015)

Sample	Parameter:	pH (SU)				Temperature (C)				Total P (mg/L)		Reduction from Raw @ 0 hr. (%)	Diss. Total P (mg/L)		Reduction from Raw @ 0 hr. (%)	TSS (mg/L)		Reduction from Raw @ 0 hr. (%)	Alkalinity (mg/L)		Reduction from Raw @ 0 hr. (%)	Sulphate (mg/L)		Reduction from Raw @ 0 hr. (%)	Total Al (ug/L)		Reduction from Raw @ 0 hr. (%)	Diss. Al (ug/L)		Reduction from Raw @ 0 hr. (%)	Chloride (mg/L)		Reduction from Raw @ 0 hr. (%)	Conductivity (uS/cm)		Reduction from Raw @ 0 hr. (%)
Date	Time:	0	+ 1 min.	+3.0 hrs.	+ 24 hrs.	0	+ 1 min.	+3.0 hrs.	+ 24 hrs.	0	+ 24 hrs.		0	+ 24 hrs.		0	+ 24 hrs.		0	+ 24 hrs.		0	+ 24 hrs.		0	+ 24 hrs.		0	+ 24 hrs.		0	+ 24 hrs.		0	+ 24 hrs.	
	Aqua Hawk 1100 - Alum, 4.4% Aluminum																																			
6-12-2015	Raw Sample A	7.41		7.32	7.07	8.8		18.1	23.1	0.198	0.111	43.9%	0.0733	0.0729	0.5%	37.7	3.67	90.3%	44.9	44.9	0.0%	8.05	6.68	17.0%	465	84.8	81.8%	44.5	25.7	42.2%	27.6	27.4	0.7%	190	189	0.5%
6-12-2015	4 mg/L Al		6.66	6.80	6.65		9	18	23		0.0185	90.7%		ND	96.6%		ND	96.8%		23.3	48.1%		25.6	-218.0%		412	11.4%		25.6	42.5%		30.4	-10.1%		206	-8.4%
6-12-2015	6 mg/L Al		6.28	6.34	6.37		8.9	17.7	23.2		0.0176	91.1%		ND	96.6%		ND	96.8%		18.7	58.4%		34.4	-327.3%		526	-13.1%		13.2	70.3%		27.3	1.1%		207	-8.9%
6-12-2015	8 mg/L Al		5.90	6.10	6.02		9.3	17.8	23.6		0.0217	89.0%		ND	96.6%		3.75	90.1%		11.3	74.8%		42.5	-428.0%		807	-73.5%		42.7	4.0%		27.5	0.4%		212	-11.6%
	Aqua Hawk 3507 - ACH, 12.59% Aluminum																																			
6-12-2015	Raw Sample B	7.47		7.31	6.35	8.7		18.1	23.4	0.194	0.109	43.8%	0.0796	0.0788	1.0%	42.7	2.5	94.1%	45.5	45.3	0.4%	6.95	7.1	-2.2%	467	64.4	86.2%	22.9	20.8	9.2%	26.9	27	-0.4%	192	191	0.5%
6-12-2015	4 mg/L Al		7.01	7.27	7.40		9.4	17.9	23.5		0.0143	92.6%		0.00617	92.2%		ND	97.2%		42.9	5.7%		6.17	11.2%		338	27.6%		13	43.2%		29.2	-8.6%		193	-0.5%
6-12-2015	6 mg/L Al		7.18	7.25	7.38		9.6	17.9	23.4		0.0157	91.9%		ND	96.9%		ND	97.2%		41.8	8.1%		5.34	23.2%		622	-33.2%		ND	78.2%		30.4	-13.0%		195	-1.6%
6-12-2015	8 mg/L Al		7.20	7.21	7.34		9.8	18.1	23.5		0.0226	88.4%		ND	96.9%		5	88.3%		41	9.9%		6.59	5.2%		1150	-146.3%		ND	78.2%		31.9	-18.6%		196	-2.1%
	Aqua Hawk 4137 - PAC (Mid Basicity), 8.96% Aluminum																																			
6-12-2015	Raw Sample C	7.50		7.31	7.54	8.6		18.1	23.6	0.203	0.111	45.3%	0.0767	0.0752	2.0%	37	3.5	90.5%	45.3	45.1	0.4%	7.63	7.26	4.8%	504	83.3	83.5%	27.2	23.6	13.2%	26.9	26.9	0.0%	190	191	-0.5%
6-12-2015	4 mg/L Al		6.94	7.03	7.01		9.1	17.9	23.6		0.0148	92.7%		ND	96.7%		ND	96.8%		33.9	25.2%		4.84	36.6%		352	30.2%		23.3	14.3%		37.1	-37.9%		202	-6.3%
6-12-2015	6 mg/L Al		6.73	7.78	6.80		9.4	17.8	23.6		0.0117	94.2%		ND	96.7%		ND	96.8%		28.3	37.5%		6.18	19.0%		385	23.6%		15.1	44.5%		41.9	-55.8%		204	-7.4%
6-12-2015	8 mg/L Al		6.66	6.66	6.68		9.6	17.9	23.6		0.013	93.6%		ND	97.4%		ND	96.8%		25.8	43.0%		5.33	30.1%		509	-1.0%		18.2	33.1%		44.4	-65.1%		206	-8.4%
	Aqua Hawk 1100 - Alum, 4.4% Aluminum																																			
7-29-2015	Raw Sample	7.17		7.18	7.41	9.4		18.5	23.2	0.225	0.132	41.3%	0.0836	0.0838	-0.2%	52.7	15.5	70.6%	206	205	0.5%	26.5	26.8	-1.1%	1750	407	76.7%	24.2	25.6	-5.8%	97.1	97.3	-0.2%	739	740	-0.1%
7-29-2015	4 mg/L Al		6.92	7.17	7.24		9.7	18.6	23.1		0.0269	88.0%		ND	97.0%		2.75	94.8%		186	9.7%		48	-81.1%		314	82.1%		71.4	-195.0%		96.9	0.2%		742	-0.4%
7-29-2015	6 mg/L Al		7.01	7.15	7.12		9.8	18.6	23.0		0.0225	90.0%		ND	97.0%		ND	97.7%		177	14.1%		59.3	-123.8%		327	81.3%		61.5	-154.1%		97.4	-0.3%		747	-1.1%
	Aqua Hawk 3507 - ACH, 12.59% Aluminum																																			
7-29-2015	Raw Sample	7.17		7.18	7.41	9.4		18.5	23.2	0.225	0.132	41.3%	0.0836	0.0838	-0.2%	52.7	15.5	70.6%	206	205	0.5%	26.5	26.8	-1.1%	1750	407	76.7%	24.2	25.6	-5.8%	97.1	97.3	-0.2%	739	740	-0.1%
7-29-2015	4 mg/L Al		7.38	7.52	7.45		10.4	18.3	23.0		0.0227	89.9%		ND	97.0%		2.75	94.8%		202	1.9%		26.8	-1.1%		284	83.8%		16.7	31.0%		98.9	-1.9%		739	0.0%
7-29-2015	6 mg/L Al		7.44	7.49	7.47		10.1	18.4	23.1		0.0196	91.3%		ND	97.0%		3.75	92.9%		197	4.4%		26.2	1.1%		454	74.1%		17.8	26.4%		103	-6.1%		734	0.7%
	Aqua Hawk 4137 - PAC (Mid Basicity), 8.96% Aluminum																																			
7-29-2015	Raw Sample	7.17		7.18	7.41	9.4		18.5	23.2	0.225	0.132	41.3%	0.0836	0.0838	-0.2%	52.7	15.5	70.6%	206	205	0.5%	26.5	26.8	-1.1%	1750	407	76.7%	24.2	25.6	-5.8%	97.1	97.3	-0.2%	739	740	-0.1%
7-29-2015	4 mg/L Al		7.33	7.42	7.37		10.3	18.6	23.2		0.0256	88.6%		ND	97.0%		3.33	93.7%		189	8.3%		26.5	0.0%		433	75.3%		104	-329.8%		109	-12.3%		743	-0.5%
7-29-2015	6 mg/L Al		7.24	7.3	7.28		10.6	18.8	23.3		0.0194	91.4%		ND	97.0%		ND	97.7%		183	11.2%		26.3	0.8%		318	81.8%		78.9	-226.0%		115	-18.4%		750	-1.5%
	Aqua Hawk 3507 - ACH, 12.59% Aluminum																																			
10-28-2015	Raw Sample	6.6	6.60	7.05	7.00	14.3	14.3	19.2	21.6	0.217	0.192	11.5%	0.155	0.147	5.2%	25	6	76.0%	56.1	54.5	2.9%	10.2	10.2	0.0%	120	109	9.2%	18.3	15.6	14.8%	39.2	39.3	-0.3%	255	251	1.6%
10-28-2015	4 mg/L Al		6.67	7.05	7.02		14.3	19.1	21.4		0.0226	89.6%		0.00516	96.7%		3.67	85.3%		52.8	5.9%		7.89	22.6%		319	-165.8%		18.5	-1.1%		41.4	-5.6%		254	0.4%
10-28-2015	6 mg/L Al		6.83	7.09	7.10		14.4	19.1	21.4		0.0149	93.1%		ND	98.4%		3.33	86.7%		54.8	2.3%		6.66	34.7%		299	-149.2%		ND	72.7%		39.9	-1.8%		254	0.4%
	Aqua Hawk 3507 - ACH, 12.59% Aluminum (Cold)																																			
10-28-2015	Raw Sample	6.6	6.60	7.05	7.00	14.3	14.3	19.2	21.6	0.217	0.192	11.5%	0.155	0.147	5.2%	25	6	76.0%	56.1	54.5	2.9%	10.2	10.2	0.0%	120	109	9.2%	18.3	15.6	14.8%	39.2	39.3	-0.3%	255	251	1.6%
10-28-2015	4 mg/L Al		6.73	6.99	7.25		14.3	8.1	4.6		0.0342	84.2%		0.0102	93.4%		3.33	86.7%		55.7	0.7%		7.52	26.3%		485	-304.2%		ND	72.7%		38.8	1.0%		253	0.8%
10-28-2015	6 mg/L Al		7.09	6.69	7.17		14.5	8.2	6.2		0.0241	88.9%		ND	98.4%		2.4	90.4%		54	3.7%		6.96	31.8%		575	-379.2%		ND	72.7%		40.1	-2.3%		254	0.4%
	Aqua Hawk 4137 - PAC (Mid Basicity), 8.96% Aluminum																																			
10-28-2015	Raw Sample	6.6	6.60	7.05	7.00	14.3	14.3	19.2	21.6	0.217	0.192	11.5%	0.155	0.147	5.2%	25	6	76.0%	56.1	54.5	2.9%	10.2	10.2	0.0%	120	109	9.2%	18.3	15.6	14.8%	39.2	39.3	-0.3%	255	251	1.6%
10-28-2015	4 mg/L Al		6.98	6.77	6.93		14.7	19.1	22.1		0.0212	90.2%		ND	98.4%		3.67	85.3%		48	14.4%		7.48	26.7%		332	-176.7%		26.3	-43.7%		44.8	-14.3%		260	-2.0%
10-28-2015	6 mg/L Al		6.82	6.87	6.84		14.8	19.1	22.1		0.0159	92.7%		ND	98.4%		ND	95.2%		41.3	26.4%		6.57	35.6%		390	-225.0%		16.5	9.8%		50.4	-28.6%		264	-3.5%

* Table A-1 updated on 12/10/18 to correct Alkalinity values from 5/27/15 sample

Table A-2. Observed Floc Depth in Graduated Cylinders

Table A - 2 Observed Floc Depth in Graduated Cylinders									
Starkweather Creek Coagulant Treatment Phase I			All original sample volumes are 1.75 L.						
Coagulant:	**A 1100.3**	**A 1100.6**	**A 1100.9**	**B 3507.3**	**B 3507.6**	**B 3507.9**	**C 4137.3**	**C 4137.6**	**C 4137.9**
Sample Date	4/8/2015	4/8/2015	4/8/2015	4/8/2015	4/8/2015	4/8/2015	4/8/2015	4/8/2015	4/8/2015
Analysis Date	4/8/2015	4/8/2015	4/8/2015	4/8/2015	4/8/2015	4/8/2015	4/8/2015	4/8/2015	4/8/2015
Observation Date	5/31/2015	5/31/2015	5/31/2015	5/31/2015	5/31/2015	5/31/2015	5/31/2015	5/31/2015	5/31/2015
Floc Vol. (ml)	2	4	7	3	7	11	2	5	8
Coagulant:	**A 1100.3**	**A 1100.6**	**A 1100.9**	**B2192.3**	**B2192.6**	**B2192.9**	**C5507.3**	**C5507.6**	**C5507.9**
Sample Date	5/4/2015	5/4/2015	5/4/2015	5/4/2015	5/4/2015	5/4/2015	5/4/2015	5/4/2015	5/4/2015
Analysis Date	5/4/2015	5/4/2015	5/4/2015	5/4/2015	5/4/2015	5/4/2015	5/4/2015	5/4/2015	5/4/2015
Observation Date	8/6/2015	8/6/2015	8/6/2015	8/6/2015	8/6/2015	8/6/2015	8/6/2015	8/6/2015	8/6/2015
Floc Vol. (ml)	2	4	5	1	4	9	2	5	12
Coagulant:	**A 1100.4**	**A 1100.6**	**A 1100.8**	**B 3507.4**	**B 3507.6**	**B 3507.8**	**C 4137.4**	**C 4137.6**	**C 4137.8**
Sample Date	5/26/2015	5/26/2015	5/26/2015	5/26/2015	5/26/2015	5/26/2015	5/26/2015	5/26/2015	5/26/2015
Analysis Date	5/27/2015	5/27/2015	5/27/2015	5/27/2015	5/27/2015	5/27/2015	5/27/2015	5/27/2015	5/27/2015
Observation Date	5/29/2015	5/29/2015	5/29/2015	5/29/2015	5/29/2015	5/29/2015	5/29/2015	5/29/2015	5/29/2015
Floc Vol. (ml)	8	10	15	16	26	32	11	19	19
Observation Date	5/31/2015	5/31/2015	5/31/2015	5/31/2015	5/31/2015	5/31/2015	5/31/2015	5/31/2015	5/31/2015
Floc Vol. (ml)	5	8	10	11	16	21	9	13	12
Observation Date	8/6/2015	8/6/2015	8/6/2015	8/6/2015	8/6/2015	8/6/2015	8/6/2015	8/6/2015	8/6/2015
Floc Vol. (ml)	3	4	5	4	7	8	4	6	7
Coagulant:	**A 1100.4**	**A 1100.6**	**A 1100.8**	**B 3507.4**	**B 3507.6**	**B 3507.8**	**C 4137.4**	**C 4137.6**	**C 4137.8**
Sample Date	6/12/2015	6/12/2015	6/12/2015	6/12/2015	6/12/2015	6/12/2015	6/12/2015	6/12/2015	6/12/2015
Analysis Date	6/15/2015	6/15/2015	6/15/2015	6/15/2015	6/15/2015	6/15/2015	6/15/2015	6/15/2015	6/15/2015
Observation Date	6/18/2015	6/18/2015	6/18/2015	6/18/2015	6/18/2015	6/18/2015	6/18/2015	6/18/2015	6/18/2015
Floc Vol. (ml)	7	11	14	8	13	19	9	14	17
Observation Date	8/6/2015	8/6/2015	8/6/2015	8/6/2015	8/6/2015	8/6/2015	8/6/2015	8/6/2015	8/6/2015
Floc Vol. (ml)	3	5	6	4	9	14	2	6	9
Coagulant:	**A 1100.4**	**A 1100.6**	**A 1100.8**	**B 3507.4**	**B 3507.6**	**B 3507.8**	**C 4137.4**	**C 4137.6**	**C 4137.8**
Sample Date	7/29/2015	7/29/2015	7/29/2015	7/29/2015	7/29/2015	7/29/2015	7/29/2015	7/29/2015	7/29/2015
Analysis Date	7/30/2015	7/30/2015	Not Analyzed	7/30/2015	7/30/2015	Not Analyzed	7/30/2015	7/30/2015	Not Analyzed
Floc Vol. (ml)	8/6/2015	8/6/2015	8/6/2015	8/6/2015	8/6/2015	8/6/2015	8/6/2015	8/6/2015	8/6/2015
ml	4	5	Not Analyzed	8	12	Not Analyzed	5	8	Not Analyzed
Observation Date	9/3/2015	9/3/2015		9/3/2015	9/3/2015		9/3/2015	9/3/2015	
Floc Vol. (ml)	2	3		4	8		3	4	
Coagulant:	**B 3507.4**	**B 3507.6**		**B 3507.4 (Cold)**	**B 3507.6 (Cold)**		**C 4137.4**	**C 4137.6**	
Sample Date	10/28/2015	10/28/2015		10/28/2015	10/28/2015		10/28/2015	10/28/2015	
Analysis Date	10/28/2015	10/28/2015		10/28/2015	10/28/2015		10/28/2015	10/28/2015	
Observation Date	11/13/2015	11/13/2015		11/13/2015	11/13/2015		11/13/2015	11/13/2015	
Floc Vol. (ml)	5	9		5	10		3	7	

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Appendix B: Stream Sampling Field Sheets and USGS Rain Graphs for Sample Dates

1. USGS Rain Graphs

2. Stream Sampling Field Sheets

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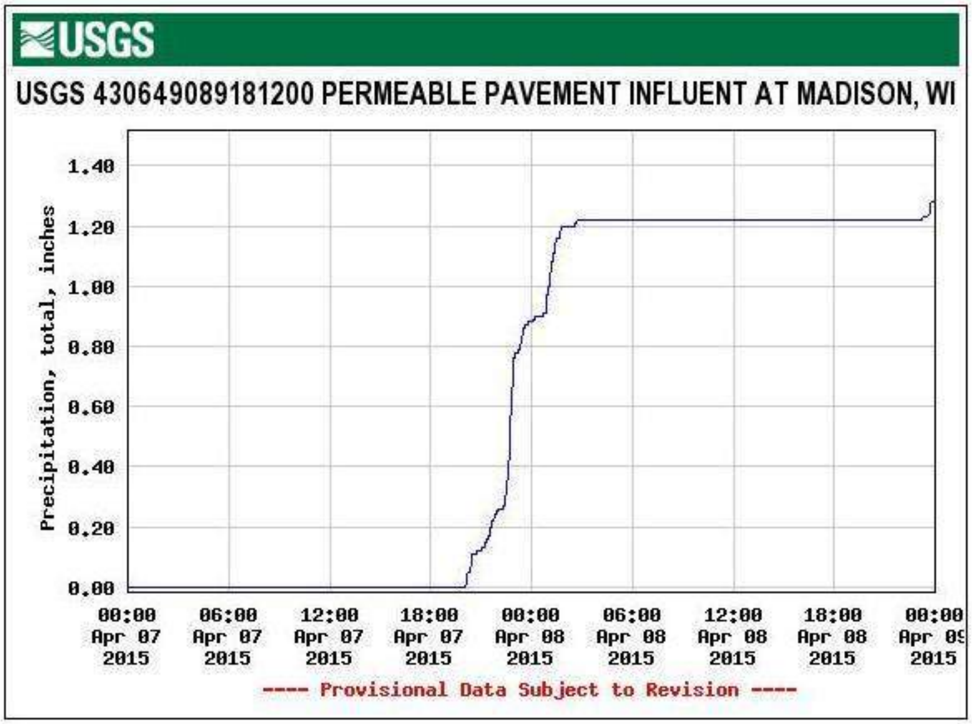
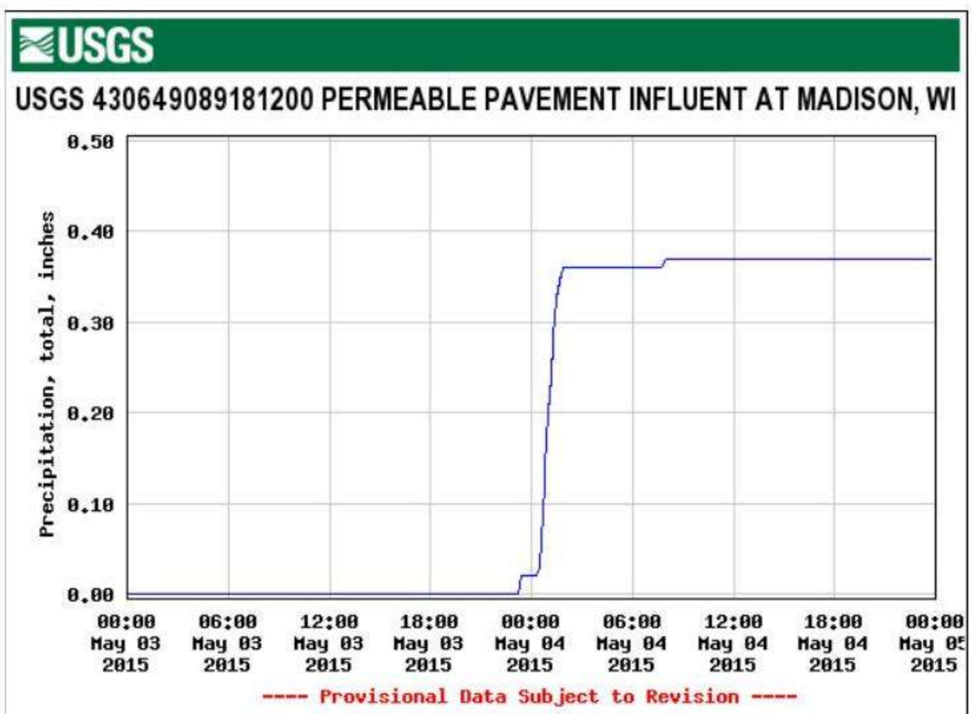
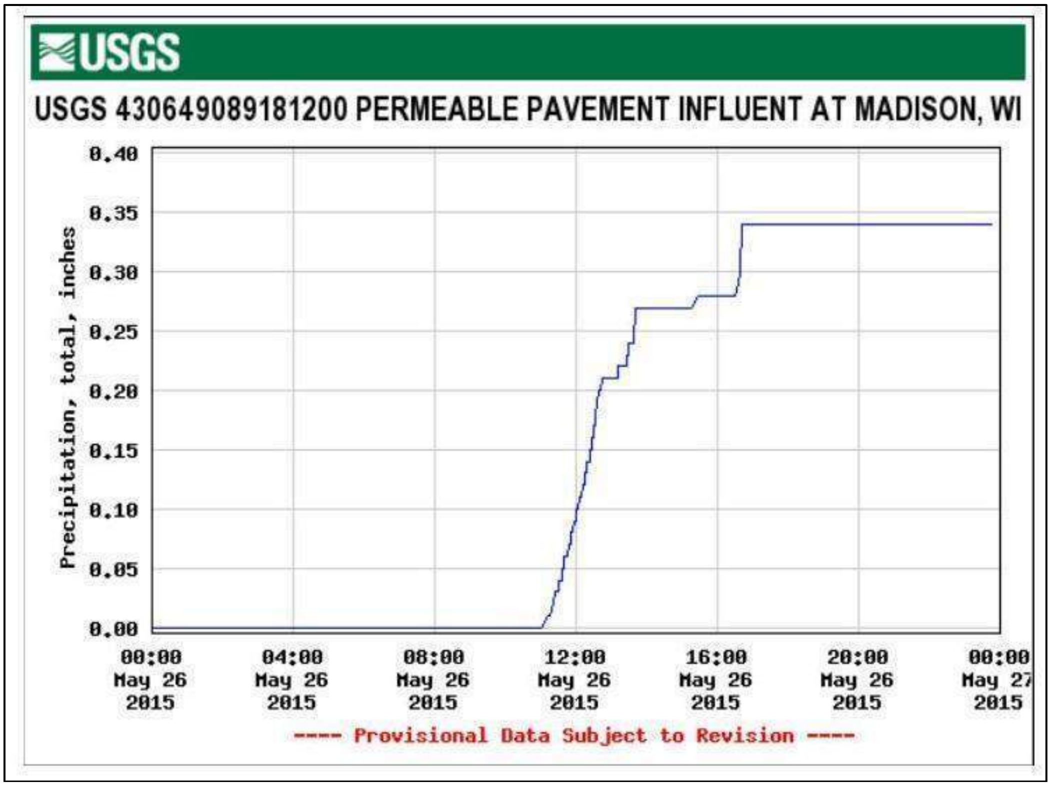
Section B-1: Coagulant Testing Dates Measured Rain at USGS Permeable Pavement Site; Sycamore Park, Madison



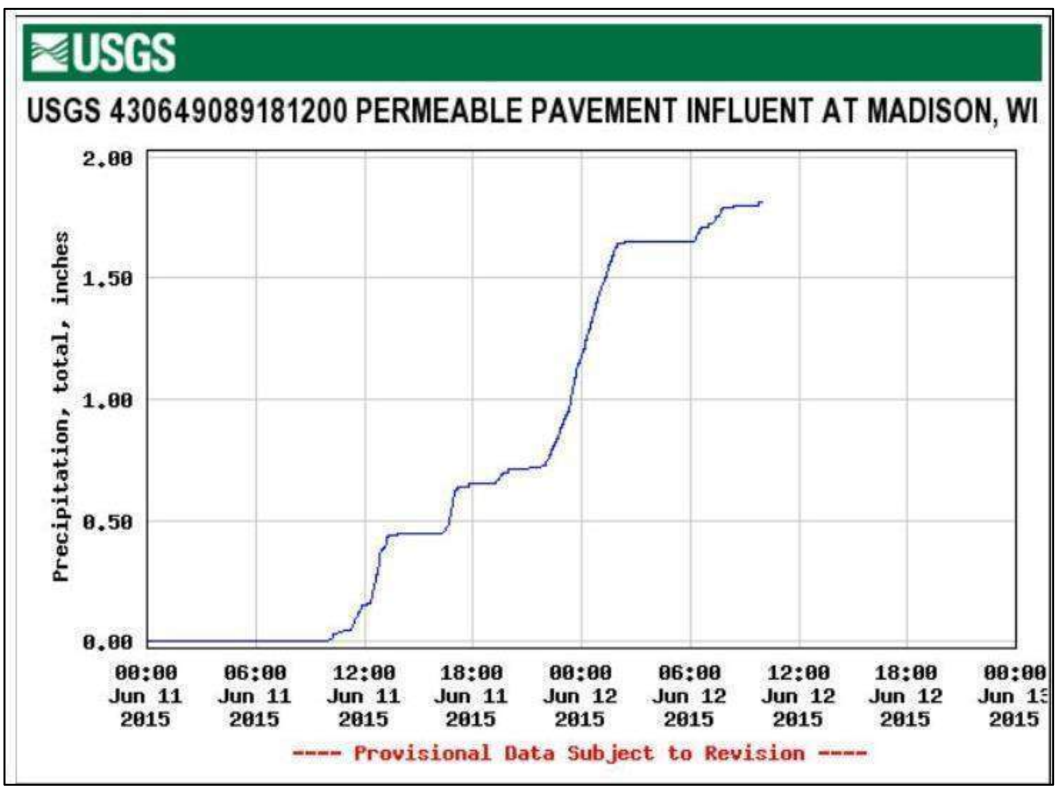
April 7 – 8, 2015



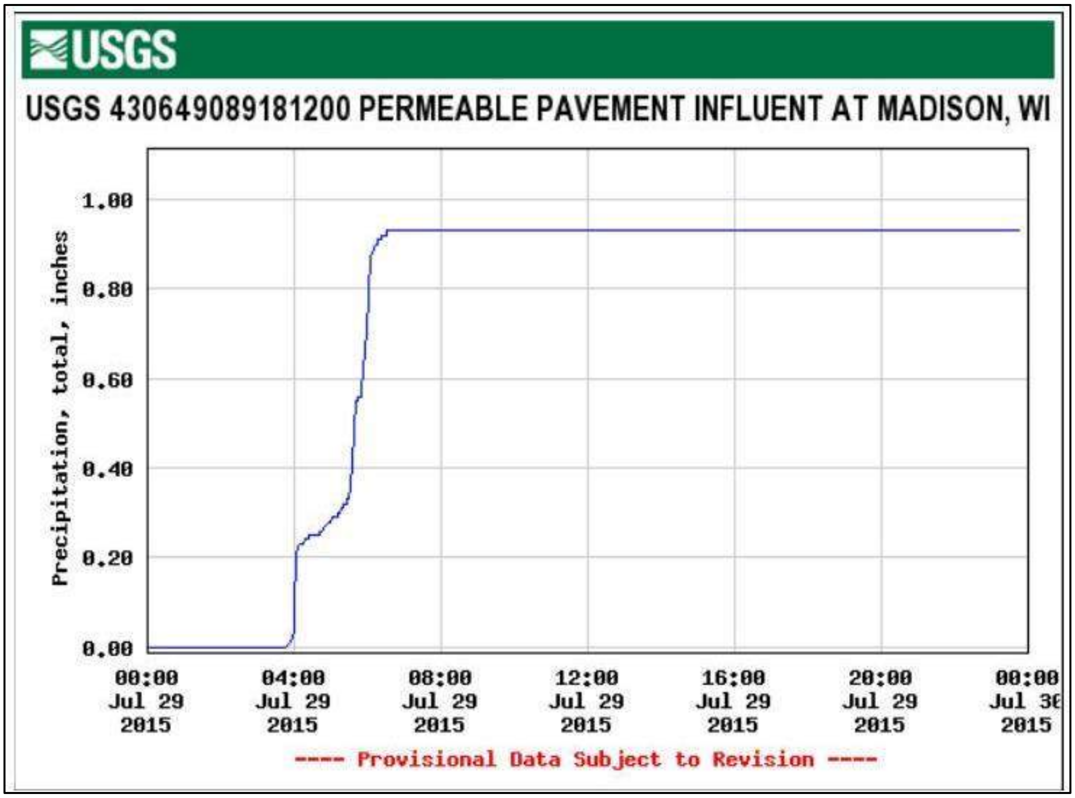
May 3 – 4, 2015



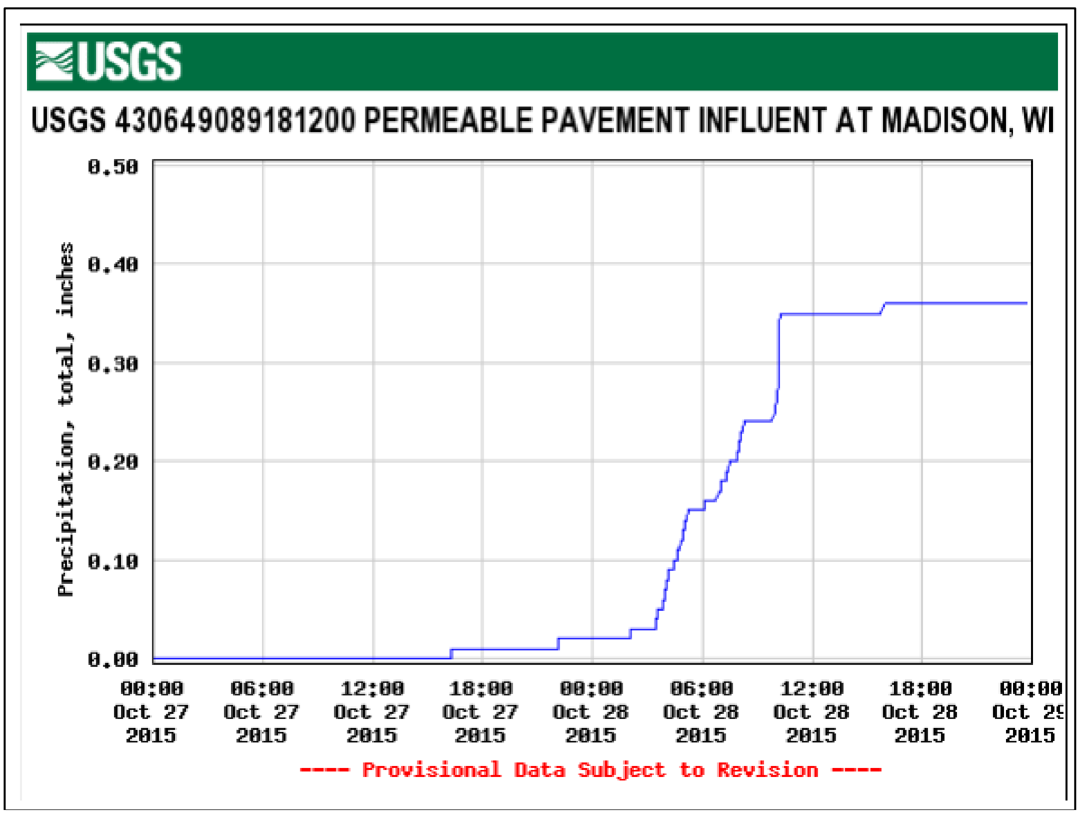
May 26, 2015



June 11 – 12, 2015



July 29, 2015



October 28, 2015

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Section B-2: Coagulant Testing Field Notes

Field Staff Name(s):	1 Mike Wagner	**Collection Date/Time:**	4-8-15
	2 Jim Bachhuber	**Weather:** T = 39 overcast	
	3 Roger Bannerman	Winds calm	
	4 Louise Stiegl		

Truax NOAA Reported Rain:	**Inches**
Previous 3 hrs:	
Previous 6 hrs:	
Previous 12 hrs:	1.01 - Truax; 0.78 USGS
Previous 24 hrs:	

Visual Water Quality: flowing/turbid

Observed Flow (qualitative and measure-down): 10' 7" down from top of rail, upstream side, 4th vertical bearing Ivy Street. 10' 8" at 9:20. 10' 8" @ 09:40

Water Collection Data:	**Start Time**	**End Time**	**Volume Collected**
Sample A:	08:44	09:04	10 L
Sample B:	09:05	09:20	10 L
Sample C:	09:22	09:40	10 L

Other Comments:

Field Staff Name(s):	1 Mike Wegner	**Collection Date/Time:**	4-24-15
	2 Jim Bachhuber	**Weather:** Cloudy 41° 07:30	
	3		
	4		

Truax NOAA Reported Rain:	**Inches**
Previous 3 hrs:	
Previous 6 hrs:	
Previous 12 hrs:	0.30
Previous 24 hrs:	

USGS: 0.30" 4/24/15 15:00 – 19:00

Truax: 0.24" 4/24/15 14:53 – 18:53

Visual Water Quality: turbid; not much floating. Very slow flow. Water Level: 10' 6½" from bridge rail. Water Level down ~3¼" based on water marks on rocks

Observed Flow (qualitative and measure-down):

Water Collection Data:	**Start Time**	**End Time**	**Volume Collected**
Sample A:			
Sample B: No Sample			
Sample C:			

Other Comments: Missed rising limb and peak

Field Staff Name(s):	1 Mike Weaver	**Collection Date/Time:**	May 4, 2015 8:00 am
	2 Lauren Streitz	**Weather:**	60° Mostly Cloudy Thunderstorm overnight - 0.49" of rain in 2 hours Midnight - 2am
	3		
	4		

Truax NOAA Reported Rain:	**Inches**
Previous 3 hrs:	
Previous 6 hrs:	
Previous 12 hrs:	0.49
Previous 24 hrs:	-

Visual Water Quality:

Cloudy, Some leaves, pollen, etc

Observed Flow (qualitative and measure-down):

8:10a 10' 2½" Steady D/s Flow Observed
9:45a 10' 2½"

Water Collection Data:	**Start Time**	**End Time**	**Volume Collected**
Sample A:	8:15am	8:50	
Sample B:	8:50	9:15	
Sample C:	9:15	9:40	

Other Comments:

Field Staff Name(s):	1 Jim Bachhuber	**Collection Date/Time:**	5-25-15
	2 Phillip Goebler	**Weather:**	T~75, Windy, Mostly sun Wind: 10-15 fr SW
	3		
	4		

Truax NOAA Reported Rain:	**Inches**
Previous 3 hrs:	
Previous 6 hrs:	
Previous 12 hrs:	
Previous 24 hrs:	1.25

Visual Water Quality:

Sampled water clear
leaves + seeds + veg. on surface

Observed Flow (qualitative and measure-down):

Measure Down @ 2:55 = 10'0" Surface flow - upstream - wind driven

Water Collection Data:	**Start Time**	**End Time**	**Volume Collected**
Sample A:	No Samples Taken - water too clear		
Sample B:			
Sample C:			

Other Comments:

Field Staff Name(s):	1 Jim Bachhuber	**Collection Date/Time:**	5-26-15 14:45
	2 Mike Wegner	**Weather:** Prtly Cloud T~70; Windy	
	3 Phillip G		
	4		

Truax NOAA Reported Rain:	**Inches**
Previous 3 hrs:	
Previous 6 hrs:	~0.25"
Previous 12 hrs:	
Previous 24 hrs:	

Visual Water Quality: much floating vegetation or clumps of algae
water in bottle not very turbid

Observed Flow (qualitative and measure-down): flowing strong;

Water Collection Data:		**Start Time**	**End Time**	**Volume Collected**
Sample A:	Stage = 9' 11"	14:48	15:05	10L
Sample B:		15:10	15:32	10L
Sample C:	stage 9' 10.75"	15:35	15:55	10L

Other Comments:
Water

Field Staff Name(s):	1 Mike Wegner	**Collection Date/Time:**	6-12-15
	2 Jim Bachhuber	**Weather:** 61°F Cloudy; Drizzel	
	3		
	4		

Truax NOAA Reported Rain:	**Inches**
Previous 3 hrs:	
Previous 6 hrs:	
Previous 12 hrs:	
Previous 24 hrs:	

Visual Water Quality: Not much floating debris

Observed Flow (qualitative and measure-down): MDe 06:10 = 9' 7 3/4" rapid flow across stream
07:24 9' 8 1/2"

Water Collection Data:	**Start Time**	**End Time**	**Volume Collected**
Sample A:	6:14pm	7:24	30 L - integrated across time of sampling
Sample B:			
Sample C:			

Other Comments:
rain off and on during sampling
took "city split" sample (3L) during sample period

Field Staff Name(s):		**Collection Date/Time:**	7/29 7am
	1 Mike Wegner	**Weather:**	
	2 Lauren Streigl	Cloudy, 70°	
	3		
	4		

Truax NOAA Reported Rain:	**Inches**
Previous 3 hrs:	
Previous 6 hrs:	
Previous 12 hrs:	
Previous 24 hrs:	

Visual Water Quality:
Brown, Lots of Algae

Observed Flow (qualitative and measure-down):
9'9" 7:05

Water Collection Data:	**Start Time**	**End Time**	**Volume Collected**
Sample A:	7:10am	8:10	20L
Sample B:			
Sample C:			

Other Comments:

Field Staff Name(s):		**Collection Date/Time:**	10/28 6:30 am
	1 Mike Wegner	**Weather:**	50° Cloudy, Light Rain
	2 Jim Bachhuber		
	3 Lauren Streigl		
	4		

Truax NOAA Reported Rain:	**Inches**
Previous 3 hrs:	
Previous 6 hrs:	
Previous 12 hrs:	~1.14
Previous 24 hrs:	

Visual Water Quality:
leaves/turbid

Observed Flow (qualitative and measure-down):
6:37: 9'9" - positive flow visible
7:35 9'11"

Water Collection Data:	**Start Time**	**End Time**	**Volume Collected**
Sample A:	06:35	07:30	20L
Sample B:			
Sample C:			

Other Comments:

Appendix C: Quarry Pond Monitoring Results

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Starkweather Creek Coagulant Treatment Project
Madison, WI
Quarry Pond Monitoring

May 12, 2015 (7:15 am - 10:30 am)

Weather: mostly cloudy, temperature 45 - 50 F; winds WNW 5 - 15

Field staff:	Jeff Herr (BC)	Roger Bannerman (USGS)
	Jim Bachhuber (BC)	Lauren Striegl (City of Madison)
	Caroline Burger (BC)	Greg Fries (City of Madison)
	Mike Wegner (BC)	Phillip Gaebler (City of Madison)
Secchi Disk:	12 - 13'	

Dissolved Oxygen Profiles

DO Meter: YSI 550 A, air calibrated at field site.

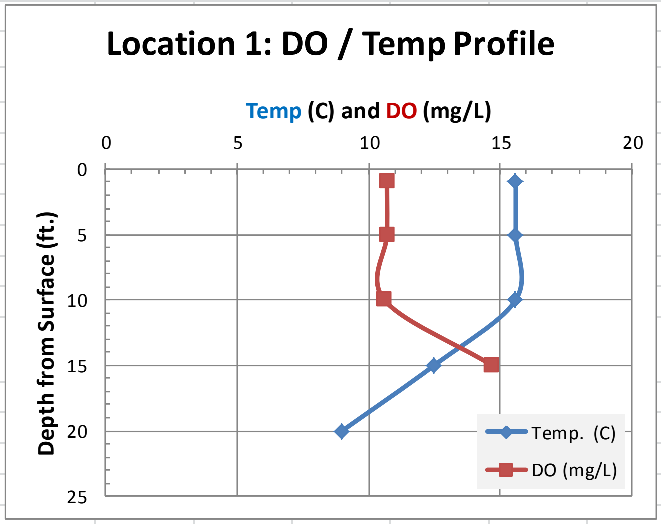
May 12, 2015

Location 1: Lat: 40° 43'6' N; 89°19' 36" W

Long.: -89°19' 36" W

Depth (ft)	Temp. (C)	DO (mg/L)
1	15.6	10.7
5	15.6	10.7
10	15.6	10.6
15	12.5	14.7
20	9	

NOTE: probe not vertical in water column and canoe drifted during measurements.



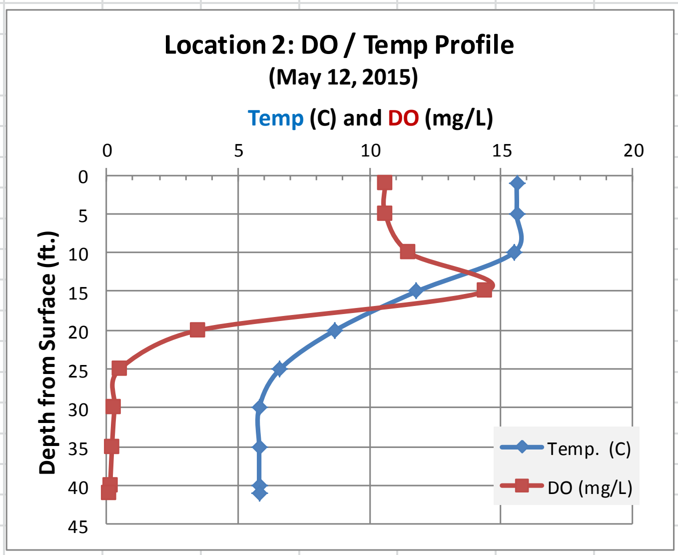
May 12, 2015

Location 2: Lat.: 43° 6' 10.1442"

Long.: -89° 19' 36.0588"

Depth (ft)	Temp. (C)	DO (mg/L)
1	15.6	10.6
5	15.6	10.6
10	15.5	11.5
15	11.8	14.4
20	8.7	3.5
25	6.6	0.5
30	5.8	0.3
35	5.8	0.2
40	5.8	0.13
41	5.8	0.09
Bottom		

NOTE: new anchor used and weight added to probe.

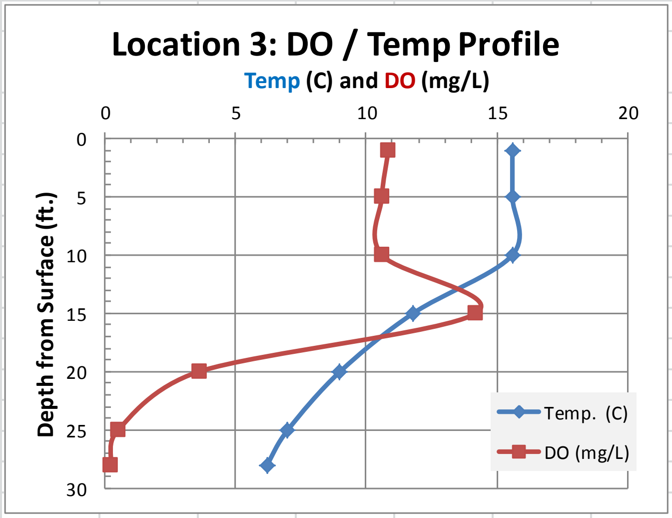


May 12, 2015

Location 3: Lat: 43° 6' 10.6014"
Long: -89° 19' 34.827"

Depth (ft)	Temp. (C)	DO (mg/L)
1	15.6	10.85
5	15.6	10.6
10	15.6	10.6
15	11.8	14.2
20	9	3.6
25	7	0.5
28	6.2	0.2
Bottom		

NOTE: new anchor used and weight added to probe.

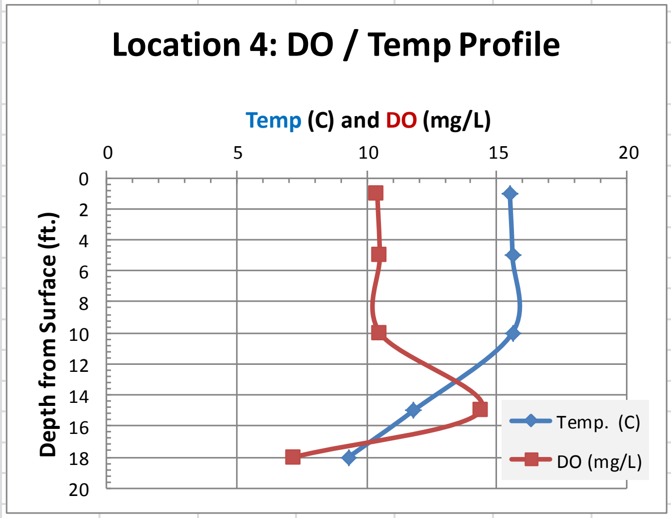


May 12, 2015

Location 4: Lat.: 43° 6' 12.4374"
Long.: -89° 19' 36.555"

Depth (ft)	Temp. (C)	DO (mg/L)
1	15.5	10.4
5	15.6	10.5
10	15.6	10.5
15	11.8	14.4
18	9.3	7.2
Bottom		

NOTE: new anchor used and weight added to probe.



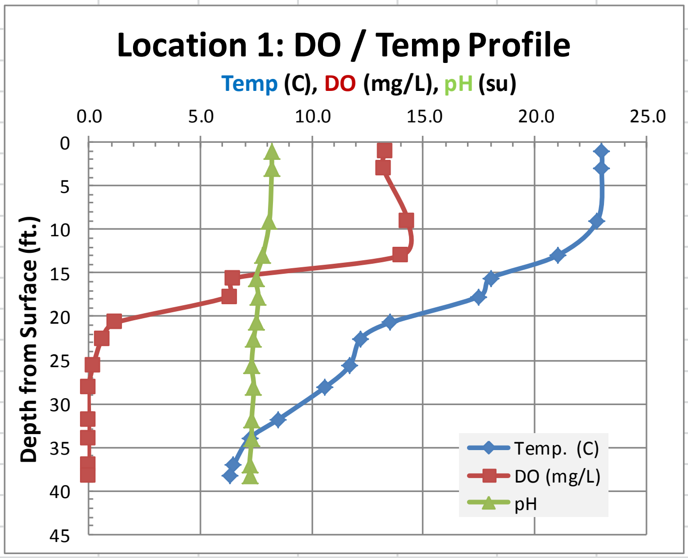
Starkweather Creek Coagulant Treatment Project
Madison, WI
Quarry Pond Monitoring
June 29, 2015

Weather:	mostly cloudy, T = 70; light sprinkles for 1/2 hr. around 7:45, then sunny, wind calm	
Field staff:	Jeff Herr (BC)	Roger Bannerman (USGS)
	Jim Bachhuber (BC)	Lauren Striegl (City of Madison)
Secchi Disk:	6.' 0"; 6' 1"; 6' 6"	

Dissolved Oxygen Profiles
In-Situ smarTROLL Multiparameter Handheld Water Quality Meter

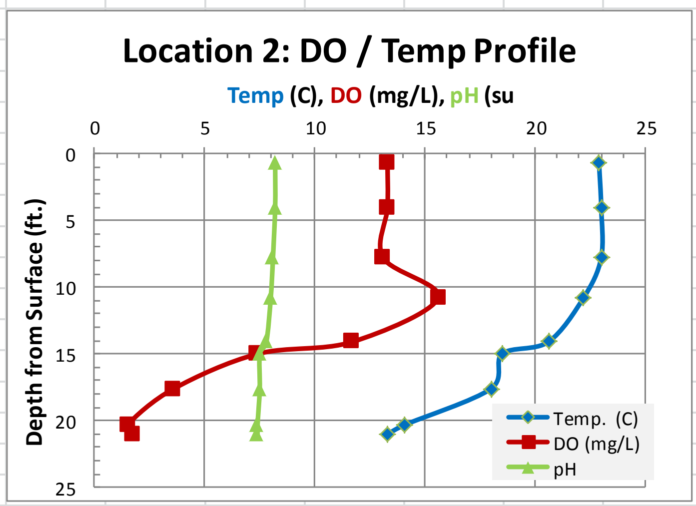
June 29, 2015

Location 1:	Lat: 40 deg 6 mih. 17 sec. N Long: 80 deg. 19 min. 44 sec. W			
	Depth (ft)	**Temp. (C)**	**DO (mg/L)**	**pH**
1	1	23.0	13.3	8.2
2	3	23.0	13.2	8.2
3	9	22.8	14.3	8.1
4	13	21.0	14.0	7.8
5	15.6	18.0	6.5	7.5
6	17.7	17.5	6.3	7.6
7	20.7	13.5	1.2	7.5
8	22.5	12.2	0.6	7.4
9	25.6	11.7	0.2	7.3
10	28.1	10.6	0.0	7.4
11	31.8	8.5	0.0	7.3
12	34	7.2	0.0	7.3
13	37	6.5	0.0	7.2
14	38.2	6.3	0.0	7.2
15				



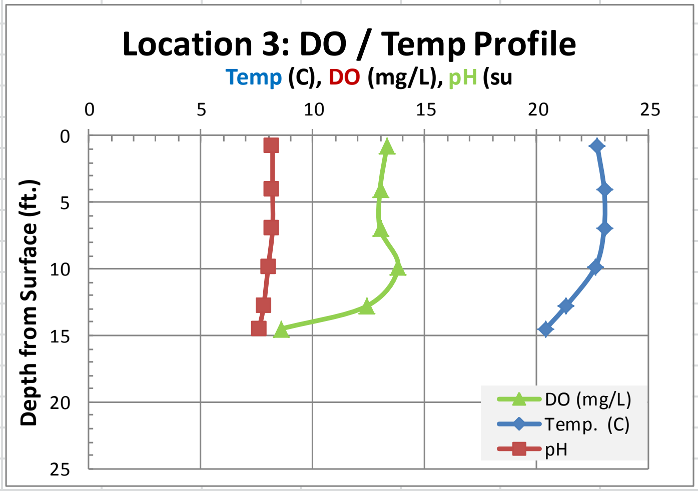
June 29, 2015

Location 2:	Lat: 43 deg. 6 min. 18 sec Long: 89 Deg. 19 min. 44 sec.			
	Depth (ft)	**Temp. (C)**	**DO (mg/L)**	**pH**
1	0.65	22.9	13.3	8.2
2	4	23	13.3	8.2
3	7.8	23	13.1	8.1
4	10.8	22.2	15.6	8
5	14.1	20.6	11.7	7.8
6	15	18.5	7.4	7.5
7	17.6	18	3.6	7.5
8	20.3	14.1	1.5	7.4
9	21	13.3	1.7	7.4



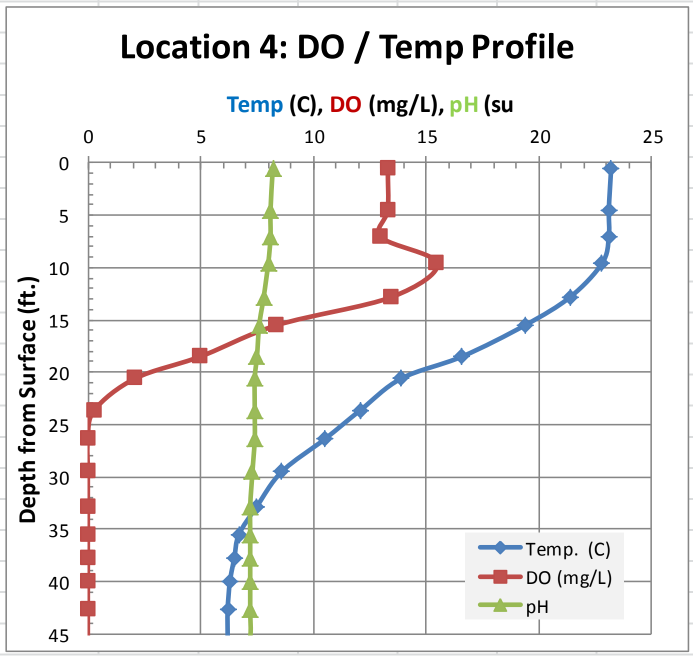
June 29, 2015

Location 3:	Lat: 43 deg. 6 min. 30 sec. Long: 89 deg. 19 min. 53 sec.			
	Depth (ft)	Temp. (C)	DO (mg/L)	pH
1	0.8	22.7	13.3	8.2
2	4	23	13	8.2
3	7	23	13	8.2
4	9.9	22.6	13.8	8
5	12.8	21.3	12.4	7.8
6	14.5	20.4	8.6	7.6



June 29, 2015

Location 4:	Lat: 43 deg. 6 min. 10 sec. Long: 89 deg. 19 min. 36 sec.			
	Depth (ft)	Temp. (C)	DO (mg/L)	pH
1	0.6	23.2	13.3	8.2
2	4.5	23.1	13.3	8.1
3	7.1	23.1	13.0	8.1
4	9.6	22.8	15.5	8
5	12.8	21.4	13.5	7.8
6	15.5	19.4	8.4	7.6
7	18.5	16.6	5.0	7.5
8	20.6	13.9	2.1	7.4
9	23.6	12.1	0.3	7.4
10	26.4	10.5	0.0	7.4
11	29.5	8.6	0.0	7.3
12	32.8	7.5	0.0	7.2
13	35.5	6.7	0.0	7.2
14	37.7	6.5	0.0	7.2
15	40	6.3	0.0	7.2
16	42.7	6.2	0.0	7.2
17	45.2	6.2	0.0	7.2
18	45.6	6.2	0.0	6.9



Appendix D: Hydrologic and Hydraulic Modeling Support Information

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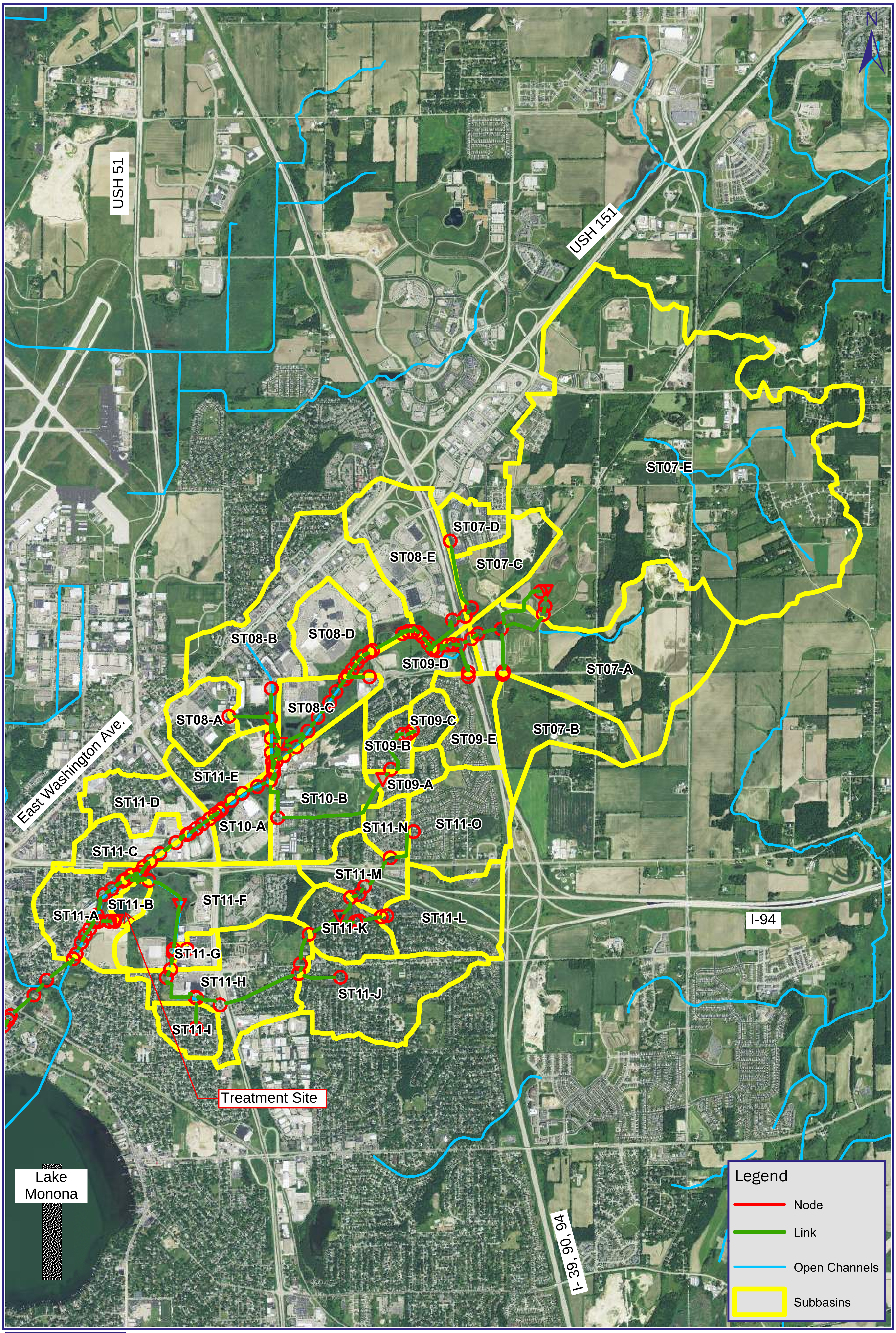

2/10/2016

Path: C:\Users\cburger\Documents\Projects\Starkweather\GIS\MXDs\Report Figures\Figure D-1 XP-SWMM Model Links and Nodes.mxd

Brown AND Caldwell

Figure D-1. XP-SWMM Model Links and Nodes
Starkweather Creek Phosphorus Reduction Study
City of Madison, WI

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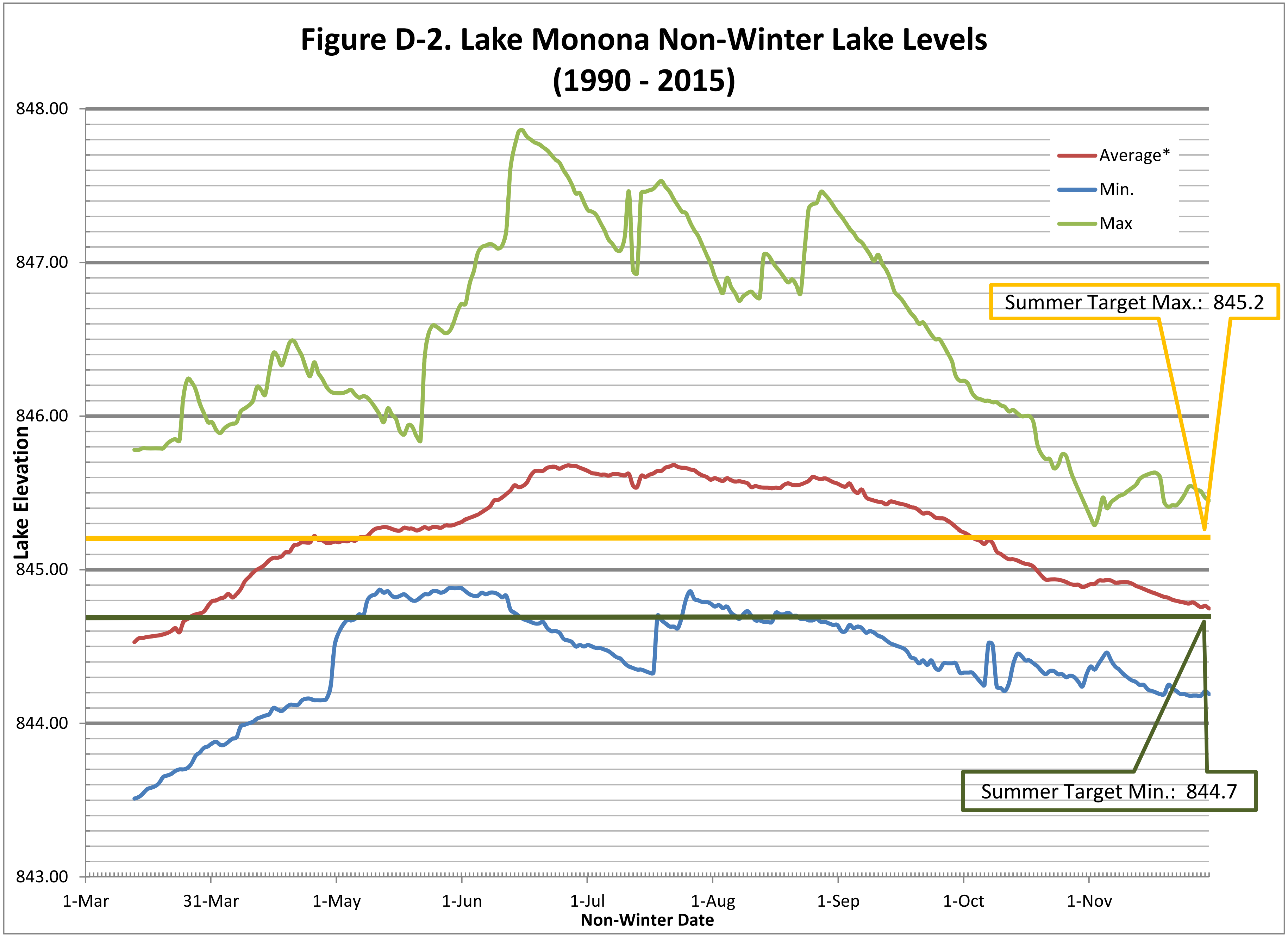
Figure D-2. Lake Monona Non-Winter Lake Levels
(1990 - 2015)
848.00
847.00
846.00
845.00
844.00
843.00
Lake Elevation
1-Mar
31-Mar
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
Non-Winter Date
Average*
Min.
Max
Summer Target Max.: 845.2
Summer Target Min.: 844.7

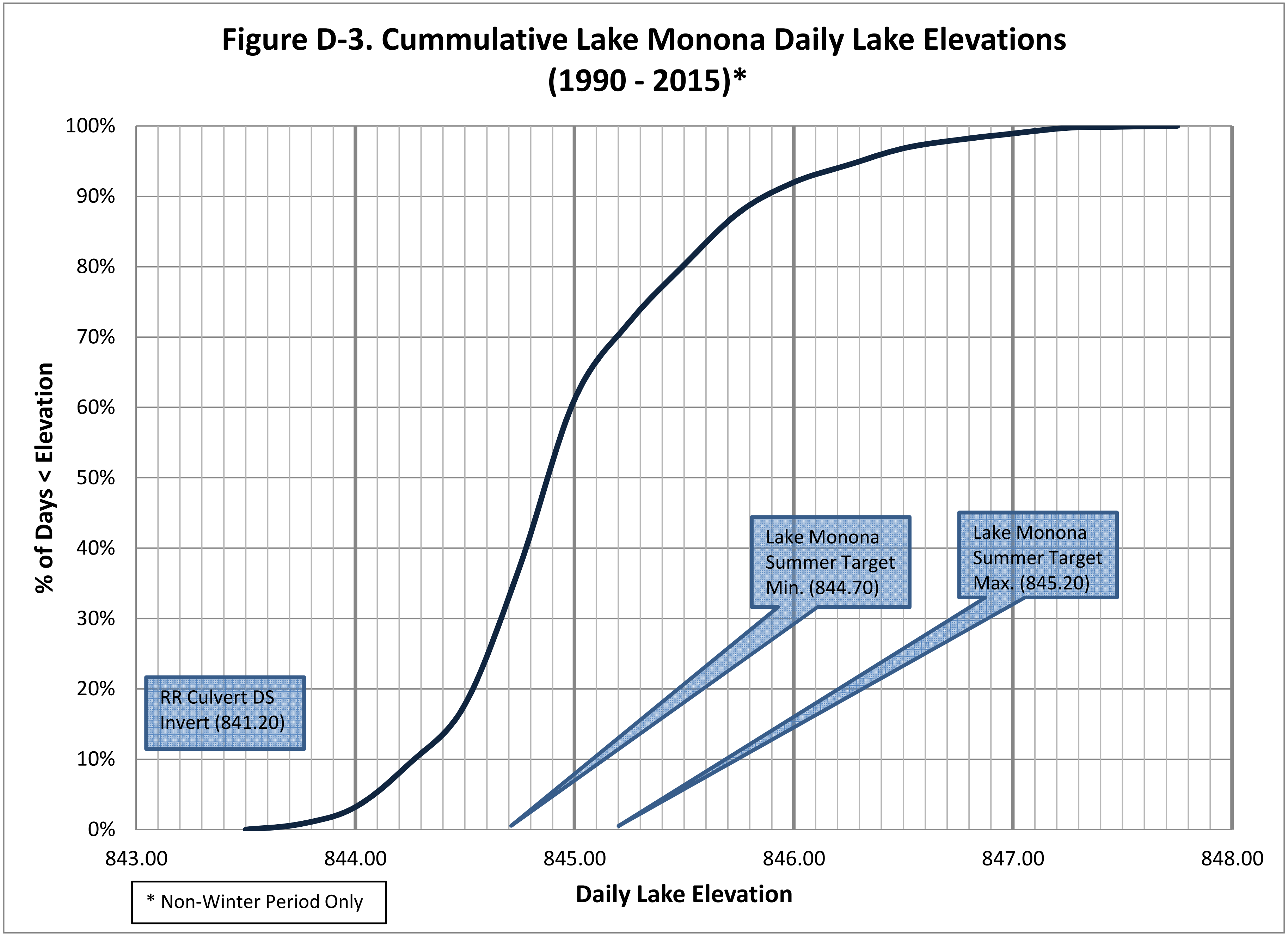
Figure D-3. Cummulative Lake Monona Daily Lake Elevations
(1990 - 2015)*
% of Days < Elevation
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
843.00
844.00
845.00
846.00
847.00
848.00
Daily Lake Elevation
RR Culvert DS Invert (841.20)
Lake Monona Summer Target Min. (844.70)
Lake Monona Summer Target Max. (845.20)
* Non-Winter Period Only

Table D-1. City of Madison Subbasins and Revised Project Subbasins Starkweather Creek Phosphorus Treatment Phase I Study				
Major Basin	City of Madison Basin	Area (ac)	Model Subbasin Name	Notes
ST07	ST07-A-0012-F-MAD-C	735.2	ST07-A	Spit watershed - drainage to Autumn Lake vs. other
ST07	ST07-A-0013-F-BUR-T	148.4	ST07-B	
ST07	ST07-A-0014-B-BUR-T	1,063.1		Enters Autumn Lake - Combine with all Autumn Lake drainage
ST07	ST07-A-0469-N-MAD-C	37.4		Enters Autumn Lake - Combine with all Autumn Lake drainage
ST07	ST07-A-0512-N-MAD-C	36.9		Enters Autumn Lake - Combine with all Autumn Lake drainage
ST07	ST07-A-0516-N-MAD-C	101.5		Enters Autumn Lake - Combine with all Autumn Lake drainage
ST07	ST07-A-0578-N-MAD-C	35.0		Enters Autumn Lake - Combine with all Autumn Lake drainage
ST07	ST07-B-0357-H-MAD-C	52.7	ST07-D	
ST07	ST07-B-0358-H-MAD-C	105.1	ST07-C	
ST08	ST08-A-0141-D-MAD-C	66.4	ST08-A	
ST08	ST08-A-0142-H-MAD-C	347.2	ST08-B	
ST08	ST08-A-0397-D-MAD-C	15.6		Combine with ST08-A
ST08	ST08-B-0259-H-MAD-C	104.5	ST08-D	
ST08	ST08-B-0578-H-MAD-C	37.3	ST08-C	
ST08	ST08-C-0356-H-MAD-C	210.0	ST08-E	
ST08	ST08-U-0140-D-MAD-C	52.3		Combine with ST08-C
ST09	ST09-A-0309-I-MAD-C	44.8	ST09-B	
ST09	ST09-A-0310-I-MAD-C	36.5	ST09-C	
ST09	ST09-A-0316-I-MAD-C	63.2	ST09-E	Name based on whether the other watershed is split
ST09	ST09-A-0576-I-MAD-C	42.1	ST09-A	
ST09	ST09-U-0317-F-MAD-C	145.2	ST09-D	Split watershed. Combine part with ST09-E
ST10	ST10-A-0144-K-MAD-C	141.5	ST10-B	
ST10	ST10-B-0373-H-MAD-C	52.6	ST10-A	
ST10	ST10-U-0143-D-MAD-C	92.8		Split watershed. Combine part with ST10-A and part with ST10-B
ST11	ST11-A-0147-H-MAD-C	130.4	ST11-D	
ST11	ST11-A-0311-H-MAD-C	148.3	ST11-O	
ST11	ST11-A-0528-H-MAD-C	28.6		Combine with of ST11-O
ST11	ST11-B-0148-D-MAD-C	70.3	ST11-C	
ST11	ST11-C-0149-H-MAD-C	26.5	ST11-G	
ST11	ST11-C-0569-H-MAD-C	180.0	ST11-F	

Table D-1. City of Madison Subbasins and Revised Project Subbasins
Starkweather Creek Phosphorus Treatment Phase I Study

Major Basin	City of Madison Basin	Area (ac)	Model Subbasin Name	Notes
ST11	ST11-D-0150-H-MAD-C	220.4	ST11-H	
ST11	ST11-D-0151-H-MAD-C	202.2	ST11-J	
ST11	ST11-D-0152-H-MAD-C	90.8	ST11-M	
ST11	ST11-D-0153-H-MAD-C	164.0	ST11-L	
ST11	ST11-D-0154-H-MAD-C	52.3	ST11-I	
ST11	ST11-D-0568-H-MAD-C	92.2	ST11-K	
ST11	ST11-U-0145-D-MAD-C	215.0		Split watershed: discharge to pond vs downstream of pond (Name ST11-A & ST11-B)
ST11	ST11-U-0146-H-MAD-C	86.4	ST11-E	
ST11	ST11-U-0308-H-MAD-C	40.0	ST11-N	
		5,514.7		

Table D-2. XP-SWMM and PC-SWMM Subbasin Peak Flow and Runoff Volume Results
Starkweather Creek Phosphorus Treatment Phase I Study

XP-SWMM Results			PC-SWMM Results			Per Cent Difference	
Subbasin Name	Peak Runoff (cfs)	Runoff Volume (ac-ft.)	Subbasin Name	Peak Runoff (cfs)	Runoff Volume (ac-ft.)	Peak Runoff (cfs)	Runoff Volume (ac-ft.)
ST07-A	65.3	88.27	ST07-A	62.8	91.39	4%	-4%
ST07-B	11.7	16.03	ST07-B	11.2	17.22	4%	-7%
ST07-C	12.4	17.00	ST07-C	12.5	18.81	-1%	-11%
ST07-D	38.0	51.36	ST07-D	38.5	55.76	-1%	-9%
ST07-E	183.0	245.66	ST07-E	190.8	274.63	-4%	-12%
ST08-A	61.8	82.69	ST08-A	62.6	89.64	-1%	-8%
ST08-B	224.2	322.12	ST08-B	227.3	350.41	-1%	-9%
ST08-C	37.4	50.03	ST08-C	38.0	54.53	-2%	-9%
ST08-D	96.5	130.02	ST08-D	98.3	142.09	-2%	-9%
ST08-E	143.0	191.47	ST08-E	145.4	208.59	-2%	-9%
ST09A	15.4	20.90	ST09A	15.8	22.92	-2%	-10%
ST09-B	20.5	27.56	ST09-B	20.6	29.65	0%	-8%
ST09-C	14.3	19.49	ST09-C	14.5	21.21	-1%	-9%
ST09-D	38.8	52.80	ST09-D	39.3	57.48	-1%	-9%
ST09-E	35.9	48.88	ST09-E	35.8	52.51	0%	-7%
ST10-A	41.2	55.09	ST10-A	41.6	59.60	-1%	-8%
ST10-B	96.7	130.53	ST10-B	98.6	142.80	-2%	-9%
ST11-A	65.6	88.49	ST11-A	66.0	95.44	-1%	-8%
ST11-B	6.7	9.21	ST11-B	6.9	10.19	-2%	-11%
ST11-C	52.7	70.52	ST11-C	53.1	76.05	-1%	-8%
ST11-D	92.9	124.89	ST11-D	94.2	135.71	-1%	-9%
ST11-E	36.0	48.26	ST11-E	36.3	52.08	-1%	-8%
ST11-F	104.1	139.26	ST11-F	103.8	148.78	0%	-7%
ST11-G	27.3	36.70	ST11-G	27.4	39.37	0%	-7%
ST11-H	121.3	164.34	ST11-H	121.9	177.26	-1%	-8%
ST11-I	23.9	31.98	ST11-I	24.2	34.71	-1%	-9%
ST11-J	84.2	112.59	ST11-J	83.8	120.15	0%	-7%
ST11-K	32.6	44.04	ST11-K	33.1	48.03	-2%	-9%
ST11-L	57.9	77.90	ST11-L	59.3	85.50	-2%	-10%

Table D-2. XP-SWMM and PC-SWMM Subbasin Peak Flow and Runoff Volume Results Starkweather Creek Phosphorus Treatment Phase I Study							
XP-SWMM Results			PC-SWMM Results			Per Cent Difference	
Subbasin Name	Peak Runoff (cfs)	Runoff Volume (ac-ft.)	Subbasin Name	Peak Runoff (cfs)	Runoff Volume (ac-ft.)	Peak Runoff (cfs)	Runoff Volume (ac-ft.)
ST11-M	48.8	65.76	ST11-M	48.6	70.25	0%	-7%
ST11-N	24.9	33.23	ST11-N	25.2	36.15	-1%	-9%
ST11-O	69.1	92.49	ST11-O	69.8	100.17	-1%	-8%

Table D-3. Modeled Conveyance System Information
Starkweather Creek Phosphorus Treatment Phase I Study

Name / ID	Downstream Invert Elevation (ft.)	Upstream Invert Elevation (ft.)	Conduit Slope (%)	Length (ft.)	Shape	Diameter/ Height (ft.)
130.8584	842.27	843.20	0.71	131	Natural	N/A
219.9056	843.20	843.21	0.01	89	Natural	N/A
250	842.50	843.20	0.10	670	Natural	N/A
405.9689	843.15	843.60	0.26	174	Natural	N/A
909.4311	843.60	842.80	-0.16	503	Natural	N/A
966.0651	842.80	842.72	0.00	57	Natural	N/A
1079.244	842.55	842.90	0.26	50	Natural	N/A
1493.086	842.90	843.10	0.05	414	Natural	N/A
1680	844.20	845.20	0.08	1,250	Natural	N/A
1680.1	843.20	844.20	0.08	1,250	Natural	N/A
1822.061	843.10	843.20	0.03	329	Natural	N/A
2351.132	843.20	843.30	0.02	303	Natural	N/A
2927.127	843.30	843.40	0.02	576	Natural	N/A
3450	845.20	845.80	0.12	483	Natural	N/A
3484.973	843.40	842.50	-0.16	558	Natural	N/A
3643.724	842.50	841.38	0.00	159	Natural	N/A
3833.119	841.48	843.10	0.53	114	Natural	N/A
4271.137	843.10	843.95	0.19	438	Natural	N/A
4413.916	843.95	843.63	-0.22	143	Natural	N/A
4867.742	843.51	843.52	0.00	231	Natural	N/A
5815.52	843.52	843.70	0.02	948	Natural	N/A
5953.351	843.70	843.56	-0.10	138	Natural	N/A
6264.834	843.50	843.46	-0.02	247	Natural	N/A
6467.063	843.46	842.90	-0.28	202	Natural	N/A
6938.498	843.38	843.19	-0.09	203	Natural	N/A
7090.218	843.19	843.38	0.13	152	Natural	N/A
7551.556	843.38	843.77	0.03	371	Natural	N/A
8023.543	843.77	844.18	0.09	472	Natural	N/A
8560.908	844.18	844.59	0.08	537	Natural	N/A
8913.99	844.59	844.97	0.11	353	Natural	N/A

Table D-3. Modeled Conveyance System Information
Starkweather Creek Phosphorus Treatment Phase I Study

Name / ID	Downstream Invert Elevation (ft.)	Upstream Invert Elevation (ft.)	Conduit Slope (%)	Length (ft.)	Shape	Diameter/ Height (ft.)
9038.023	844.97	845.50	0.43	124	Natural	N/A
9142.492	845.06	845.14	0.20	41	Natural	N/A
9249.497	845.38	845.36	-0.03	77	Natural	N/A
9501.784	845.36	845.37	0.00	252	Natural	N/A
9944.581	845.37	845.77	0.09	443	Natural	N/A
10776.84	845.77	846.56	0.10	832	Natural	N/A
11188.59	846.56	846.76	0.05	412	Natural	N/A
11693.76	846.76	847.18	0.08	505	Natural	N/A
12100.35	847.18	847.48	0.07	407	Natural	N/A
12467.17	847.48	847.77	0.08	366	Natural	N/A
12701.23	847.77	848.25	0.22	65	Natural	N/A
13089.7	848.25	848.68	0.11	388	Natural	N/A
13321.84	848.68	848.97	0.13	232	Natural	N/A
13499.27	848.97	848.64	-0.19	177	Natural	N/A
13776.37	848.64	849.96	0.29	117	Natural	N/A
13942.48	849.96	850.95	0.60	166	Natural	N/A
14257.65	850.95	852.00	0.33	315	Natural	N/A
14457.83	852.00	853.46	0.73	200	Natural	N/A
15191.61	853.46	857.72	0.58	734	Natural	N/A
15734.25	857.72	861.41	0.68	543	Natural	N/A
15807.46	861.41	862.01	0.82	73	Natural	N/A
15837.56	862.01	862.11	0.33	30	Natural	N/A
15926.49	862.11	862.56	0.51	89	Natural	N/A
16400.01	862.56	864.63	0.63	330	Natural	N/A
16591.13	864.63	867.05	0.58	415	Natural	N/A
16815.06	867.05	867.80	0.75	100	Natural	N/A
17318.34	867.80	872.04	-0.22	140	Natural	N/A
07B Over	905.00	907.00	2.13	94	Trapezoidal	10
07B Pipe	898.50	901.50	3.19	94	Circular	3
09A Over	860.00	918.00	1.82	3,192	Natural	N/A
09A Pipe	854.60	905.60	1.60	3,192	Circular	2.5

Table D-3. Modeled Conveyance System Information Starkweather Creek Phosphorus Treatment Phase I Study						
Name / ID	Downstream Invert Elevation (ft.)	Upstream Invert Elevation (ft.)	Conduit Slope (%)	Length (ft.)	Shape	Diameter/ Height (ft.)
09B Over	918.00	918.00	0.00	86	Trapezoidal	10
09B Pipe	910.25	912.00	2.04	86	Circular	4
09-C Over	924.00	926.00	1.44	139	Trapezoidal	10
09-C Pipe	916.30	920.40	2.95	139	Special	4.4
09D Over	856.50	857.00	0.07	690	Natural	N/A
09D Pipe	849.72	850.79	0.15	706	Special	4.4
09E Over	910.00	914.00	3.23	124	Trapezoidal	10
09E Pipe	903.00	905.67	2.10	127	Circular	3
10B Over	854.00	860.00	0.48	1,260	Natural	N/A
10B Pipe	846.04	854.60	0.68	1,260	Circular	4
11-G Over	852.00	854.00	0.56	360	Natural	N/A
11-G Pipe	845.40	846.70	0.36	360	Circular	3.5
11-H Over	854.00	866.00	1.57	765	Trapezoidal	10
11-H Pipe	848.71	860.71	1.57	765	Rectangular	5
11-J Over	883.00	902.00	1.58	1,206	Natural	N/A
11-J Pipe	867.71	893.97	2.18	1,206	Special	5.6
11-L Over	918.00	920.00	1.28	156	Trapezoidal	10
11-L Pipe	910.87	911.55	0.44	156	Circular	4
11-O Over	934.00	940.00	0.68	886	Natural	N/A
11-O Pipe	930.51	934.03	0.40	886	Special	5
1-yr flow	878.99	879.00	0.50	2	Rectangular	3
2x2 open	883.00	883.00	0.00	2	Rectangular	2
AB Channel	849.00	851.00	0.33	615	Natural	N/A
AutumnOut.1	875.29	878.99	0.20	1,850	Special	5.6
AutumnSpil						
BC2 Over	853.90	854.00	0.04	270	Trapezoidal	10
BCulv Over	854.00	854.00	0.00	92	Trapezoidal	10
Box Culv	845.20	845.20	0.00	92	Rectangular	5
Box Culv2	845.80	847.10	0.48	270	Rectangular	5
box over	849.00	849.00	0.00	33	Trapezoidal	10
Conspan	879.40	879.50	0.15	65	Rectangular	5

Table D-3. Modeled Conveyance System Information
Starkweather Creek Phosphorus Treatment Phase I Study

Name / ID	Downstream Invert Elevation (ft.)	Upstream Invert Elevation (ft.)	Conduit Slope (%)	Length (ft.)	Shape	Diameter/ Height (ft.)
FP Dum 1	850.95	851.00	0.50	10	Trapezoidal	10
FP Dum 2	850.00	850.50	5.00	10	Trapezoidal	10
FP Dum 3	850.00	850.05	0.50	10	Trapezoidal	8
HC P L Flo	877.40	883.00	4.55	123	Circular	2.5
HC P Over	897.50	898.00	0.41	123	Trapezoidal	10
I-94 Culv	871.20	876.20	1.37	365	Circular	4.5
I-94 Over	915.50	916.00	0.14	365	Trapezoidal	10
Knotch						
Link605	848.91	849.80	0.11	850	Natural	N/A
Link612	880.28	884.00	0.40	930	Natural	N/A
Link613	889.50	892.00	1.25	200	Natural	N/A
Link618	893.00	910.87	2.82	634	Natural	N/A
Link620	889.40	893.94	1.36	334	Natural	N/A
Link622	897.81	905.60	2.72	286	Natural	N/A
Link631	851.00	854.00	0.25	1,190	Natural	N/A
Link632	851.00	852.00	0.12	842	Natural	N/A
Link636	867.80	903.00	4.40	800	Trapezoidal	10
Link638	875.29	898.50	1.92	1,210	Trapezoidal	10
Link639	872.04	875.29	0.28	1,165	Trapezoidal	10
Link640	875.29	879.40	0.32	1,285	Trapezoidal	10
Link641	895.00	935.00	1.97	2,030	Trapezoidal	10
Link644	862.01	871.20	0.84	1,100	Natural	N/A
Link649	848.50	849.00	0.12	416	Natural	N/A
Link650	848.00	848.50	0.19	270	Natural	N/A
Link651	847.50	848.00	0.56	90	Natural	N/A
Link655	843.20	843.20	0.00	224	Natural	N/A
Link659	843.00	843.00	0.00	116	Natural	N/A
Link660	843.00	843.00	0.00	320	Natural	N/A
Link661	843.20	843.00	-0.13	157	Natural	N/A
Link662	850.00	850.05	0.50	10	Trapezoidal	9.5
Link663	850.00	850.05	0.50	10	Trapezoidal	10

Table D-3. Modeled Conveyance System Information
Starkweather Creek Phosphorus Treatment Phase I Study

Name / ID	Downstream Invert Elevation (ft.)	Upstream Invert Elevation (ft.)	Conduit Slope (%)	Length (ft.)	Shape	Diameter/ Height (ft.)
Link664	853.95	854.00	0.50	10	Trapezoidal	10
Link665	851.95	852.00	0.50	10	Trapezoidal	10
Link666	846.00	846.05	0.50	10	Trapezoidal	9
Link667	846.00	846.05	0.50	10	Trapezoidal	10
Link668	846.00	846.10	1.00	10	Trapezoidal	10
Over Weir						
Path Culv	848.71	848.91	0.20	100	Circular	4
Path Over	853.90	854.00	0.10	100	Trapezoidal	10
Path2 Over	893.90	894.00	0.14	72	Trapezoidal	10
Path2 Pipe	883.95	884.00	0.07	72	Circular	1
PP Over	876.00	883.00	0.29	2,397	Natural	N/A
PP Pipe	860.71	867.71	0.29	2,397	Rectangular	4
PP2 Over	883.00	886.00	1.08	279	Natural	N/A
PP2 Pipe	867.71	880.28	4.52	278	Rectangular	4
qu box	843.00	843.00	0.00	33	Rectangular	5.5
Qu Culv	843.00	843.00	0.00	16	Circular	2.5
Qu Over	848.00	848.00	0.00	16	Trapezoidal	10
RWood Pond	915.32	916.30	0.58	170	Trapezoidal	10
Stein Culv	893.94	897.81	1.30	298	Special	6.3
Stein Over	900.00	904.00	1.34	298	Natural	N/A
STH30 Culv	905.60	916.00	0.70	1,495	Circular	4
STH30 Over	933.50	934.00	0.03	1,495	Trapezoidal	10
Thomp Culv	892.00	893.00	1.00	100	Circular	4
Thomp Over	899.90	900.00	0.10	100	Trapezoidal	10
W Po Over	918.00	922.00	0.28	1,440	Natural	N/A
W Po Pipe	912.00	915.32	0.23	1,440	Circular	4
Woodmans	847.10	848.71	0.13	1,255	Natural	N/A

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Appendix E: Cost Estimating Support Information

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Table E-1a. Site Work and Conveyance Construction Cost Estimate Construction Cost Estimate
Starkweather Creek Phosphorus Treatment Phase I Study

Item No.	Description	Est. Qty	Unit	Unit Cost	Total Cost	Comments/Source
1	Mobilization	1	LS	$30,000.00	$30,000.00	Unit Costs from City of Madison (placeholder estimate)
2	Furnish, Install, Maintain & Remove Silt Fence	5,200	LF	$1.85	$9,620.00	Unit Costs from City of Madison; quantity estimated from preliminary drawings
3	Furnish, Install, and Remove Tracking Pad	1	LS	$1,300.00	$1,300.00	Unit Costs from Oshkosh: average of 23 bid tabs
4	Furnish, Install, Maintain & Remove Other Erosion Control	1	LS	$10,000.00	$10,000.00	Other measures not itemized
5	Furnish & Install Turbidity Barrier (for in-stream box culvert construction)	100	LF	$35.00	$3,500.00	Unit Costs from City of Madison; quantity estimated from preliminary drawings
6	Clearing & Grubbing	1	LS	$8,000.00	$8,000.00	Unit Costs: RS Means @ $5,000/ac.
7	Common Excavation	55,200	CY	$5.00	$276,000.00	Unit Costs from City of Madison; quantity estimated from preliminary drawings
8	Fill and Regrading	20,100	CY	$20.00	$402,000.00	Unit Costs from City of Madison; quantity estimated from preliminary drawings
9	Excess Soil Hauling & Disposal	35,100	CY	$2.00	$70,200.00	Unit Costs from City of Madison; quantity estimated from preliminary drawings
10	Demo / Remove Existing Southern 5' Diameter CMP Culverts (two 54', 60" dia. CMPs)	1	LS	$10,000.00	$10,000.00	City of Madison estimate
11	Furnish and Install 6 'x 8' In-Stream Box Culverts	100	LF	$500.00	$50,000.00	City of Madison estimate
12	Furnish and Install (Grout) 18" diameter PVC pipe in Existing northern CMP Culvert	54	LF	$100.00	$5,400.00	City of Madison estimate
13	Furnish & Install Weir Gates and Controls at Culverts	2	LS	$33,600.00	$67,200.00	Assume 2 6'x8' gates (one for each culvert opening); Vendor quote: DYNAMIC Water Control Gates Inc. (2/16/16) = $16,800, Assume install cost = 2x product cost
14	Furnish & Install Diversion Gate & Controls	1	EA	$33,600.00	$33,600.00	Vendor quote: DYNAMIC Water Control Gates Inc. (2/16/16) = $16,800, Assume install cost = 2x product cost
15	Furnish & Install 48" RCP Pipe	550	LF	$215.00	$118,250.00	Unit costs from Appleton: average of 17 bids; quantity estimated from preliminary drawings
16	Furnish & Install Cast-in-Place Inlet and Gate Structure	1	LS	$40,000.00	$40,000.00	Estimate: Concrete Junction Box (8'x8')= $25,000; Headwall: $15,000 (Means, 2014)
17	Furnish & Install Storm Riser / Manholes (1@8'; 1 @ 12')	20	EA	$675.00	$13,500.00	Appleton, WI; average of 7 bids
18	Furnish & Install Apron Endwalls (at pond discharge)	1	EA	$5,000.00	$5,000.00	Cost from City of Oshkosh, high value from 3 bid tabs
19	Furnish & Install Pond Outlet Pump Station & Controls (25 cfs)	1	EA	$650,000.00	$650,000.00	Submersible pump; controls and electronics in an above ground panel; reviewed bid tabs from Cities of Green Bay and Fond du Lac, WI in consultation with BC pump designer
20	Furnish & Install Groundwater Pump Station & Controls (3 cfs)	1	LS	$55,000.00	$55,000.00	3 cfs pump
21	Furnish & Install Pond Outlet Structure	1	EA	$20,000.00	$20,000.00	May be integrated with outlet pump station
22	Furnish and Install Pond Silt Curtain (800')	1	LS	$32,920.00	$32,920.00	Quote from GEI Works (2/17/16); 10' deep curtain, plus reefing line and PDEA anchor system = $16,460; Assume install cost = 2x product cost
23	Furnish & Install Topsoil (6" depth)	41,500	SY	$3.00	$124,500.00	Unit Costs from City of Madison; quantity estimated from preliminary drawings
24	Furnish & Install Gravel Access Road (~ 4,000' @ 20' width)	9,000	SY	$8.02	$72,180.00	Unit Costs from City of Madison; quantity estimated from preliminary drawings
25	Gravel Parking / Snow Storage Area (2.0 acres)	10,100	SY	$8.02	$81,002.00	Unit Costs from City of Madison; quantity estimated from preliminary drawings

Table E-1a. Site Work and Conveyance Construction Cost Estimate Construction Cost Estimate Starkweather Creek Phosphorus Treatment Phase I Study						
Item No.	Description	Est. Qty	Unit	Unit Cost	Total Cost	Comments/Source
26	Furnish & Install Riprap & Filter Fabric (48" pond inlet)	180	SY	$31.28	$5,630.40	Unit Costs from Oshkosh: avg. 23 bids; quantity estimate from preliminary drawings
27	Furnish & Install Erosion Control Mat, Class I Urban, Type A	17,500	SY	$1.50	$26,250.00	Unit Costs from City of Madison; quantity estimated from preliminary drawings
28	Furnish & Install Turf Grass Seed, Mulch, and Fertilizer	39,000	SY	$1.50	$58,500.00	Unit Costs from City of Madison; quantity estimated from preliminary drawings
29	Allowance for Additional Grading	0		$0.00	$0.00	No allowance estimated
				Site Work Sub-Total	$2,279,552	

Table E-1b. Coagulant Treatment System Starkweather Creek Phosphorus Treatment Phase I Study						
Item No.	Description	Est. Qty	Unit	Unit Cost	Total Cost	Comments/Source
30	1-inch HDPE Coagulant Feed Line	150	LF	$25.00	$3,750.00	From Building to point of addition
31	1-inch PRGS Conduit & 4-20 mA Signal Cable & Pull Boxes to Point of Flow Measurement	1,045	LF	$40.00	$41,800.00	From Building to point of flow measurement 75' above flash mixer and to outlet channel below pump station
32	Flow Measurement Location (includes flow meter, conduit, etc.)	1	EA	$75,000.00	$75,000.00	Depth and velocity meters in 48", plus in outlet channel
33	Coagulant Addition Location (includes structure, "Flash-mixer", valves, pipe, etc.)	1	EA	$100,000.00	$100,000.00	Based on previous project estimates from other locations.
34	WQ monitoring stations and equipment (2 stations)	1	LS	$56,920.00	$56,920.00	Vendor quote on 3/24/16: 2 auto samples, refrigerated; housing, 2 rain gauges, 2 flow meters, 2 WQ sondes, software. In-situ monitoring for Turbidity, Conductivity, pH; ISCO samplers for TP, Ortho P, etc. Install labor = vendor rep. @ $800 for 2 days; city labor @ 16 hrs.*$45 = $720
35	Coagulant Flow Meter	1	EA	$15,000.00	$15,000.00	
36	Equipment / Controls Bldg.: 30 ft. x 40 ft., split face concrete block w/ metal roof (does not include interior equipment, electrical, or plumbing)	1,200	SF	$150.00	$180,000.00	Structural building only, no equipment, tanks,
37	Equipment / Controls Building Electrical /Mechanical/Plumbing/HVAC	1	LS	$100,000.00	$100,000.00	Based on previous project estimates from other locations.
38	Equipment / Controls Building piping, valves, & appurtenances	1	LS	$100,000.00	$100,000.00	Based on previous project estimates from other locations.
39	Building drain Line, and holding tank	1	LS	$5,000.00	$5,000.00	Assume 750 gallon holding tank to receive building wash water.
40	Self Contained Wash/water system	1	LS	$1,800.00	$1,800.00	Bradley Eye Wash Station and Drench Hose (15 gallon)

Table E-1b. Coagulant Treatment System Starkweather Creek Phosphorus Treatment Phase I Study						
Item No.	Description	Est. Qty	Unit	Unit Cost	Total Cost	Comments/Source
41	5,000 Gallon Double Wall FRP Tank, Heated, & Leak Detection System	2	EA	$25,000.00	$50,000.00	Based on previous project estimates from other locations.
42	Coagulant Pumps & Control Panel (with integrated control from WQ Monitoring Station)	1	LS	$100,000.00	$100,000.00	Located in Controls / Equipment Building; includes coagulant dosing controls, flash mixing controls
43	Telemetry/Remote Monitoring	1	LS	$25,000.00	$25,000.00	Based on previous project estimates from other locations.
44	Floc Discharge Assembly and line to geotextile dewatering bags	1	LS	$15,000.00	$15,000.00	Assembly for dredge, plus 400' of 6" pipe to dewatering location
45	Dredge for Floc Removal from Pond	1	LS	$242,250.00	$242,250.00	Vendor estimate for remote control, portable dredge; @ 450 gpm pumping rate
46	Electrical Service to Bldg./Pump Station	1	LS	$90,000.00	$90,000.00	Estimate from MG&E: 3 phase power brought to building, pond lift station, and diversion / gate structure.
				Coagulant Treatment System Sub-Total	$1,201,520	
				Construction Sub-Total	$3,481,072	
				Construction Contingency (30%)	$1,044,322	AACE Cost Estimating Protocol
				Construction Sub-Total + Contingency	$4,525,394	
				Design & CRS (20%)	$905,079	assume build date of 2017
				Cost Escalation from 2016 (3%)	$135,762	
				Total Amount	$5,566,235	

Items Not Included in the Construction Cost Estimate

1. Assume no clay liner required
2. Land acquisition
3. Wetland plants or wetland restoration
4. No backup power or pump station redundancy

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Table E-2. Annual Operation and Maintenance Cost Estimate
Starkweather Creek Phosphorus Treatment Phase I Study

Item No.	Description	Est. Qty	Unit	Unit Cost	Total Cost	Comments/Source
1	Weekly Site Visits & Testing (8 hours per week for 8 months)	275	HRS	$45.00	$12,375.00	City staff labor rate provide by Engineering
2	Mowing/General Site Maintenance (assume 4 visits per year, 2 person crew, 4 hours)	32	HRS	$45.00	$1,440.00	City staff labor rate provide by Engineering
3	Miscellaneous equipment/supplies ($200/month)	12	MO	$200.00	$2,400.00	
4	Coagulant Purchase (ACH @ 5 mg/L dose)	33,800	GAL	$4.69	$158,500.00	Unit cost provided by Hawkins Inc. (vendor)
5	Floc Removal and Transfer to Geotubes (labor) (2 staff x 180 hours)	180	Hrs.	$75.00	$13,500.00	Annual time estimate for city staff to perform the operation; Based on: 4,000,000 gallons floc removal @ 400 gpm (dredging rate) = 167 hours; 1 staff at dredge and 1 staff at geotubes; include 1 1/2 days for mobilization / demobilization
	Floc Disposal in Sediment Dewatering Bags (Geotubes) (4,000,000 gallons wet floc)	5	Units	$5,500.00	$27,500.00	Geotubes: 60' circumference (30' wide) x 100' length; need 5 tubes (@ $4,900 ea.) plus polymer feed
	Polymer additive to floc disposal process	1	LS	$5,000.00	$5,000.00	Vender estimate from 3/23/16 based on annual "bone dry" tonnage of 334 tons @ 1,670 lbs. of polymer ~ $2.50/lb. + feed unit
6	Loading from geotube to truck and hauling to landfill	2,500	CY	$10.00	$25,000.00	Off site disposal of dried floc. (hauling cost); disposal under City agreement with County
7	WQ Monitoring (40 events/yr.)	40	Events	$332.00	$13,280.00	City lab costs for parameters (TP, OP, TSS, Total Al, Diss AL, Alkalinity) = $121/ suite x 2 (up & down stream) = $242.00 / event City staff for labor costs = 2 hrs. @ $45/hr. = $90/event
8	Equipment Renewal and Replacement (assume 20 year life, 5% per year)	1	LS	$17,522.25	$17,500.00	All meters, pumps, monitoring instruments, electronics, = $360,065 @ 5%/yr. = $18,000
9	Power requirement for Pond outlet pump station and Flashmixer (1 year)	200,000	kWh/yr.	$0.08	$16,000.00	Pond Outlet Pump Run Time (WY 2006) = 1,995 hrs. x 100 HP x 0.75kw/hp = 149,625 kwh + Mixer Run Time for WY 2006 = 1,995 hrs. x 25 hp x 0.75 kw/hp = 37,406 kwh + miscellaneous for bldg. and chemical feed pump.
				Annual O&M Sub-Total	$292,495	
				Annual O&M Contingency (20%)	$58,499	
				Total Amount	$350,994	

Table E-3. Life Cycle Cost ($ / lb. TP Removed over 20 years):		
Item	Value	Notes
TP Removal (lbs.):	33,160	(1,658/yr.)
Capital Costs:	$5,566,235	
20 yrs. O&M Costs:	$7,019,880	
	$ 379.56	$/lb. Phosphorus Removal over 20 years