GRABER POND
HYDROLOGIC STUDY AND MANAGEMENT PLAN

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PROJECT NO. 1404

FOR:

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1. INTRODUCTION

1.1 Background

Graber Pond is located in the northern portion of the City of Middleton, Wisconsin (*Figure A1*), and can generally be classified as a prairie pothole. Physically speaking, a prairie pothole can be considered a feature that has no surface outlet, such as a river, under normal conditions. From a hydrologic perspective, prairie potholes are defined over the long term with significant seasonal and inter-annual variability in water levels. The reason for the variability is that the only mechanism for water that has entered the pothole to leave is through seepage and evapotranspiration. These two processes are quite slow compared to watershed runoff entering the pothole. For example, it might take weeks for the pond to seep and evaporate runoff from a single storm event that lasted only several hours. This unique feature of prairie potholes is drastically different than a riverine system such as Pheasant Branch Creek where the river can return to pre-storm flow conditions within hours or days after a storm event.

The unique hydrologic characteristics of prairie potholes make them especially vulnerable to the effects of urbanization. When the watersheds of prairie potholes are predominantly undeveloped (either pre-settlement or agricultural), prairie potholes typically are wetter in the spring and dry out during the summer and fall during years of normal precipitation. This natural hydrologic condition allows the prairie pothole to maintain a dynamic balance of open water and large areas of emergent and wetland vegetation on the fringe of the pothole. As urbanization in a prairie pothole watershed increases, summer rainfall events generate significant runoff to prairie potholes, which does not allow the pothole to dry out in the summer. Therefore, the pothole tends to become dominated by open water, and the potential for extended flooding of nearby development increases. The City of Middleton has first-hand experience with these consequences of urbanization in prairie pothole watersheds, as evidenced by Stricker, Tiedeman, and Esser Ponds. All three of these ponds have required engineered outlets to lower water levels because of flooding problems caused by urbanization.

Graber Pond's watershed is currently only partially developed (See *Figure A2*). The watershed is approximately 400 acres with approximately 68.5 acres developed in some type of urban land use. The most notable urban features in the watershed are the Springs Industries facility located to the south of Graber Pond and the USH 12 corridor located to the west of Graber Pond. Other development in the watershed include the National Electrostatics facility immediately to the west of Graber Pond, residential development located to the southeast, and scattered rural residential development. One unique characteristic of Graber Pond's watershed compared to the other prairie pothole watersheds in Middleton is the presence of two non-contact cooling water dischargers: Springs Industries and National Electrostatics. Currently, the discharge from these two facilities are modest; however, historically, Springs Industries discharge prior to the installation of cooling towers in the 1990's was a significant inflow to Graber Pond. Although the discharge from these two facilities appears to be minor at present, the potential exists for future expansion of these facilities.

Additional hydrologic impacts to Graber Pond could occur due to future development in the watershed that does not have appropriate stormwater management practices installed. The City of Middleton recognizes the potential for hydrologic change to occur as a result of development within the watershed and has recognized a unique opportunity to develop the Graber Pond watershed in a manner as to preserve the pond as a prairie pothole and possibly restore it to predevelopment conditions. To this end, the City has already recently adopted both a stormwater ordinance specifying stringent stormwater standards for development within a closed depression watershed and a Master Plan for Graber Pond outlining the goal of managing the pond as a prairie pothole and describing restoration and recreation opportunities that exist surrounding Graber Pond.

1.2 Previous Studies

Three previous studies have been completed on Graber Pond that are relevant to this study:

- USGS completed a study titled "Simulation of the Effects of Hypothetical Residential Development on Water Levels in Graber Pond, Middleton, Wisconsin" in 1993 (Leo House, USGS Report 92-4029). The study looked at the difference in water levels between the current and fully-developed watershed conditions over the course of a single year. The study concluded that the effects of urbanization could increase the water level in the pond 0.7 to 2 feet, although a wide range of inter-annual climatic conditions were not evaluated.
- UW-Madison completed a study titled "Hydrologic Study of Graber Pond Watershed for City of Middleton" (Jim Bosma, 1996). The study was more extensive than the USGS study in that the simulation period was 27 years instead of a single summer. The focus of this study was evaluating the effect of urbanization and Springs Industries inflow on Graber Pond water levels. At the time of the study, Springs Industries was discharging substantial amounts of non-contact cooling water into Graber Pond (approximately 250,000 gallons per day), and the Middleton Water Resources Management Commission had recommended that Springs Industries utilize cooling towers to reduce by approximately 90% the amount of discharge flowing into Graber Pond. The study, however, did not develop management proposals to mitigate for the increased inflow from Springs Industries and future development.
- Ken Saiki Design and JF New developed the "Graber Pond Master Plan" (2006). The primary relevance of this Master Plan to this study is that it outlines the goal to manage Graber Pond as a prairie pothole. Further, it describes many of the ecologic and habitat restoration and recreation opportunities surrounding the pond that could be implemented provided the hydrology of the pond is restored to a more natural condition.

1.3 Purpose of Study

The purpose of this study is three-fold:

- Expand on the previously completed studies,
- Define, from a hydrologic perspective, what it means for Graber Pond to be a prairie pothole under pre-developed watershed conditions, and
- Develop a long-term hydrologic management plan for Graber Pond aimed at preserving the pond as a prairie pothole while allowing for sustainable development to occur within its watershed.

This report documents the data collection, analysis, conclusions, and recommendations developed for this study.

2. DATA

2.1 Collected Data

Data collection at Graber Pond began in mid-July 2008 and ended in December 2009. Monitoring equipment was removed during the winter of 2008-2009.

In total, there were five separate sensors/loggers installed at Graber Pond collecting a variety of water- and weather- related information:

- Rain Gage: A HOBO non-heated tipping bucket rain gage was installed immediately northeast of Graber Pond along the existing bike path. Because of the relatively small size of the Graber Pond watershed, precipitation measured at this gage was assumed to be representative of rainfall over the entire watershed. The tipping bucket rain gage records precipitation in 0.01 inch increments, logging as often as the bucket tips or every 15 minutes, whichever is more frequent.
- Evapotranspiration: A Weather Hawk weather station was installed for the purposes of monitoring climatic variables (such as air temperature, wind speed, solar radiation, humidity, etc.) that are needed to estimate evapotranspiration (ET). This particular weather station automatically computes ET based on the climatic data using the Penman-Monteith Equation. ET was computed every half hour.
- Water Depth: A YSI sonde was used to measure water depth in the pond. The sonde is vented to the atmosphere so no atmospheric pressure correction is needed. The sonde was installed in the northeast corner of Graber Pond. Effects of wind fetch were assumed to be negligible.
- Water Quality: The YSI sonde was also used to collect water quality parameters, including water temperature, pH, dissolved oxygen, and conductivity in the pond. However, evaluating water quality was not the focus of this study, and therefore, the level of quality control on these data is not as high as the climatic and water depth data.
- Non-Contact Cooling Water Discharge: Inflow quantities to Graber Pond during the monitoring period from National Electrostatics and Springs Industries was either severely limited or completely unavailable. A HOBO pressure transducer was installed at both the National Electrostatics (NEC) outfall and the City storm sewer outfall (which includes the Springs Industries outfall). The pressure transducers are not vented to the atmosphere to atmospheric pressure corrections are needed to obtain accurate water depth readings. Flow volume for NEC discharge was estimated using grab samples and the water depth readings. Flow volume for Springs Industries were qualitatively estimated based on a weir rating relationship and the water depth readings, accounting for storm flow from the sewer contributing area.

A summary of raw monitored data manipulation and accommodating data gaps for the purposes of model calibration is contained in *Appendix B*. Detailed monitoring data is contained in *Appendix B and D*.

2.2 Data Sources

Additional data that was utilized as part of this study include:

- 2008 National Agriculture Imagery Program Orthophoto;
- NRCS soils data obtained from the NRCS;
- 1-foot contours obtained from City of Middleton;
- Dane County 2005 Digital Elevation Model;
- USDA/NRCS Dane County DRG;
- Hourly rainfall and Daily minimum and maximum temperature from Dane County Regional Airport obtained through the National Weather Service; and
- References as described in the text of this report.

3. HYDROLOGIC MODEL DEVELOPMENT/ CALIBRATION

The hydrologic model that was selected for use in this Graber Pond study was a modified version of the USGS Precipitation Runoff Modeling System (PRMS) model. The modifications that are referred to were completed to tailor the PRMS model to closed depression watersheds and were completed as part of a UW-Madison Master's Thesis study of Stricker and Tiedeman Ponds (J. Lefers, 2001). PRMS model modifications and approach are described in detail in that Master's Thesis. As part of this Graber Pond study, minor additional modifications were completed to further tailor the Stricker and Tiedeman Ponds model to Graber Pond; however, the model framework and modeling methodology remains the same.

The theory behind the modified PRMS model is that prairie potholes can be hydrologically modeled using a water budget equation, which is shown below:

$$\Delta S = (Q_i + P + G_i - Q_o - E - G_o) * \Delta t \qquad \text{(General Water Budget Equation)}$$

where ΔS = Change in storage (ac-ft)
Q_i = surface inflow (ac-ft/day)
P = precipitation directly on water surface (ac-ft/day)
G_i = groundwater inflow (ac-ft/day)
Q_o = surface outflow (ac-ft/day)
E = evapotranspiration (ac-ft/day)
G_o = groundwater outflow or seepage (ac-ft/day)
Δt = change in time (days)

Prairie potholes are unique in that they are typically perched above the regional water table, so the groundwater inflow term (G_i) is typically zero. Further, as described previously, under normal conditions, surface outflow (Qo) is also zero. However, one complicating factor with Graber Pond is the potential for non-contact cooling water discharge from either Springs Industries or National Electrostatics to enter the pond. Therefore, during the majority of time, the water budget equation for Graber Pond is:

$$\Delta S = (Q_{i,SR} + Q_{i,NCCD} + P - E - G_o) * \Delta t \qquad \text{(Graber Pond Normal Conditions Water Budget Equation)}$$

where $Q_{i,SR}$ = surface runoff inflow (ac-ft/day)
$Q_{i,NCCD}$ = non-contact cooling water discharge (ac-ft/day)

During dry periods, the equation can be further simplified to:

$$\Delta S = (Q_{i,NCCD} - E - G_o) * \Delta t \qquad \text{(Graber Pond No Rain Conditions Water Budget Equation)}$$

A brief summary of the estimated and/or calibrated parameters that were utilized is described below. A detailed model calibration description is enclosed in *Appendix B*.

- Watershed Runoff ($Q_{i,SR}$)
  - Watershed Area: 400.7 acres (prior to Tribeca Development)
  - Total Impervious Area: 17.1 percent (68.5 acres)
  - Directly Connected Impervious Area: 3.0 percent (12 acres)
  - Watershed Pervious Soils Saturated Hydraulic Conductivity: 0.065 inches/hour
- Non-Contact Cooling Water Discharge ($Q_{i,NCCD}$)
  - Based on monitoring data from 2009, inflow from Springs Industries and National Electrostatics was insignificant (See *Figure B1 and Figure B2*) compared to the other water budget terms, most notably evapotranspiration and seepage. Therefore, for the calibration period, these inflow terms were assumed to be zero.
- Precipitation directly on water surface (P)
  - Used monitoring data from a tipping bucket rain gage (*Figure B3*) and used pond area at the modeled pond elevation to compute volume inflow to pond from direct precipitation.
- Seepage or Groundwater Outflow (G_o)
  - Varies with pond elevation and ranges from approximately 0.016 ft/day to 0.04 ft/day. Rate is converted to volume by multiplying rate by pond area, which varies based on pond elevation.
- Evapotranspiration (E)
  - Modeled with Penman-Monteith Equation (where data exists); otherwise utilized regional monthly pan evaporation rates corrected with a pan coefficient (See *Figure B3 through Figure B5*). These rates were then multiplied by the pond area to obtain an evapotranspiration volume.
- Pond Overflow (Q_o)
  - The lowest elevation at which Graber Pond begins to overflow to the east is at elevation 905.1. Overflow was modeled using a weir equation.

Figure B6 through *Figure B8* display the 2008 (non-winter), 2009 (non-winter), and 2008-2009 (winter) calibration results, respectively. The results appear excellent for the entire calibration period except for late-August 2009 until late-September 2009 when the pond level was approximately elevation 901 to 903. Possible explanations for this discrepancy are outlined in *Appendix B*.

The apparent model error in late 2009 does not affect the overall objective of the study which is to establish management strategies aimed at restoring the hydrology of Graber Pond to a prairie pothole.

4. DEVELOPMENT AND MANAGEMENT SCENARIOS

In order to quantify the magnitude of hydrologic impact of current and future developments within the watershed over "undeveloped" conditions, multiple model scenarios were evaluated for the Graber Pond Watershed:

- Existing Watershed Conditions,
- Predevelopment Watershed Conditions,
- Future Watershed Conditions with Tribeca and Graber Highlands Developed with stormwater controls,
- Future Watershed Conditions with Tribeca Development and Highwood Circle Estates Diverted, and
- Future Watershed Conditions with Tribeca Development, Graber Road, and Springs Industries Diverted.

These four scenarios were evaluated using historical climate data from August 1948 through September 2009; however, results are only reported for October 1949 through September 2009 which equates to sixty years of simulation. The October 1 start date and the September 30 end date were selected to correspond with the USGS definition of a Water Year (Water Year 1950 through Water Year 2009).

The sixty years of hourly precipitation and daily maximum and minimum temperatures were obtained from Dane County Regional Airport. Evaporation data was obtained by using average regional monthly average Class A Pan Evaporation corrected with a pan coefficient (0.77).

4.1 Existing Watershed Conditions

For the existing conditions scenario, the watershed land use utilized in the calibration analysis and described in *Section 3* was selected. Both the 2008 and 2009 calibrated seepage rates (0.016 and 0.024-0.04 ft/day, See *Appendix B* for further discussion) were evaluated in the existing conditions analysis; however, the stage-duration curves *(Figure C1)* suggest that the lower seepage rate (0.016) results in unrealistically high pond stages in Graber Pond. In other words, using the lower seepage rate resulted in overflow from Graber Pond occurring 35% of the time, which is much higher than what was observed during monitoring and anecdotal observations by Middleton staff over the years. The 2009 seepage rate of 0.024-0.04 ft/day resulted in the pond overflowing approximately 4-5% of the time which appears to be more reasonable. Therefore, the 2009 calibrated seepage rate was utilized for the comparison of scenarios.

Table 4-1 below summarizes the stage-duration statistics that are shown graphically in *Figure C2*. By comparing the median pond level (902.0) for existing watershed conditions to the bathymetry data shown in *Figure A2*, much of the flat wetland area on the northwest side of the pond and the smaller flat area on the east side of the pondwould be above water half of the time; however, around the remaining pond perimeter, little area would be exposed at this water level due to the relatively steep near-shore slopes. *Table 4-2* summarizes the pond area duration statistics.

Table 4-1: Existing Watershed Conditions Water Level Statistics

Rank	Existing Watershed Conditions
Maximum Water Level	~906.0
75th Percentile	903.1
50th Percentile (Median)	902.0
25th Percentile	901.0
Minimum Water Level	~898 (dry)

Table 4-2: Existing Watershed Conditions Pond Area Statistics

Rank	Existing Watershed Conditions
Maximum Pond Area	24.2
75th Percentile	19.1
50th Percentile (Median)	15.4
25th Percentile	12.6
Minimum Pond Area	0.5

*Note: Pond Area data from 1994 survey, which was not independently verified as part of this study.

4.2 Predevelopment Watershed Conditions

For the predevelopment conditions scenario, the landuse in the model was modified to 100% pervious surfaces. *Figure C2* and *Table 4-3* below indicate that the water levels under a pre-development watershed condition are approximately one foot lower except at the extreme high and low water levels which are approximately the same. The pond area statistics shown in *Table 4-4* suggest that more of the flat, northwestern portion of the pond along with the smaller flat area on the east side of the pond would be above the water level half of the time. Along the remaining perimeter of the pond; however, little additional area is gained by the lower water levels suggesting that historically speaking much of the reliable stands of wetland vegetation has been in the northwestern portion of the pond with a narrow fringe around the remaining part of the pond.

Table 4-3: Water Level Statistics for Existing and Pre-Development Watershed Conditions

Rank	Existing Watershed Conditions	Pre-Development Watershed Conditions	Difference
Maximum Water Level	~906.0	~906.0	~0.0 feet
75th Percentile	903.1	902.1	-1.0 feet
50th Percentile (Median)	902.0	901.0	-1.0 feet
25th Percentile	901.0	899.9	-1.1 feet
Minimum Water Level	~898 (dry)	~898 (dry)	~0.0 feet

Table 4-4: Pond Area Statistics for Existing and Pre-Development Watershed Conditions

Rank	Existing Watershed Conditions	Pre-Development Watershed Conditions	Difference
Maximum Pond Area	24.2	24.2	0 acres
75th Percentile	19.1	15.7	3.4 acres
50th Percentile (Median)	15.4	12.6	2.8 acres
25th Percentile	12.6	8.7	3.9 acres
Minimum Pond Area	0.5	0.5	0.0 acres

*Note: Pond Area data from 1994 survey, which was not independently verified as part of this study.

4.3 Future Conditions with Tribeca and Graber Highlands Developed

Based on conversations with the City of Middleton, there are two potential areas within the watershed that may undergo development looking at a 20-year development horizon (Figure A5):

- The currently-proposed Tribeca Development is located southwest of Graber Pond between Springton Road, Parmenter Street, and USH 12. Approximately 17 acres of the development is located within the current Graber Pond watershed; however, the current proposal is to divert most of the runoff from the development to the south and out of the Graber Pond watershed. The development plan is currently undergoing detailed planning and review by the City and will likely develop in the next few years.

- Graber Highlands is an approximately 34-acre proposed development northwest of Graber Pond in an area that is currently agricultural. The proposed development is currently in the conceptual planning phase, and may develop in the next 20 years. The current conceptual plan consists of mainly commercial, medium to high density residential, and neighborhood center land uses.

  Table 4-5 below summarizes the division of land uses within the current conceptual plan for Graber Highlands. In addition, a percent directly connected impervious, percent partially connected impervious, and percent pervious area estimate is listed for each landuse based on modeling guidance from John Panuska (Memorandum titled "Drainage System Connectedness for Urban Areas", dated December 30, 1998) summarizing data collected from Madison and Milwaukee. Directly connected impervious area is considered impervious area whose runoff does not flow over pervious ground prior to reaching Graber Pond (such as a curb and gutter street, parking lot and driveways). Partially connected impervious area is impervious area whose runoff flows onto pervious ground (such as a typical rooftop or a road served by swales) such that during small rainfall events, runoff from the impervious area infiltrates into the adjacent pervious ground but during large rainfall events, the impervious area runoff begins to reach Graber Pond.

Table 4-5: Graber Highlands Landuse Summary

Landuse	Area (acres)	Directly Connected Impervious (acres, %)*	Partially Connected Impervious (acres, %)*	Pervious Area (acres, %)
Vacated Highway	1.95	0 (0%)	0 (0%)	1.95 (100%)
Commercial	2.37	2.04 (86%)	0 (0%)	0.33 (14%)
Commercial / Lodging	3.53	2.65 (75%)	0 (0%)	0.88 (25%)
Neighborhood Center	8.41	3.45 (41%)	0 (0%)	4.96 (59%)
High Density Residential	1.57	0.8 (51%)	0 (0%)	0.77 (49%)
Medium-High Density Residential	7.00	1.68 (24%)	0.91 (13%)	4.41 (63%)
Road	9.40	9.4 (100%)	0 (0%)	0 (0%)
Total	34.2	20.01 (58.5%)	0.92 (2.7%)	13.3 (38.9%)

*Percentages of directly and partially connected impervious area are typical values for these types of land uses and not actual percentages proposed for Graber Highlands.

Graber Highlands will be subject to the City of Middleton's stormwater ordinance, as outlined in Chapter 26 of the City ordinances. The ordinance describes stormwater management performance standards related to peak discharge, water quality, and infiltration. For analyzing benefits of a stormwater management system as it relates to water levels in prairie potholes, the infiltration requirements are the only relevant criterion. The City has required additional stormwater management criteria for closed depressions, which are described as follows:

- Closed Watersheds. For new and redevelopment sites located wholly or in part within a closed watershed, practices shall be designed to infiltrate one-hundred percent of the average annual predevelopment infiltration volume, regardless of the effective area of the infiltration system.

In order to approximate the area of infiltration practices such as raingardens, several preliminary RECARGA runs were performed with the following assumptions:

- Native soils within Graber Highlands are dominated by Dresden loam (DrD2), Dresden silt loam (DsC2), Troxel silt loam (TrB), and Dodge silt loam (DnC2). Based on the engineering properties of these soils, provided by NRCS, textures of sandy loam to sand and gravel can be encountered at 3 to 5 feet from the surface. Therefore, a median native soil infiltration rate of 1.63 inches per hour was used in our analysis, which is the infiltration rate provided in WDNR guidance for loamy sand.

- As the impervious area dominates annual runoff from an urban land use, the contributing area to the raingardens was assumed to be 100 percent impervious.

- All impervious area (directly and partially connected impervious area was assumed to drain to raingardens.
- The raingarden was assumed to not have additional improvements (i.e. no underdrain or storage layer) other than placing a highly-infiltrative soil such that the native soil is the limiting infiltration rate (1.63 inches per hour).
- The ponding depth before overflow for the raingardens was assumed to be 6 inches.

The ratio of the raingarden area to the contributing impervious area, or facility area ratio, that yields one-hundred percent infiltration with these assumptions is 20 percent, or one-fifth the impervious area.

The Graber Pond watershed land use with the Tribeca mostly diverted from the watershed and the Graber Highlands developed with stormwater management practices is summarized in *Table 4-6* below.

Table 4-6: Summary of Impervious Allocation with Tribeca and Graber Highlands Developed

Scenario	Directly Connected Impervious Area (Acres)	Partially Connected Impervious Area (Acres)	Impervious Area Connected to Infiltration (Acres)	Pervious Surfaces (Acres)	Total (acres)
Existing	12.0	56.5	0.0	332.2	400.7
Tribeca and Graber Highlands Developed	12.0	56.5	20.9	294.4	383.8

The results indicate that the hydrology of Graber Pond with Tribeca and Graber Highlands developed would be very similar to existing conditions as evidenced by the stage-duration results shown in *Table 4-7 and Figure C2*; however, negligible gain is made towards restoring the hydrologic regime of Graber Pond to pre-development conditions. As expected, the pond area fluctuations suggest the same conclusion that the future development, if managed as described above, will not further degrade Graber Pond, but will not improve it beyond its current condition (*Table 4-8*).

Table 4-7: Water Level Statistics for Existing, Pre-Development, and Tribeca / Graber Highlands Developed Watershed Conditions

Rank	Existing	Pre-Dev.	Tribeca / Graber Highlands	Difference (Existing)	Difference (Pre-Dev)
Maximum Water Level	~906.0	~906.0	~906.0	~0.0 feet	~0.0 feet
75th Percentile	903.1	902.1	903.0	-0.1 feet	+0.9 feet
50th Percentile (Median)	902.0	901.0	902.0	0.0 feet	+1.0 feet
25th Percentile	901.0	899.9	900.9	-0.1 feet	+1.0 feet
Minimum Water Level	~898 (dry)	~898 (dry)	~898 (dry)	~0.0 feet	~0.0 feet

Table 4-8: Pond Area Statistics for Existing, Pre-Development, and Tribeca / Graber Highlands Developed Watershed Conditions

Rank	Existing	Pre-Dev.	Tribeca / Graber Highlands	Difference (Existing)	Difference (Pre-Dev)
Maximum Pond Area	24.2	24.2	24.2	0.0 acres	0.0 acres
75th Percentile	19.1	15.7	19.0	0.1 acres	3.3 acres
50th Percentile (Median)	15.4	12.6	15.4	0.0 acres	2.8 acres
25th Percentile	12.6	8.7	12.3	0.3 acres	3.6 acres
Minimum Pond Area	0.5	0.5	0.5	0.0 acres	0.0 acres

*Note: Pond Area data from 1994 survey, which was not independently verified as part of this study.

4.4 Future Conditions with Tribeca and Highwood Circle Estates Diverted

Based on the findings from the previous scenario, it appears that appropriate stormwater management of new development in the Graber Pond watershed is effective at maintaining the existing hydrologic regime; however, this approach does little to mitigate the effects of already-constructed development in the watershed. One approach to further reducing the watershed runoff to Graber Pond is to divert additional watershed area from the Graber Pond watershed.

One of the potentially more cost-effective opportunities is diverting the Highwood Circle Estates development that currently drains under USH 12 and into the Tribeca Development site (See *Figure A6*). The current proposal is to route this runoff around the Tribeca site to the north such that it remains within the Graber Pond watershed; however, it may be possible to divert this runoff to the south into Pheasant Branch's watershed instead. The change in the Graber Pond watershed land use and area would change as summarized in *Table 4-9* below. Highwood Circle Estates is a low density development with a rural cross section road (roadside swales instead of curb and gutter), so it was assumed that the impervious area within this development is only "partially connected" to Graber Pond, i.e. in small rainfall events, runoff from impervious areas infiltrates into the adjacent ground, but during large rainfall events, the impervious area runoff begins to reach Graber Pond.

It should be noted that this study did not evaluate the feasibility of diverting this area to the south, such as evaluating elevation and capacity constraints downstream. Further, following discussion with the City of this potential diversion approach for the Highwood Circle Estates runoff, the City decided not to pursue with Tribeca Development the potential to divert the Highwood Circle Estates runoff through the Tribeca Development. However, this alternative is still presented in this report for the purposes of describing the hydrologic effects on Graber Pond that a watershed diversion would have.

Table 4-9: Summary of Impervious Allocation with Tribeca and Highwood Circle Estates Diverted

Scenario	Directly Connected (Acres)	Partially Connected (Acres)	Connected to Infiltration (Acres)	Pervious Surfaces (Acres)	Total (acres)
Existing	12.0	56.5	0.0	332.2	400.7
Tribeca and Highwood Circle Estates Diverted from the Watershed	12.0	45.7	0	284.7	342.4

In general, diverting the Tribeca and Highwood Circle Estates developments out of Graber Pond's watershed could be considered a midway point between existing and pre-development conditions, as evidenced by the results shown in *Table 4-10, Table 4-11, and Figure C2.*

Table 4-10: Water Level Statistics for Existing, Pre-Development, and Tribeca and Highwood Circle Estates Diverted Watershed Conditions

Rank	Existing	Pre-Dev.	Tribeca and Highwood Circle Estates Diverted	Difference (Existing)	Difference (Pre-Dev)
Maximum Water Level	~906.0	~906.0	~906.0	~0.0 feet	~0.0 feet
75th Percentile	903.1	902.1	902.7	-0.4 feet	+0.6 feet
50th Percentile (Median)	902.0	901.0	901.6	-0.4 feet	+0.6 feet
25th Percentile	901.0	899.9	900.5	-0.5 feet	+0.6 feet
Minimum Water Level	~898 (dry)	~898 (dry)	~898 (dry)	~0.0 feet	~0.0 feet

Table 4-11: Pond Area Statistics for Existing, Pre-Development, and Tribeca and Highwood Circle Estates Diverted Watershed Conditions

Rank	Existing	Pre-Dev.	Tribeca and Highwood Circle Estates Diverted	Difference (Existing)	Difference (Pre-Dev)
Maximum Pond Area	24.2	24.2	24.2	0.0 acres	0.0 acres
75th Percentile	19.1	15.7	17.9	-1.2 acres	+2.2 acres
50th Percentile (Median)	15.4	12.6	14.3	-1.1 acres	+1.7 acres
25th Percentile	12.6	8.7	10.9	-1.7 acres	+2.2 acres
Minimum Pond Area	0.5	0.5	0.5	0.0 acres	0.0 acres

*Note: Pond Area data from 1994 survey, which was not independently verified as part of this study.

4.5 Future Conditions with Tribeca, Graber Road, and Springs Industries Diversion

Although diverting both Tribeca and Highwood Circle Estates creates a more pre-development-like hydrologic regime compared to the current condition, this approach still would not achieve the ideal goal of restoring Graber Pond hydrology to pre-development levels. The portion of the Graber Pond watershed that has the highest hydrologic impact on Graber Pond is the area immediately south of

Graber Pond, which includes the storm-sewered Graber Road, Springs Industries, and suburban residential area, because this area is predominantly directly connected impervious area.

The existing surface of Graber Road drains to the west towards Parmenter Street, but the storm sewer system generally drains to the east and then north into Graber Pond. If the storm sewer were to be reconstructed to drain in the same direction as the road surface, additional storm sewer work could be completed to divert this area to the south along Parmenter Street and into Pheasant Branch Creek's watershed. *Figure A7* displays the new Graber Pond watershed if Tribeca, Graber Road, and Springs Industries are diverted. *Table 4-12* summarizes the new Graber Pond watershed for this scenario.

Diverting the Springs Industries facility to Pheasant Branch Creek would also significantly reduce concern about potential operational changes by Springs Industries that would send higher non-contact cooling discharge volumes into Graber Pond.

Table 4-12: Summary of Impervious Allocation with Tribeca and Springs Industries Diverted

Scenario	Directly Connected (Acres)	Partially Connected (Acres)	Connected to Infiltration (Acres)	Pervious Surfaces (Acres)	Total (acres)
Existing	12.0	56.5	0.0	332.2	400.7
Tribeca and Springs Industries Diverted from the Watershed	0.0	44.8	0.0	300.0	344.8

The results indicate that diverting Tribeca, Graber Road, and Springs Industries out of the Graber Pond watershed yields a hydrologic regime in Graber Pond that is very similar to predevelopment conditions, as evidenced by the stage-duration results shown in *Table 4-13, Table 4-14, and Figure C2.*

Table 4-13: Water Level Statistics for Existing, Pre-Development, and Tribeca / Graber Road / Springs Industries Diverted Watershed Conditions

Rank	Existing	Pre-Dev.	Tribeca and Springs Industries Diverted	Difference (Existing)	Difference (Pre-Dev)
Maximum Water Level	~906.0	~906.0	~906.0	~0.0 feet	~0.0 feet
75th Percentile	903.1	902.1	902.2	-0.9 feet	+0.1 feet
50th Percentile (Median)	902.0	901.0	901.1	-0.9 feet	+0.1 feet
25th Percentile	901.0	899.9	900.0	-1.0 feet	+0.1 feet
Minimum Water Level	~898 (dry)	~898 (dry)	~898 (dry)	~0.0 feet	~0.0 feet

Table 4-14: Pond Area Statistics for Existing, Pre-Development, and Tribeca / Graber Road / Springs Industries Diverted Watershed Conditions

Rank	Existing	Pre-Dev.	Tribeca and Springs Industries Diverted	Difference (Existing)	Difference (Pre-Dev)
Maximum Pond Area	24.2	24.2	24.2	0.0 acres	0.0 acres
75th Percentile	19.1	15.7	16.1	-3.0 acres	+0.4 acres
50th Percentile (Median)	15.4	12.6	12.9	-2.5 acres	+0.3 acres
25th Percentile	12.6	8.7	9.2	-3.4 acres	+0.5 acres
Minimum Pond Area	0.5	0.5	0.5	0.0 acres	0.0 acres

5. CONCLUSIONS

Although the current extent of development in Graber Pond's watershed is modest compared to the watersheds of Stricker, Tiedeman, and Esser Ponds, hydrologic regime changes are still noticeable (*Figure C2*). Water levels in Graber Pond are approximately one-foot higher with the current land use compared to when no impervious area existed in the watershed.

The City's current stormwater management ordinance for new or re-development in closed depressions, which stipulates that 100 percent of the pre-development average annual infiltration must be maintained, appears to be effective at maintaining the status quo water levels in Graber Pond as evidenced by the evaluation of developing Graber Highlands with the City's required stormwater management practices (*Figure C2*); however, other management strategies such as retro-fitting infiltration practices or diverting a portion of the watershed will be needed to restore the pond levels to pre-development conditions.

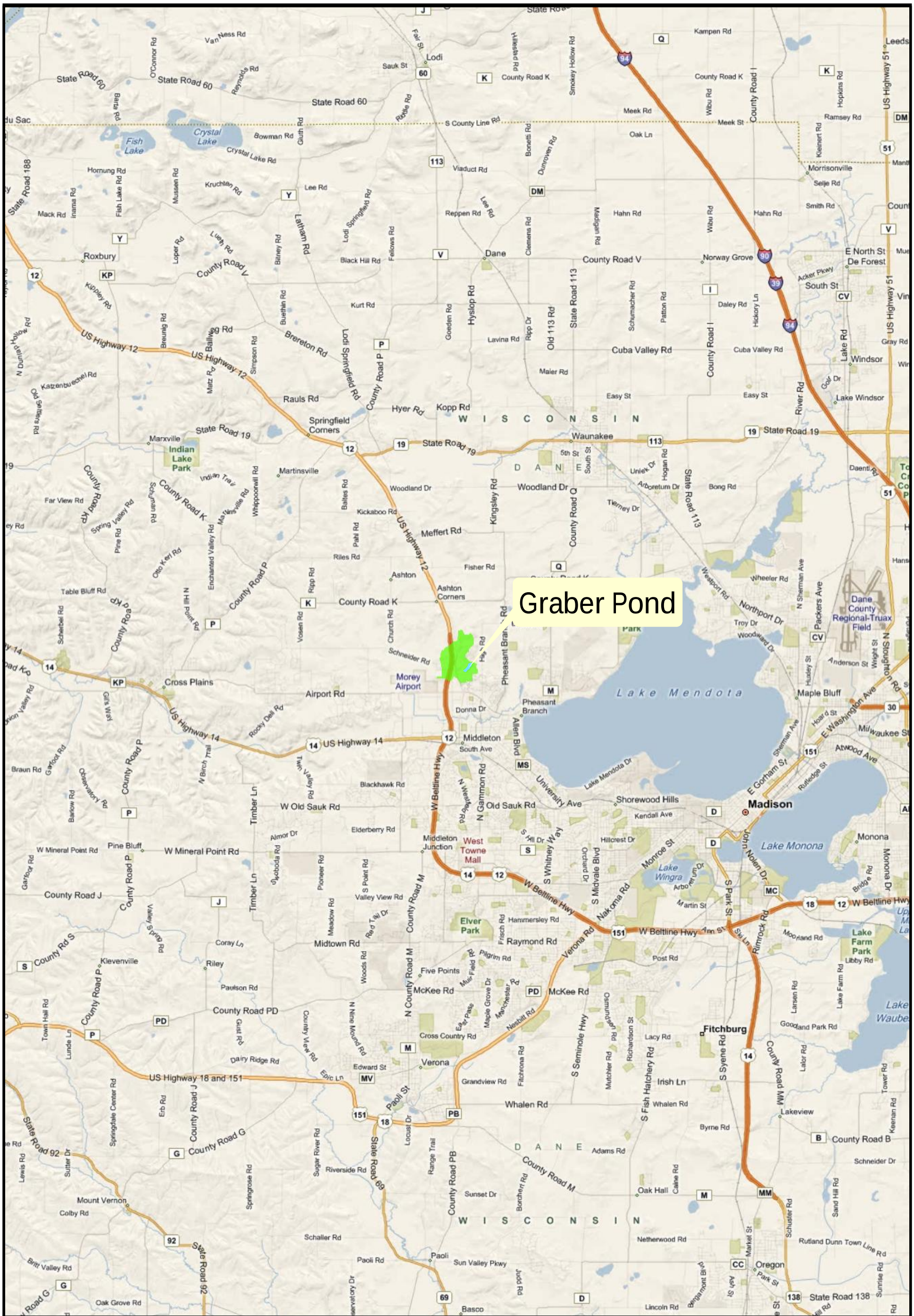
Two potential watershed diversion scenarios that were evaluated were the Tribeca / Highwood Circle Estates Diversion (shown in *Figure A6*) and the Tribeca / Graber Road / Springs Industries Diversion (*Figure A7*). The Tribeca / Highwood Circle Estates is a potentially cost-effective approach to lowering Graber Pond water levels; however, this approach yields a "midway point" hydrologic restoration to pre-development conditions (*Figure C2*). The Tribeca / Graber Road / Springs Industries diversion is likely a higher cost mitigation approach due to the storm sewer work that would need to be completed in Graber Road, but this approach nearly accomplishes the Graber Pond Master Plan goal of hydrologically restoring Graber Pond to pre-development conditions (*Figure C2*). This hydrologic restoration is an important aspect to also achieving ecologic restoration, which is also described in the Graber Pond Master Plan.

Maintaining the current level of non-contact cooling-water discharge from Springs Industries and National Electrostatics will also play an important role in being able to restore Graber Pond as a prairie pothole. The non-contact cooling water discharge rates at this time appear to be negligible, but profound hydrologic impacts can occur if the discharges were increased significantly. Diverting the surface runoff from Graber Road and the Springs Industries facility would have the added benefit of also diverting the Springs Industries non-contact cooling water discharge as their discharge is through the existing storm sewer system.

6. RECOMMENDATIONS

Based on the findings of this study, the following recommendations to the City should be considered:

- Require that Tribeca divert most of their runoff to the south and out of Graber Pond's watershed, as is currently proposed.
- Evaluate the feasibility (capacity constraints and necessary infrastructure improvements) and possible impacts to Pheasant Branch Creek from diverting a portion of the Graber Pond watershed to Pheasant Branch Creek. As described previously, following discussion with the City, the City decided not to further pursue the potential diversion of the Highwood Circle Estates runoff through the Tribeca Development project. However, other more costly diversion options still exist.
- When Graber Highlands develops, require that Graber Highlands implement stormwater management practices to meet the infiltration requirement for closed depressions (i.e. not allow fees in lieu of compliance)
- Continued discussion with both Springs Industries and National Electrostatics, so that the City at the very least is aware of potential future changes to their discharge rates and can plan accordingly.



0 0.5 1 2 Miles

1 inch = 2 miles

Figure A1 – Regional Location Map

GRABER POND HYDROLOGIC STUDY & MANAGEMENT PLAN

City of Middleton | Dane County, Wisconsin

Montgomery Associates
119 South Main Street | Suite A
Cottage Grove, WI 53527
www.ma-rs.org | (608) 223-9585

Watershed Properties

- Graber Pond Watershed
- Graber Pond

Developed by: Danielle Lee | 03/08/2010

1. Graber Pond Watershed Boundary: Montgomery Associates, 2010
2. Bing Maps- Roads: Microsoft Corporation, 2009
3. Graber Pond: WDNR 24K Hydrography

Main Map Projection: Albers Equal Area Conic with Standard Lines at 43.120° N, 43.125° N, 89.511 W°, WI Map Projection: Albers Equal Area Conic with Standard Lines at 44.0° N, 45.5° N, 89.0° W

Notes:
1.) 2008 ORTHOPHOTO FROM NATIONAL AGRICULTURE IMAGERY PROGRAM
2.) 1-FOOT CONTOUR DATA FROM SURVEY PERFORMED BY AYRES AND ASSSOCIATES (JUNE 1994)

DRAWN BY	CHECKED BY
LMS	JDL

NO.	REVISION / ISSUE	DATE

MONTGOMERY ASSOCIATES:
RESOURCE SOLUTIONS, LLC
119 SOUTH MAIN STREET
SUITE A
COTTAGE GROVE, WI 53527
www.ma-rs.org

GRABER POND NEARSHORE
TOPOGRAPHY AND BATHYMETRY

GRABER POND

CITY OF MIDDLETON

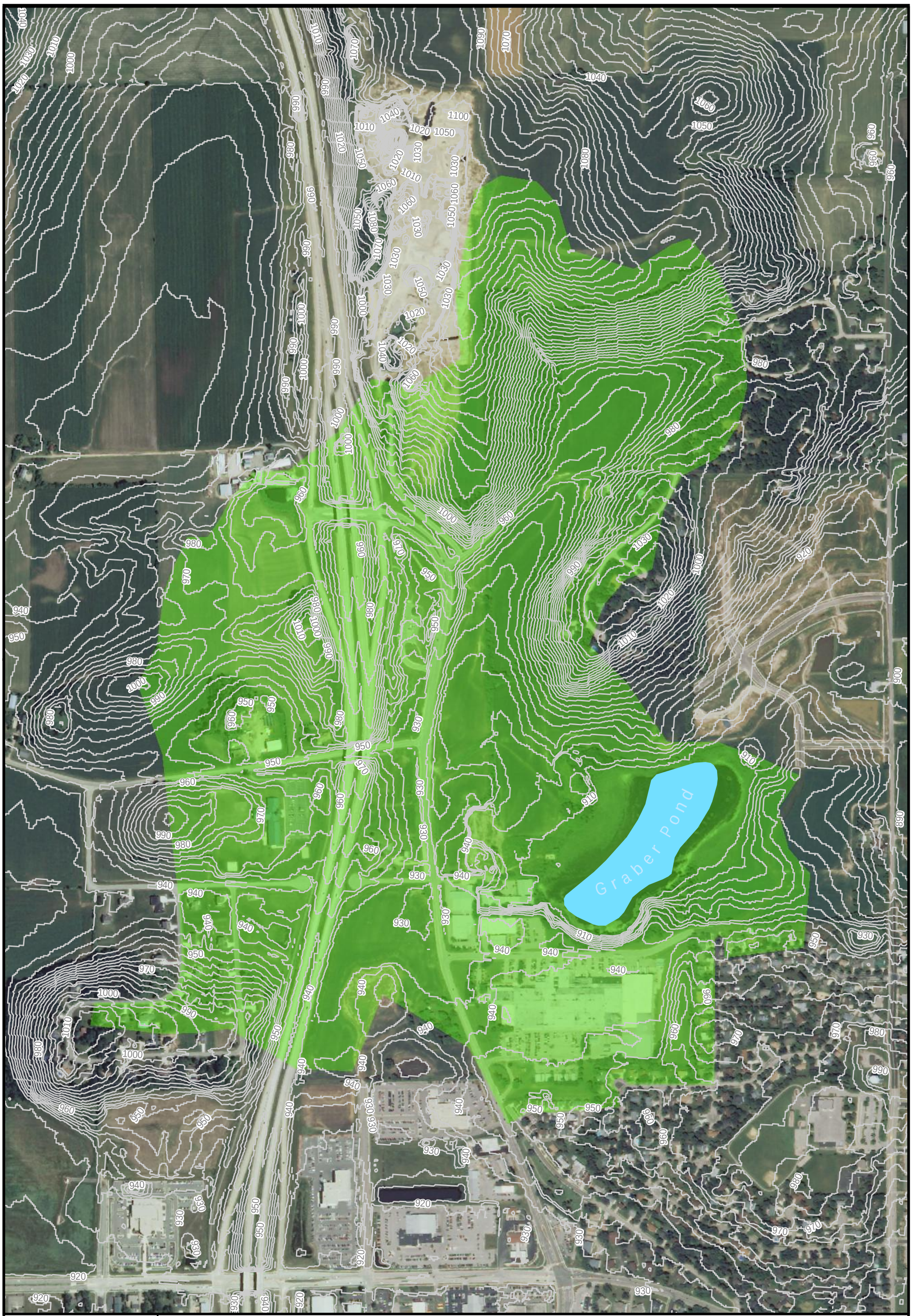
IF THIS BAR DOES NOT MEASURE 1"
THEN DRAWING IS NOT TO SCALE
0 ½ 1

SCALE
1"=200'

PROJECT NO.	DATE
1404	03/09/10

FIGURE NO.
A2

P:\1404 City of Middleton Graber Pond\Drawings\FIGURE_A2.dwg



Main Map Projection: Albers Equal Area Conic with Standard Lines at 43.120° N, 43.125° N, 89.511 W°, WI Map Projection: Albers Equal Area Conic with Standard Lines at 44.0° N, 45.5° N, 89.0° W

0 150 300 600 Feet

1 inch = 600 feet

Figure A3 – Existing Watershed Boundary and Topography

GRABER POND HYDROLOGIC STUDY & MANAGEMENT PLAN

City of Middleton | Dane County, Wisconsin

Montgomery Associates
119 South Main Street | Suite A
Cottage Grove, WI 53527
www.ma-rs.org | (608) 223-9585

Watershed Properties

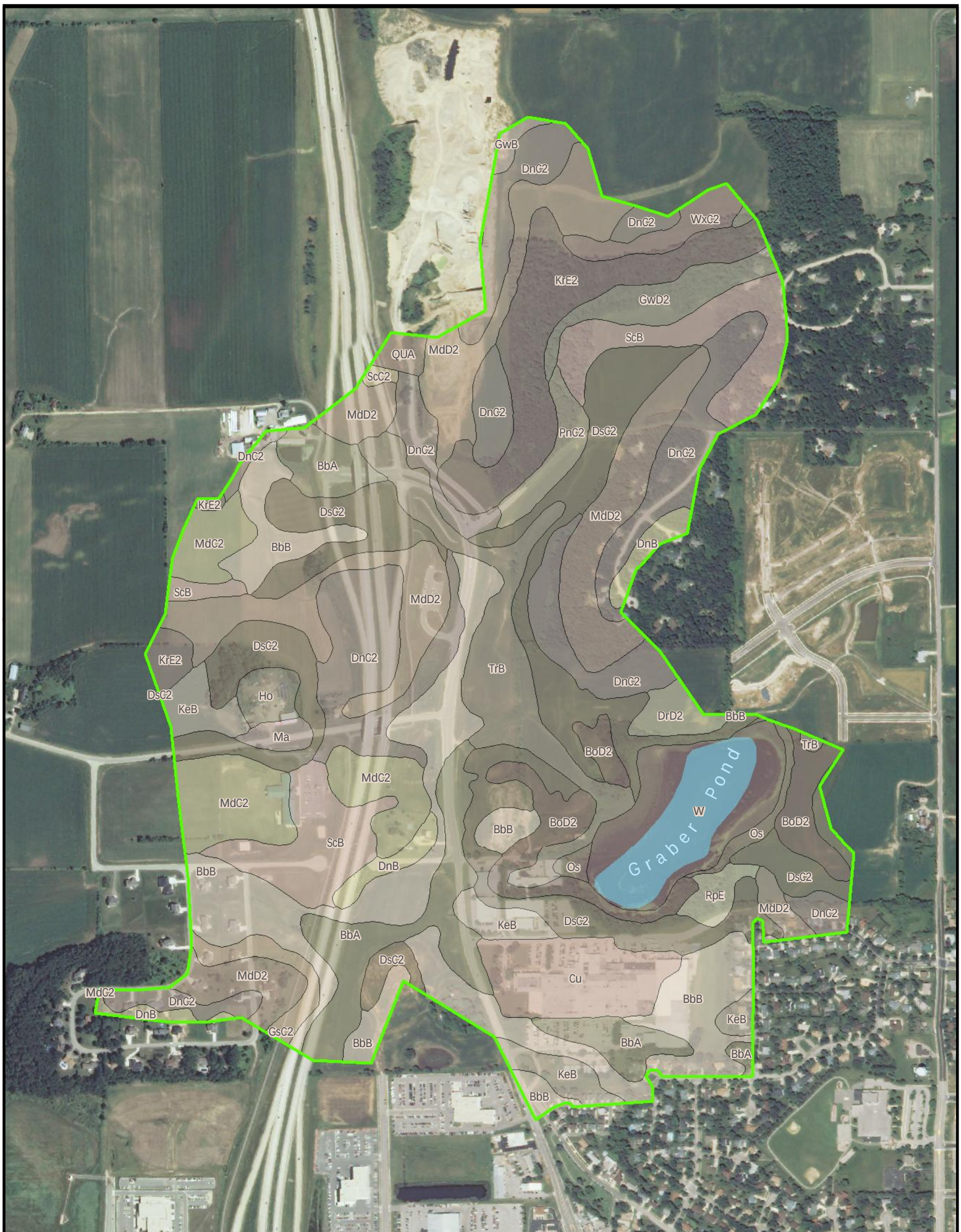
Graber Pond Watershed

Graber Pond

5-Foot Interpolated Contours

Developed by: Danielle Lee | 03/08/2010

1. Graber Pond Watershed Boundary: Montgomery Associates, 2010
2. 2008 NAIP Aerial Photography
3. Graber Pond: WDNR 24K Hydrography



SOIL MAP UNIT INDEX

BbA	Batavia silt loam, gravelly substratum, 0 to 2 percent slopes	GwB	Griswold loam, 2 to 6 percent slopes	Os	Orion silt loam, wet
BbB	Batavia silt loam, gravelly substratum, 2 to 6 percent slopes	GwD2	Griswold loam, 12 to 20 percent slopes, eroded	PnC2	Plano silt loam, 6 to 12 percent slopes, eroded
BoD2	Boyer sandy loam, 12 to 20 percent slopes, eroded	Ho	Houghton muck	QUA	Quarry
Cu	Cut and fill land	KdD2	Kidder loam, 12 to 20 percent slopes, eroded	RpE	Rodman sandy loam, 12 to 35 percent slopes
DnB	Dodge silt loam, 2 to 6 percent slopes	KeB	Kegonsa silt loam, 2 to 6 percent slopes	ScB	St. Charles silt loam, 2 to 6 percent slopes
DnC2	Dodge silt loam, 6 to 12 percent slopes, eroded	KrE2	Kidder soils, 20 to 35 percent slopes, eroded	ScC2	St. Charles silt loam, 6 to 12 percent slopes, eroded
DrD2	Dresden loam, 12 to 20 percent slopes, eroded	Ma	Made land	TrB	Troxel silt loam, 1 to 3 percent slopes
DsC2	Dresden silt loam, 6 to 12 percent slopes, eroded	MdC2	McHenry silt loam, 6 to 12 percent slopes, eroded	Wa	Water
GsC2	Grays silt loam, 6 to 12 percent slopes, eroded	MdD2	McHenry silt loam, 12 to 20 percent slopes, eroded	WxC2	Whalan silt loam, 6 to 12 percent slopes, eroded

0 150 300 600 Feet

1 inch = 600 feet

Figure A4 – Soil Map

GRABER POND HYDROLOGIC STUDY & MANAGEMENT PLAN

City of Middleton | Dane County, Wisconsin

Montgomery Associates
119 South Main Street | Suite A
Cottage Grove, WI 53527
www.ma-rs.org | (608) 223-9585

Watershed Properties

Graber Pond Watershed

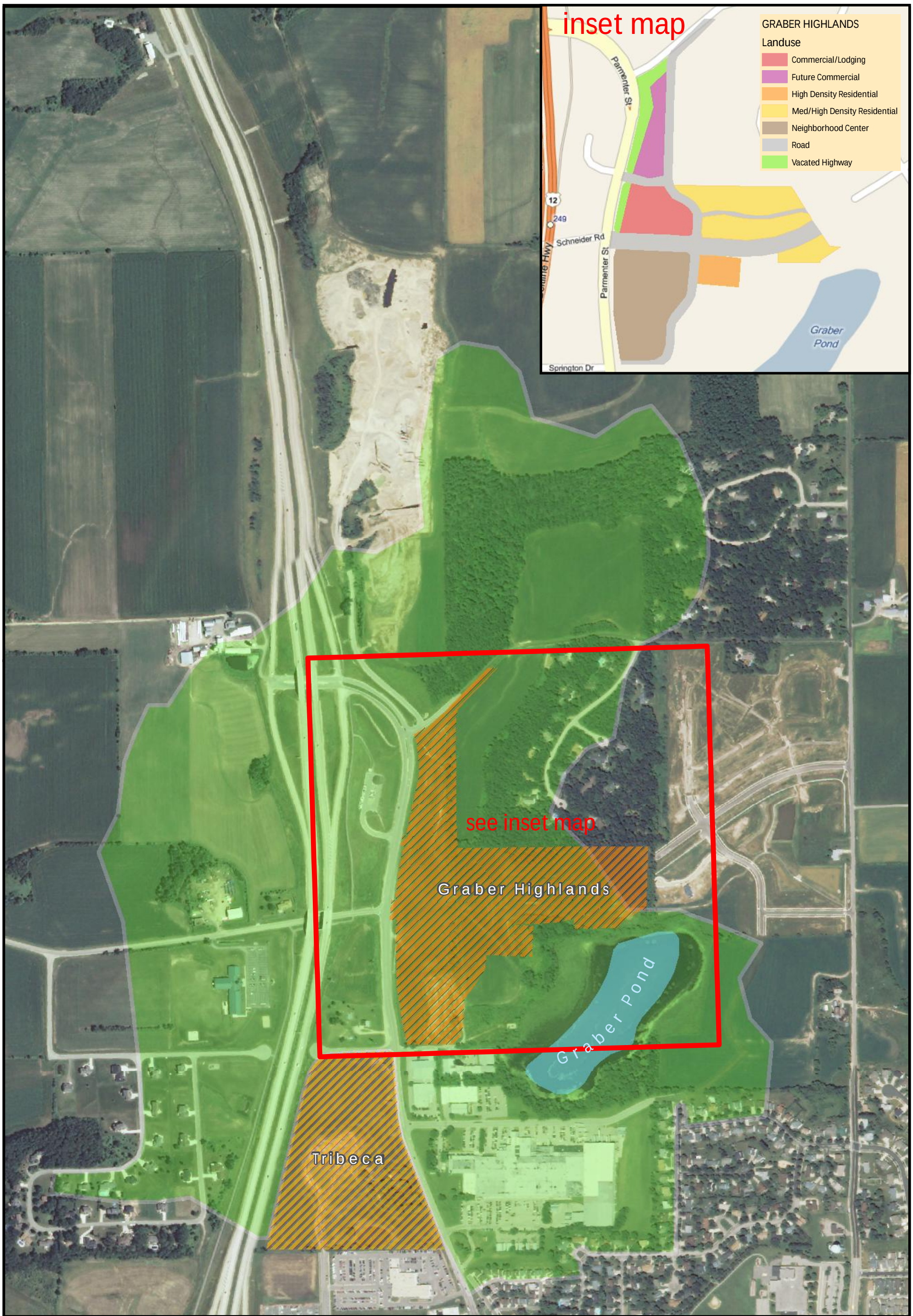
Soil Map Unit

Graber Pond

Developed by: Danielle Lee | 03/08/2010

1. Graber Pond Watershed Boundary: Montgomery Associates, 2010
2. Soils Data Source: USDA, NRCS, Soil Survey Geographic (SSURGO) Database
3. Graber Pond: WDNR 24K Hydrography
4. 2008 NAIP Aerial Photography

Main Map Projection: Albers Equal Area Conic with Standard Lines at 43.120° N, 43.125° N, 89.511 W°, WI Map Projection: Albers Equal Area Conic with Standard Lines at 44.0° N, 45.5° N, 89.0° W



Main Map Projection: Albers Equal Area Conic with Standard Lines at 43.120° N, 43.125° N, 89.511 W°, WI Map Projection: Albers Equal Area Conic with Standard Lines at 44.0° N, 45.5° N, 89.0° W

0 150 300 600 Feet

1 inch = 600 feet

Figure A5 – Tribeca and Graber Highlands Redevelopment Areas

GRABER POND HYDROLOGIC STUDY & MANAGEMENT PLAN

City of Middleton | Dane County, Wisconsin

Montgomery Associates
119 South Main Street | Suite A
Cottage Grove, WI 53527
www.ma-rs.org | (608) 223-9585

Watershed Properties

Graber Highlands

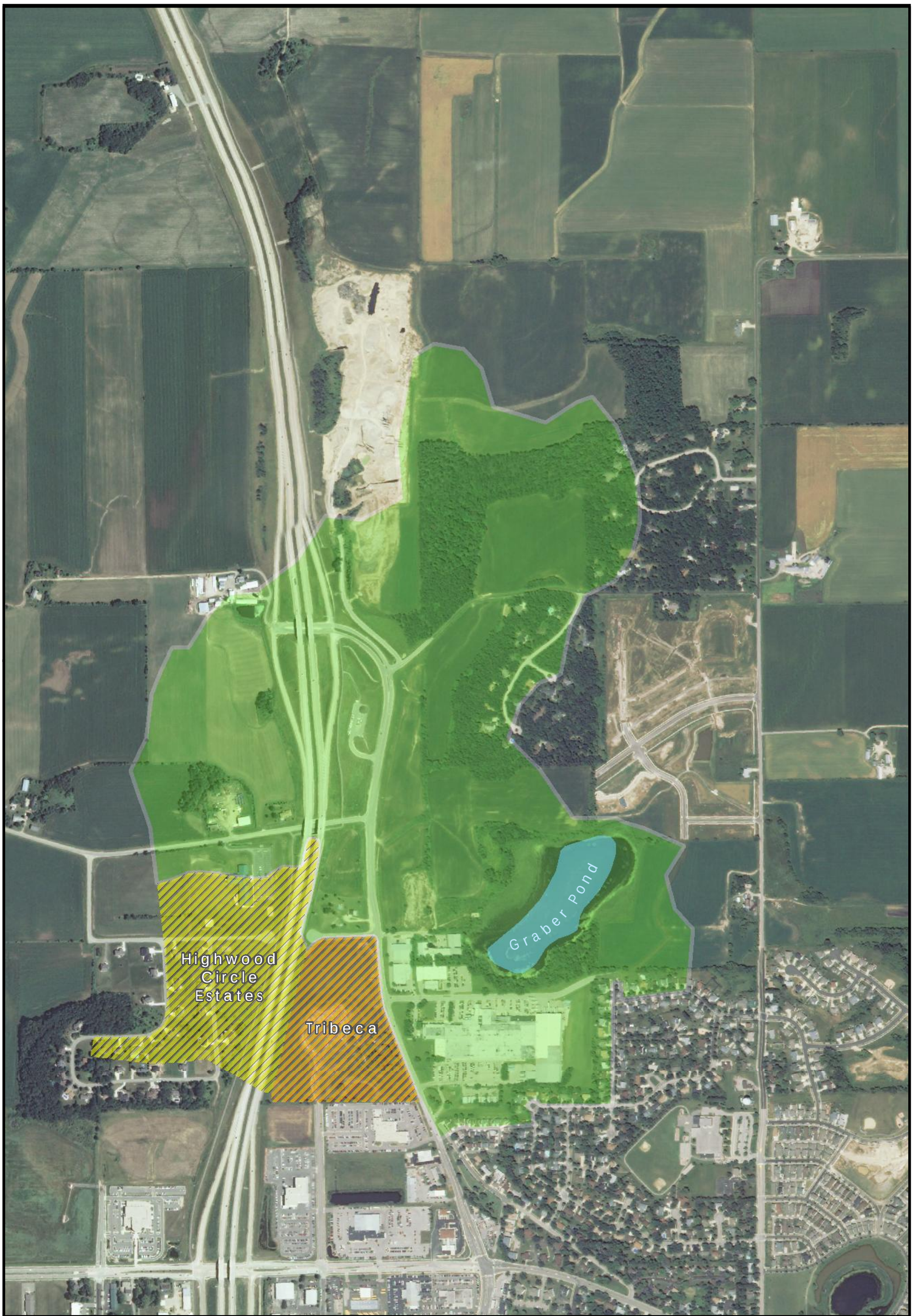
Tribeca Development

Graber Pond

Graber Pond Watershed

Developed by: Danielle Lee | 03/08/2010

1. Graber Pond Watershed Boundary: Montgomery Associates, 2010
2. 2008 NAIP Aerial Photography
3. Graber Pond: WDNR 24K Hydrography



Main Map Projection: Albers Equal Area Conic with Standard Lines at 43.120º N, 43.125º N, 89.511 Wº, WI Map Projection: Albers Equal Area Conic with Standard Lines at 44.0º N, 45.5º N, 89.0º W

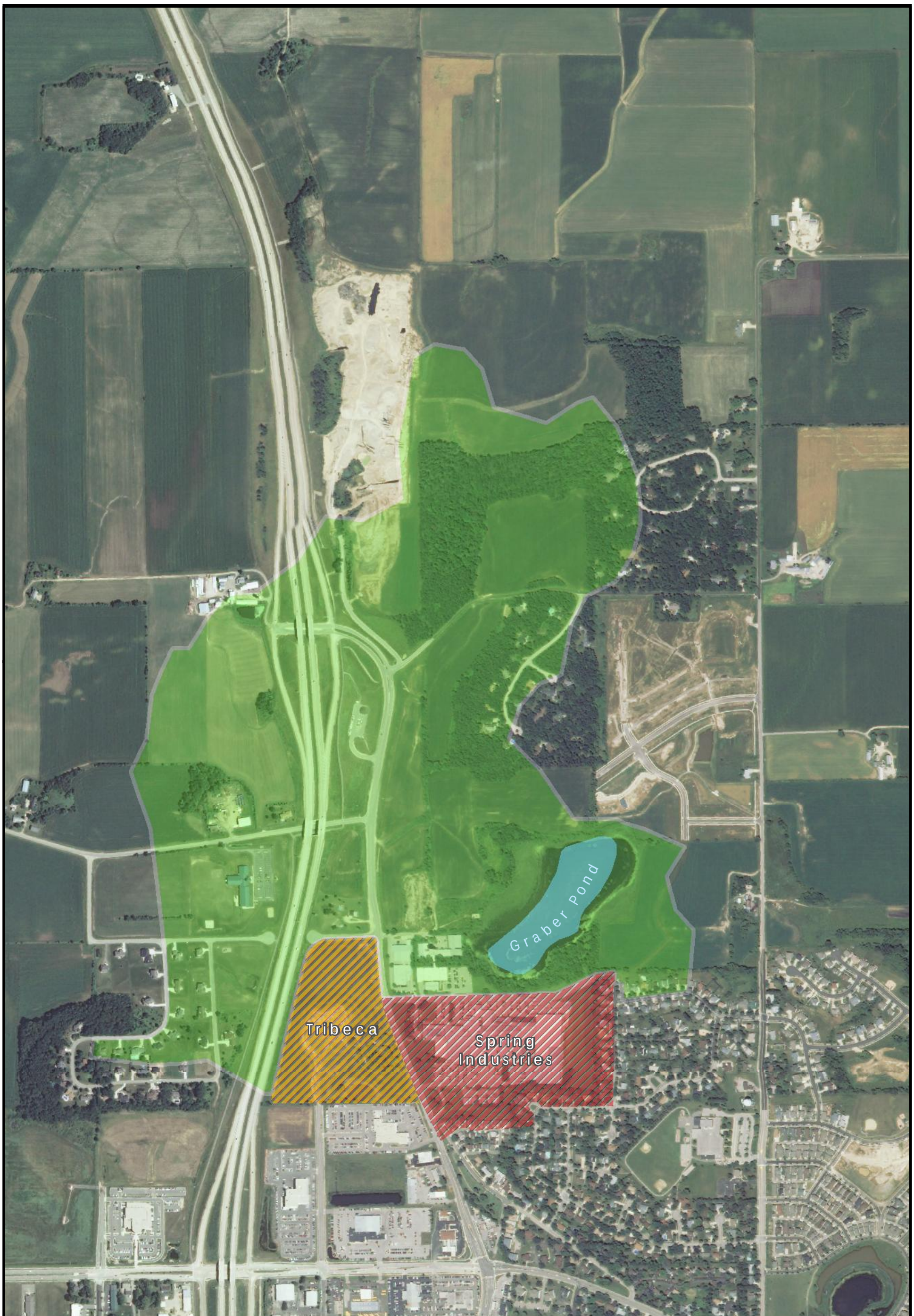
Figure A6 – Graber Pond Watershed with Tribeca Development and Highwood Circle Estates Diversion
PRAIRIE POTHOLE STUDY & MANAGEMENT PLAN FOR GRABER POND
City of Middleton | Dane County, Wisconsin

Montgomery Associates
119 South Main Street | Suite A
Cottage Grove, WI 53527
www.ma-rs.org | (608) 223-9585

Feet
0 200 400 600 800

Graber Pond Watershed

Developed by: Danielle Lee | 03/04/2010
1. Graber Pond Watershed Boundary: Montgomery Associates, 2010
2. 2008 NAIP Aerial Photography
3. Graber Pond: WDNR 24K Hydrography



Main Map Projection: Albers Equal Area Conic with Standard Lines at 43.120° N, 43.125° N, 89.511 W°, WI Map Projection: Albers Equal Area Conic with Standard Lines at 44.0° N, 45.5° N, 89.0° W

0 200 400 600 800 Feet

Figure A7 – Graber Pond Watershed with Tribeca Development, Graber Road, & Springs Industries Diversion
PRAIRIE POTHOLE STUDY & MANAGEMENT PLAN FOR GRABER POND
City of Middleton | Dane County, Wisconsin

Montgomery Associates
119 South Main Street | Suite A
Cottage Grove, WI 53527
www.ma-rs.org | (608) 223-9585

Watershed Properties

- Graber Highlands
- Spring_Industries
- Graber Pond
- Graber Pond Watershed

Developed by: Danielle Lee | 03/04/2010
1. Graber Pond Watershed Boundary: Montgomery Associates, 2010
2. 2008 NAIP Aerial Photography
3. Graber Pond: WDNR 24K Hydrography

Appendix B

Detailed Model Calibration Description

B.1 Raw Monitored Data Manipulation and Accommodating Data Gaps

As described in Section 2 of the report, monitoring equipment was installed to collect both water- and weather-related data for the purposes of calibrating the Graber Pond hydrologic model. For several reasons (e.g. removing equipment for the winter, equipment malfunction, etc.) gaps in the data exist during the monitoring period from June 2008 through December 2009. Below is a description of how the raw data from the monitoring equipment was manipulated and how data gaps were accommodated to develop the necessary data input record for the model calibration.

- Graber Pond Water Level
  Sonde depth measurements in 2008 and early 2009 were converted to NGVD29 based on a survey completed by Spatial Data Surveys, LLC on 11/20/2008. Due to low water levels, the Sonde was moved to deeper water; depth values after 8/26/2009 were converted to elevations based on a survey completed by MARS on 11/3/2009, using a previously established local benchmark. Values less than 0.10 inches were taken as invalid because of low water levels. The raw 15-minute increment readings values were averaged for each hour to create an hourly record.

- Precipitation
  When available, precipitation data from the HOBO rain gage was used; the data was summed over its time increment to create hourly data. In the event that the HOBO rain gage malfunctioned or became clogged with debris, the precipitation data was taken from the USGS Streamflow Monitoring Station for Pheasant Branch Creek (Station No. 05427948). A comparison of the rainfall data from the USGS station and the HOBO rain gage showed an excellent match between the two stations of recorded precipitation. For the period during the winter when both the HOBO rain gage and USGS rain gage were not in service (November 2008 through April 2009), precipitation data recorded at Dane County Regional Airport by the NOAA National Climatic Data Center was substituted. Although this data source is several miles away, precipitation variability during the late fall through early spring period is les pronounced than in the summer. Trace values were assumed to be zero.

- Air Temperature
  Air temperature raw data from the Weather Hawk was converted from °C to °F. For the winter and July-August 2008 (before the weather station was installed) NOAA Quality Controlled Local Climatological Data from Dane County Regional Airport was substituted.

- Evapotranspiration
  When available, Weather Hawk ET raw data was converted from mm/hour to inches/hour and summed to create hourly time steps. Small negative values for evapotranspiration were

set to zero. When Weather Hawk data was not available, regional monthly pan evaporation data were utilized, which is described in more detail later in this appendix.

B.2 Water Budget Parameters

As described in the report, the Graber Pond water budget can be computed as follows:

$$\Delta S = (Q_{i,SR} + Q_{i,NCCD} + P - Q_o - E - G_o) * \Delta t \quad \text{(Graber Pond Water Budget Equation)}$$

where ΔS = Change in storage (ac-ft)
$Q_{i,SR}$ = surface runoff inflow (ac-ft/day)
$Q_{i,NCCD}$ = non-contact cooling water discharge (ac-ft/day)
P = precipitation directly on water surface (ac-ft/day)
Q_o = surface outflow (ac-ft/day)
E = evapotranspiration (ac-ft/day)
G_o = groundwater outflow or seepage (ac-ft/day)
Δt = change in time (days)

The following sections describe the estimation and calibration of each of these parameters.

B.2.1 Pond Storage (S)

Storage in the pond was estimated for the near-shore topography and bathymetry data collected by Ayres and Associates in June 1994, and also utilized by Bosma in his 1996 thesis work. *Table B1* summarizes the elevation-area-cumulative storage relationship for Graber Pond. Please note that based on the map obtained from the City showing the 1994 survey data, it is unclear what method was utilized to collect below water elevations. No independent verification of these data was completed as part of this study.

Table B1: Graber Pond Elevation-Area-Volume Relationship

Elevation (NGVD29)	Pond Area (acres)	Cumulative Pond Volume (ac-ft)
898	0.52	0
899	4.30	2.41
900	9.20	9.16
901	12.61	20.07
902	15.36	34.05
903	18.96	51.21
904	20.33	70.86
905	22.02	92.03
906	24.19	115.14

B.2.1 Surface Runoff ($Q_{i,SR}$)

Surface runoff from the watershed was modeled using the approach as described in the Lefers' Master Thesis. The watershed was delineated using best available data (either City 1-foot contours from mid 1990's or Dane County 4-foot contours from 2005). The watershed was modeled as a single watershed sized at 400.68 acres (See *Figure A3 and Table B2*).

Total impervious area was delineated using ArcGIS and the 2008 NAIP orthophoto, which was determined to be approximately 17% (See *Figure A3 and Table B2*). Directly connected impervious area, which are impervious areas that discharge directly to Graber Pond such as a storm-sewered street, was a calibration parameter. Because runoff from small precipitation events generally are driven exclusively by directly-connected impervious area, this watershed runoff parameter was calibrated first. The calibrated directly connected impervious percentage is 3% (See *Table B2*), which is a small fraction of the total impervious area. Much of the watershed impervious area (such as USH 12 and the rural residential areas) drain over a substantial amount of pervious area, so it is reasonable to expect these areas are only partially connected (i.e. in small events, runoff infiltrates on the adjacent pervious ground but in larger events, the runoff exceeds the infiltration capacity of the soil and the impervious runoff begins to reach Graber Pond). The most likely source of directly connected impervious area is the development south of Graber Pond (Graber Road, Springs Industries, National Electrostatics, and the residential area along Lynn Street and Companion Lane). The total impervious area from these areas is approximately six percent, so the calibration indicates that approximately half the total impervious area is directly connected, which is reasonable.

For non-winter (not frozen ground conditions), the soil saturated hydraulic conductivity rate (ksat) was also a calibration parameter. After setting the amount of directly and partially connected impervious area, the best fit to the pond fluctuations from precipitation events was a ksat rate of 0.065 inches/hour (See *Table B2*). By comparison, Rawls, et. al. 1988 paper lists a saturated conductivity rate for silt loam soils, which are the dominant soils in the watershed (*Figure A4*), of 0.13 inches per hour. Because soil saturated hydraulic conductivities can vary by orders of magnitude, a factor of two difference between a calibrated value and published value is reasonable.

For winter (frozen ground conditions), utilizing a soil infiltration model such as Green-Ampt equation is not appropriate because frozen ground conditions can drastically alter the soil structure, particularly in agricultural and urban areas. Further complicating winter modeling approaches is that the effects of snow plowing and road salting alters the melting temperature and location of fallen precipitation. Therefore, an approach of simply assuming an average fraction of the watershed winter runoff reaches Graber Pond was made. This simplifying assumption is appropriate as no robust winter calibration is possible given that there is no pond level data for the winter (frozen water surface). The winter runoff coefficient was estimated to be 0.12 (or 12 percent of winter precipitation reaches Graber Pond).

Table B2: Summary of Watershed Parameters

Area (acres)	Directly Connected Impervious Area (%)	Partially Connected Impervious Area (%)	Total Impervious Area (%)	Pervious Ksat (inches/hour)
400.7	3.0%	14.1%	17.1%	0.065

B.2.2 Non-Contact Cooling Water Discharge ($Q_{i,NCCD}$)

Springs Industries and National Electrostatics (NEC) discharge of non-contact cooling water was monitored for only 2009. No data for the volume of discharge from Springs Industries is available. Quarterly discharge volumes from National Electrostatics were obtained from NEC staff.

In order to more accurately define the volumes and the times of discharge from both facilities, water depth was measured at each of the respective outfalls. Each outfall has its complications from extrapolating a water depth reading to a flow volume.

National Electrostatics

The National Electrostatics outfall is a 6-inch PVC pipe, and therefore, installation of a HOBO pressure transducer in the pipe affects the flow characteristics of the pipe. Sporadic grab sample flow measurements combined with the quarterly flow volumes were sufficient to generally estimate the flow volume into the pond sufficient for the level of detail of this study. *Table B3* summarizes the quarterly flow volumes from NEC. The largest quarterly flow volume is for the second quarter of 2008. Assuming an average Graber Pond size of 15 acres, a flow rate of approximately 6,600 gallons per day translates to 0.0014 ft/day. By comparison, the seepage rate (described later in this appendix) is approximately 0.016 to 0.04 ft/day, which is ten to thirty times higher than the NEC discharge rate. The monitoring data suggests that the water depth (and hence flow) does not vary drastically over time (See *Figure B1*); therefore, it is reasonable to ignore the NEC discharge for purposes of calibrating the Graber Pond hydrologic model.

Table B3: Summary of Quarterly Non-Contact Cooling Water Discharge from National Electrostatics

Quarter	Average Discharge (Gallons Per Day)
Quarter 1 2008	5,110
Quarter 2 2008	6,611
Quarter 3 2008	2,813
Quarter 4 2008	1,430
Quarter 1 2009	2,057
Quarter 2 2009	2,448
Quarter 3 2009	4,107

Springs Industries

Springs Industries discharges their non-contact cooling water into a City storm sewer at an unknown location. The most straightforward location to install a means to monitor water depth (and hence a flow estimate) was at the 36-inch storm sewer outfall on the southern edge of Graber Pond. However, complicating flow measurements of the non-contact cooling water discharge is the fact that a large area is served by this storm sewer. So in storm events, the water level will fluctuate in the storm sewer but not be related to non-contact cooling water discharge from Springs Industries.

A small, 90-degree, V-notch weir was constructed at the outfall of the City storm sewer to in order to be able to measure fluctuations in water levels that accounted for a small change in flow as the amount of expected discharge was essentially unknown. *Figure B2* displays both precipitation and water depth in the storm sewer, which illustrates that that water level fluctuations in the storm sewer are well correlated with precipitation events. This finding suggests that during the 2009 calibration period that discharge from Springs Industries was negligible for the purposes of calibrating a hydrologic model.

B.2.3 Precipitation Directly on Water Surface (P)

Precipitation directly on the water surface was simply estimated based on the monitored precipitation data and the pond surface area.

B.2.4 Pond Overflow (Q_o)

The lowest elevation at which Graber Pond begins to overflow is at elevation 905.1 (NGVD29). The geometry of the overflow weir section was based on survey data collected in November 2008. Overflow was modeled using the weir equation, which is shown below.

$$\text{Overflow} = 3.43 \cdot (\text{Stage} - 905.1)^{1.5} \cdot \Delta t * 3600 / 43{,}560$$

where Overflow = volume of overflow (ac-ft/timestep)
Stage = pond water level (NGVD29)
905.1 = lowest elevation at which overflow occurs
Δt = timestep (in hours)
3,600 = conversion from the weir equation flow rate in cfs to cubic feet / hour
43,560 = conversion from cubic feet to acre-feet

B.2.5 Evapotranspiration (E)

Evapotranspiration (ET) from the pond surface was predicted using the Penman-Monteith equation. The ET rates computed using this equation based on climatological variables were unadjusted (i.e. no coefficient was applied to the rates). When sufficient climatological data was unavailable to compute Penman-Monteith ET rates, regional monthly pan evaporation rates were utilized and corrected using a pan coefficient. A pan coefficient of 0.77 was selected based on data presented in the "Climatic Atlas of the United States" (1968). *Figure B3 through Figure B5* contain data plots of evapotranspiration data.

B.2.6 Seepage or Groundwater Outflow (G_o)

The model calculates a seepage volume at each time-step by multiplying a seepage rate (depth per timestep) by the pond area. Calibration on individual years (2008 and 2009) resulted in different seepage rates between years. For 2008, the best fit seepage rate was 0.016 feet per day (See *Table B4*). For 2009, the best fit seepage rate varied based on stage ranging from 0.024 feet per day at stages less than elevation 903.0 up to 0.04 feet per day for pond elevations greater than 905.0 (*Table B4*). One possible explanation for the much higher seepage rate in 2009 compared to 2008 was that the total precipitation that fell from August 2007 through June 2008 could have led to an extremely

high regional water table which could have reduced the degree that Graber Pond was perched. The potential that high non-contact cooling water discharge from Springs Industries buffered the losses from the pond during 2008 was deemed an unlikely cause.

Although frozen conditions likely affect the seepage rate in the pond to some degree, because no pond level data was collected during the winter months, the assumption was made to not alter the seepage rate during the winter.

As described in the report, for the long-term scenario evaluations, the 2009 seepage relationship was utilized as the 2008 seepage rate appeared to yield pond levels that were unrealistically high for both current and pre-development conditions.

Table B4: Seepage Rate by Year

Year	Seepage Rate (ft/day)
2008	0.016
2009	0.024 (Pond Elev < 903.0) Linear Interpolation between 0.024 at Elev 903.0 and 0.04 at Elev 905.0 0.04 (Pond Elev > 905.0)

B.2.7 Timestep (Δt)

The timestep for the Graber Pond hydrologic model was set to 1 hour.

B.3 Calibration Results

Figure B6 through *Figure B8* display the 2008 (non-winter), 2009 (non-winter), and 2008-2009 (winter) calibration results, respectively. The results appear excellent for the entire calibration period except for late-August 2009 until late-September 2009 when the pond level was approximately elevation 901 to 903. A few possible explanations for the model error include:

- Errors in the pond elevation – storage relationship which was derived from a 1994 survey. The water level at the time of the survey was above 903.0 and there are limited data points from between elevations 900.0 and 903.0. Further the method for collecting the below-water data points is unknown, so possible errors in the data collection could exist.

- The period leading up to August-September 2009 was quite dry, and the watershed of Graber Pond is substantially larger than the pond itself. Therefore, small errors in the modeling methodology, which tend to be more common at low soil moisture, would be more pronounced in the pond (i.e. a 0.1-inch error in the computed runoff for an event would convert to an approximately 3-inch error in the pond). The late September event that occurred was 2.5 inches of precipitation over several hours.

The apparent model error in late 2009 does not affect the overall objective of the study which is to establish management strategies aimed at restoring the hydrology of Graber Pond to a prairie pothole.

Figure B1
National Electrostatics Discharge Pipe 2009 Water Level Data

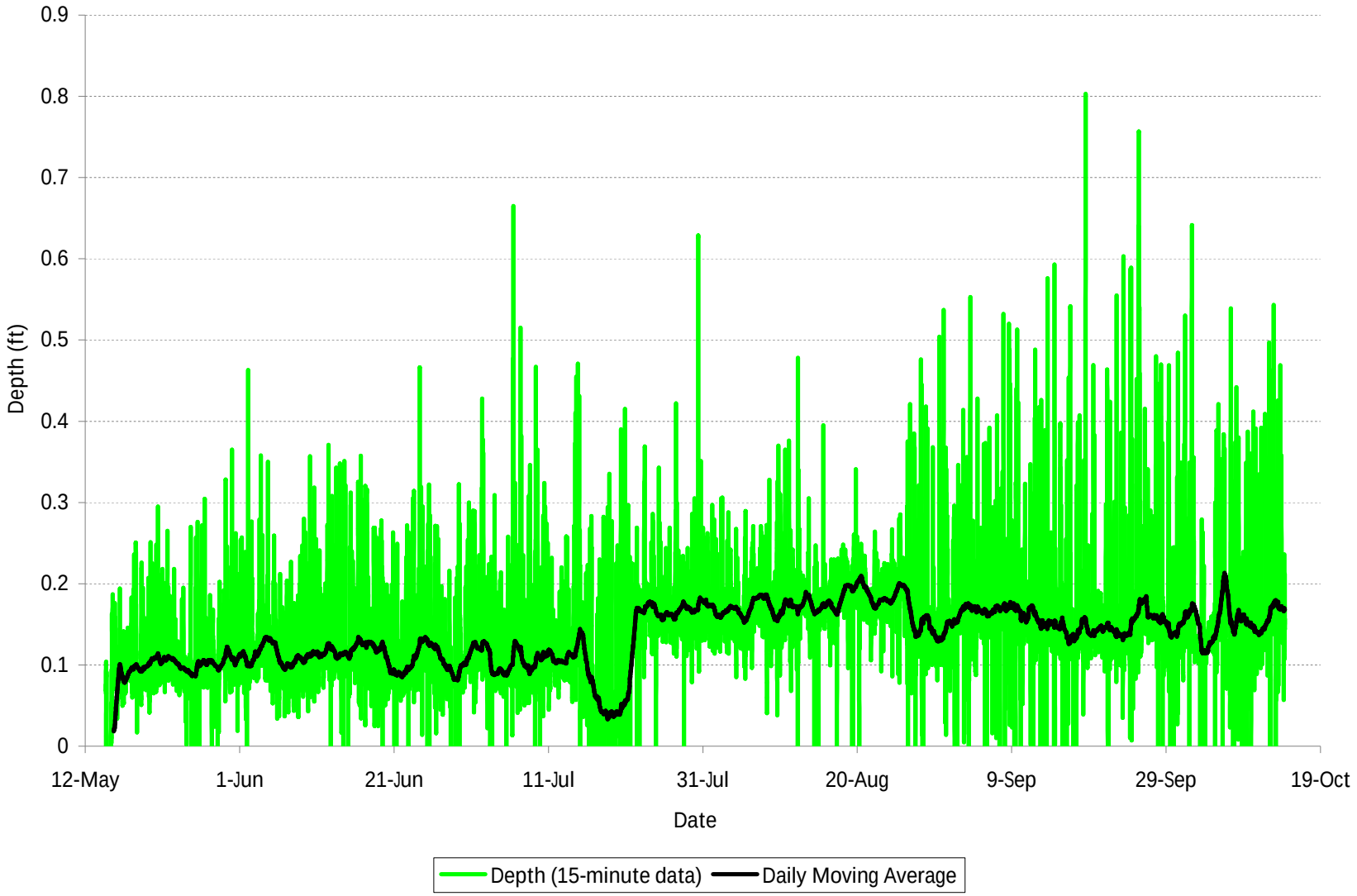


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Figure B2
Storm Sewer Outfall 2009 Water Level and Precipitation Data

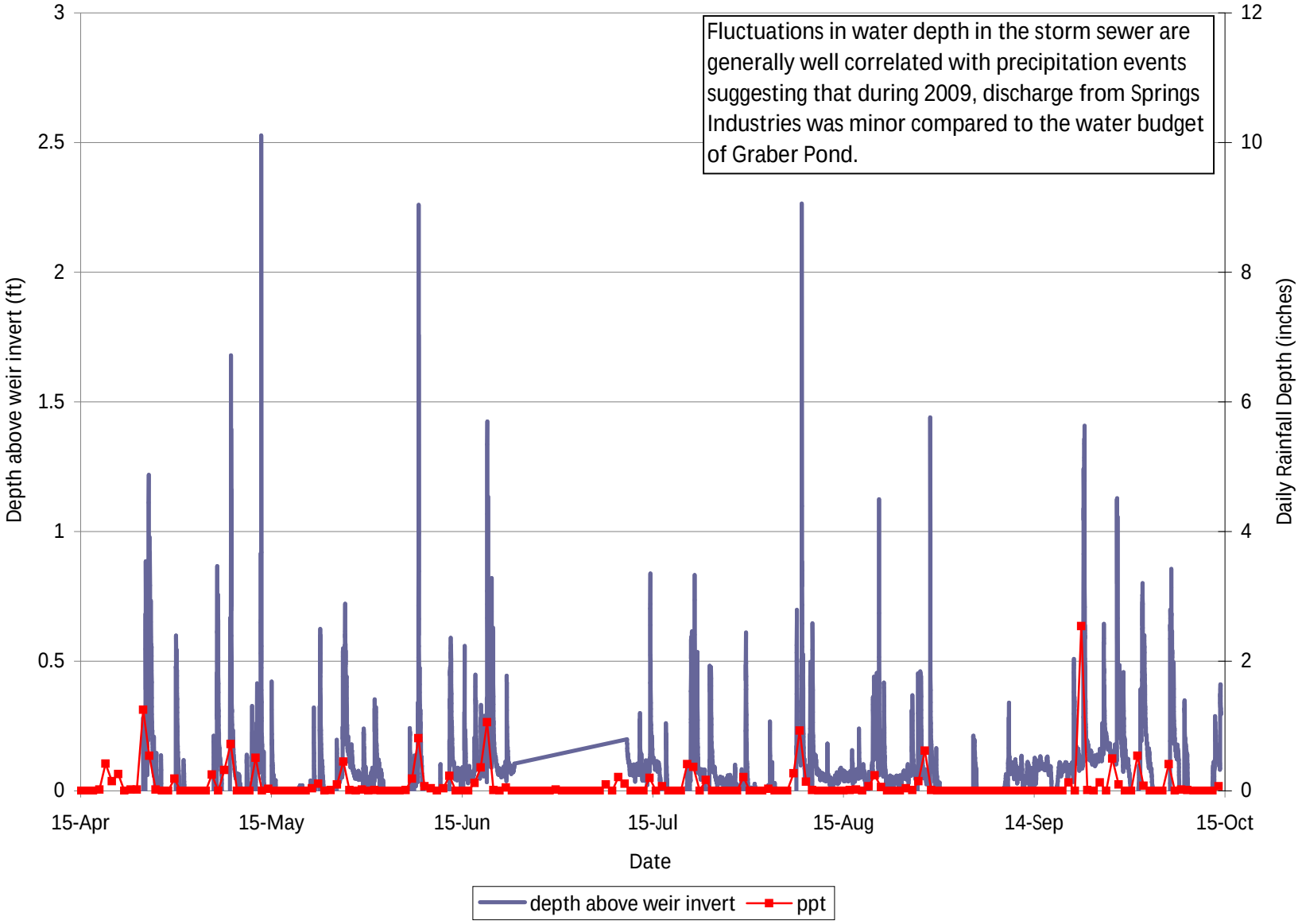

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Figure B3
2008-2009 Daily Precipitation and Evapotranspiration Data

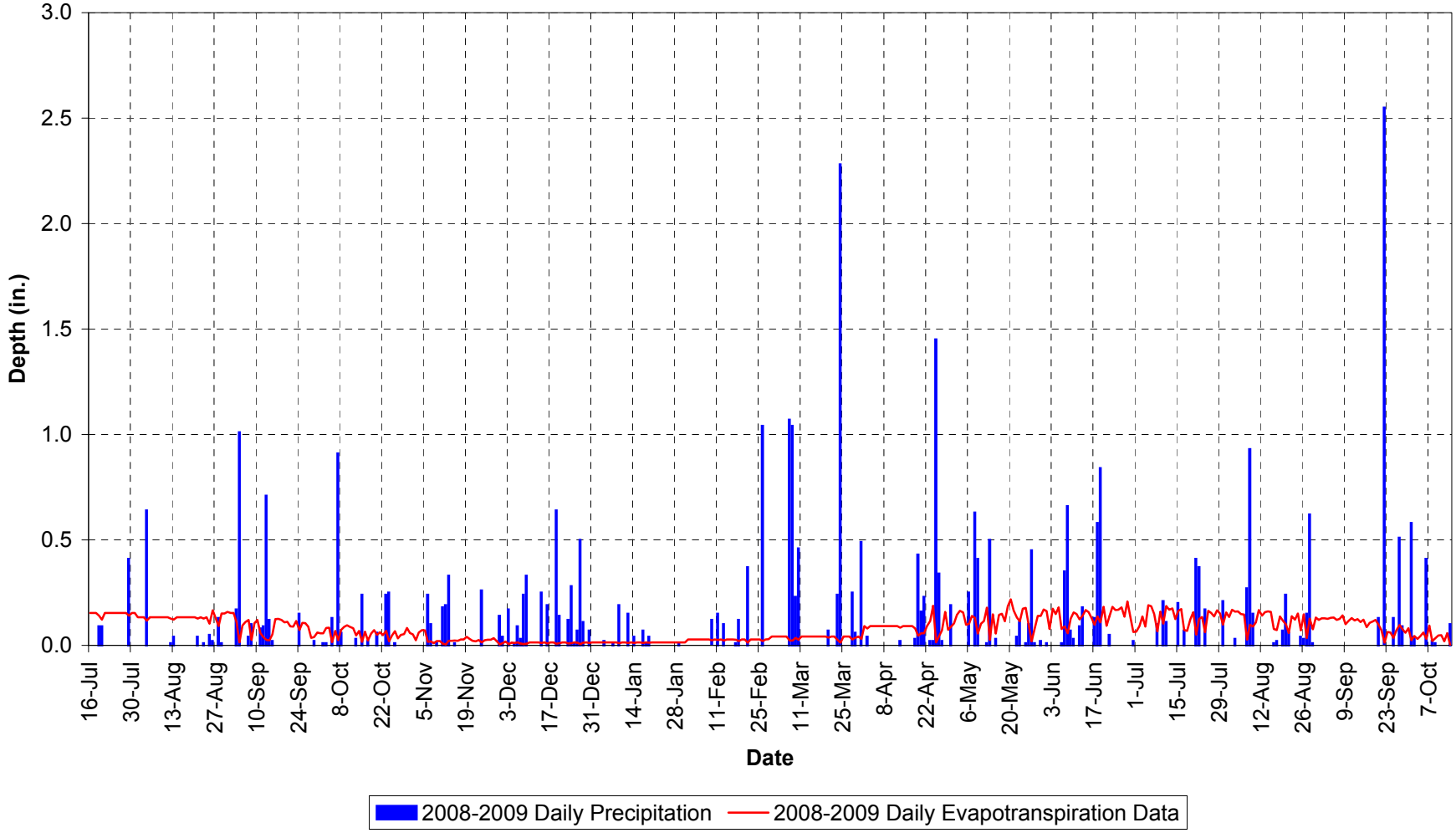

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Figure B4
2008 (Excerpt) Hourly Penman-Monteith Evapotranspiration Data

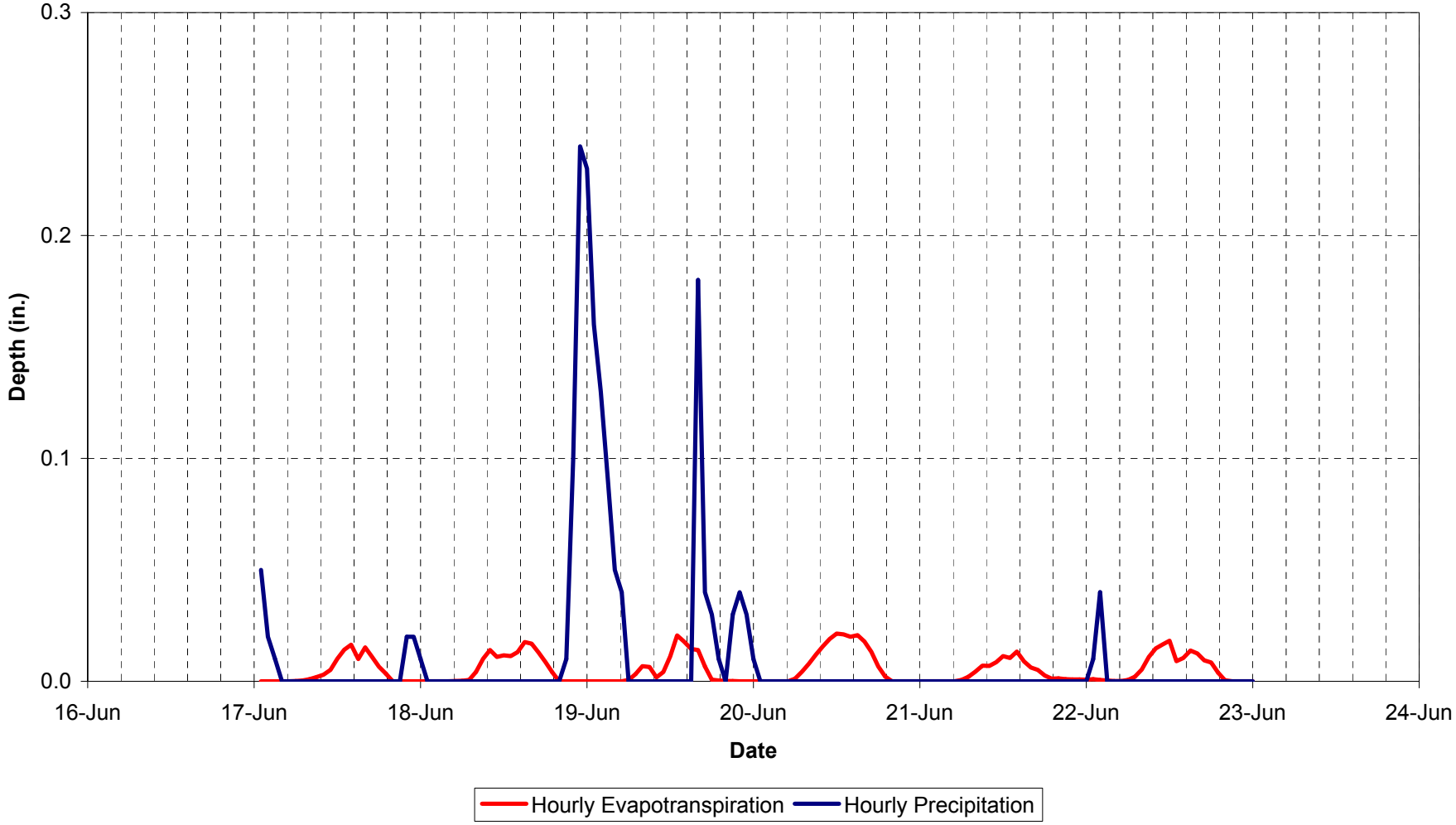

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Figure B5
Monthly Pan Evaporation Data

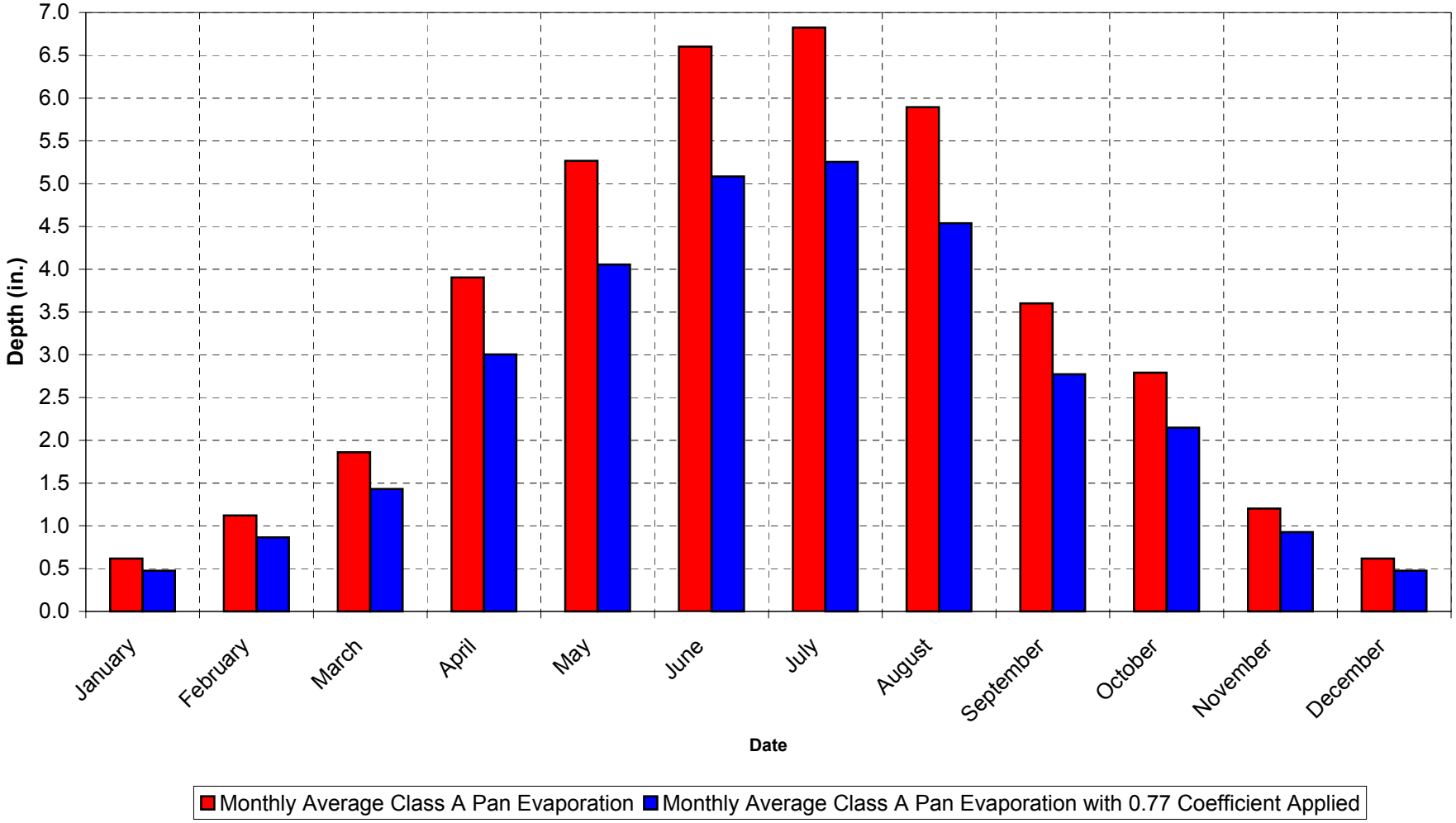

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Figure B6
2008 Non-Winter Calibration Results

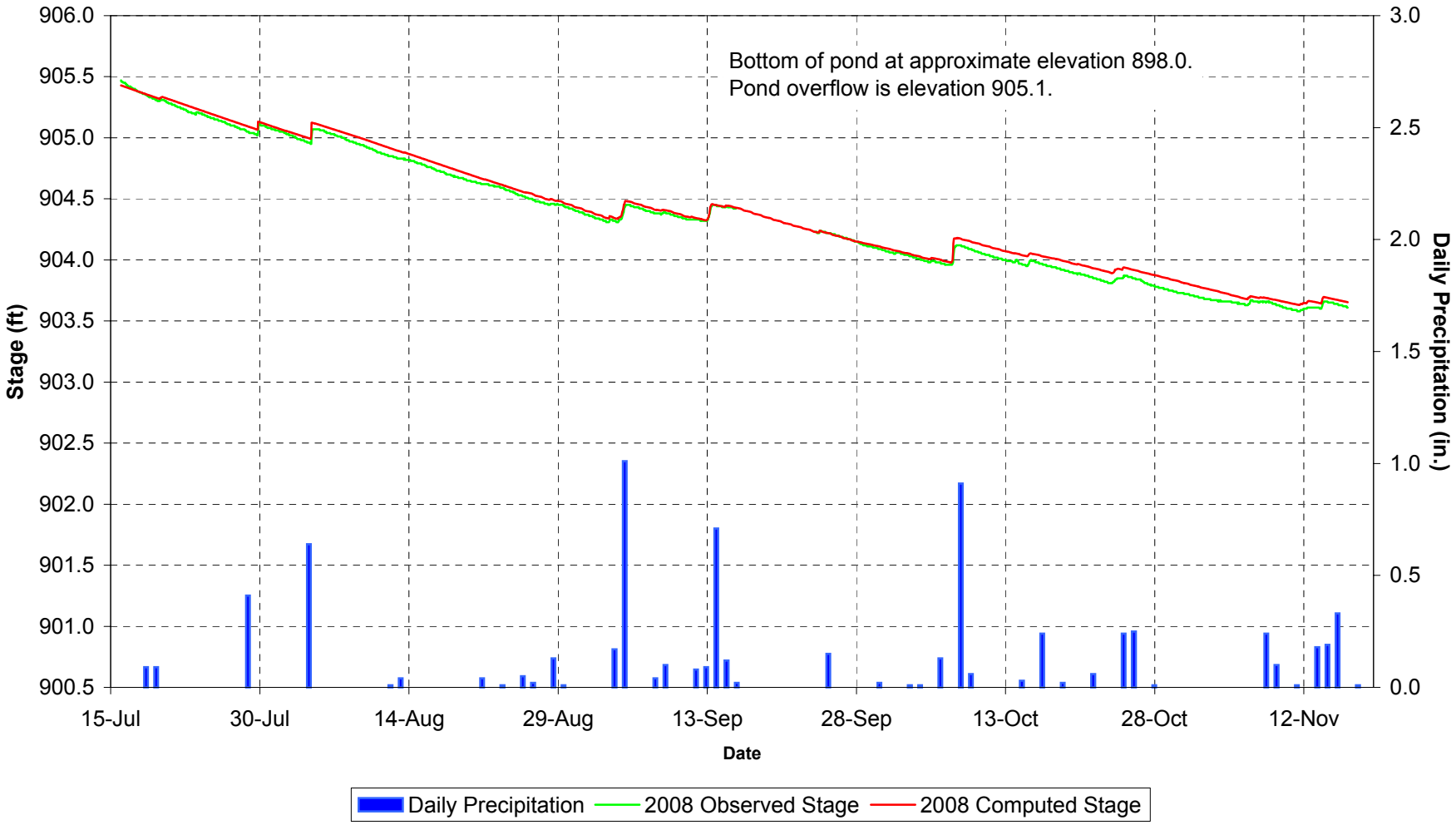

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Figure B7
2009 Non-Winter Calibration Results

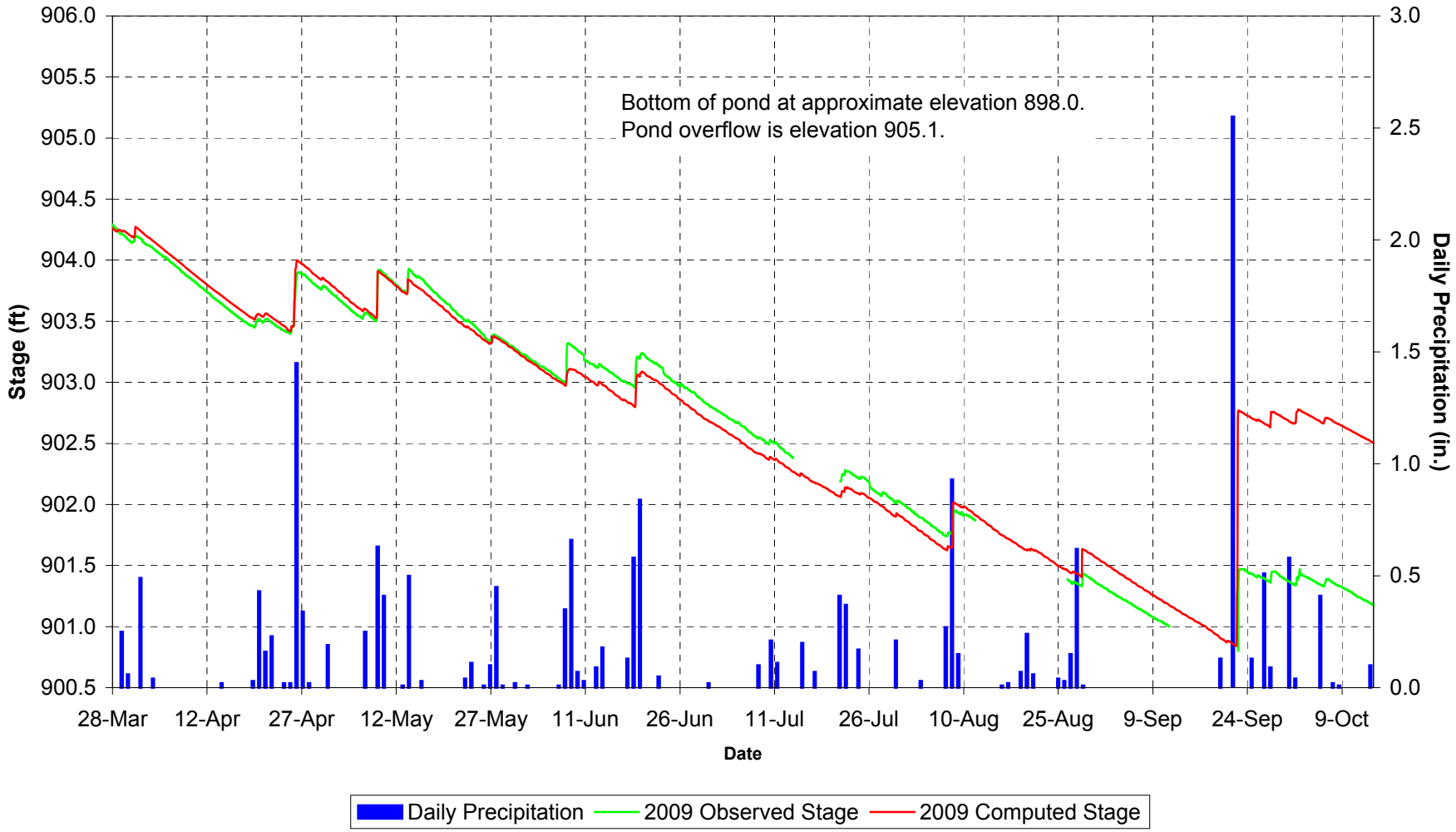

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Figure B8
2008-2009 Winter Calibration Results

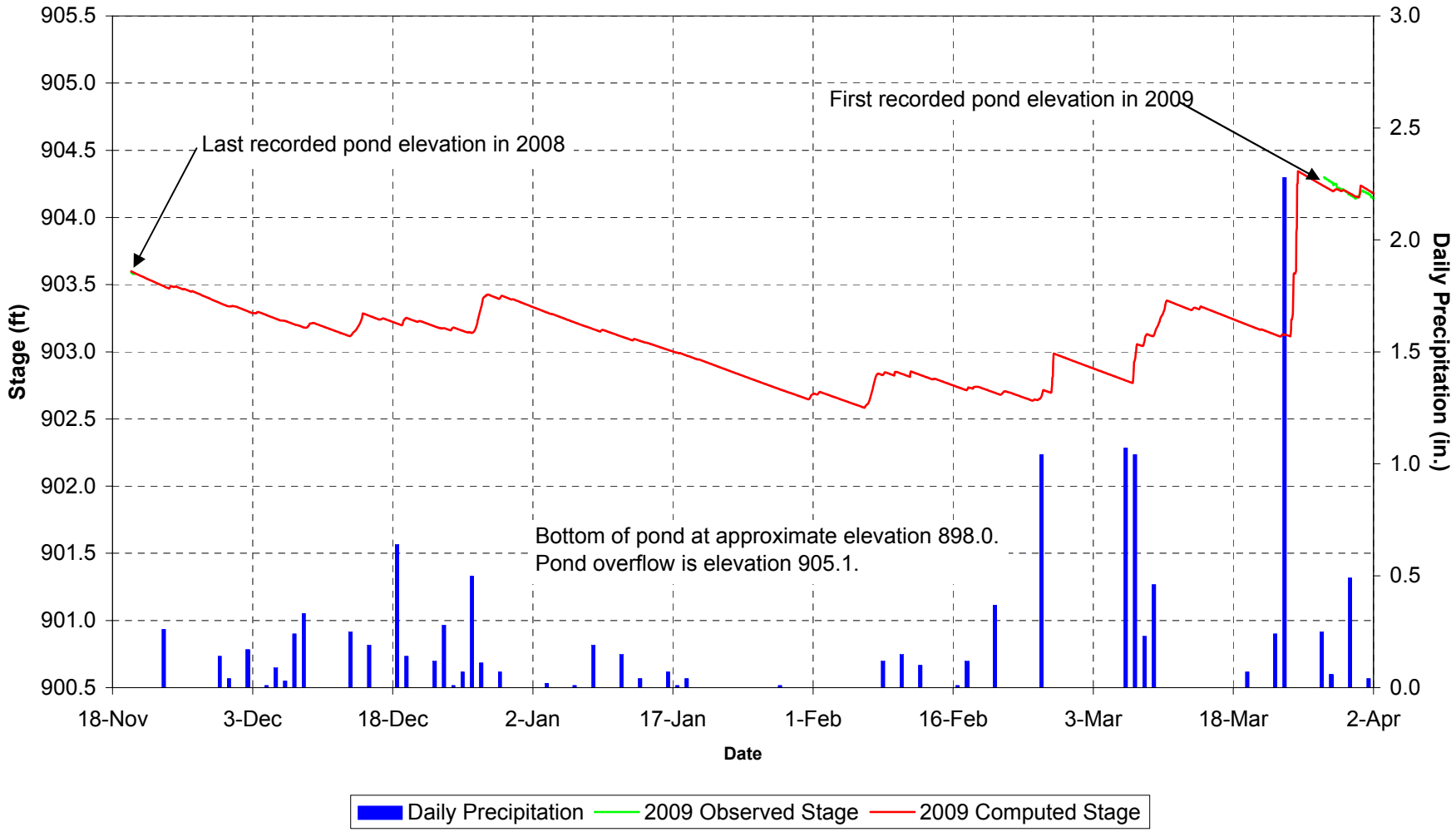

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Figure C1
Stage Duration Curves for Existing Conditions Scenario: Both Seepage Rates
(WY 1950 - WY 2009)

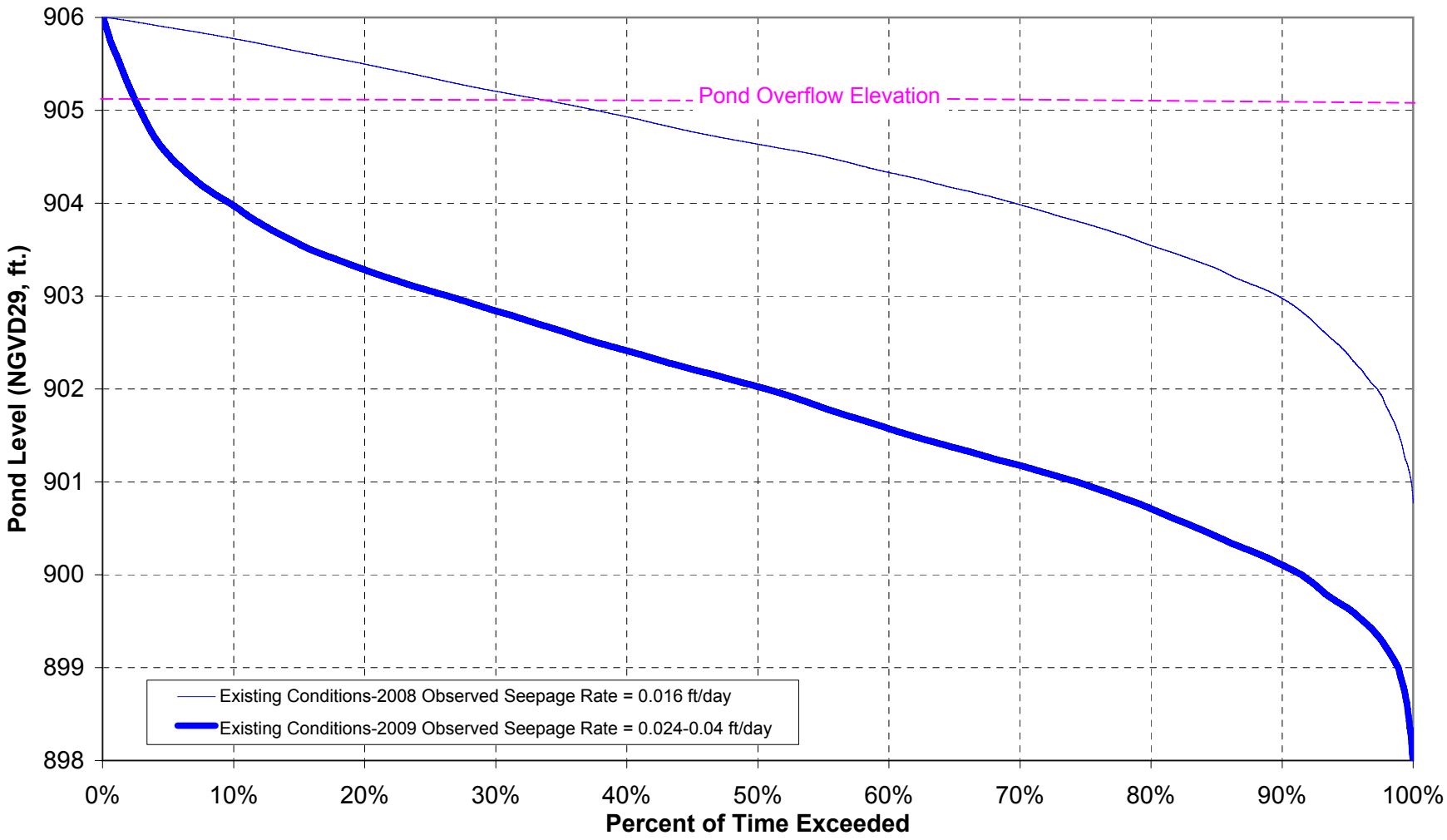

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Figure C2
Stage Duration Curves for all Scenarios
(WY 1950 - WY 2009)

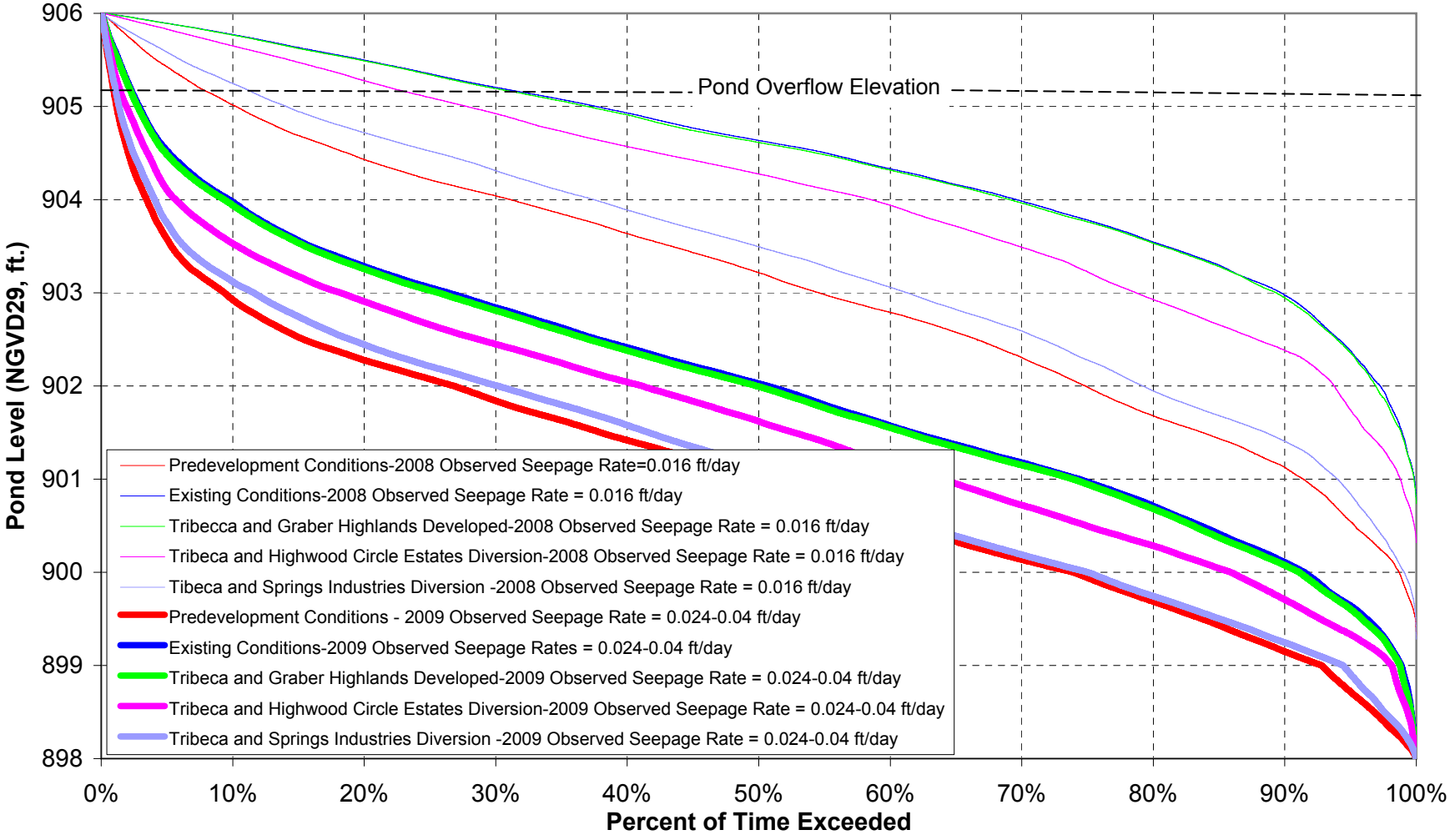

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Figure C3
Predevelopment Conditions Water Balance Statistics
(WY 1950 - WY 2009)

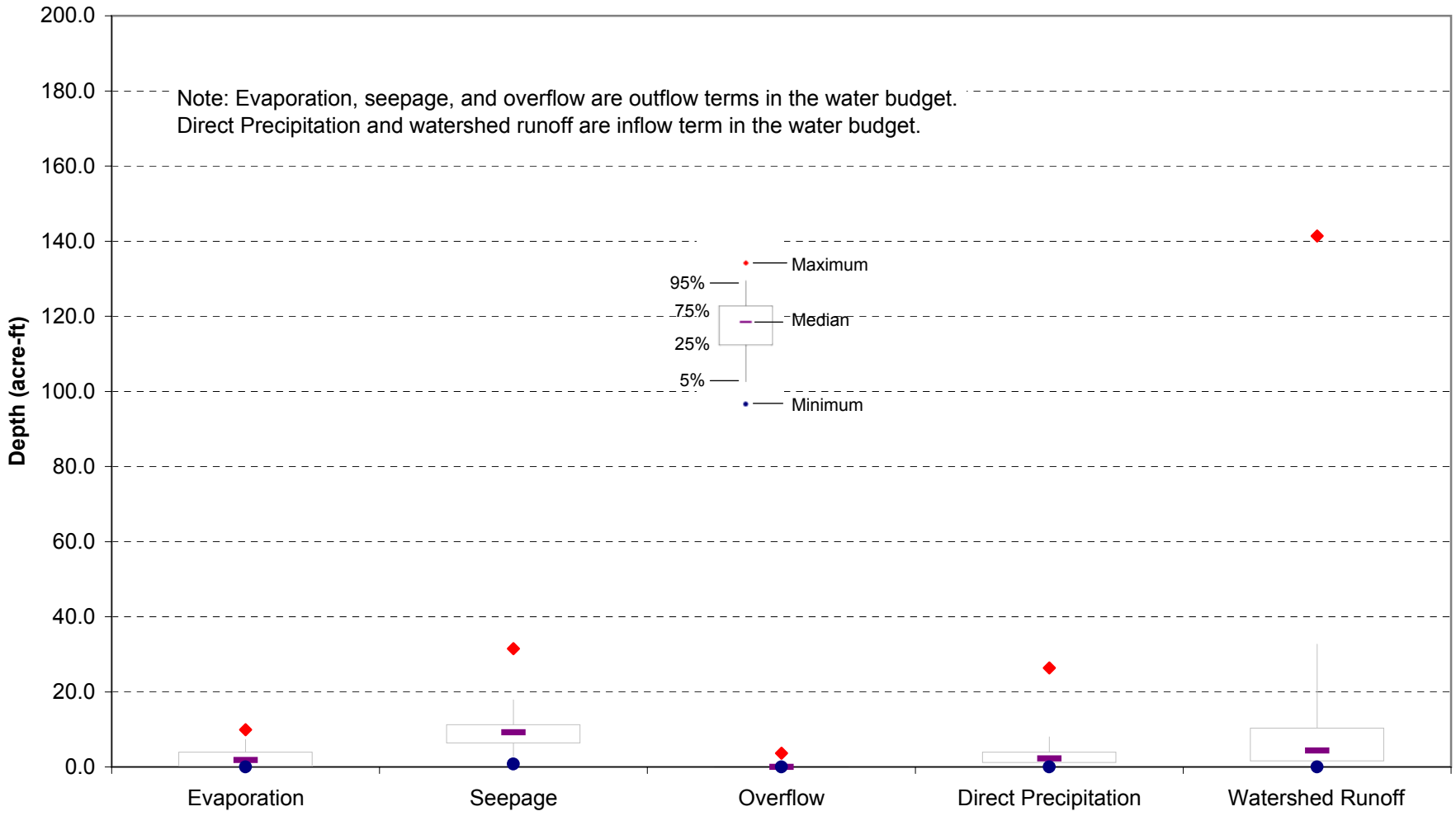

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Figure C4
Existing Conditions Water Balance Statistics
(WY 1950 - WY 2009)

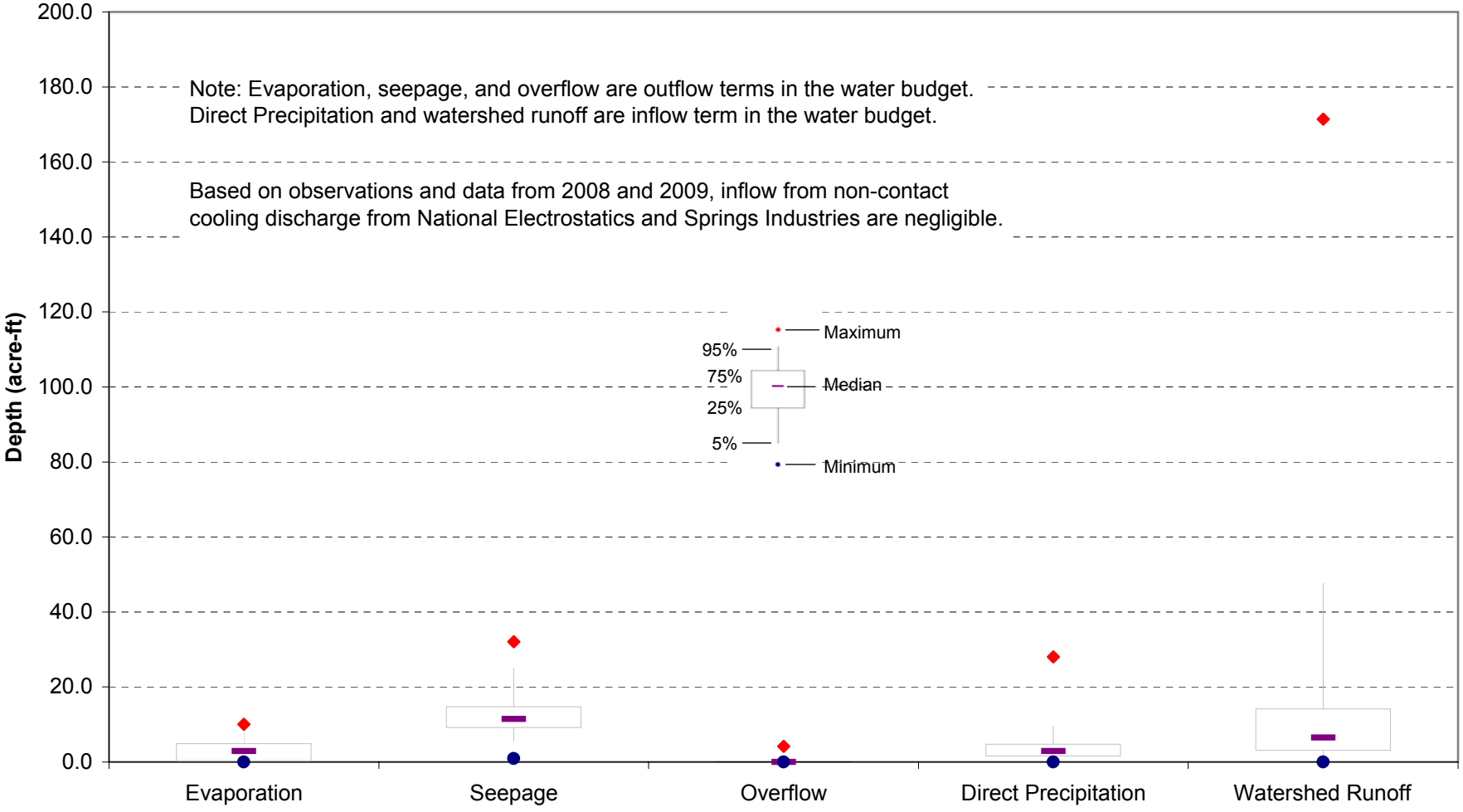

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Figure C5
Tribeca and Graber Highlands Developed Water Balance Statistics
(WY 1950 - WY 2009)

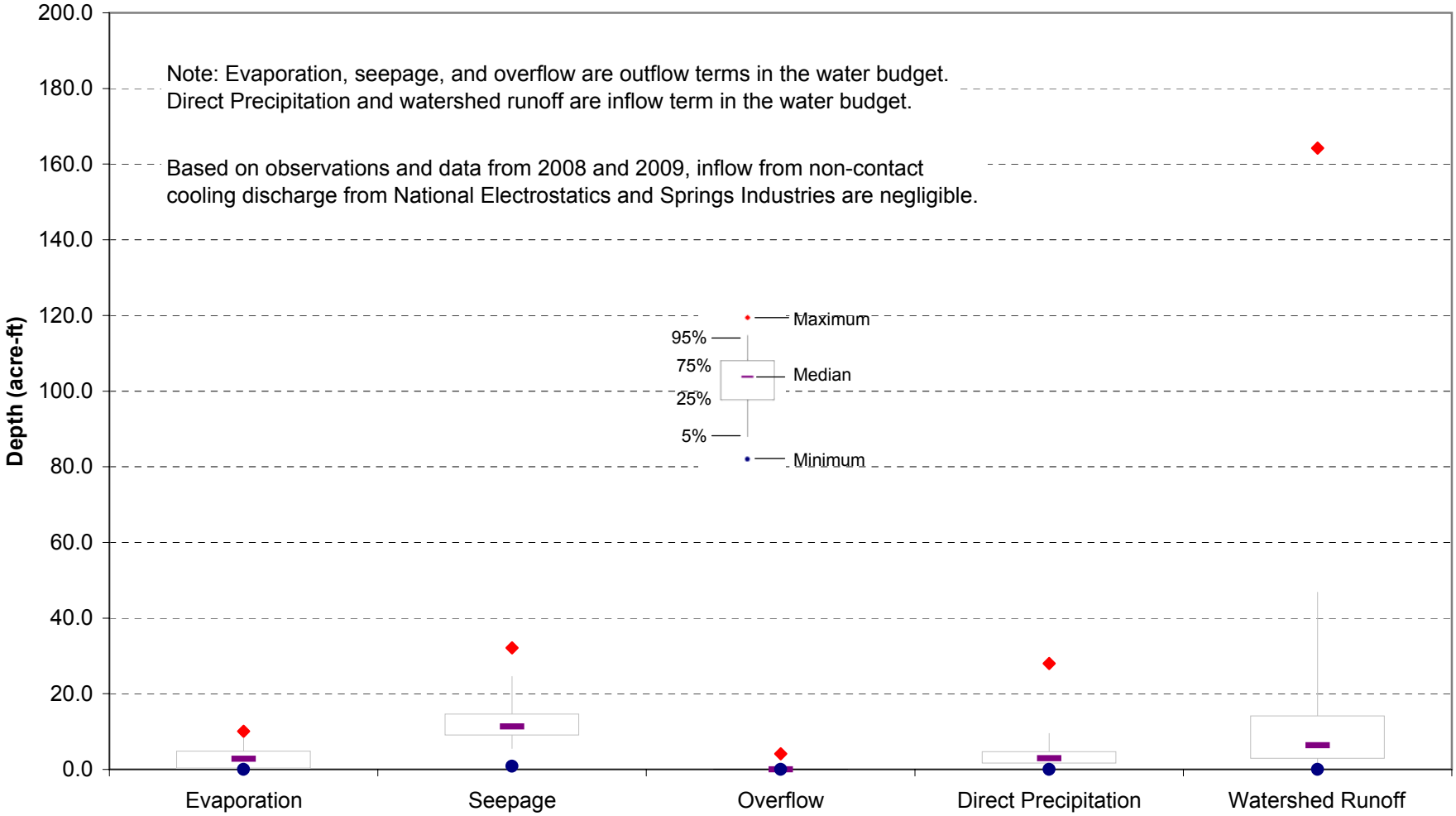

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Figure C6
Tribeca Development and Highwood Circle Estates Diversion Water Balance Statistics
(WY 1950 - WY 2009)

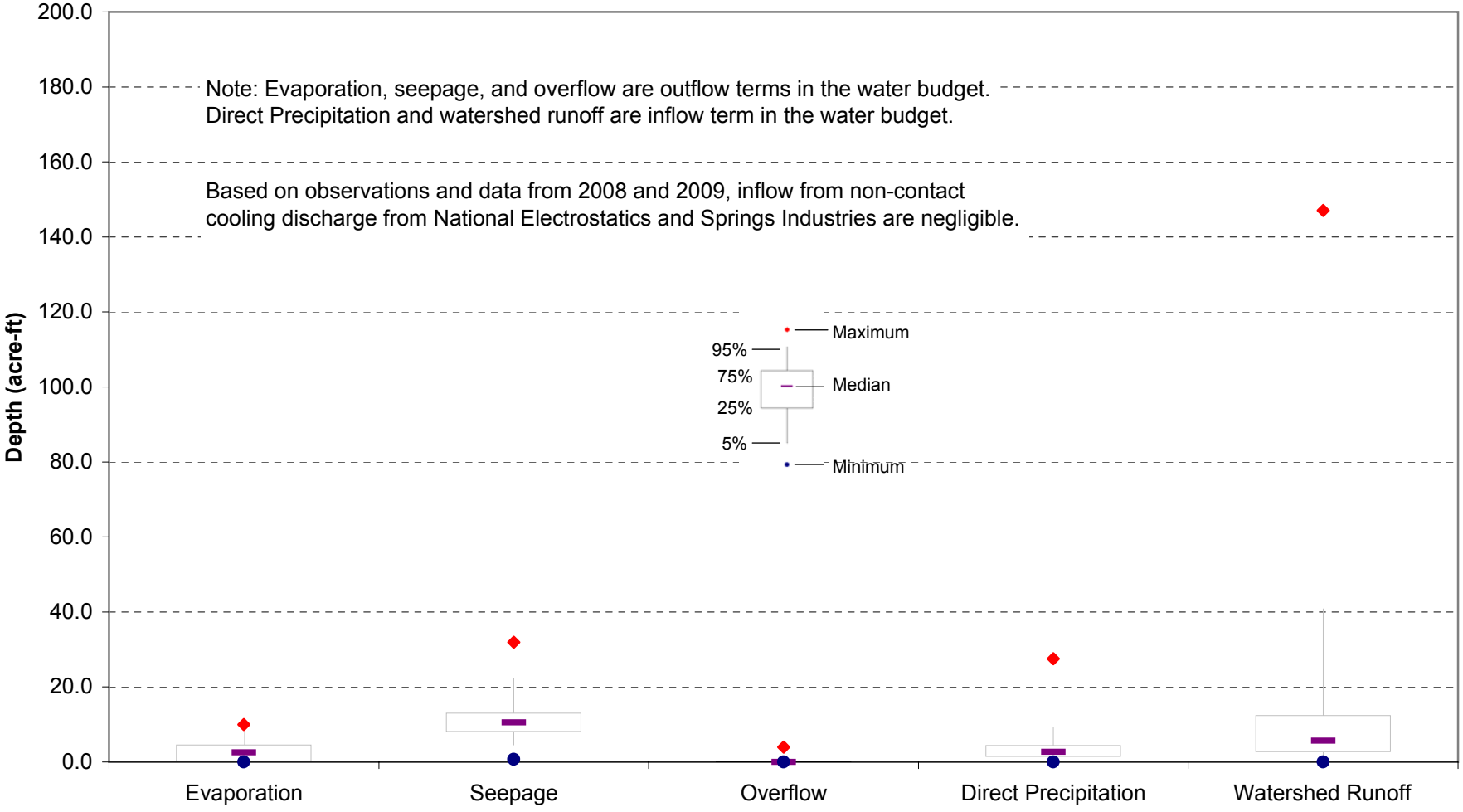

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Figure C7
Tribeca Development, Graber Road, and Springs Industries Diversion Water Balance Statistics
(WY 1950 - WY 2009)

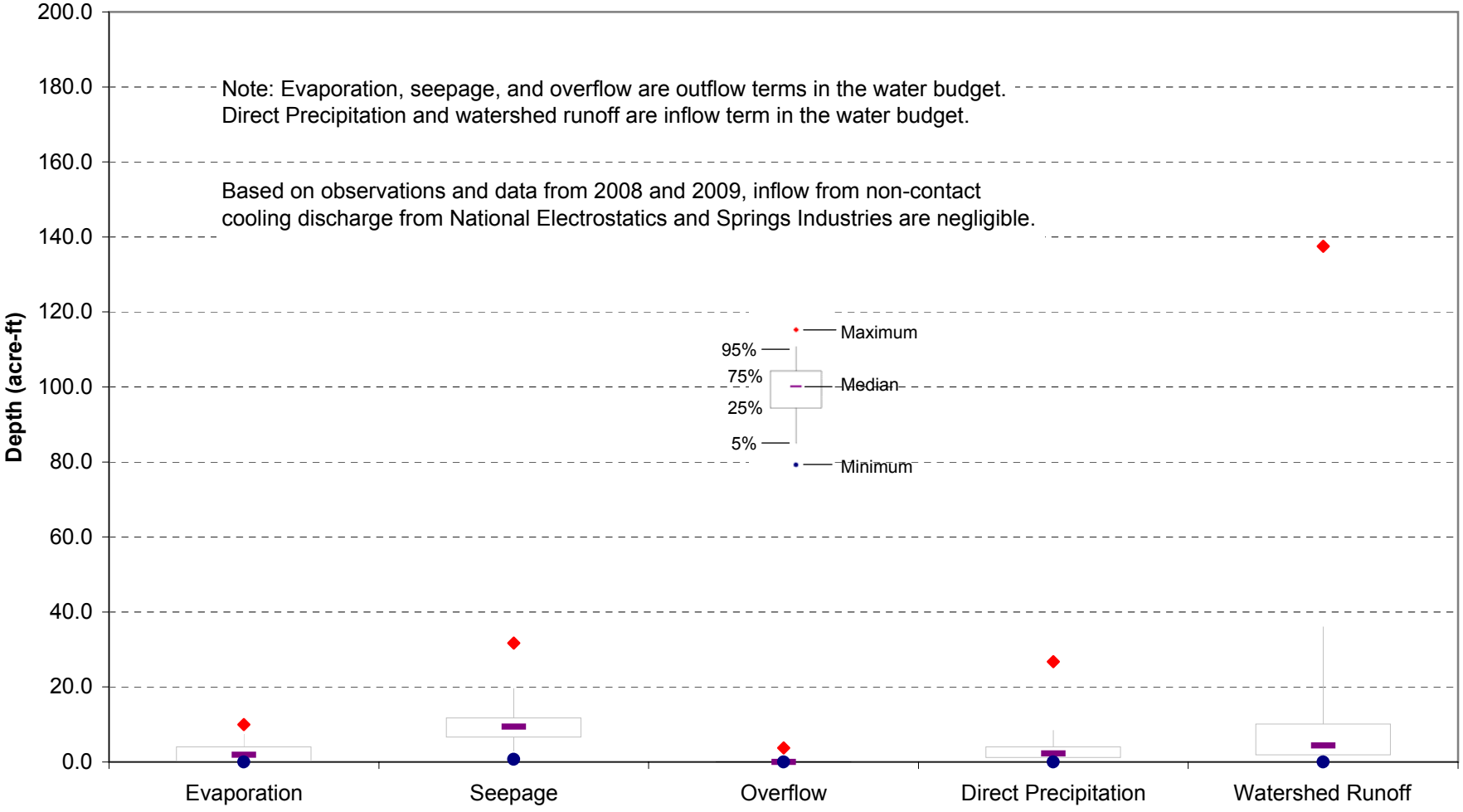

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Figure D1
2008 Water Quality Data

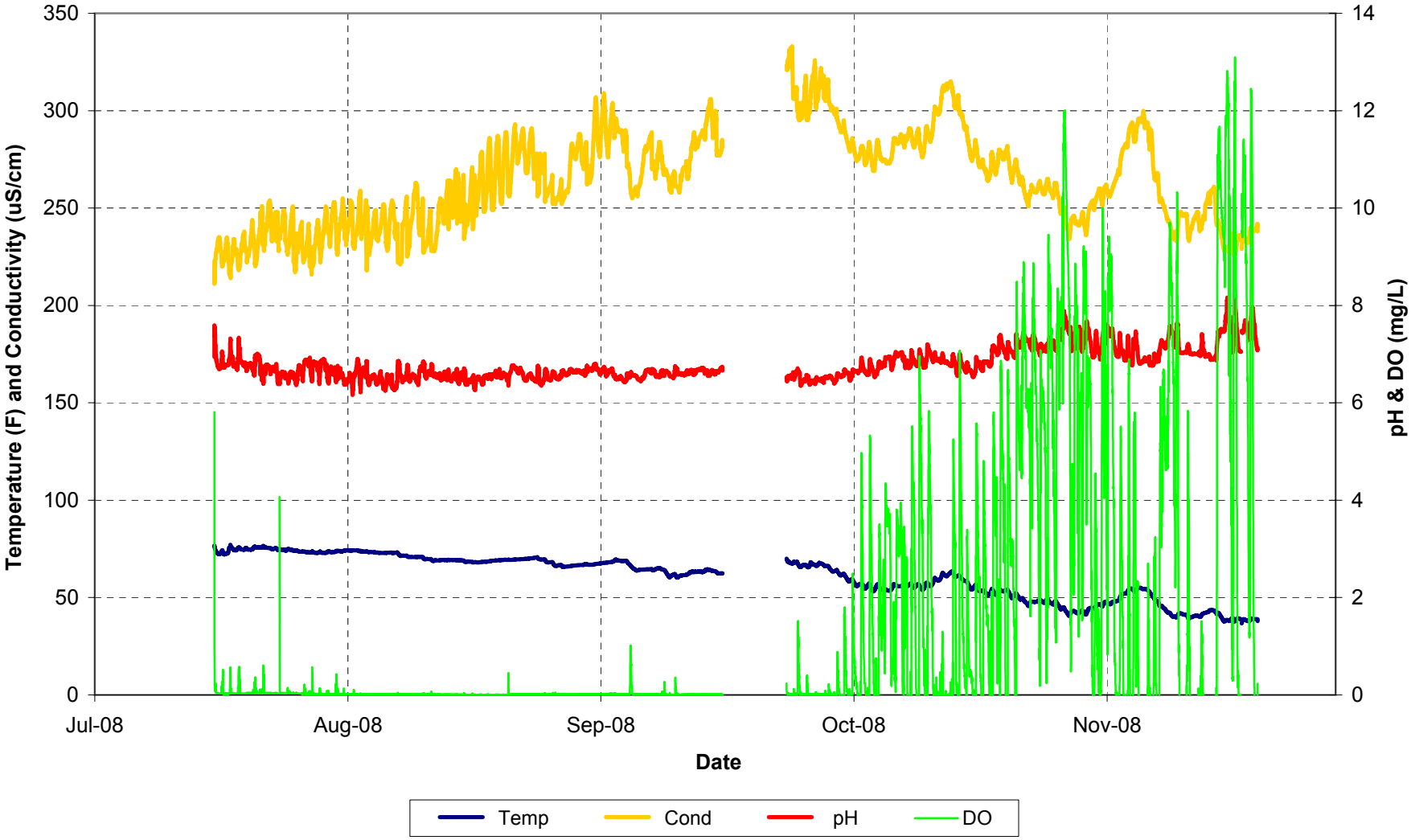

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Figure D2
2008 (Excerpt) Water Quality Data

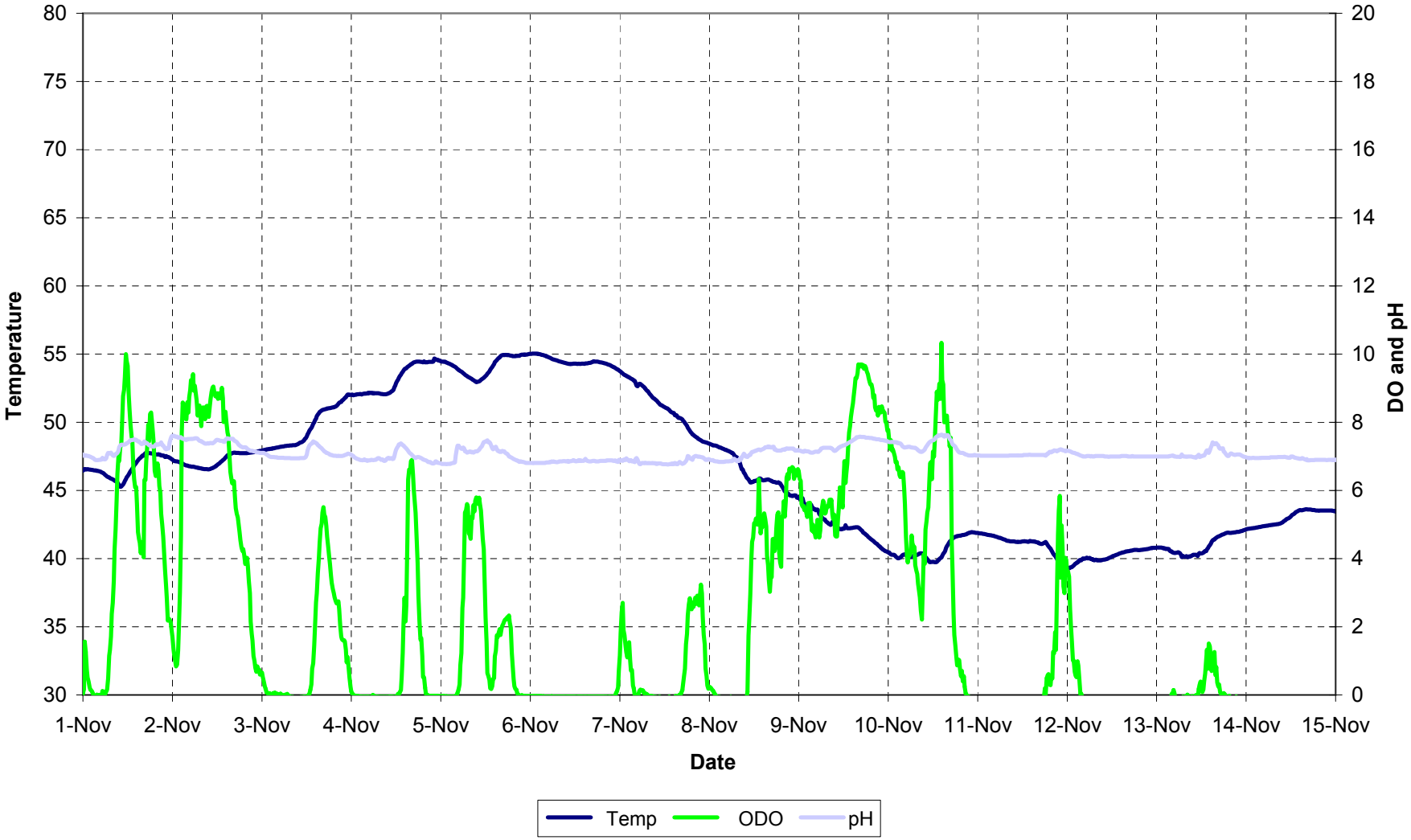

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Figure D3
2009 Water Quality Data

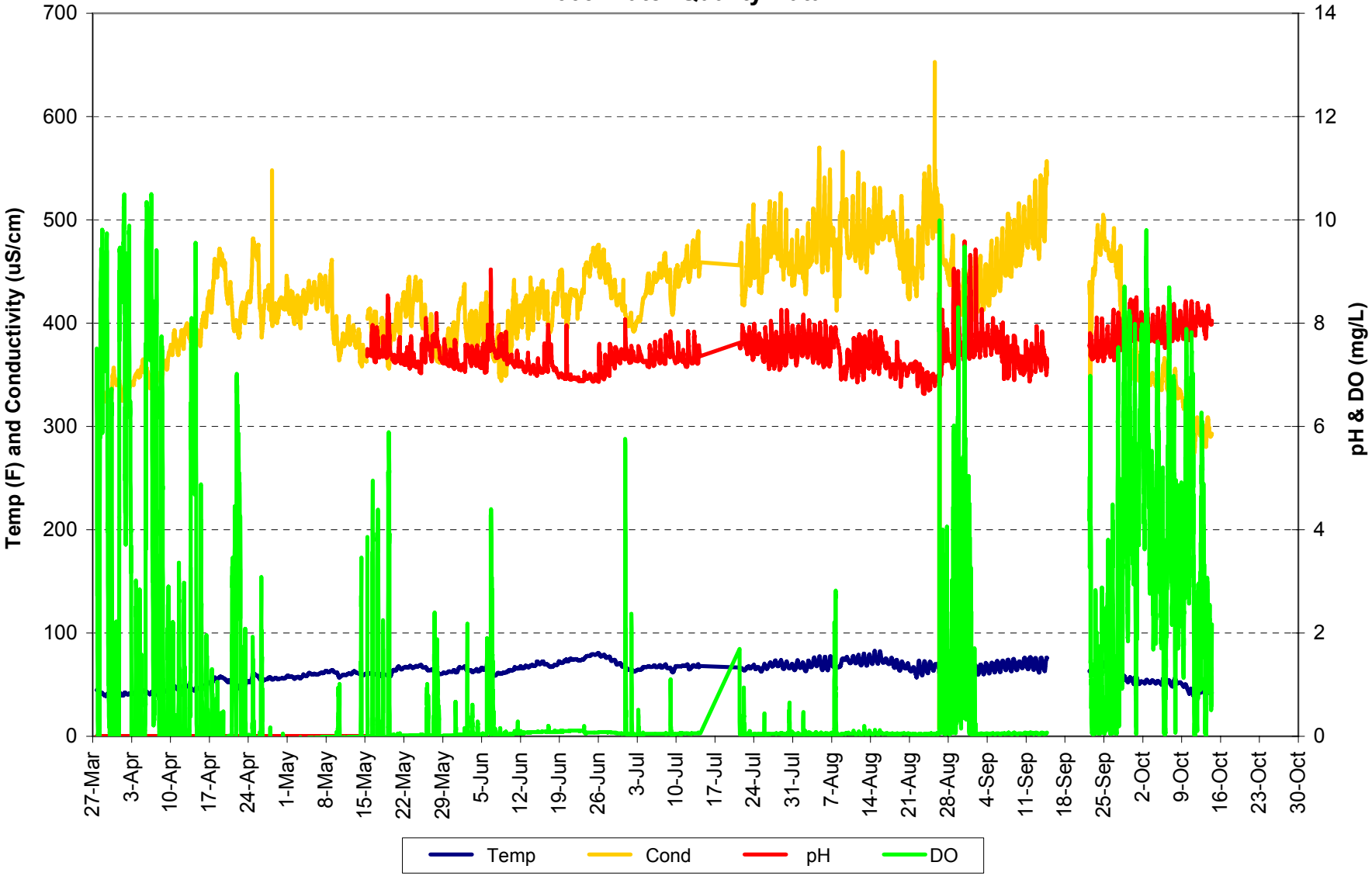

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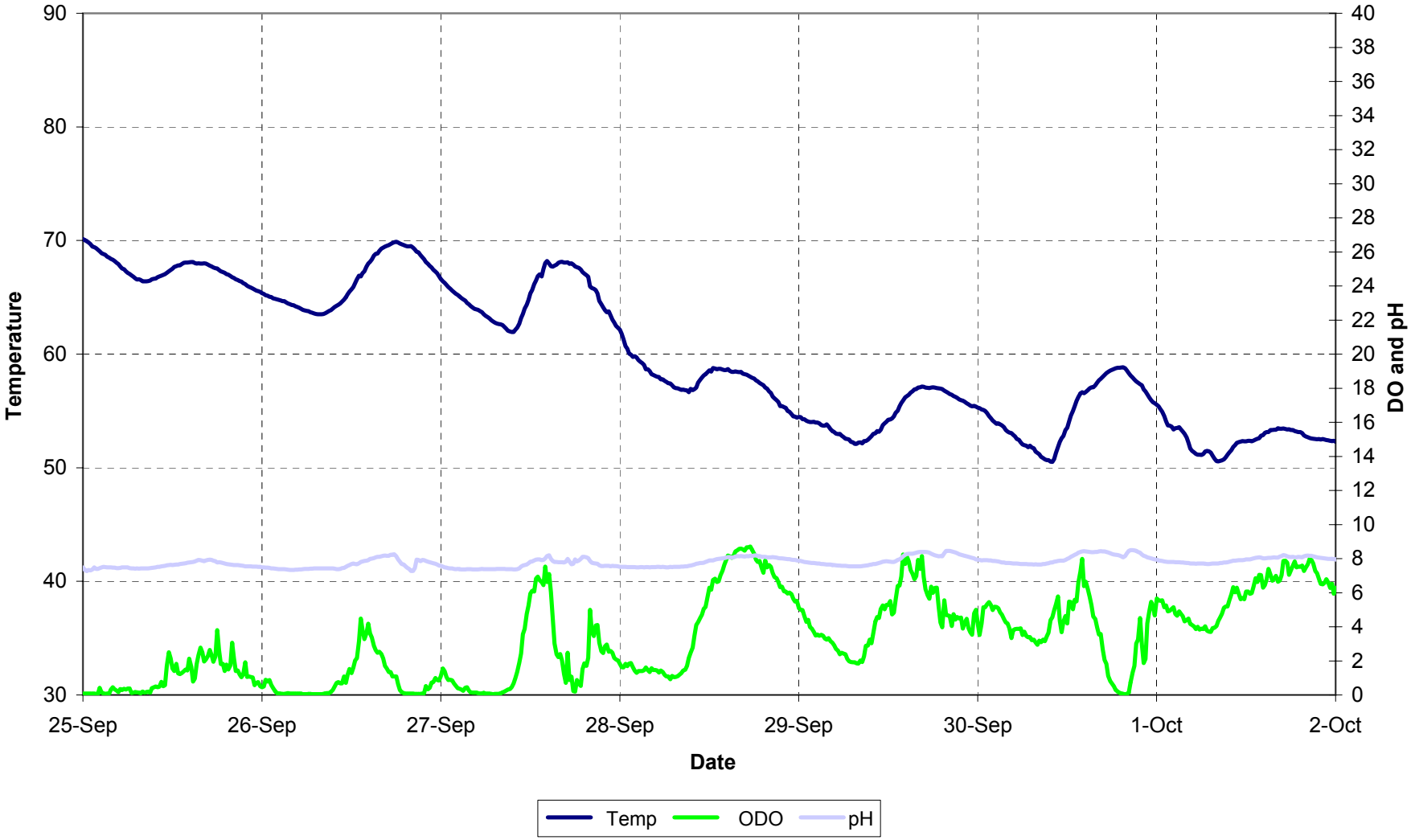
Figure D4
2009 (Excerpt) Water Quality Data



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