BARR

Memorandum

To: Paul Nelson, Prior Lake-Spring Lake Watershed District (PLSLWD)

From: Greg Wilson

Subject: Final Technical Memorandum #1--County Ditch 13 Wetland and Ferric Chloride System Sediment and Phosphorus Removal Performance Assessment

Date: March 18, 2003

Project: 23/70-158 GJW 001

This final technical memorandum has been prepared to discuss our assessment of the County Ditch 13 Wetland and Ferric Chloride Treatment System (Treatment System) for removal of phosphorus and sediment from the watershed runoff between 1999 and 2002. This assessment is based on monitoring, completed by the PLSLWD, from three locations (see Figure 1, following this memo) within the County Ditch 13 watershed. This final memorandum is intended to:

- Summarize conclusions from previous assessments of the Treatment System
- Describe the methodology used to develop the rating curves and update the data for the monitoring locations
- Discuss results of this Treatment System assessment
- Provide recommendations for future study or Treatment System improvements

Conclusions from Previous Treatment System Assessments

This section discusses four previous assessments of the Treatment System conducted between 1999 and 2001. A February 4, 2000 memorandum to the PLSLWD Managers (*Paul Nelson and Sabrina Cook; Re: Highway 13 Wetland and FeCl Treatment System Performance*), discussing the 1999 monitoring results, determined that the Treatment System:

- Provided significant reductions in ortho-phosphorus (49%) and some total phosphorus (TP) reduction (21%)
- May actually increase total suspended solids (TSS), apparently due to significant growth of duckweed in the wetland that floats through the system
- Is not performing at the desired TP reduction goal (40-50% removal), but is performing well and at the targeted reduction goal for ortho-phosphorus (DP)

The Watershed Restoration Action Strategy for the Second Implementation Phase of the Prior-Spring Lake Improvement Project (*Prior Lake-Spring Lake Watershed District*), discussing the 2000 monitoring results, determined that:

- Low flows were experienced during 2000, with observed flows at the upstream monitoring site (CD1) essentially the same as observed flows at the wetland outlet monitoring site (CD2)

- The Treatment System provided significant reductions in DP (40%) and TP (47%) during snowmelt runoff monitoring, and experienced significant reductions in DP (40%) and some TP reduction (11%) during the remainder of the year
- The Treatment System provided some reduction in TSS (25%) and no change in volatile suspended solids (VSS), excluding snowmelt runoff
- Most of the pollutant reductions are occurring between the wetland outlet monitoring site (CD2) and the desiltation basin outlet (CD3)
- Increases in TP and TSS concentrations occur within the wetland portion of the system, apparently due to the production of organic solids in the form of duckweed and algae in the wetland (although this is not supported by VSS monitoring results)
- Longer settling times from lower flows in 2000 and/or floating boom (installed just above the wetland outlet) appears to be responsible for increased TSS removal in 2000, compared to 1999 monitoring results

A December 6, 2001 memorandum to the PLSLWD Managers (*Paul Nelson; Re: County Ditch 13 Treatment System Performance*), discussing the monitoring results from 1999 through 2001, provided the following new information:

- TSS concentrations increased through the Treatment System during 2001, due in large part, to one statistically dominant storm event on April 24, 2001 when flows reached 110 cfs
- All particulate pollutant forms (TSS, VSS, and TP) increased through the Treatment System, particularly through the FeCl system and desiltation pond, as a result of high flow velocities and resuspension of particles and iron floc on April 24, 2001
- Snowmelt runoff samples collected during 2000 and 2001 indicate that TSS and VSS concentrations increase through the Treatment System, while TP and DP concentrations (which are disproportionately higher than other portions of the year) decrease through the Treatment System
- Most of the phosphorus reductions are occurring in the FeCl system and desiltation basin
- It appears that the performance of the Treatment System could be improved by increasing the settling times downstream of the iron addition system, and may also be improved with the expansion of the settling areas in the wetland

The 2001 Annual Report (*Prior Lake-Spring Lake Watershed District*), discussing the monitoring and FLUX modeling results from 1999 through 2001, indicated that:

- TP flow-weighted concentrations from FLUX increased slightly, TSS increased significantly and DP decreased from upstream to downstream of the system during 2001, with the TP and TSS results being heavily influenced by the high flow event on April 24, 2001
- Most of the phosphorus reductions, during the entire 3-year monitoring period, are occurring in the FeCl system and desiltation basin
- Potential reasons for the poor performance of the wetland portion of the Treatment System include:
  - Resuspension of particulates and phosphorus by wind and carp
  - Growth of algae and duckweed in the wetland that float through the system

- Soils in the area contain a lot of fine textured clay particles
- Changes in pH, in combination with the organic soils of the wetland, may be triggering pH induced phosphorus release from the wetland
- The wetland may be hydrologically overloaded, with limited time for settling and uptake

Development of Rating Curves and Updating Data for All Monitoring Sites

For our assessment of the performance of the Treatment System, Barr was supplied with historical flow monitoring records, stage-discharge relationships, and FLUX modeling results for 3 monitoring sites located along County Ditch 13 from 1999 through 2001 (one site each upstream of the Highway 13 Wetland, and upstream and downstream of the FeCl injection/settling system). Our approach for this portion of the project began with a review of the available stage-discharge flow monitoring records or field notes used to establish the relationships that were previously established. Flow monitoring records and field notes from 2002 were then used to determine whether any changes should be made to the stage-discharge relationships for each of the three monitoring sites.

Figure 2 shows the updated stage-discharge relationship for CD1, following the addition of two measurements observed during 2002. The figure shows that a fourth-order polynomial equation provided the best fit, with an R^2 value of 0.96. The equation that had been previously used for the stage-discharge relationship did not provide the best fit at lower flow rates and would typically over-predict flow rates for the remaining stages with more recent observations. The new equation was used to recalculate flow rates, based on stage readings from CD1 for the entire period of record.

Figure 2: CD1 Stage Discharge with All Measurements

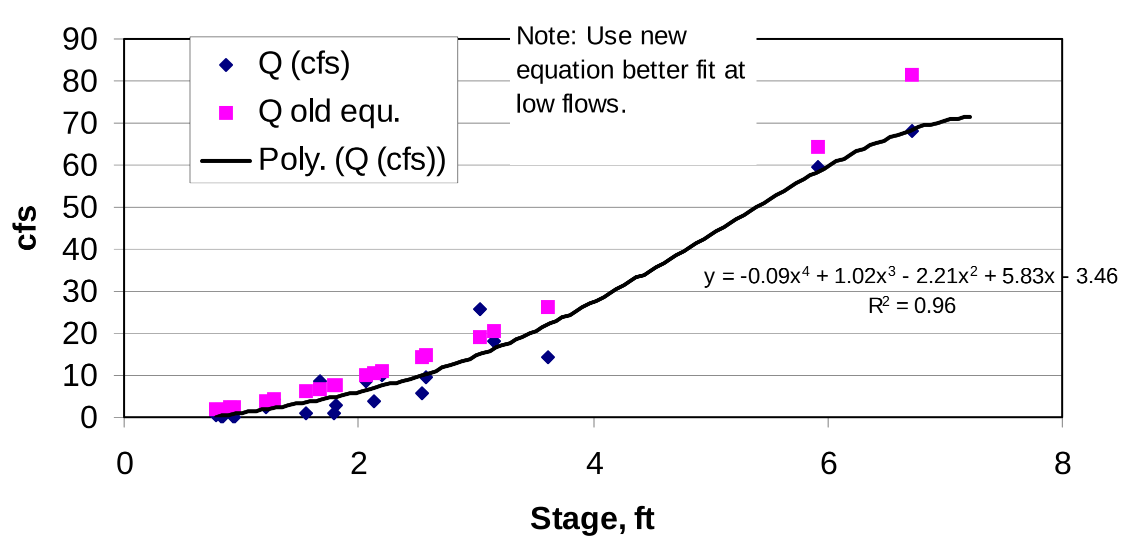
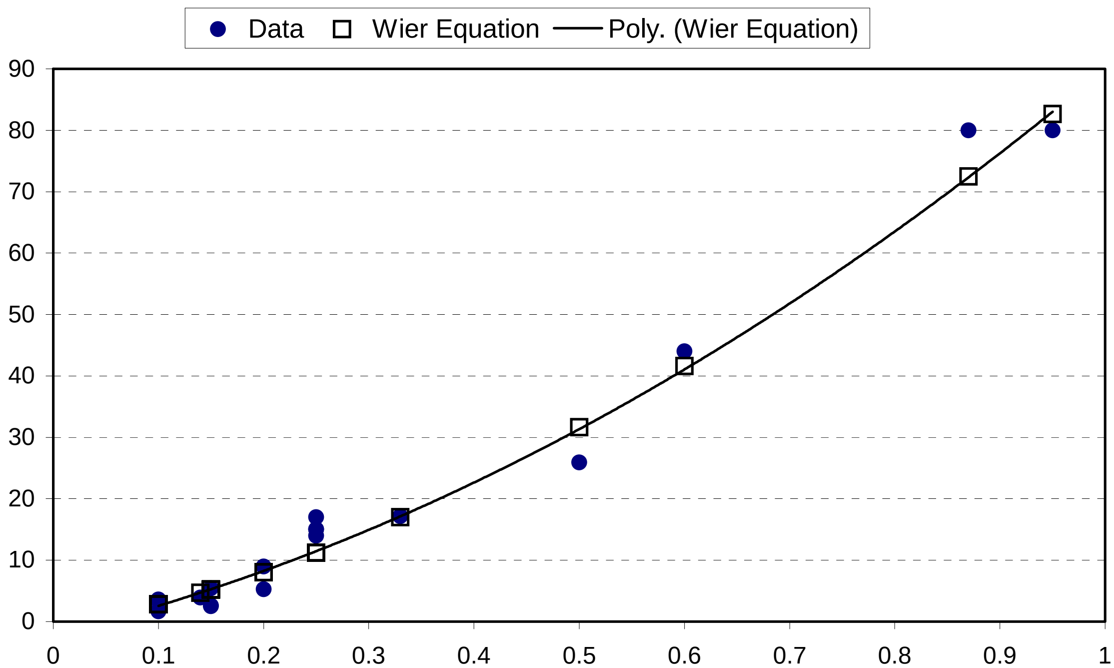
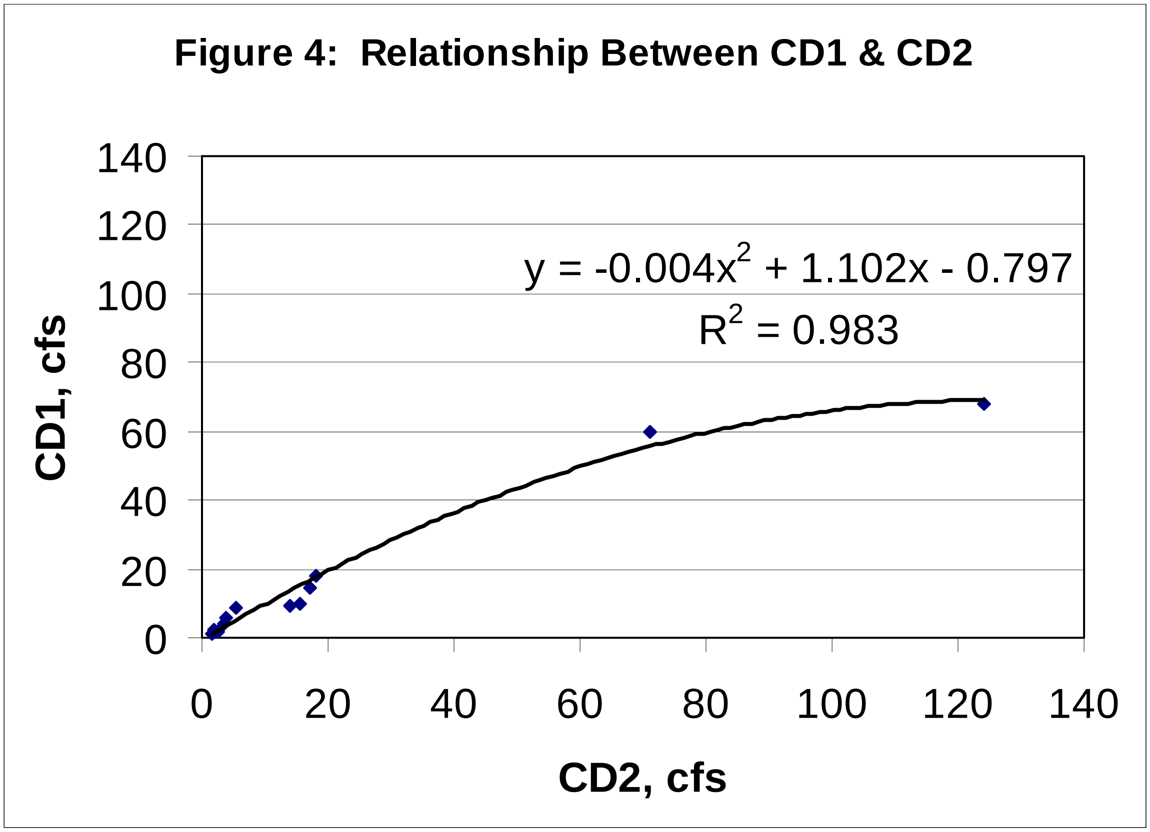


Figure 3 shows the stage-discharge relationship for CD2, including the addition of three measurements from 2002. The figure shows that the weir equation, used in previous assessments, provided a good fit to all of the measurements between 1999 and 2002. As a result, this equation was again used for the CD2 stage-discharge relationship in the analysis for this study.

Figure 3: CD2 Rating Curve



There were several times in which there were missing readings from the flow records at either of the monitoring sites (CD1 or CD2), or the predicted flow at CD1 (upstream) was higher than the predicted flow at CD2 (downstream). As a result, Figure 4 shows a relationship that was developed between the observed flow rates at CD1 and CD2. Missing 2002 flow measurements at CD1 and CD2 were completed with field observations, if available; otherwise missing CD2 values were estimated by interpolation with the closest observed average daily flow measurements. Then missing average daily flow estimates at CD1, or average daily flow estimates that were greater than CD2, were calculated using the relationship shown in Figure 4. In this way, the calculated flow estimates at CD1, used for the FLUX Model analysis, were always equal to or less than the estimated average daily flows from CD2. The difference in the flow between CD1 and CD2 was attributed to the unmonitored portion (approximately 1.34 square miles) of the watershed between CD1 and the wetland. Since a negligible amount of runoff enters the Treatment System between CD2 and CD3, the average daily flow estimates for CD3 were set to the average daily flow estimates at CD2.



The water quality sample test results, from grab samples collected by the PLSLWD, along with the average daily flow estimates, were compiled and used as input for the FLUX modeling. Samples collected from 1999 through 2002 were analyzed for TSS, TP, and DP. Samples were also analyzed for VSS from 2000 through 2002. Sample results that were less than the laboratory detection limits were assumed to be one-half the respective detection limit for use in this assessment. VSS is that portion of the TSS that burns (or volatilizes) at a certain temperature, and is therefore, a measure of organic solids in the water (such as algae, duckweed, plant tissue, leaves, for example). Subtracting VSS from TSS provides a measure of the inorganic solids, such as sand, silt, clay or other mineral particles. DP is the dissolved form of TP, which is more readily available for uptake by algae. Subtracting DP from TP provides a measure of phosphorus that is bound up or attached to particles or solids. In 2002, the PLSLWD also analyzed grab samples for suspended solids (SS). The analysis for SS is exactly the same as TSS, except that the sample is allowed to settle for 24 hours before it is drawn from the bottle for analytical testing. Subtracting SS from TSS provides a measure of the solids or particles that would likely settle from suspension with a detention time of 24 hours or greater. Finally, the PLSLWD also completed field testing at each of the monitoring sites for temperature, dissolved oxygen and pH.

As previously mentioned, the FLUX Model was used to estimate the flow-weighted average concentrations and loadings at each of the monitoring sites (CD1, CD2 and CD3) for each of the constituents (TP, DP, TSS, VSS, SS) over the entire monitoring period. This larger sample size, along with its distribution over several years, allows for more sophisticated analysis of flow and seasonal stratification schemes and a greater confidence in the results. A FLUX worksheet (originally developed by the Minnesota Pollution Control Agency), documenting the methods used to calculate the flow-weighted average concentrations and loadings, was completed for each constituent at each of the monitoring sites. In virtually all cases, the load calculation method and stratification scheme chosen from the FLUX Model, produced the lowest coefficient of variation and convergence of methods, without correlation of the residuals versus either flow, date or month.

Results of Current Treatment System Assessment

This section discusses the results of our Treatment System assessment, based on the monitoring and FLUX modeling results between 1999 and 2002. The FLUX modeling results are presented in Tables 1 and 2. Table 1 shows the flow-weighted mean concentrations (and corresponding coefficients of variation) estimated by FLUX for each of the constituents at each monitoring site, while Table 2 shows the estimated constituent loadings (based on the overall period of monitoring completed for the respective constituents).

Table 1: County Ditch 13 Monitoring--Flow-Weighted Mean Concentrations (Coefficient of Variation), 1999-2002[1]

	TP (μg/L)	DP (μg/L)	TSS (mg/L)	VSS (mg/L)	SS (mg/L)
CD1	382 (0.072)	267 (0.100)	23 (0.160)	6.1 (0.129)	19 (0.282)
CD2	326 (0.076)	213 (0.126)	22.2 (0.199)	6.3 (0.208)	20 (0.407)
CD3	269 (0.096)	147 (0.178)	22.9 (0.256)	5.8 (0.164)	17.3 (0.339)
CD1 to CD3 % Change	-30%	-45%	0%	-5%	-9%
CD2 to CD3 % Change	-17%	-31%	3%	-8%	-14%

Table 2: County Ditch 13 Monitoring--Constituent Loadings (kg), 1999-2002[1]

	TP	DP	TSS	VSS	SS
CD1	4584	3212	276781	55545	94901
CD2	6155	4018	418510	77892	121650
CD3	5077	2771	432967	71158	104966
CD1 to CD3 % Change[2]	11%	-14%	56%	28%	11%
CD2 to CD3 % Change	-18%	-31%	3%	-9%	-14%

NOTES: [1] – SS monitoring was conducted during 2002, only. VSS monitoring was not completed during 1999.
[2] – Measured flow volume at CD1 was 36% less than CD2 & CD3 flow volume during 1999-2002, 26% less during 2000-2002, and 18% less during 2002. Assuming that runoff from unmonitored upstream watershed has water quality similar to CD1, then Table 1 provides a better estimate of percentage reductions for each constituent.

Based on a review of Tables 1 and 2, and assuming that runoff from the unmonitored upstream watershed has water quality similar to CD1, the following conclusions can be drawn about Treatment System efficiencies for each individual constituent:

- The Treatment System provided significant reductions in DP (45%) and TP (30%), with more of the pollutant reductions occurring between the wetland outlet monitoring site (CD2) and the desiltation basin outlet (CD3)
- The Treatment System provided no reduction in TSS (0%), with a possible increase in the TSS concentration occurring within the wetland portion of the system
- The Treatment System provided minor reductions in VSS (5%) and SS (9%), with all of the pollutant reductions occurring between the wetland outlet monitoring site (CD2) and the desiltation basin outlet (CD3)

Comparing the modeling results, shown in Tables 1 and 2, of each constituent against the others provides the following indications about the Treatment System effectiveness:

- Approximately 70% of the TP entering the Treatment System is in the form of DP, with the DP fraction dropping to 65% through the wetland, and to 55% at the outlet of the desiltation pond, indicating that the dissolved phosphorus is being taken up by algae and duckweed and then removed by the precipitation of floc as the flow progresses through the Treatment System
- VSS consistently represents approximately 25% of the TSS flow-weighted concentration at each of the three monitoring locations, indicating that most of the solids flowing through the Treatment System consists of inorganic or mineral particles

- SS represents between 75 and 90% of the TSS flow-weighted concentration at the three monitoring locations, indicating that less than 25% of the solids flowing through the Treatment System would likely settle out following 24 hours of detention time or that a significant portion of the overall particle size distribution consists of finer silt- or clay-size particles
- Due to the more limited sample set, the coefficients of variation (CVs) for SS is somewhat higher (0.2 to 0.4) than the CVs for DP, TSS and VSS (0.10 to 0.26), which were higher than the CVs for TP (0.07 to 0.10), indicating that the predicted loadings for the phosphorus species may be more accurate than the various solids constituents

A closer examination of the FLUX Model diagnostics, estimated flow rates and water quality data collected for each of the monitoring sites indicates the following:

- The FLUX Model diagnostics indicated that there is a weak positive relationship ($R^2 = 0.196$) between flow rate and SS concentration at CD2
- With the exception of SS sample results from CD2, a regression analysis and the FLUX Model diagnostics indicated that there was not a statistically significant relationship between constituent concentrations and flow rates through the Treatment System, even though several of the FLUX Model load computation methods resulted in lower CVs, following stratification of flow into two or three strata
- The FLUX Model diagnostics and stratification scheme used for TP at CD2 and DP at CD1 showed that there was seasonality, with a positive relationship with flow rate before July 1 and a weak negative relationship with flow after July 1, while the stratification scheme used for TP at CD1 showed that there was a weak positive relationship with flow rate before August 1 and a weak negative relationship with flow after August 1
- The sensitivity of the estimated constituent loadings to the removal of individual samples, as part of the FLUX Model diagnostics, shows that removing the most sensitive sample result from consideration for the calculation of each constituent load at each site would yield:
  - Lower predicted loads (between 4 and 34%) for all constituents at all monitoring sites
  - Lower predicted loads for TP, DP and TSS at CD3 relative to CD1 and CD2, which would result in respective overall Treatment System load reductions of 31, 50 and 14%, instead of those shown at the bottom of Table 1 for each of the four constituents
  - Lower predicted loads for VSS and SS at CD2 relative to CD1 and CD3
- While TSS concentrations increased through the Treatment System during a statistically dominant storm event on April 24, 2001 (when flows reached the highest observed rate of 110 cfs), this effect was not regularly observed with other particulate pollutants during other higher flow events
- Comparing the low dissolved oxygen readings (less than 2 mg/L) from CD2 with the analytical results of the grab samples taken from CD1 and CD2 on June 27th and July 3rd, 2002, indicates that these conditions may have resulted in phosphorus release from the

bottom sediments, which likely minimized the phosphorus treatment effectiveness in the wetland during this time

A detailed examination of Figure 1, along with a review of the observed volumes and estimated detention times, also reveals the following about the Treatment System:

- The average depths of the desiltation basin and Hwy. 13 wetland are approximately 3.5 and 2.7 feet, respectively; the average depth recommended for NURP-basin design is 4 feet
- Comparing the estimated average overflow velocities in the wetland and desiltation basin during the April 24, 2001 runoff event (when flows reached the highest observed rate of 110 cfs) with the settling velocities of various particle sizes indicates that the wetland and desiltation basin should have been able to effectively remove particle sizes down to 10 and 19 microns, respectively
- There is a significant quantity of duckweed present in the wetland treatment system, the pattern of which, indicates that there is a smaller preferential flow path midway down the longitudinal axis (due to shallow areas on either side of the wetland) that is likely minimizing detention time and the corresponding treatment efficiency
- The locations of the inlet and outlet, combined with a small island in the southwest corner of the desiltation basin, indicate that the preferential flow path would be along the eastern edge of the basin, with less treatment occurring within the western edge of the basin

The Minnesota Department of Natural Resources Permit for operation of the Ferric Chloride Treatment System requires monitoring for iron in the effluent from the system (CD3), with a monthly average iron concentration not-to-exceed 1,275 μg/L, based on a minimum of three samples per month. An evaluation of the water quality monitoring results from 2002 revealed that the only monthly average iron concentration exceeding the permit limit occurred during May with an average concentration of 1,832 μg/L. However, monitoring of the inflows (CD2) to the Ferric Chloride Treatment System during May, 2002 revealed that the average iron concentration was 1,395 μg/L, which was already above the permit limit. The remaining monthly average iron concentrations from the Treatment System outflows were at or below 1,020 μg/L.

Recommendations for Treatment System Improvements

In summary, it appears that one or more of the following conditions may explain the observed overall pollutant load reductions in the Treatment System:

- Presence of carp throughout the Treatment System during the entire period of record
- Short-circuiting of flow through the wetland and desiltation basins, especially during very high flow events

- Inflowing sediment from watershed runoff may generally be too small for treatment (sedimentation) by wetland and desiltation basins during typical flow rates
- Periods of low dissolved oxygen in the treatment wetland may result in phosphorus release from the bottom sediments, minimizing its phosphorus treatment effectiveness

The District's goals for the Treatment System were to achieve 50% DP and 30% TP removals. Table 1 shows that the Treatment System provided reductions in DP (45%) and TP (30%) that were very close to achieving those goals. However, it appears that it may be possible to improve the existing Treatment System performance. Based on this Treatment System performance assessment, Barr has the following recommendations for future study and/or Treatment System improvements:

- Draw down levels of the wetland and desiltation basins, or remove carp; and install (and check the effectiveness of) fish barriers downstream of the Treatment System
- Collect bathymetric data from the wetland treatment system and evaluate the preferential flow paths and potential for short-circuiting in the system; consider excavation in the middle shallow areas on either side of the wetland, along with excavation of a deeper forebay immediately downstream of the inlet to minimize scour and facilitate future maintenance dredging of the coarser material; and plant macrophytes around the perimeter of the wetland
- Collect bathymetric data from the desiltation basin and evaluate the preferential flow paths and potential for short-circuiting in the system; consider excavation of the small island in the southwest corner of the desiltation basin and a deeper forebay immediately downstream of the inlet to minimize scour and facilitate future maintenance dredging of the coarser material, along with possibly installing a baffle or berm to prevent flow from preferentially hugging the eastern edge of the basin to the outlet
- The locations of the inlet and outlet, combined with a small island in the southwest corner of the desiltation basin, indicate that the preferential flow path would be along the eastern edge of the basin, with less treatment occurring within the western edge of the basin
- Collect effluent samples from the wetland treatment system (CD2) and desiltation basin (CD3) during three different runoff events, consisting of low, medium and high runoff rates, and analyze them for particle size distribution, in addition to the regular monitoring constituents (TSS, VSS, SS, TP, DP and Fe)
- Monitor the water column for temperature and dissolved oxygen in the deepest portion of the wetland to evaluate the potential for sediment phosphorus release
- Either continue to use the flotation silt curtain, or consider installing Lemna Duckweed System floating barrier grid (similar to that shown at http://www.lemnatechnologies.com/wtduck.html), to capture duckweed within the Treatment System. Promoting the growth, and possibly harvesting, the duckweed should enhance dissolved phosphorus removal and minimize algae growth.