# Implementation of Hybrid Wetland Treatment Technology in the Northern Everglades Watershed

***<u>Task 45 Deliverable: Final Report</u>***
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# Executive Summary

Four Hybrid Wetland Treatment Technology (HWTT) systems were constructed in the northern Lake Okeechobee watershed in late 2007 and early 2008. Two of the systems are being utilized to treat tributaries (Nubbin Slough and Mosquito Creek) to Lake Okeechobee, a third is being utilized to treat dairy lagoon waters (Larson Barn #8), and the fourth, which drains to the Indian River Lagoon, treats citrus (Ideal Grove) runoff. Design and construction of the HWTT systems was initiated in November 2007, and all systems were operational before early summer 2008.

Initial optimization efforts for these systems focused on maximizing treatment effectiveness, primarily through minimization of outflow TP concentrations by manipulation of key design and operational parameters. The Site 3 Mosquito Creek HWTT system (0.44-acre) reduced inflow (stream-water) TP levels from a mean of 492 to 35µg/L, a 93% reduction. A larger companion HWTT system (1.4 acre) at this site has not yet been operated, due to insufficient creek flows, which were low to moderate during the optimization period. The Site 2 HWTT system (0.7-acre) in the Ideal Grove in St. Lucie County reduced mean inflow TP levels from 151 to 21 µg/L (86% reduction). The Site 1 Nubbin Slough HWTT (1.7 acre), despite experiencing large fluctuations in flow rates and inflow water chemistry during our optimization period, reduced inflow TP levels from an average of 754 to 118 µg/L (84% reduction). The best monthly performance observed at this site was a TP reduction from 1012 to 31 µg/L (97% reduction). The Site 4 lagoon-treatment HWTT reduced TP inflows of 16,700 to 950 µg/L, a 94% reduction. Nitrogen (N) removal performance also was characterized at the Nubbin Slough and Ideal Grove HWTT sites. Total N concentrations were reduced by 57% at Ideal (1.48 to 0.64 mg/L) and 39% at the Nubbin facility (1.42 to 0.87 mg/L).

HWTT systems utilize the strengths of treatment wetlands and conventional chemical treatment systems to provide removal efficiencies beyond those attainable by either separate technology. The HWTT includes intellectual property represented by and in United States Patent 7,014,776 for “Contaminant Removal Method for a Body of Water” and United States patent 7,179,387 for “Treatment System and Method Remediating a Body of Water”. Phosphorus removal in HWTT systems is markedly higher than in treatment wetlands due to the use of chemical amendments.

Unlike conventional chemical treatment systems, however, HWTT systems incorporate several design and operational components that minimize amendment use. These include:

- Passive and active recycling/reuse of chemical flocs
- Sequencing and configuring of the wetland unit processes to provide desirable P species transformations
- Use of wetland components, rather than chemical amendments, for pH buffering
- Utilization of the wetland biota to transform/remove additional contaminants, such as N

During this effort, we observed wide spatial and temporal variations in water chemistry within the Lake Okeechobee tributaries, and this factor, along with the multiplicity of HWTT control variables, indicates a relatively rigorous optimization period is required for initial HWTT installations in this watershed. HWTT design and operational factors that can be adjusted include: relative size and configuration of the wetland (floating and/or submerged vegetation) unit processes; type and dose of coagulants, coagulant aid and buffers; and amendment dosing cycles. Once optimized, HWTT systems should prove to be a predictable, sustainable and cost-effective technology for achieving water quality targets in the Northern Everglades watershed.

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# Introduction

The purpose of this effort is to demonstrate the superior technical efficacy and cost effectiveness of the Hybrid Wetland Treatment Technology (HWTT). During late 2007 and 2008, four innovative HWTT nutrient removal facilities were deployed in the Northern Everglades watershed. The HWTT includes intellectual property represented by and in United States Patent 7,014,776 for "Contaminant Removal Method for a Body of Water" and United States patent 7,179,387 for "Treatment System and Method Remediating a Body of Water". The HWTT exhibits considerable promise as a means of achieving significant phosphorus (P) load reductions to tributaries within the watersheds, Lake Okeechobee, and the estuaries. This project entailed the design, deployment and monitoring of the four HWTT systems. This Final Technical Report describes results from our Period 1 through 10 (ending June 30, 2008) optimization and monitoring efforts.

## *Overview of Project Activities*

The start date for the HWTT project was October 24, 2007. During November, a HWTT mesocosm facility was constructed at Mosquito Creek, and has been operated since that time in a "test and adjust" mode.

During the design and construction of the four full-scale HWTT systems, we conducted baseline sampling to characterize flows and water quality at the four sites. By the end of February 2008, one of the full-scale systems (Nubbin Slough) was operational in an optimization & monitoring (test and adjust) mode, two of the full-scale systems (Mosquito Creek and Ideal #2 Grove) were nearing completion, and the fourth (Larson Lagoon) was still under construction. As of March 31, 2008, three of the full-scale systems (Nubbin Slough, Mosquito Creek small pond, and Ideal #2 Grove) were operational in an optimization & monitoring mode, and the fourth (Larson Lagoon) was still under construction. During May 2008, two of the full-scale systems (Nubbin Slough, Mosquito Creek small pond, and Ideal #2 Grove) were in operational and testing mode, the third (Mosquito Creek large pond) was kept off line due to a lack of flow in the creek, and the fourth (Larson Lagoon) was still under construction. During June 2008, all of the full-scale systems (Nubbin Slough, Mosquito Creek small pond, Ideal #2 Grove and Larson Lagoon) were in an operational and testing mode. Detailed descriptions of facility designs are provided in Final Technical Documents, Tasks #5 and #14.

As part of our ongoing routine optimization efforts, we collected water samples at each of the four HWTT sites, i.e. Ideal #2 Grove, Davie Dairy – Nubbin Slough, Mosquito Creek Small Pond and Larson Lagoon. Flow data for Mosquito Creek and Nubbin Slough were obtained from USGS data archives and evaluated on a monthly basis. The water samples collected for routine monitoring were analyzed for phosphorus (total P, soluble reactive P, particulate P and dissolved organic P), alkalinity, color, turbidity, pH and conductivity. Water samples were analyzed for additional parameters on a periodic basis, including nitrogen species (total Kjeldahl N, nitrate+ nitrite and total ammonia), aluminum (total and dissolved Al), and sulfate. Results of monitoring and optimization efforts at the sites are described in the following sections.

# Treatment Performance of the Four HWTT Systems

## *Site 1: Nubbin Slough Tributary Treatment HWTT*

We converted the existing conventional chemical treatment facility located at Nubbin Slough (Davie Dairy) in Okeechobee County to a HWTT system (Figure 1). The drainage area is shown in Appendix A. The 1.55 acre HWTT system was completed in mid-February, and was operational for one week during February (third week of the month) for an initial testing period. One purpose of this initial testing was to deplete stores of a chemical (Hyperion 1090) stockpiled from the previous Dairy "Best Available Technology" BAT project, but which was not utilized for the HWTT system.

**Figure 1**. **The Nubbin Slough HWTT. The mixing chamber and inflow manifold is in the foreground, and the outflow riser is in the upper right of the photo.**

Continuous optimization and monitoring of the 1.55 acre Nubbin Slough HWTT system began in March 2008. During the optimization period, system flow rates ranged from 0.1 to 27.1 cfs, and averaged 1.7 cfs (Figure 2). This resulted in a mean HRT of 4.3 days. After we had operated the HWTT system for a number of weeks with low "dry season" flows, we experienced a heavy rain event and the flow through the pond (27 cfs) exceeded our desired maximum. This degraded the treatment efficiency due to the excessively short HRT (i.e., 6 hours). We subsequently designed and deployed a flow restrictor orifice on the pond inflow pipe at the weir, and provided an overflow elbow on one of the three slide valves that pass water through the weir in the stream. The effectiveness of this flow restrictor at limiting the maximum flow during high-runoff events is depicted in Figure 2, where the flow through the pond is shown with the downstream USGS gauging station flow versus time. It should be noted that this device can be adjusted to select a "maximum" flow, which for the Davie Dairy HWTT we believe to be in the range of 5 to 10 cfs.

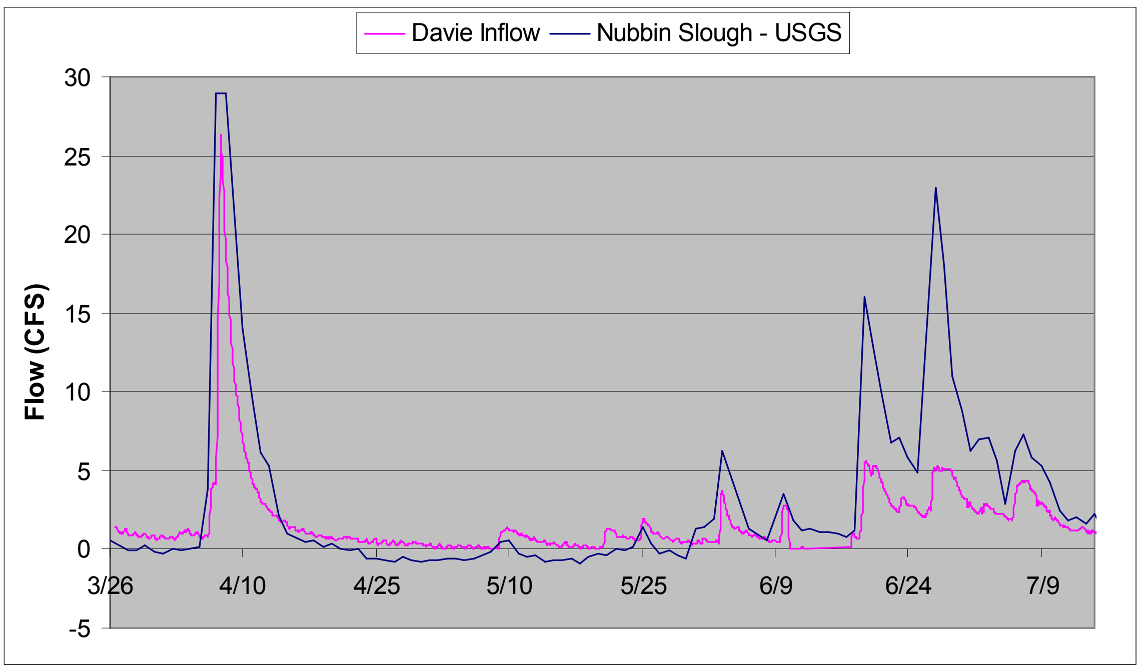



**Figure 2. Nubbin Slough flow (downstream USGS station 02275625 data) and Davie dairy HWTT pond flow (on-site instrumentation) before and after deployment of the flow restrictor on 14 June 2008.**

Chemical dosing rates were varied during the operational period in response to temporal changes in water chemistry, and this is described in more detail later in this report. As of late June 2008, we were providing both alum (4 mg Al/L) and sodium aluminate (8 mg Al/L) to the system mixing chamber.

Inflow water samples were collected for chemical analyses from the HWTT diversion weir (system inflow). Initially (during March), "outflow" samples were collected from a location near the front end of the treatment pond (designated "pond contact zone"). Water chemistry in the pond during this initial startup period reflected the fact that the residual (untreated) pond water had not yet been flushed out of the pond by the inflow of treated water. We selected the end of the first pond compartment, a.k.a. the "contact zone" site as the best location to characterize the quality of treated water during that time. All parameters were monitored at this site during March, with the exception of pH, which was measured at the pond outflow. After the initial startup period during March, all "outflow" samples were collected from the pond outflow structure. Water chemistry data for the entire monitoring period, spanning the pre-operational and HWTT operational phases, are presented in Figure 3 through Figure 11.

Total P concentration in the inflow stream (Nubbin Slough) was highly variable during the entire monitoring period, with an overall mean of 743 µg/L and a median value of 701 µg/L (Figure 3). The mean inflow TP concentration during the HWTT operational period, beginning in late February 2008, was similar (754 µg/L) to the overall mean, despite the extremely high values measured during late April and early May. Concentration of TP in the Davie HWTT system outflow (post-startup) was generally low, as indicated by the minimum and median values of 16 and 40 µg/L, although much higher concentrations were measured during system optimization, as reflected by the mean TP value of 118 µg/L. The highest outflow TP values occurred during the early April maximum flow pulse.

The speciation of P in the Davie HWTT inflow stream from Nubbin Slough was, on average, 82% SRP, 11% DOP and 7% PP. In contrast, the speciation of P in the HWTT (treated) outflow stream was 15% SRP, 12% DOP and 73% PP. During the HWTT optimization/monitoring period, mean SRP concentration was 614 µg/L in the inflow stream, compared with 40 µg/L in the outflow stream (Figure 4). Mean DOP concentration during the same period was 118 µg/L at the inflow and 17 µg/L at the outflow (Figure 5), while mean PP concentration was 60 µg/L at the inflow and 108 µg/L at the outflow (Figure 6). The higher outflow PP values suggest some release of small (pinpoint) flocs from the system.

Alkalinity at the system inflow averaged 25 mg/L over the entire period, compared with 16 mg/L in the HWTT (treated) outflow (Figure 7). Color was, in general, substantially reduced between the HWTT inflow and outflow, averaging 326 CPU at the inflow and 96 CPU at the outflow (Figure 8). During a brief period of extremely high flow in Nubbin Slough, and through the HWTT system itself, in April 2008, color levels at the HWTT outflow were roughly the same as for the inflow (Nubbin Slough). Turbidity was lower in the outflow stream than in the inflow during much of the HWTT optimization period, with the exception of sharp increases during the early system startup phase, when samples were taken at the end of the pond mixing zone, and during the extreme high flow event in April (Figure 9).

The pH in the HWTT system outflow was somewhat lower than inflow pH during the initial startup period (sampled at the end of the pond mixing zone), averaging 5.7 in the outflow and 6.3 at the inflow (Figure 10). During the remainder of the optimization period, pH at both inflow and outflow averaged 6.2. Conductivity levels were relatively consistent in both the inflow and outflow streams, although outflow conductivity (mean = 421 μS/cm) was approximately 25% higher than inflow conductivity (mean = 337 μS/cm) (Figure 11).

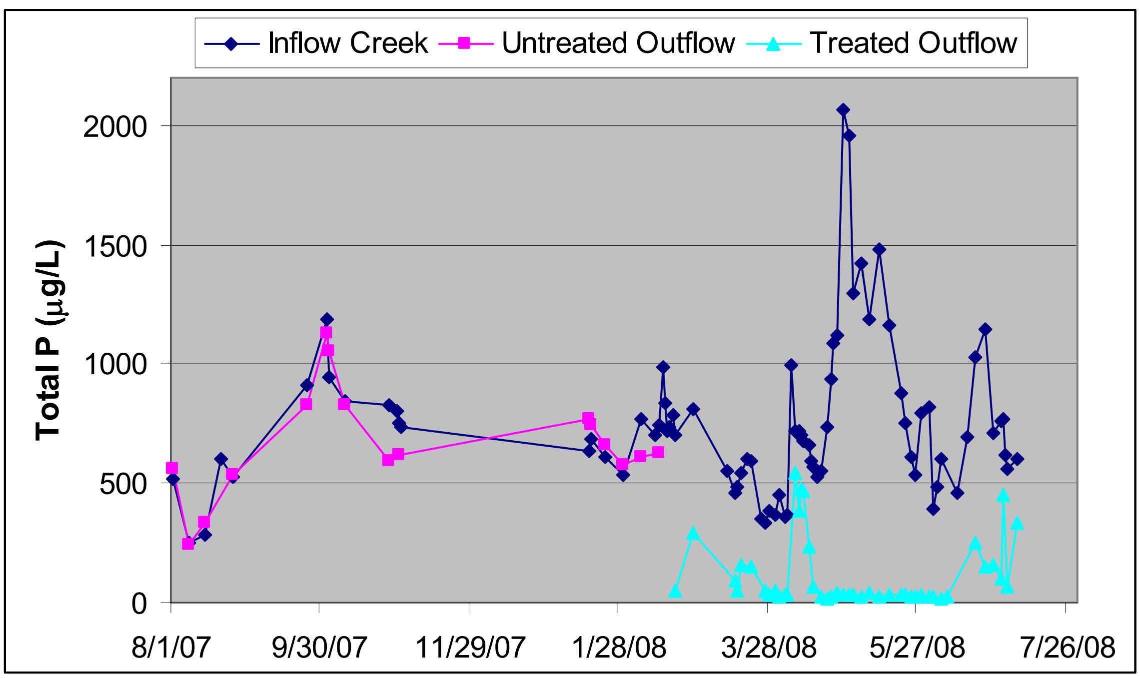



**Figure 3. Total P (TP) concentration in the inflow and outflow streams at the Davie Dairy – Nubbin Slough HWTT.**

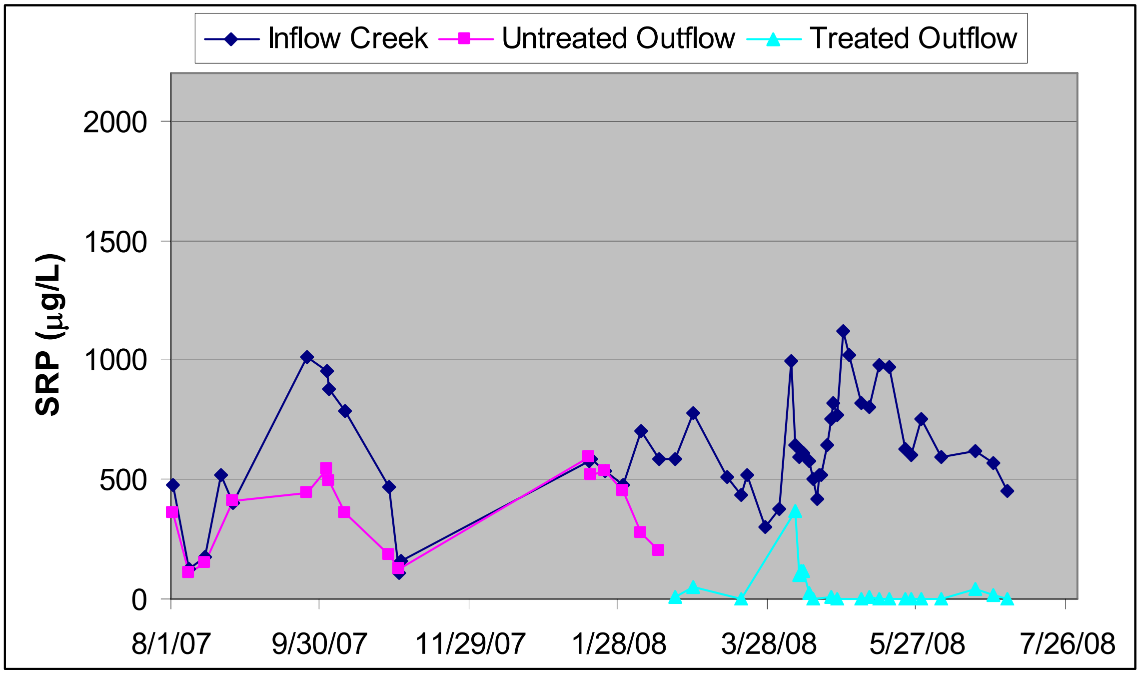



**Figure 4. Soluble reactive P (SRP) concentration in the inflow and outflow streams at the Davie Dairy – Nubbin Slough HWTT.**

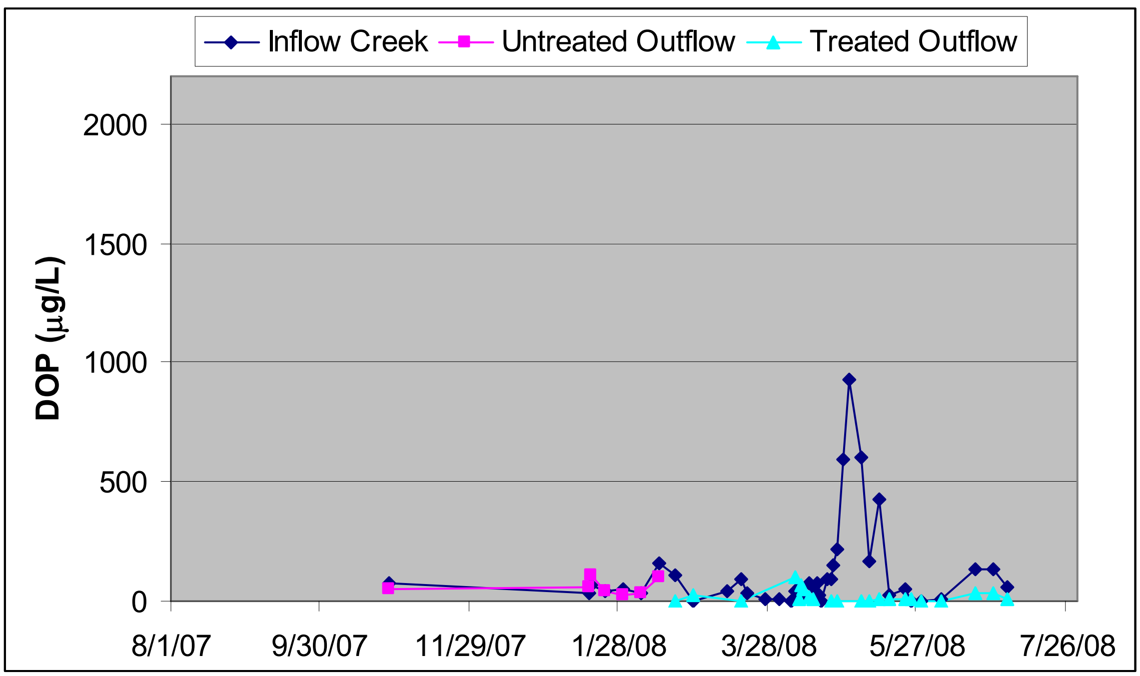



**Figure 5. Dissolved organic P (DOP) concentration in the inflow and outflow streams at the Davie Dairy – Nubbin Slough HWTT.**

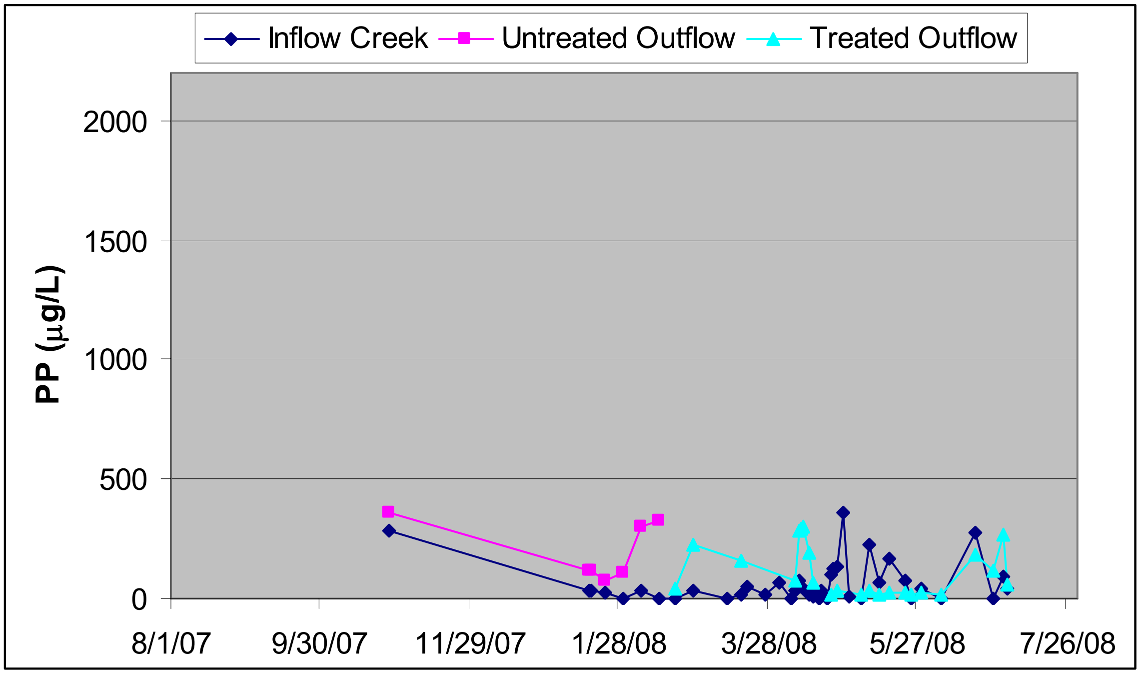



**Figure 6. Particulate P (PP) concentration in the inflow and outflow streams at the Davie Dairy – Nubbin Slough HWTT.**

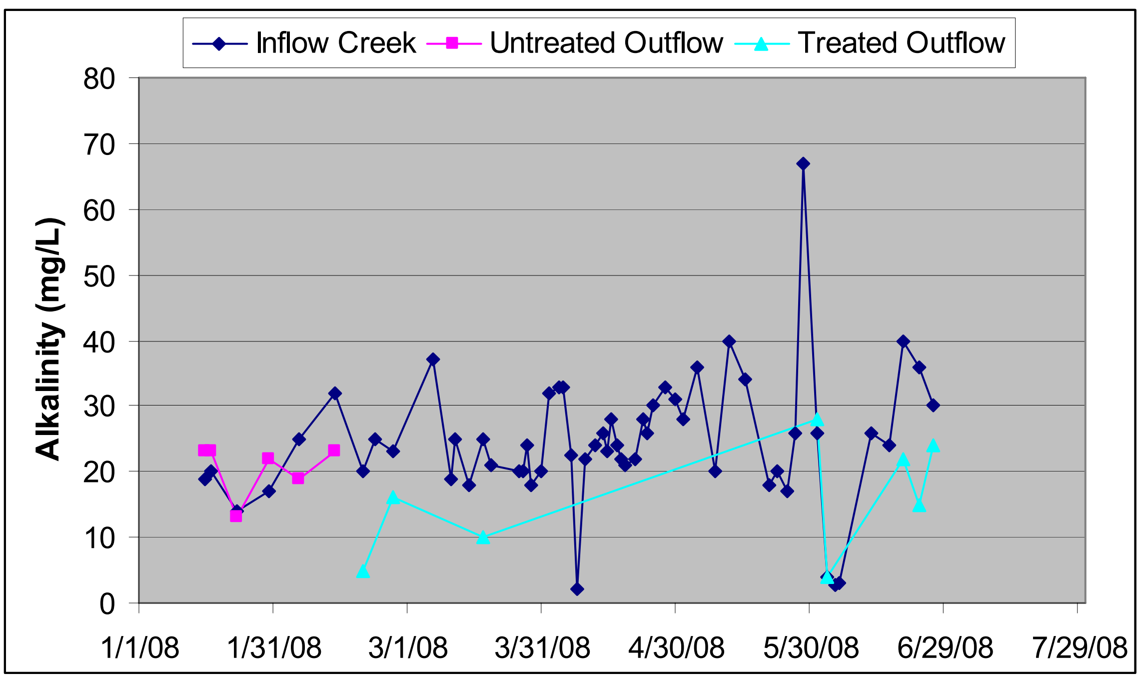



**Figure 7. Alkalinity in the inflow and outflow streams at the Davie Dairy – Nubbin Slough HWTT.**

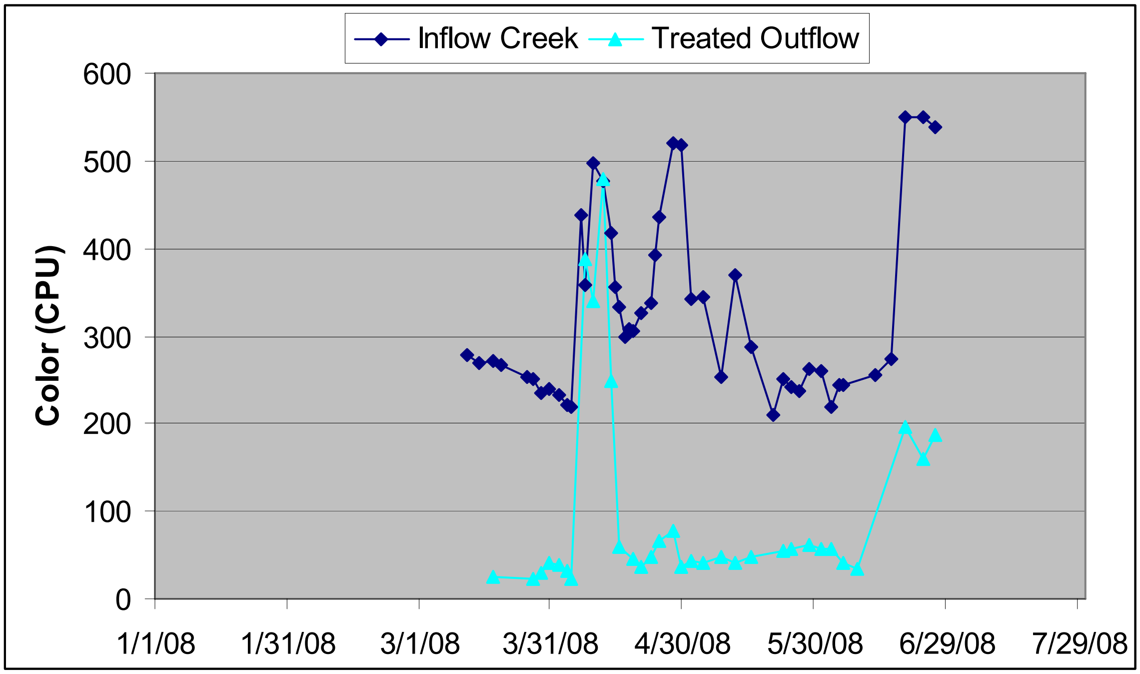



**Figure 8. Color in the inflow and outflow streams at the Davie Dairy – Nubbin Slough HWTT.**

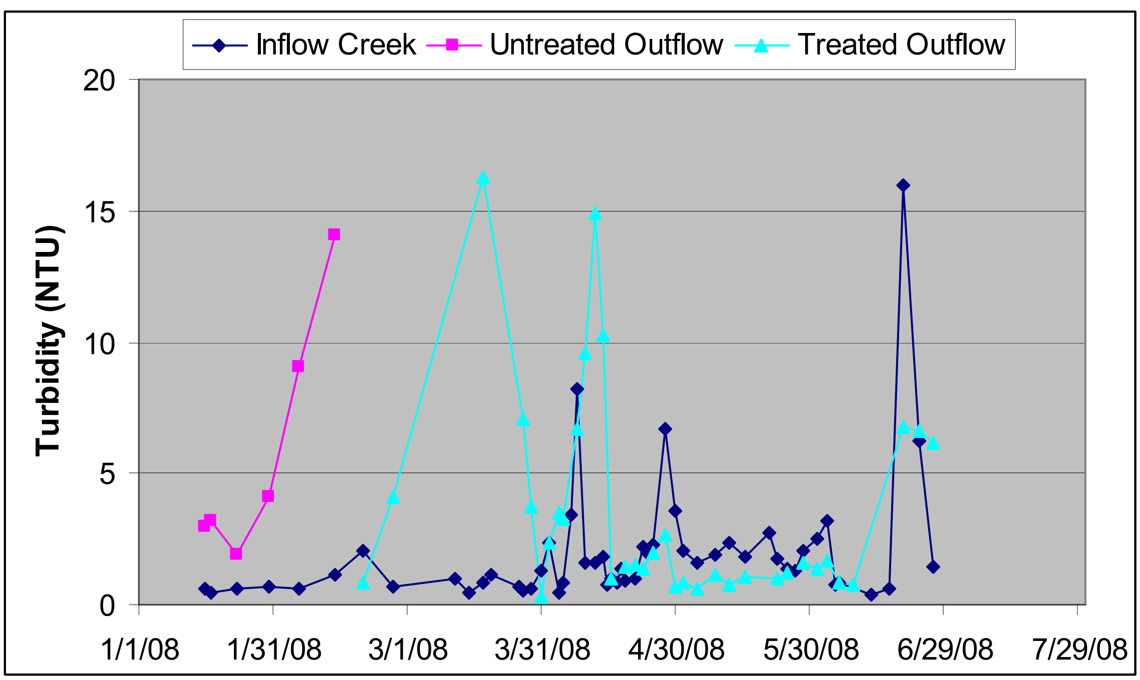



**Figure 9. Turbidity in the inflow and outflow streams at the Davie Dairy – Nubbin Slough HWTT.**

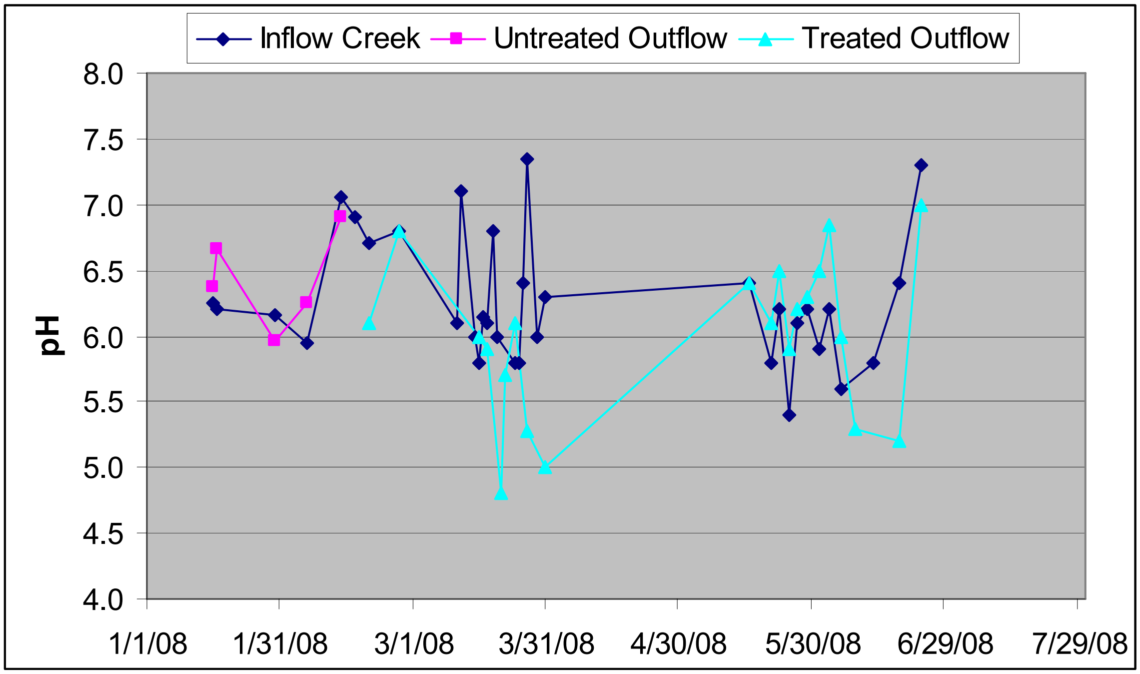



**Figure 10. pH in the inflow and outflow streams at the Davie Dairy – Nubbin Slough HWTT.**

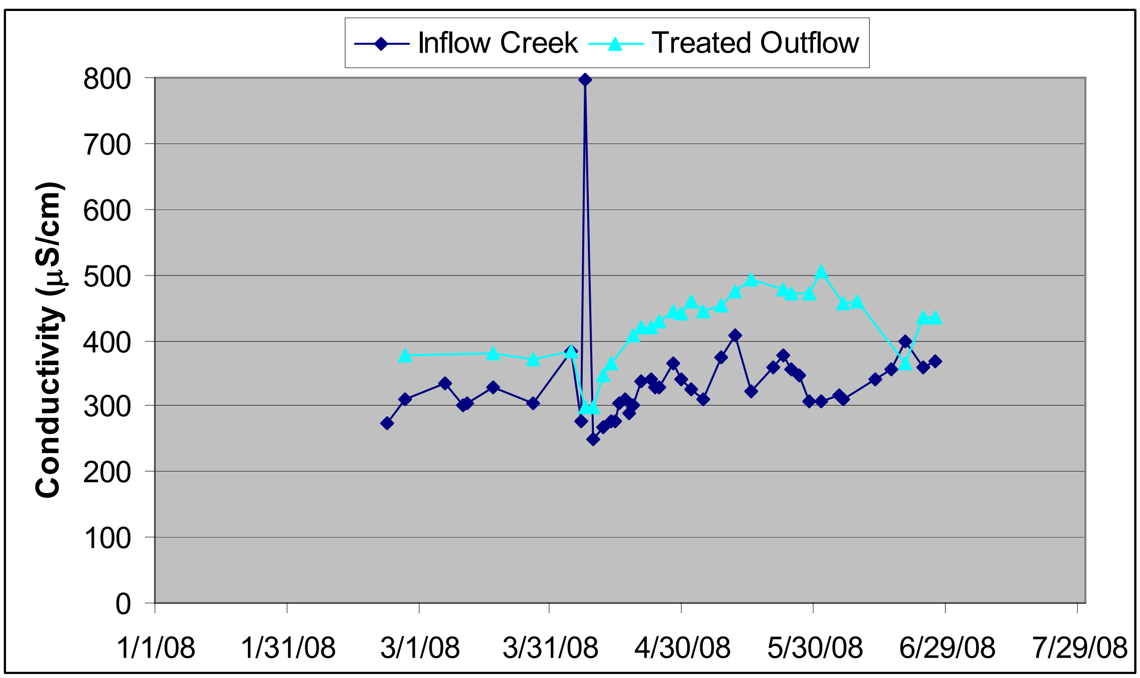



**Figure 11. Conductivity in the inflow and outflow streams at the Davie Dairy – Nubbin Slough HWTT.**

### *Temporal and Spatial Water Quality Characteristics*

During a period of low flow in late April 2008, we performed temporal and spatial sampling within the Nubbin Slough HWTT in order to characterize internal chemical and physical profiles after two months of operation, but prior to the wet season high flow conditions.

The Nubbin Slough HWTT is divided by floating booms and flexible barriers into three distinct zones (Figure 12 and Figure 13): a contact zone, where chemical flocs generated by amendment additions settle, and are re-contacted with inflow waters; a filtration zone that is partially covered by floating aquatic vegetation; and a final settling zone.

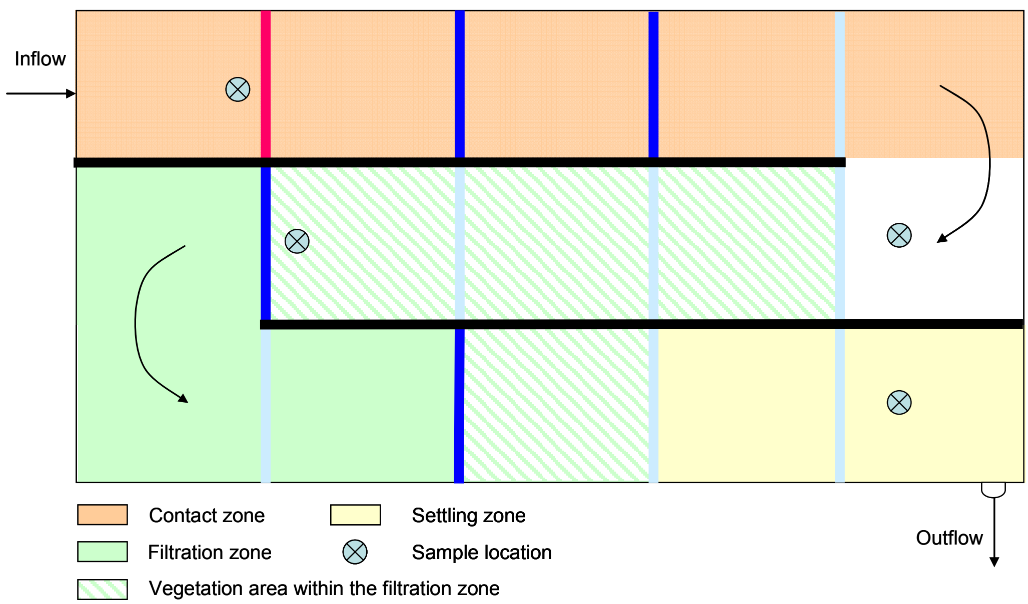



**Figure 12. Schematic of the Nubbin Slough HWTT, depicting the water flow path created by floating booms and flexible barriers. Amendments are injected in the inflow mixing chamber (not shown), and chemical flocs settle in the contact zone. The filtration zone, a portion of which contains floating vegetation, creates quiescent conditions to enhance floc removal. The settling zone comprises the final region prior to discharge. The black lines on the schematic depict surface-to-bottom barriers that guide the water along three flow paths. The red line represents a boom and partial barrier that allows water passage near the pond bottom. The dark blue lines represent a boom and partial barrier that allows water passage near the surface, and the light blue lines represent floating booms (no barrier), for vegetation containment.**

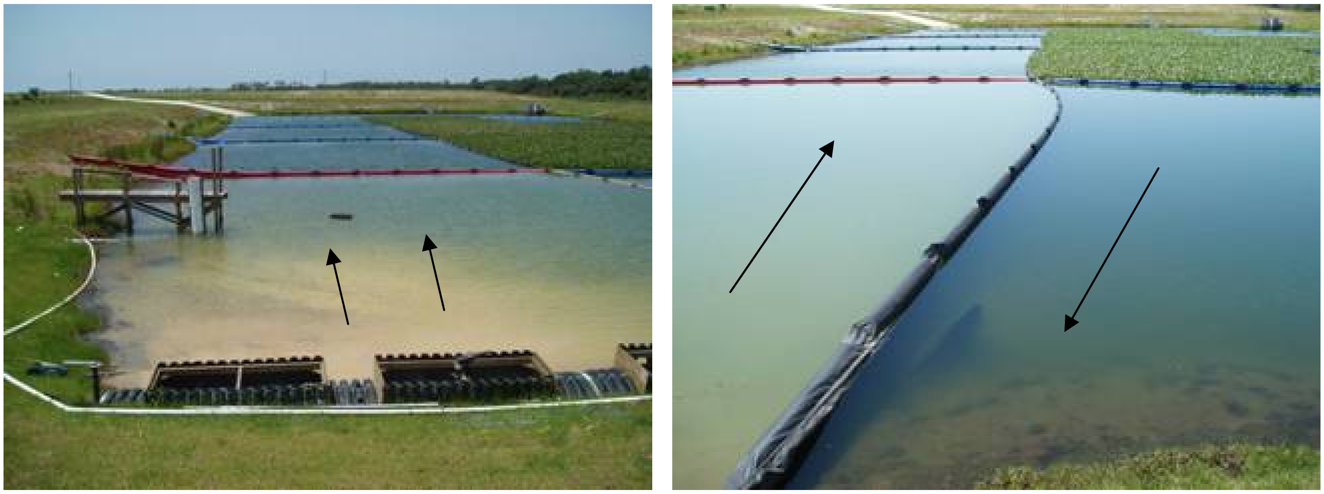


**Figure 13**. **The Nubbin Slough HWTT contact zone (left photo), and the barrier dividing the contact zone from the filtration zone at the north end of the pond (right photo). Arrows depict direction of water flow.**

Late in April, we initiated a diel and spatial characterization of water quality in the Nubbin Slough HWTT. We deployed continuous recording datasondes at five locations: within the inflow conveyance manhole; in the contact zone, adjacent to the first (red) barrier; in the post-contact zone; in the filtration zone; and near the system outflow (Figure 12 and Figure 14). These instruments provided a continuous record of dissolved oxygen concentrations, specific conductance, pH and temperature for a three-day period.

**Figure 14**. **The Davie Dairy HWTT system inflow culvert in Nubbin Slough (left) and the system outflow (right) at the time of the spatial and temporal water quality assessment.**

Additionally, a few days following datasonde deployment and retrieval (under comparable flow conditions), we collected water samples during mid-day from several stations, at two to three water depths, within the Nubbin Slough HWTT system. Station locations for water sample collection are depicted in Figure 38. The samples were analyzed for total P, total soluble P (TSP), soluble reactive P (SRP), color and turbidity.

The inflow total P concentration was 1420 μg/L on this sampling date (Figure 15), and was comprised largely of SRP and DOP (Figure 16). At the contact zone, where floc accumulates, the surface (2 ft depth) TP concentration was 91 μg/L, while at a 6 ft depth it was 4,500 μg/L. As would be expected, due to the accumulation of an amendment floc, essentially all of the TP at the 6 ft depth in the contact zone was comprised of particulate P (4,494 μg/L) (Figure 15 and Figure 16). Through the remainder of the HWTT pond, TP levels generally were low, with deeper water column samples typically exhibiting higher TP concentrations than shallow samples. The bulk of the TP at all internal sampling locations was comprised of particulate P (Figure 15 and Figure 16).

Inflow color levels (344 CPU) were reduced sharply following chemical additions prior to entering the HWTT pond, and remained low through the system, with deepest stations exhibiting highest color values (Figure 17). Outflow color concentrations on this date were 41 CPU. Inflow turbidity levels of 1.6 NTU were reduced to 0.6 NTU at the outflow. Internal to the HWTT, we observed one high turbidity value at the deep sampling location in the contact chamber (Figure 18). The inflow specific conductance levels were increased by amendment additions prior to entering the pond, and remained relatively stable through system (Figure 18).

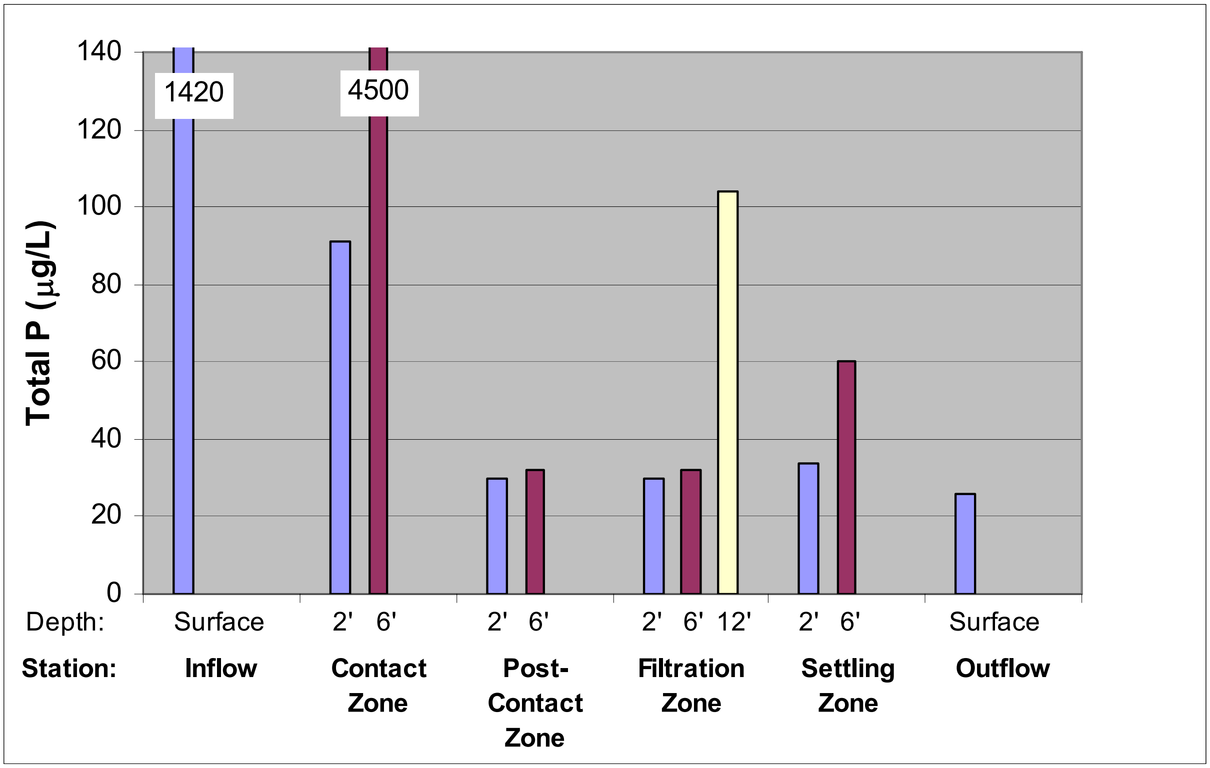



**Figure 15**. **Spatial characterization of TP for the inflow, outflow, and several internal sampling stations in the Nubbin Slough HWTT. Sample collection locations are depicted in Figure 12.**

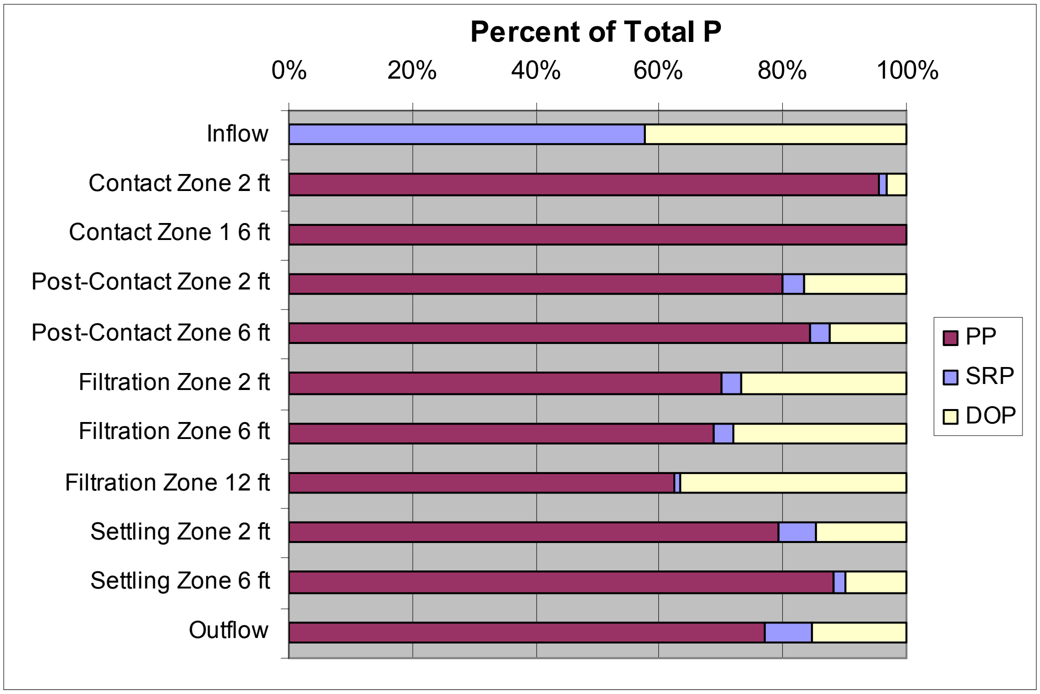



**Figure 16**. **Percentage composition (particulate P [PP], soluble reactive P [SRP], dissolved organic P [DOP]) of TP in the Nubbin Slough inflow, outflow, and internal pond waters at several locations and depths (see Figure 38 for sample locations).**

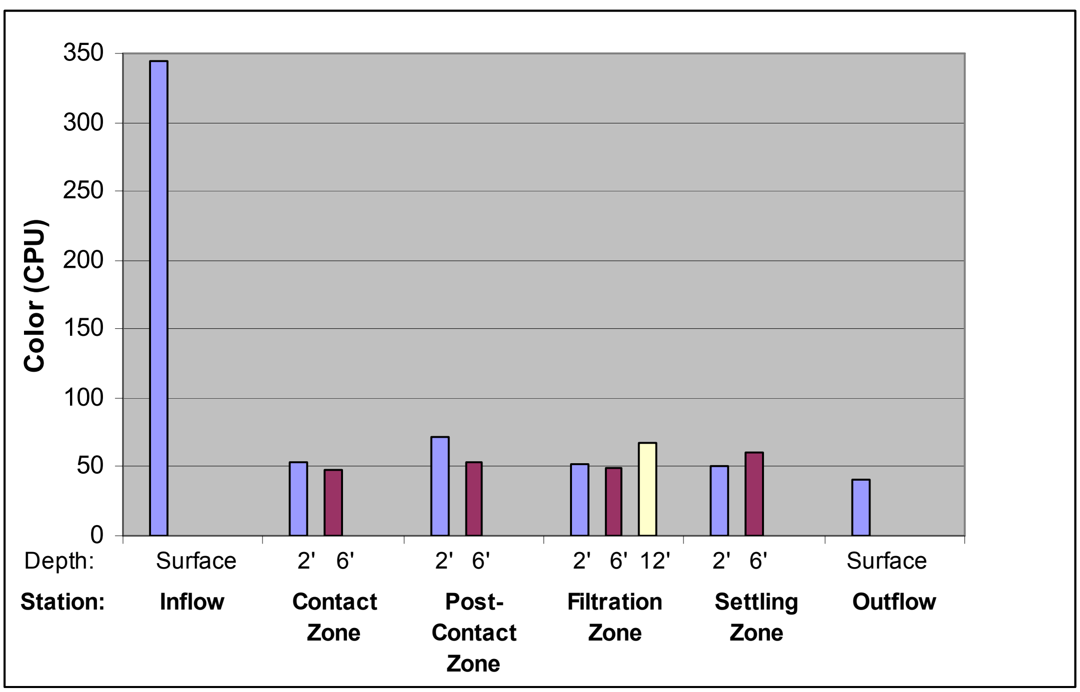



**Figure 17**. **Color in the Nubbin Slough inflow, outflow, and internal pond waters at several locations and depths (see Figure 38 for sample locations).**

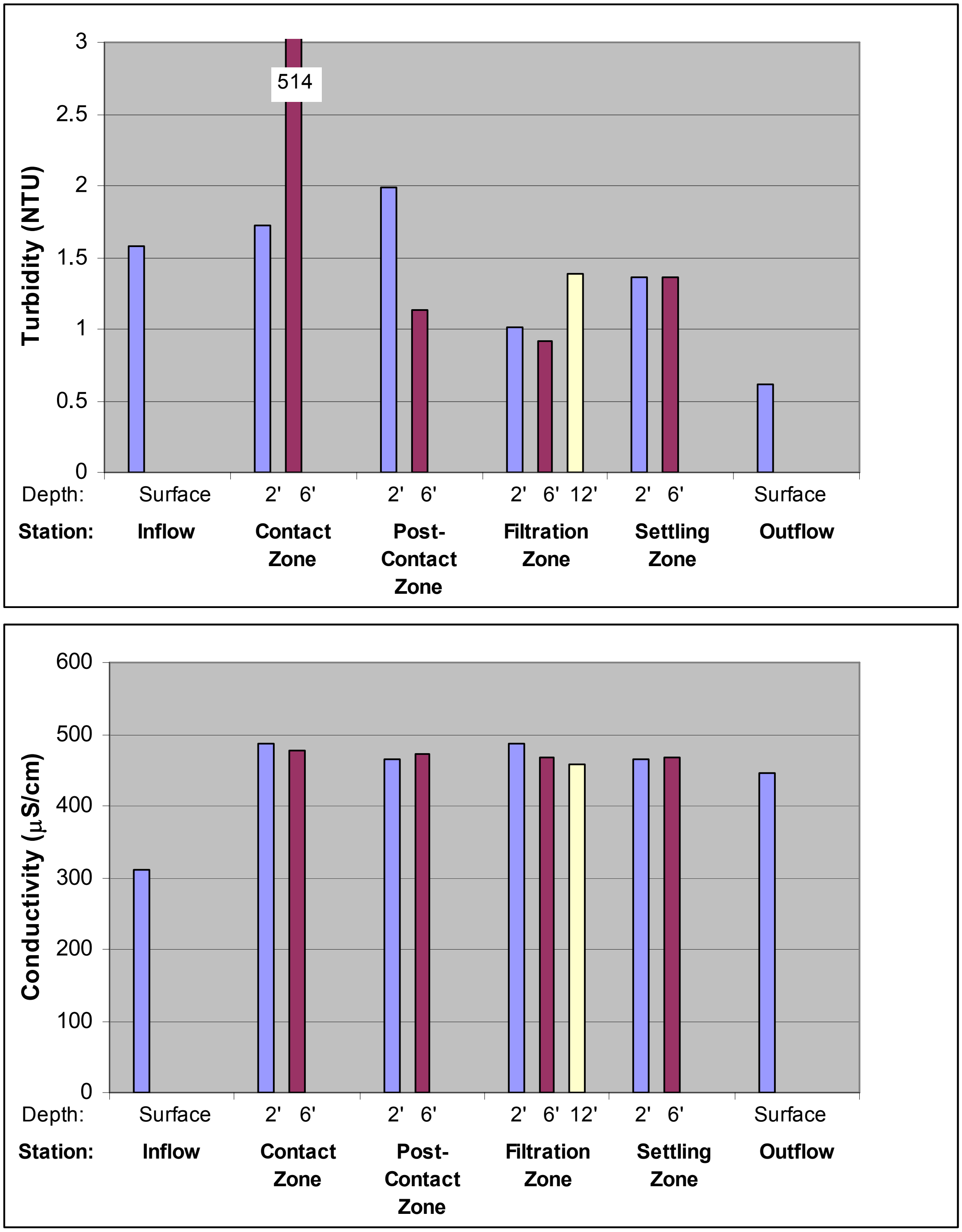



**Figure 18**. **Turbidity (top) and specific conductance (bottom) in the Nubbin Slough inflow, outflow, and internal pond waters at several locations and depths (see Figure 38 for sample locations).**

Using data from the diel monitoring effort, we calculated median pH, conductivity, dissolved oxygen (DO) and temperature levels for the Nubbin Slough HWTT inflow, contact zone, post-contact zone, filtration zone and outflow (Figure 19). The median water column pH remained relatively consistent through the system, whereas DO exhibited a marked increase from the inflow to the post-contact zone, and then a gradual increase through the system to the outflow. The low system inflow DO was related to the dense cover of vegetation (emergent grasses and *Salvinia* sp.) in Nubbin Slough (Figure 14), as well as the cover of duckweed (*Lemna* sp.) in the instrumentation manhole in which the datasonde was deployed (Figure 20). Most of the remaining datasonde deployment locations were in open water, which allowed for re-aeration of the water. No DO measurements were obtained at the contact zone, due to an instrument (membrane) failure. The observed increase in median specific conductance in the HWTT above inflow levels was due to the addition of amendments at the mixing chamber, just upstream of the contact chamber.

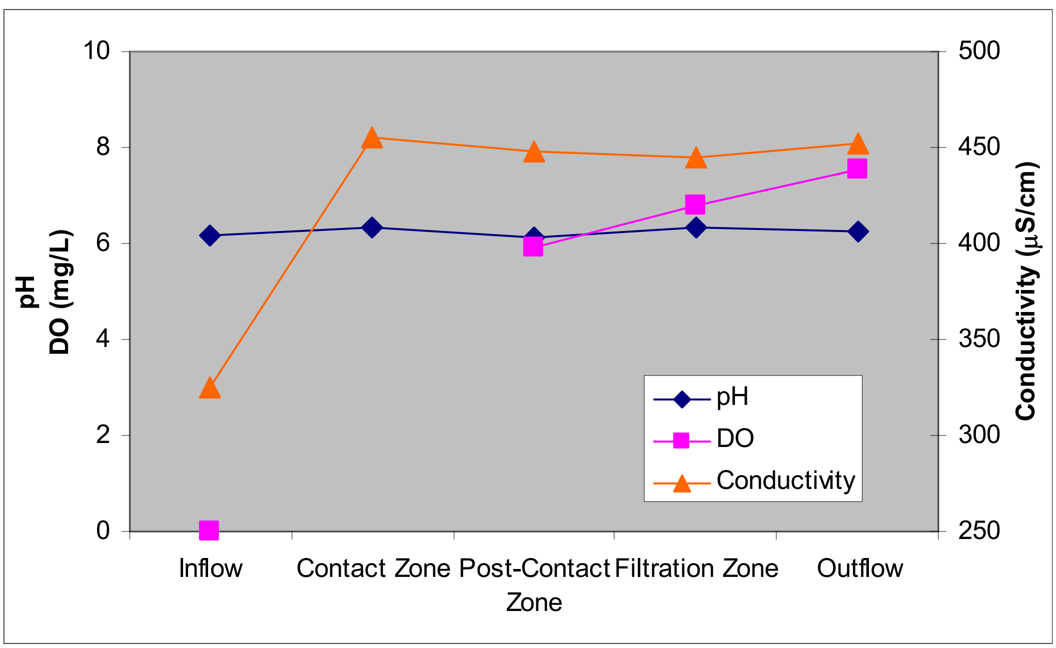



**Figure 19**. **Median pH, dissolved oxygen and conductivity for the Nubbin Slough HWTT at five locations within the system during the diel study**

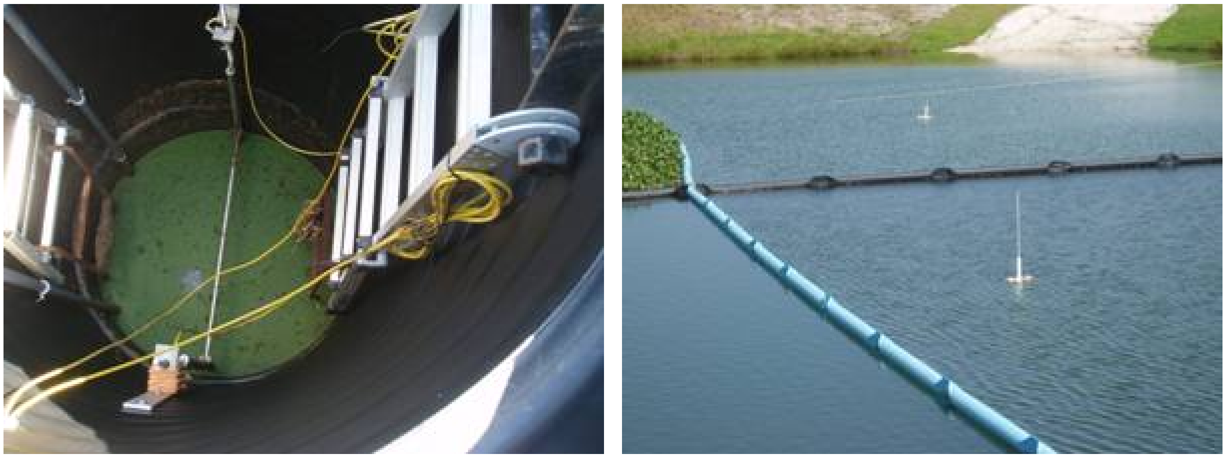


**Figure 20**. **Instrumentation manhole in which the inflow datasonde was deployed (left), and locations of the post-contact chamber and outflow datasondes within the HWTT (white and brown floats in right photo).**

The inflow water exhibited little diel response in pH or DO (Figure 21), probably because of the low flow rate at the time of sampling, and the dense cover of macrophytes in Nubbin Slough and within the instrumentation manhole. The minimum and maximum pH values observed at this location were 6.07 and 6.21, respectively. Inflow DO levels remained below 0.1 mg/L for the three-day monitoring period. The inflow water conductivity was stable, ranging from 317 – 329 µS/cm, while inflow temperature exhibited a slight degree of diel variability, ranging from 18.8 to 21.8 °C (Figure 22).

Diel changes in chemical and physical constituents were more pronounced internal to the HWTT and at the system outflow. For example, at the filtration zone, approximately two-thirds down the HWTT flow path, the pH ranged from 6.21 to 6.56, the DO from 6.96 to 8.44 mg/L, conductivity from 437 to 450 µS/cm, and temperature from 22.4 to 25.4 °C (Figure 21 and Figure 22). At the HWTT outflow, pH over the three-day monitoring period ranged from 6.14 to 6.41, the DO from 6.04 to 7.83 mg/L, conductivity from 438 to 457 µS/cm, and temperature from 22.5 to 25.5 °C (Figure 21 and Figure 22).

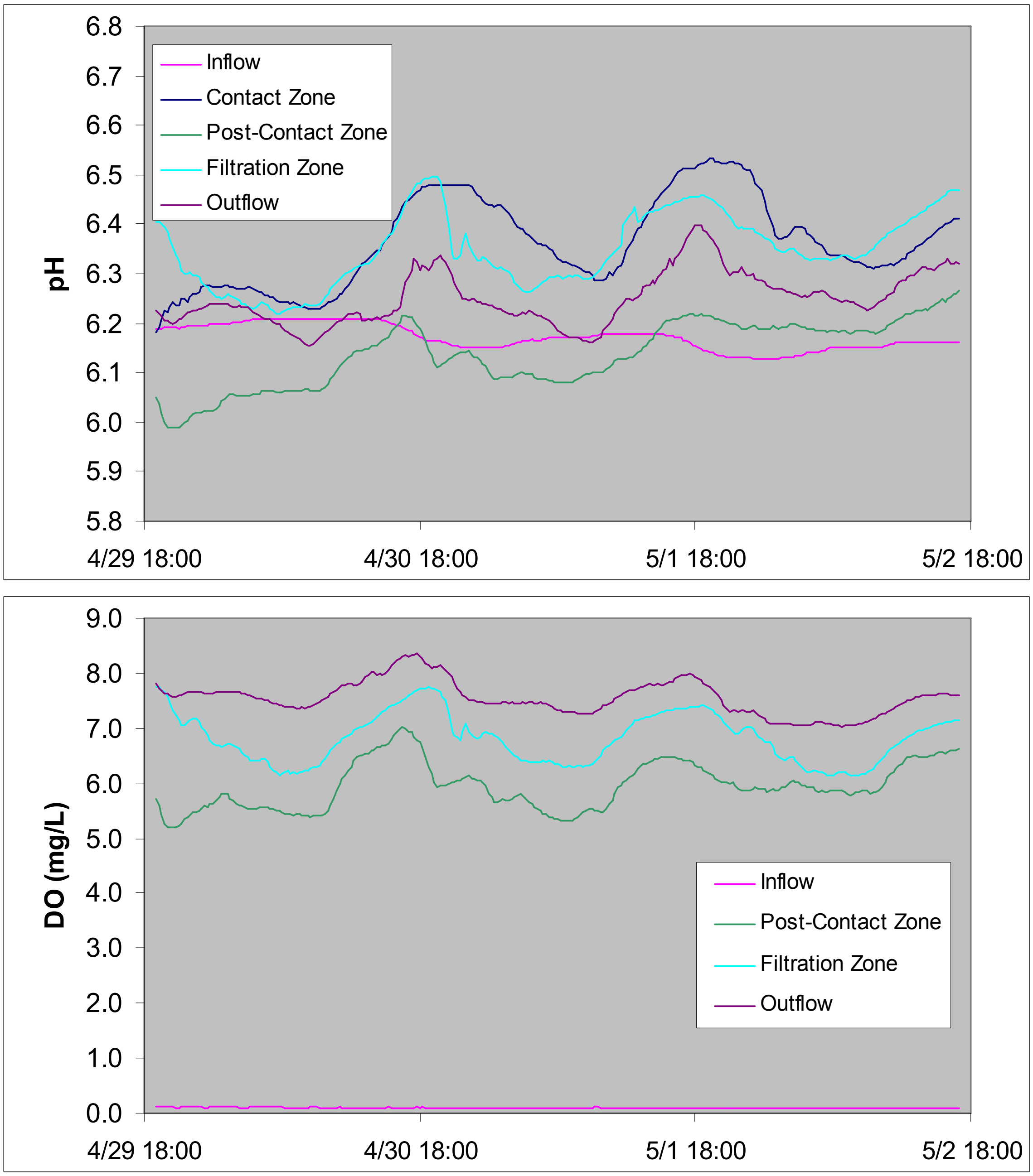



**Figure 21**. **Diel changes in pH (top) and dissolved oxygen (bottom) for several locations in the Nubbin Slough HWTT.**

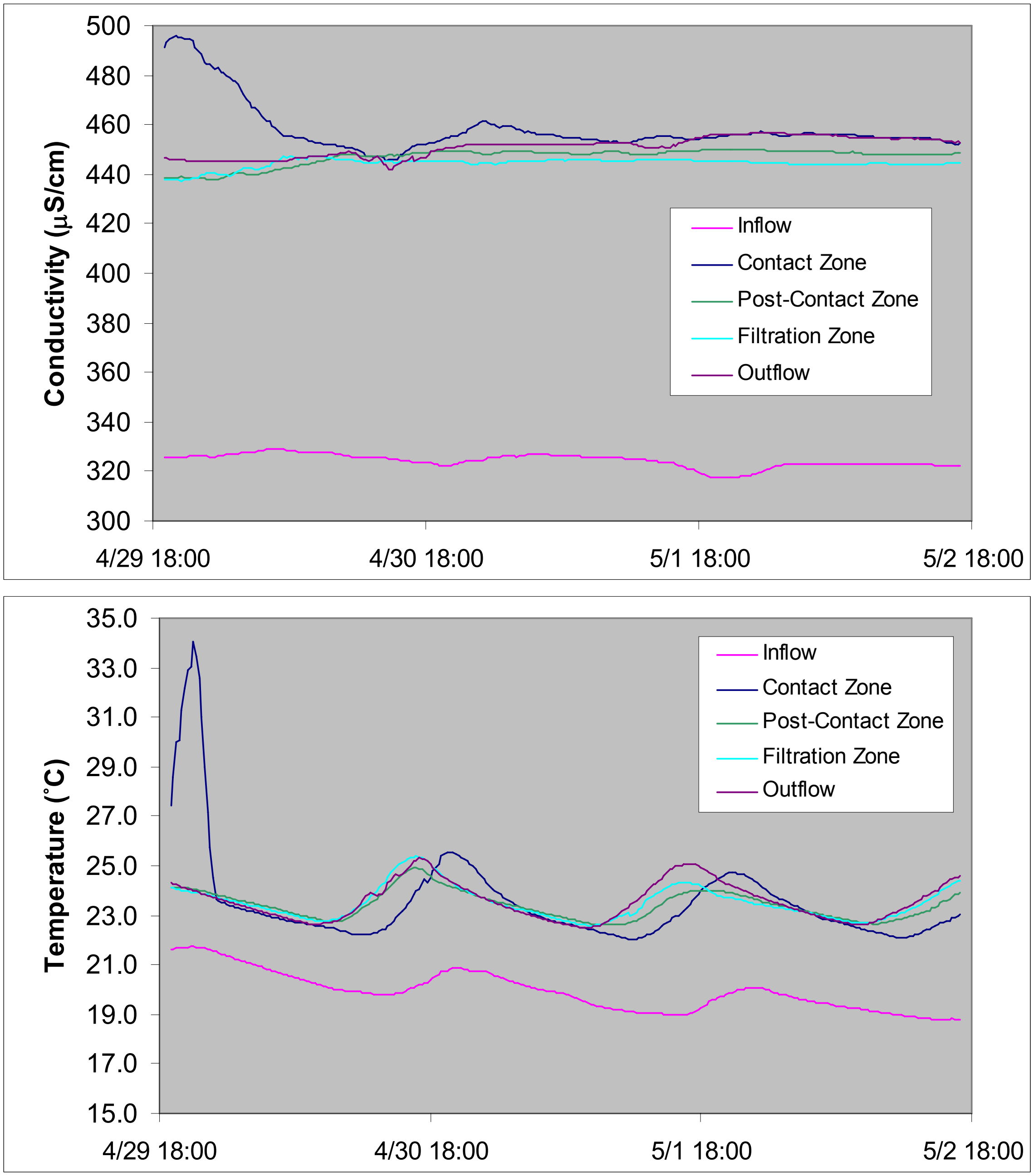



**Figure 22**. **Diel changes in conductivity (top) and temperature (bottom) for several locations in the Nubbin Slough HWTT.**

The results of the spatial monitoring event at the Nubbin Slough HWTT indicate that the system is providing efficient removal of nutrients, especially P, from the inflow stream. As noted in the Ideal system, most of the reduction in TP concentrations during initial operations occurred within a short distance of the treatment pond inflow, prior to the filtration (vegetated) zone. The vegetated filtration zone becomes a more critical component following the accumulation of greater amounts of floc in the contact zone, and the implementation of floc recirculation/reuse operations, which at the time of this report had not yet been initiated in this HWTT system.

### *Site 2: Ideal #2 Grove HWTT*

The Ideal #2 Grove site is situated within an irrigated citrus grove in western St. Lucie County. The drainage area is shown in Appendix A. The small canal to the north of the treatment system ("North Canal") serves as a collector ditch for grove runoff and groundwater. Due to fertilizer usage in the grove, the water in the collection canals is nutrient-enriched. A large regional canal (the "Rim Ditch") immediately west of the grove site serves as a pumped supply of water to the canal that runs along the south side ("South Canal") of the treatment facility. This relatively large canal carries Rim Ditch water from west to east, and then a lateral canal flows about ½-mile north to a grove irrigation pump, which feeds water into drip irrigation emitters throughout the grove.

We completed construction of the Ideal Grove HWTT during March. This system consists of a 0.7 acre pond, equipped with both shallow and deep zones, that is divided into equal size parallel flow paths with a flexible boom and barrier (Figure 23). This configuration facilitates the demonstration of different amendment types and doses, as well as various operational schemes (e.g. different hydraulic loading rates). The shallow zone was stocked with floating macrophytes, in this case water hyacinth (*Eichhornia crassipes*). The deep zones contained several species of submerged aquatic vegetation (SAV).

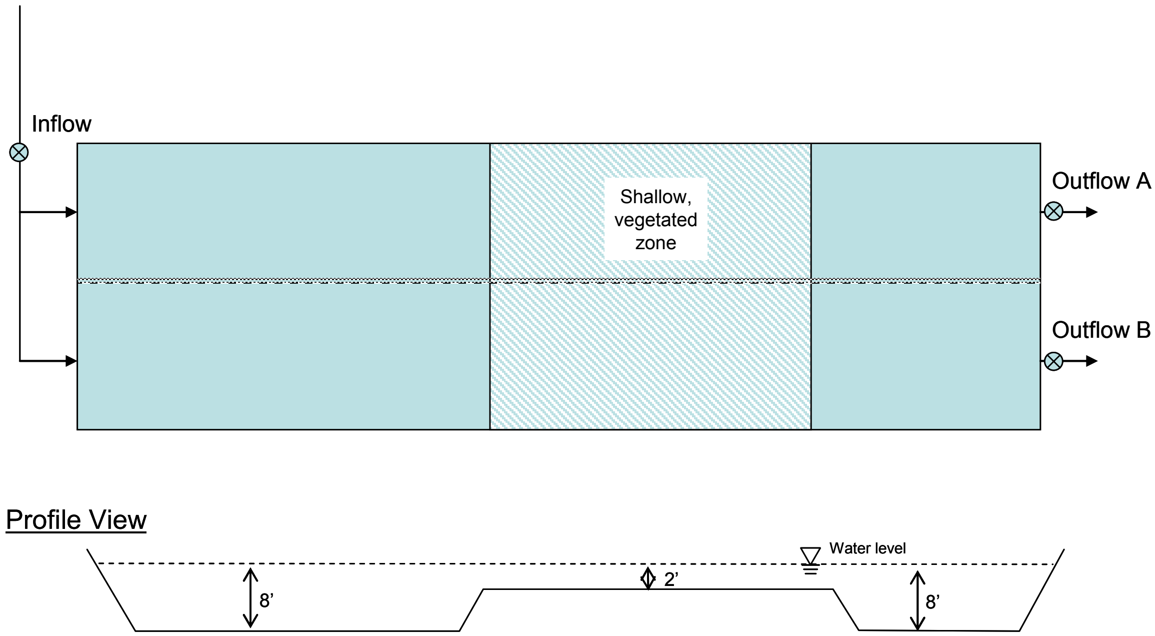



**Figure 23. Schematic of the Ideal Grove HWTT, depicting the A and B flow paths.**

During late March 2008, we began operation of the southern flow path (path B) (Figure 24). In early May, we initiated continuous amendment (alum at 20 - 25 mg Al/L) dosing in the northern flow path ("A"), a flow path that previously had been off-line. We also initiated intermittent dosing in the southern flow path ("B") during mid-May. This flow path previously had been dosed continuously. To compensate for the reduced addition frequency of chemicals, flow path B is equipped with a novel floc "recirculation" device, which helps maintain system performance while minimizing amendment use (Figure 25). Flow rates for the A and B flow paths during the optimization period are depicted in Figure 26. During this period, flow ranged from 0.15 to 0.27 cubic feet per second (cfs) (mean = 0.20) in flow path A and from 0.12 to 0.25 cfs (mean = 0.19) in flow path B. These mean flow rates provided an average hydraulic retention time (HRT) of 3.4 days.

Water samples were collected from the North and South Canals prior to the HWTT system startup. Following startup in late March, water samples were collected from the pond inflow (pumped from the North Canal), and from the outflows of the A and B flow paths, while South Canal sampling was terminated. Water quality monitoring results are summarized in Figure 27 through Figure 35.

**Figure 24. The outflow region of the Ideal Grove HWTT, with the northern (A) flow path on the right, and the southern (B) flow path on the left. The northern flow path receives continuous amendment additions, while the southern flow path receives amendments only intermittently.**

**Figure 25. Floc recirculation infrastructure on the southern (B) HWTT flow path.**

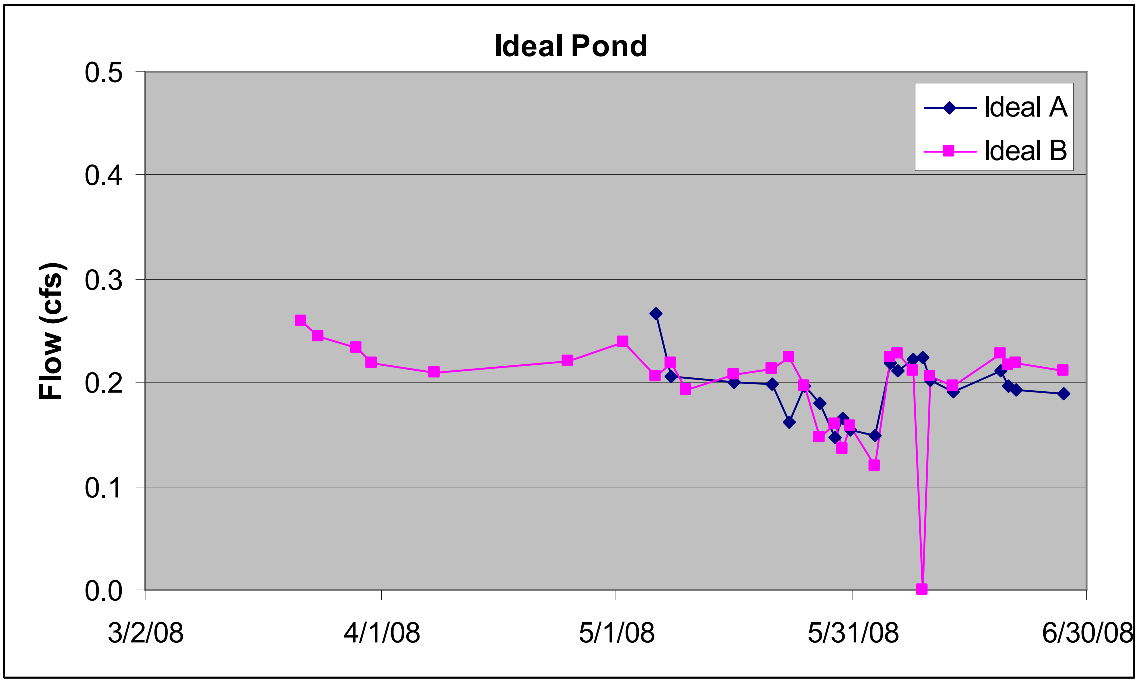



**Figure 26. Flows in the northern (A) and southern (B) flow paths of the Ideal Grove HWTT system.**

Inflow (North Canal) TP concentration for the Ideal Grove HWTT averaged 164 µg/L, with a median value of 137 µg/L, during the monitoring period beginning in mid-January 2008 (Figure 27). Inflow TP was highly variable during the monitoring period (min. = 47 µg/L, max. = 532 µg/L), with a downward trend during January – May interrupted by a sharp spike in early April, associated with a major rain event. During June the inflow TP concentration trended upward. Mean TP concentration in the outflow farm canal (South Canal) prior to the HWTT system startup was 72 µg/L (median = 73 µg/L). Post-startup monitoring showed an immediate reduction in outflow TP concentration through flow path B, with a similar reduction achieved in flow path A after it was brought on line in May (Figure 27). Mean and median TP concentrations in the path B outflow during the operational monitoring period (through early July) were 21 and 17 µg/L, respectively. During the months of May and June, with both flow paths A and B on line, mean outflow TP concentrations were 15 and 14 µg/L for A and B, respectively. Therefore, our initial optimization practice of intermittent chemical dosing (yielding a 33% reduction in amendment use) resulted in no discernable reduction in system P removal performance.

The speciation of P in the Ideal HWTT inflow stream from the North Canal was, on average, 30% soluble reactive P (SRP), 20% dissolved organic P (DOP) and 50% particulate P (PP). This contrasts sharply with the speciation of P in the Davie-Nubbin Slough and Mosquito Creek HWTT inflow streams, for which SRP and PP accounted for roughly 80% and <10% of total P. Speciation of P in the HWTT (treated) outflow streams was 18% SRP, 39% DOP and 43% PP in flow path A (continuous amendment dosing) outflow and 12% SRP, 36% DOP and 52% PP in flow path B (intermittent dosing) outflow. During the operational monitoring period, mean SRP concentration was 58 μg/L in the HWTT inflow stream, compared with 4 μg/L and 3μg/L in the path A and path B outflow streams (Figure 28). Mean DOP concentration during the same period was 31 μg/L for the inflow, and 9 μg/L and 8 μg/L for the A and B outflows (Figure 29), while mean PP concentration was 91 μg/L for the inflow, and 12 μg/L and 13 μg/L for the A and B outflows (Figure 30). For the months of May and June, mean outflow concentrations of SRP, DOP and PP were 2, 8 and 7 μg/L for flow path A and 1, 6 and 7 μg/L for flow path B. It should be noted that these values add up to higher values than the mean TP concentrations reported above, due to the unequal number of samples collected for P speciation vs. TP analyses.

Alkalinity of the inflow stream showed a slightly decreasing trend during the monitoring period, as well as a relatively high degree of shorter-term variability (Figure 31). Alkalinity of the outflow streams for paths A and B was also quite variable, but generally lower than for the inflow (from the North Canal) and the untreated system outflow (South Canal) monitored during the pre-operational period. Mean values for alkalinity in the inflow, outflow A and outflow B streams were 147, 64 and 116 mg/L (as $CaCO_3$), respectively.

Color in the Ideal HWTT system was reduced from an average of 195 CPU in the inflow stream to 76 CPU in outflow A and 67 CPU in outflow B (Figure 32). Color levels in the outflows were higher and more variable during the first few weeks of the HWTT operational phase, then decreased to levels around 50 CPU from mid-May through the end of the monitoring period. Turbidity in the inflow stream was highly variable, averaging 6.7 NTU, but exceeding 25 NTU during two sampling events (Figure 33). Turbidity levels in the South Canal (pre-operational) and outflows of flow paths A and B were consistently less than 5 NTU, averaging 1.2 and 1.4 NTU at outflows A and B during the HWTT operational period.

Mean inflow pH was 7.5, and ranged from 6.5 to 8.3, during the monitoring period (Figure 34). Outflow pH was slightly lower than inflow pH, averaging 6.8 for both flow paths A and B during the HWTT operational period. Conductivity levels were slightly higher at the outflows of flow paths A and B (mean = 1556 and 1543 µS/cm, respectively) than at the HWTT system inflow (mean = 1469 µS/cm). Conductivity displayed a distinct temporal trend at system inflow and outflow sampling locations (Figure 35), presumably in response to local or regional rainfall patterns.

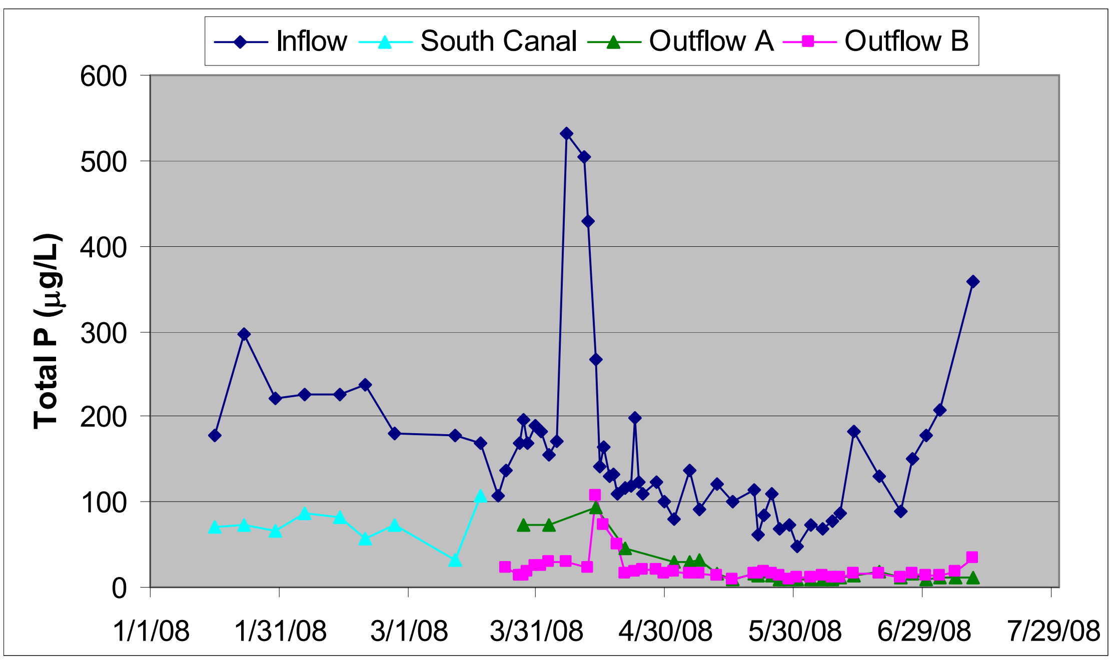



**Figure 27. Total P (TP) concentration in the inflow and outflow (South Canal – untreated; flow paths A and B - treated) streams at the Ideal #2 Grove HWTT. Flow path A received continuous chemical dosing, while flow path B was dosed intermittently.**

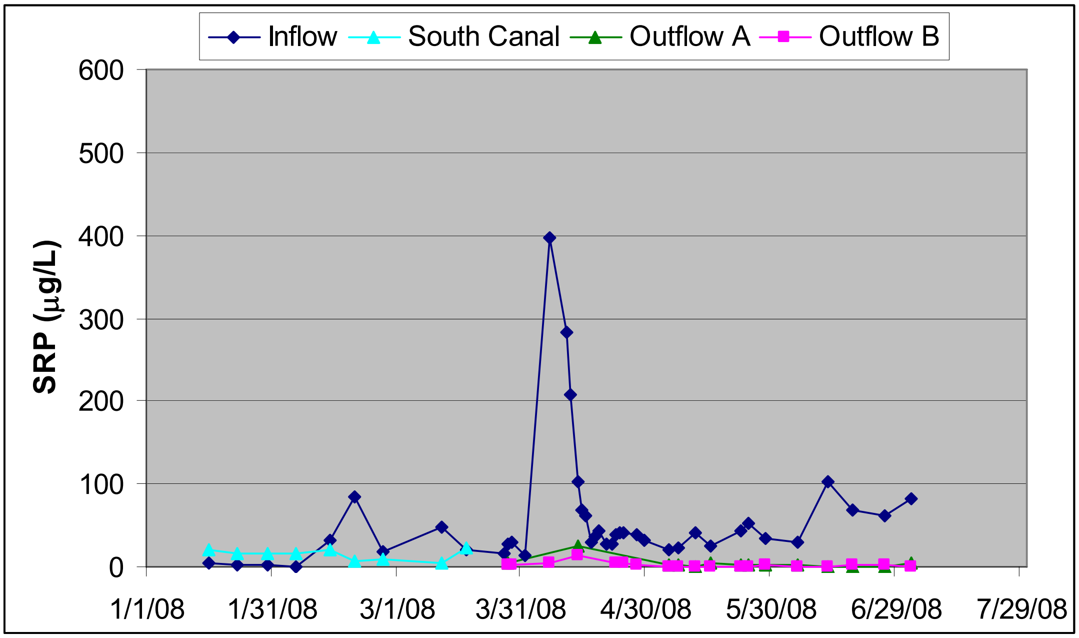



**Figure 28 Soluble reactive P (SRP) concentration in the inflow and outflow (South Canal – untreated; flow paths A and B - treated) streams at the Ideal #2 Grove HWTT. Flow path A received continuous chemical dosing, while flow path B was dosed intermittently.**

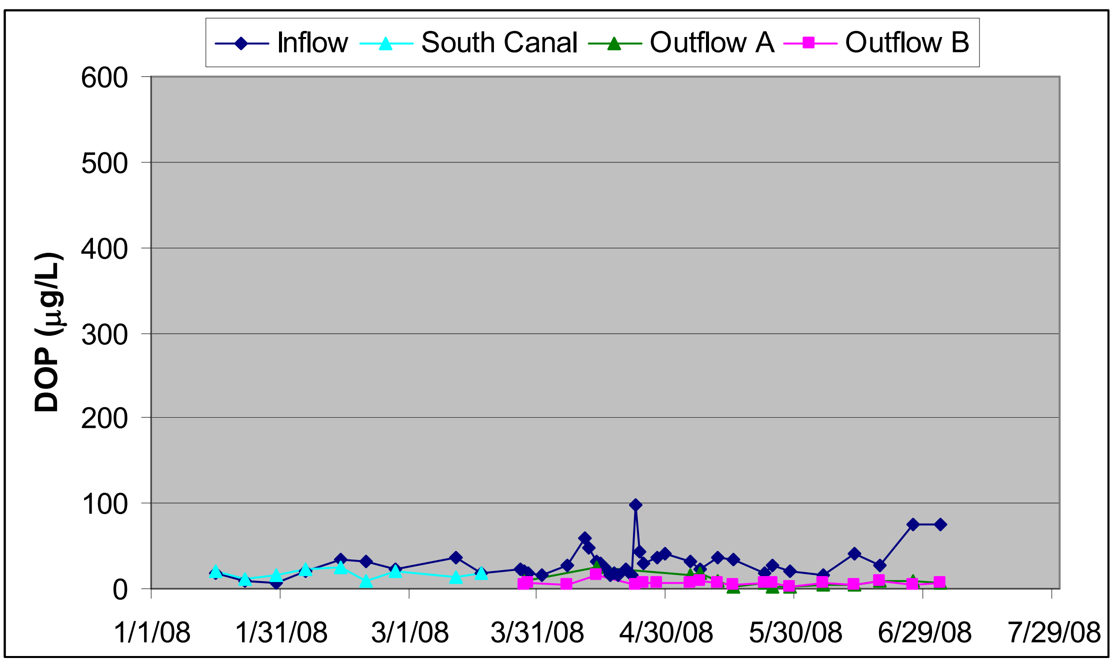



**Figure 29. Dissolved organic P (DOP) concentration in the inflow and outflow (South Canal – untreated; flow paths A and B - treated) streams at the Ideal #2 Grove HWTT. Flow path A received continuous chemical dosing, while flow path B was dosed intermittently.**

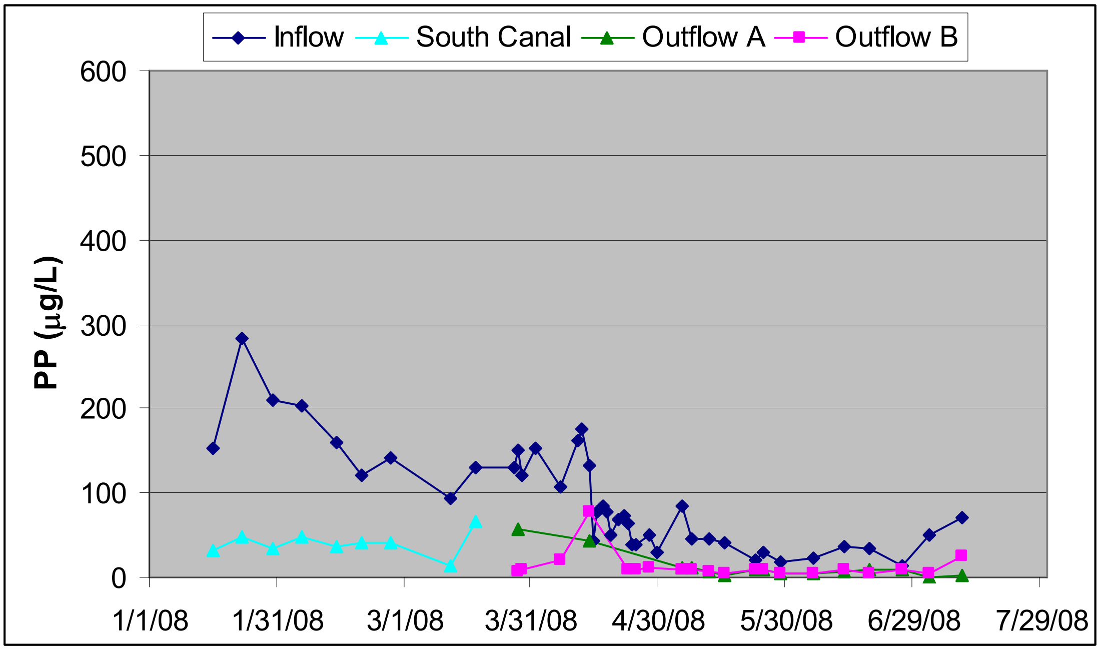



**Figure 30. Particulate P (PP) concentration in the inflow and outflow (South Canal – untreated; flow paths A and B - treated) streams at the Ideal #2 Grove HWTT. Flow path A received continuous chemical dosing, while flow path B was dosed intermittently.**

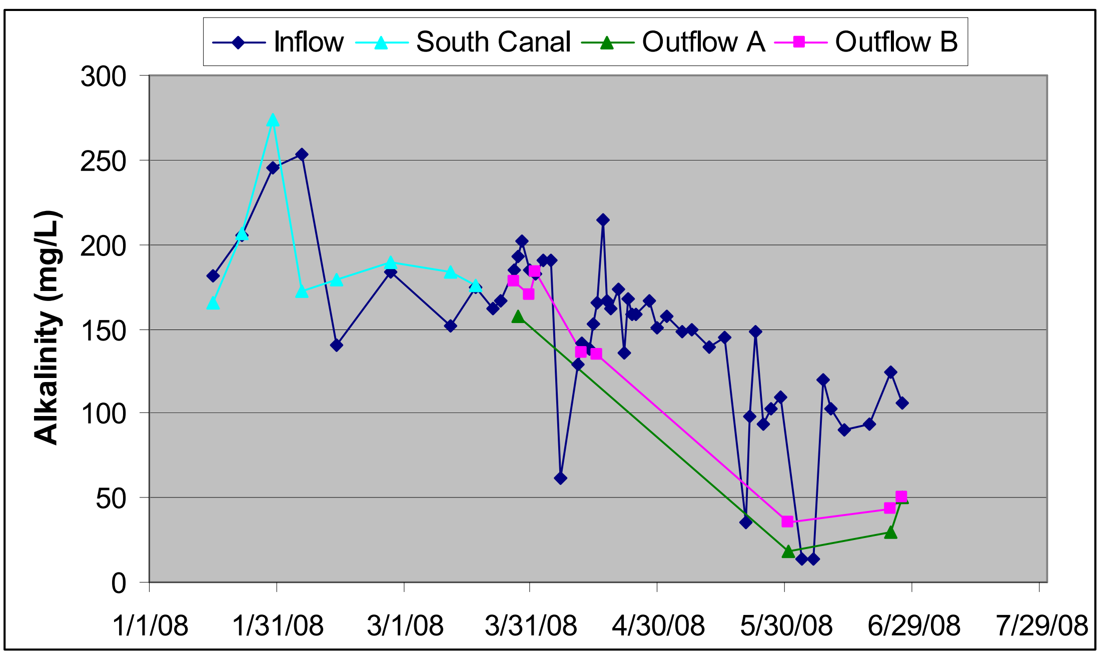



**Figure 31. Alkalinity in the inflow and outflow (South Canal – untreated; flow paths A and B - treated) streams at the Ideal #2 Grove HWTT. Flow path A received continuous chemical dosing, while flow path B was dosed intermittently.**

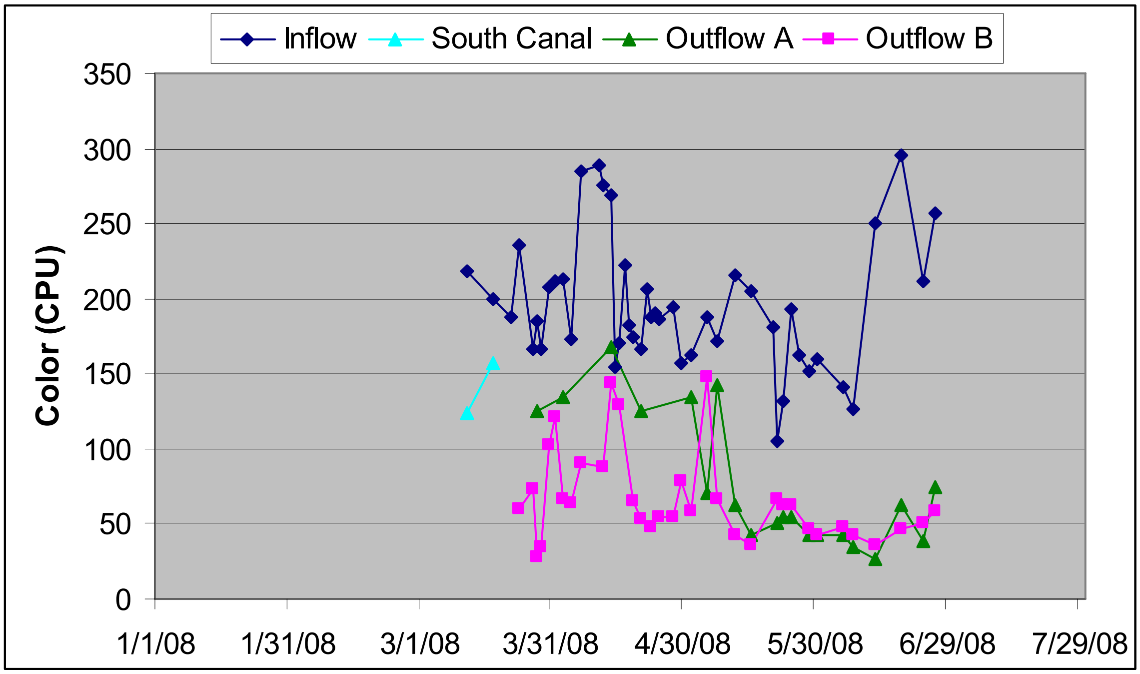



**Figure 32. Color in the inflow and outflow (South Canal – untreated; flow paths A and B - treated) streams at the Ideal #2 Grove HWTT. Flow path A received continuous chemical dosing, while flow path B was dosed intermittently.**

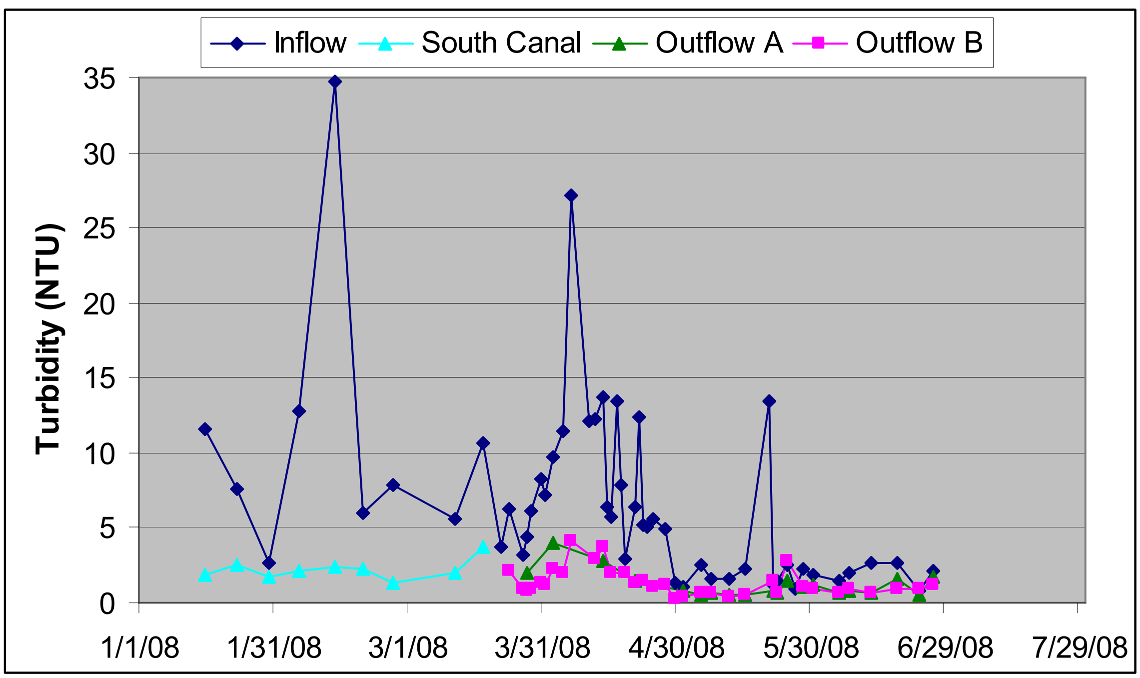



**Figure 33. Turbidity in the inflow and outflow (South Canal – untreated; flow paths A and B - treated) streams at the Ideal #2 Grove HWTT. Flow path A received continuous chemical dosing, while flow path B was dosed intermittently.**

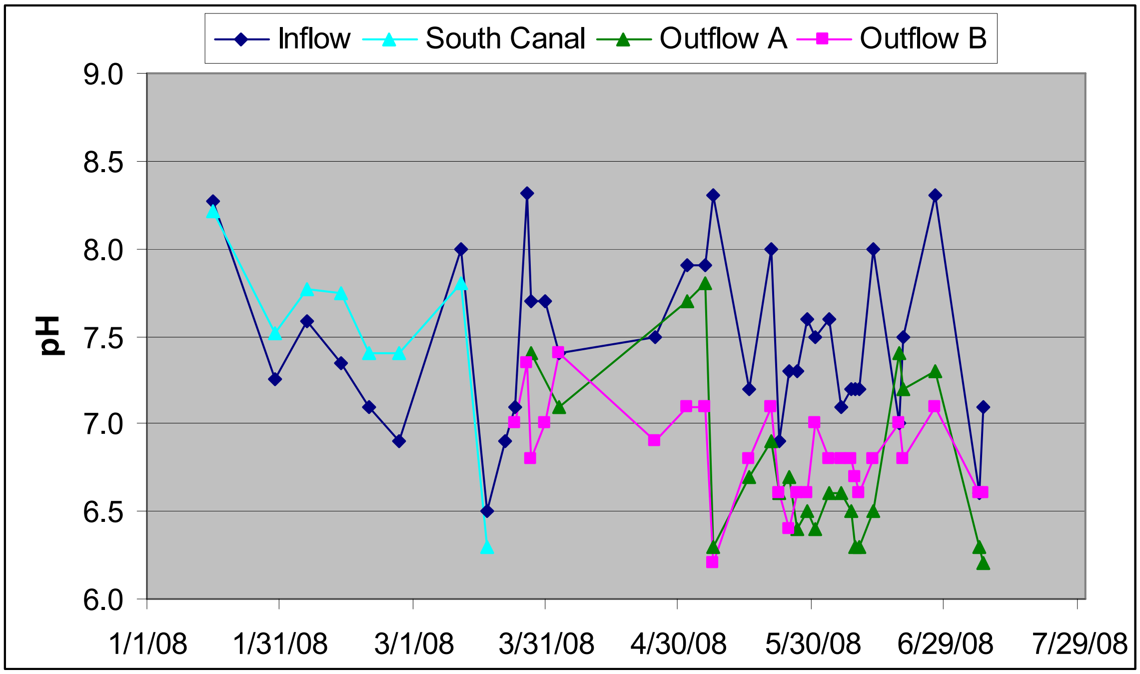



**Figure 34. pH in the inflow and outflow (South Canal – untreated; flow paths A and B - treated) streams at the Ideal #2 Grove HWTT. Flow path A received continuous chemical dosing, while flow path B was dosed intermittently.**

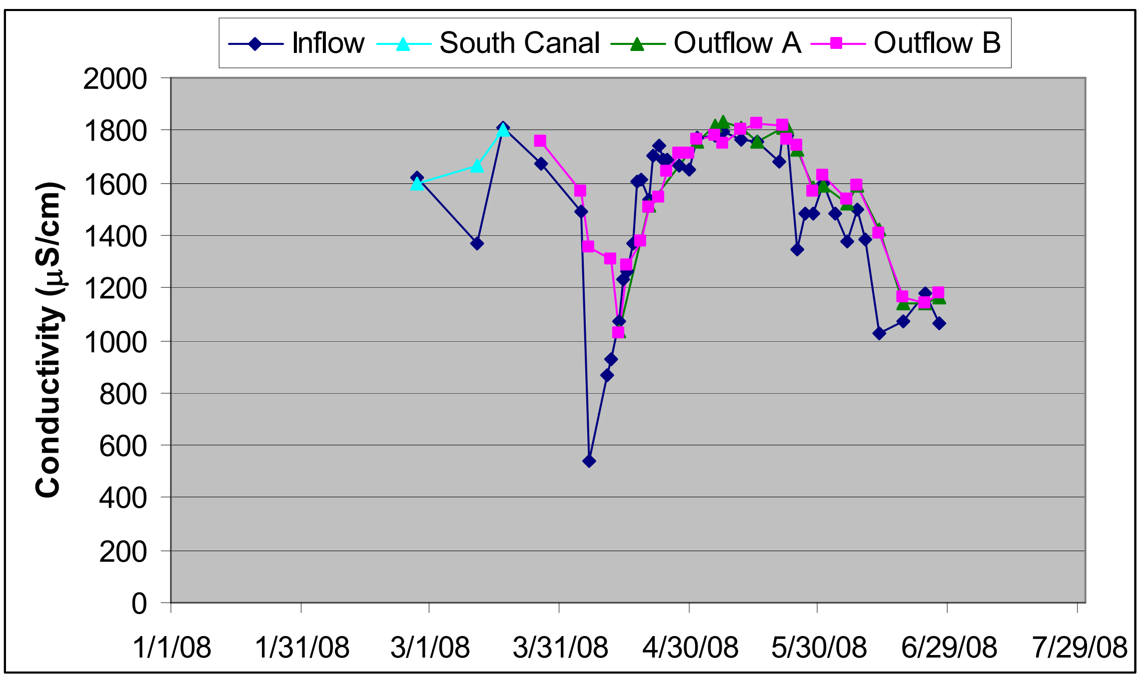



**Figure 35. Conductivity in the inflow and outflow (South Canal – untreated; flow paths A and B - treated) streams at the Ideal #2 Grove HWTT. Flow path A received continuous chemical dosing, while flow path B was dosed intermittently.**

**Temporal Variations in Water Quality**

Late in March, we performed a diel characterization of water quality in the southern ("B") and northern ("A") flow paths. All of our previous sampling efforts had been performed as "grab samples" collected during daytime. Despite constant, pumped flows to the HWTT, we believed it important to characterize temporal changes in the chemistry of the system inflow and outflow waters, to determine whether grab samples are providing an accurate characterization of performance. Additionally, diel chemistry changes in outflow waters can provide insight into system nutrient removal mechanisms.

At the time of this assessment, the southern flow path was receiving a continuous amendment dose, whereas no amendments were being added to the northern flow path. We deployed continuous recording datasondes in the inflow (North) canal, and at the outflows from the southern and northern flow paths. We also deployed a datasonde within the filtration zone (shallow, with floating vegetation) of the southern flow path (Figure 36). These instruments provided a continuous record of dissolved oxygen concentrations, specific conductance, pH and temperature. Additionally, beginning at noon on March 28, we collected water samples approximately every six hours, over a 30-hour period, from the inflow and outflow of the southern (treated) flow path. The samples were analyzed for total P, total soluble P (TSP), soluble reactive P (SRP), color and turbidity. One sample also was collected at the northern (untreated) flow path at the beginning of the monitoring period for characterization of these same parameters.

The inflow (= north canal) TP concentration averaged 179 μg/L for the 30-hour monitoring period. The minimum TP was 160 μg/L and the maximum was 215 μg/L (Figure 37). Soluble reactive P levels for the inflow were more consistent, averaging 28 μg/L and ranging from 25 to 30 μg/L. Inflow dissolved organic P (DOP) levels also were quite consistent, ranging from 16 to 23 μg/L with a mean of 19 μg/L. The observed temporal variations in TP levels were caused primarily by differences in particulate matter in the inflow: particulate P (PP) levels ranged from 112 to 167 μg/L, and averaged 132 μg/L (Figure 37).

The treated outflow TP concentrations were low and consistent over the 30-hour monitoring period, averaging 16 μg/L, with a maximum of 20 μg/L and minimum of 11 μg/L (Figure 37). On average, PP comprised the dominant fraction (50%) of the outflow TP, followed by DOP (38%) and SRP (12%). In general, diel changes in outflow P species were less pronounced than for inflow P species (Figure 37).

**Figure 36**. **Locations of datasonde deployment at the Ideal Grove HWTT. Clockwise, from top left: the inflow (north) canal; the southern flow path filtration zone; the southern flow path outflow culvert; and, the northern flow path outflow culvert.**

The inflow water pH exhibited a diel response, with lowest pH values observed at 06:00 (7.4) and highest values at 18:00 (~ 8.1). Dissolved oxygen and temperature levels followed a similar pattern, with minimum and maximum DO values of 4.6 and 12 .3 mg/L, and temperatures of 21.3 and 25.8 °C (Figure 38). Color of the inflow waters ranged from 159 to 198 CPU, and turbidity from 3.3 to 7.2 NTU (Figure 38). Specific conductance varied temporally, but not in a consistent manner, averaging 1.69 mS/cm.

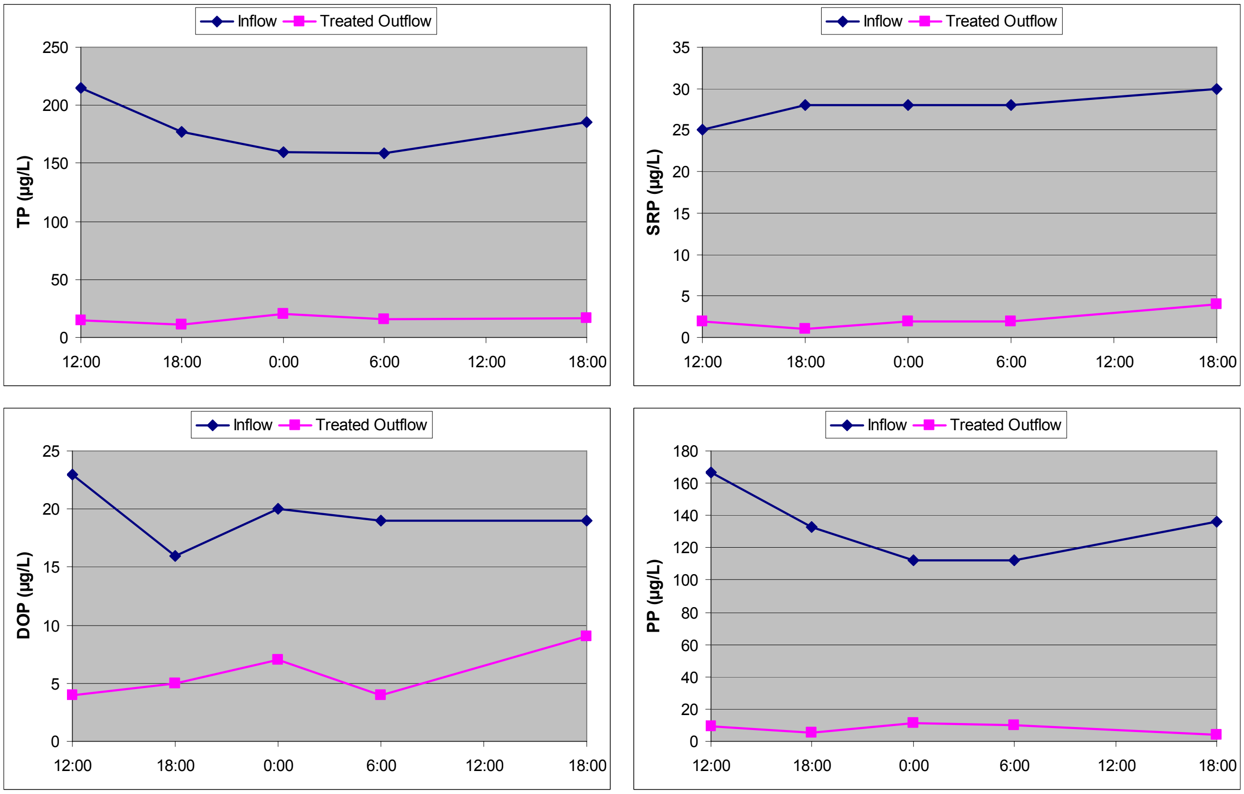



**Figure 37. Inflow and outflow P species for the Ideal Grove HWTT (southern flow path) over a 30 hour monitoring period in late March 2008.**

The HWTT system dampened the diel variations in most chemical and physical parameters. Ranges in southern flow path outflow pH (6.58 – 6.71), DO (6.92 – 7.38) and temperature (21.3 – 22.8 °C) were narrower relative to inflow values. Passage of water through the HWTT resulted in marked reductions in color (outflow range: 28 – 36 CPU) and turbidity (outflow range: 0.7 – 1.1 NTU) (Figure 38).

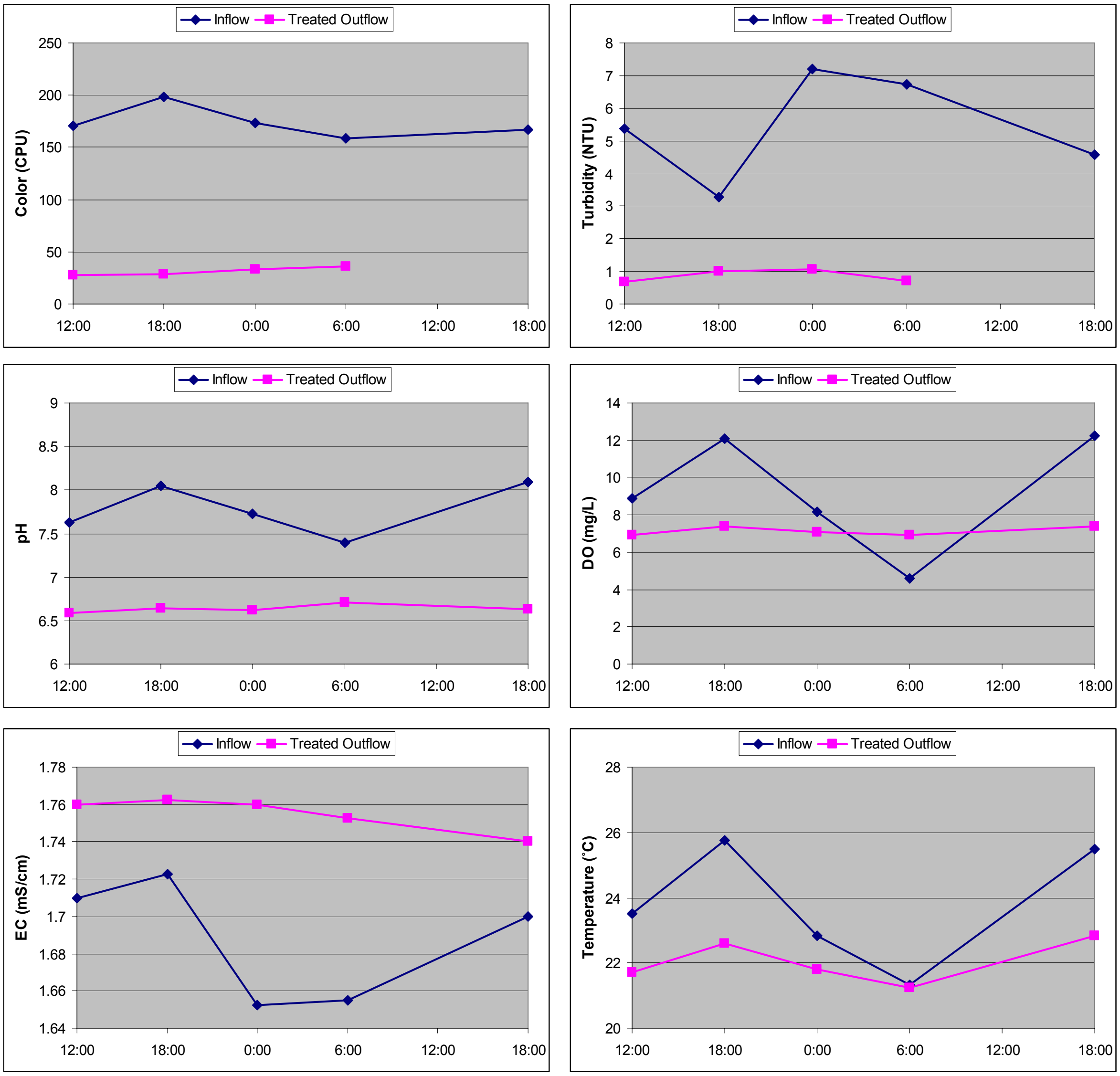



**Figure 38**. **Inflow and outflow chemical and physical water quality characteristics for the Ideal Grove HWTT (southern flow path) over a 30 hour monitoring period in late March 2008.**

While the water samples were collected during one diel cycle (approximately 30 hours), the datasondes were deployed for three diel cycles (~ 72 hours) to characterize longer-term profiles in selected parameters. These instruments were situated at the inflow canal, the outflow of the southern (treated) flow path, and the outflow of the northern (untreated) flow path (Figure 36). One additional datasonde was deployed in the shallow, vegetated filtration zone of the southern flow path, approximately mid-way down the length of the treatment system.

During this 72-hour period, ranges in physical parameters for inflow waters were as follows: pH (7.35 – 8.24), DO (3.2 - 12.6 mg/L), specific conductance (1.63 – 1.78 mS/cm) and temperature (20.6 – 28.7 °C) (Figure 39). The mid-region, vegetated filtration zone of the HWTT southern flow path exhibited the following ranges: pH (6.35 – 6.61), DO (5.63 – 7.34 mg/L), specific conductance (1.66 – 1.75 mS/cm) and temperature (21.3 – 24.6 °C). Ranges for these constituents in the outflow of the treated, southern flow path were: pH (6.35 – 6.52), DO (6.41 – 7.43 mg/L), specific conductance (1.69 – 1.77 mS/cm) and temperature (21.2 – 23.9 °C) (Figure 39).

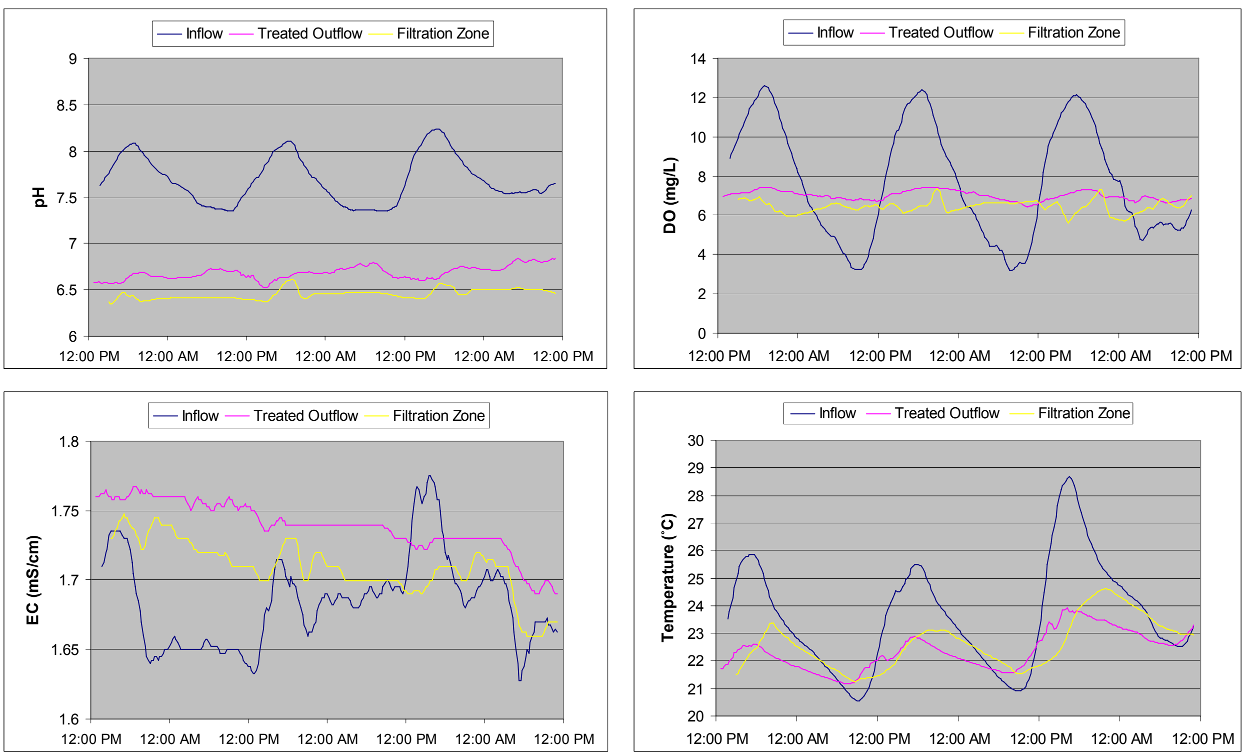



**Figure 39. Chemical and physical water quality characteristics for the Ideal Grove HWTT (southern flow path) over a 72-hour monitoring period in late March. Sample locations are depicted in Figure 14.**

The northern flow path, which during the diel assessment was serving as an untreated "control" (wetland treatment without amendment additions), provided outflow TP, SRP, DOP and PP concentrations (based on one sample, at beginning of diel study) of 72, 5, 10 and 58 µg/L, respectively. Hence, the northern (wetland only) flow path was providing approximately 60% TP removal, while the southern HWTT system was providing 91% TP removal during the diel study. Outflow color levels for the northern flow path were considerably higher than those for the southern flow path (125 vs. 32 CPU), whereas turbidity levels were comparable (2.0 vs. 0.9 NTU). Datasonde monitoring of the northern flow path outflow revealed the following water quality characteristics during the 72-hour study: pH (7.28 – 7.72), DO (5.93 – 8.78 mg/L), specific conductance (1.66 – 1.75 mS/cm) and temperature (21.2 – 24.5 °C) (Figure 40).

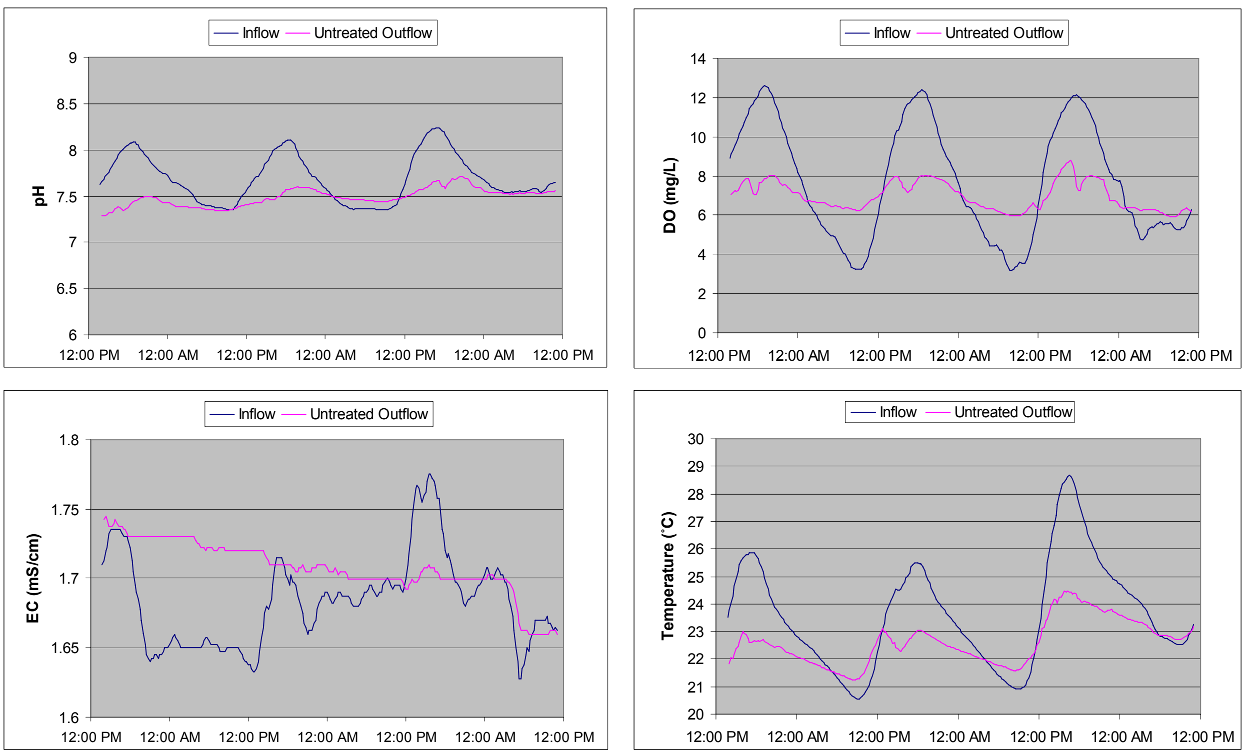



**Figure 40. Chemical and physical water quality characteristics for the Ideal Grove northern flow path (wetland only, with no amendment additions) over a 72-hour monitoring period in late March. Sample locations are depicted in Figure 14.**

### *Spatial Water Quality Characteristics*

Following the temporal assessment described above, we modified the operational regimes for the flow paths. During May, this entailed continuous dosing for flow path A, and only intermittent dosing for flow path B. On May 31, 2008 we evaluated spatial patterns in water chemistry and physicochemical properties of both flow paths. Water samples were collected at multiple sites along single, mid-channel, longitudinal transects in flow paths A and B (north and south channels, respectively), spanning the length of the initial (contact) zone of the treatment pond.

Water samples were collected near the top (2 ft. depth) and bottom (5 ft. depth) of the water column, at sites located 30, 60, 90 and 120 ft. from the inflow manifolds of the respective flow paths. Note that all of these sites are within the inflow region "contact zone". Additional samples were taken at the system inflow and A and B outflow structures. Color, turbidity, pH and temperature were measured on all samples. Samples collected at the inflow, outflows and 120 ft. distance (surface only) were also analyzed for TP, TKN, $NO_3^- + NO_2^-$ and total ammonia.

Results of this monitoring event indicate that the majority of total P removal during the initial operations of this treatment system occurred within the contact zone, prior to the water hyacinth (filtration) and secondary deep-water zones. Total P concentration was reduced from 47 µg/L in the inflow stream to 9 and 18 µg/L at the back end of the contact zone (120-foot distance from inflow) in flow paths A and B, respectively (Figure 41). Total P concentration at both A and B outflows was 9 µg/L, suggesting that additional removal of low-level P was occurring in the water hyacinth zone of flow path B. It should be noted that reduction of total P by the HWTT was probably underestimated in this short-term assessment, since the inflow concentration of TP during several previous sampling events was substantially higher than the 47 µg/L measured on the day of this monitoring event, including the TP value (73 µg/L) measured two days prior.

A site-dependent, but relatively strong, relationship between color and TP concentration has been inferred by water chemistry data collected previously at the HWTT field sites. Based on this relationship, the color concentration data collected at all Ideal transect stations (Figure 42) suggest that significant P removal occurred within the first 30 feet of the A and B flow paths. Color data also reflect the increased reduction of P concentration in the contact zone of flow path A relative to flow path B. Increased turbidity levels were observed near the bottom at the 30-foot distance of both flow paths, suggesting the presence of suspended floc at the front end of the contact zone (Figure 43). Water column pH decreased downstream from the inflow, due to amendment addition and, overall, was slightly higher in flow path B (Figure 44). Sample depth had little effect on color or pH; however, temperature decreased with sample depth, as expected for the summer months (Figure 45).

Total Kjeldahl N (TKN) exhibited a moderate concentration reduction, occurring primarily within the contact zone, with a nearly identical reduction in concentration (40%) in both the A and B flow paths (Figure 46). Nitrate + nitrite and total ammonia concentrations also decreased between the inflow and outflow of both flow paths (Figure 47 and Figure 48). These inorganic forms of N represented only a small fraction of total N in the inflow and outflow, meaning that the bulk of the N in the Ideal HWTT system was present in organic compounds.

The results of this spatial monitoring event indicate that the Ideal HWTT system provided efficient removal of nutrients, especially P, from the inflow stream pumped from the adjacent North Canal. Much of the reduction in TP concentration observed during this sampling event occurred near the front end of the system (deep, open water cell), with additional P reduction occurring in the shallower water hyacinth zone and secondary deep-water cell. However, HWTT mesocosm-scale data has shown that the vegetated zone provides a significant amount of supplemental P removal, via accumulation of floc in the root zone (filtration) and inhibition of phytoplankton (particulate P) growth in the water column. As this field study was conducted early in the operational period, the accumulation of floc was still well below the root zone of the shallow vegetated zone (unlike the mesocosms), thus limiting the amount of interaction between plant roots and floc. We anticipate that, later in the operational period, the vegetated zone (water hyacinths) will serve as a highly efficient filter for both particulate and dissolved P.

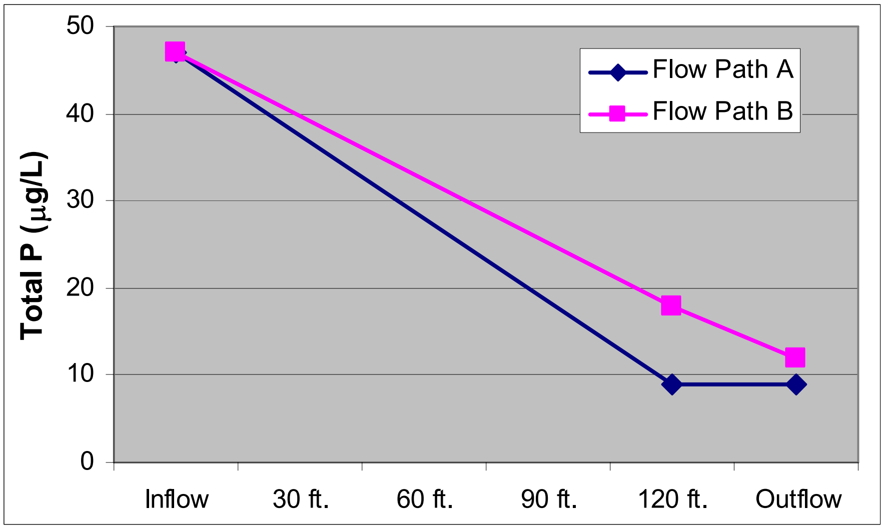



**Figure 41. Total P concentration at surface depth (2-feet) along the A and B flow paths in the Ideal Grove HWTT system. Samples were collected at the system inflow, outflow and at a distance of 120 feet from the inflow.**

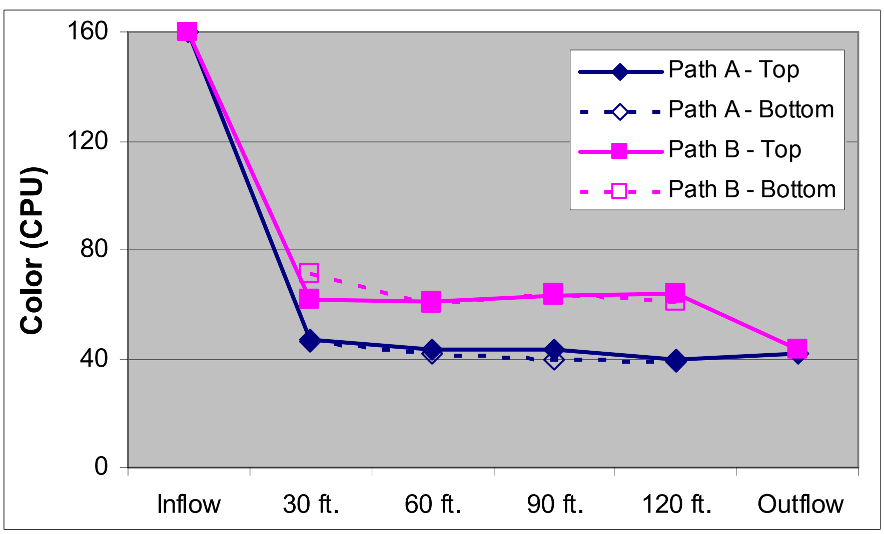



**Figure 42. Color concentration at surface (2-feet) and bottom depth (5-feet) along the A and B flow paths in the Ideal Grove HWTT system. Samples were collected at the system inflow, outflow and at distances of 30, 60, 90 and 120 feet from the inflow.**

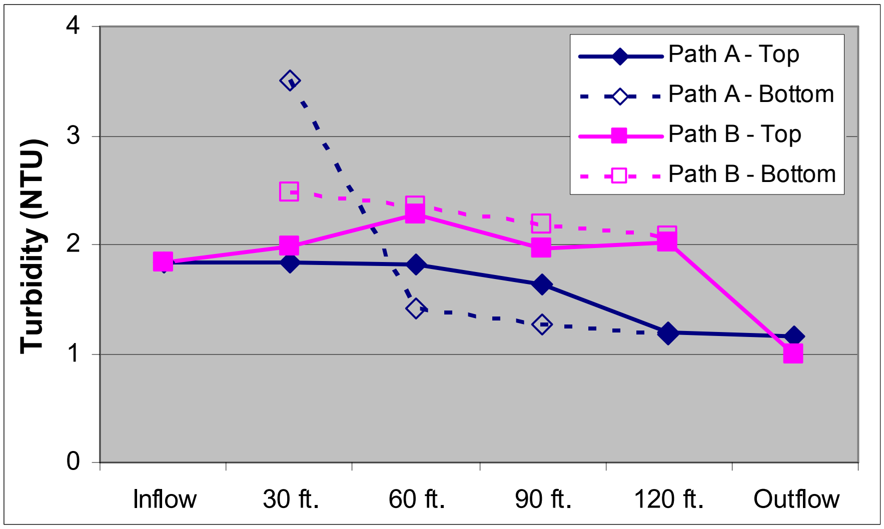



**Figure 43**. **Turbidity measured at surface (2-feet) and bottom depth (5-feet) along the A and B flow paths in the Ideal Grove HWTT system. Samples were collected at the system inflow, outflow and at distances of 30, 60, 90 and 120 feet from the inflow.**

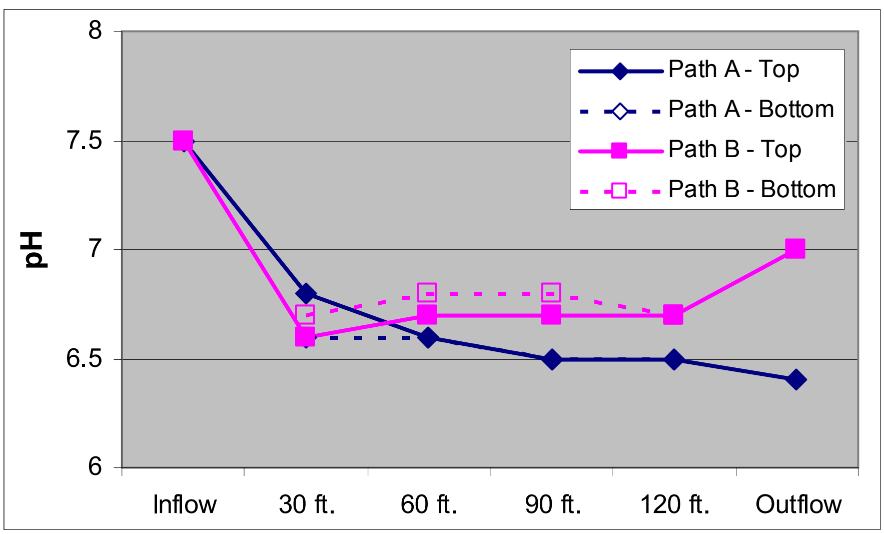



**Figure 44**. **pH measured at surface (2-feet) and bottom depth (5-feet) along the A and B flow paths in the Ideal Grove HWTT system. Samples were collected at the system inflow, outflow and at distances of 30, 60, 90 and 120 feet from the inflow.**

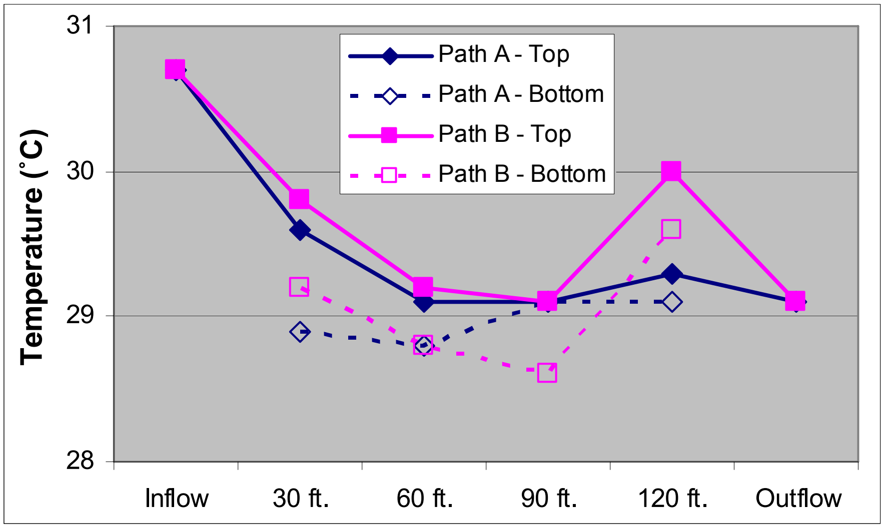



**Figure 45. Water temperature measured at surface (2-feet) and bottom depth (5-feet) along the A and B flow paths in the Ideal Grove HWTT system. Measurements were taken at the system inflow, outflow and at distances of 30, 60, 90 and 120 feet from the inflow.**

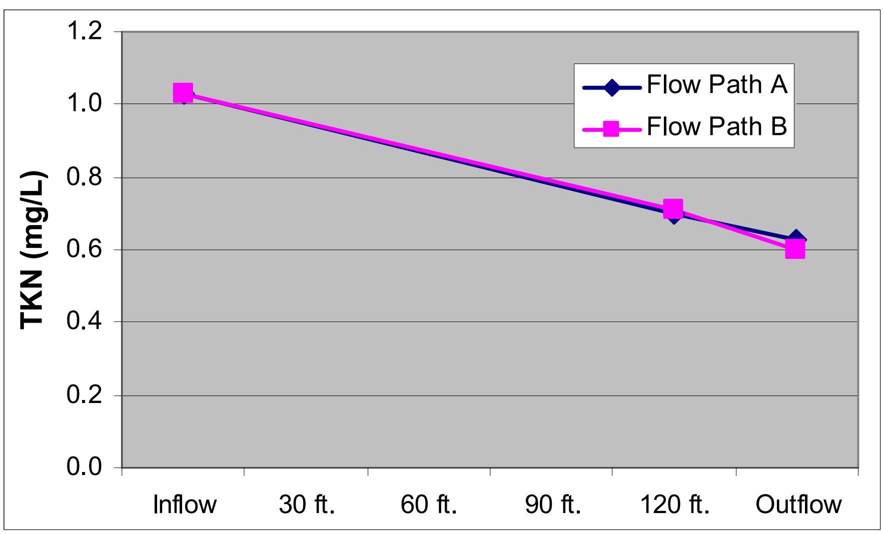



**Figure 46. TKN concentration at surface (2-feet) and bottom depth (5-feet) along the A and B flow paths in the Ideal Grove HWTT system. Samples were collected at the system inflow, outflow and at distances of 30, 60, 90 and 120 feet from the inflow.**

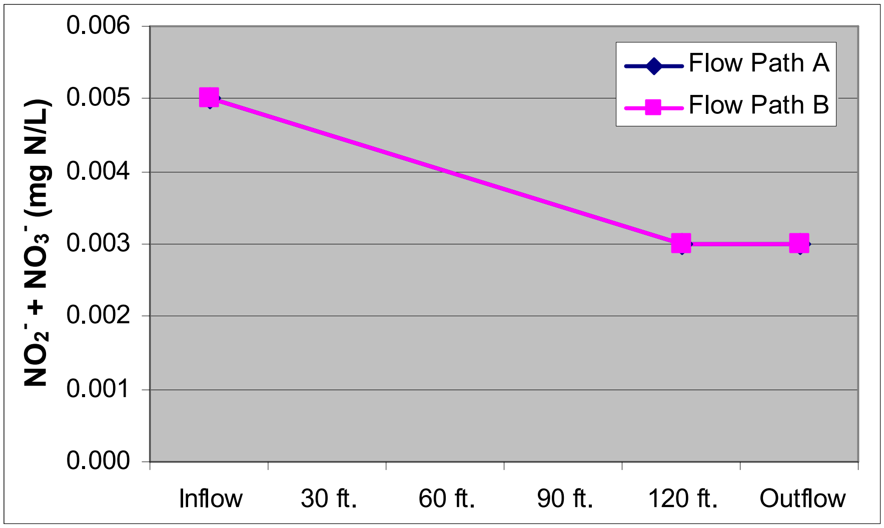



**Figure 47**. **Nitrate + nitrite concentration at surface (2-feet) and bottom depth (5-feet) along the A and B flow paths in the Ideal Grove HWTT system. Samples were collected at the system inflow, outflow and at distances of 30, 60, 90 and 120 feet from the inflow.**

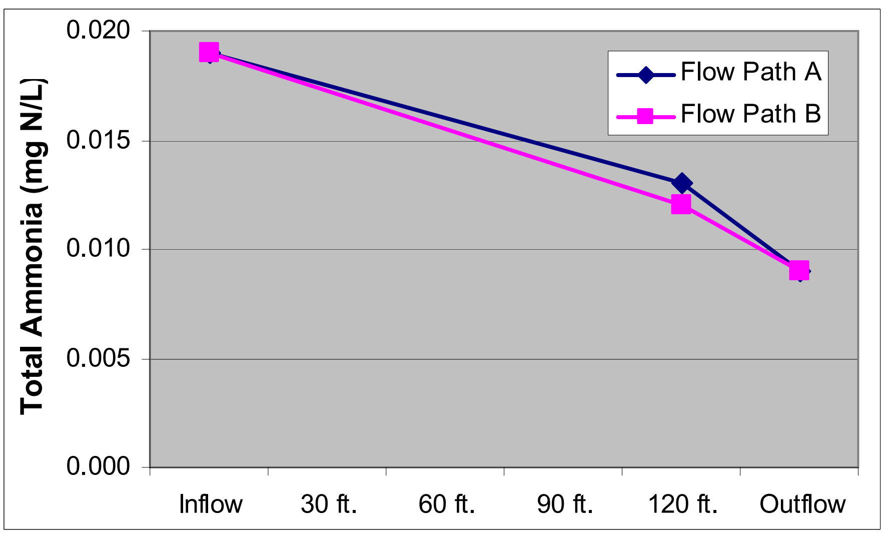



**Figure 48**. **Total ammonia concentration at surface (2-feet) and bottom depth (5-feet) along the A and B flow paths in the Ideal Grove HWTT system. Samples were collected at the system inflow, outflow and at distances of 30, 60, 90 and 120 feet from the inflow.**

### *Site 3: Mosquito Creek Tributary Treatment HWTT*

We constructed a Tributary Treatment HWTT system on Larson Dairy property, adjacent to Mosquito Creek. The drainage area is shown in Appendix A. The Tributary Treatment system consists of one large HWTT (1.3 acre) and one small (0.44 acre) HWTT (Figure 49).

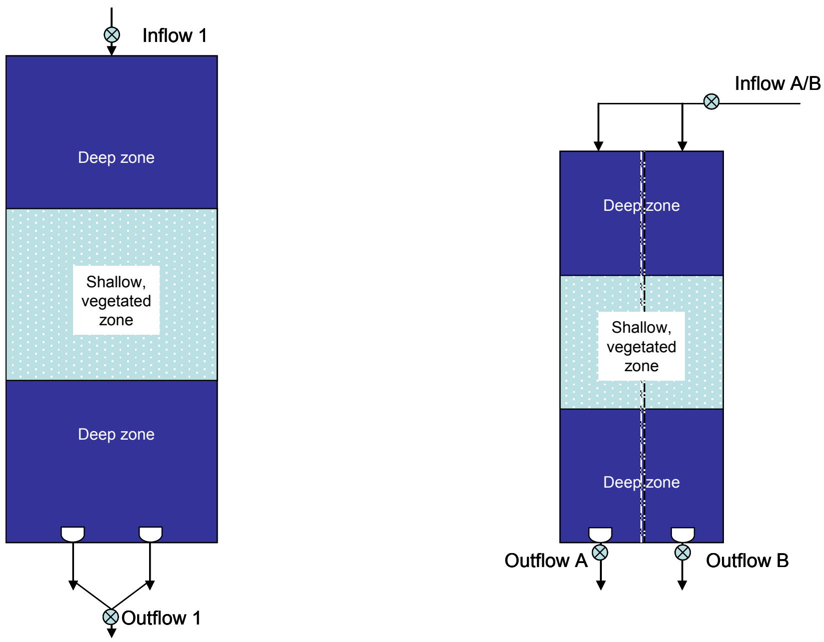



**Figure 49. Schematic of the large and small HWTT systems at Mosquito Creek.**

The 0.44 acre HWTT was brought on line during March 2008, and water chemistry was monitored in this system on a regular basis during the optimization period. Optimization and monitoring activities were suspended for the month of May, during which time the flows in Mosquito Creek were insufficient for operation of the HWTT system. When operation was resumed in June, the flow in the small pond was divided into two parallel flow trains (using a flexible boom and barrier), denoted as "small pond east" and "small pond west". System flow rates for these various operational regimes are depicted in Figure 50. Total flow in the small pond (initial operational period) ranged from 0.4 to 1.6 cfs (mean = 1.2 cfs). During the second operational period, flow in the eastern flow path ranged from 0.28 to 0.49 cfs (mean = 0.37 cfs) and flow in the western flow path ranged from 0.27 to 0.47 cfs (mean = 0.36 cfs). The initial and second operational period HRTs averaged 0.8 and 1.3 days, respectively. As of the time of this report, the large HWTT systems had not been operated, due to inadequate creek flows.

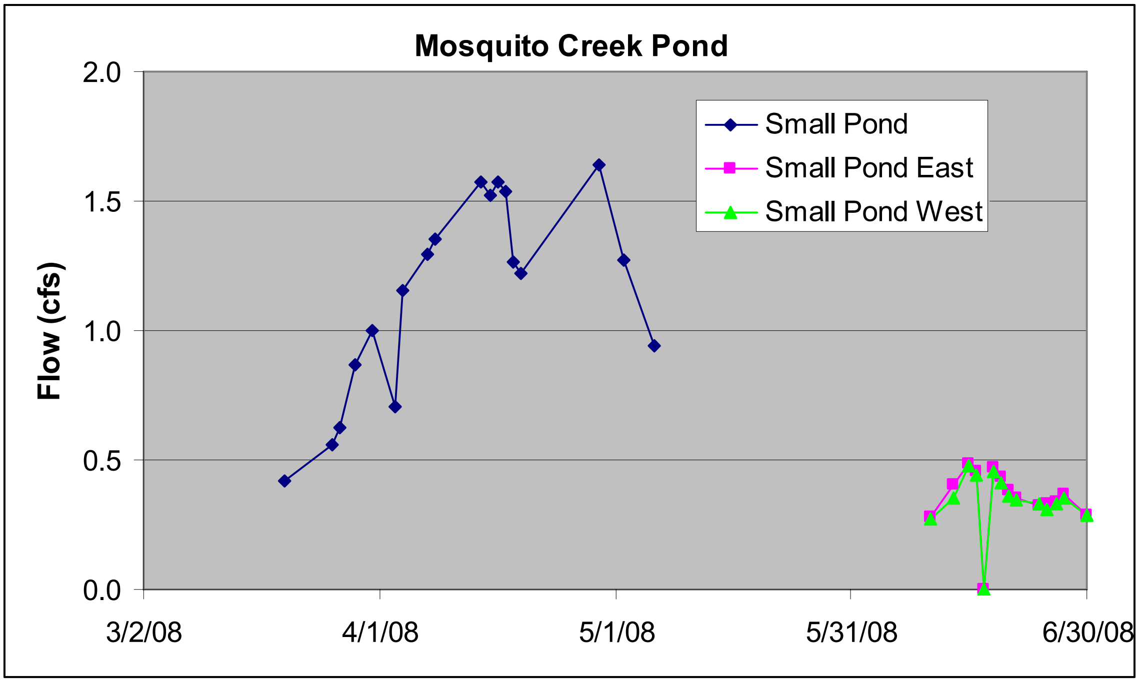



**Figure 50. Flows into the small HWTT system at Mosquito Creek. "Small pond" flows represent the initial operational period, prior to dividing the system into east and west flow paths.**

Due to the highly colored waters, the HWTT system was typically dosed with alum at 20 – 25 mg Al/L, but at times lower doses could be utilized. During the first 3.5 months of water quality monitoring and system optimization at the Mosquito Creek small pond, including the first 1.5 months of HWTT operation, TP concentration in the creek inflow (Figure 51) fluctuated around a mean value of 400 µg/L (median = 385 µg/L). For the remainder of the optimization period, following the interruption in system operation, inflow TP concentration was initially elevated, possibly due to flushing of residual organic matter in Mosquito Creek, and subsequently declined to more "typical" levels. The mean inflow TP concentration during this second optimization period was 692 µg/L (median = 645 µg/L). Outflow TP concentration was substantially lower than inflow TP, for both the initial and second optimization periods. Mean TP concentration for the HWTT system (single) outflow during the initial period was 37 µg/L, with a median value of 26 µg/L. During the second optimization period, mean TP concentrations were 32 and 24 µg/L (median values = 27 and 21 µg/L) at the east and west pond outflows, respectively, despite the fact that inflow TP concentration was 75% higher than during the initial period.

The speciation of P in the Mosquito Creek HWTT inflow stream was, on average, 77% SRP, 14% DOP and 9% PP, similar to the inflow stream (North Canal) for the Ideal #2 Grove HWTT. In contrast, the speciation of P in the HWTT (single) outflow stream was 18% SRP, 12% DOP and 70% PP during the initial optimization period. For the second optimization period, the speciation of P was 11% SRP, 13% DOP and 76% PP for the east outflow and 9% SRP, 24% DOP and 67% PP for the west outflow. The overall mean concentrations of SRP, DOP and PP in the inflow stream were 314, 60 and 36 μg/L (Figure 52, Figure 53 and Figure 54). Outflow concentration of SRP averaged 13 μg/L at the single pond outflow and 4 and 2 μg/L at the east and west outflows (second optimization period). Outflow concentration of DOP averaged 4 μg/L at the single pond outflow and 3 and 5 μg/L at the east and west outflows; mean PP concentration was 26 μg/L at the single pond outflow and 3 and 5 μg/L at the east and west outflows.

Alkalinity averaged 79 mg/L at the HWTT pond inflow during the monitoring period but showed considerable temporal variability (Figure 55). Alkalinity was monitored on an occasional basis at the pond outflows, with all values below 20 mg/L. Color was reduced from an average of 298 CPU in the inflow stream to 55 CPU in the outflow stream during the initial operational period, and 56 and 51 CPU in the east and west outflow streams during the second operational period (Figure 56). Turbidity levels were less than 10 NTU in the inflow and outflow streams throughout the monitoring period (Figure 57). Mean turbidity level in the outflow stream was slightly lower than in the inflow stream during the initial operational period and slightly higher during the second operational period.

pH in the inflow stream from Mosquito Creek varied between approximately 5.5 and 7.5 during the monitoring period, with an average value of 6.7 (Figure 58). Outflow pH averaged 6.1 during the initial optimization period, and 5.1 (both outflows) during the second optimization period. Conductivity was slightly higher at the pond outflows than at the system inflow (Figure 59), and showed an overall increase in both inflow and outflows during the second period.

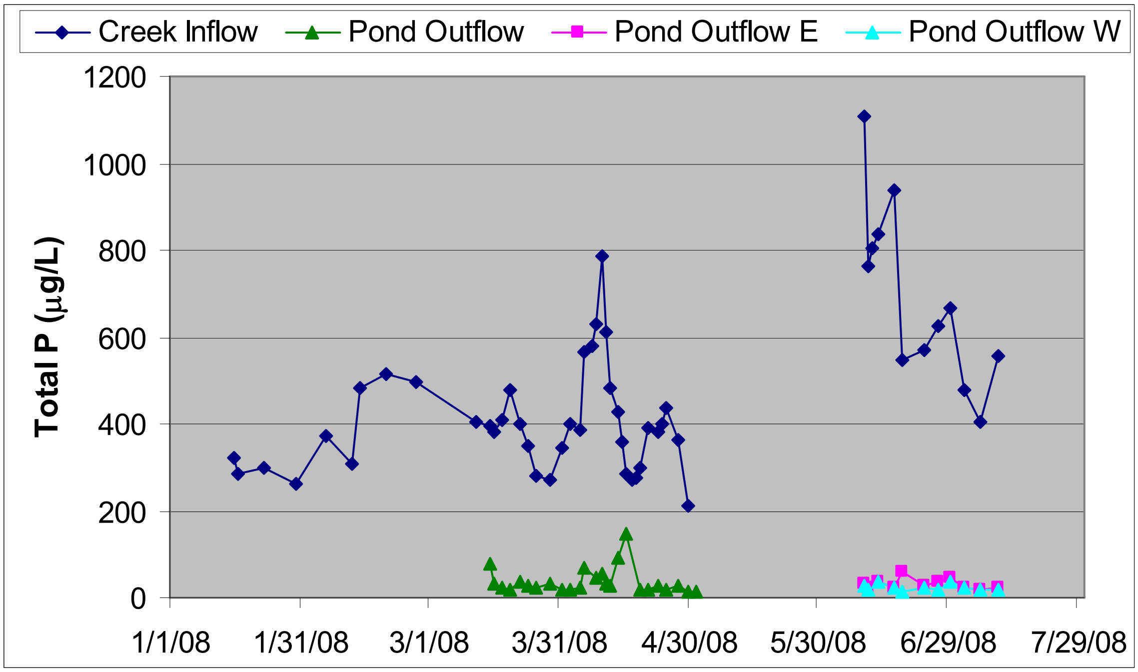



**Figure 51. Total P (TP) concentration in the inflow and outflow (single and parallel configurations) streams at the Mosquito Creek Tributary Treatment (Small Pond) HWTT.**

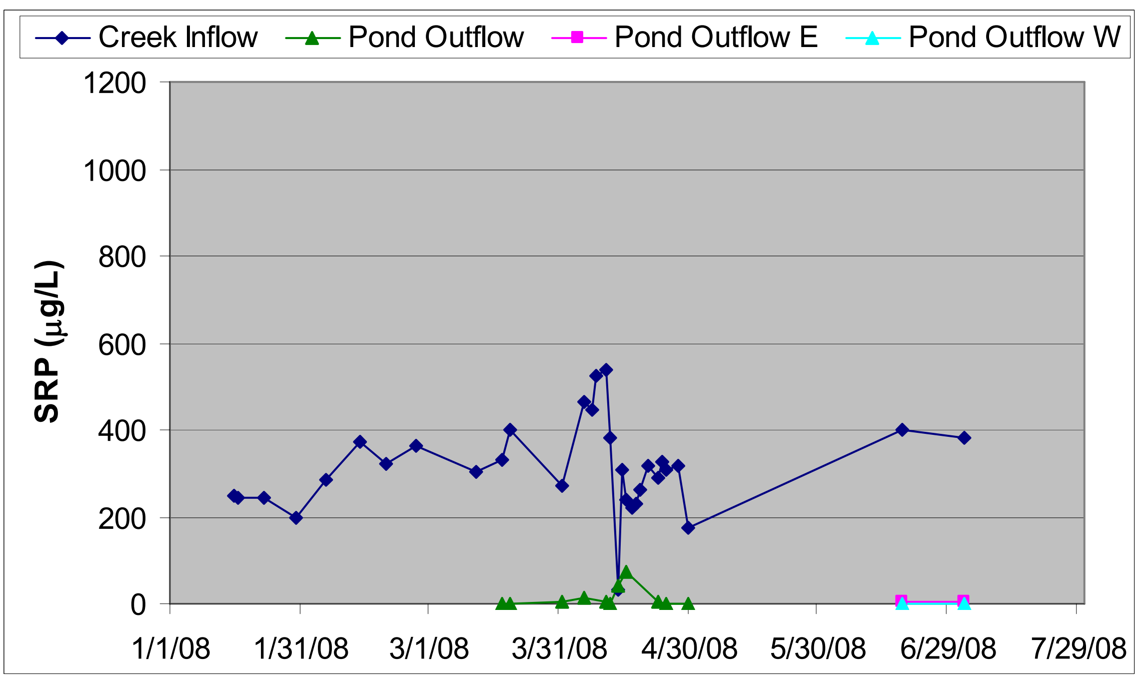



**Figure 52. Soluble reactive P (SRP) concentration in the inflow and outflow (single and parallel configurations) streams at the Mosquito Creek Tributary Treatment (Small Pond) HWTT.**

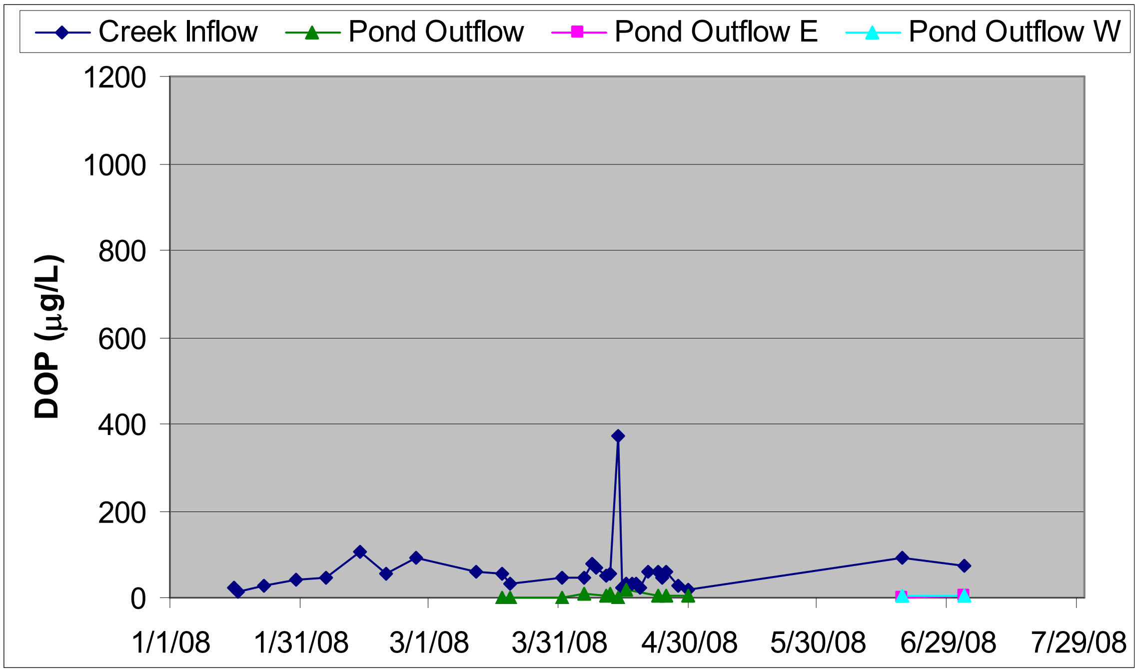



**Figure 53. Dissolved organic P (DOP) concentration in the inflow and outflow (single and parallel configurations) streams at the Mosquito Creek Tributary Treatment (Small Pond) HWTT.**

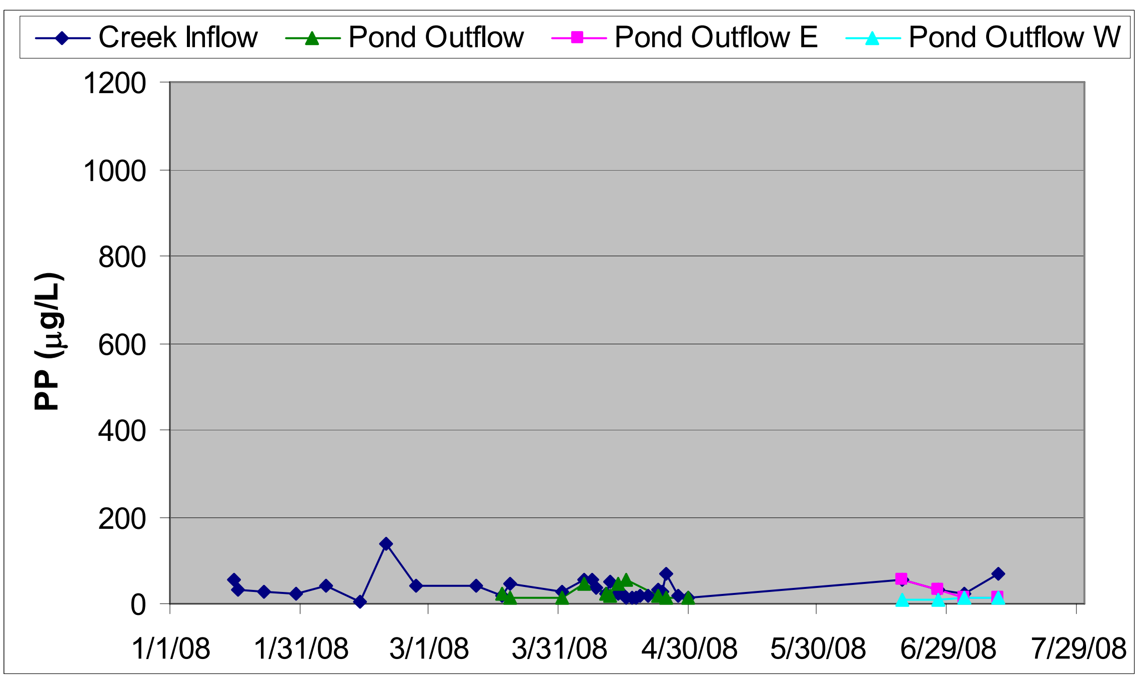



**Figure 54. Particulate P (PP) concentration in the inflow and outflow (single and parallel configurations) streams at the Mosquito Creek Tributary Treatment (Small Pond) HWTT.**

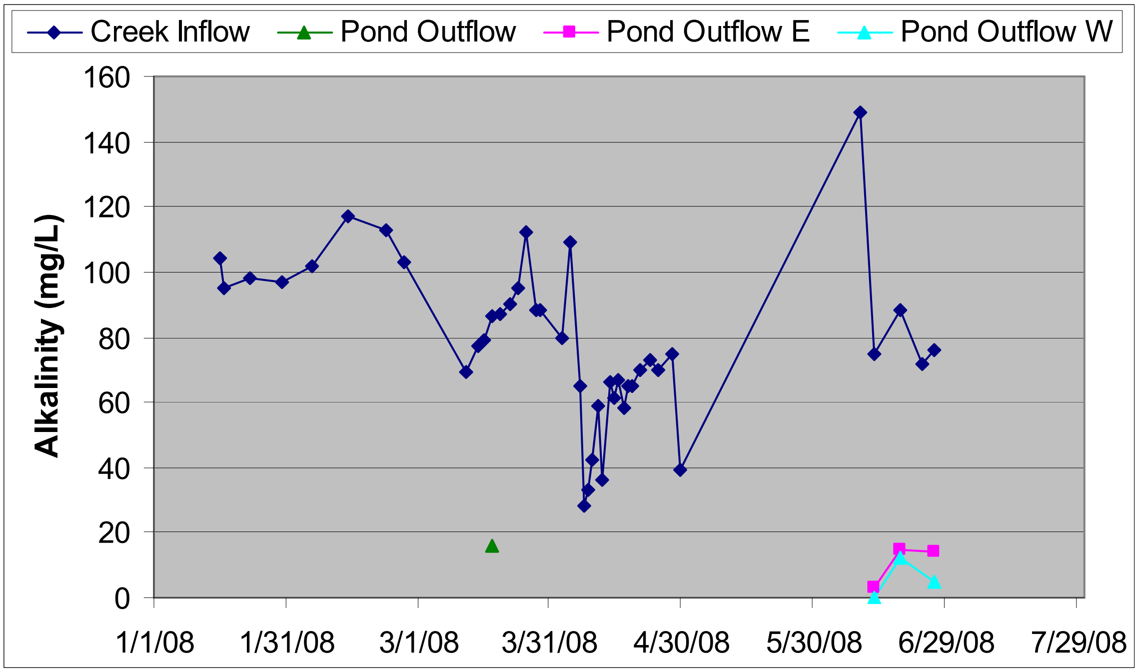



**Figure 55. Alkalinity in the inflow and outflow (single and parallel configurations) streams at the Mosquito Creek Tributary Treatment (Small Pond) HWTT.**

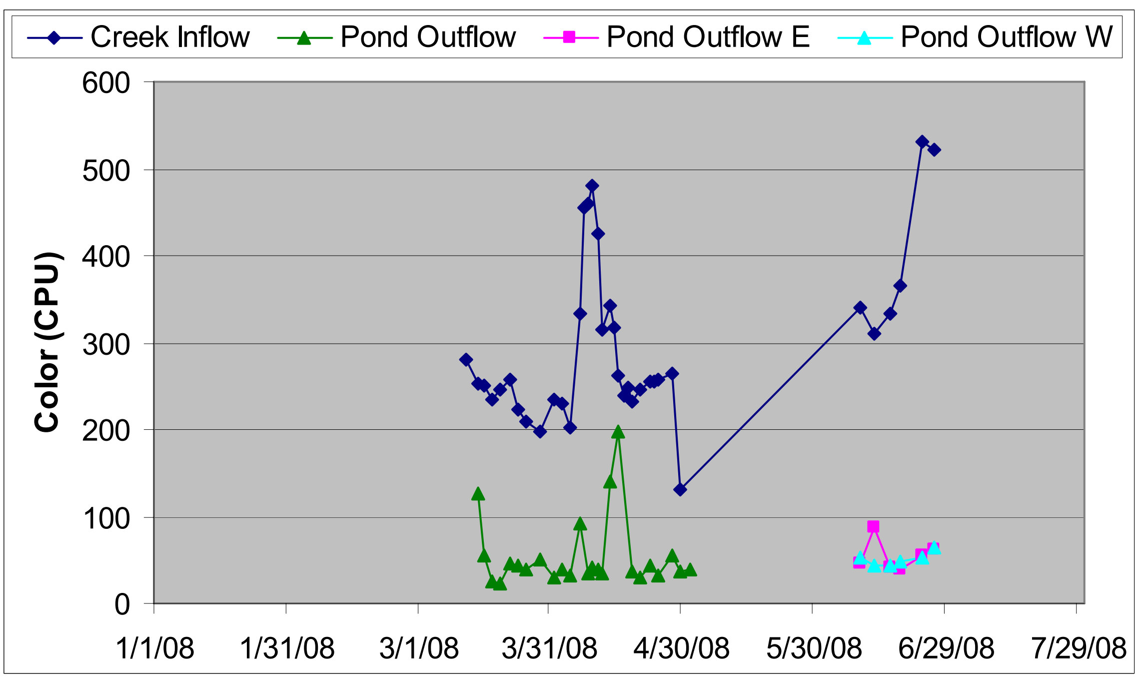



**Figure 56. Color in the inflow and outflow (single and parallel configurations) streams at the Mosquito Creek Tributary Treatment (Small Pond) HWTT.**

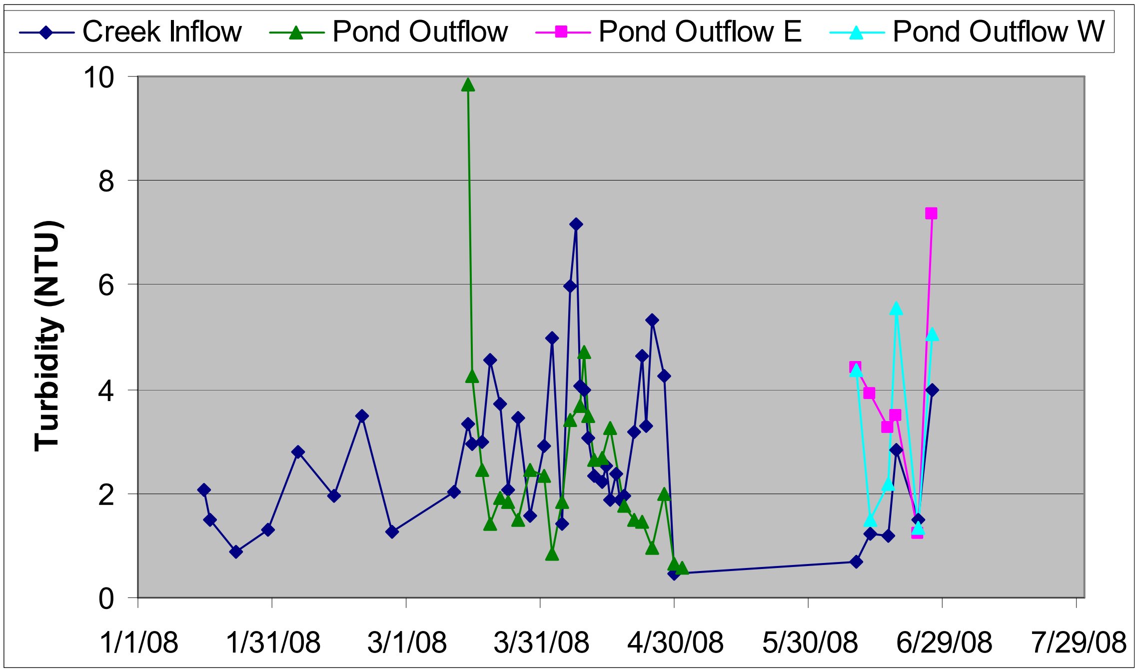



**Figure 57. Turbidity in the inflow and outflow (single and parallel configurations) streams at the Mosquito Creek Tributary Treatment (Small Pond) HWTT.**

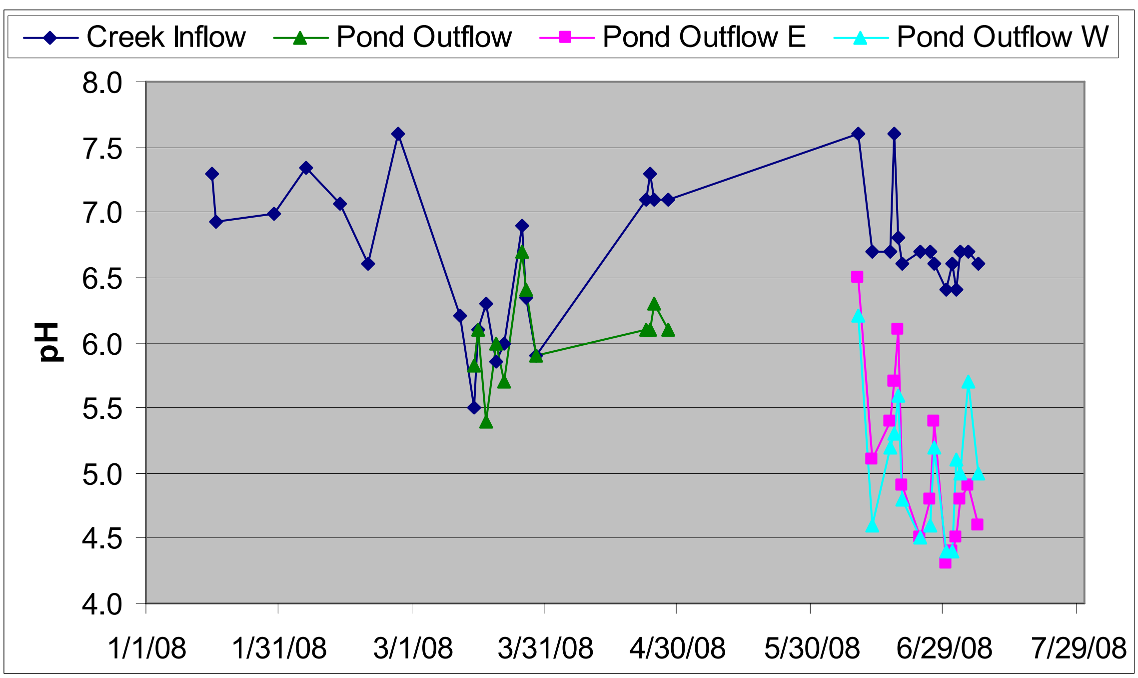



**Figure 58. pH in the inflow and outflow (single and parallel configurations) streams at the Mosquito Creek Tributary Treatment (Small Pond) HWTT.**

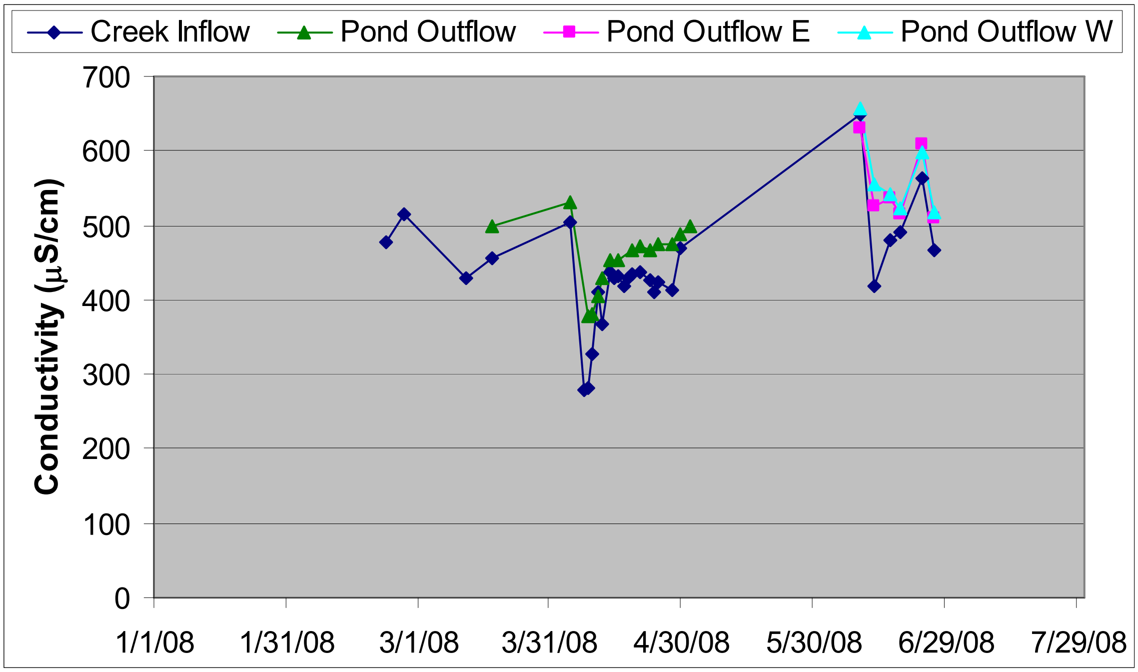



**Figure 59. Conductivity in the inflow and outflow (single and parallel configurations) streams at the Mosquito Creek Tributary Treatment (Small Pond) HWTT.**

### *Spatial Characterization of the Small HWTT in March 2008*

During late March 2008, we performed an intensive sampling effort to characterize spatial water quality profiles within the Mosquito Creek "small pond" HWTT system.

We established eight sampling locations within the 0.44 acre HWTT system: the inflow, the outflow, and stations at two depths (2 ft. and 6 ft.) within the inflow contact zone, the mid-region filtration zone, and the outflow region settling zone (Figure 60). The 2 ft and 6 ft deep samples from the three regions were collected using *in situ* lengths of sample tubing, which were suspended from a float and deployed several days prior to sampling.

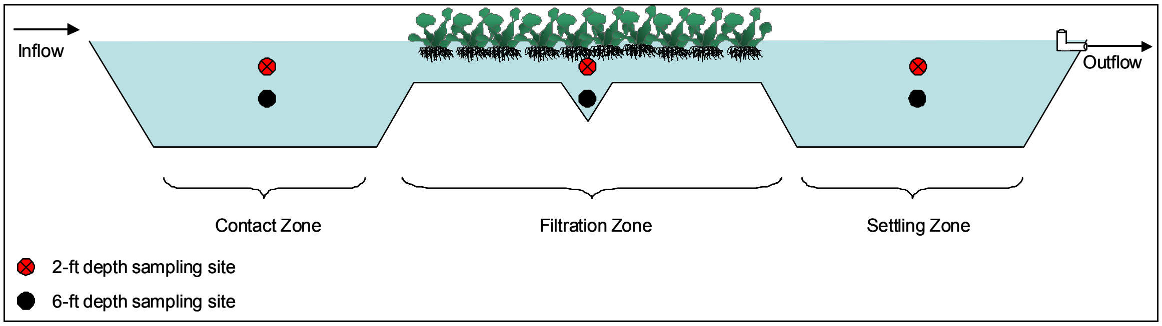



**Figure 60. Schematic depicting sites at the 0.44 acre Mosquito Creek HWTT system that were sampled in late March, and subsequently in late April, for the spatial water quality assessment.**

On the date of sampling, inflow TP levels were reduced from 346 to 20 µg/L during passage through the HWTT system. The bulk of the inflow TP consisted of SRP, whereas samples from all locations within the pond, and at the outflow, were dominated by PP (Figure 61). In the two deep zones (contact and settling), PP concentrations were higher at the 6 ft depth than at the 2 ft depth, which probably reflects the gradual settling of amendment flocs within these regions. The 6 ft deep sample from the contact zone, near the inflow of the pond, contained the highest PP concentration in the HWTT system, at 104 µg/L. Turbidity generally was low at the pond inflow, outflow and internal sampling locations, with all values lower than 4.0 NTU. There was a trend for the deeper sampling stations to exhibit slightly higher turbidities (Figure 62). Inflow color levels of 234 CPU were reduced to 30 CPU in the outflow. All locations in the pond, with the exception of the 6 ft deep sample from the settling zone, exhibited color values lower than 50 CPU (Figure 63).

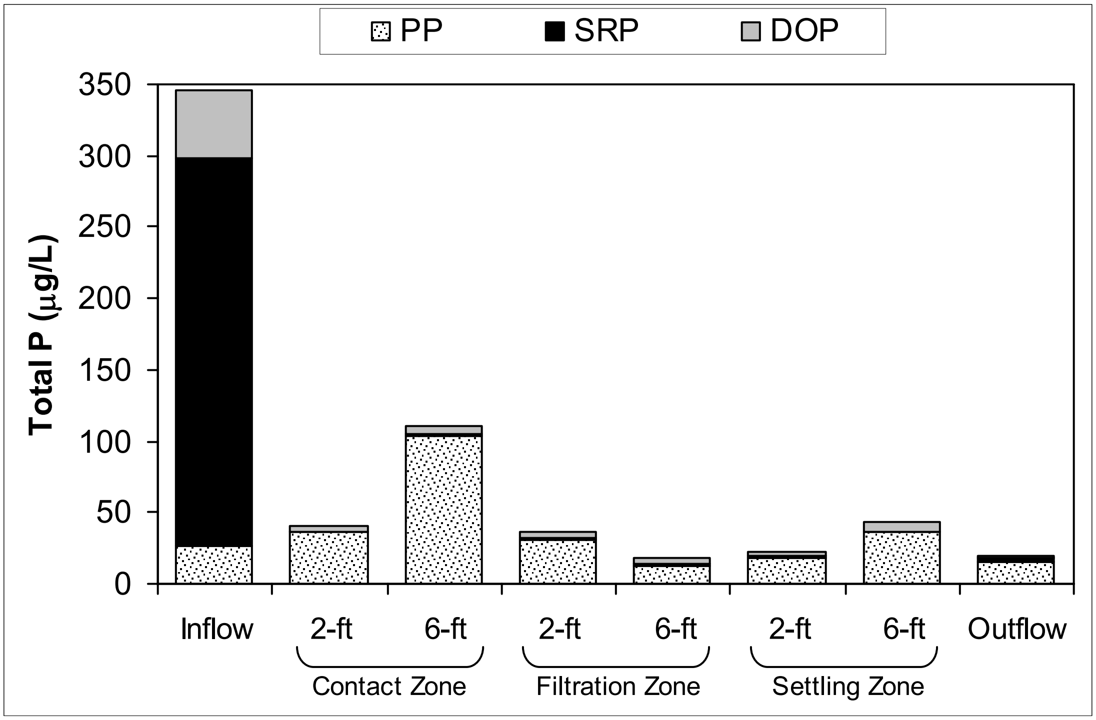



**Figure 61. Inflow, outflow and internal P species concentrations at the 0.44 acre Mosquito Creek HWTT system. Samples were collected from two depths (2 ft and 6 ft) from within each of the contact, filtration and settling zones.**

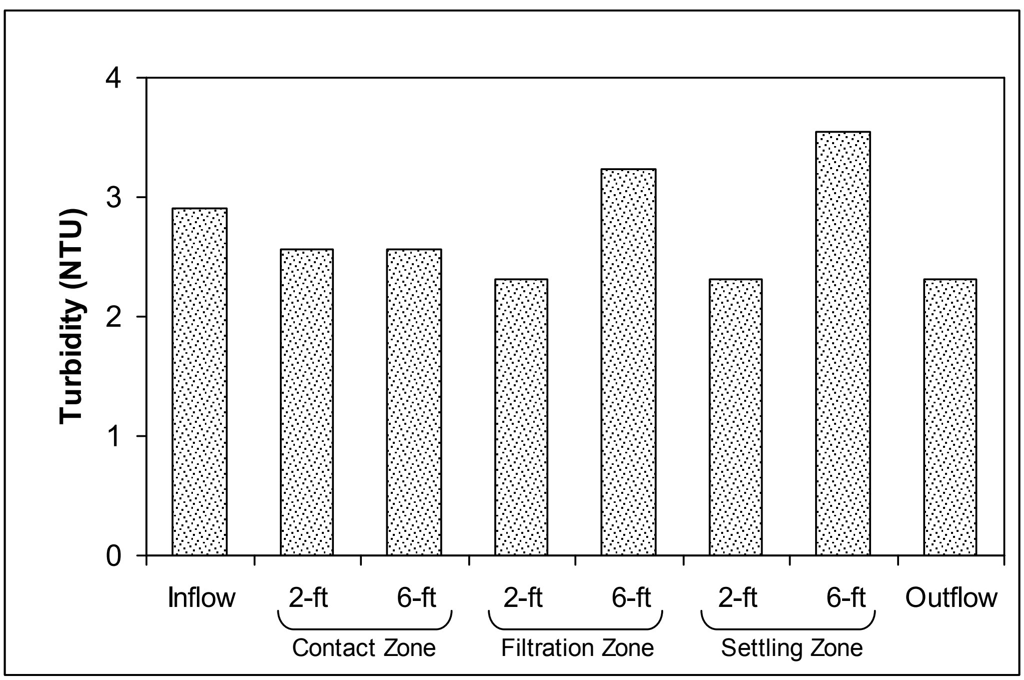



**Figure 62. Inflow, outflow and internal turbidity levels at the 0.44 acre Mosquito Creek HWTT system. Samples were collected from two depths (2 ft and 6 ft) from within each of the contact, filtration and settling zones.**

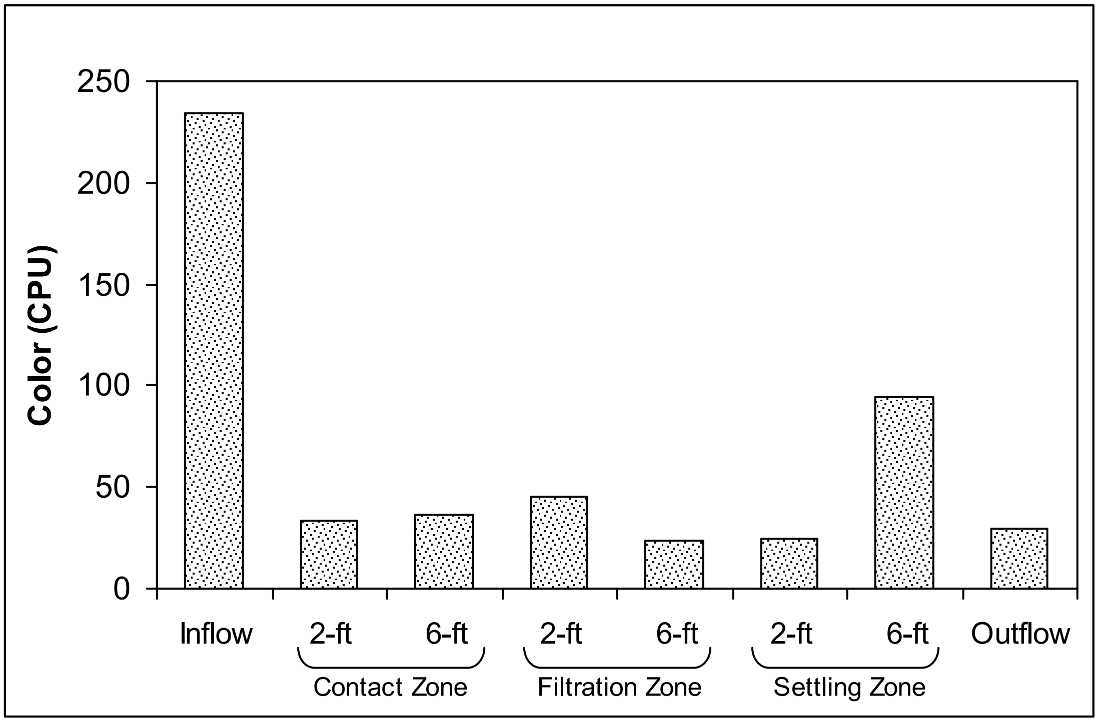



**Figure 63. Inflow, outflow and internal color levels at the 0.44 acre Mosquito Creek HWTT system. Samples were collected from two depths (2 ft and 6 ft) from within each of the contact, filtration and settling zones.**

The amendment additions to the HWTT resulted in a 10% increase in conductivity, from 481 µS/cm at the inflow to 528 µS/cm at the outflow. Following the increase at the inflow, conductivity levels were relatively constant within the pond, at all locations and depths sampled (Figure 64). Water temperatures exhibited a slight increase (inflow of 23.7 °C; outflow of 24.8 °C) during passage through the HWTT system; with surface sampling locations exhibiting temperatures about 2 – 3 degrees C higher than deeper stations (Figure 65).

These water quality profiles provide a useful characterization of "start-up" conditions for the 0.44 acre Mosquito Creek HWTT system. We anticipate spatial profiles of chemical and physical parameters to change over time, particularly in the contact zone where amendment flocs will tend to accumulate. Such changes in spatial water chemistry patterns will improve our system optimization efforts, and facilitate long-term sustainable management of the HWTT systems.

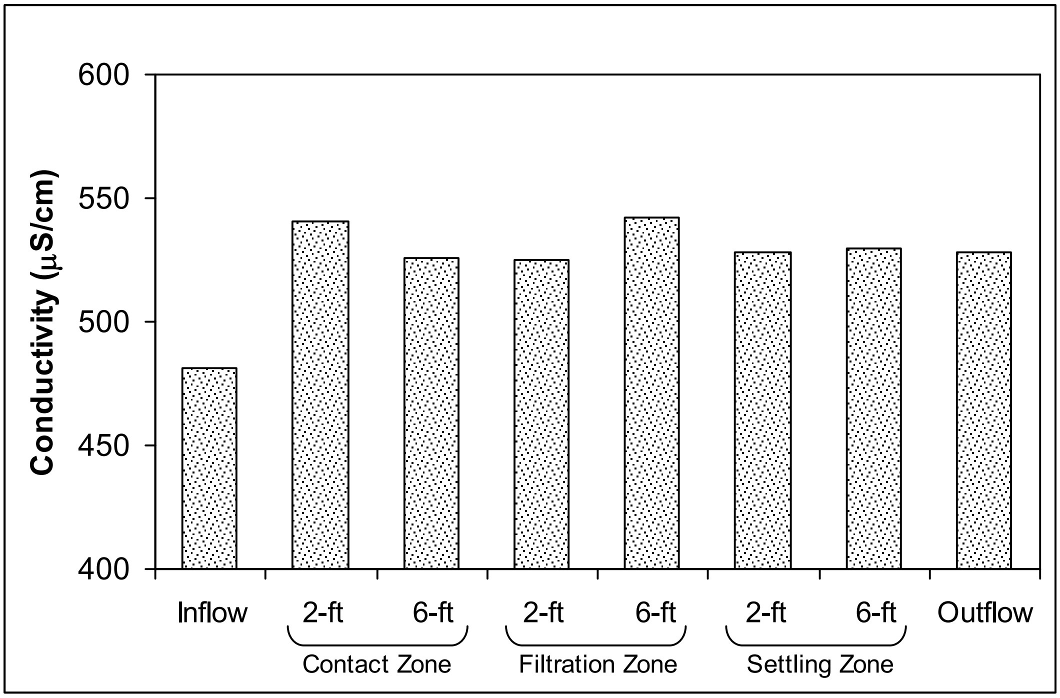



**Figure 64. Inflow, outflow and internal specific conductance at the 0.44 acre Mosquito Creek HWTT system. Samples were collected from two depths (2 ft and 6 ft) from within each of the contact, filtration and settling zones.**

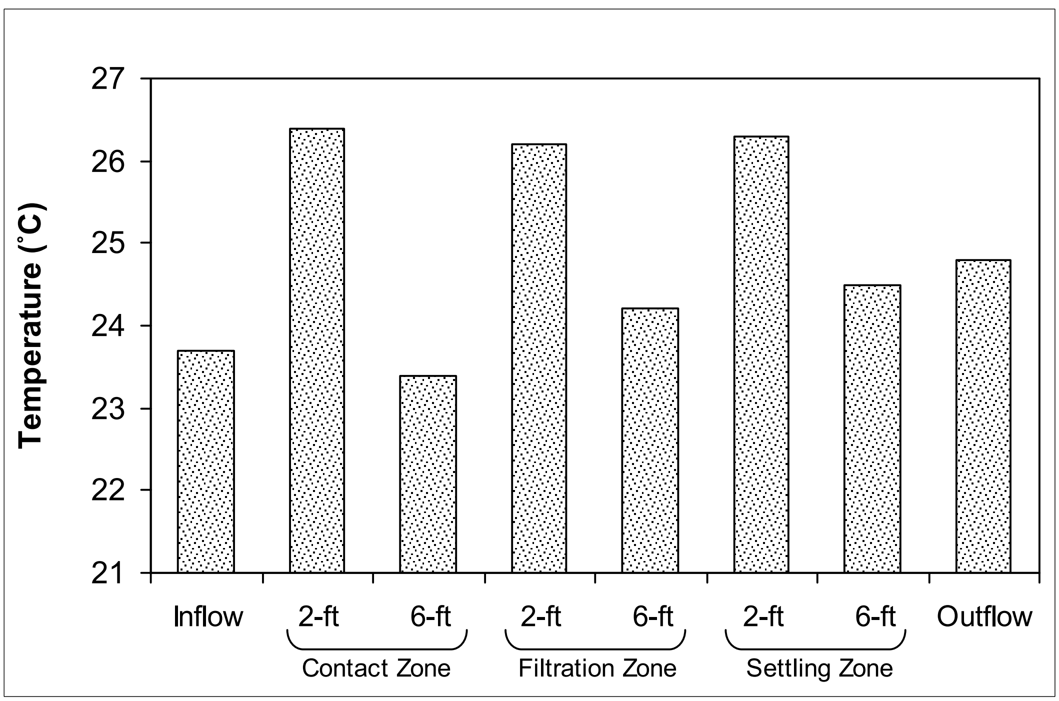



**Figure 65. Inflow, outflow and internal water temperatures at the 0.44 acre Mosquito Creek HWTT system. Samples were collected from two depths (2 ft and 6 ft) from within each of the contact, filtration and settling zones.**

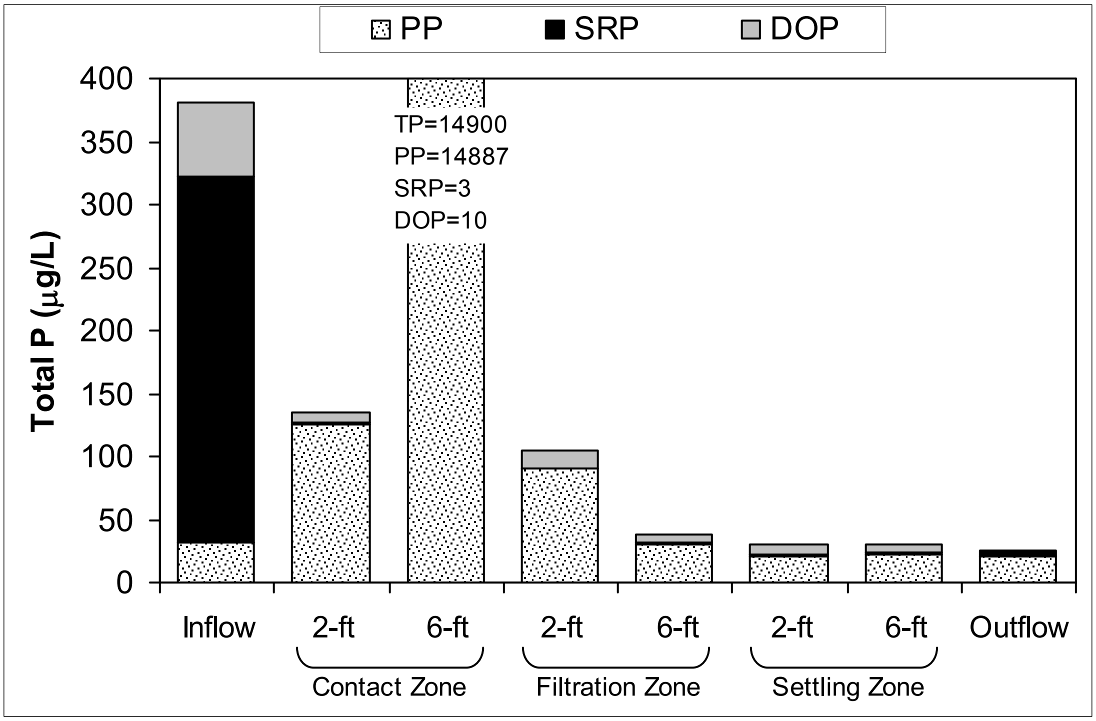
### *Spatial Characterization of the Small HWTT in April 2008*

During late April, we performed a second internal sampling effort at the 0.44 acre HWTT, and results are described below. We used eight previously established sampling locations within the 0.44 acre HWTT system: the inflow, the outflow, and stations at two depths (2 ft. and 6 ft.) within the inflow contact zone, the mid-region filtration zone, and the outflow region settling zone (Figure 60). The 2 ft and 6 ft deep samples from the three regions were collected using *in situ* lengths of sample tubing, which were suspended from a float and deployed several days prior to sampling.

On the date of internal sampling, inflow TP levels were reduced from 381 to 26 μg/L during passage through the HWTT system. As was observed during our March internal sampling, the bulk of the inflow TP consisted of SRP, whereas samples from all locations within the pond, and at the outflow, were dominated by PP (Figure 66). In the contact zone, PP concentrations were dramatically higher at the 6 ft depth than at the 2 ft depth, which clearly reflects the gradual settling and accumulation of amendment flocs within these regions. The 6 ft deep sample from the contact zone, near the inflow of the pond, contained the highest PP concentration in the HWTT system, at 14,887 μg/L. All locations in the pond, with the exception of the 6 ft deep sample from the contact zone, exhibited color values lower than 55 CPU (Figure 66). Inflow color levels of 256 CPU were reduced to 43 CPU in the outflow. With the exception of the contact zone, turbidity generally was low at the pond inflow, outflow and internal sampling locations, with all values lower than 5.0 NTU (Figure 67).

The amendment additions to the HWTT resulted in a 9% increase in conductivity, from 427 μS/cm at the inflow to 467 μS/cm at the outflow. Following the increase at the inflow, conductivity levels were relatively constant within the pond, at all locations and depths sampled (Figure 67). Inflow pH values of 7.1 were reduced to 6.1 at the system outflow (Figure 68).

Results of the March and April internal monitoring efforts demonstrate that spatial profiles of chemical and physical parameters within the Mosquito Creek HWTT changed as a function of operation time, particularly in the contact zone where amendment floc accumulated. We anticipate that, as additional floc accrues in the filtration (water hyacinth) zone, the system P removal efficiency will remain high, via enhanced filtration by the floating plant root mat. By June 2008, we observed dense layers of floc in the Mosquito HWTT system downstream of the inflow manifold, and just upstream of the floating vegetation mat (Figure 69). Despite this accrual of floc material, outflow TP concentrations remained quite low at the system outflow (Figure 51), indicating the effective filtration and removal of floc (and associated PP) by the water hyacinth mat. Additionally, at the time of this report, the floc recirculation/reuse infrastructure had been deployed in the W flow path, but had not yet been implemented. This results in floc resuspension in the contact zone, which can increase the floc load to the filtration zone.



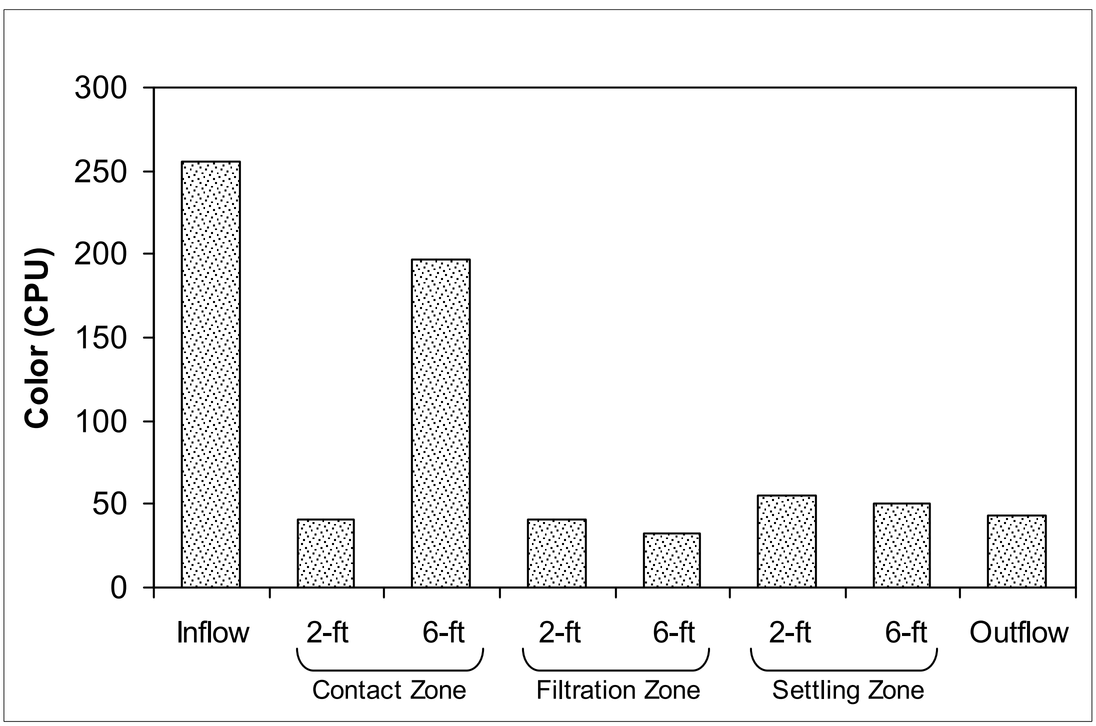




**Figure 66. Inflow, outflow and internal P species concentrations (top) and color (bottom) at the 0.44 acre Mosquito Creek HWTT system. Samples were collected in April from two depths (2 ft and 6 ft) from within each of the contact, filtration and settling zones.**

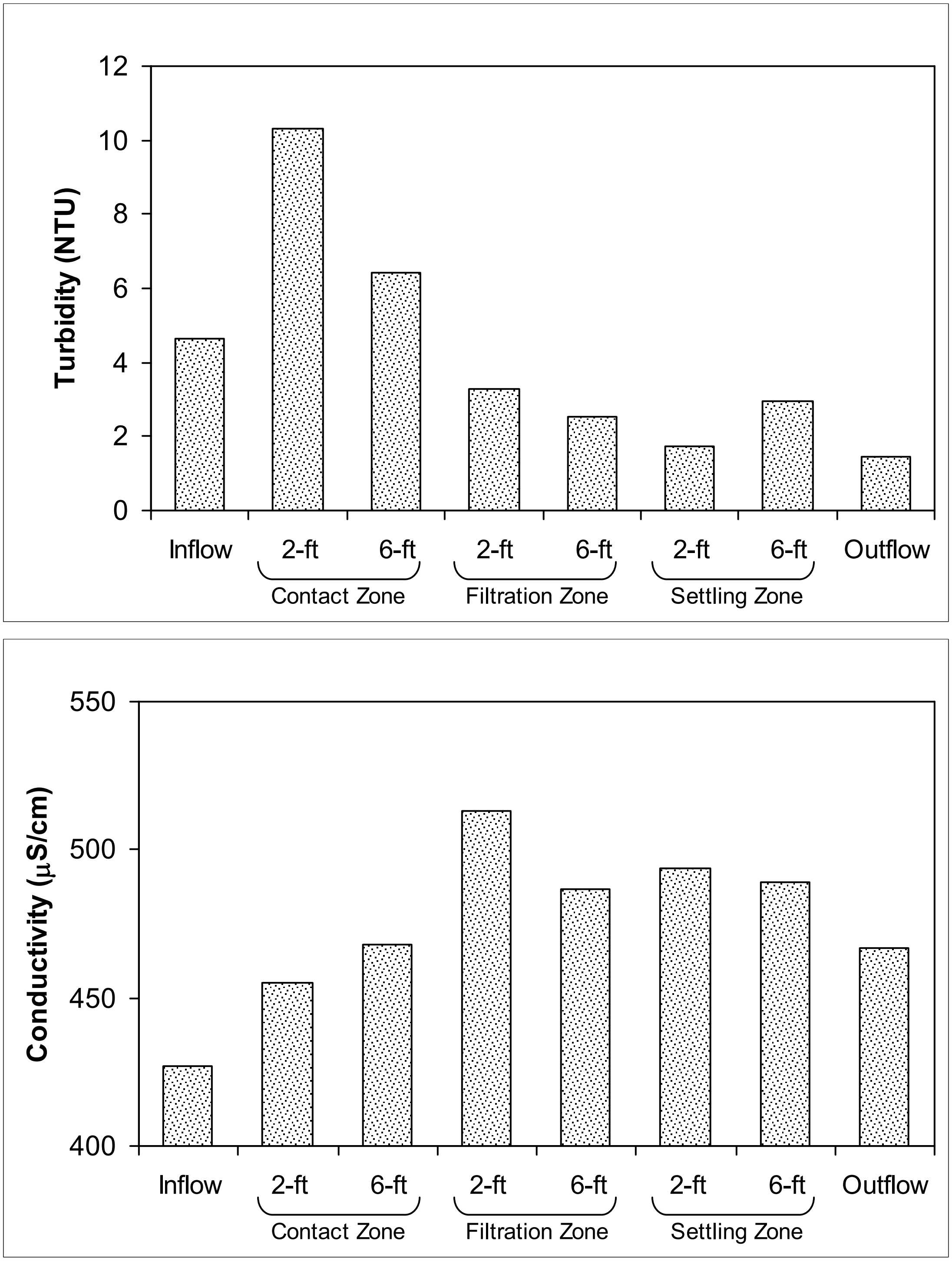



**Figure 67. Inflow, outflow and internal turbidity (top) and conductivity (bottom) at the 0.44 acre Mosquito Creek HWTT system. Samples were collected in April from two depths (2 ft and 6 ft) from within each of the contact, filtration and settling zones.**

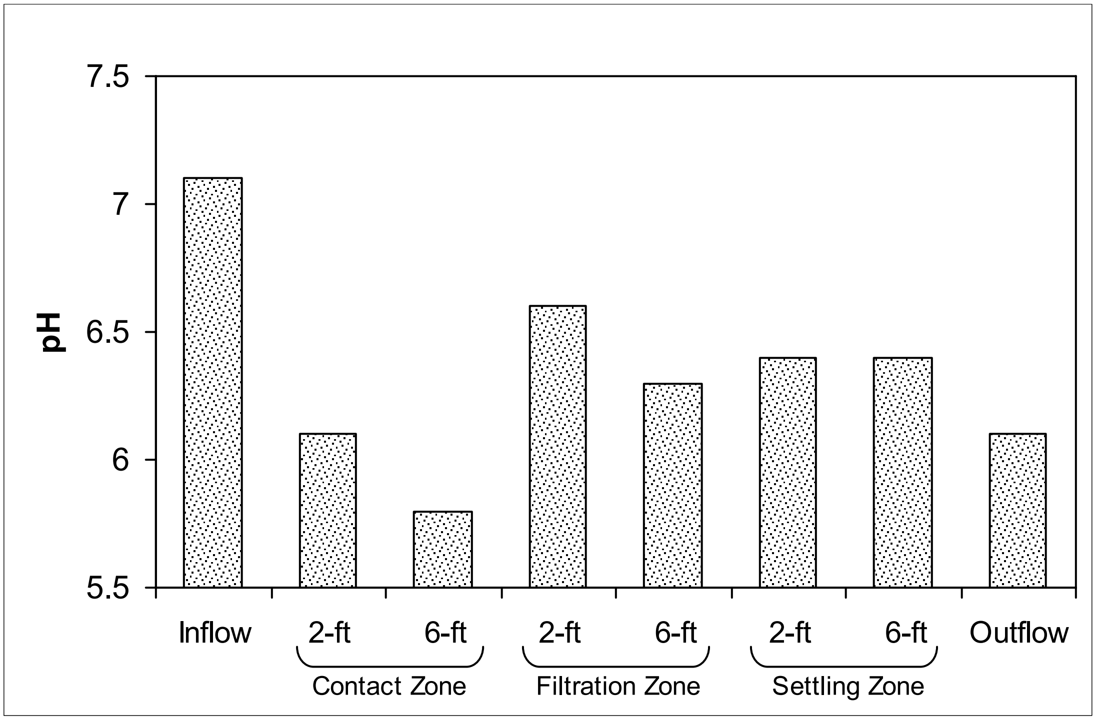



**Figure 68. Inflow, outflow and internal pH at the 0.44 acre Mosquito Creek HWTT system. Samples were collected in April from two depths (2 ft and 6 ft) from within each of the contact, filtration and settling zones.**

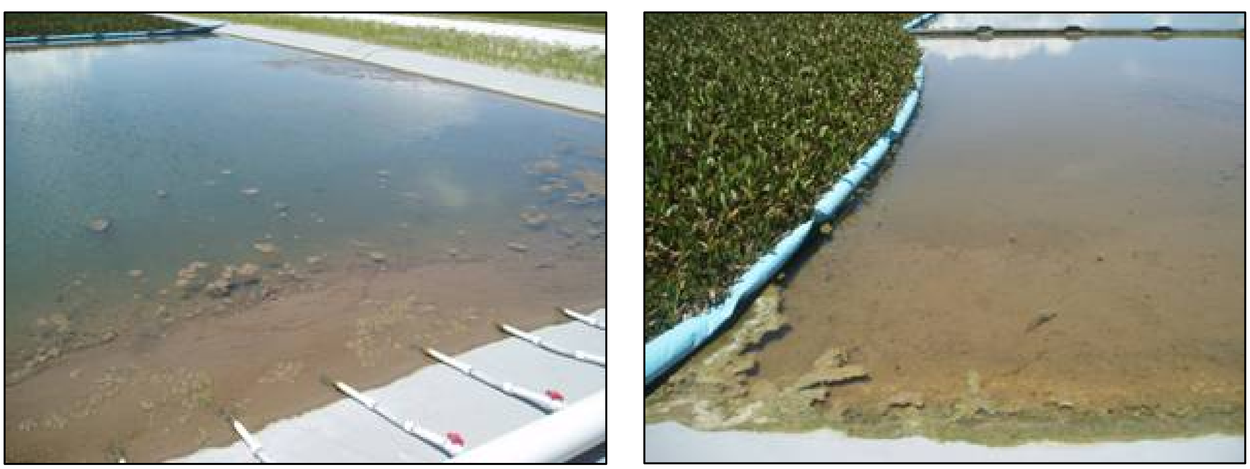


**Figure 69. Deposits of floc in the Mosquito HWTT in June 2008, just downstream of the inflow manifold (left) and upstream of the water hyacinth filtration zone (right).**

### *Site 4: Larson Lagoon HWTT*

The Larson Barn 8 lagoon system is highly enriched with P, due to its direct capture of barnwash and rainfall-generated runoff from the high intensity animal holding areas. The drainage area is shown in Appendix A. In 2008, a HWTT was deployed at a site along the northern shoreline of the secondary lagoon.

The purpose of the Lagoon HWTT is to demonstrate and refine the capability to produce low P water from the exceedingly high P water in the lagoon. Periodic samples have shown TP values of up to 25,000 µg/L, with roughly 30% of that as SRP. This can be contrasted with the proposed regulatory TP criterion of 113 µg/L for selected tributaries to Lake Okeechobee. The lagoon TP concentration is roughly 30 to 40 times the TP concentration typically seen in surface waters treated at the other HWTT facilities, but we believe we can achieve 80% or better removal of those extremely high levels using only 5 to 8 times more chemical amendment. The chemical cost per kilogram of P removed at this site may therefore be relatively low.

The second opportunity relates to reuse and recycle of floc in a multistage batch process. Coagulation using alum in the sweep floc regime produces an aluminum hydroxide floc that destabilizes and enmeshes dissolved organic P (DOP), but that floc also adsorbs and removes considerable SRP. Since the SRP level is only 30% of the total, we expect the first-stage floc to have latent SRP-adsorbing capability, and reuse of that floc may also lead to improvements in economic feasibility. Upon depletion of the P-sorbing ability of the floc, which will be determined by on-site testing, it will be pumped to a separate, enclosed containment area in the secondary lagoon.

The third opportunity related to the HWTT front end is the potential for a mat of floating vegetation to convert a portion of the PP to SRP, which is then more effectively removed using less amendment in the chemical treatment downstream processes. Organic particles in the lagoon water settle within the floating vegetation zone due to the long retention time (~ 7 days), and they subsequently release SRP upon decomposition. The vegetation roots contribute to particle filtering, and the mat shades the water column, thereby inhibiting phytoplankton growth.

Overall mean total P concentration in the secondary lagoon was 20.4 mg/L (20429 µg/L) during the pre-operational monitoring period (Figure 70). Most of the P was in particulate form, with SRP, DOP and PP accounting for 26%, 12% and 62% of total P, respectively. Mean concentrations of SRP, DOP and PP were 5704, 2547 and 12726 µg/L during pre-operational monitoring (Figure 71, Figure 72 and Figure 73). Alkalinity, color, turbidity, pH and conductivity levels were all significantly higher than those measured in the Ideal, Davie (Nubbin) and Mosquito Creek HWTT systems (Figure 74, Figure 75, Figure 76, Figure 77 and Figure 78). Mean values for these parameters during the pre-operational period were: alkalinity = 1075 mg/L, color = 4705 CPU, turbidity = 184, pH = 8.0 and conductivity = 3649 µS/cm.

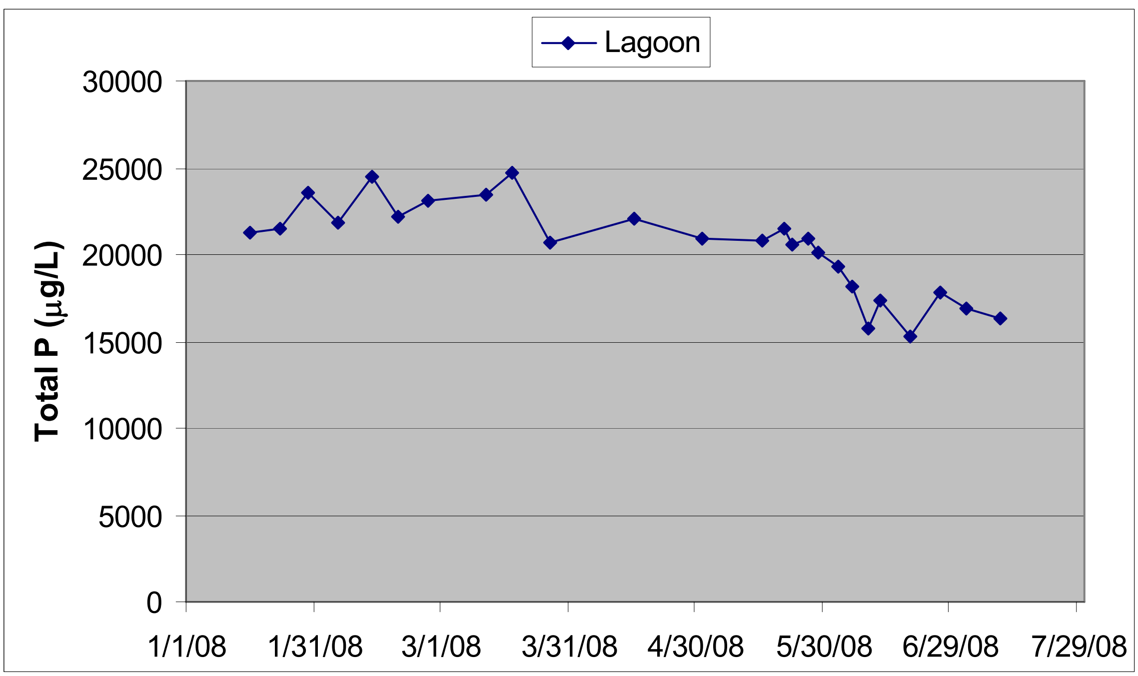



**Figure 70. Total P (TP) concentration in the Larson Barn 8 secondary lagoon HWTT system during the pre-operational monitoring period..**

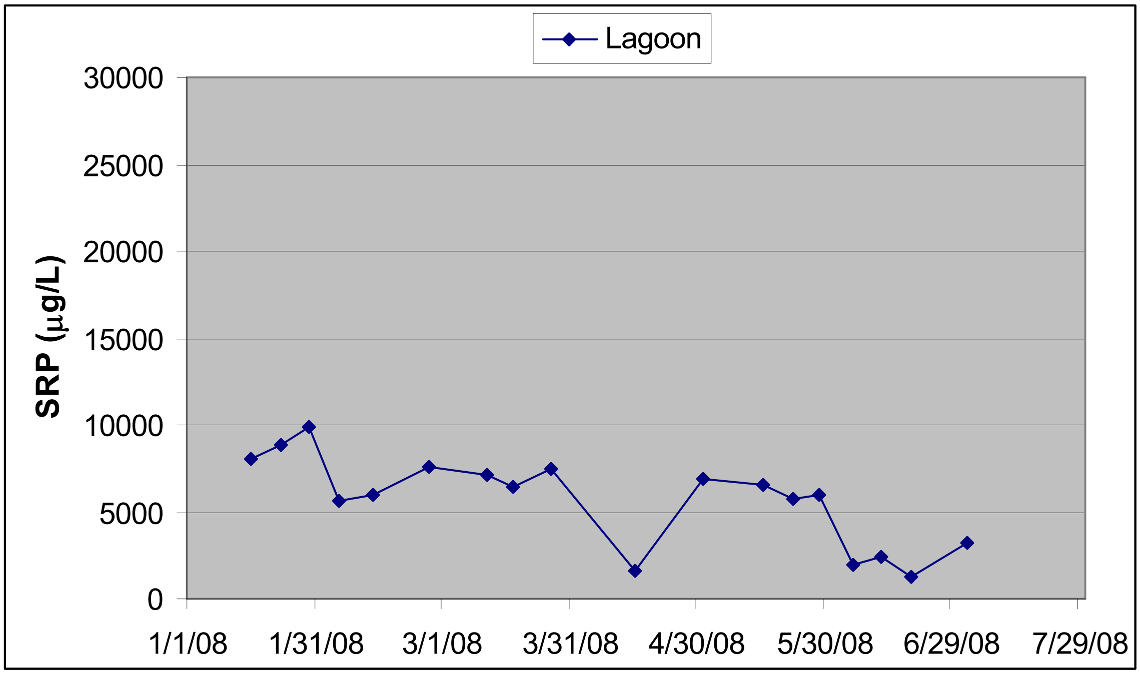



**Figure 71**. **Soluble reactive P (SRP) concentration in the Larson Barn 8 secondary lagoon HWTT system during the pre-operational monitoring period.**

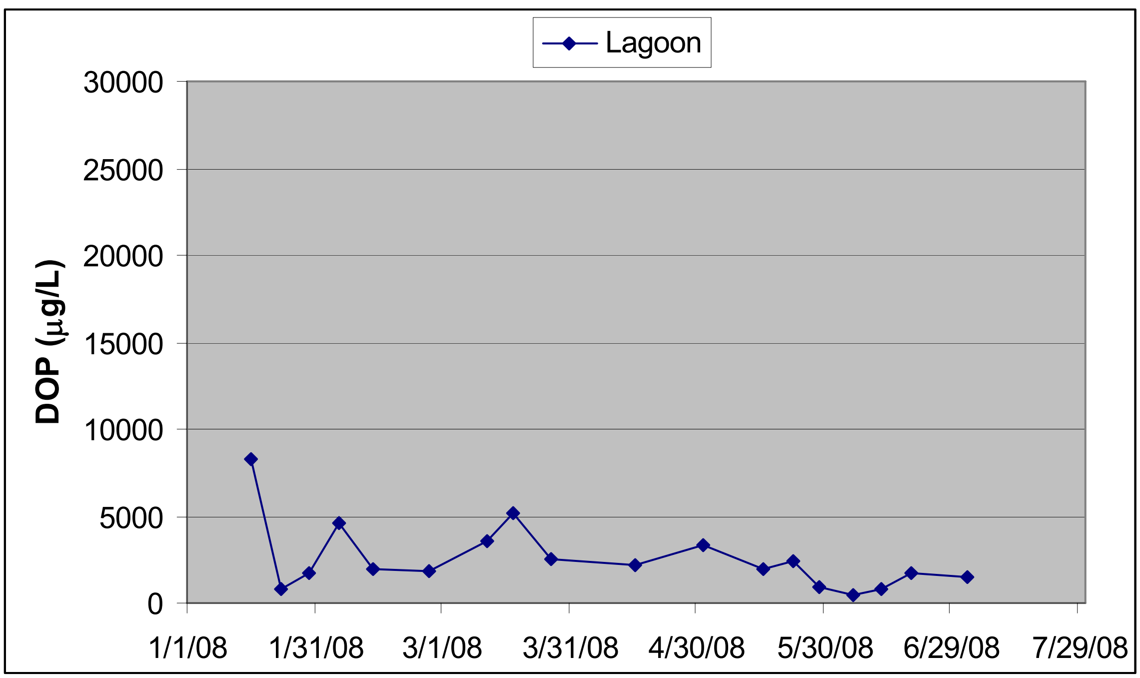



**Figure 72. Dissolved organic P (DOP) concentration in the Larson Barn 8 secondary lagoon HWTT system during the pre-operational monitoring period.**

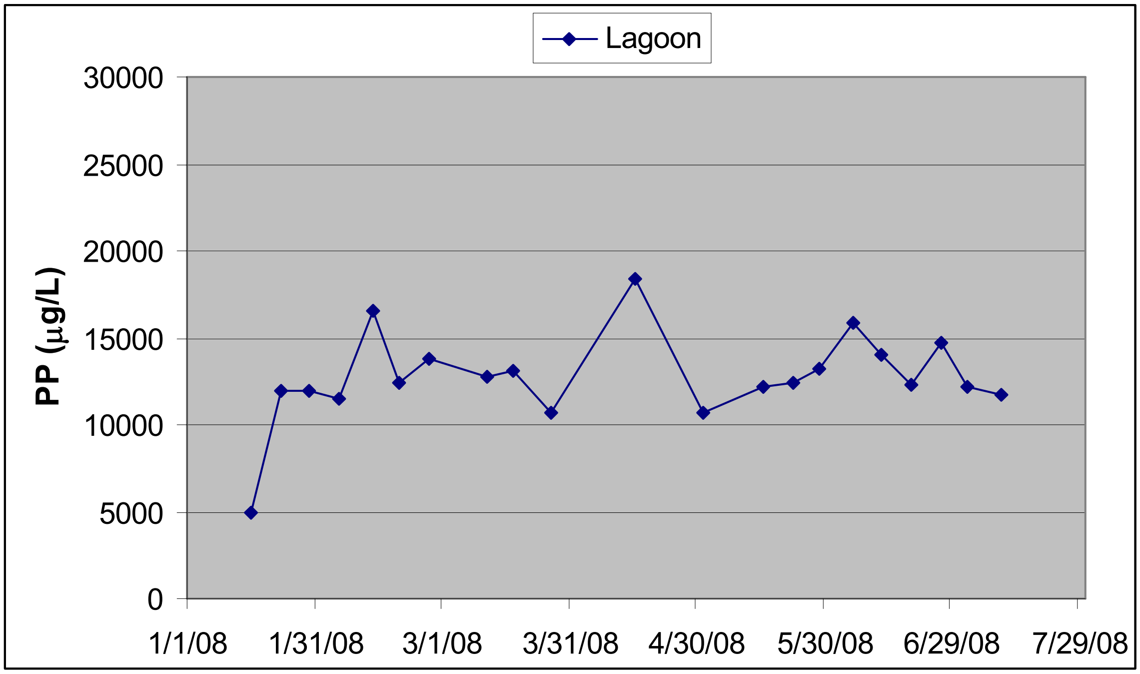



**Figure 73. Particulate P (PP) concentration in the Larson Barn 8 secondary lagoon HWTT system during the background monitoring period.**

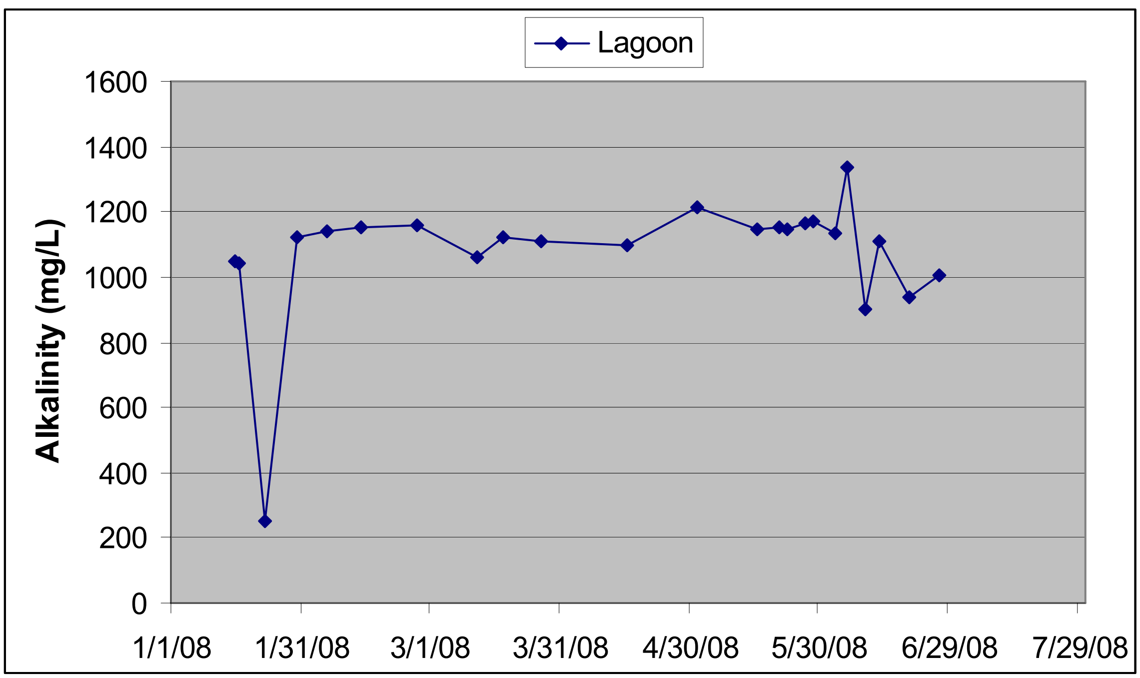



**Figure 74. Alkalinity in the Larson Barn 8 secondary lagoon HWTT system during the background monitoring period.**

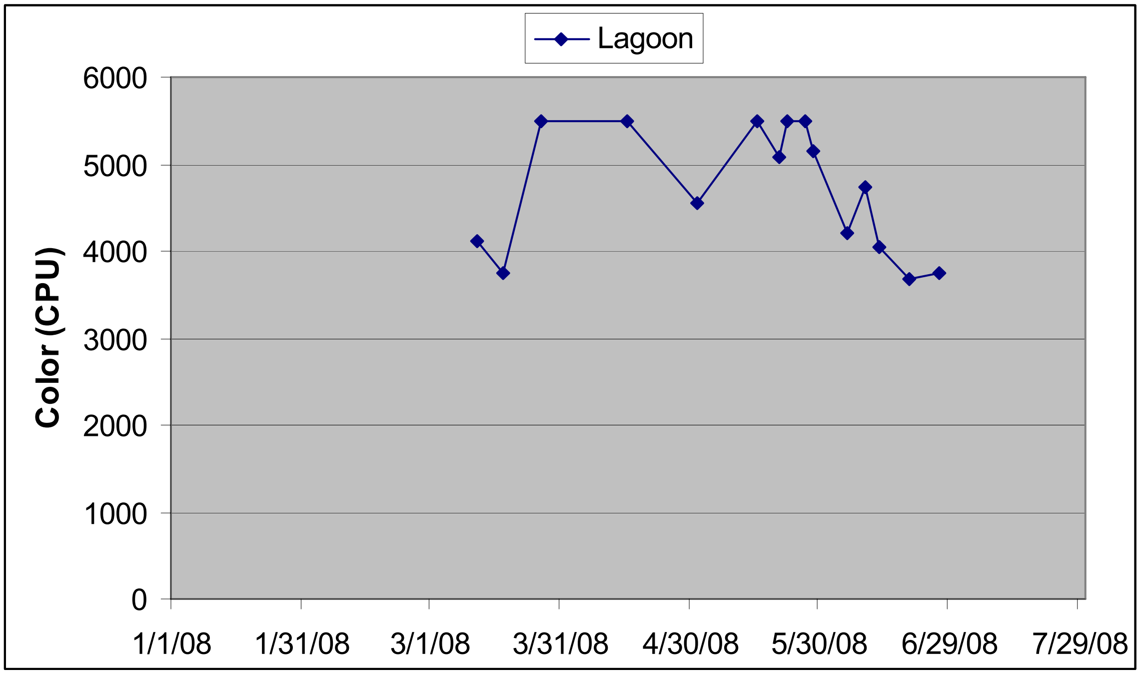



**Figure 75. Color in the Larson Barn 8 secondary lagoon HWTT system during the background monitoring period.**

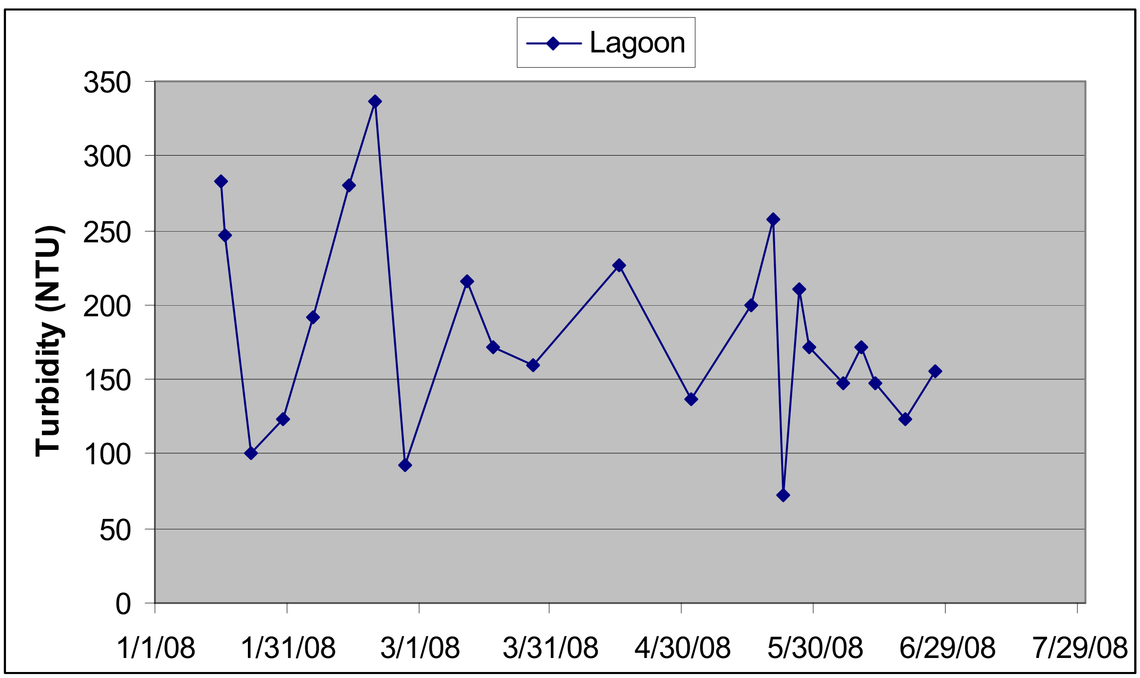



**Figure 76. Turbidity in the Larson Barn 8 secondary lagoon HWTT system during the background monitoring period.**

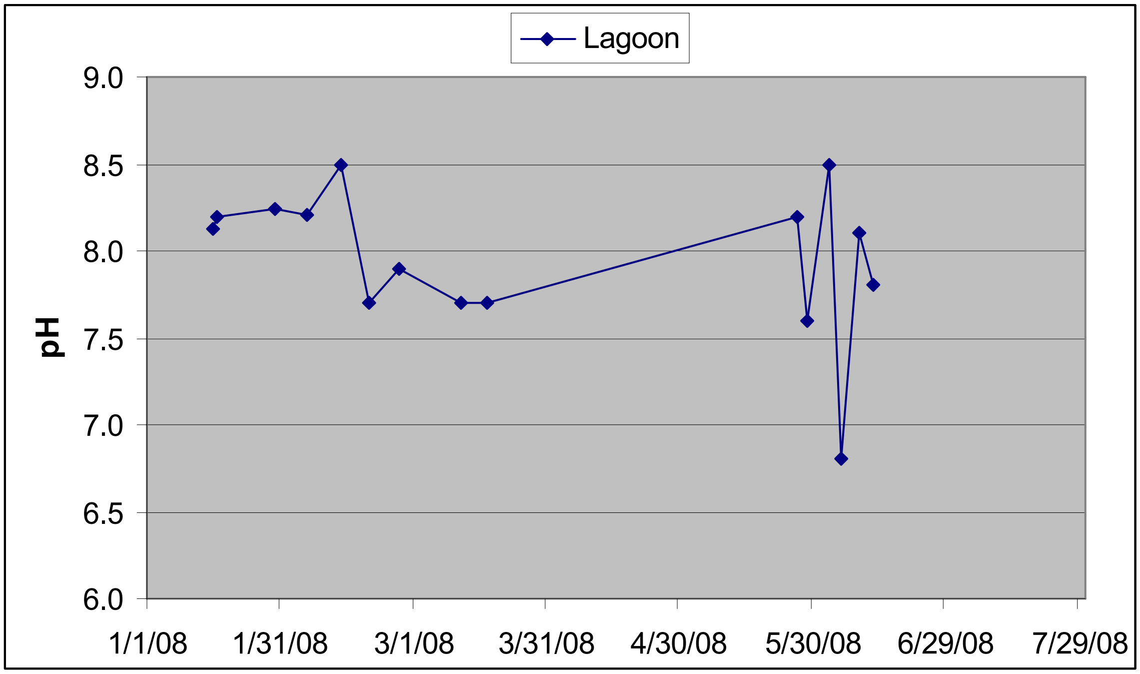



**Figure 77. pH in the Larson Barn 8 secondary lagoon HWTT system during the background monitoring period, prior to treatment.**

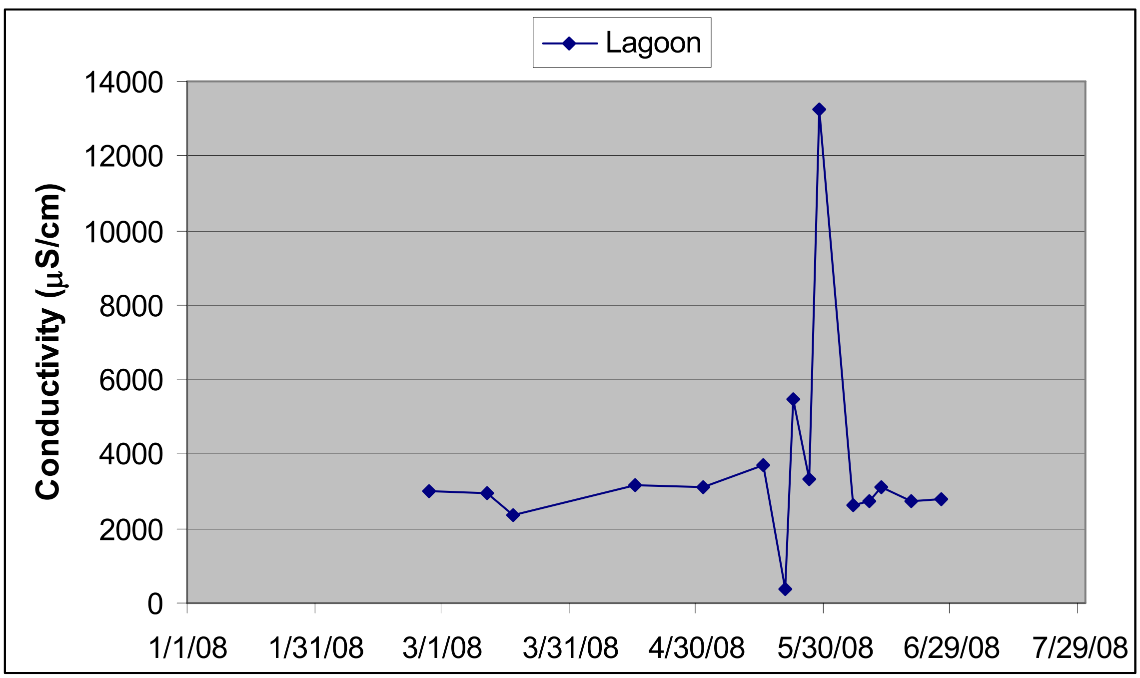



**Figure 78. Conductivity in the Larson Barn 8 secondary lagoon HWTT system during the background monitoring period.**

The Barn #8 HWTT system consists of a front-end compartment of floating vegetation deployed in the lagoon. The compartment is roughly circular, and consists of a floating boom and barrier that extends into the lagoon sediments. Submersible pumps are used to feed water from this compartment to the back-end flocculation unit process, comprised of four 1500 – 2000 gallon tanks (Figure 79 and Figure 80). The tanks are equipped with conical bottoms to facilitate withdrawal of both floc and clarified supernatant. This unit process also incorporates plumbing to facilitate floc recirculation, which, once optimized, should markedly reduce chemical use.

The spent floc is discharged into an isolated earthen compartment within the secondary lagoon. The treated supernatant is discharged behind a barrier situated along the northern bank of the lagoon (Figure 79 and Figure 80). System capacity is approximately 70 gals/min., which under continuous operation is comparable to the daily discharge of barnwash to the lagoon (~100,000 gpd).

Because the floating plant (water hyacinths) had not completed the grow-in stage of the "front-end" lagoon system at the time of this report, we do not have data to demonstrate its effective conversion of relatively stable PP form to the more desirable, highly reactive SRP form. We therefore present data from one of our prior studies at an adjacent lagoon (Larson Barn #8), in which several different wetland configurations were utilized to treat lagoon waters. Given adequate hydraulic retention times, all of the wetland configurations, including water hyacinth, effectively converted much of the PP to SRP (Figure 81).

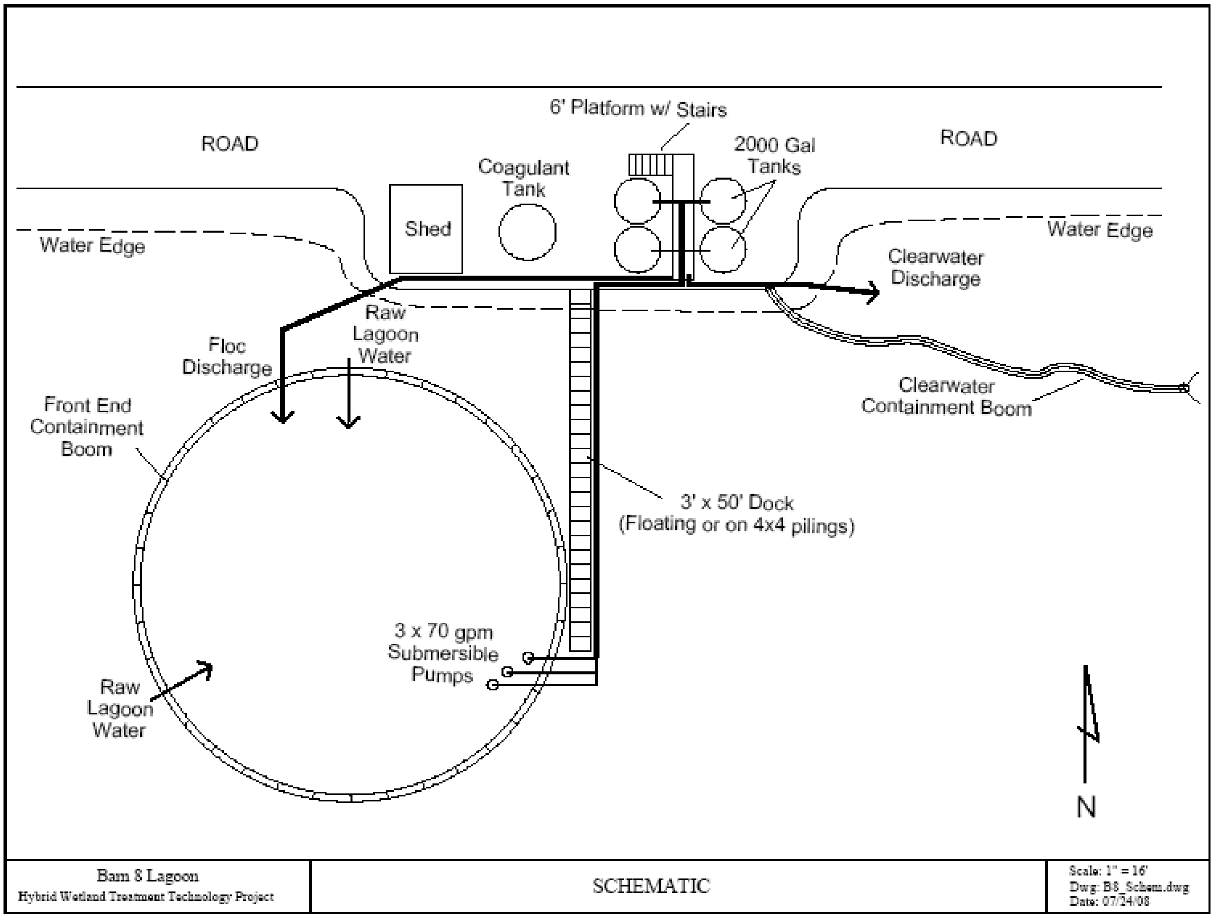



**Figure 79. Schematic of the Barn #8 lagoon HWTT system.**

**Figure 80. Unit processes and operation of the Barn #8 lagoon HWTT system. Clockwise, from top left: floating vegetation compartment; floc contact and clarification chambers; untreated lagoon water being fed to a floc chamber; treated effluent discharged to the northern edge of the lagoon.**

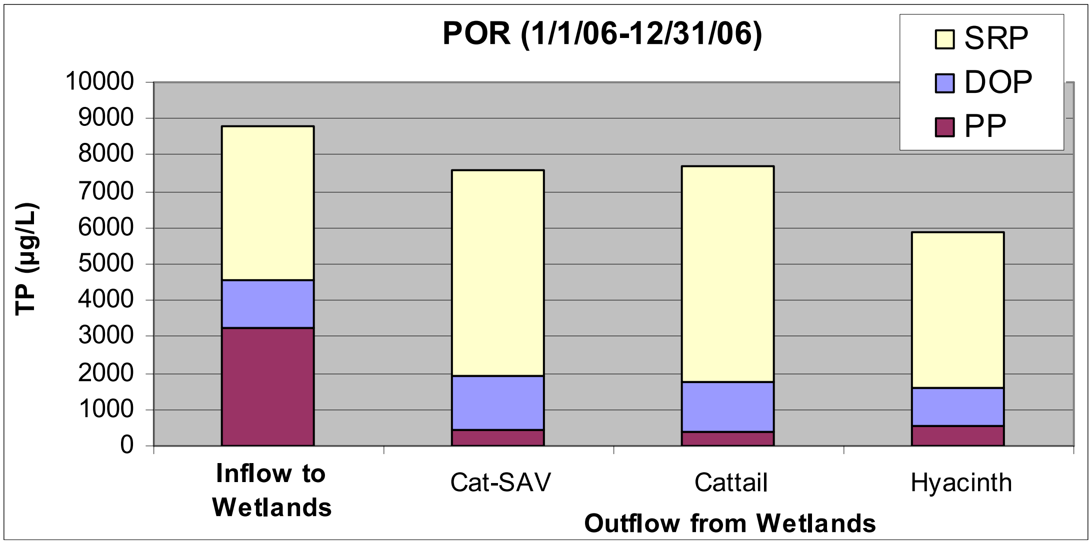



**Figure 81. Data from a prior study using pilot-scale wetlands to treat Larson Barn #5 lagoon waters. Note the reduced particulate P (PP) levels, and the high percentage of soluble reactive P (SRP) in the wetland outflows relative to the raw lagoon water.**

Our initial tests of the back-end HWTT (Figure 79 and Figure 80) show that the system reduced lagoon TP levels from 16,700 µg/L to 1470 µg/L, and SRP levels from 6800 µg/L to 7 µg/L, using an alum dose of 200 mg/L (Figure 82). We also tested the effectiveness of supplemental floc recycling, achieving a reduction in TP levels from 16,700 µg/L to 4920 µg/L, and SRP levels from 6800 µg/L to 37 µg/L, using an alum dose of 100 mg/L (one-half the previous rate) supplemented with recycled floc (Figure 82). Additional reduction of TP to 950 µg/L and SRP to 5 µg/L was achieved after a second alum dose of 100 mg/L (total of 200 mg/L). Thus, the utilization of floc recycling resulted in a 35% lower final (effluent) TP concentration than alum dosing alone. The effectiveness of floc reuse will be further optimized and refined during future operations. The effective removal of SRP by the coagulation/flocculation unit process (Figure 82) also illustrates the importance of converting as much of the PP and DOP as possible to SRP in the system's front-end vegetated compartment. It also should be noted that the lagoon water is highly buffered, so only minimal declines in pH were observed as a result of coagulant additions.

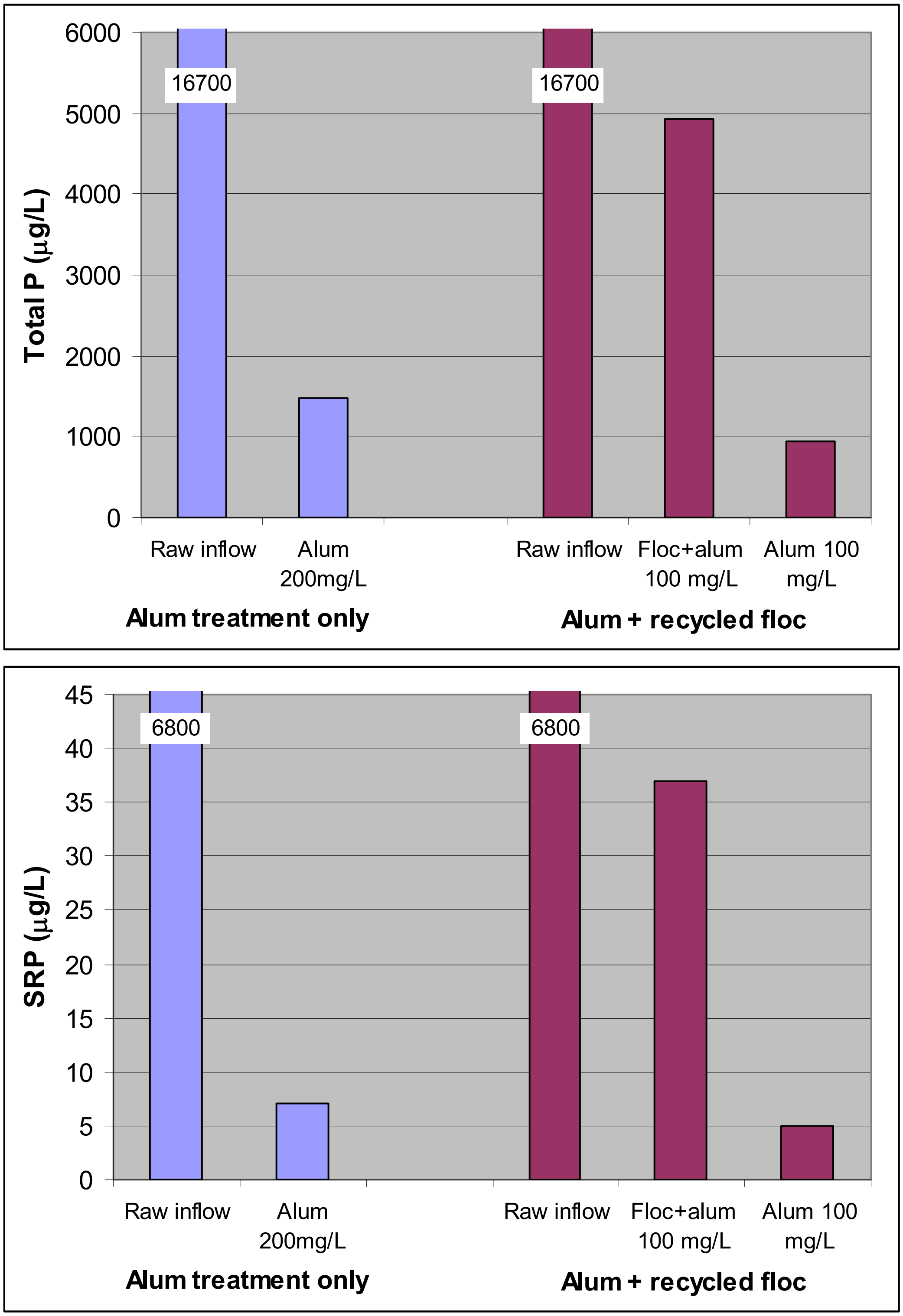



**Figure 82. Phosphorus (TP and SRP) removal performance by the HWTT lagoon treatment system, operated without (left) and with (right) floc recycle.**

# Amendment Use in HWTT Systems

## *Buffer Optimization for pH Control*

One factor that influences overall HWTT facility amendment costs is the requirement for buffering of the inflow water. Many of the common coagulants (alum, ferric chloride) are acidic, and during times when the inflow waters contain insufficient alkalinity, a buffer must be added to prevent large declines in pH. At Nubbin Slough, the previous “Dairy BAT” chemical treatment project addressed this issue by using a polyaluminum chloride compound (“Hyper-ion”). This chemical is quite expensive, and we found it to be ineffective when the site inflow waters contain high color concentrations, such as occur under rainfall-driven flow events.

Instead of Hyper-ion, for the HWTT facility at Nubbin Slough we have been using a blend of alum and sodium aluminate ($Na_2Al_2O_4$) to maintain optimal pH levels. We had previously evaluated proper dosing ratios using laboratory “jar tests”. Following the installation of our process control instrumentation, however, it has become simple to perform real-time adjustments of coagulant and buffer dosing rates to the mixing chamber using our computer and programmable logic controller. We therefore performed an assessment to “fine-tune” buffer (sodium aluminate) dosing rates under actual operational conditions.

For this assessment mixing intensity in the mixing chamber was held constant, and the alum feed rate was set at 5.5 mg Al/L. The evaluation consisted of varying the feed rate of sodium aluminate, with the alum feed rate held constant. Four treatments were used: 0.0, 4.11, 8.22, and 12.3 mg Al/L as sodium aluminate. As in the mixing evaluation, at least 30 minutes was allowed between sample collection times to allow the mixing chamber to equilibrate to the new feed rate.

We found that reducing the aluminate feed rate had a dramatic effect on both pH and floc settling. With no aluminate addition, pH after one hour of settling was 4.1 (±0.1 SD), compared to a final pH of 6.6 at an aluminate feed rate of 12.3 mg Al/L (Table 1). For each unit increase in the aluminate feed rate, there was a 0.22 increase in pH (Figure 83).

The depth of settled floc was also directly proportional to the aluminate feed rate, and did not seem to show any tendency to decline at the highest rate used in this experiment (Figure 84). There was considerable suspended floc remaining in the water column in the "no aluminate" treatment at the end of the one-hour settling period.

**Table 1. Temperature, pH, and settled alum floc thickness during the sodium aluminate dosing assessment. Sodium aluminate feed rate is expressed as mg Al/L.**

| Treatment | | Temperature, $^{o}$C | | pH, units | | thickness., cm | |
|---|---|---|---|---|---|---|---|
| mg Al/L | Rep. | t = 0 | t = 1hr | t = 0 | t = 1hr | t = 0.5 | t = 1hr |
| 0.00 | I | 28 | 29.5 | 4.3 | 4.1 | 0.5 | 0.5 |
| 0.00 | II | | 29.3 | | 4 | 0.5 | 0.5 |
| 4.11 | I | 26.5 | 28.6 | 5.4 | 4.4 | 1.0 | 1.0 |
| 4.11 | II | | 29.2 | | 4.5 | 1.0 | 1.0 |
| 8.22 | I | 29.2 | 28.9 | 6.5 | 5.6 | 2.5 | 1.5 |
| 8.22 | II | | 28.8 | | 5.8 | 2.5 | 1.6 |
| 12.3 | I | 31.4 | 31.1 | 6.5 | 6.6 | 3.5 | 2.5 |
| 12.3 | II | | 30.4 | | 6.6 | 3.3 | 2.5 |

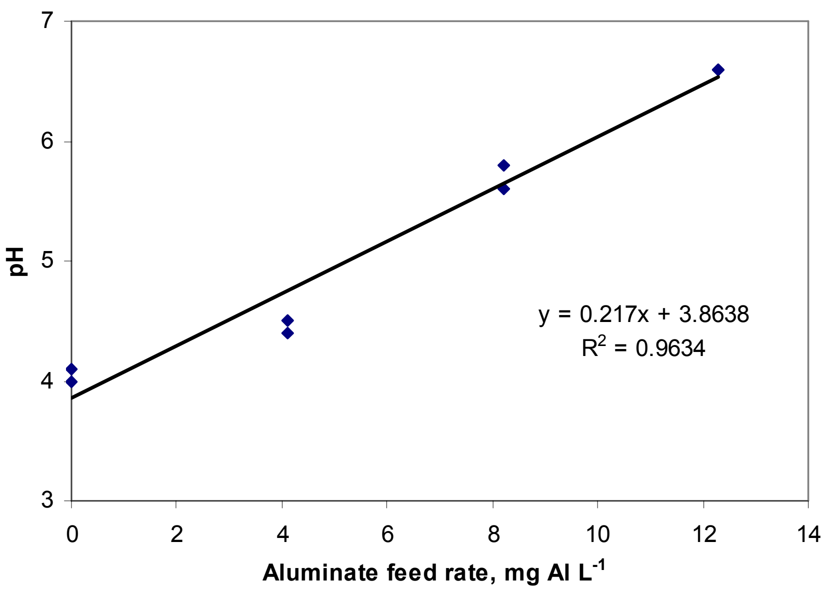



**Figure 83. Relationship between the sodium aluminate feed rate and pH in settling columns containing samples collected from the Nubbin Slough HWTT mixing chamber.**

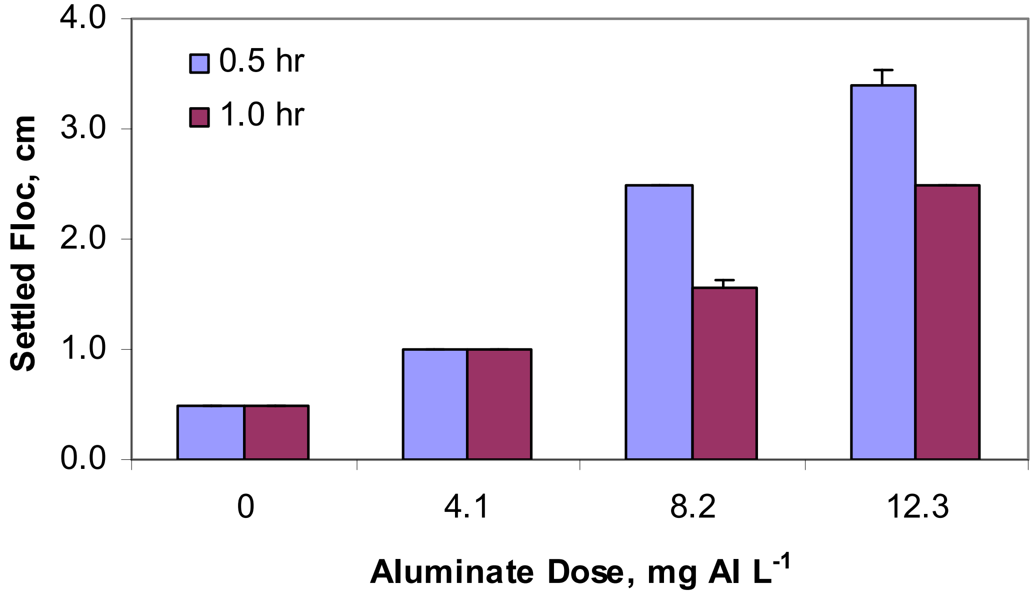



**Figure 84. Depth of settled floc in settling columns containing samples collected from the Nubbin Slough HWTT mixing chamber. Error bars represent one standard deviation.**

Aluminate feed rate had a pronounced effect on water quality. Even with no aluminate added, TP was reduced with alum addition alone, from 482 μg/L in the untreated influent water, to 198 μg/L after one hour of settling (Figure 85). Similar reductions were observed in both color (Figure 86) and turbidity (Figure 87). Addition of alum caused a large initial increase in turbidity as a result of floc formation. Lower levels of turbidity and color were associated with lower TP levels after one hour of settling (Figure 88 and Figure 89).

In summary, the sodium aluminate feed rate to the Nubbin Slough HWTT mixing chamber had a pronounced effect on both pH and depth of settled floc. Cessation of sodium aluminate feed resulted a final water column pH of approximately 4.0, considerable turbidity remaining in the water column, and very little settled floc. The highest feed rate (12.3 g Al $L^{-1}$) produced a settled floc thickness of 2.5 cm and a final pH of 6.6. Greater aluminate feed rates resulted in increased removal of TP, color, and turbidity.  While aluminate additions improved performance, it is important to note that this chemical is more expensive than alum, and that system operational costs increase markedly with its use.

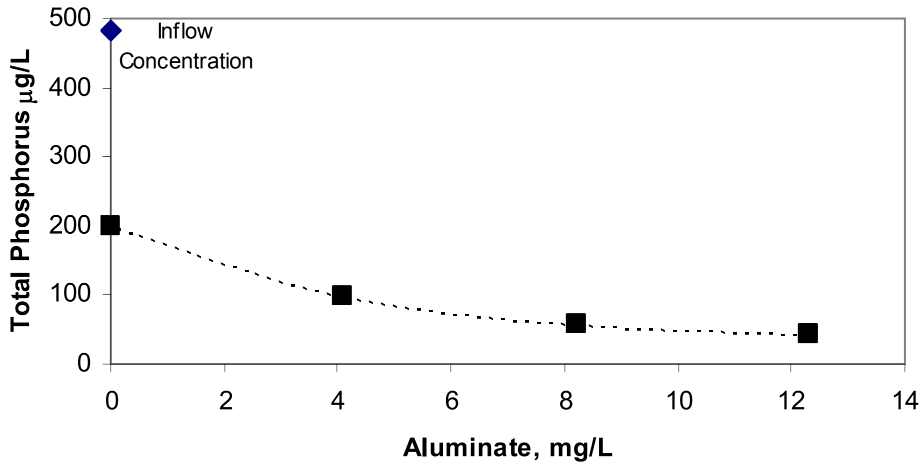



**Figure 85. Relationship between sodium aluminate feed rate and supernatant TP in settling columns containing waters collected from the Nubbin Slough HWTT mixing chamber. Column supernatant samples were collected for analysis after one hour of settling.**

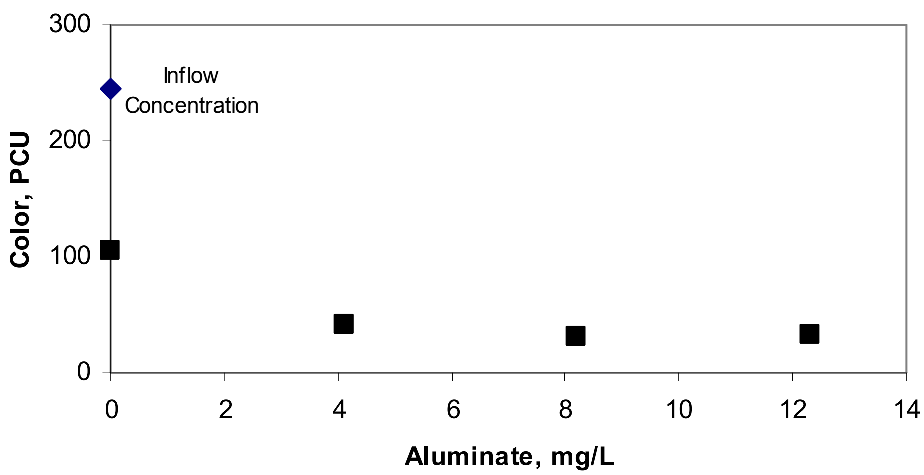



**Figure 86. Relationship between sodium aluminate feed rate and color in settling columns containing waters collected from the Nubbin Slough HWTT mixing chamber. Measurements were performed after one hour of settling.**

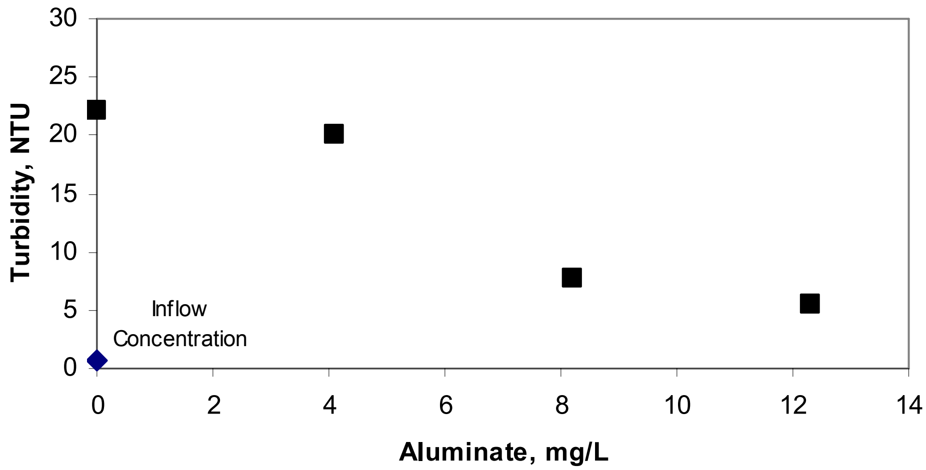



**Figure 87. Relationship between sodium aluminate feed rate and turbidity in settling columns containing waters from the Nubbin Slough HWTT mixing chamber. Measurements were performed after one hour of settling.**

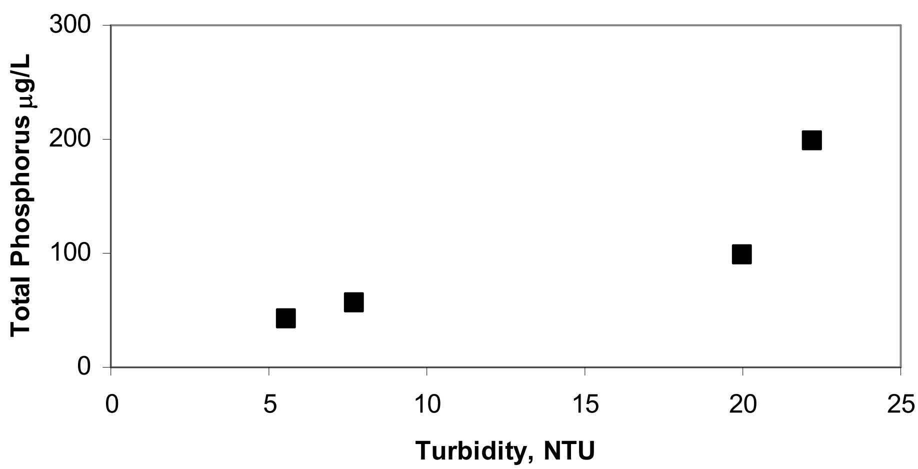



**Figure 88. Relationship between turbidity and TP in settling columns containing waters from the Nubbin Slough HWTT mixing chamber. Column supernatant samples were collected for analysis after one hour of settling.**

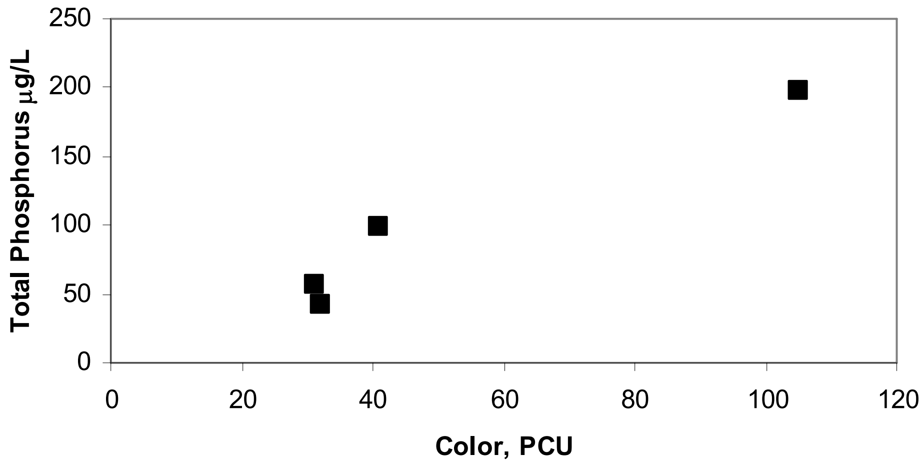



**Figure 89. Relationship between color and total phosphorus in settling columns containing waters from the Nubbin Slough HWTT mixing chamber. Column supernatant samples were collected for analysis after one hour of settling.**

## *Utilization of the Back-End HWTT Wetland Components for Buffering and Polishing*

The HWTT concept focuses on utilizing the wetland vegetation community, downstream of the amendment dosing process, to help minimize amendment use and to provide additional polishing. One technique we have evaluated previously is to incorporate a submerged aquatic vegetation/limerock (SAV/LR) system as part of the downstream wetland configuration. SAV/LR systems can be very effective at providing a low P concentration effluent, due to the SAV community's ability to compete well with phytoplankton for nutrients and light. Moreover, it provides effective pH control, typically elevating the pH of the inflow waters. Our project team pioneered the SAV/LR concept in the 1990's, and it has been tested and utilized in the Everglades STAs.

With the onset of the wet season in summer 2008, we observed a decrease in the alkalinity of the Mosquito Creek waters. Low alkalinity levels are problematic for many chemical amendment systems (such as those that utilize alum), because they require the addition of a second chemical, to serve as a buffer. Without adequate buffering, outflow pH levels can be acidic, as shown above for the Nubbin Slough HWTT. Moreover, buffers often are hazardous and difficult to handle (e.g., NaOH), and/or relatively expensive (e.g., sodium aluminate). During late May and June, we therefore utilized our mesocosm facility (Figure 90) to demonstrate the use of a SAV/LR unit process as an effective back-end for polishing, and for counteracting the pH reductions caused by alum additions.

Mesocosm Trains 1 and 4 (vegetated, 1 and 2-day HRT, respectively) were configured with a SAV-limerock polishing stage (similar to the SAV mesocosm shown in Figure 91), while Train 2 (vegetated, 4-day HRT) and Train 3 (non-vegetated control, 1-day HRT) were unchanged. All systems received the same concentration of amendment (alum) dose, approximately 20 mg Al/L.

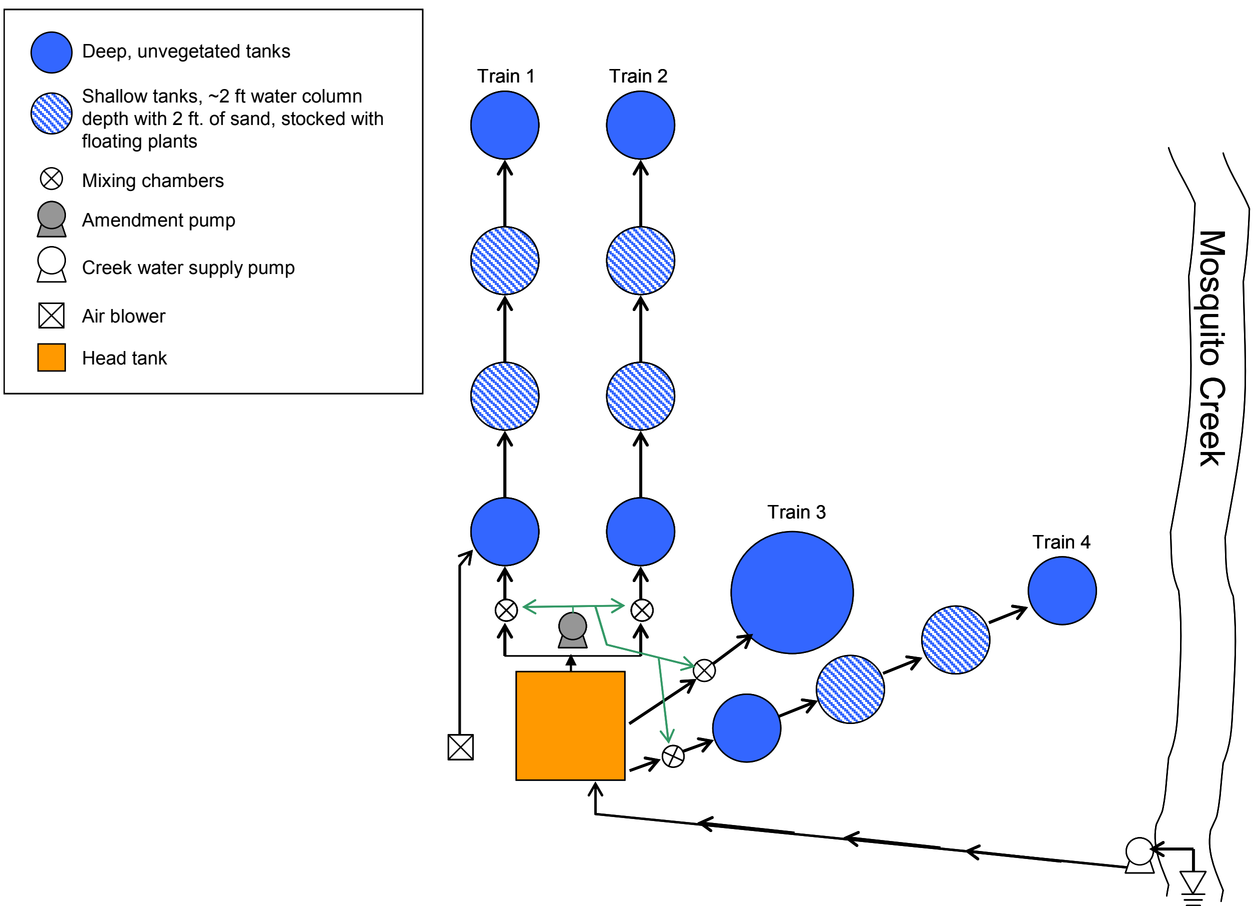



**Figure 90. Schematic of Mosquito Creek mesocosm facility. In addition to the tanks shown, Trains 4 and 1 were equipped with a final SAV/LR unit process for polishing and buffering.**

**Figure 91**. **Mesocosm facility (left), and mesocosm containing submerged aquatic vegetation (SAV) at the Mosquito Creek optimization facility.**

Water chemistry in Trains 1 and 4 was monitored during May and June at the mesocosm inflow and at the outflows of the contact zone, filtration zone (post-water hyacinths), and polishing zone (post-SAV-limerock). Based on these monitoring results, the SAV-limerock treatment stage was consistently effective in providing supplemental TP removal in the 1-day HRT vegetated HWTT system.

Time series plots for TP, alkalinity, pH, color and turbidity, comparing levels measured in the Train 1 outflow with mesocosm inflow and Train 3 (non-vegetated control) outflow are shown in Figure 92 - Figure 96. These monitoring results indicate that the Train 1 vegetated HWTT treatment system (HRT = 1 day) with SAV-limerock post treatment consistently outperformed the non-vegetated treatment system (Train 3) during the comparative-monitoring period, for removal of TP and color from inflow water, and for maintaining desirable levels of alkalinity, pH and turbidity along the flow path.

Mean values for TP, alkalinity, pH, color and turbidity in mesocosm inflow and outflows (Trains 1-4) are presented in Figure 97 - Figure 101. These results show that the Train 1 vegetated HWTT treatment system (HRT = 1 day) with SAV-limerock post treatment provided the greatest reduction in TP concentration during the study period, followed closely by the Train 2 vegetated HWTT system (HRT = 4 days) and the Train 4 vegetated HWTT treatment system (HRT = 2 days) with SAV-limerock post treatment (Figure 97). Mean TP concentration in the mesocosm inflow was 1023 μg/L, compared with outflow concentrations of 26 μg/L in Train 1, 43 μg/L in Train 2, 48 μg/L in Train 4 and 160 μg/L in Train 3.

In addition to achieving a high levels of TP removal, Trains 1 and 4 (SAV-limerock post treatment) maintained alkalinity levels in the outflow stream that were comparable to the alkalinity of the inflow stream (Figure 98). Mean alkalinity values at the Train 1 and 4 outflows were 79 and 82 mg/L, respectively, compared to 72 mg/L in the inflow stream. In contrast, mean alkalinity was 14 mg/L at the outflows of both Trains 2 and 3. Similarly, pH levels in the outflows of Trains 1 (6.5) and 4 (6.7) were comparable to inflow pH (6.4), and substantially higher than outflow pH of Trains 2 (5.3) and 3 (4.9) (Figure 99).

Trains 1 and 4 also outperformed Trains 2 and 3 in reducing color levels in the flow path (Figure 100). Mean values for color were 461 CPU in the mesocosm inflow and 85, 94, 183 and 259 CPU at the outflows of Trains 1, 4, 2 and 3, respectively. Trains 1, 2 and 4 all achieved markedly lower turbidity levels in the outflow than did Train 3, the only non-vegetated treatment train (Figure 101).

The results of this comparative study show that Trains 1 and 4, both vegetated (HWTT) systems with the incorporation of a SAV-limerock stage, provided a high level of TP removal, as did the vegetated system without SAV-limerock post-treatment (Train 2), while also maintaining inflow levels of alkalinity and pH, in contrast to the Train 2 and 3 (non-vegetated) mesocosm systems. Overall, Train 1 represented the most effective treatment system configuration during the May-June monitoring period, particularly when the shorter HRT is taken into account. During 2008 – 2009, we plan to incorporate SAV/LR unit processes, where appropriate, into selected northern Everglades HWTT systems.

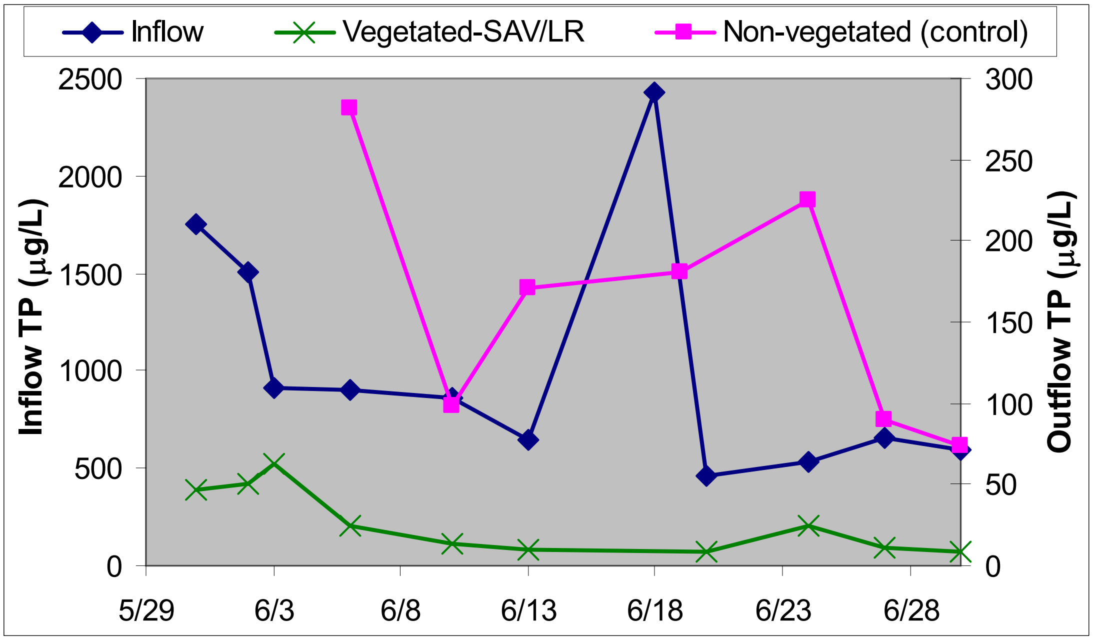



**Figure 92. Total P at the mesocosm inflow and outflows of Train 1 (vegetated HWTT with SAV-limerock) and Train 3 (non-vegetated control). Note that outflow TP values are on the axis to the right.**

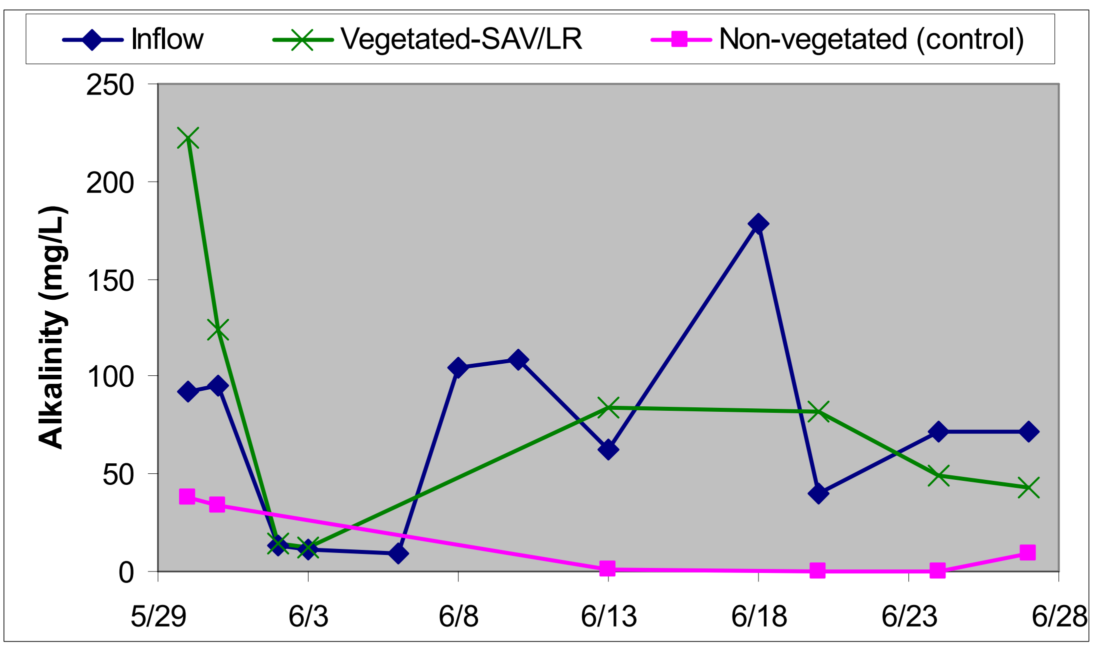



**Figure 93. Alkalinity at the mesocosm inflow and outflows of Train 1 (vegetated HWTT with SAV-limerock) and Train 3 (non-vegetated control).**

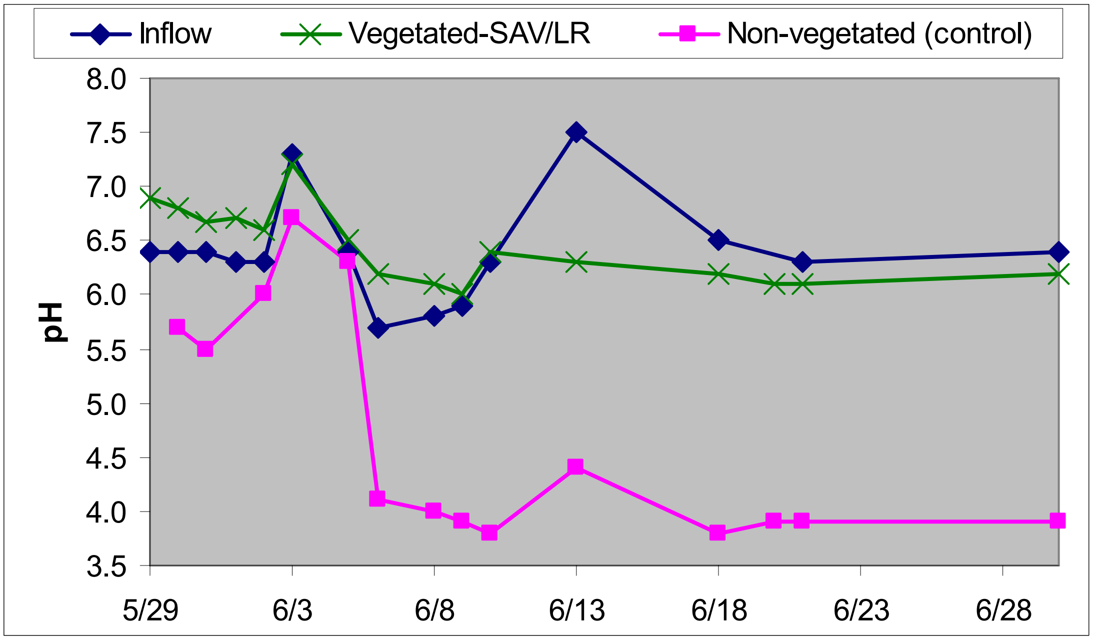



**Figure 94**. **pH at the mesocosm inflow and outflows of Train 1 (vegetated HWTT with SAV-limerock) and Train 3 (non-vegetated control).**

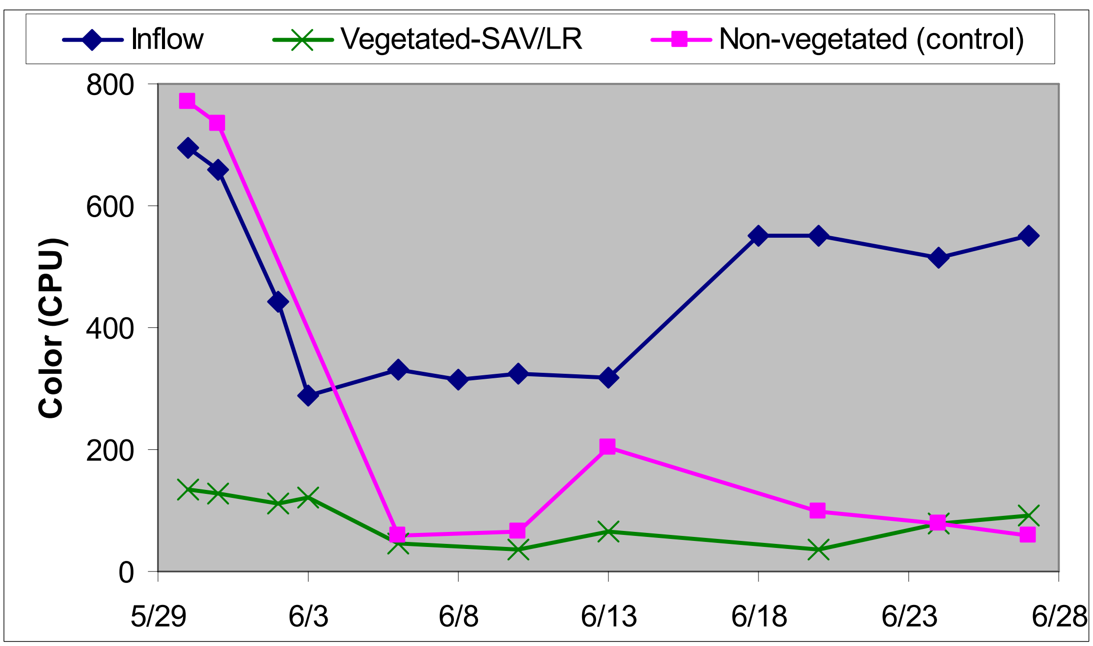



**Figure 95**. **Color at the mesocosm inflow and outflows of Train 1 (vegetated HWTT with SAV-limerock) and Train 3 (non-vegetated control).**

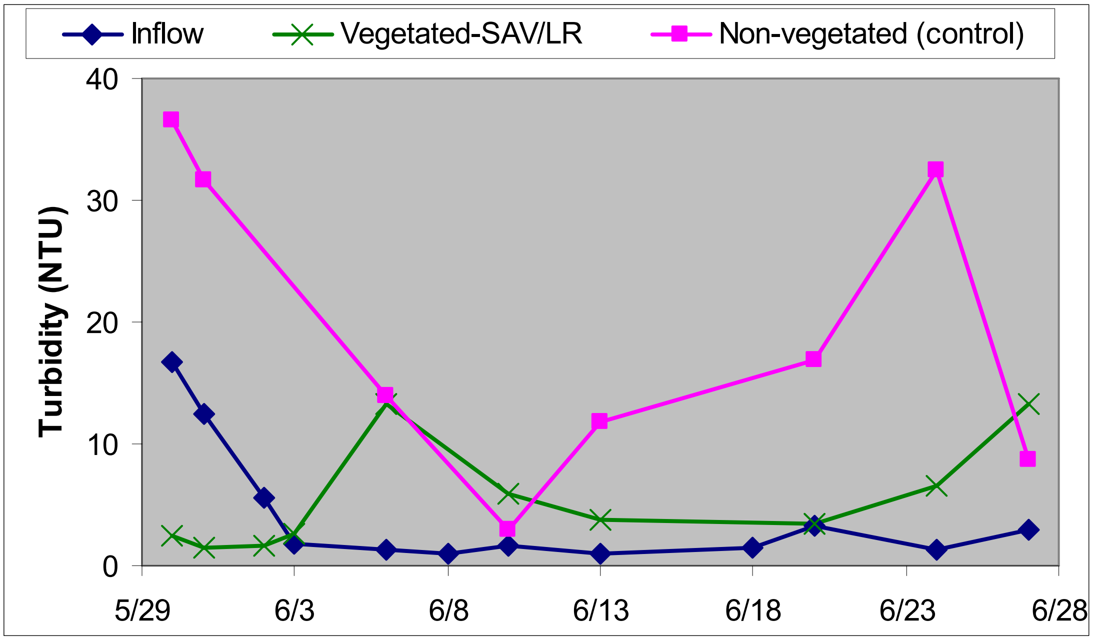



**Figure 96**. **Turbidity at the mesocosm inflow and outflows of Train 1 (vegetated HWTT with SAV-limerock) and Train 3 (non-vegetated control).**

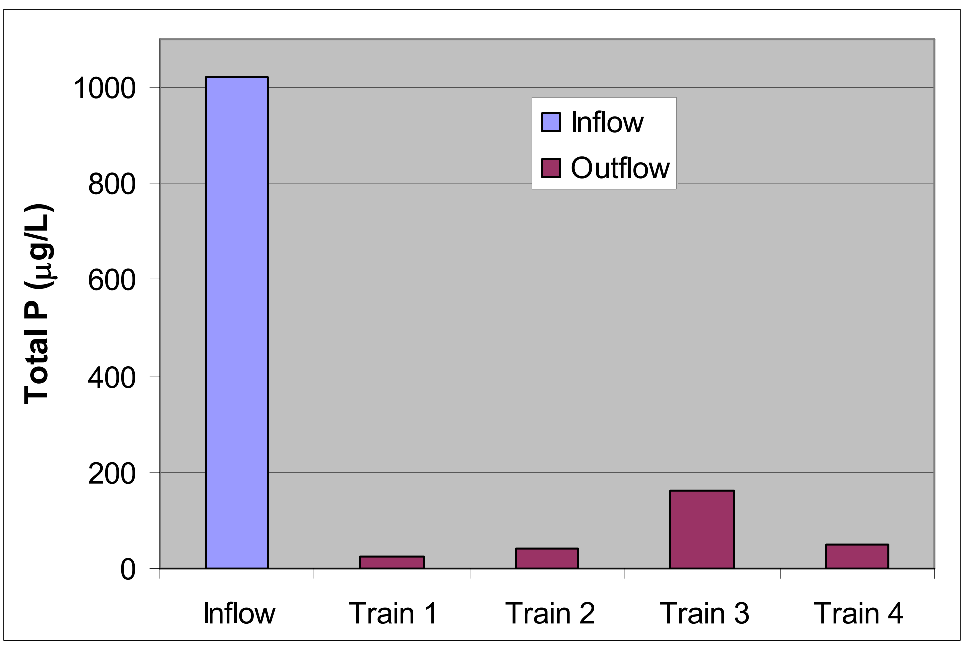



**Figure 97**. **Comparison of mean values for TP in mesocosm inflow and outflows of Trains 1-4. Trains 1 and 4 are HWTT systems with SAV/LR, Train 2 is a HWTT without SAV/LR and Train 3 is a control (conventional chemical treatment).**

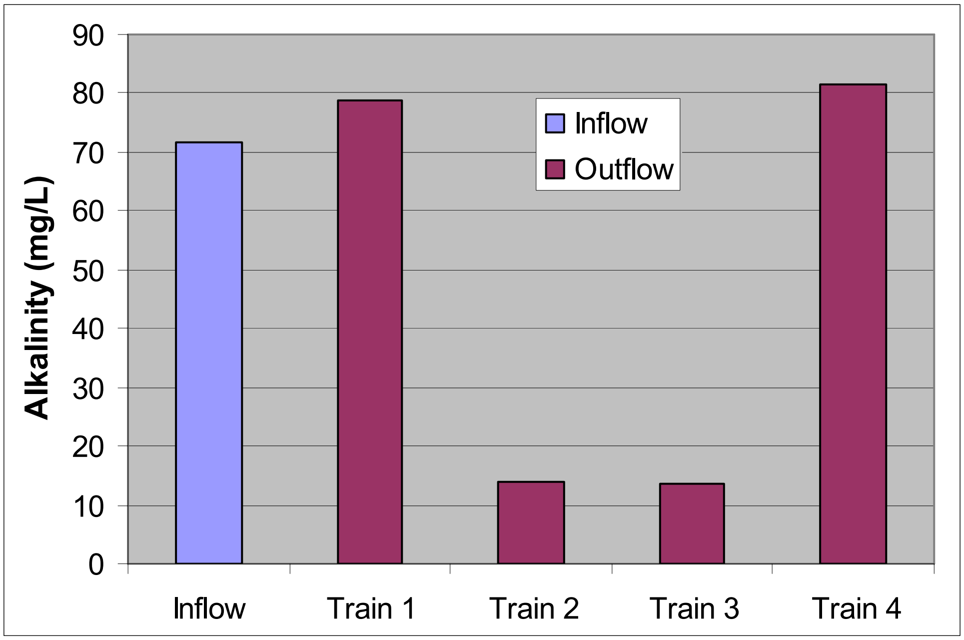



**Figure 98.  Comparison of mean values for alkalinity in mesocosm inflow and outflows of Trains 1-4. Trains 1 and 4 are HWTT systems with SAV/LR, Train 2 is a HWTT without SAV/LR and Train 3 is a control (conventional chemical treatment).**


**Figure 99.  Comparison of mean values for pH in mesocosm inflow and outflows of Trains 1-4. Trains 1 and 4 are HWTT systems with SAV/LR, Train 2 is a HWTT without SAV/LR and Train 3 is a control (conventional chemical treatment).**

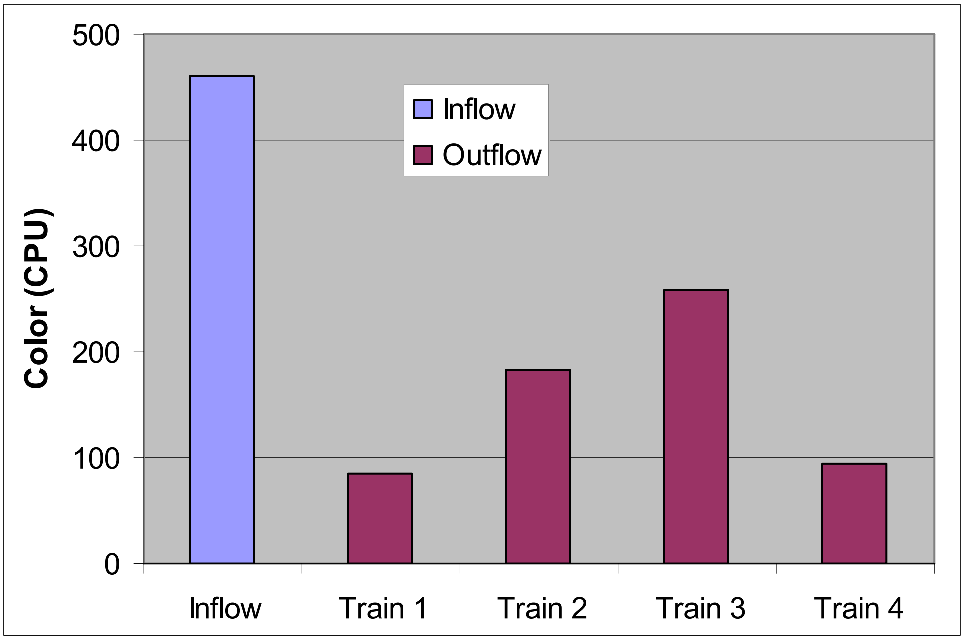



**Figure 100**. **Comparison of mean values for color in mesocosm inflow and outflows of Trains 1-4. Trains 1 and 4 are HWTT systems with SAV/LR, Train 2 is a HWTT without SAV/LR and Train 3 is a control (conventional chemical treatment).**

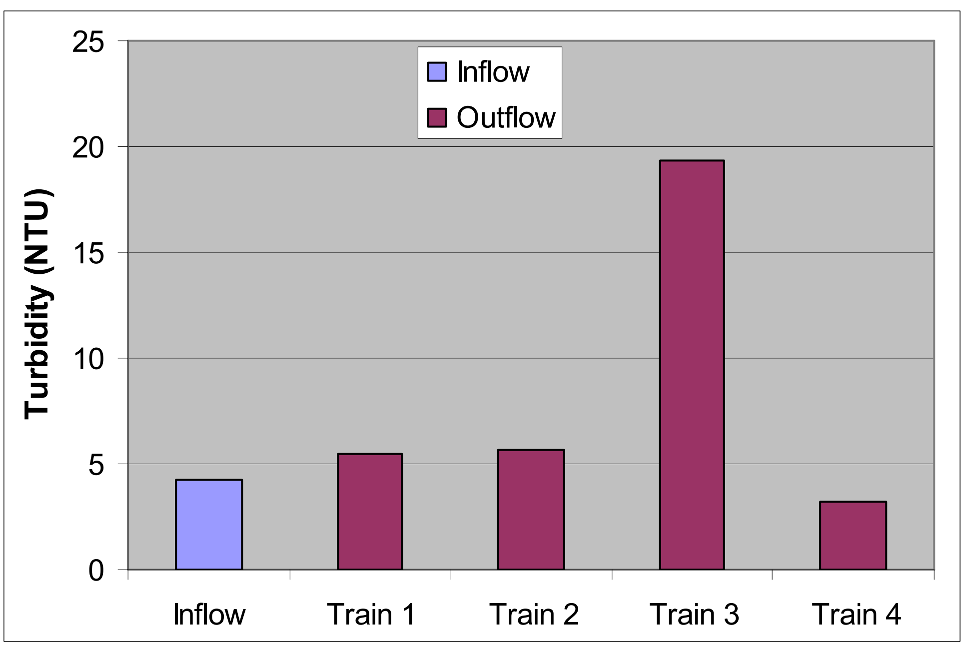



**Figure 101**. **Comparison of mean values for turbidity in mesocosm inflow and outflows of Trains 1-4. Trains 1 and 4 are HWTT systems with SAV/LR, Train 2 is a HWTT without SAV/LR and Train 3 is a control (conventional chemical treatment).**

### *Diel Monitoring of Mesocosm pH and Temperature*

For the SAV/LR unit process to serve as a buffer and polishing system, it needs to function effectively even during nighttime, at time when no photosynthesis (and associated pH) elevation is occurring. We therefore evaluated diurnal variability of pH and temperature in mesocosm treatment Trains 1 and 4 during a 24-hour period on 5/30 – 5/31/08. Measurements were taken approximately every 6 hours at the mesocosm inflow and the outflows of the contact zone (tank A), filtration zone (tank D) and polishing zone (tank F) of Trains 1 and 4. Results of the diel study, presented in Figure 102 -Figure 105, indicate a relatively small degree of diurnal variability in pH for all stages in the treatment train. In contrast, variability in pH was much greater along the flow path, with highest levels measured in the inflow and outflow (post SAV-limerock) and depressed levels in the contact and filtration zones (pre SAV-limerock). Temperature showed a general increase through the treatment trains, relative to the inflow water, and exhibited typical diurnal variability in all stages of both flow trains.

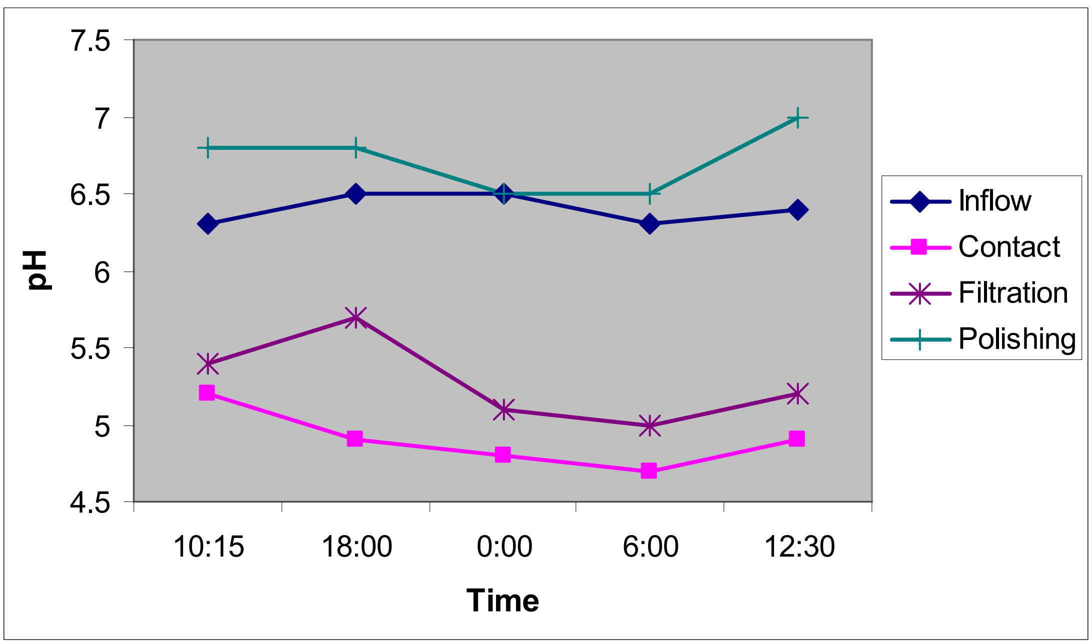



**Figure 102. Diurnal variability of pH in mesocosm inflow and outflow of Contact Zone (pre-hyacinth), Filtration Zone (post-hyacinth and SAV), and Polishing Zone (post SAV-limerock) in Train 1 (HRT=1d).**

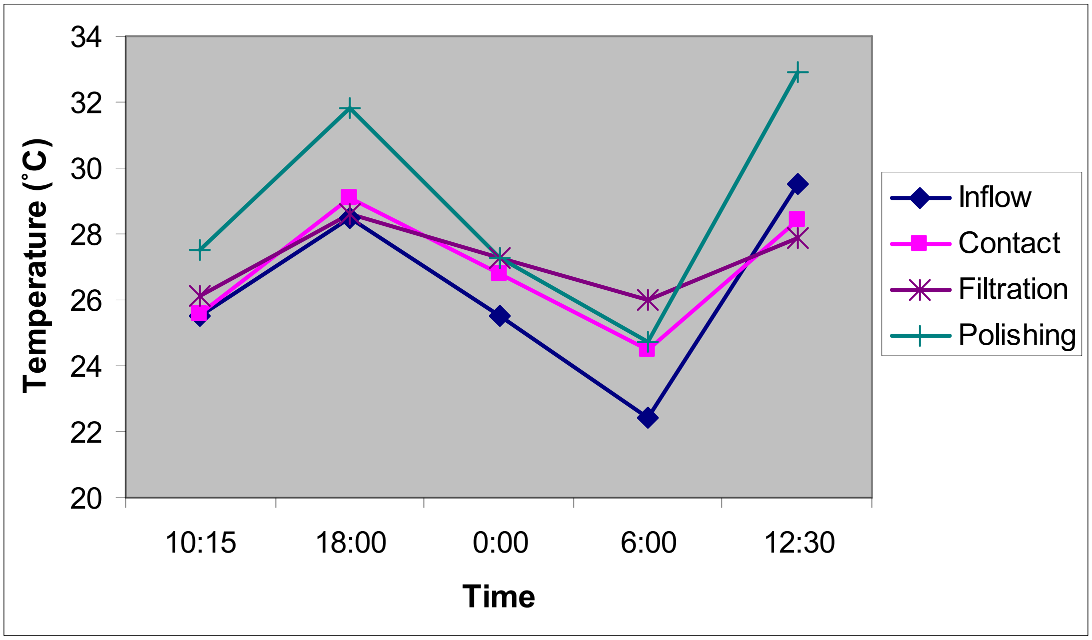



**Figure 103**. **Diurnal variability of temperature in mesocosm inflow and outflow of Contact Zone (pre-hyacinth), Filtration Zone (post-hyacinth and SAV), and Polishing Zone (post SAV-limerock) in Train 1 (HRT=1d).**

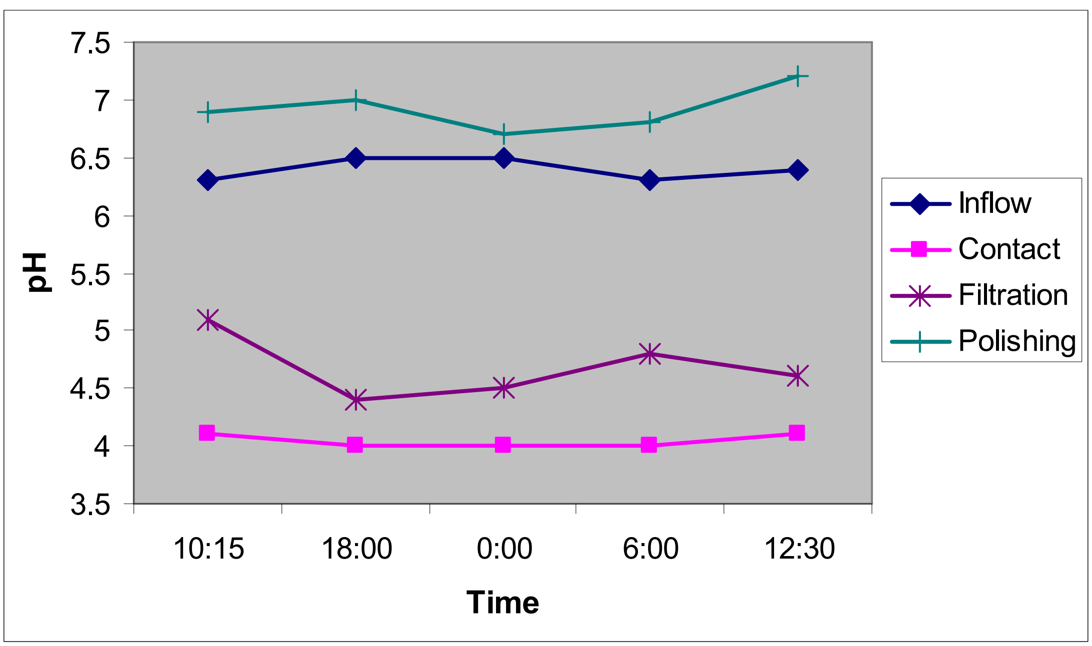



**Figure 104**. **Diurnal variability of pH in mesocosm inflow and outflow of Contact Zone (pre-hyacinth), Filtration Zone (post-hyacinth and SAV), and Polishing Zone (post SAV-limerock) in Train 4 (HRT=2d).**

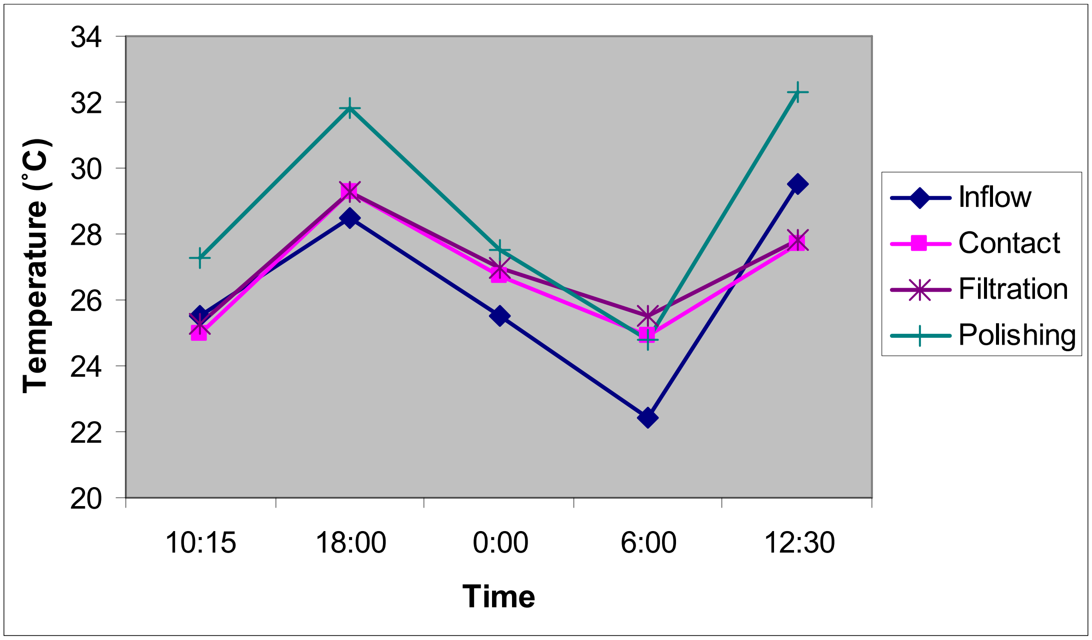



**Figure 105**. **Diurnal variability of pH in mesocosm inflow and outflow of Contact Zone (pre-hyacinth), Filtration Zone (post-hyacinth and SAV), and Polishing Zone (post SAV-limerock) in Train 4 (HRT=2d).**

## *Vegetation Effects on HWTT Performance*

With the exception of our initial measurements at the Ideal facility (see Figure 39 & Figure 40), none of our spatial and side-by-side comparisons at the demonstration sites (i.e., Ideal Grove 2, Mosquito Creek, Nubbin Slough) elucidate a direct measure of the effects of vegetation on performance. Our previous assessments have shown that vegetation plays an integral role with respect to performance of HWTT systems, and can also help minimize amendment use. In a conventional treatment wetland, a principal role of vegetation is to assimilate nutrients, and to provide an attachment site (as well as decomposition products, or exudates) for microbial communities that process water column nutrients. In HWTT systems, the vegetation not only provides these same functions, but it also serves as a filter and provides an attachment site for flocs created by upstream amendment additions (Figure 106).

To better illustrate beneficial effects of vegetation, we performed a three-month long assessment at the Mosquito Creek mesocosm facility in which we compared P removal performance of a vegetated HWTT system with a mesocosm without vegetation. During this period, the mesocosms were operated at a hydraulic retention time (HRT) of 28 hours, with coagulant dosing (alum at ~20 mg Al/L) provided on either a continuous basis.

The mesocosm inflow TP averaged 403 µg/L during this period, while mean outflow TP concentrations from the vegetated and non-vegetated systems were 95 and 175 µg/L, respectively (Figure 107). Study results indicate that, while the non-vegetated treatment system achieved substantial reduction of TP, the vegetated treatment system (HWTT) provided an additional measure of TP reduction. The vegetated mesocosm process train also provided superior color and turbidity reductions, compared to the non-vegetated system (Figure 108 and Figure 109).

Mean color concentration in the mesocosm inflow during the study period was 292 CPU, compared with 157 CPU in the non-vegetated system and 134 CPU in the vegetated system. Mean turbidity levels were 6.6 NTU in the inflow stream, 8.7 NTU in the non-vegetated system, and 4.5 in the vegetated system.

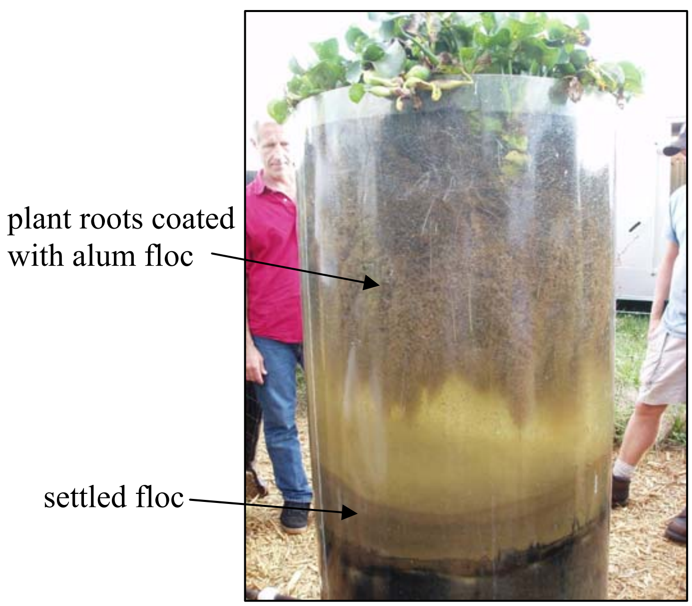



**Figure 106. Accumulation of amendment flocs on the roots of water hyacinth (*Eichhornia crassipes*) in the Mosquito Creek mesocosms, following six weeks of amendment (in this case, alum) additions.**

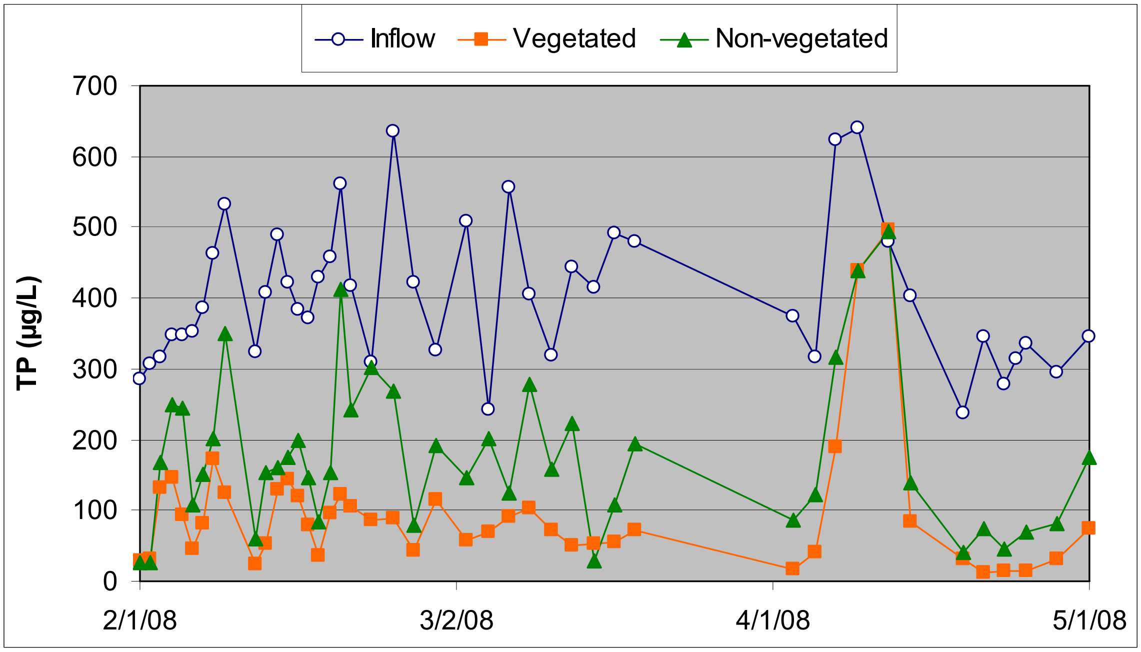



**Figure 107. Inflow (representing Mosquito Creek waters) and outflow TP concentrations for vegetated (Train 1D) and non-vegetated (Train 3) mesocosm process trains during February - April 2008.**

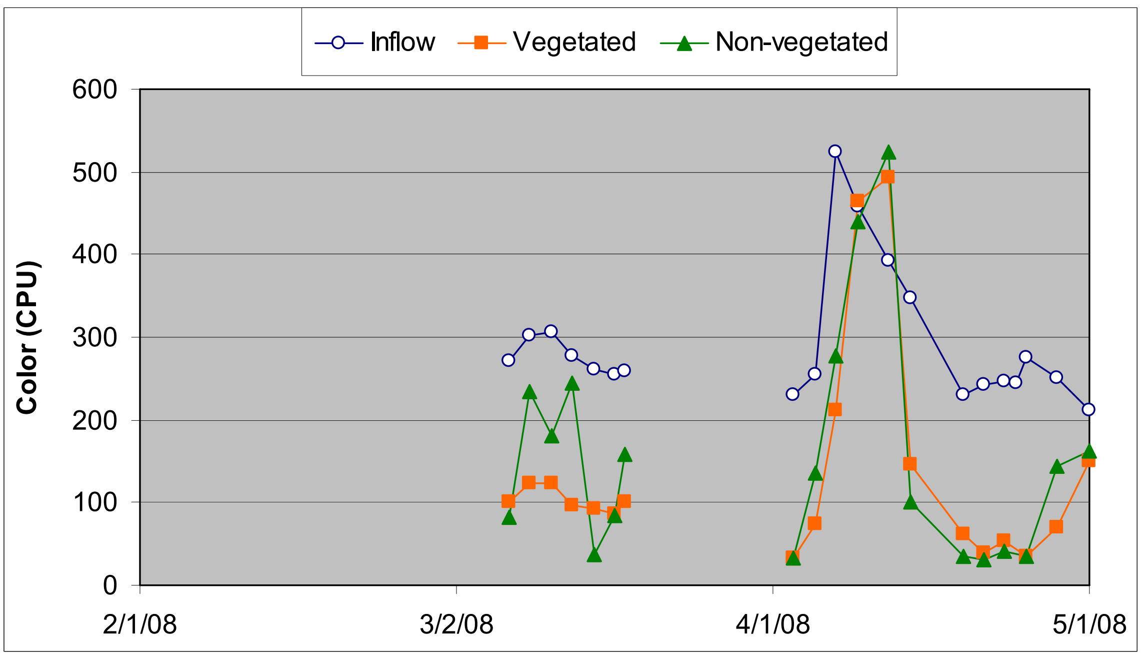



**Figure 108. Inflow (representing Mosquito Creek waters) and outflow color levels for vegetated (Train 1D) and non-vegetated (Train 3) mesocosm process trains during February - April 2008.**

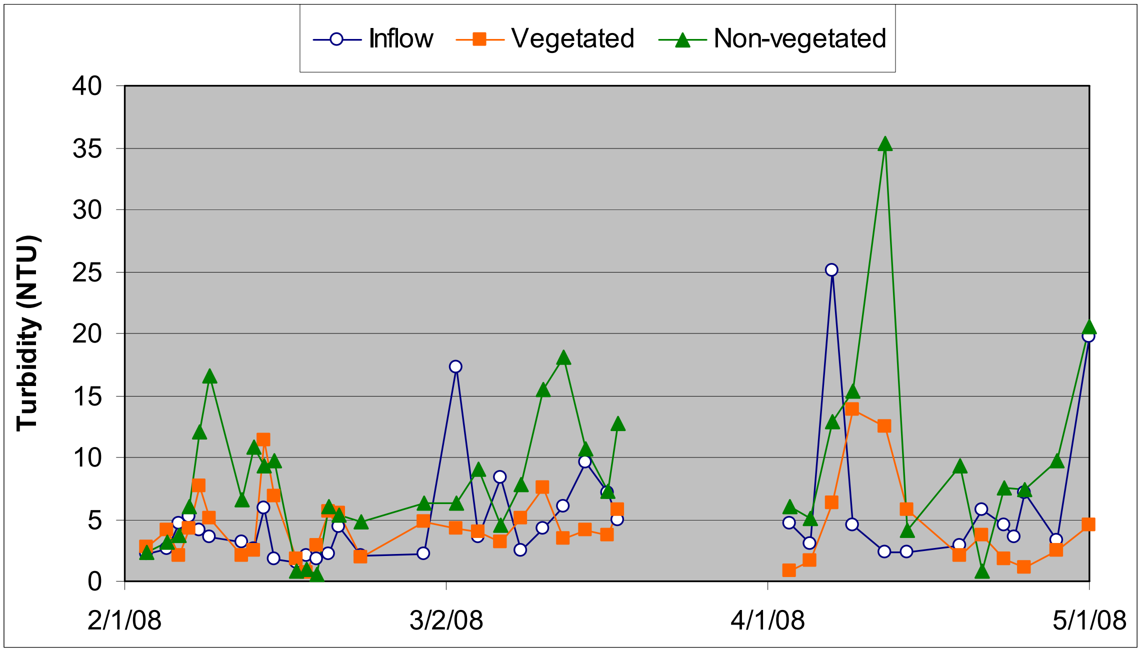



**Figure 109. Inflow (representing Mosquito Creek waters) and outflow turbidity levels for vegetated (Train 1D) and non-vegetated (Train 3) mesocosm process trains during February - April 2008.**

On several dates during this study, we also characterized the speciation of P in the Mosquito Creek mesocosm inflow and outflow waters. Summary data in Figure 110 indicate that the bulk of the inflow TP consisted of SRP, followed by PP and DOP. For both the vegetated and non-vegetated process trains, soluble P (SRP and DOP) concentrations were quite low in the outflow stream, and the primary P fraction in the out-flowing water was PP (Figure 110). Our monitoring results also show that the vegetated (HWTT) treatment system provided much greater reduction in PP concentration, as was also suggested by the lower level of turbidity in the vegetated mesocosm outflow (Figure 109). Due to the high percentage of P associated with particles within HWTT systems, the strong affinity of floating vegetation roots for particulate matter markedly reduces outflow P concentrations.

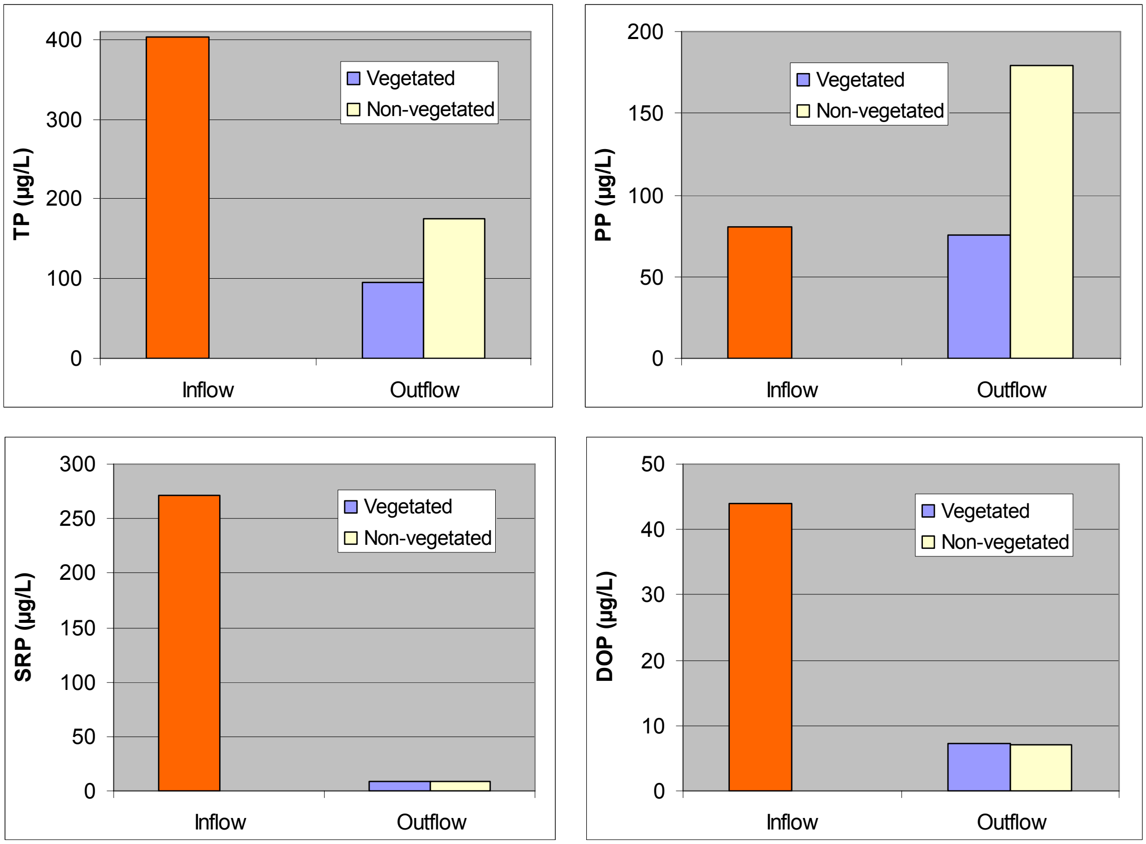



**Figure 110. Mean inflow and outflow P species concentrations for vegetated (Train 1) and non-vegetated (Train 3) mesocosm process trains during February - April 2008.**

# Residuals Management

## *Evaluation of Floc Accumulation at the Nubbin Slough and Ideal Grove HWTTs*

Over time, floc material that is created by the addition of amendments at the inflow of HWTT systems will accumulate in the "front end" contact region. In order to manage this floc material, the water level in the HWTT will be lowered during the dry season, exposing the soil in the downstream, shallow filtration zone. At this time, the floc that has accrued in the contact zone will be pumped onto the filtration zone soils, where it will be allowed to dry. The resulting mixture of plant biomass (from floating vegetation in the filtration zone) and floc material will be plowed into the shallow zone soils, and the pond will be reflooded.

It is important to note that as floc accumulates in the contact zone, it may have an influence on HWTT hydraulic characteristics, due to its effective reduction of the water depth. Early in June 2008, we performed measurements in the contact zones of the Nubbin Slough and Ideal Grove HWTTs to document the extent and depth of settled floc.

The accumulation of settled alum floc was measured on June 2-3, 2008 at the two HWTT systems. At the time of measurement, water level at the Nubbin Slough HWTT was 173.4 cm below the top surface of the concrete saddle overlying the outflow weir. This corresponds to a pond stage, relative to a site benchmark, of 109.53 feet (arbitrary datum). During the measurement of floc thicknesses and water depths, discharge was approximately 2 cfs at the HWTT. Stage at the Ideal HWTT was 41 inches according to a staff gauge within the pond.

Measurements of water depth and floc layer thickness were made with a modified flocculent sediment detector originally developed for determining the interface between the water column and soft sediment in lakes (Figure 111). The detector consists of an infrared light source and an infrared-sensitive transistor. When the light source is blocked, an electronic circuit is activated, sounding a buzzer. The device is modified such that both the interface between water and soft material can be determined, as well as the total soft bed thickness. All measurements were taken from a canoe.

**Figure 111. Flocculent sediment detector being deployed at the Ideal Grove HWTT.**

Three transects were established along the eastern flow path of the Nubbin Slough HWTT. The transects were oriented north-south along the long dimension of the HWTT “contact zone”, as follows: transect one was located 2 meters eastward of the barrier curtain, transect two was eight meters (along the center line of the flow path), and transect three was 14 meters east of the curtain (2 meters westward of the edge of the pond). Water depth and floc thickness measurements were taken every 4 meters along these transects (Table 2). Station locations were located by aligning with the floats that support the barrier curtains and cell dividers, since each float assembly is 2 meters in length. The north origin of each transect was the centerline of the mixing manifold and all transect distances are relative to this line. For example, the first station on all three transects was 3.6 meters south of the manifold. We describe results in terms of “cell” location. Cell 1 represents the northernmost (closest to inflow) cell of the contact zone, and Cell 5 represents the southernmost cell of the contact zone.

For the Ideal Grove HWTT, four parallel transects were used to determine water and floc depth, and contact zone bathymetry. The transects were numbered one through four, from north to south, with transects one and two in the northern (A) flow path, and three and four in the southern (B) flow path. Transect one was located 8 meters north of the barrier curtain, transect two was 2 meters north, transect three was 2 meters south, and transect four was eight meters south of the barrier curtain. Distance along the transects was measured from the manifold at the inflow edge of the pond.

Contour maps of settled floc thickness were developed using JMP statistical software, ver. 7 (SAS Institute, Carey, NC). Thicknesses between sampling locations were determined using a linear interpolation technique commonly known as triangulated irregular network, or “TIN”.

At the Nubbin Slough HWTT, the settled floc thickness varied from undetectable to 206 cm (Table 2 - Table 4). Thickness was greatest in the northwest inflow region of cell #1, approximately 10 meters south of the inflow manifold (Figure 112 and Figure 113). Floc layer thickness declined with distance southwestward of the inflow. Greater floc thicknesses on the western side of the first 5 cells probably were due to the bathymetry of the pond. For example, the average depth along the eastern-most transect was 166 (±26 SD) cm, whereas the average depth of transect 3 was 386 (±74 SD) cm (Figure 114). Therefore, floc seemed to be settling in the deeper regions of the pond that were closest to the inflow. Other evidence of accumulation of floc near the west side of cell #1 was a distortion in the barrier curtain in this region that may have been caused by the effect of slightly denser floc on one side of the barrier, relative to open water on the other side. Water depth varied from 350 cm near the barrier in cell 4, to 20 cm near the inflow, at the northern end of transect 1. Water depth was a function of both settled floc thickness and pond bathymetry.

**Table 2. Water depth, pond depth, and floc thickness along transect 3 for the Nubbin Slough HWTT in June 2008.**

| Transect | Cell | Distance from Inflow | Distance from Barrier | Water Depth | Pond Bottom | Floc Thickness |
|---|---|---|---|---|---|---|
| | | m | m | cm | cm | cm |
| 3 | 1 | 3.6 | 2 | 114 | 126 | 12 |
| 3 | 1 | 5.6 | 2 | 170 | 210 | 40 |
| 3 | 1 | 9.6 | 2 | 176 | 300 | 124 |
| 3 | 1 | 13.6 | 2 | 197 | 376 | 179 |
| 3 | 1 | 17.6 | 2 | 205 | 410 | 205 |
| 3 | 1 | 21.6 | 2 | 230 | 436 | 206 |
| 3 | 2 | 25.6 | 2 | 259 | 424 | 165 |
| 3 | 2 | 29.6 | 2 | 290 | 425 | 135 |
| 3 | 2 | 33.6 | 2 | 305 | 436 | 131 |
| 3 | 2 | 37.6 | 2 | 315 | 430 | 115 |
| 3 | 2 | 41.6 | 2 | 327 | 431 | 104 |
| 3 | 2 | 45.6 | 2 | 335 | 422 | 87 |
| 3 | 3 | 49.6 | 2 | 322 | 420 | 98 |
| 3 | 3 | 53.6 | 2 | 322 | 415 | 93 |
| 3 | 3 | 57.6 | 2 | 326 | 416 | 90 |
| 3 | 3 | 61.6 | 2 | 320 | 402 | 82 |
| 3 | 3 | 65.6 | 2 | 333 | 406 | 73 |
| 3 | 4 | 69.6 | 2 | 350 | 413 | 63 |
| 3 | 4 | 73.6 | 2 | 350 | 414 | 64 |
| 3 | 4 | 77.6 | 2 | 350 | 403 | 53 |
| 3 | 4 | 81.6 | 2 | 340 | 410 | 70 |
| 3 | 4 | 85.6 | 2 | 340 | 384 | 44 |
| 3 | 4 | 89.6 | 2 | 337 | 380 | 43 |
| 3 | 5 | 101.6 | 2 | 325 | 365 | 40 |
| **Mean** | | | | **289** | **386** | **97** |
| **Std. Dev.** | | | | **69** | **74** | **53** |
| **n** | | | | **24** | **24** | **24** |
| **Max.** | | | | **350** | **436** | **206** |
| **Min.** | | | | **114** | **126** | **12** |

**Table 3. Water depth, pond depth, and floc thickness along transect 2 for the Nubbin Slough HWTT in June 2008.**

| Transect | Cell | Distance from Inflow | Distance from Barrier | Water Depth | Pond Bottom | Floc Thickness |
|---|---|---|---|---|---|---|
| | | m | m | cm | cm | cm |
| 2 | 5 | 101.6 | 8 | 274 | 274 | 0 |
| 2 | 4 | 89.6 | 8 | 310 | 310 | 0 |
| 2 | 4 | 85.6 | 8 | 305 | 310 | 5 |
| 2 | 4 | 81.6 | 8 | 315 | 335 | 20 |
| 2 | 4 | 77.6 | 8 | 315 | 324 | 9 |
| 2 | 4 | 73.6 | 8 | 318 | 318 | 0 |
| 2 | 4 | 69.6 | 8 | 307 | 328 | 21 |
| 2 | 3 | 65.6 | 8 | 298 | 316 | 18 |
| 2 | 3 | 61.6 | 8 | 295 | 335 | 40 |
| 2 | 3 | 57.6 | 8 | 277 | 308 | 31 |
| 2 | 3 | 55.6 | 8 | 270 | 310 | 40 |
| 2 | 3 | 51.6 | 8 | 267 | 322 | 55 |
| 2 | 3 | 47.6 | 8 | 261 | 300 | 39 |
| 2 | 2 | 45.6 | 8 | 259 | 302 | 43 |
| 2 | 2 | 41.6 | 8 | 271 | 296 | 25 |
| 2 | 2 | 37.6 | 8 | 269 | 310 | 41 |
| 2 | 2 | 33.6 | 8 | 257 | 300 | 43 |
| 2 | 2 | 29.6 | 8 | 250 | 302 | 52 |
| 2 | 2 | 25.6 | 8 | 232 | 307 | 75 |
| 2 | 1 | 21.6 | 8 | 160 | 290 | 130 |
| 2 | 1 | 17.6 | 8 | 137 | 289 | 152 |
| 2 | 1 | 13.6 | 8 | 125 | 310 | 185 |
| 2 | 1 | 9.6 | 8 | 105 | 254 | 149 |
| 2 | 1 | 5.6 | 8 | 72 | 150 | 78 |
| 2 | 1 | 3.6 | 8 | 54 | 125 | 71 |
| **Mean** | | | | **240** | **293** | **53** |
| **Std. Dev.** | | | | **81** | **50** | **51** |
| **n** | | | | **25** | **25** | **25** |
| **Max.** | | | | **318** | **335** | **185** |
| **Min.** | | | | **54** | **125** | **0** |

**Table 4. Water depth, pond depth, and floc thickness along transect 1 for the Nubbin Slough HWTT in June 2008.**

| Transect | Cell | Distance from Inflow | Distance from Barrier | Water Depth | Pond Bottom | Floc Thickness |
|---|---|---|---|---|---|---|
| | | m | m | cm | cm | cm |
| 1 | 4 | 89.6 | 14 | 165 | 165 | 0 |
| 1 | 4 | 85.6 | 14 | 157 | 157 | 0 |
| 1 | 4 | 81.6 | 14 | 182 | 182 | 0 |
| 1 | 4 | 77.6 | 14 | 175 | 175 | 0 |
| 1 | 4 | 73.6 | 14 | 176 | 176 | 0 |
| 1 | 4 | 69.6 | 14 | 160 | 160 | 0 |
| 1 | 3 | 65.6 | 14 | 164 | 166 | 2 |
| 1 | 3 | 61.6 | 14 | 182 | 182 | 0 |
| 1 | 3 | 57.6 | 14 | 179 | 179 | 0 |
| 1 | 3 | 53.6 | 14 | 180 | 180 | 0 |
| 1 | 3 | 49.6 | 14 | 179 | 179 | 0 |
| 1 | 2 | 45.6 | 14 | 161 | 161 | 0 |
| 1 | 2 | 41.6 | 14 | 159 | 186 | 27 |
| 1 | 2 | 37.6 | 14 | 186 | 188 | 2 |
| 1 | 2 | 33.6 | 14 | 181 | 183 | 2 |
| 1 | 2 | 29.6 | 14 | 194 | 196 | 2 |
| 1 | 2 | 25.6 | 14 | 158 | 160 | 2 |
| 1 | 1 | 21.6 | 14 | 132 | 170 | 38 |
| 1 | 1 | 17.6 | 14 | 83 | 170 | 87 |
| 1 | 1 | 13.6 | 14 | 53 | 168 | 115 |
| 1 | 1 | 9.6 | 14 | 26 | 98 | 72 |
| 1 | 1 | 5.6 | 14 | 20 | 130 | 110 |
| 1 | 1 | 3.6 | 14 | 36 | 95 | 59 |
| **Mean** | | | | **143** | **165** | **23** |
| **Std. Dev.** | | | | **56** | **26** | **38** |
| **n** | | | | **23** | **23** | **23** |
| **Max.** | | | | **194** | **196** | **115** |
| **Min.** | | | | **20** | **95** | **0** |

**Figure 112. Inflow region of the Nubbin Slough HWTT (left), depicting the light colored floc material in Cell 1 of the contact zone. The right photo depicts the barrier separating the Cell 1 of contact zone on the left from the “hyacinth end” location on the right.**

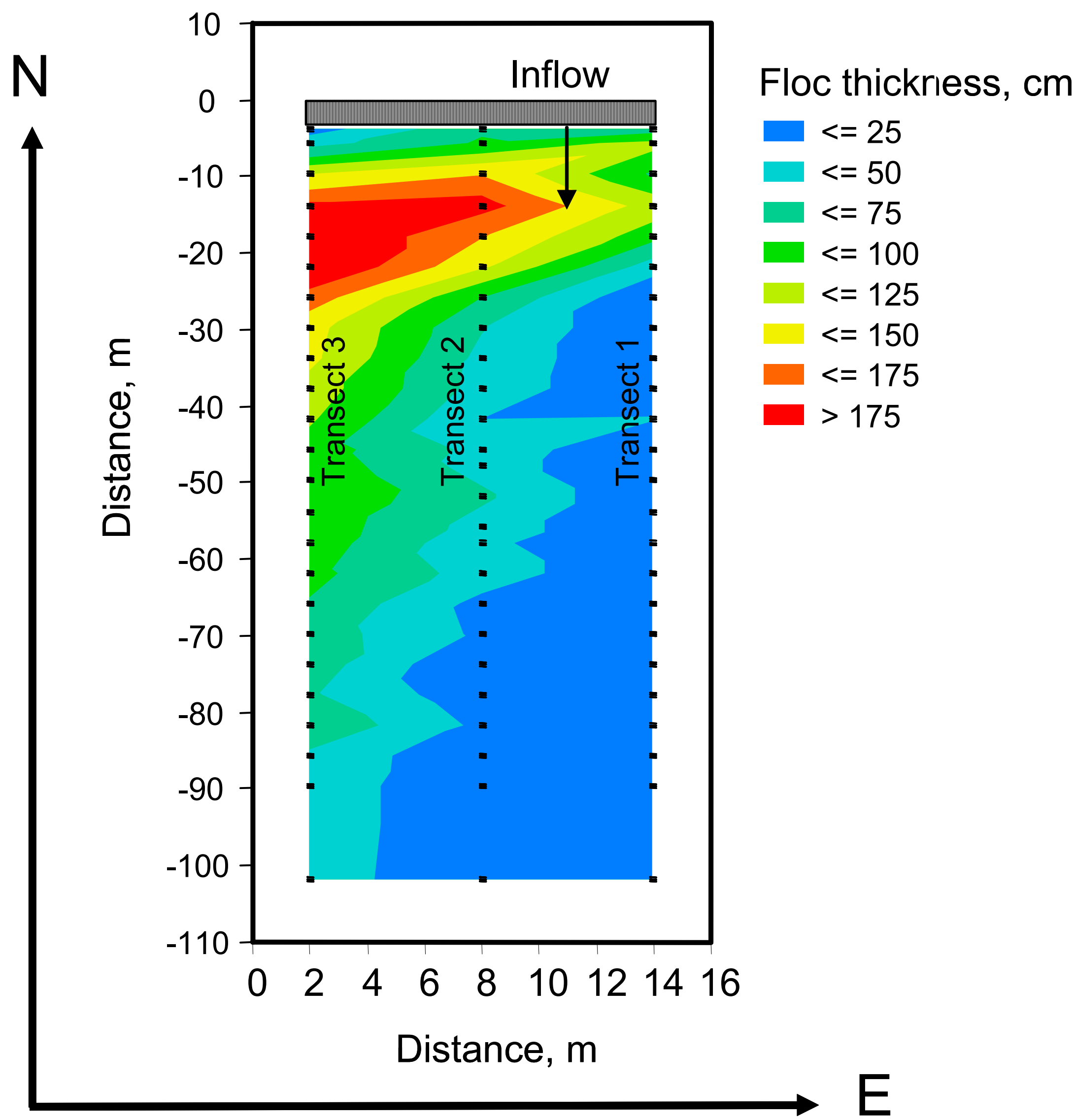



**Figure 113. Location of sampling transects, stations, and settled floc thickness in the flow path (contact zone) of the Nubbin Slough HWTT in June 2008.**

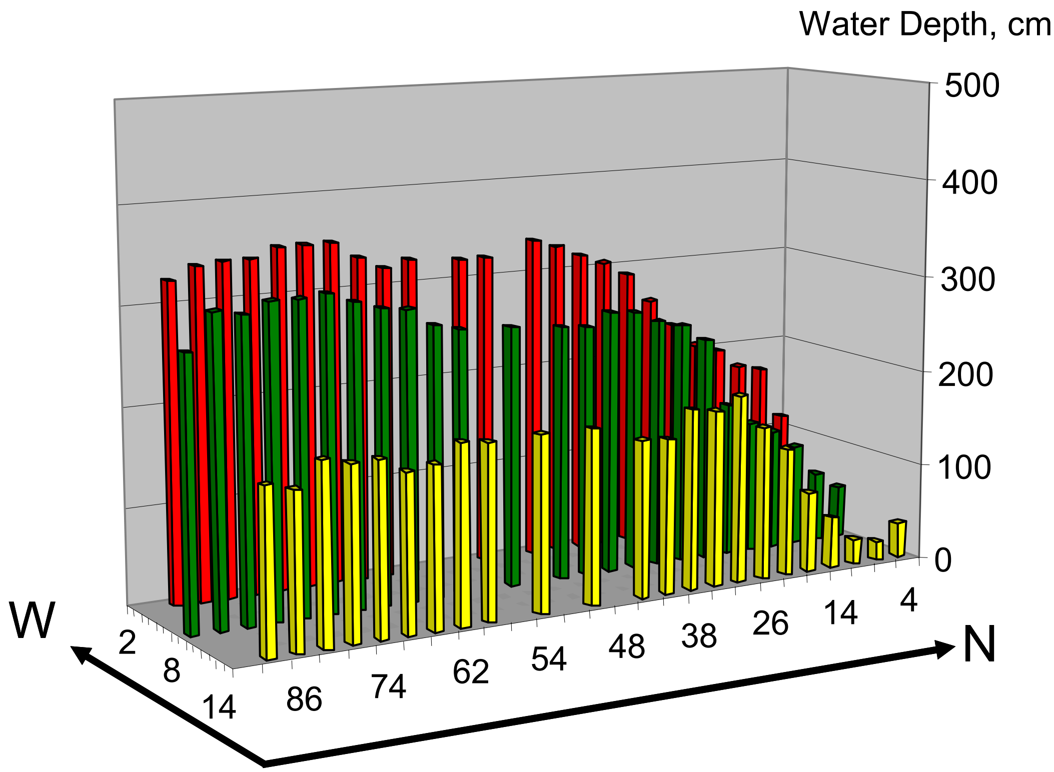



**Figure 114. Water depths in the eastern flow path (contact zone) of the Nubbin Slough HWTT in June 2008. The pond inflow is on the right side (north) of the figure, and water flows north to south through the contact zone. For perspective, see Figure 112, which provides a view of the contact zone from the northern end of the flow path.**

Floc thickness at the Ideal Grove HWTT contact zone (Table 5 and Table 6; Figure 115) was considerably less than measured at the Nubbin Slough HWTT. Average floc thickness was greatest in the southern flow path (B), with an average thickness of 33 (± 12 SD) cm, compared to 20 (± 11 SD) cm in the north flow path (A) (Figure 116). This was expected, due to the shorter operational period of the northern flow path (1 month) versus the southern flow path (3 months) at the time of floc depth measurements. The depth of settled floc was greatest in the south flow path along transect three, varying from 53 cm eight meters east of the inflow, to approximately 28 cm near the shelf at the eastern end of the first cell (contact zone). Water depth was slightly greater nearest the barrier (transect 2 and 3) for both flow paths, averaging 183 (±14 SD) cm, compared to 179 (±16 SD) cm for the outer transects (transect 1 and 4) (Figure 117). This is probably a reflection of the fact that transects 2 and 3 were sited closer to the centerline (deeper region) of the pond and the tendency for floc to accumulate in deeper regions.

In summary, the two HWTTs have accumulated new deposits of settled floc, which in localized regions are relatively thick. At present, due to the deep water column the floc deposits are not thought to significantly influence pond hydraulics or performance.

**Figure 115. Inflow region of the Ideal Grove HWTT contact zone (left), with the southern flow path in the foreground and the northern flow path in the background. Also in the foreground is the floc recirculation device. The right photo shows the junction of the southern flow path contact zone (to left of barrier) and filtration zone (to right of barrier).**

**Table 5. Water depth, pond depth, and floc thickness in the northern (A) flow path of the Ideal Grove HWTT in June 2008.**

| Transect | Distance from Barrier | Distance from Inflow | Water Depth | Pond Bottom | Floc Thickness |
|---|---|---|---|---|---|
| | m | m | cm | cm | cm |
| 1 | -8 | 4 | 135 | 159 | 24 |
| 1 | -8 | 8 | 186 | 219 | 33 |
| 1 | -8 | 12 | 170 | 207 | 37 |
| 1 | -8 | 16 | 183 | 202 | 19 |
| 1 | -8 | 20 | 185 | 200 | 15 |
| 1 | -8 | 24 | 191 | 204 | 13 |
| 1 | -8 | 28 | 194 | 200 | 6 |
| 1 | -8 | 32 | 195 | 197 | 2 |
| 1 | -8 | 36 | 201 | 208 | 7 |
| 2 | -2 | 4 | 150 | 163 | 13 |
| 2 | -2 | 8 | 185 | 223 | 38 |
| 2 | -2 | 12 | 179 | 209 | 30 |
| 2 | -2 | 16 | 178 | 215 | 37 |
| 2 | -2 | 20 | 185 | 210 | 25 |
| 2 | -2 | 24 | 200 | 215 | 15 |
| 2 | -2 | 28 | 202 | 215 | 13 |
| 2 | -2 | 32 | 202 | 219 | 17 |
| 2 | -2 | 36 | 202 | 217 | 15 |
| **Mean** | | | **185** | **205** | **20** |
| **Std. Dev.** | | | **18** | **18** | **11** |
| **n** | | | **18** | **18** | **18** |
| **Max.** | | | **202** | **223** | **38** |
| **Min.** | | | **135** | **159** | **2** |

**Table 6. Water depth, pond depth, and floc thickness in the southern (B) flow path of the Ideal Grove HWTT in June 2008.**

| Transect | Distance from Barrier | Distance from Inflow | Water Depth | Pond Bottom | Floc Thickness |
|---|---|---|---|---|---|
| | m | m | cm | cm | cm |
| 3 | 2 | 4 | 174 | 187 | 13 |
| 3 | 2 | 8 | 170 | 223 | 53 |
| 3 | 2 | 12 | 180 | 205 | 25 |
| 3 | 2 | 16 | 168 | 219 | 51 |
| 3 | 2 | 20 | 172 | 220 | 48 |
| 3 | 2 | 24 | 177 | 220 | 43 |
| 3 | 2 | 28 | 192 | 214 | 22 |
| 3 | 2 | 32 | 180 | 214 | 34 |
| 3 | 2 | 36 | 190 | 217 | 27 |
| 4 | 8 | 4 | 150 | 200 | 50 |
| 4 | 8 | 8 | 167 | 203 | 36 |
| 4 | 8 | 12 | 176 | 203 | 27 |
| 4 | 8 | 16 | 177 | 213 | 36 |
| 4 | 8 | 20 | 180 | 209 | 29 |
| 4 | 8 | 24 | 190 | 208 | 18 |
| 4 | 8 | 28 | 170 | 205 | 35 |
| 4 | 8 | 32 | 190 | 207 | 17 |
| 4 | 8 | 36 | 188 | 210 | 22 |
| **Mean** | | | **177** | **210** | **33** |
| **Std. Dev.** | | | **11** | **9** | **12** |
| **n** | | | **18** | **18** | **18** |
| **Max.** | | | **192** | **223** | **53** |
| **Min.** | | | **150** | **187** | **13** |

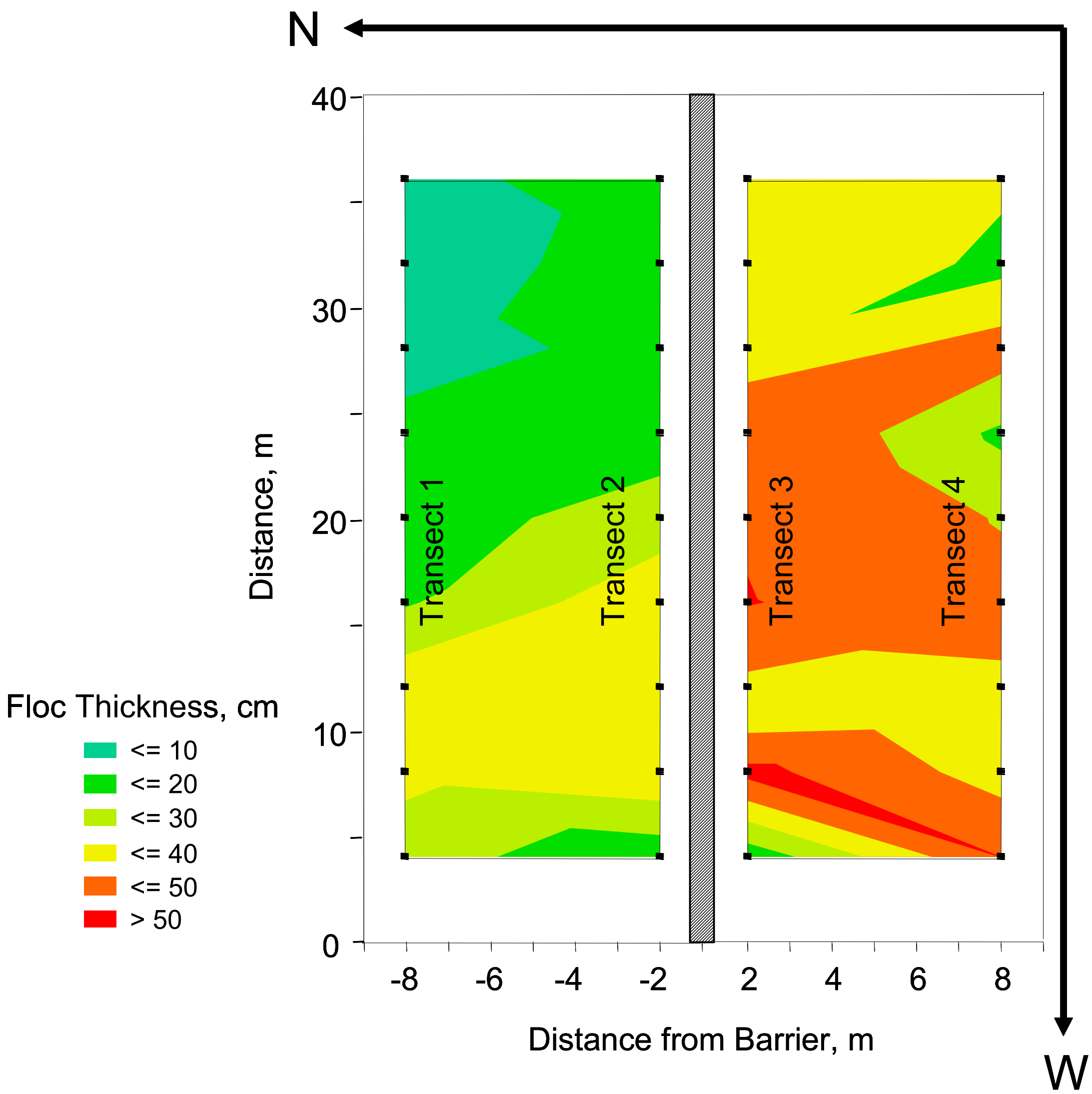



**Figure 116**. **Location of sampling transects, stations, and settled floc thickness in the Ideal Grove HWTT in June 2008. Flow paths A and B are on the left- and right-hand sides of the diagram, respectively, with the flow path inflows at the bottom (west) of the diagram. The zone of reduced floc thickness (yellow band) at the 10m location in flow path B represents the location of the floc resuspension device.**

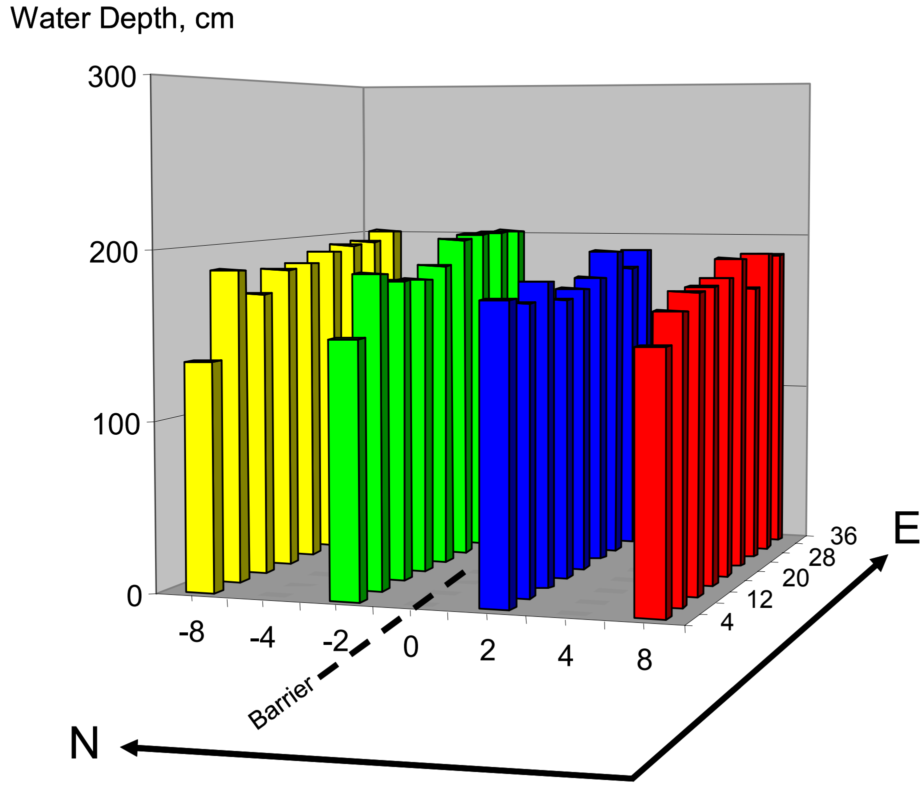



**Figure 117**. **Water depths in the Ideal Grove HWTT flow paths in June 2008. Flow paths A and B are on the left- and right-hand sides of the diagram, respectively, with the pond inflow at the north side of the diagram.**

It is important to note that even though substantial amounts of floc can accumulate within the settling zones in HWTT systems, the water content of this material is extremely high. During March, we completed an assessment to characterize the volume reduction that occurs for amendment flocs upon drydown. We collected ~ 1.7L of floc material that had settled for 3 months (it therefore was relatively compact), and placed it in a laboratory oven. The resulting volume reduction upon drying was 93.5% (i.e., a 15-fold volume reduction).

**Figure 118**. **The photo on the left depicts alum floc entering the first compartment of the Nubbin Slough HWTT from the mixing chamber/manifold. Upon drying, the wet floc (cylinder in right photo) exhibits a dramatic volume reduction (granular material in bottom of beaker).**

### *Impacts of Amendment Chemicals on Water Quality*

The HWTT systems are designed to operate on a range of coagulant types. For the current optimization effort, alum and other aluminum-based chemicals (sodium aluminate) were utilized, primarily due to their relatively low cost. An incidental consequence of using these amendments, however, is the potential for export of aluminum and sulfate from the HWTT system to downstream receiving waters. In order to characterize this export, we monitored the outflow stream of the Davie – Nubbin Slough and Ideal #2 Grove HWTT systems for total aluminum, dissolved aluminum, and sulfate during May and June 2008.

Time series data from both the Nubbin Slough and Ideal sites show that dissolved Al concentration was generally lower in the outflow stream than in the inflow water (Figure 119 and Figure 120). Total Al concentration, largely representing Al bound in floc material, varied from lower to higher in the outflow stream compared with inflow total Al, for both sites (Figure 121 and Figure 122). This may reflect the occurrence of episodic resuspension and export of settled floc in the HWTT pond systems. Outflow total Al concentration in the Ideal Grove HWTT system (Figure 122) was higher for flow path A (continuous alum dosing) than for flow path B (intermittent dosing), reflecting the lower rate of aluminum loading to flow path B.

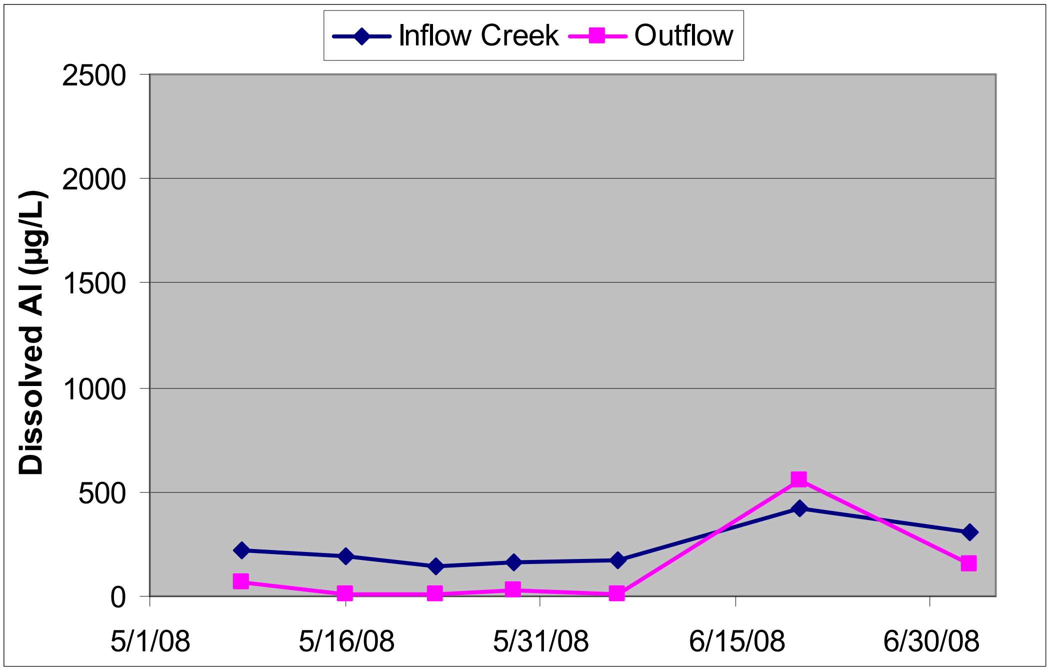



**Figure 119**. **Time series of dissolved Al concentration at the inflow and outflow of the Davie-Nubbin Slough HWTT system.**

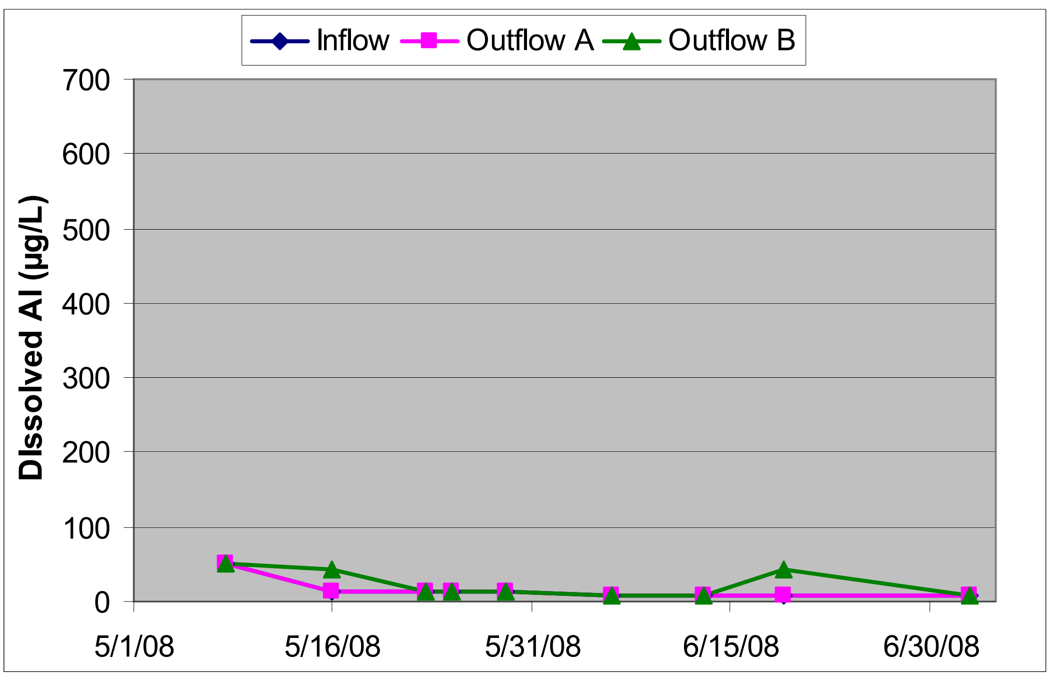



**Figure 120**. **Time series of dissolved Al concentration at the inflow and outflows (A = continuous dosing, B = intermittent dosing) of the Ideal Groves HWTT system.**

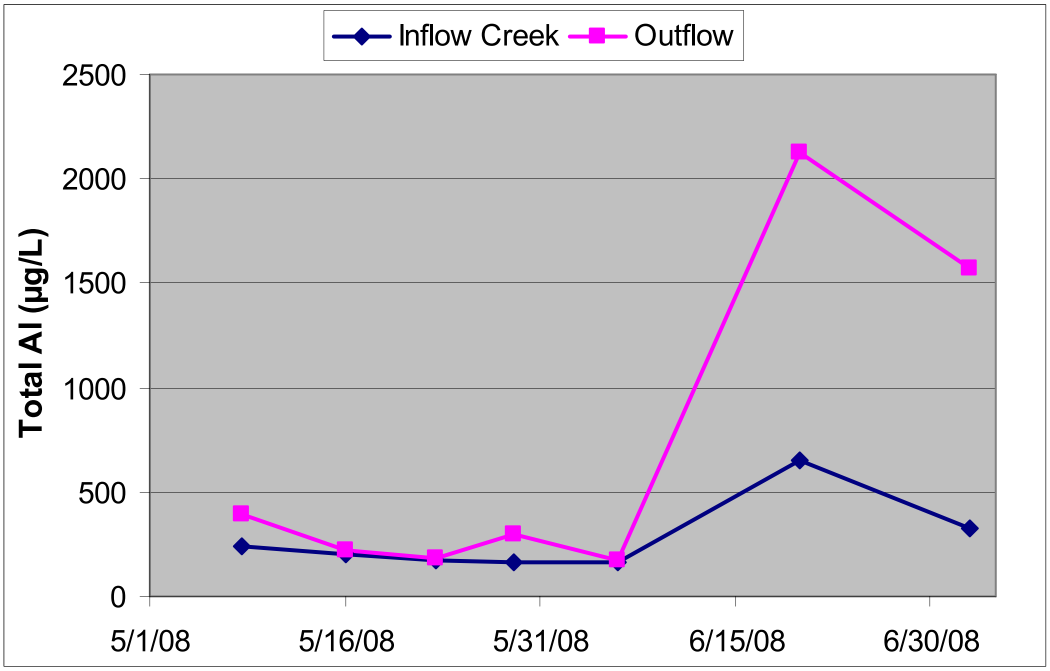



**Figure 121**. **Time series of total Al concentration at the inflow and outflow of the Davie-Nubbin Slough HWTT system.**

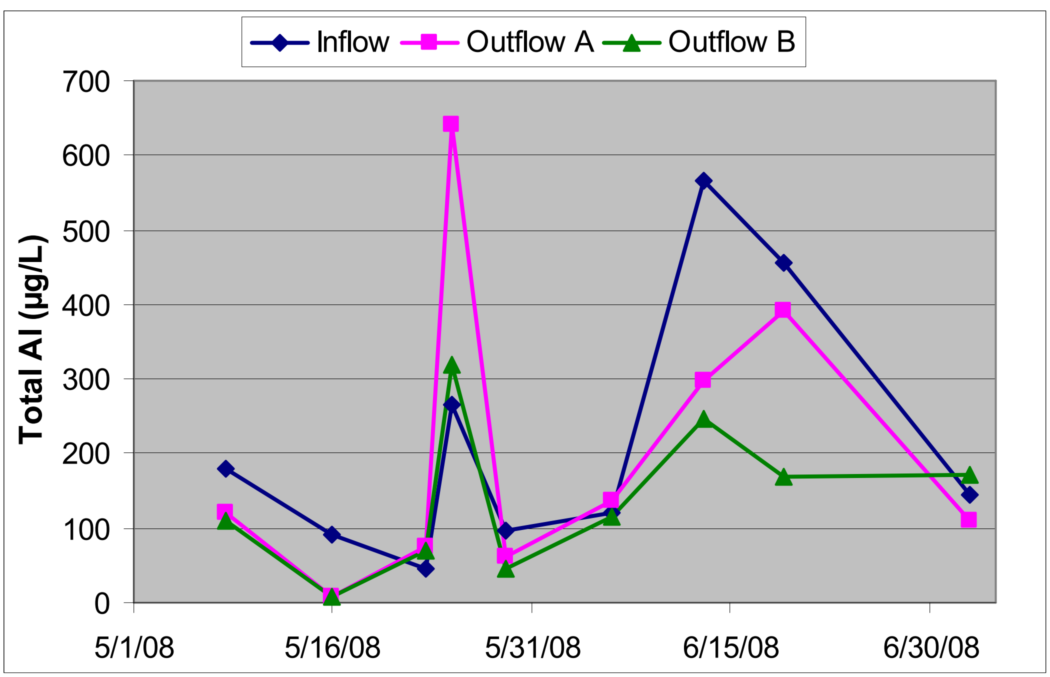



**Figure 122**. **Time series of total Al concentration at the inflow and outflows (A = continuous dosing, B = intermittent dosing) of the Ideal Groves HWTT system.**

Total Al concentrations at depths of 6 and 12 feet along the Davie HWTT pond flow path indicate the presence of suspended (or resuspended) floc above the "settled" floc layer (Figure 123). The plots in Figure 123 also reflect the sequence of alum introduction and floc formation in the mixing chamber, and subsequent settling of particulate (floc-bound) Al along the flow path, with suspended particulate Al confined (on this sampling date) to lower depths closer to the pond outflow. Plots of dissolved Al along the same flow path (Figure 124) show that dissolved Al concentration decreases between the system inflow and outflow, as aluminum in the inflow (Nubbin Slough) water is pulled out of solution in the alum mixing chamber, and farther along the flow path.

For both the Davie and Ideal HWTT systems, sulfate concentrations were approximately 2 to 4 times higher in the outflow stream than in the inflow water (Figure 125 and Figure 126). Sulfate is released to the water column upon addition of alum (aluminum sulfate) via a hydrolysis reaction, and is therefore subject to being exported from the system as long as sulfate-reducing conditions do not exist in the water column. Outflow sulfate concentration in the Ideal Grove HWTT system (Figure 126) was higher for flow path A (continuous alum dosing) than for flow path B (intermittent dosing), reflecting the lower rate of sulfate loading to flow path B.

Since these two HWTT systems are still in the test-and-adjust phase of operation, these results should be regarded as preliminary. However, they elucidate several important points. First, effective floc formation and separation (either settling and/or filtration) in the treatment system will minimize the export of the metal ion (typically iron [Fe] or Al) in the coagulant. Second, minimizing the coagulant dose, through jar-test optimization of dosages of coagulant and coagulant aids, will reduce the concentration of the associated anion (typically sulfate or chloride) in the system outflow. Finally, the recycling and reuse of amendment flocs, as incorporated in the HWTT systems, will further minimize amendment use, as well as the overall accumulation of floc material and the potential for chemical export in the system outflow.

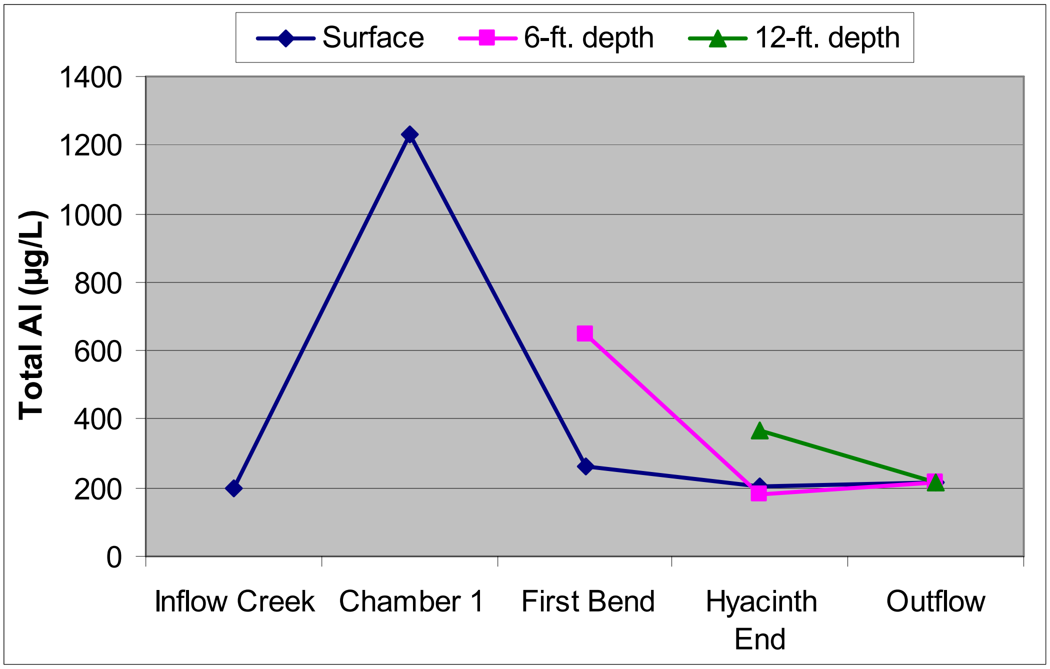



**Figure 123**. **Total Al concentration along the flow path of the Davie-Nubbin Slough HWTT system, with data shown for three sampling depths. Samples were collected on 5/16/08.**

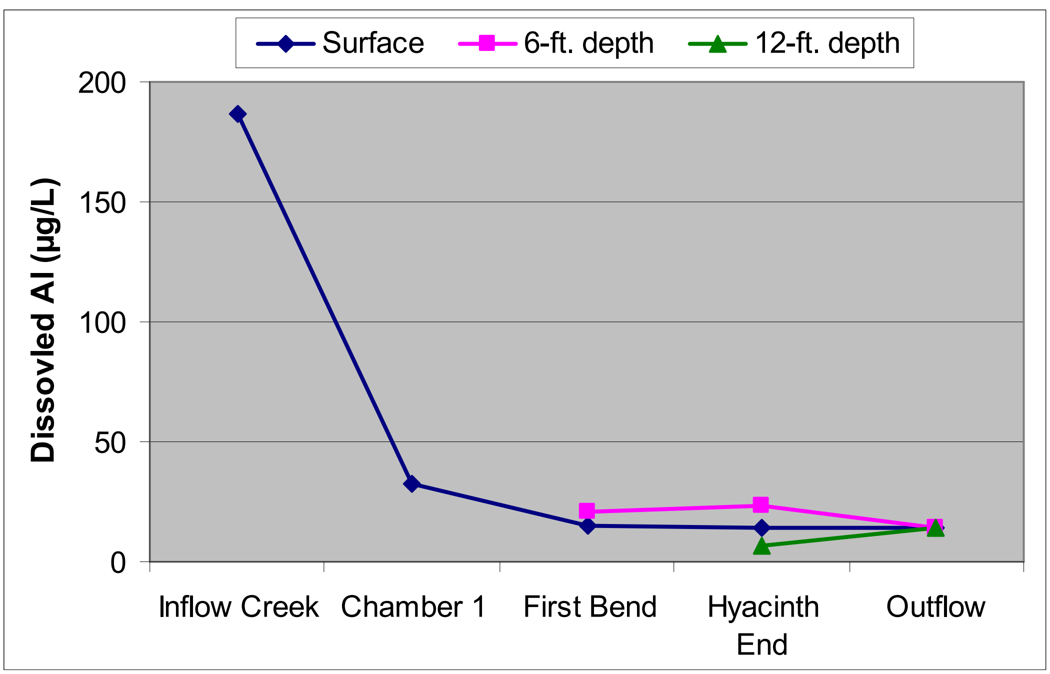



**Figure 124**. **Dissolved Al concentration along the flow path of the Davie-Nubbin Slough HWTT system, with data shown for three sampling depths. Samples were collected on 5/16/08.**

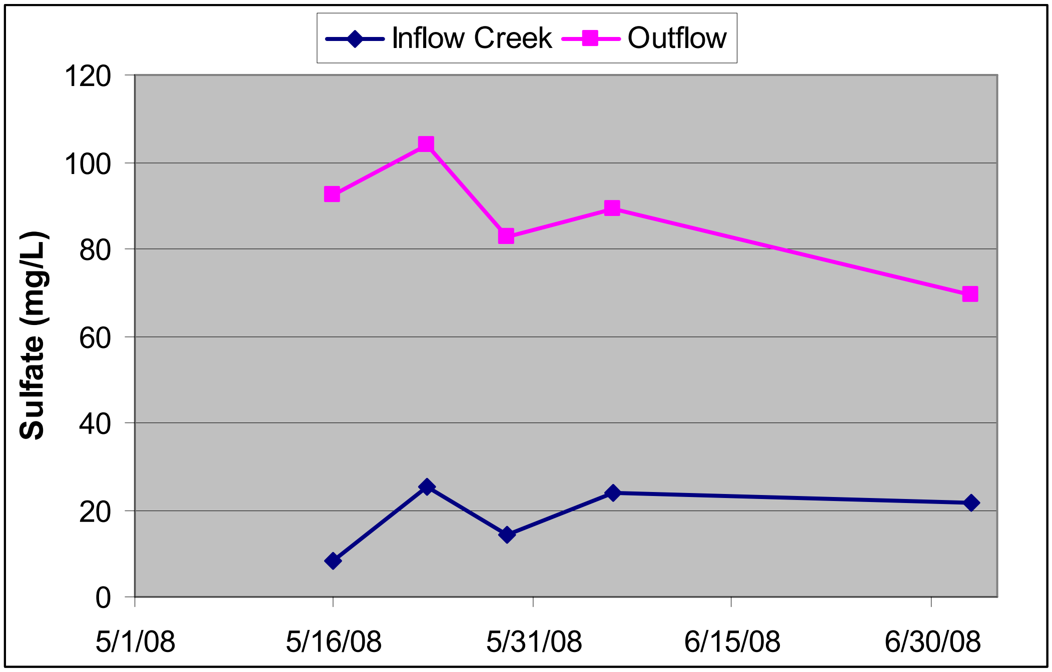



**Figure 125**. **Time series of sulfate concentration at the inflow and outflow of the Davie-Nubbin Slough HWTT system.**

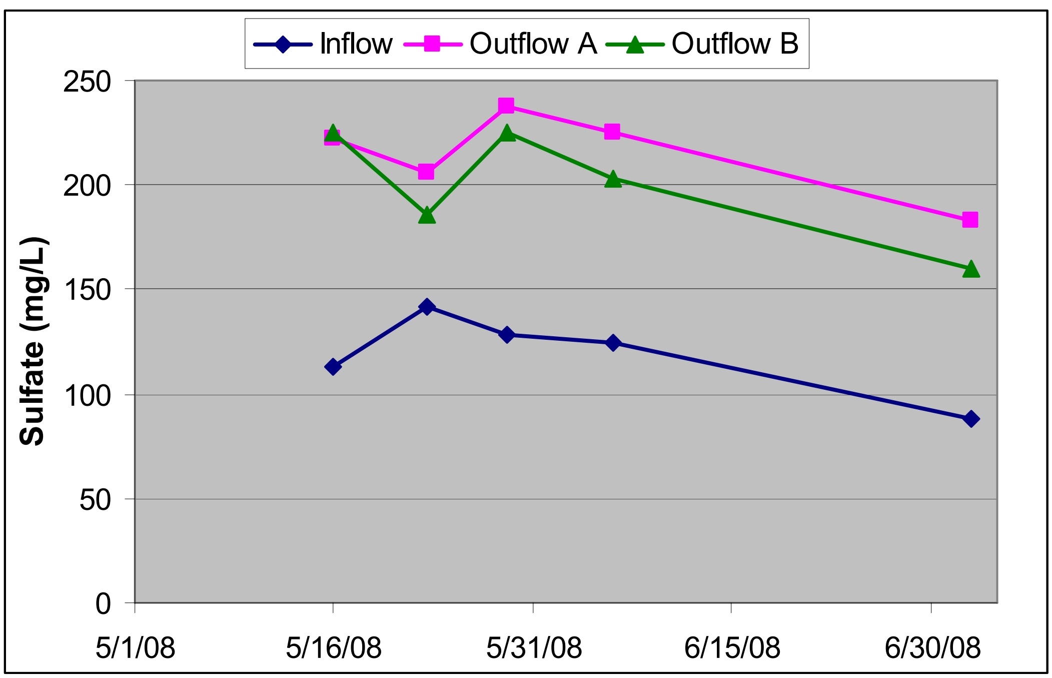



**Figure 126**. **Time series of sulfate concentration at the inflow and outflows (A = continuous dosing, B = intermittent dosing) of the Ideal Groves HWTT system.**

## Optimization of HWTT Systems for the Northern Everglades

As noted throughout this report, HWTT systems incorporate features of both treatment wetlands and conventional chemical treatment systems. Treatment wetlands typically have low operating costs but are land intensive, particularly when utilized for P removal. During Water Year 2007, the Everglades Stormwater Treatment Areas (STAs) south of Lake Okeechobee reduced mean inflow TP concentrations of 187 µg/L to 58 µg/L, and provided average mass and percentage removal rates of 1.1 $gP/m^2$-yr and 71%, respectively (Pietro et al., 2008). The best performing STAs attained outflow TP levels of ~ 20 µg/L. Average HRTs for the STAs ranged from 9 to 28 days. By contrast, surface water chemical treatment systems are much less land intensive than treatment wetlands, with settling ponds and floc drying beds comprising most of the facility's footprint. Typical HRTs for conventional chemical treatment clarifiers range from 2 - 4 hours (AWWA, 1990), and HRTs for settling ponds utilized in surface water treatment systems may be as high as 12 – 18 hrs. While capital costs are not overly high for surface water chemical treatment technologies, operating costs for the systems, the bulk of which is devoted to coagulants, coagulant aids, and buffers, can be quite high.

The HWTT systems constructed for this demonstration project utilized modest sized treatment wetlands, in conjunction with chemical coagulant additions, and provided exceptional performance with respect to outflow TP concentrations. The HRTs of the HWTT facilities ranged from 3.4 days (Ideal Grove site) to slightly less than 1 day (Mosquito Creek site, and under high flows, the Nubbin Slough site). In order to compare HWTT performance with that of a conventional treatment wetland, we use the Ideal Grove facility, which on average has the largest system area per unit of flow (or mass of P) treated.

The two flow paths of the Ideal Grove HWTT, one (A) dosed continuously (100% of time), the second (B) dosed intermittently (66% of time, with recycling/reuse of the settled floc), produced similar outflow N and P concentrations. The time series of outflow TP concentrations from the two flow paths is shown in Figure 27, and the mean inflow and outflow TN values for two sampling dates are shown in Figure 127, below.

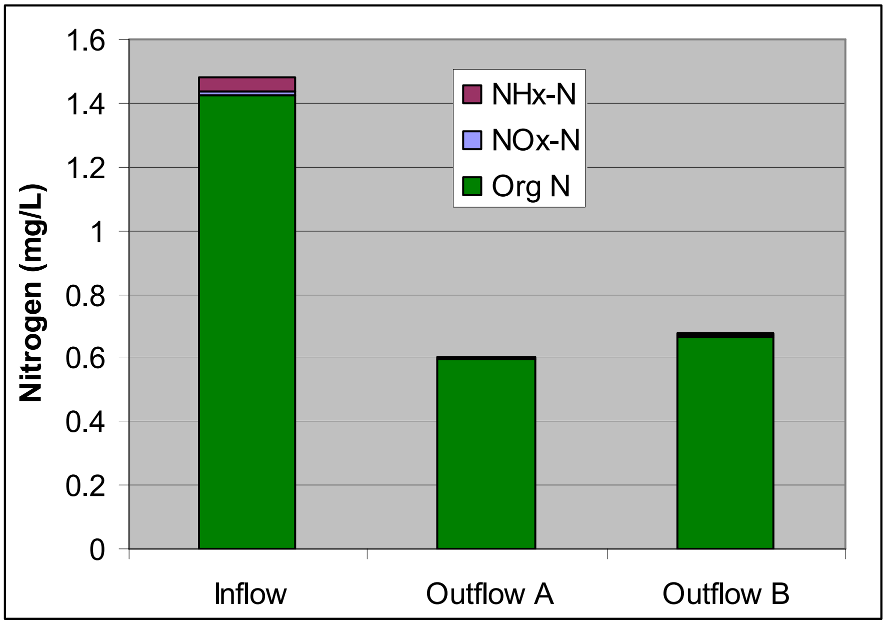



**Figure 127**. **Mean total N concentration and N speciation at the system inflow and the outflows of flow path A (continuous dosing) and flow path B (intermittent dosing) of the Ideal Groves HWTT treatment system. Data are from two sampling events conducted in early summer 2008.**

Mass and percentage TP removal rates by the two Ideal HWTT flow paths were comparable, at 11 g P/m$^2$-yr and 86% (Table 7). It should be noted that the mass removal rates for the Mosquito Creek and Nubbin Slough HWTT facilities would be higher than those calculated here for the Ideal Grove HWTT, due to the higher TP inflow concentrations and generally shorter HRTs at those sites. For TN, the continuously dosed flow path A achieved slightly greater mass (108 vs. 101 g N/m$^2$-yr) and percentage (59 vs. 54%) removal rates than the intermittently dosed path B (Table 7). These P removal rates, on a mass per unit area basis, are dramatically higher than levels achieved by STAs operated at comparable inflow TP concentrations. Additionally, most of the Everglades STAs exhibit outflow TN levels above 2 mg/L, due to their inability to effectively process/remove organic N. By contrast, the Ideal Grove HWTT provided an approximate 50% reduction in inflow organic N levels (Figure 127).

**Table 7. Mass balance (loading and removal) for N and P at the Ideal Groves HWTT during the operational period of May 6 – June 30, 2008.**

| | TP | | TN | |
|---|---|---|---|---|
| | **Path A** | **Path B** | **Path A** | **Path B** |
| Flow (cfs) | 0.19 | 0.20 | 0.19 | 0.20 |
| Flow ($m^3$/day) | 476 | 488 | 476 | 488 |
| Inflow conc. (µg/L) | 102 | 102 | 1480 | 1480 |
| Outflow conc. (µg/L) | 14 | 14 | 604 | 677 |
| Mass loading (g/day) | 48.7 | 49.9 | 704.5 | 722.2 |
| Mass export (g/day) | 6.8 | 6.7 | 287.6 | 330.2 |
| Mass removal (g/day) | 41.8 | 43.2 | 416.9 | 392.0 |
| Mass removal (g/$m^2$-yr) | 10.8 | 11.1 | 107.5 | 101.0 |
| Percent removal | 86.0 | 86.5 | 59.2 | 54.3 |

The superior performance of these Northern Everglades HWTT systems compared to conventional treatment wetland designs is due in large part to the chemical dosing component. It therefore is appropriate and useful to compare the efficiencies of a HWTT system with a conventional chemical treatment facility. Laboratory jar tests commonly are used to characterize the appropriate type and doses of coagulants, coagulant aids and buffers, to be employed in a chemical treatment facility. An example jar test for Mosquito Creek waters (dry season conditions) is depicted in Figure 128. These data show that the relationship between coagulant dose and outflow P concentration is not linear, primarily because a critical level of coagulant (and at times, a coagulant aid) is needed to achieve successful flocculation. Below this dose, flocculation is inadequate, and pinpoint flocs formed during the coagulation process remain in suspension and can be exported in the system outflow. For the Mosquito Creek waters on that sampling date, the optimum alum dose to achieve an outflow TP below 100 µg/L would be between 10 and 15 mg/L (Figure 128).

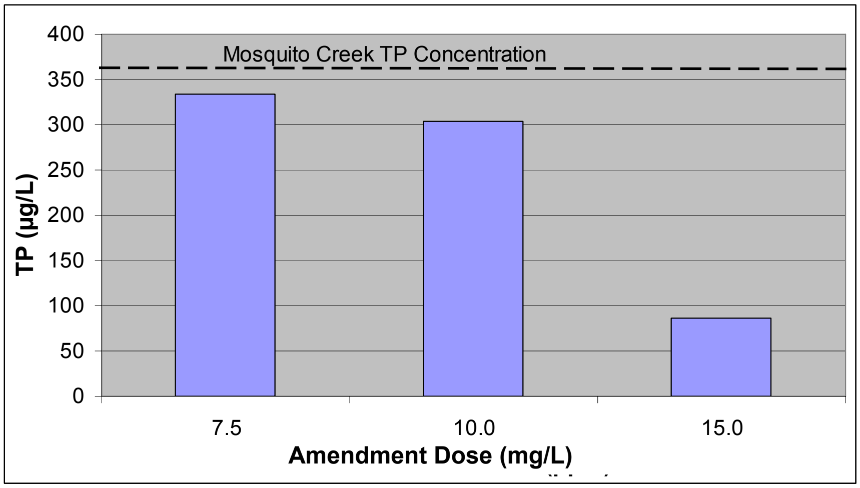



**Figure 128. Relationship between amendment dose (alum, as mg Al/L) and TP concentrations of Mosquito Creek mesocosm inflow waters, as determined from a laboratory jar test. Inflow waters were collected and tested during the dry season.**

HWTT systems are operated using a coagulant dose just high enough to provide effective flocculation and settling, which for the Mosquito Creek mesocosm waters in the dry season (Figure 128) we initially selected to be 15 mg Al/L. A unique feature of HWTT systems, however, is that effective treatment can be maintained using only intermittent dosing. For many mesocosm trials, and for the Ideal Grove HWTT, we operated selected flow paths under lower dosing frequencies, such as 66% of the time. These systems continued to provide effective treatment, due to the capture of active flocs on plant stems and roots (Figure 129), and the periodic recycling/reuse of settled flocs. In terms of chemical use and costs, the net effect is that the system can be operated successfully under a coagulant dose that would not be effective in a conventional chemical treatment facility. For example, 66% of a 15 mg Al/L dose is equivalent to the chemical consumption incurred with a full-time dosing of 10 mg Al/L, which in jar tests show yields a supernatant (outflow) TP concentration of 300 µg/L (Figure 128).

**Figure 129. Floc attached to a submerged macrophyte in the contact zone of the Ideal Grove HWTT flow path B.**

Depending on outflow concentration targets, additional reductions in chemical use in HWTTs are possible. For example, a HWTT deployed in eutrophic central Florida lake operated at a one week HRT received batch coagulant inputs once-monthly, equivalent to a semi-continuous dosing frequency of 25%. This system reduced inflow TP levels from 168 to 84 µg/L, and provided a mass removal rate of 11 g P/m$^2$-yr over a one-year period (DeBusk et al., 2005). This mass removal rate is comparable to that achieved in the Ideal Grove HWTT.

For many of the Northern Everglades tributaries (Mosquito Creek, for example), where alkalinity can drop sharply in response to wet season rainfall events, even further savings in chemical costs can be achieved through the incorporation of the SAV/LR unit process in the HWTT, which would obviate the need of a front-end chemical buffer.

For selected sites, it is possible that the use of a different coagulant, such as ferric chloride, or a coagulant aid (e.g., a polymer) in conjunction with aluminum or iron coagulants, would result in a lower chemical dose requirement. However, pilot investigations on chemical treatment of highly colored agricultural runoff south of Lake Okeechobee, targeting 10 µg/L, utilized ferric chloride doses ranging from 33 to 120 mg Fe/L and polymer doses of approximately 0.5 mg/L

(Bratby, 2006). These other approaches are under investigation as part of our optimization effort at each HWTT facility.

A key finding from our effort is that the optimization of the HWTT process (namely, the minimization of chemical use and system footprint for a given outflow TP and/or TN target) at each of the Northern Everglades demonstration sites will take some time, due to the spatial and temporal variability in water chemistry observed within the watershed tributaries, as well as the multiplicity of control variables that can be adjusted to optimize capital and operating costs. Example variables that can be adjusted include: relative size and configuration of the wetland (floating and/or submerged vegetation) unit processes; type and dose of coagulants, coagulant aid and buffers; and chemical dosing cycles. Once optimized, however, the HWTT facilities should be a predictable, sustainable and cost-effective technology for achieving water quality targets in the Northern Everglades watershed.

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DeBusk, T.A., R. Baird, D. Haselow and T. Goffinet. 2005. Evaluation of a floating wetland for improving water quality in an urban lake. In: Proceedings of 8th Biennial Conference on Stormwater Research and Watershed Management, pp. 175 – 184. Southwest Florida Water Management District, Brooksville, FL.

Pietro, K., R. Bearzotti, M. Chimney, G. Germain and Nenad Iricanin. 2008. South Florida Environmental Report, Chapter 5: STA Performance, Compliance and Optimization. South Florida Water Management District, West Palm Beach, FL.

# APPENDIX A – HWTT SITE Contributing Areas

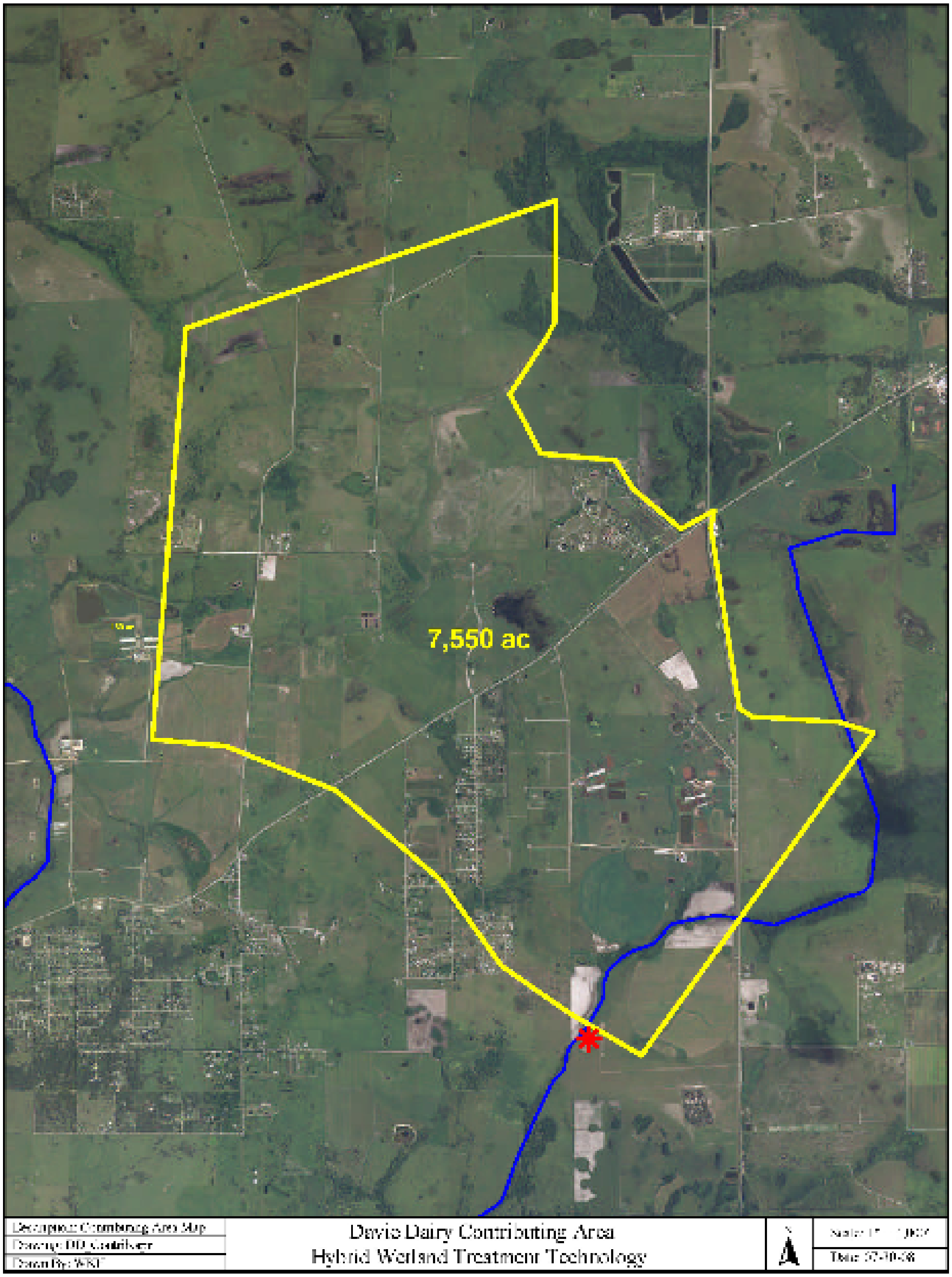


**Figure 130. Site 1 Nubbin Slough HWTT Contributing Area**

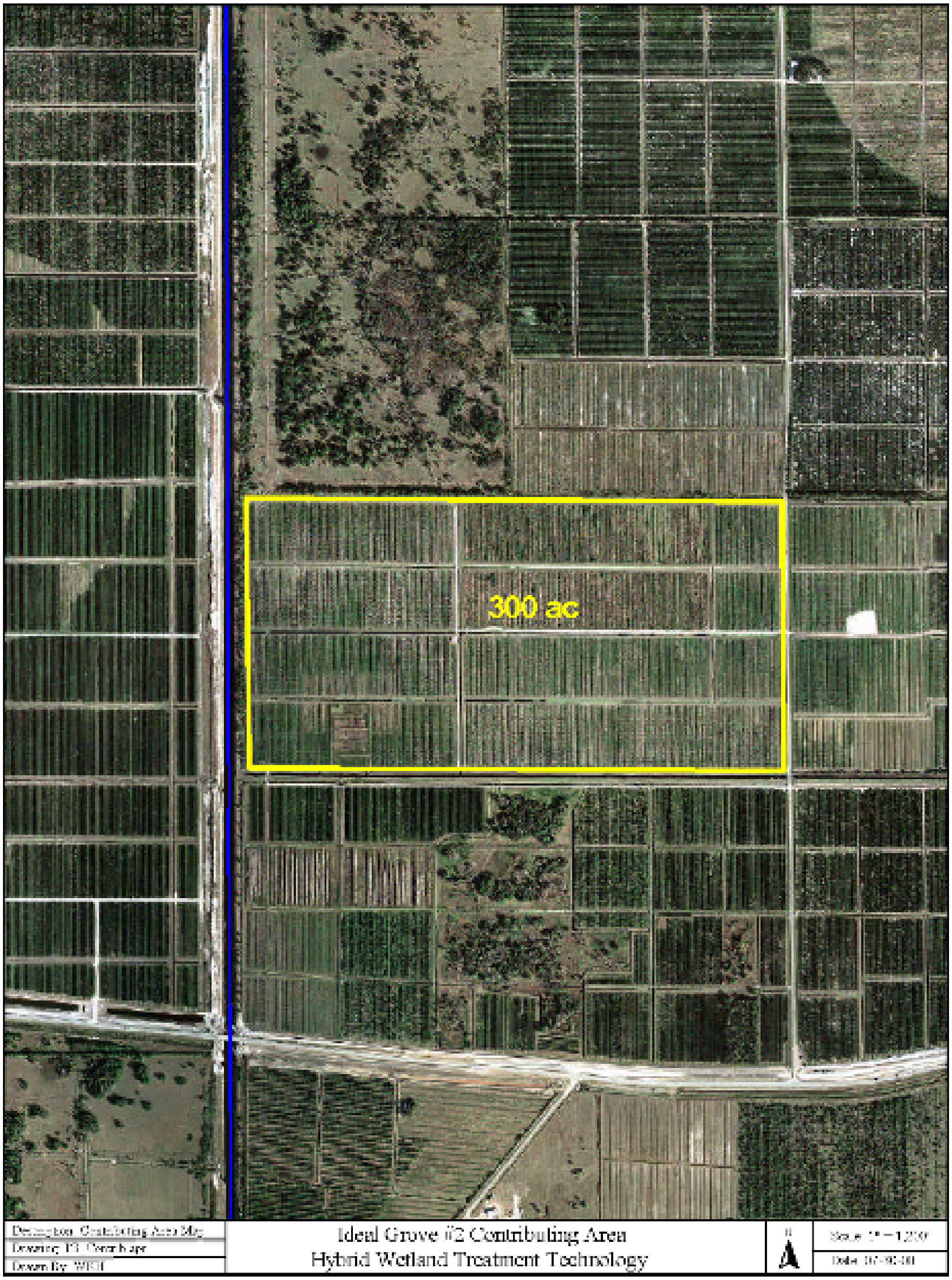


**Figure 131. Site 2 Ideal Grove 2 HWTT Contributing Area**

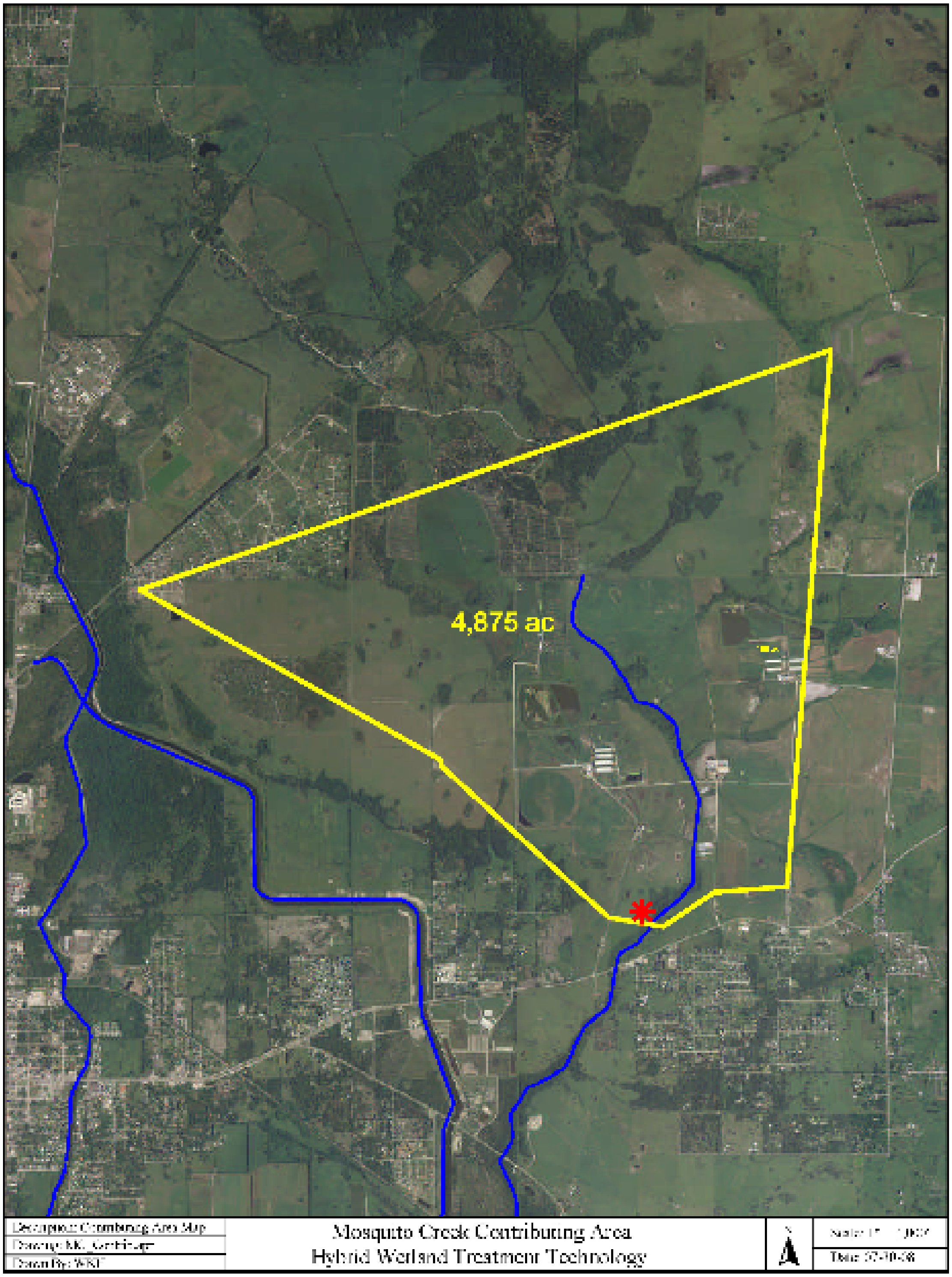


**Figure 132. Site 3 Mosquito Creek HWTT Contributing Area**

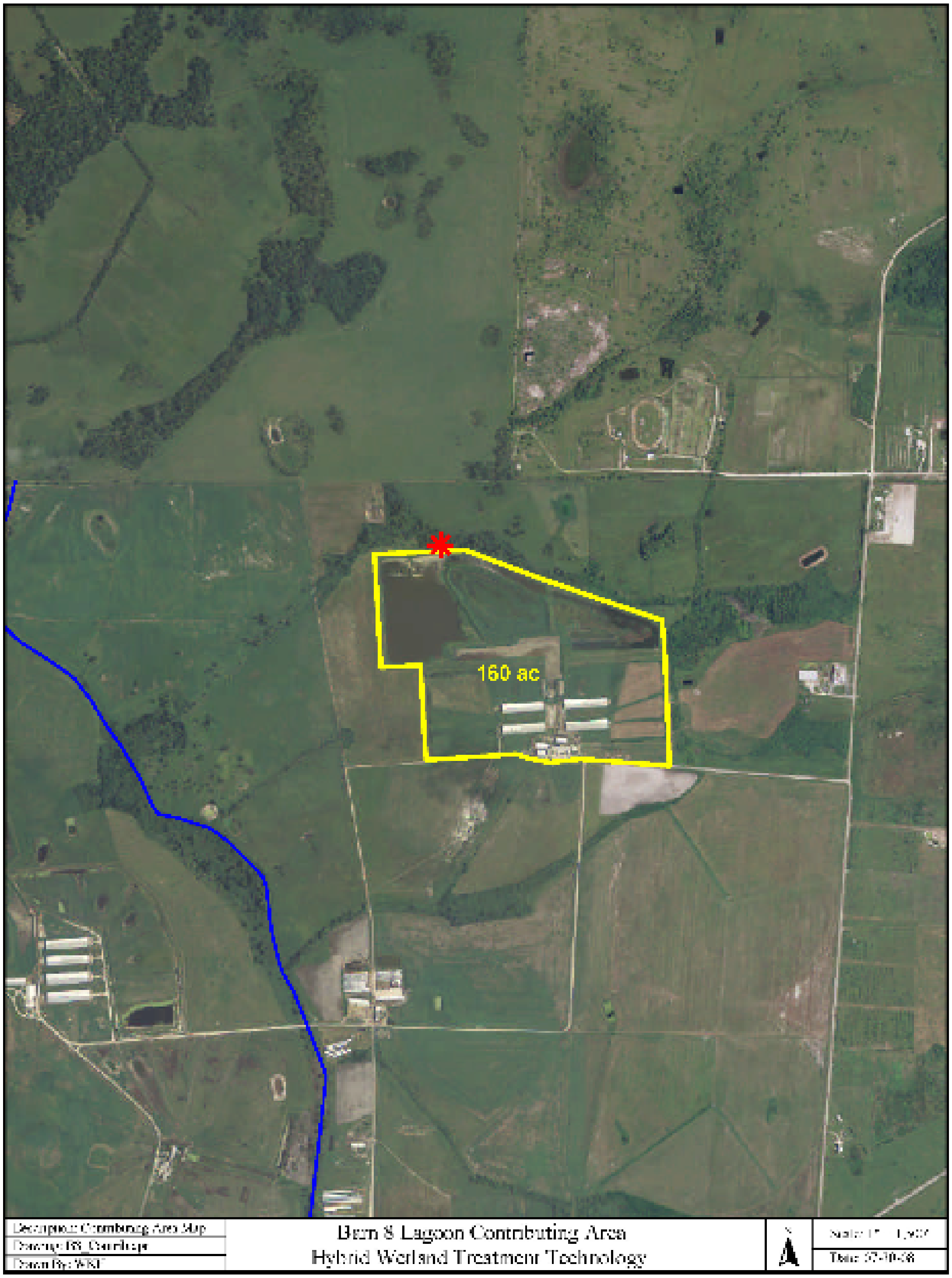


**Figure 133. Site 4 Larson Lagoon HWTT Contributing Area**