CHAPTER V
The Hybrid Wetland Treatment Technology

INTRODUCTION

For decades, chemical treatment systems and treatment wetlands have been utilized independently for treating wastewaters and surface waters. Chemical treatment systems typically have low land area requirements, but moderate to high operating costs due to the continuous consumption of chemicals (i.e., coagulant, buffers, coagulant aids). Chemical treatment systems are often capable of achieving extremely low outflow total phosphorus (TP) concentrations (range of 10 μg/L) (SFWMD 2000), with the pollutant removal efficiency (and outflow concentrations) controlled largely by inflow pollutant concentrations, levels of other runoff constituents (alkalinity, color, turbidity) and the coagulant dose. While extremely effective for removing many water column pollutants such as P, chemical treatment is less effective at removing other constituents, such as dissolved inorganic nitrogen (N) species. In these systems, pollutants are removed from the water column by adsorption to, or incorporation into, a chemical floc that settles to the bottom of a pond or clarifier. The floc is periodically removed from the system, dried, and transported to an alternative site for land application or disposal, often at a relatively high cost.

In contrast with chemical treatment systems, treatment wetlands occupy a much larger area (footprint), and differ markedly with respect to contaminant removal efficiencies. For example, wetlands are quite effective (on an areal basis) at removing inorganic N species, but require large amounts of land for effective P removal (DeBusk et al 2005a). Pollutant removal in treatment wetlands is usually controlled by manipulating system hydraulic residence time (HRT) (i.e., footprint) (Kadlec and Wallace 2009), and to a lesser extent, the type(s) of dominant vegetation. Unlike chemical treatment systems, pollutant removal in treatment wetlands is accomplished through both transformations and sequestration. For example, constituents such as N and carbon (C) typically are transformed within treatment wetlands, with a portion liberated as gaseous forms and the remainder sequestered in the sediments. Other constituents, such as P and heavy metals, rely solely on sediment sequestration (burial) as an ultimate removal mechanism. Extremely large treatment wetlands, know as Stormwater Treatment Areas (STAs), have been constructed throughout south Florida for reducing P levels in runoff. Depending on environmental conditions, P in wetland sediments that is associated with either recalcitrant organic matter, or bound to metal (iron, calcium and particularly, aluminum) compounds in the sediments, can remain permanently sequestered. Environmental perturbations, such as system drydown, can result in the release of sediment P associated with organic matter, thereby impairing the long-term removal efficiency.

During recent years, a number of "combination" systems have been proposed and/or deployed that utilize a sequence of treatment wetlands, conventional chemical treatment systems and reservoirs. Different benefits have been attributed to the various sequencing approaches of the unit processes. For example, the placement of a reservoir or detention system upstream of a chemical treatment facility can provide peak flow attenuation and a modest amount of nutrient removal, and act as a hydraulic buffer for the downstream unit process. An alternative configuration, with a chemical treatment system upstream of the wetland, is considered advantageous because the constructed wetland can "polish" the chemically treated water before discharge to the natural environment. One such approach, termed a "Managed Wetland", was evaluated for its effectiveness in treating farm runoff to extremely low-level outflow TP concentrations (SFWMD 2000). The necessity for large tracts of land is a major component of the "Managed Wetland" system.

The Hybrid Wetland Treatment Technology (HWTT) concept was developed with the intent of harnessing and integrating the strengths of both wetland and chemical treatment technologies. The goal of HWTT systems is to provide the effectiveness and reliability of chemical treatment systems, and to utilize the wetland vegetation to the maximum extent possible to minimize chemical amendment use, to eliminate the need for off-site disposal of residual floc materials and to facilitate the removal of nitrogen species.

OVERVIEW OF TECHNOLOGY

The patented Hybrid Wetland Treatment Technology (HWTT) represents a combination of chemical and wetland treatment approaches, with the system comprised of vegetated zones(primarily with floating and/or submerged macrophytes), non-vegetated zones, internal floc recycling mechanisms and the drying of floc material with subsequent re-introduction into the treatment train. Chemical coagulants are added to the front-end of the system, which is equipped with one or more deep zones to capture and store the resulting chemical flocs. A fundamental concept of the HWTT is that the floc material resulting from coagulant addition remains at least temporarily viable, and can be "re-used" for additional P removal. Both passive and active re-use of floc material can be practiced in a HWTT. Passive re-use refers to the accumulation of viable flocs on plant roots and stems that are situated near the front-end and mid-regions of the system (Figure 1). Active re-use refers to the periodic resuspension of settled floc. Re-use is achieved by exposing existing viable flocs within the system, in either an active or passive manner, to "untreated parcels" of water and also by the re-use of dried floc. Coagulants typically are dosed to the front end of the HWTT only intermittently, such that untreated parcels of water pass through into the HWTT system at selected time intervals. It should be noted that active resuspension of previously settled floc results in the need for additional downstream floc settling/filtering areas, which are incorporated within the HWTT footprint.

Figure 1. Coagulant floc attached to submerged macrophytes near the inflow region of a HWTT system.

The concept and benefits of active floc re-use are readily depicted using laboratory jar tests. In one example, an alum dose of 15 mg Al/L (an optimum dose, based on prior jar tests) was added to a sample of Mosquito Creek water. Floc from this initial alum dose removed 97% of the creek water TP. One day later, the supernatant was removed, a fresh aliquot of creek water was added, and the floc was resuspended. This re-use of the previously formed floc yielded 79% removal of TP. This was repeated a third time, for which the TP removal rate declined to 30%. These bench-scale data show that wet flocs resulting from an initial coagulant application can be re-used to remove additional P from creek waters in the Lake Okeechobee watershed (Figure 2).

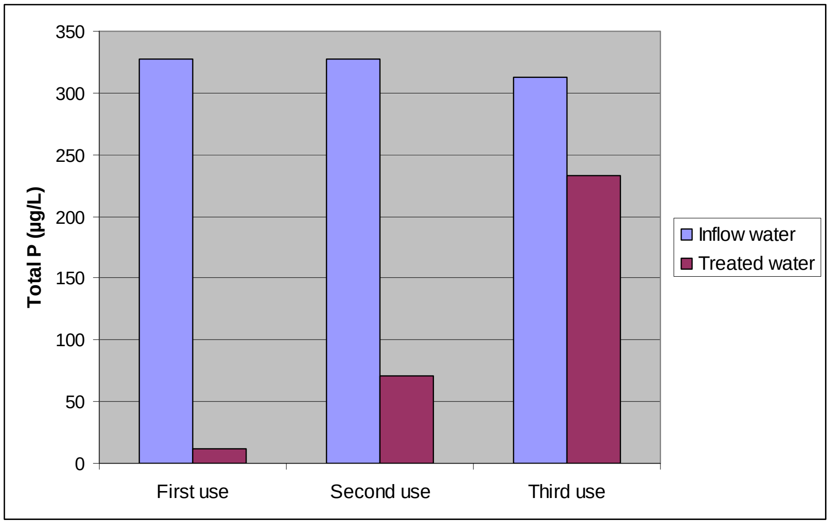

Figure 2. Effects of alum coagulant addition (15 mg Al/L) and subsequent floc re-use on TP concentration in Mosquito Creek waters. One day after the floc settled (first use), the supernatent was removed, additional (untreated) creek water was added, and the existing floc was resuspended (second use). This cycle was repeated a final time, one day later (third use).

The observed incremental reduction in the P removal ability of the wet floc (Figure 2) is in part due to the eventual depletion of P sorption sites in the material. Because of the gradually diminishing P removal capacity of reused floc, and the large volume displacement of this low-density material, the wet floc material must ultimately be cycled out of the HWTT systems. In conventional chemical treatment systems, the floc often is pumped to an adjacent drying bed, (which may be larger than the treatment system itself) and then transported off-site following drying. A key aspect of floc drying is that it provides an approximate 90% volume reduction, plus the resulting material continues to exhibit a strong affinity to adsorb P. As a final coagulant-savings component of HWTT systems, the dry floc can be re-introduced into the treatment facility, either to remove water column P or to help immobilize sediment P in the zones containing wetland vegetation. This dry material is stable and low-volume, so it can be incorporated into the relatively large footprint HWTT system on a sustainable basis.

It should be noted that conventional chemical treatment technologies were developed and refined largely during the design and conduct of “concrete-and-steel” water and wastewater treatment projects, where it is imperative to achieve rapid floc settling (solid-liquid separation) in order to minimize clarifier size and costs. While larger than standard chemical treatment systems, land requirements for HWTT systems remain, however, much smaller than those of traditional treatment wetlands (such as the STAs). Because agriculture is the dominant land use in the Northern Everglades watershed, there exist numerous locations that can accommodate HWTT systems in this region.

In addition to passive and active re-use of chemical flocs, HWTT systems utilize several novel design and operational strategies including:

1. Sequencing and configuring of the wetland unit processes to provide desirable P species transformations,
2. Use of wetland (biotic) components, rather than chemical amendments, for pH buffering,
3. Utilization of the wetland biota to transform/remove additional contaminants, such as N.

A further description of the technology is provided in the following sections.

APPLICATIONS AND SUCCESS STORIES

The reduction of P loads to Lake Okeechobee from the watershed represents a formidable challenge. In order to meet the lake's P load reduction targets, hundreds of tons of P inputs must be curtailed each year. Water managers propose to accomplish this reduction by deploying a combination of Best Management Practices, "Edge of Field" treatment systems, and "Regional" treatment systems. A recent review (SWET, 2001) of Dairy "Best Available Treatment Technologies" indicates that chemical treatment is likely to play a key role in reducing P inputs to the lake.

Because the operating (i.e., chemical) costs for removing a significant fraction of the inflow P load to the lake will be quite high, it is extremely important to identify and implement techniques for increasing the efficiency of chemical use. Examples of "typical" optimization approaches include: targeting sources with high P concentrations, where the mass of P removed per mass of coagulant added is likely to be highest; rigorous jar testing to optimize chemical doses; and use of coagulant aids (i.e., polymers) and buffers, as appropriate, to minimize coagulant costs. The HWTT configuration offers yet another optimization approach that can be considered for deployment in many sites being considered for chemical treatment.

Several applications are presented below, representing various design and implementation strategies for HWTT systems. 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 aids and buffers; and amendment dosing cycles. The first HWTT application described below addresses a system that was used for remediation of lake waters (DeBusk et al 2005b). Rather than continuous dosing, chemicals (coagulant and buffer) were added only once monthly, on a batch basis over a two-year operational period. Because the HWTT system had a HRT of approximately 7 days, this dosing cycle resulted in the addition of chemicals during only one of every four HRTs. The second and third HWTT applications describe findings from the initial deployment of two systems in south Florida, one to treat citrus grove runoff, and the second to treat a continuous flow of stream water (Watershed Technologies 2008). The second site illustrates some of the HWTT floc recycling concepts, while the third demonstrates the challenges to optimization of chemical treatment in the highly variable (in chemical composition) stream waters of the Northern Everglades.

Lake June, Orange Co., Florida

A HWTT system was deployed in Lake June, a 1.6 hectare (ha) lake in central Florida, during August 2003. This system was comprised of a circular floating boom 18 meters in diameter, equipped with a weighted, flexible fabric skirt that extended from the water's surface to the sediments, effectively isolating a parcel of water from the lake's water column (Figure 3). A floating mat of vegetation consisting of plants in the genera *Eichhornia, Hydrocotyle, Bidens, Sagittaria*, and *Pontederia* was established in the system.

The HWTT system was equipped with a solar powered pump to provide a semi-continuous water exchange from the lake's water column into the compartment at a rate of approximately 100 m^3/day (Figure 3), providing a hydraulic retention time (HRT) within the compartment of 7 days. At this exchange rate, a volume of water equal to the lake's entire water column would pass through the wetland compartment in 10.5 months.

Figure 3. The HWTT system deployed in Lake June, Orange Co., FL.

The HWTT was dosed once monthly with alum beneath the wetland vegetation, at a concentration of 12.5 mg Al/L. This alum concentration was selected based on results of jar tests, which demonstrated formation of a moderate to rapidly settling floc at this dose. Chemical analyses also revealed that the lake is poorly buffered, so a buffering agent was injected immediately before injecting alum.

Lake nutrient concentrations varied widely during the two-year study, from 84 to 379 μg/L for TP and 0.76 to 1.25 mg/L for TN (Table 1). We observed no obvious increasing or decreasing trend in lake water TP concentrations during the evaluation: maximum and minimum lake water TP levels were observed in April and August 2004, respectively (Figure 4). The HWTT system exhibited effective nutrient removal, removing 45% of the inflow TP (two year monitoring period) and 40% of the inflow TN (monitored only for a six month period). Despite widely varying lake TP concentrations, the outflow from the HWTT system was relatively consistent, averaging 82 μg/L and ranging from 34 to 150 μg/L (Figure 4). Neither the system inflow (= lake water) nor outflow contained substantial amounts of soluble reactive P (Table 1). The HWTT system outflow TN concentrations averaged 1.08 mg/L, and ranged from 0.76 to 1.25 mg/L (Table 1).

Table 1. Summary of the water quality treatment performance of the Lake June HWTT system. Total P and soluble reactive P were measured approximately every week for two years. Other constituents were measured every 4 – 6 weeks for six months.

	System inflow (Lake)		**System outflow**	
total phosphorus (µg/L)	148	(84 – 379)	82	(34 – 150)
soluble reactive phosphorus (µg/L)	6	(<2 – 27)	8	(<2 – 29)
total nitrogen (mg/L)	1.80	(1.36 – 2.17)	1.08	(0.76 – 1.25)
chlorophyll *a* (mg/m^3)	78	(34 – 123)	26	(15 – 35)
total suspended solids (mg/L)	17	(6 – 26)	6	(2 – 10)
Turbidity (NTU)	12	(8 – 18)	6	(4 – 11)
total aluminum (mg/L)	0.161	(0.057 – 0.260)	0.142	(0.060 – 0.260)
sulfate (mg/L)	18.1	(10 – 21)	20.9	(12 – 44)

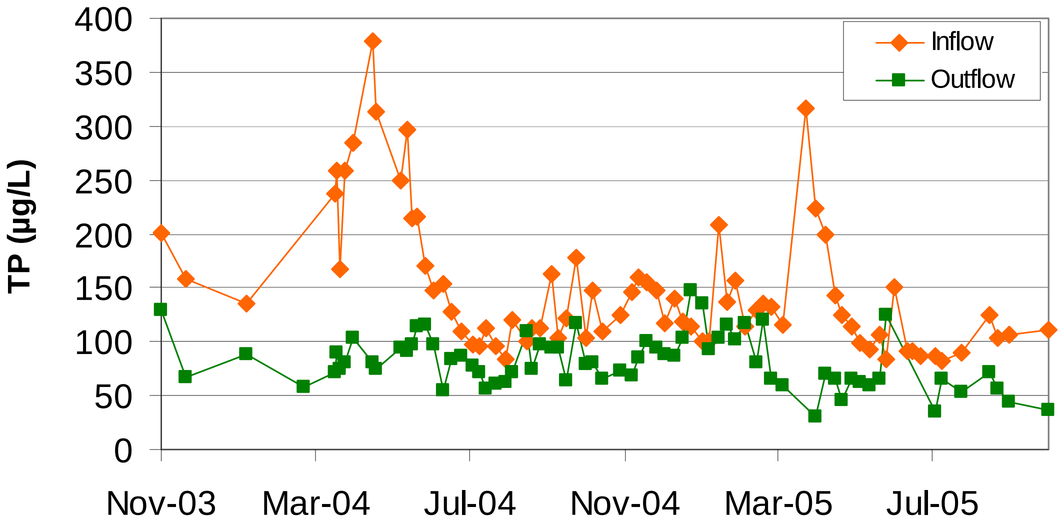

Figure 4. Inflow (= lake water) and outflow TP concentrations from the Lake June HWTT system for a two-year period.

The HWTT system was effective at removing particulate matter, providing a 65, 50 and 67% reduction of total suspended solids, turbidity and chlorophyll *a*, respectively (Table 1). Visual inspection of the water samples, coupled with chlorophyll *a* analyses, suggest that phytoplankton comprised the bulk of the particulate matter in the relatively turbid wetland inflow samples (Table 1). By contrast, the outflow from the HWTT system was quite clear.

Although the monthly injection of alum into the water beneath the HWTT system vegetation undoubtedly enhanced water column pollutant removal, no clear temporal relationship between HWTT system outflow TP levels and the timing of alum applications was observed. Despite the periodic use of alum, mean total aluminum levels in the HWTT system outflow were slightly lower than those of the influent lake water (Table 1). Outflow sulfate levels, by contrast, were slightly higher in the system outflow than in the inflow waters (Table 1).

Based on an average estimated flow rate of 100m^3/day through the wetland, the Lake June HWTT system removed a total mass of 25.6 kg N and 2.81 kg P/yr from the lake water column. On an areal basis, this is equivalent to mass removal rates of 101 gN and 11.3 gP/m^2-yr. As a comparison, the Taylor Creek and Nubbin Slough STAs near Lake Okeechobee were projected to remove 3.0 and 1.6 gP gP/m^2-yr, respectively (Stanley Consultants 2002). Therefore, with a very modest use of chemicals (a batch dose injected once/monthly), the Lake June HWTT was able to sustain a P removal rate that markedly exceeds the projected P removal rate of treatment wetlands. Further optimization efforts, manipulating factors such as system HRT and dosing frequencies, would lead to a better understanding of the treatment potential, with respect to minimum attainable outflow TP levels and maximum attainable mass removal rates, and associated costs of the HWTT for treating lake waters.

Ideal #2 Grove, St. Lucie County, Florida

The Ideal #2 Grove HWTT is situated within a citrus grove in western St. Lucie County. This system, deployed in March 2008, consists of a 0.7-acre pond equipped with both shallow and deep zones, and divided into parallel flow paths with a flexible boom and barrier (Figures 5 and 6). The shallow zone was stocked with floating macrophytes, in this case water hyacinth (*Eichhornia crassipes*), while the deep zones contain several species of submerged aquatic vegetation (SAV). The floating and submerged vegetation contribute to the passive recycling of floc materials (Figure 7).

In May 2008, continuous amendment (alum at 20 - 25 mg Al/L) dosing was initiated in the northern flow path (“A”), and intermittent dosing (same dose, but coagulant provided only 66% of the time) in the southern flow path (“B”). To compensate for the reduced addition frequency of chemicals, flow path B was equipped with a novel floc “recirculation” device, which helps maintain system performance while minimizing amendment use (Figure 8). The flow rate in each parallel path was ~480 m^3/day, providing an average HRT of 3.4 days.

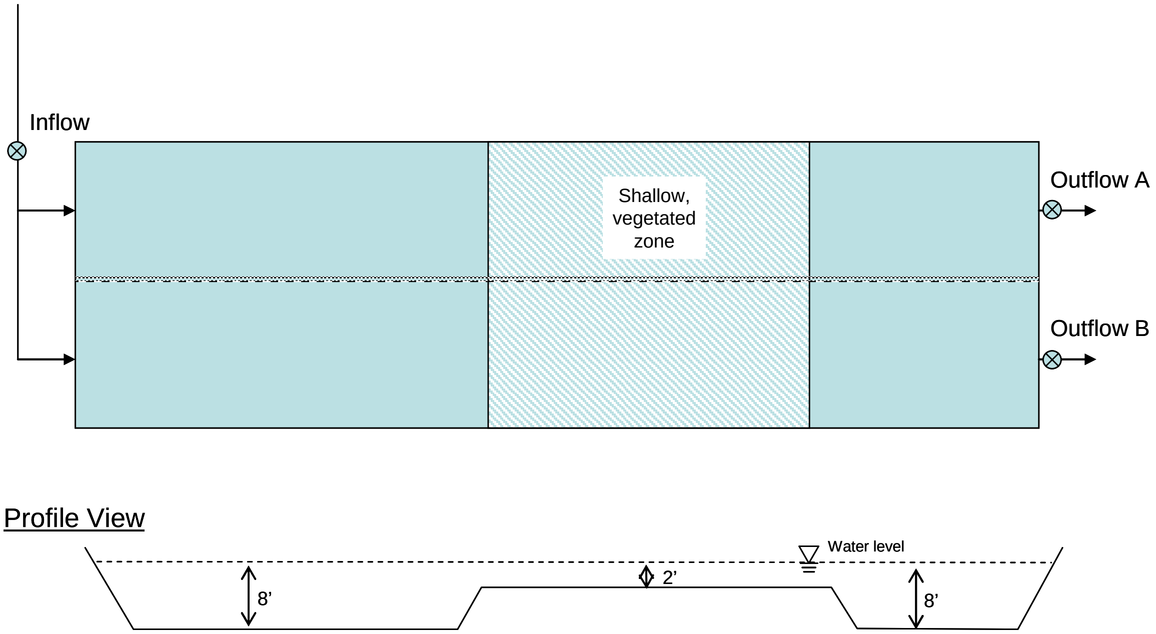

Figure 5. Schematic of the Ideal Grove HWTT, depicting the A and B flow paths and the shallow, central region containing *Eichhornia crassipes*.

Figure 6. 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.

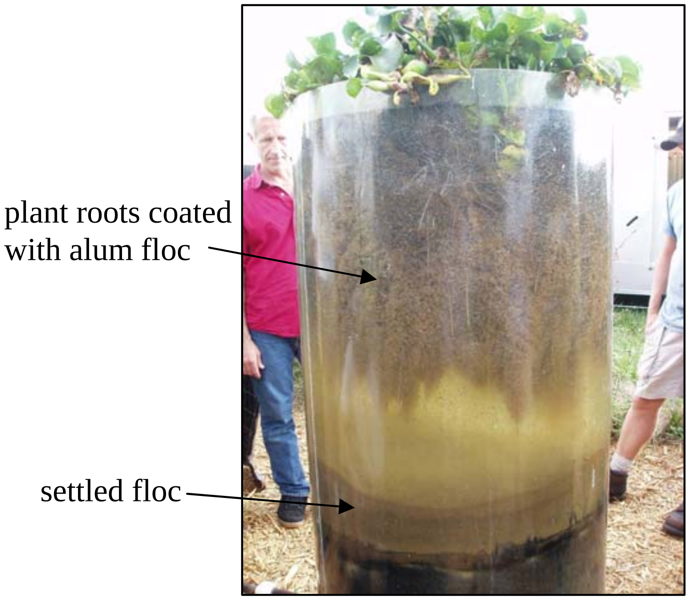

Figure 7. Accumulation of amendment (alum) floc on the roots of water hyacinth (*Eichhornia crassipes*) in a pilot-scale mesocosm. "Passive recycling" occurs in HWTT systems as unamended waters flow past the floc-laden plant roots.

Figure 8. Floc recirculation infrastructure on the southern (B) HWTT flow path.

During 2008, the system was operated for two distinct operational periods, separated by a five-week period when the system was taken off line so that instrumentation upgrades could be performed. From May 2 – July 19, 2008, the southern (B) flow path was operated with intermittent dosing (66% of the time) and active floc recycle, and from August 29, 2008 – January 7, 2009, this same flow path was operated with intermittent dosing and passive floc recycle. During both periods, the northern flow path (A) was dosed continuously (100% of time) with coagulant.

During the initial operational period, the mean inflow TP concentration averaged 202 μg/L, and outflows TP levels from flow paths A (continuous dose) and B (intermittent dose) were 15 and 17 μg/L, respectively. A spike in the flow path B outflow (to 67 μg/L) occurred as inflow TP levels exceeded 1000 μg/L in response to a heavy rain event (Figure 9). During the start of the second operational period, inflow concentrations were high due to the heavy rains from Tropical Storm Fay, with TP levels at 3610 μg/L. At this time, flow path B exhibited an outflow TP of 166 μg/L, and the flow path A outflow was 62 μg/L (Figure 9). Once inflow TP levels declined to below 1000 μg/L, performance of the two flow paths became more comparable. Mean inflow TP levels for the second operational period were 527 μg/L. During this time, the outflow TP levels for the continuously dosed flow path A averaged 28 μg/L, and the mean TP outflow for the intermittently dosed flow path B (with only passive floc recycle during the period) averaged 44 μg/L. This trial of intermittent chemical dosing (yielding a 33% reduction in amendment use) therefore resulted in minor differences in outflow P levels, particularly when inflow TP values were below 1000 μg/L.

Nitrogen removal performance of the two flow paths of the Ideal Grove HWTT was characterized during the first operational period, and at that time the two flow paths produced similar outflow N (and P) concentrations, and mass removal rates (Table 2). Nitrogen values were not measured during the second optimization period, but the 2.5X higher inflow TP concentration during this period (527 vs. 198 μg/L) suggests that mass P removal rates were in the range of 20 – 25 gP/m^2-yr for the latter portion of 2008.

Initial operations of the Ideal Grove site reveal that extremely low outflow TP concentrations can be attained by HWTT systems, and that intermittent dosing of chemicals (with associated operating costs savings) can provide comparable system outflow concentrations to continuously dosed systems. Additional optimization efforts are underway at this site, to evaluate TP removal performance under varying dosing regimes and using different coagulants.

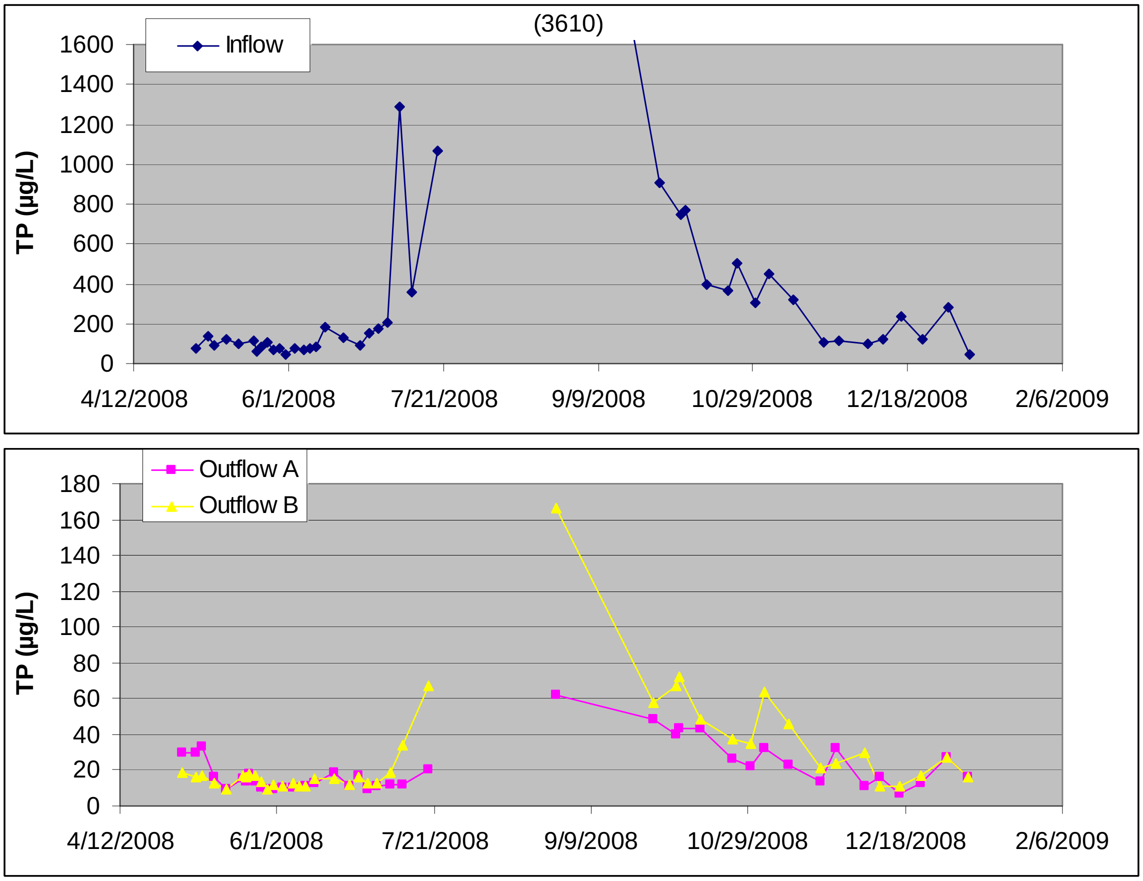

Figure 9. Total P concentrations for the Ideal #2 Grove HWTT during two operational periods. Flow path A received continuous chemical dosing, while flow path B was dosed intermittently (33% reduction in chemical use). Active floc resuspension was performed during the initial operational period, while only passive floc recycle occurred during the second period.

Table 2**.** Mass balance (loading and removal) for N and P at the Ideal Groves HWTT during the period May 6 – June 30, 2008.

	TP		**TN**	
	Path A	**Path B**	**Path A**	**Path B**
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

To clarify the benefits of the intermittent dosing strategy, such as used at the Ideal facility, it is important to understand the relationship between coagulant doses and outflow TP concentrations. Data from a jar test with Ideal canal waters are used for this example. 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 (Figure 10). 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 Ideal waters on that sampling date, the optimum alum dose to achieve an outflow TP below 100 µg/L was between 22.5 and 25 mg Al/L (Figure 10).

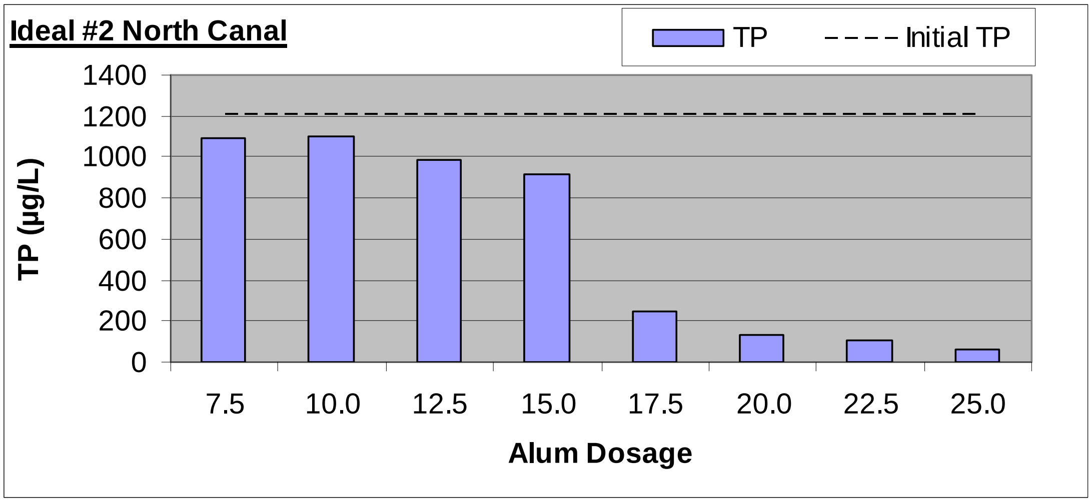

Figure 10. Relationship between amendment dose (alum, as mg Al/L) and TP concentrations of Ideal inflow waters (initial TP), as determined from a laboratory jar test.

HWTT systems are operated using a coagulant dose just high enough to provide effective flocculation and settling, which for the example (Figure 10) would be 17.5 - 25 mg Al/L, depending on the desired target outflow concentration. A unique feature of HWTT systems, however, is that effective treatment can be maintained using only intermittent dosing. For the Ideal Grove HWTT, the southern (B) flow path was operated under a lower dosing frequency (i.e., 66% of the time). The intermittently dosed systems continued to provide effective treatment, due to the capture of active flocs on plant stems and roots (Figure 7) 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 be much less effective in a conventional chemical treatment facility. For example, 66% of a 20 - 25 mgAl/L dose (the dose range actually used during 2008) is equivalent to the chemical consumption incurred with a full-time dosing of 13 – 16.5 mgAl/L. Jar tests indicate that this dosing range should yield a supernatant (outflow) TP concentration of ~950 - 250 µg/L (Figure 10). These TP concentrations are considerably higher than the Ideal flow path outflow TP levels, even during the periods of highest inflow TP concentrations (Figure 9).

Nubbin Slough, Okeechobee County, Florida

The Nubbin Slough HWTT system is noteworthy because it is a gravity-fed, continuous flow system, and it illustrates the unique challenges of deploying chemical treatment technologies in the Northern Everglades watershed. The Nubbin Slough (Davie Dairy) facility originally was a conventional chemical treatment facility constructed for the Dairy "Best Available Technology" program (Figure 11). A diversion weir was situated in Nubbin Slough, and diverted water was fed into a large settling pond, and then returned at a downstream location into the slough. Chemical coagulants were injected into the inflow piping, on a flow proportional basis, just upstream of the settling pond. This chemical treatment system was converted to a HWTT system in 2008.

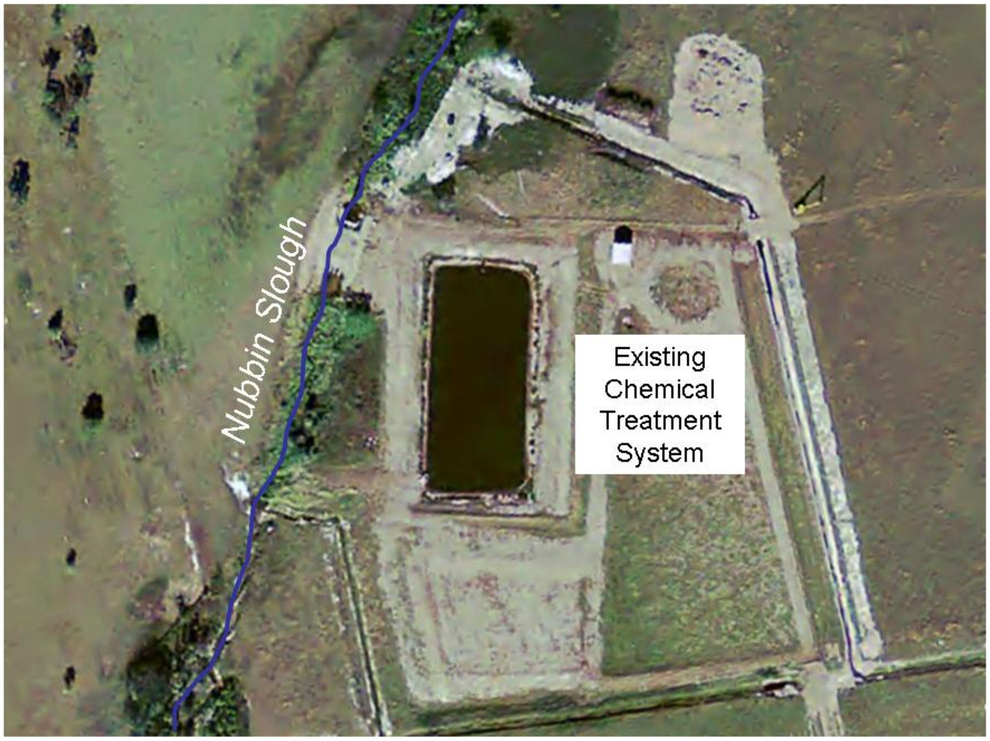

Figure 11. Aerial photo of Nubbin Slough "Davie Dairy" conventional chemical treatment system at Davie Dairy. The building housing the chemical storage tanks and dosing pumps is located to the upper right of the settling pond. In 2008, this system was modified into a HWTT facility.

Prior to its conversion to a HWTT facility, a poly-aluminum chloride compound (Hyperion 1090) was utilized in the treatment system as a coagulant at a dosing rate of 7.5 mg Al/L. This dose was arrived at through jar testing, which actually revealed effective TP removal at Hyperion 1090 doses as low as 4.0 mg/L. The dose of 7.5 mg/L was selected for operational purposes, providing a safety factor above the levels observed in the laboratory tests.

As part of the initial design efforts for the HWTT system in the latter half of 2007, the P removal effectiveness of the Hyperion 1090 compound for floc formation and P removal was evaluated for the Davie facility. This effort revealed minimal floc production in the settling pond, and poor TP removal performance within the system. Because of the apparent poor performance of the Hyperion 1090 coagulant, an aliquot of this material was obtained from the chemical storage tank, and transported to the laboratory for testing. Coagulant dosing rates of 7.5 up to 30 mgAl/L were tested with Nubbin Slough waters. No floc formation was observed at the lower doses. Small, micro-floc formation was observed at Hyperion 1090 doses of 15 and 17.5 mg Al/L. The 25 and 30 mg Al/L doses successfully clarified the water column, and did not adversely impact the pH (reduction of raw water pH of 6.9 to 6.7 for both doses).

The great disparity in dose requirements was undoubtedly related to temporal changes in Nubbin Slough water chemistry. The initial jar testing, that prescribed a 7.5 mgAl/L dose, was performed using samples collected during the dry season, while the latter testing (which resulted in a much higher dose) was performed in the wet season. Because Hyperion 1090 is a relatively expensive coagulant (particularly at a dose of 25 – 30 mgAl/L), tests with other coagulant(s) were performed prior to deployment of the HWTT system. A combination of alum and sodium aluminate, at typical doses of 5 and 10 mg Al/L, was eventually selected as a suitable coagulant/buffer blend for waters this site. During implementation of the HWTT facility, other improvements were made to the site infrastructure, including baffling in the settling pond, installation of a mixing chamber, and vegetation stocking (Figure 12).

Figure 12**.** The Nubbin Slough HWTT. The mixing chamber and inflow manifold are 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 initial optimization period (mid-March to mid-July 2008), system flow rates ranged from 0.1 to 27.1 cfs, and averaged 1.7 cfs. This resulted in a mean HRT of 4.3 days. After the HWTT system had operated for a number of weeks with low “dry season” flows, a heavy rain event occurred in April, and the flow through the pond (27 cfs) exceeded the desired maximum. This degraded the treatment efficiency due to the excessively short HRT (i.e., 6 hours) (Figure 13). Subsequently, a flow restrictor orifice was designed and deployed on the pond inflow pipe at the weir, with an overflow elbow on one of the three slide valves that pass water through the weir in the stream. This device can be adjusted to select a “maximum” flow, which for the Nubbin Slough HWTT is probably in the range of 5 to 10 cfs.

From mid-March through mid-July 2008 (the initial testing period), the system inflow TP averaged 754 µg/L and the system outflow averaged 122 µg/L, an 84% reduction (Figure 13). During this period, the variations in inflow TP levels, and other key chemical constituents of the stream water, were dramatic (Figure 13). Alkalinity averaged 26 mg/L as $CaCO_3$, and ranged from 2 to 67 mg/L as $CaCO_3$. Color averaged 336 CPU, and ranged from 211 to 550 CPU. Chemical dosing rates, particularly of the buffer (sodium aluminate), had to be varied frequently during the operational period in response to temporal changes in water chemistry. The broad temporal variations in inflow water quality observed for the Nubbin Slough HWTT have profound implications to operational costs, with chemical doses (and associated costs) at times being extremely high, particularly when color levels were elevated and alkalinity levels were low.

While the widely varying inflow chemistry of Nubbin Slough waters presents an operational challenge, it is not insurmountable. Indeed, the HWTT system offers several features that allow it to effectively address widely varying water chemistry regimes. One HWTT component to be deployed during 2009 at both Nubbin Slough (initially using mesocosms) and at Mosquito Creek (full-scale facility) is a submerged vegetation/limerock (SAV/LR) community. This unit process will be established at the HWTT system outflow region to restore alkalinity and pH to desirable levels prior to discharge. This in turn will eliminate the use of a costly liquid buffer, as well as the monitoring and control instrumentation needed to optimize buffer additions.

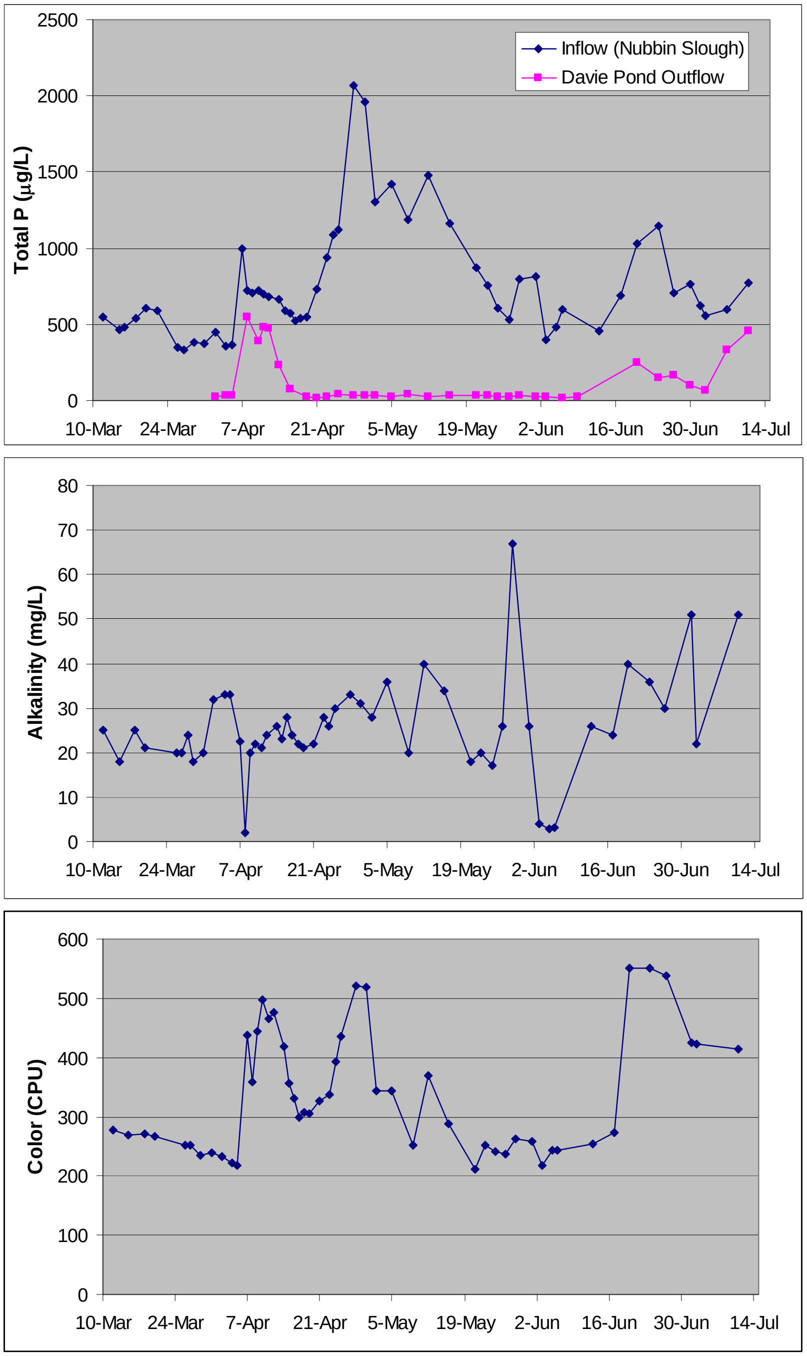

Figure 13. Temporal changes in TP, alkalinity and color during mid-2008 for the inflow Nubbin Slough HWTT waters. Outflow TP values for the HWTT facility also are depicted in the top graph.

IMPLEMENTATION ISSUES

In the following section, we address questions pertinent to the implementation of HWTT systems in the Northern Everglades watershed.

What P concentrations and/or species will respond to chemical treatment cost effectively?
Soluble reactive P, particulate P and dissolved organic P, in order of ease of treatment in a HWTT system.

What volume or flow rate is logistically feasible for treatment?
Due to the large parcels of land available in the Okeechobee watershed, and the potential for additional reservoir/STA construction, there are almost no constraints on the flows that can be treated with a HWTT system in the watershed.

Where in the KOE planned features can chemical treatment be applied?
A HWTT system can be deployed at edges of fields, adjacent to creeks, in existing lagoons or STAs/ reservoirs, or in concert with planned STAs/ reservoirs.

What water quality parameters affect chemical treatment P-reduction efficiency? Do we have sufficient existing data or is additional data required?
Alkalinity, color, suspended solids, soluble reactive P, particulate P and dissolved organic P are all parameters that will influence treatment within a HWTT system. We have sufficient data to understand the major controlling water quality variables in HWTT systems. Additional data are currently being collected in selected areas of the watershed to refine our understanding of the spatial and temporal variability of these parameters.

What water quality standards must be met for chemically treated discharges to various receiving waters?
A fully implemented HWTT process employs desirable back-end vegetation communities that assure a discharge that is biologically compatible with receiving waters. Stormwater and surface water treatment systems utilizing some form of chemical treatment that have minimal impacts to water resources and can be operated in a manner that does not cause violations of water quality standards can be permitted under FDEP’s Noticed General Environmental Resource Permits [Chap 62-341, F.A.C.].

What is the best aerial economy of scale for treatment system implementation (parcel, sub-basin, STA, reservoir)?
HWTT systems can be efficient with virtually no scale or placement limitations. Existing land ownership patterns (public vs. private) will largely dictate the appropriate scale and locations. Publically owned land (regardless of scale) is advantageous from a capital expense standpoint, where positive savings will accrue through elimination of land costs. By contrast, edge of farm systems may prove more effective from an operating cost standpoint, due to potentially higher TP concentrations at these locations.

Can the chemical treatment be permitted?
Stormwater and surface water treatment systems utilizing some form of chemical treatment that have minimal impacts to water resources and can be operated in a manner that does not cause violations of water quality standards can be permitted under FDEP's Noticed General Environmental Resource Permits [Chap 62-341, F.A.C.]. These systems may be eligible for the existing Sec. 62-341.485 "General Permit to Water Management Districts for Environmental Restoration or Enhancement." If not, the FDEP rule chapter can be amended by the Department to create another more specific general permit for each type of treatment system using chemical additions.

What are the monitoring requirements of planned solutions?
Parameters that should be monitored include major elements/compounds that are added to or removed from the inflow waters. Also parameters that have water quality standards coupled with the potential to significantly alter the receiving body should be monitored.

What are the cost-benefits of planned solutions?
Benefits include efficient total mass nutrient removal; high percent nutrient removal; removal of biologically active nutrient forms; reduced costs through highly efficient utilization and reuse of floc; reduced chemical costs achieved through the use of wetland components of the HWTT process; large-scale reduction in land costs compared to traditional wetland treatment systems; and HWTT projects well-suited to implementation on existing SFWMD properties and/or private property with associated cost/benefits to the landowner. Economic viability of a technology is highly dependent on isolation of system components and attendant costs; e.g. existing detention areas that provide significant treatment capacity but have no capital value assigned will distort performance of associated chemical processes. HWTT is a complete system that integrates the best of chemical and wetland treatment. All benefits, including tangible and intangible, should be considered and weighted against other treatment technologies.

With respect to developing specific technology costs, our findings reveal that the dramatic spatial and temporal variability in water chemistry among sites in the Northern Everglades will render "general" cost estimates for chemical treatment meaningless. Site-specific cost estimates will need to be developed; using actual operational data (or on-site pilot-scale data) collected through both wet and dry seasons (and wet and dry years).

What factors affect settling and residuals management?
and,
What are cost effective options for residual management?
Physical characteristics (size, density) largely control the settling rate of flocs. The HWTT does not require large tracts of land to be set aside for residual drying and storage, as was incorporated at the Davie Dairy BAT site. The most cost effective approach for managing flocs is to detain, dry and re-use residuals on-site, by incorporating them into the HWTT treatment system footprint for additional P removal.

What chemicals and treatment configurations should be further evaluated?
Aluminum compounds, iron compounds, appropriate polymers and polymer-metal blends can all be utilized in HWTT systems. Water chemistry conditions at each particular site will dictate which chemicals should be further evaluated.

SUMMARY

HWTTs can be successfully deployed in the Northern Everglades watershed, due to their strong potential for maximizing the efficiency of coagulant use. Initial work with waters in the Lake Okeechobee watershed, however, indicates that metal coagulant and buffer dose requirements can significantly vary both spatially and temporally within the basin. This factor, along with the multiplicity of HWTT control variables, suggests that an optimization period is required for initial HWTT installations. 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.

REFERENCES

DeBusk, T.A., K. A. Grace and F.E. Dierberg. 2005a. Treatment wetlands for removing phosphorus from agricultural drainage waters. In: E. J. Dunne, K. R. Reddy and O.T. Carton, Eds, Nutrient Management in Agricultural Watersheds: A Wetlands Solution. Pp. 167 – 178. Wageningen Academic Publishers, The Netherlands.

DeBusk, T.A., R. Baird, D. Haselow and T. Goffinet. 2005b. 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, USA

Kadlec, R.H. and S.D. Wallace. 2009. Treatment Wetlands. 2nd. Edition. CRC Press, Boca Raton, FL, USA.

SFWMD. 2000. Everglades Consolidated Report, Chapter 8: Advanced Treatment Technologies for Treating Stormwater Discharges into Everglades Protection Area. South Florida Water Management District, West Palm Beach, FL, USA

Stanley Consultants, Inc. 2002. Lake Okeechobee Water Retention and Phosphorus Removal Project. Design Analysis Report, Vol. 1. Prep. for Army Corps of Engineers, Jacksonville, FL, USA.

SWET. 2001. Dairy Best Available Technologies in the Okeechobee Basin: Literature Review, Prep. By Soil and Water Engineering Technology, Inc. Project Report for South Florida Water Management District, West Palm Beach, FL, USA

Watershed Technologies, 2008. Implementation of Hybrid Wetland Treatment Technology in the Northern Everglades Watershed. Final project report submitted to the Florida Department of Agriculture and Consumer Services, Tallahassee, FL, USA.