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Evaluation of the Design, Operation and Treatment Performance of Periphyton Stormwater Treatment Area (PSTA) Platforms

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Summary of Key Points

1. This report summarizes the period-of-record (POR) treatment performance of PSTA platforms that were investigated by the District and other researchers in 50 separate trials conducted as part of 13 studies. Data collection for these studies spanned 20 years from 1998 to 2017. Trials were conducted using an assortment of platforms of different sizes and construction design: mesocosms, raceways, flow-ways and wetland cells.
2. There was a progression in the size of the PSTA platforms used in District-sponsored studies, starting with small raceways and mesocosms, moving to larger test cells, then to even larger field-scale cells and finally culminating in the 41-ha (100-ac) STA-3/4 PSTA Project Field-scale Cell. This was done to increase study realism and reduce potential artifacts associated with small platforms. In addition, the complexity of study designs decreased with increasing platform size, both out of necessity (i.e., there were fewer large platforms to work with) and based on what had been learned with the smaller platforms.
3. A mean outflow TP concentration of 13 µg L^{-1} was used as a benchmark to evaluate treatment performance of the different PSTA platforms. While almost all trials reduced inflow-to-outflow TP concentration to some extent, only five of the 50 trials (10%) successfully achieved a mean outflow TP concentration ≤ 13 µg L^{-1} when their mean inflow TP concentrations were > 13 µg L^{-1}. These five trials all had a limerock/ shellrock substrate.
4. Although some trials with a limerock/shellrock or sand substrate had better TP removal than trials with a peat/muck substrate within the same study, there was no statistically significant difference among substrate types when trials were analyzed with a Kruskal-Wallis one-way analysis of variance on ranks.
5. Mean outflow TP concentrations from the STA-3/4 PSTA Project Field-scale Cell over its 10-year POR and within each year were all ≤ 13 µg L^{-1}. This platform was the most successful of the PSTA platforms investigated and demonstrated that PSTA, in theory, could be implemented at full-scale in the Everglades STAs.
6. Based on the results of simple linear regressions, there were no strong predictors of mean outflow TP concentration among the independent variables tested for a data set that excluded the HydroMentia ATS studies; all r^2 values were < 0.50 or not statistically significant for mean inflow TP concentration, phosphorus loading rate, hydraulic loading rate, hydraulic retention time, % TP concentration reduction, water depth, platform length: width ratio and platform surface area.

Background & History

The Florida Everglades is a vast oligotrophic (nutrient-poor) freshwater wetland[1] that supports diverse habitat types (e.g., open-water slough, wet prairie, sawgrass marsh, tree island) and dominates the landscape of south Florida (Davis 1943a, 1943b; Loveless, 1959; Lodge, 1994). This unique ecosystem is of immense ecological importance on both a national and international level (Maltby and Dugan, 1994). Agricultural and urban development over the last 100+ years has reduced the present-day size of the Everglades to ~ 960,000 ha (2.4 x 10^6 ac), which is only 50 percent of its historic extent. In addition, portions of the Everglades have experienced eutrophication (nutrient enrichment) primarily due to the influx of phosphorus (P)-rich runoff from the Everglades Agricultural Area (EAA), which has altered the biological community in these areas (Davis, 1994; Lodge, 1994).

The Everglades Stormwater Treatment Areas (STAs) are a complex of five large constructed wetlands that are integral components of State and Federal efforts to protect what remains of the Everglades (Chimney and Goforth, 2001; Sklar *et al.*, 2005). These STAs are operated by the South Florida Water Management District (District or SFWMD) and currently encompass 23,000 ha (57,000 ac) of treatment area. Because the Everglades is sensitive to P enrichment (Davis, 1994), the primary function of the Everglades STAs is to reduce the total P (TP) concentration in EAA runoff to levels that will protect today's Everglades ecosystem. Accordingly, these STAs have very stringent treatment performance requirements mandated by a state-issued operating permit that implements a water quality based effluent limit (WQBEL) for TP: annual flow-weighted mean outflow TP concentrations from each STA cannot exceed 19 µg L^{-1} in any single year nor be greater than 13 µg L^{-1} in more than three years within a five-year period (State of Florida, 2017).

Pristine portions of the present-day Everglades typically have water-column TP concentrations that are ≤ 10 µg L^{-1} on a long-term basis. The vegetation community in these areas is characterized by abundant calcareous periphyton[2] mats interspersed with relatively sparse emergent macrophytes. This observation suggested that nutrient uptake by periphyton is important to achieving ultra-low water-column TP concentrations and generated interest in incorporating this community type into the design of the Everglades STAs. The advisory panel that the District assembled for the Everglades Nutrient Removal Project (ENRP)[3] recommended that this wetland

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[1] The present-day Everglades includes Everglades National Park and Water Conservation Areas 1, 2A, 2B, 3A and 3B, known collectively as the Everglades Protection Area.

[2] Periphyton is the community of algae, cyanobacteria and heterotrophic microbes attached to submerged surfaces in aquatic systems. Periphyton is found in all freshwater wetlands. Because the algae and cyanobacteria components of periphyton are light dependent, periphyton biomass and productivity are influenced by irradiance at the water's surface. Therefore, for a given water-column nutrient level, periphyton biomass and productivity should be lower in well-shaded systems (e.g., forested and dense emergent-macrophyte wetlands) compared to wetlands with sparse emergent macrophytes that receive unfiltered sunlight.

[3] The ENRP was a 1,544 ha (3,816 ac) prototype STA built by the District adjacent to Water Conservation Area 1 (Chimney and Goforth, 2006). The ENRP operated from 1994 through 1999, after which time it was incorporated into the footprint of STA-1 West. The ENRP advisory panel made recommendations on how to operate this facility and suggested research projects to be conducted within it.

have “algal polishing cells” at its outflow region and that research be conducted on the treatment efficacy of algae-dominated wetlands (SAPENRP, 1991). A variant of an algal polishing cell, the “Periphyton Stormwater Treatment Area” (PSTA) concept, was later proposed by Drs. Robert Doren and Ronald Jones (Doren and Jones, 1996; Jones, 1996, 1997). They envisioned a very shallow periphyton-dominated wetland without any submerged aquatic vegetation (SAV), only sparse emergent macrophyte coverage and removal of most of the native soil to expose the underlying limestone bedrock (caprock). The soil would be removed to discourage the widespread establishment of emergent macrophytes that would shade out periphyton.

Concerns subsequently were raised about the feasibility of large-scale implementation of PSTA in the Everglades STAs (Kadlec 1996a, 1996b, 1998, 1999; and Kadlec and Walker, 1996). The *Desktop Evaluation of Alternative Technologies* study reviewed treatment technologies that might be superior to the STAs, and initially included the PSTA concept, but eventually eliminated it from consideration due to (1) the lack of any experimental or operational treatment performance data for a PSTA system, (2) uncertainty regarding constructability of PSTA on a large scale and (3) the lengthy research period needed before such a system could be designed (PEER/Brown and Caldwell, 1996). Questions about PSTA feasibility notwithstanding, the Section 404 permit issued to the District by the U.S. Army Corps of Engineers (USACE) for the construction of the Everglades STAs required that the District conduct research on “periphyton STAs” along with eight other treatment technologies (USACE, 1997). The District initiated its *Advanced Treatment Technology (ATT) Program* in 1997 to comply with this mandate; one of the ATT projects focused solely on PSTA. In addition, other research and demonstration projects conducted in south Florida have investigated what is regarded in this report as being PSTA (see below). The District funded most of these research efforts, while others were conducted independently (see **Table 1**).

Report Objectives

The objective of this report is to summarize the POR treatment performance from investigations of different PSTA test systems (hereafter referred to as “platforms”) conducted in south Florida and is restricted to only those studies with summary documentation that was available to the author[4]. The report provides a description of each study’s design and operation, including its chronology and duration, and documents the POR treatment performance achieved during the study. The surface-water TP concentration at the platform outflow is used as the measure of treatment performance and compared to a target outflow TP concentration. A meta-analysis[5] of

[4] The Kadlec and Walker (2004) review of periphyton stormwater treatment lists the following studies/monitoring efforts that are not included in this report due to the unavailability of treatment performance documentation: FIU/SFWMD Limerock Pads, the USACOE S-332B Scrape-down Basin Monitoring, CH2M Hill/USACOE S-332D Scrape-down Basin Monitoring, FIU C-111 Scrape-down Patch Studies, SFWMD C111 Natural Marsh Studies, SFWMD WCA-2A Natural Marsh Studies, and Hole-in-the-Donut Restoration Studies.

[5] A meta-analysis is a statistical analysis that examines data from a number of independent studies of the same subject to determine overall trends.

the relationship between treatment performance and potential controlling variables such as substrate type, water depth, inflow TP concentration and other operational parameters was performed. This report extends previous PSTA summaries provided by CH2M Hill (2003a), Kadlec and Walker (2004), Goforth (2011) and DBEL (2015).

What is PSTA?

The characterization of what constitutes a PSTA has evolved from the original concept of Doren and Jones (1996; see definition above). The different platforms studied by the District and other researchers were all described as being a PSTA and ranged from having shallow (9 cm) to moderately deep (60+ cm) water columns, usually with sparse coverage of emergent macrophytes, generally supported a robust SAV community and with the native soil left undisturbed, removed down to the caprock or covered with a layer of crushed limestone or other material, such as sand or lime sludge[6]. In addition to these studies, this report also evaluates the Hydro-Mentia Algal Turf Scrubber™ (ATS) studies. While the ATS technology differed markedly from other PSTA platforms in many respects[7], the ATS studies are included because nutrient uptake in this technology is accomplished entirely by periphyton. For simplicity, the term PSTA is used hereafter in a generic sense that encompasses all the above-mentioned platforms.

Description of PSTA Studies

Thirteen studies conducted in south Florida that investigated a variety of PSTA platforms are summarized in this report (**Table 1**). These platforms varied in construction design and surface area from small mesocosms (2 to 93 m^2), to shallow raceways and flow-ways (13 m^2 to 1.4 ha), to test and field-scale wetland cells (496 m^2 to 41 ha) and the variables (experimental treatments) that were manipulated such as water depth, substrate type, plant community composition or other parameters. Note that studies based on soil cores are not included because this platform was judged too small and artificial in nature, and the studies conducted in them too short in duration, to be comparable to results from the larger and longer PSTA studies. The data set assembled for this report contains results from 50 separate "trials" that were part of these 13 studies. Each trial monitored the treatment performance of a single platform type under a suite of experimental treatments for a minimum of six months (see **Appendix 1** for details on each trial).

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[6] Kadlec and Walker (2004; pg. 8) consider PSTA and SAV systems to be variants of the same wetland type, which they characterized as a "Non-emergent Wetland System" (NEWS). The only consistent difference between PSTA and SAV systems is that SAV has no manipulation of the native soil (removal or covered with a material) whereas the soil in a PSTA is (usually) manipulated. In practice, the management of PSTA systems has allowed a SAV community to become established, and both PSTA and SAV systems control emergent macrophytes to some extent.

[7] The ATS systems (Craggs *et al*., 1996) were extremely shallow (≤ 2 cm water depth) with no substrate, emergent macrophytes or SAV; were operated under exceptionally short hydraulic retention times (~ 6 to 30 min); had their periphyton mechanically harvested at regular intervals; and had inflow and outflow TP concentrations that were generally an order of magnitude greater than TP concentrations in the other PSTA studies (**Appendix 1**). No attempt was made to coordinate any aspect of the ATS studies with the other PSTA studies evaluated in this report.

Table 1. Studies of PSTA platforms conducted in south Florida that are evaluated in this report. Studies shaded in blue were funded either partially or entirely by the District.

#	Study	Reference
1	CH2M Hill Porta-PSTA Mesocosms	CH2M Hill (2003a)
2	CH2M Hill STA-1W Test Cells	CH2M Hill (2003a)
3	CH2M Hill STA-2 Field-scale Cells	CH2M Hill (2003a)
4	CH2M Hill Wellington Wetland Demonstration Study Test Cells	CH2M Hill (2003b)
5	DBEL STA-1W Mesocosms	DeBusk *et al*. (2011)
6	DBEL STA-1W Raceways	DeBusk *et al*. (2004)
7	HydroMentia Powell Creek Algal Turf Scrubber™ Raceway	Hydromentia (2010a)
8	HydroMentia S-154 Algal Turf Scrubber™ Flow-ways	Hydromentia (2005)
9	HydroMentia STA-1W Algal Turf Scrubber™ Raceway	Hydromentia (2009)
10	HydroMentia Taylor Creek Algal Turf Scrubber™ Flow-way	Hydromentia (2010b)
11	SFWMD STA-3/4 PSTA Project Field-scale Cell	Zamorano *et al*. (2018)
12	USACE Flying Cow Road Mesocosms	WSI & ANAMAR (2011)
13	USACE STA-1E Field-scale Cells	WSI & ANAMAR (2011)

1. CH2M Hill Porta-PSTA Mesocosms

CH2M Hill, Inc. conducted a 19-month study from April 1999 through October 2000 (**Figure 1**) in 24 small above-ground fiberglass mesocosms (referred to as "Porta-PSTAs") located at the STA-1W South Research site as part of the District's Advanced Treatment Technology (ATT) Program's *Periphyton-Based Stormwater Treatment Area (PSTA) Research and Demonstration Project* (CH2M Hill, 2003a). All mesocosms were constructed of fiberglass; 22 mesocosms measured 6 m long x 1 m wide (surface area = 6 m^2; cell length:width aspect ratio = 6.0) while the remaining two mesocosms measured 6.0 m long x 3.0 m wide (surface area = 18 m^2; cell length:width aspect ratio = 2.0). The bottoms of all but two mesocosms were filled with either peat, shellrock or limerock, while the bottom of one mesocosm was covered with a synthetic membrane (Aquamat™) and the bottom of other mesocosm was left bare. Most of the mesocosms with a peat/shellrock/limerock substrate were sparsely planted with Gulf Coast spikerush (*Eleocharis cellulosa*) and bladderwort (*Utricularia* sp.) to provide structure for periphyton attachment, while one mesocosm filled with peat and another filled with shellrock were left unplanted and treated with Aquashade™, a dye used in pond management to limit light penetration into the water column and inhibit the growth of algae. Nineteen different combinations of experimental treatments were tested during the two phases of the study that involved manipulating water depth, soil type, hydraulic loading rate (HLR), mesocosm width and the presence/absence of periphyton (**Appendix 1**). Water was pumped into the mesocosms from the outflow region of STA-1W and maintained at a depth of either 30 or 60 cm, depending on the experimental treatment. Grab samples were collected from the common inflow to the mesocosms and each mesocosm's outflow on a weekly basis and analyzed for TP. Mean POR outflow TP concentrations ranged from 14.2 to 20.0 $\mu g\ L^{-1}$ among the trials.

2. CH2M Hill STA-1W Test Cells

CH2M Hill, Inc. conducted a 27-month study from February 1999 through April 2001 (**Figure 1**) in three of the STA-1W South Test Cells (Test Cells 3, 8 and 13) as part of the District's ATT Program's *Periphyton-Based Stormwater Treatment Area (PSTA) Research and Demonstration Project* CH2M Hill (2003a). Each test cell is rectangular in shape (~ 80 m long x ~ 27 m wide; cell length:width aspect ratio = 3.0) and approximately 0.2 ha (0.5 ac) in size (**Appendix 1**). All three test cells were lined with a commercial-grade landfill liner to hydrologically isolate them from adjacent test cells and the surrounding Cell 3 of STA-1W. This allowed for independent control of water depth and inflow rate in each test cell. Two of the test cells were filled first with 100 cm of sand and then 30 cm of shellrock during construction, while the remaining test cell was filled first with 75 cm of sand, then 30 cm of shellrock and finally 30 cm of peat. Water was pumped into the test cells from Cell 3 of STA-1W and maintained at a nominal depth of 30 or 60 cm. The test cells were sparsely planted with Gulf Coast spikerush and bladderwort to provide structure for periphyton attachment. Six different experimental treatments were tested in two phases during the study (Phase 1: February 1999 to March 2000 and Phase 2: April 2000 to April 2001) that involved manipulating water depth and amending the peat soil with calcium. Grab and composite autosampler samples were collected from the common inflow to the test cells and each test cell's outflow on a weekly basis and analyzed for TP. Mean POR outflow TP concentrations ranged from 11.7 to 29.1 µg L^{-1} among the trials.

3. CH2M STA-2 Field-scale Cells

CH2M Hill, Inc. conducted a 15-month study from July 2001 through September 2002 (**Figure 1**) in four wetland "field-scale" cells that were constructed adjacent to STA-2, Cell 3 as part of the District's ATT Program's *Periphyton-Based Stormwater Treatment Area (PSTA) Research and Demonstration Project* (CH2M Hill, 2003a). Each cell was rectangular in shape and approximately 1.9 ha (4.8 ac) in size; three cells (Cells 1, 3, and 4) had a linear 317-m long flowpath (x 61 m wide; cell length:width aspect ratio = 5.2), while the remaining cell (Cell 2) had a 951-m sinuous flow-path (x 21 m wide; cell length:width aspect ratio = 45.3) created by two internal longitudinal berms (**Appendix 1**). Water was pumped into these cells from either Cell 3 of STA-2 or the STA-2 seepage control canal. Two of the cells had a 60-cm layer of limerock placed over the original peat soil, a third cell had all its peat soil removed to expose the underlying caprock, while the original soil in the remaining cell was not disturbed. Low densities of Gulf Coast spikerush was planted in bands across the width of each cell to help retain the periphyton mat within the cell. With time, sparse to moderate coverage of macrophytes (emergent + SAV) developed in all cells. Average water depth in the cells ranged between 1 and 30 cm over their POR. The experimental treatments were cell length:width ratio, water depth, hydraulic retention time (HRT) and sedi-ment type. Grab and composite autosampler samples were collected from the common inflow to the cells and each cell's outflow on a weekly basis and analyzed for TP. Mean POR outflow TP concentrations ranged from 14.9 to 27.7 µg L^{-1} among the trials. This facility was decommissioned at the end of the research project; the levees, internal berms and other infrastructure were re-moved, and the site incorporated into the footprint of STA-2, Cell 4.

4. *CH2M Hill Village of Wellington Wetland Demonstration Study Test Cells (Wellington, FL)*

CH2M Hill, Inc., under contract to the Village of Wellington and independent of the District, conducted an 11-month study from April 2002 through February 2003 (**Figure 1**) in two test wetlands that were part of the *Village of Wellington's Aquatics Pilot Program: Wetlands Treatment Technology `Demonstration Study* (CH2M Hill, 2003b). Two of the cells at this facility were managed for a SAV/periphyton community. These cells were rectangular in shape (124 m long x 4 m wide; cell length: width aspect ratio = 31.0) and approximately 500 m^2 (0.1 ac) in size (**Appendix 1**). A layer of limerock gravel (No. 57 stone) initially was placed over the original soil and later amended with a material composed primarily of Riviera sand. Water was pumped into the test facility from the adjacent C-7 canal. Average water depth in the cells was 15 cm. Both cells were sparely planted with Gulf Coast spikerush to provide structure for periphyton attachment. Sparse to moderate coverage of macrophytes (emergents + SAV) developed in both cells over time. The experimental treatment was HLR. Water samples were collected from each cell's inflow and outflow on a weekly basis and analyzed for TP. Mean POR outflow TP concentrations from the two test cells were 17.0 and 41.1 µg L^{-1}. This facility was decommissioned at the end of the demonstration study; the levees and other infrastructure were removed, and the site returned to its original land use as pasture.

5. *DBEL STA-1W Mesocosms*

DB Environmental Laboratory, Inc., under contract to the Everglades Protection District and the District, operated four small above-ground mesocosms located at the STA-1W South Research site for 73 months from July 1999 through July 2005 (**Figure 1**) (DeBusk *et al*., 2011). Each mesocosm consisted of three elliptical, polyurethane tubs (~1.13 m long x ~0.78 m wide x 0.61 m deep; cell length:width aspect ratio = 1.4) plumbed in series to create a "process train" having a combined surface area of 2.1 m^2 (**Appendix 1**). A fixed water depth of 40 cm was maintained in each mesocosm throughout the study. Water was pumped into the mesocosms from the outflow region of STA-1W. Two mesocosms were filled with 15 cm of organic muck collected from within STA-1W while the other two mesocosms were filled with 15 cm of limerock obtained from a nearby sand and gravel quarry. All mesocosms initially were stocked with equal amounts of three SAV species: southern naiad (*Najas guadalupensis*), coontail (*Ceratophyllum demersum*) and muskgrass (*Chara zeylanica*). Grab water samples were collected at the inflow and outflow of each mesocosm process train and analyzed for TP; samples were collected weekly from July 1999 to February 2004 and biweekly from March 2004 through July 2005. Mean POR outflow TP concentrations ranged from 14 to 19 µg L^{-1} among the trials.

6. *DBEL STA-1W Raceways*

DB Environmental Laboratory, Inc. operated three elevated raceways located at the STA-1W South Research site as part of the District's ATT Program's *A Demonstration of Submerged Aquatic Vegetation/Limerock Treatment System Technology for Removing Phosphorus from Everglades Agricultural Area Waters Project* for 19 months from July 1998 through January 2000 (**Figure 1**) (DeBusk *et al*., 2004). Raceways were fabricated from fiberglass and measured 44.0 m long x 0.3 m wide x 0.15 m deep (length:width aspect ratio = 146.7) with a surface area of 13.2 m^2 (**Appendix 1).** All raceways were filled with 2 – 3 cm of limerock and inoculated with mats of calcareous cyanobacteria collected from Water Conservation Area 2A and three SAV species (southern naiad, coontail and muskgrass) obtained from STA-1W at the beginning of the study. Inflow water to the raceways was pumped from the outflow region of STA-1W. A fixed water depth of 9 cm was maintained in each raceway throughout the study. Grab water samples were collected at the common inflow to the raceways and each raceway's outflow from late morning to early afternoon on a weekly basis and analyzed for TP. Weekly inflow and outflow grab water samples were analyzed for TP. The mean POR outflow TP concentrations among the raceways was 13.0 µg L^{-1}.

7. *HydroMentia Powell Creek Algal Turf Scrubber™ Raceway*

HydroMentia, Inc., under contract to Lee County and independent of the District, operated a pilot Algal Turf Scrubber™ (ATS) (Craggs *et al*., 1996) at a facility located on the west bank of the Powell Creek By-Pass canal in North Ft. Myers, FL for 12 months from December 2008 through December 2009 (**Figure 1**) (Hydromentia, 2010a). The ATS consisted of a single elevated aluminum raceway lined with a high-density polyethylene geomembrane that measured 152.4 m long x 0.3 m wide (length:width aspect ratio = 500.0) with a 1.0% inflow-to-outflow slope gradient and a surface area of 46 m^2 (**Appendix 1**). Inflow water was pumped from the Powell Creek canal into the ATS. The ATS was extremely shallow (~ 1.5 cm deep) without any bottom sediment and supported abundant periphyton but no emergent macrophytes or SAV. Composite autosampler and grab samples were collected at the ATS inflow and outflow on a weekly basis and analyzed for TP. The mean POR outflow TP concentration from the raceway was 110 µg L^{-1}.

8. *HydroMentia S-154 Algal Turf Scrubber™ Flow-ways*

HydroMentia, Inc., under contract to the District, operated three pilot ATS systems at a facility located within the S-154 basin adjacent to the L-62 Canal for 7 months from May to December 2004 (**Figure 1**) (Hydromentia, 2005). Each ATS consisted of a single rectangular flow-way lined with a high-density polyethylene geomembrane that measured 91.4 (South and Central flow-ways) or 97.5 (North flow-way) m long x 1.5 m wide (length:width aspect ratio = 60.0 or 64.0) with a 1.5% inflow-to-outflow slope gradient and a surface area of 139 (South and Central) or 149 m^2 (North) (**Appendix 1**). Each ATS was extremely shallow (~ 1.5 cm deep) without any bottom sediment and supported abundant periphyton but no emergent macrophytes or SAV. Inflow water to each flow-way was pumped from the L-62 canal. The experimental treatment was HLR, which varied among flow-ways (92, 157 or 368 cm d^{-1}). Water samples from the inflow and outflow of each flow-way were collected on a time-proportioned basis using autosamplers and analyzed for TP. The treatment performance considered in this report was the outflow TP concentration produced by the flow-ways before the effluent was filtered through a 10 µ microscreen to remove particulates. Mean POR outflow TP concentrations ranged from 249 to 258 µg L^{-1} among the trials.

9. <u>HydroMentia STA-1W Algal Turf Scrubber™ Raceway</u>

HydroMentia, Inc., under contract to the District, operated a pilot ATS system located at STA-1W for 12 months from August 2008 to August 2009 (**Figure 1**) (Hydromentia, 2009). The ATS was constructed along the west bank of the STA-1W effluent canal and consisted of a single elevated aluminum raceway lined with a high-density polyethylene geomembrane that measured 365.8 m long x 0.3 m width (length:width aspect ratio = 1200) with a 0.5% inflow-to-outflow slope gradient and a surface area of 110 m^2 (**Appendix 1**). The ATS was extremely shallow (~ 1.5 cm deep) without any bottom sediment and supported abundant periphyton but no emergent macrophytes or SAV. Inflow water to the ATS was pumped from the STA-1W outflow canal. Composite autosampler samples were collected at the flow-way inflow and outflow on a weekly basis and analyzed for TP. The treatment performance considered in this report was the outflow TP concentration produced by the raceway before the effluent was filtered through a 10 µ microscreen to remove particulates. The POR mean outflow TP concentration from the raceway was 24 µg L^{-1}.

10. <u>HydroMentia Taylor Creek Algal Turf Scrubber™ Flow-way</u>

HydroMentia, Inc., under contract to the District, operated a full-scale ATS system at a facility located within the Taylor Creek-Nubbin Slough basin in Okeechobee County, FL for 36 months from January 2007 to January 2010 (**Figure 1**) (Hydromentia, 2010b). The ATS consisted of a single rectangular flow-way lined with a high-density polyethylene geomembrane that measured 91 m long x 158 m wide (length:width aspect ratio = 0.6) with a 0.5% inflow-to-outflow slope gradient and a surface area of 1.4 ha (3.6 ac) (**Appendix 1**). The ATS was extremely shallow (~ 2 cm deep) without any bottom sediment and supported abundant periphyton but no emergent macrophytes or SAV. Inflow water was pumped from Taylor Creek into the ATS. Composite autosampler samples were collected at the flow-way inflow and outflow on a weekly basis and analyzed for TP. HydroMentia tested pre-treating the inflow to the ATS with foam fractionation or a water hyacinth scrubber at times during the study in an attempt to reduce what was assumed to be intermittent toxicity in the Taylor Creek water. The POR mean outflow TP concentration from the flow-way was 374 µg L^{-1}.

11. <u>SFWMD STA-3/4 PSTA Project Field-scale Cell</u>

The District has monitored the treatment performance of a single PSTA wetland (PSTA Cell) at a facility built for the *STA-3/4 Periphyton-Based Stormwater Treatment Area Demonstration Project* for 10 years from July 2007 to April 2017 (**Figure 1**) (Zamorano *et al*., 2018). The original purpose of the PSTA Project was to address uncertainties associated with the engineering design needed to implement the PSTA technology throughout STA-3/4 (Chimney, 2010). The PSTA Project comprises a 162-ha (400-ac) portion of Cell 2B in STA-3/4 that was isolated by constructing new levees and water control structures to form an upstream cell (the Upper SAV Cell) and two adjacent downstream cells (the Lower SAV and PSTA Cells). The PSTA Cell is rectangular (~1,140 m long x ~360 m wide; cell length: width aspect ratio = 3.2) with a surface area of 41 ha (101 ac) (**Appendix 1**).This size of the PSTA Cell was considered to be full-scale relative to the size of cells within the Everglades STAs. Most of the native peat soil in the PSTA Cell was excavated down to the caprock as this material would have provided a rooting medium for emergent macrophytes and was a potential source of soil P that could flux into the water column and reduce the cell's treatment efficiency. Consequently, the floor of the PSTA Cell is approximately 55 cm (1.8 ft) lower than the floor of the adjacent Upper and Lower SAV cells. The PSTA Cell has been managed to promote a SAV/periphyton community. Some of the excavated soil from the PSTA Cell was formed into 12 low berms (~ 30 cm [1 ft] high) that ran across the cell's width perpendicular to the direction of flow and were spaced equidistant down the cell's length. The berms were planted with Gulf Coast spikerush, although other wetland plants (e.g., cattail [*Typha* sp.]) invaded over time. Periodic herbicide applications (up through 2015) were used to suppress the establishment of emergent wetland plants in the areas between the berms. Surface inflow to the PSTA Cell is from the Upper SAV Cell through two gated culverts (G-390A & B), while outflow is via two electric pumps at the outflow pump station (G-388). Initially, the capacity of each outflow pump was 100 cfs (~ 244,000 m^3 d^{-1}); the capacity of one pump was later reduced to 60 cfs (~ 147,000 m^3 d^{-1}). Surface inflow was regulated by adjusting gate openings to achieve a nominal HRT within the PSTA Cell of approximately five days during the first six years of operation (water year [WY]2008 to WY2013); annual HRT was increased in the following years (range = 9.4 to 16.7 d). Operation of the outflow pumps is controlled by a float switch and maintains the PSTA Cell within a narrow range of water depths; the average depth was approximately 37 cm (1.2 ft) through WY2013 and was increased to approximately 52 cm (1.7 ft) thereafter. Flow-through operation in the PSTA Cell began in WY2008 and has continued through this report, with interruptions only during dry periods when there was insufficient water available in STA-3/4. Grab and composite autosampler samples were collected weekly at the PSTA Cell inflow and outflow structures during periods of flow and analyzed for TP. The POR mean outflow TP concentration from the PSTA Cell was 10.4 µg L^{-1}. The PSTA Cell received a substantial water load; the mean PSTA Cell HLR from WY2008 through WY2014 was 3 times greater than the mean HLR for all of STA-3/4 (6.7 versus 2.2 cm d^{-1}, respectively). However, because of lower inflow TP concentrations, the PSTA Cell mean phosphorus loading rate (PLR) over the same period was less than one-half that of STA-3/4 (0.30 versus 0.77 g m^{-2} yr^{-1}, respectively).

12. <u>USACE Flying Cow Road Mesocosms</u>

The USACE, in conjunction with Science Applications International Corporation (SAIC), Dr. Ronald Jones (Portland State University) and Broward Aquatic Services, and independent of the District, operated four medium-sized above-ground mesocosms (Cells 1 - 4) at a facility located in the northeast corner of STA-1E from 2001 through 2011. However, only 29 months of water quality data from two periods, March to June 2003 and March 2006 to March 2008 (**Figure 1**), were available for analysis (WSI & ANAMAR, 2011). Each mesocosm was constructed of concrete and measured 30.5 m long x 3.0 m wide (surface area = 92.9 m^2; cell length:width aspect ratio = 10.0) (**Appendix 1**) and had both surface and subsurface outflow piping. Mesocosms were filled with approximately 30 cm of limestone, sand or a combination of limestone and sand; one mesocosm also had a 2.5-cm layer of surface-applied lime sludge obtained from a local wastewater treatment plant. Inflow water to the mesocosms was first pumped from the adjacent C-51 Canal into two aboveground swimming pools that were plumbed in series and then gravity flowed into the mesocosms. The swimming pools served as a pretreat system to reduced TP concentrations in the influent water; one swimming pool was stocked with water lettuce (*Pistia stratiotes*) and the other pool with water hyacinth (*Eichhornia crassipes*). Numerous experiments were conducted in the mesocosms during the study that involved manipulating soil type, water depth and/or the HLR. Water depth in the mesocosms ranged from 15 to 60 cm depending on the experiment being conducted; the time-weighted average depth over the POR in all mesocosms was 32 cm. Grab and composite autosampler samples were collected weekly at the common inflow to the mesocosms and individual mesocosm outflows and analyzed for TP. The POR mean outflow TP concentrations ranged from 9 to 17 µg L^{-1} among the trials.

13. USACE STA-1E Field-scale Cells

The USACE, in conjunction with SAIC, Dr. Ronald Jones and Broward Aquatic Services, and independent of the District, operated three field-scale wetland cells constructed within Cell 2 of STA-1E from 2006 to 2010. However, only 14 months of water quality data from October to December 2008 and February to December 2010 (**Figure 1**) were available for analysis (WSI & ANAMAR, 2011). The cells were constructed by building new levees and water control structures; each of the new cells was rectangular in shape (1,238 m long x 152 m wide; cell length:width aspect ratio = 8.1) and 18.8 ha (46.5 ac) ha in size (**Appendix 1**). The substrate in one cell consisted of a 2.5-cm layer of lime sludge obtained from a local wastewater treatment plant applied over 13.5 cm layer of sand on top of the native soil while the other two cells had a 15-cm layer of limestone on top of the native soil. Inflow to the cells was via gravity flow from STA-1E, Cell 1 into Cell 2 or water pumped from an adjacent seepage return canal directly into Cell 2. Average water depth in the cells ranged from 26 to 31 cm. With time, *Typha* sp. and *Panicum* sp. invaded all cells to some extent. Experimental treatments included soil type and the HLR (6.5 and 11.4 cm d^{-1}). Water samples were collected at the inflow and outflow of each cell using composite autosamplers and analyzed for TP. The POR mean outflow TP concentrations ranged from 8.2 to 10.2 µg L^{-1} among the trials. The facility was decommissioned at the end of the research project and Cell 2 returned to its original configuration; the project's levees and water control structures were removed, and the sand and limestone fill material was spread throughout Cell 2 to level its sloped topography.

Chronology of PSTA Studies

The PSTA studies summarized in this report were conducted over a span of 20 years (1998 to 2017) (**Figure 1**). Data collection started in mid-1998 with the STA-1W Raceways (study #6) and continued with subsequent studies, the last of which was the Powell Creek ATS (study #7) that started in late 2008. The PSTA studies initiated from 1998 to 2001 were conducted either as part of the District's ATT Program (studies #1, #2, #3 and #6[8]) or were funded by the Everglades Protection District and the District (study #5). The study with the longest data record, the STA-3/4 PSTA Project Field-scale Cell (study #11; 10-year POR), was still in operation as of April 2017[9]. Data collection for all the other PSTA studies ended by 2011. The duration of individual trials ranged from 6 to 120 months; the length of all but one trial was ≤ 36 months and the median trial length was 14 months (**Appendix 1**).

Treatment Performance

Evaluation of treatment performance by the different PSTA platforms is based on comparing the POR mean outflow TP concentration for individual trials relative to the WQBEL TP criterion of 13 µg L^{-1}. Note that there were no regulatory criteria for any of the PSTA studies, so this TP concentration serves only as a point of reference for these comparisons. While almost all trials sequestered TP to some extent, only eight trials had a mean outflow TP concentration ≤ 13 µg L^{-1}: one trial from the STA-1W Test Cells (study #2), the STA-1W Raceways (study #6), the STA-3/4 PSTA Project Field-scale Cell (study #11), two trials from the Flying Cow Mesocosms (study #12) and all three trials in the STA-1E Field-scale Cells (study #13) (**Figure 2** and **Appendix 1**). However, the mean inflow TP concentrations for all three STA-1E Field-scale Cells (7.9 to 9.9 µg L^{-1}) already were less than the WQBEL TP outflow target of 13 µg L^{-1}; therefore, study #13 was not a useful demonstration of how to achieve the WQBEL TP target. Discounting study #13, only five of the 50 (10%) trials were successful at achieving the WQBEL TP target. Conversely, in addition to its POR TP reduction, each of the 10 annual mean outflow TP concentrations from the STA-3/4 PSTA Project Field-scale Cell was ≤ 13 µg L^{-1} (Zamorano et al., 2018). This platform was unquestionably the most successful of all the platforms investigated.

Most platforms had a substrate that consisted of either limerock/shellrock (LR/SR), peat/ muck (P/M) or sand (SD). The five trials identified above that successfully reduced outflow TP concentrations to ≤ 13 µg L^{-1} all had a LR/SR substrate (**Appendix 1**). Trials with a LR/SR substrate produced the lowest observed outflow TP concentrations, although there was overlap in the range of outflow TP concentrations among substrate types (**Figure 3**). The median outflow TP concentration for all trials with a LR/SR substrate was 16.7 µg L^{-1}, while the medians for trials with a P/M or SD substrate were 18.5 and 17.3 µg L^{-1}, respectively[10]. A Kruskal-Wallis one-way analysis of variance on ranks of outflow TP concentrations detected no statistically significant differences among substrate types ($\chi^2 = 3.85$, $p = 0.1488$). There were a few instances during studies #1 and #5 where trials with a P/M substrate outperformed companion trials that had SD

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[8] These studies were part of the District's *Periphyton-Based Stormwater Treatment Area (PSTA) Research and Demonstration Project* or the *A Demonstration of Submerged Aquatic Vegetation/Limerock Treatment System Technology for Removing Phosphorus from Everglades Agricultural Area Waters Project*.

[9] A brief history of the STA-3/4 PSTA field-scale Cell is provided in Chimney (2010). The STA-3/4 PSTA Demonstration Project ended in 2018, although inflow-outflow water quality monitoring of the PSTA Cell has continued.

[10] All statistics in this report were calculated using base R functions (v3.4.3) or the R package Rcmdr (v2.4-4) (R Core Team, 2017; Fox and Bouchet-Valat, 2018). The critical level of significance (α) used to evaluate statistics was 0.05 in all cases.

or LR/SR substrates; however, the differences in mean outflow TP concentrations in these cases were small, typically measuring only 1 to 2 µg L^{-1} (**Appendix 1**).

Scatterplots revealed linear relationships between mean outflow TP concentration (the dependent variable) and the independent variables: mean inflow TP concentration, PLR, HLR, HRT and water depth but not for % TP concentration reduction, platform length:width ratio or platform surface area (**Figure 4**). Based on coefficients of determination from simple linear regressions, mean inflow TP concentration, PLR and HLR were strong predictors of mean outflow TP concentration (r^2 = 0.97, 0.86 and 0.79, respectively), HRT and water depth accounted for only a small portion of the variance in mean inflow TP concentration (r^2 = 0.17 and 0.27, respectively) and there were no statistically significant relationships with % TP concentration reduction, platform length:width ratio or platform surface area (**Table 2**). However, it was apparent from the scatterplots that data values for the HydroMentia ATS trials were extreme outliers for many of the independent variables (**Figure 4**). Outliers can be high-leverage points that disproportionately influence a regression analysis compared to the other data values (Gotelli and Ellison, 2004).

Table 2. Coefficients of determination for simple linear regressions of mean outflow TP concentration with mean inflow TP concentration, TP loading rate, hydraulic loading rate, hydraulic retention time, percent inflow-to-outflow TP concentration reduction, platform length:width ratio, platform surface area and average water depth for trials conducted with different PSTA platforms. Regression coefficients are presented for the full data set and a censored data set that excluded the HydroMentia ATS studies.

	Inflow TP	PLR	HLR	HRT	% TP Conc. Reduct.	L:W Ratio	Area	Water Depth
Full Data Set								
Outflow TP	0.97	0.86	0.79	0.17	ns*	ns	ns	0.27
Censored Data Set								
Outflow TP	0.45	0.27	ns	ns	ns	ns	0.12	ns

*ns = Regression coefficient not statistically different from zero at a significance level (α) of 0.05.

When the ATS data were censored from the data set and the regression analyses rerun, there were no strong predictors of mean outflow TP concentration, i.e., all r^2 values were < 0.50 or not statistically significant (**Table 2**). This means that most, if not all, of the variability in mean outflow TP concentration across all studies in the censored data set was not attributable to the independent variables analyzed. Note that the STA-3/4 PSTA Project Field-scale Cell had one of the lowest mean inflow TP concentrations, a relatively low PLR and a relatively long HRT compared to the other platforms (**Figure 4**). This combination of factors may account, in part, for this platform's excellent treatment performance over its 10-year POR.

Summary & Conclusions

This report summarizes the POR treatment performance of PSTA platforms that were investigated by the District and other researchers in 50 separate trials that were part of 13 studies. Data collection for these studies spanned a 20-year period (1998 to 2017). Trials were conducted with an assortment of platforms that varied in surface area and construction design. There was a progression in the size of the platforms used in District sponsored studies, starting with small mesocosms and raceways (2 to 93 m^2), moving to larger test cells and flow-ways (496 m^2 to 1.4 ha) and finally culminating with the 41-ha (100-ac) STA-3/4 PSTA Project Field-scale Cell. This was done to increase study realism and negate any artifacts associated with small platforms, such as wall effects or the inability to scale water velocity. In addition, the complexity of study designs (i.e., the number of experimental treatments) decreased with increasing platform size both out of necessity (researchers had fewer large platforms to work with) and based on what had been learned with the smaller platforms.

The ability to reduce inflow TP concentrations to a mean POR outflow TP concentration of 13 µg L^{-1} was the metric used in a meta-analysis of treatment performance by the different platforms. While almost all trials sequestered inflow TP to some extent, only five trials with a mean inflow TP concentration above 13 µg L^{-1} achieved a mean outflow concentration ≤ 13 µg L^{-1}. These trials all had a LR/SR substrate. Although trials within the same study that had a LR/SR or SD substrate often had better TP removal than trials with a P/M substrate, there was no statistically significant difference in median outflow TP concentration when trials pooled over substrate type were compared. There were no strong predictors of mean outflow TP concentration among the eight independent variables evaluated with simple linear regression; all r^2 values were ≤ 0.45 or not statistically significant for mean inflow TP concentration, PLR, HLR, HRT, % TP concentration reduction, water depth, platform length:width ratio and platform surface area for a dataset that excluded the HydroMentia ATS data. This suggested that 1) factors other than those variables examined accounted for much of the variability in treatment performance among platforms or 2) some of the factors examined were important determinants of treatment performance but their importance varied across platforms and studies.

In conclusion, while the majority of the PSTA platforms investigated in these 13 studies did sequester TP to some extent, only 5 of the 50 trials were considered successful at achieving a POR mean outflow TP concentration ≤ 13 µg L^{-1} when their POR mean inflow TP concentrations were > 13 µg L^{-1} (POR range for these 5 trials was 16 to 26 µg L^{-1}). Furthermore, it is doubtful that the design of two small platforms that were successful (DBEL STA-1W Raceways [study #6] and USACE Flying Cow Mesocosms [study #12]) could be scaled up to work in conjunction with the Everglades STAs. Conversely, the most successful platform, the STA-3/4 PSTA Project Field-scale Cell [study #11], had a 10-year POR mean and all annual mean outflow TP concentrations ≤ 13 µg L^{-1}. This indicated that PSTA when implemented at full-scale can achieve the WQBEL TP target on a consistent basis. A subsequent feasibility study conducted by the District generated cost estimates for constructing PSTA cells within STA-1E, STA-2 and STA-5 following the design of the

STA-3/4 PSTA Cell (Piccone and Zamorano, 2017). Cost estimates ranged from $27,500 to $29,000/ac for building 100 or 200 ac PSTA cells. However, this was only a fact-finding effort and no recommendations were made as to when or where PSTA might be implemented in the Everglades STAs.

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Data Archive

All computer files used in the preparation of this document (Microsoft Word and Excel files, graphic files, R scripts, workspace data files and analysis output, etc.) are achieved in the Morpho data package: *Stormwater Treatment Area (STAs)_PSTA Platform Evaluation*, which is available on the District's internal computer network.

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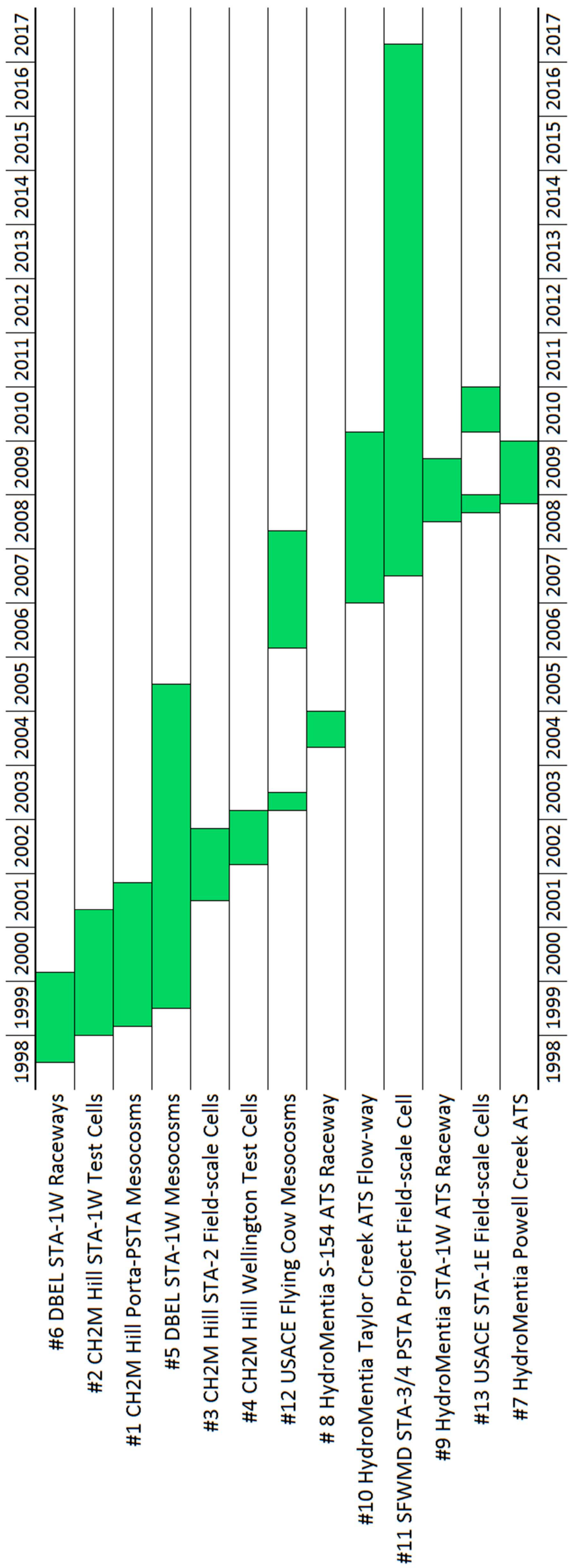

Figure 1. Chronology and duration of data collection for each of PSTA study. Studies are ordered by their start date. Timelines for the USACE studies (#12 and #13) only indicate the periods with available water quality data.

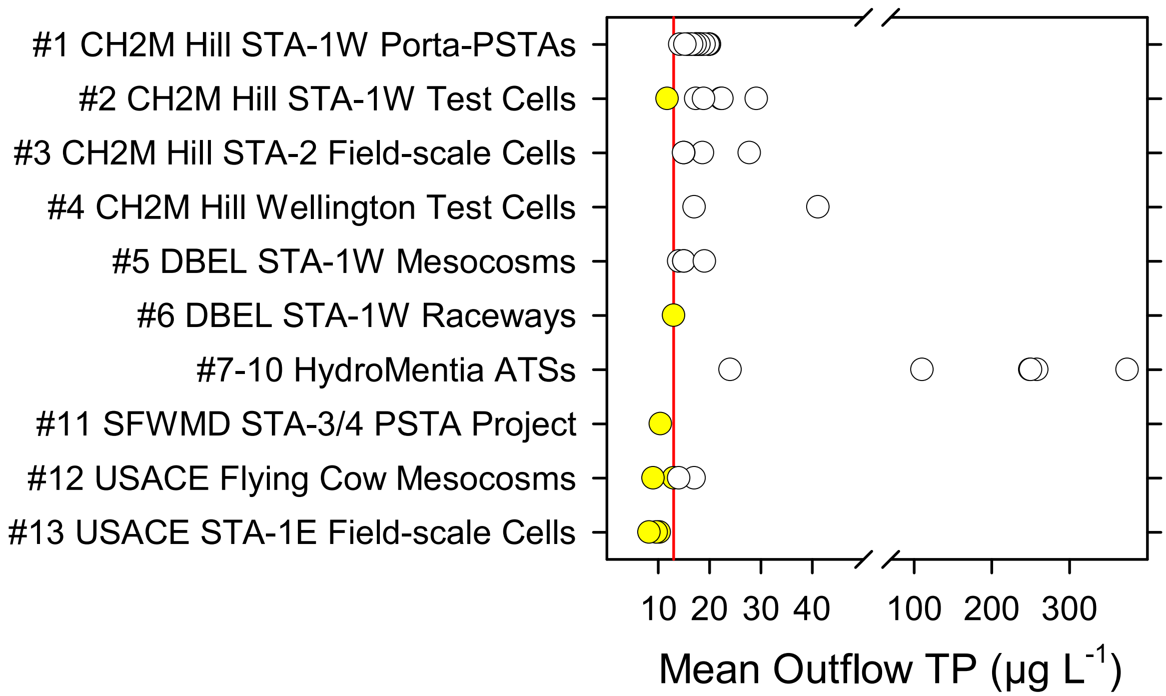

Figure 2. Mean POR outflow TP concentrations for trials conducted during each PSTA study. The vertical red line indicates a TP concentration of 13 µg L^{-1}. Yellow circles indicate trials with a mean outflow TP concentration that was ≤ 13 µg L^{-1}.

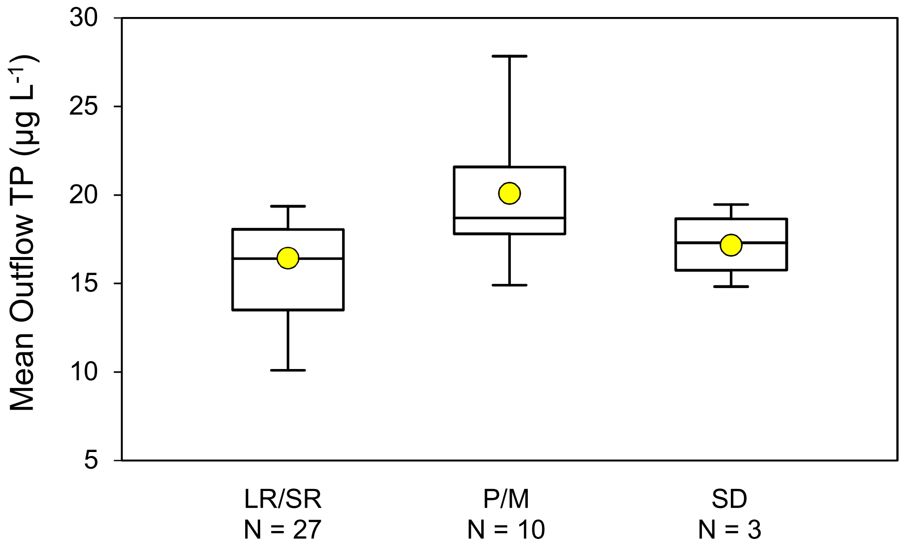

Figure 3. Comparison of mean POR outflow TP concentrations for trials conducted during the PSTA studies that had a substrate consisting of limerock/shellrock (LR/SR), peat/muck (P/M) or sand (SD). N = the number of trials. Yellow circles are arithmetic means. Boxplot description: horizontal lines within the boxes are median values; the top and bottom of the boxes are the 75th and 25th percentiles of the data distribution, respectively; the upper and lower whiskers extend to the 90th and 10th percentiles of the data distribution, respectively.

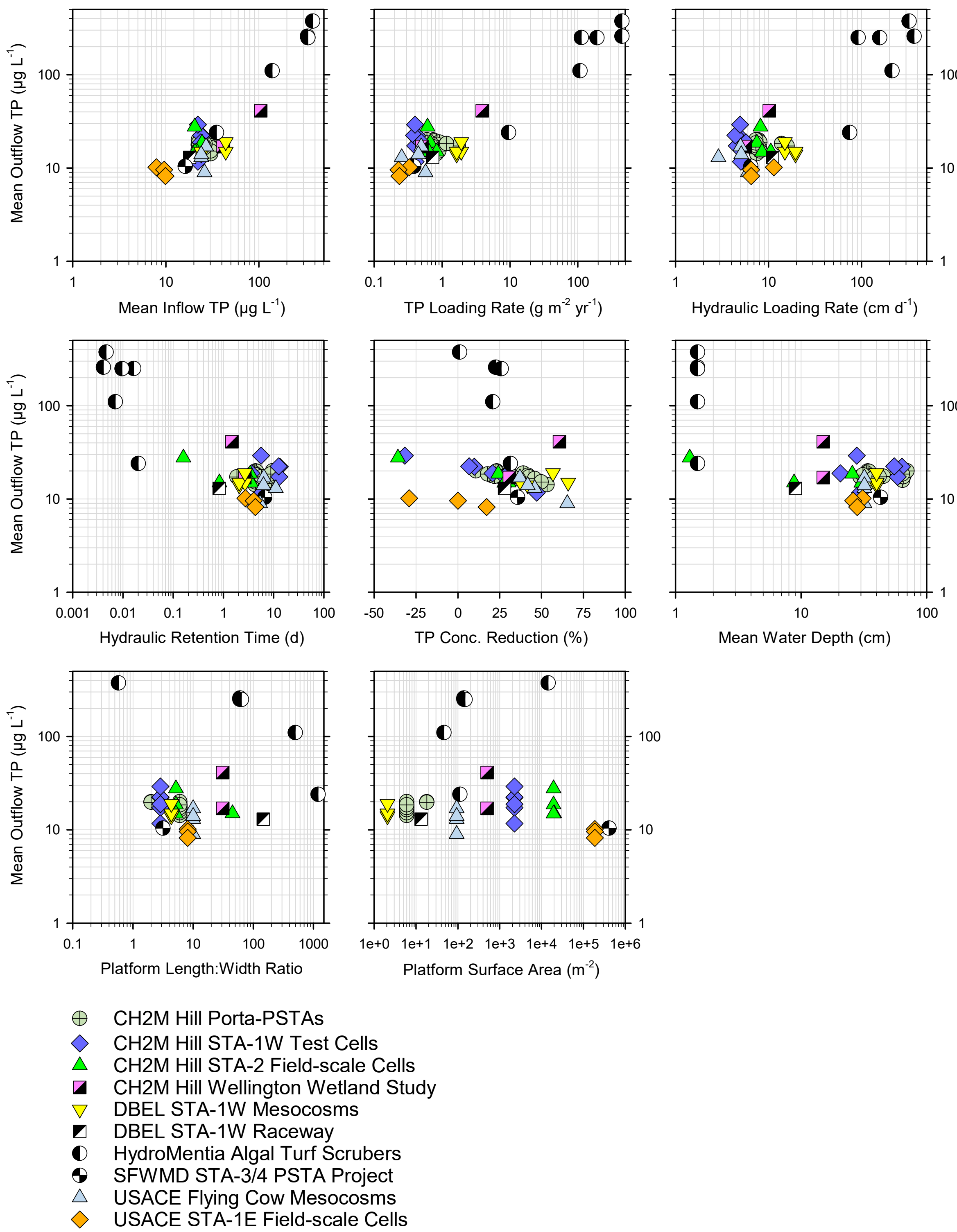

Figure 4. Scatterplots of mean outflow TP concentration from trials conducted during the PSTA studies versus mean inflow TP concentration, P loading rate, hydraulic loading rate, hydraulic retention time, percent TP concentration reduction, water depth, platform length:width ratio and platform surface area.

APPENDIX 1. Physical and operational parameters and POR summary of treatment performance in trials conducted during PSTA studies. Inflow and outflow mean TP concentrations that are ≤ to 13 µg L^{-1} are highlighted in red.

Project	Platform	Substrate	Plant Community	Surface Area (m^2)	Cell L:W Ratio	Test Duration (mon)	Water Depth (cm)	HLR (cm d^{-1})	HRT (d)	PLR (g m^{-2} yr^{-1})	TP Inflow (µg L^{-1})	TP Outflow (µg L^{-1})	TP Conc. Reduct.
CH2M Hill STA-1W Porta-PSTAs	mesocosm	Peat	periphyton, *Eleocharis*, *Utricularia*	6.0	6.0	12	66	7.2	9.2	0.58	22.3	17.7	21%
CH2M Hill STA-1W Porta-PSTAs	mesocosm	Shellrock	periphyton, *Eleocharis*, *Utricularia*	6.0	6.0	12	65	7.0	9.3	0.60	23.2	17.3	25%
CH2M Hill STA-1W Porta-PSTAs	mesocosm	Peat	periphyton, *Eleocharis*, *Utricularia*	6.0	6.0	18	31	7.2	4.3	0.69	26.4	18.1	31%
CH2M Hill STA-1W Porta-PSTAs	mesocosm	Shellrock	periphyton, *Eleocharis*, *Utricularia*	6.0	6.0	18	37	7.5	4.9	0.70	25.7	16.4	36%
CH2M Hill STA-1W Porta-PSTAs	mesocosm	Shellrock	periphyton, *Eleocharis*, *Utricularia*	6.0	6.0	12	58	13.8	4.2	1.17	23.1	18.2	21%
CH2M Hill STA-1W Porta-PSTAs	mesocosm	Shellrock	periphyton, *Eleocharis*, *Utricularia*	6.0	6.0	12	45	5.5	8.2	0.45	22.4	17.5	22%
CH2M Hill STA-1W Porta-PSTAs	mesocosm	Sand	periphyton, *Eleocharis*, *Utricularia*	6.0	6.0	18	42	7.4	5.7	0.69	25.6	17.3	32%
CH2M Hill STA-1W Porta-PSTAs	mesocosm	Sand	periphyton, *Eleocharis*, *Utricularia*	6.0	6.0	12	70	7.3	9.5	0.60	22.4	20.0	11%
CH2M Hill STA-1W Porta-PSTAs	mesocosm	Peat + Aquashade	no periphyton or macrophytes	6.0	6.0	12	64	7.3	8.8	0.60	22.5	18.5	18%
CH2M Hill STA-1W Porta-PSTAs	mesocosm	Shellrock + Aquashade	no periphyton or macrophytes	6.0	6.0	12	64	7.1	9.0	0.58	22.4	15.8	29%
CH2M Hill STA-1W Porta-PSTAs	mesocosm	Shellrock	periphyton, *Eleocharis*, *Utricularia*	18.0	2.0	18	34	7.8	4.3	0.74	25.9	19.9	23%
CH2M Hill STA-1W Porta-PSTAs	mesocosm	Peat	periphyton, *Eleocharis*, *Utricularia*	18.0	2.0	18	35	7.6	4.6	0.71	25.5	19.7	23%
CH2M Hill STA-1W Porta-PSTAs	mesocosm	Peat + Ca amendment	periphyton, *Eleocharis*, *Utricularia*	6.0	6.0	6	33	8.1	4.1	0.91	31.0	18.9	39%
CH2M Hill STA-1W Porta-PSTAs	mesocosm	Limerock	periphyton, *Eleocharis*, *Utricularia*	6.0	6.0	6	31	8.1	3.8	0.66	22.3	15.7	30%
CH2M Hill STA-1W Porta-PSTAs	mesocosm	Shellrock	periphyton, *Eleocharis*, *Utricularia*	6.0	6.0	6	35	7.4	4.7	0.83	30.8	17.9	42%
CH2M Hill STA-1W Porta-PSTAs	mesocosm	Shellrock	periphyton, *Eleocharis*, *Utricularia*	6.0	6.0	6	30	15.9	1.9	1.74	29.9	17.2	42%
CH2M Hill STA-1W Porta-PSTAs	mesocosm	Sand, HCl washed	periphyton, *Eleocharis*, *Utricularia*	6.0	6.0	6	32	7.5	4.2	0.83	30.4	14.2	53%
CH2M Hill STA-1W Porta-PSTAs	mesocosm	none, bare tank	periphyton, *Utricularia*	6.0	6.0	6	35	7.9	4.4	0.88	30.5	16.5	46%
CH2M Hill STA-1W Porta-PSTAs	mesocosm	Aquamat	periphyton, *Utricularia*	6.0	6.0	6	35	8.1	4.3	0.89	30.3	15.2	50%
CH2M Hill STA-1W Test Cells	test cell	Peat (30 cm)	periphyton, *Eleocharis*, *Utricularia*	2,240	2.9	14	64	4.8	13.3	0.43	24.6	22.2	10%
CH2M Hill STA-1W Test Cells	test cell	Shellrock (30 cm)	periphyton, *Eleocharis*, *Utricularia*	2,240	2.9	14	59	4.6	12.9	0.40	24.0	17.3	28%
CH2M Hill STA-1W Test Cells	test cell	Shellrock (30 cm)	periphyton, *Eleocharis*, *Utricularia*	2,240	2.9	14	55	4.4	12.5	0.39	24.0	22.4	7%
CH2M Hill STA-1W Test Cells	test cell	Peat (30 cm) + Ca amendment	periphyton, *Eleocharis*, *Utricularia*	2,240	2.9	13	28	5.0	5.6	0.40	22.1	29.1	-32%
CH2M Hill STA-1W Test Cells	test cell	Shellrock (30 cm)	periphyton, *Eleocharis*, *Utricularia*	2,240	2.9	13	30	5.1	5.9	0.41	22.1	11.7	47%
CH2M Hill STA-1W Test Cells	test cell	Shellrock (30 cm)	periphyton, *Eleocharis*, *Utricularia*	2,240	2.9	13	21	5.7	3.6	0.49	23.7	18.8	21%
CH2M Hill STA-2 Field-scale Cells	field-scale cell	Limerock (60 cm) on peat	periphyton, sparse/moderate macrophytes	19,337	5.2	14	26	7.49	3.4	0.67	24.5	18.6	24%
CH2M Hill STA-2 Field-scale Cells	field-scale cell	Limerock (60 cm) on peat	periphyton, sparse/moderate macrophytes	19,971	45.3	14	9	10.60	0.8	0.83	21.5	15.0	30%
CH2M Hill STA-2 Field-scale Cells	field-scale cell	Peat removed to expose limestone caprock	periphyton, sparse/moderate macrophytes	19,337	5.2	14	30	8.53	3.5	0.64	20.6	14.9	28%
CH2M Hill STA-2 Field-scale Cells	field-scale cell	Peat	periphyton, sparse/moderate macrophytes	19,337	5.2	14	1	8.19	0.2	0.61	20.4	27.7	-36%
CH2M Hill Wellington Study	test cell	Limerock + Riviera sand	periphyton, *Chara*, *Eleocharis*	496	31.0	11	15	10.2	1.5	3.89	104.6	41.1	61%
CH2M Hill Wellington Study	test cell	Limerock + Riviera sand	periphyton, *Chara*, *Eleocharis*	496	31.0	11	15	5.6	2.7	0.50	41.1	17.0	31%
DBEL STA-1W Mesocosms (yr. 1-3)	mesocosm	Muck (15 cm)	*Najas*, *Ceratophyllum*, *Chara*	2.1	4.3	36	40	19.5	2.1	1.64	24.0	14.0	42%
DBEL STA-1W Mesocosms (yr. 4-6)	mesocosm	Muck (15 cm)	*Najas*, *Ceratophyllum*, *Chara*	2.1	4.3	36	40	15.0	2.7	1.91	44.0	15.0	66%
DBEL STA-1W Mesocosms (yr. 1-3)	mesocosm	Limerock (15 cm)	*Najas*, *Ceratophyllum*, *Chara*	2.1	4.3	36	40	19.5	2.1	1.64	24.0	15.0	38%
DBEL STA-1W Mesocosms (yr. 4-6)	mesocosm	Limerock (15 cm)	*Najas*, *Ceratophyllum*, *Chara*	2.1	4.3	36	40	15.0	2.7	1.91	44.0	19.0	57%

APPENDIX 1. (continued).

Project	Platform	Substrate	Plant Community	Surface Area (m²)	Cell L:W	Test Duration (mon)	Water Depth (cm)	HLR (cm d^{-1})	HRT (d)	PLR (g m^{-2} yr^{-1})	TP Inflow (µg L^{-1})	TP Outflow (µg L^{-1})	TP Conc. Reduct. (%)
DBEL STA-1W Raceways	raceway	Limerock (2-3 cm)	*Najas, Cerato., Chara,* BG periphyton	13.2	146.7	19	9	11.0	0.8	0.72	18.0	13.0	28%
HydroMentia Powell Cr. ATS	raceway	none	periphyton	46	500.0	12	2	213.1	0.007	108.1	139	110	21%
HydroMentia S-154 ATS.C	flow-way	none	periphyton	139	60.0	7	2	368.0	0.004	447.3	333	258*	23%
HydroMentia S-154 ATS.N	flow-way	none	periphyton	149	64.0	7	2	157.0	0.010	192.5	336	249*	26%
HydroMentia S-154 ATS.S	flow-way	none	periphyton	139	60.0	7	2	92.0	0.016	112.8	336	250*	26%
HydroMentia STA-1W ATS	raceway	none	periphyton	111	1200	12	1.5	74.6	0.020	9.5	35.0	24.0*	31%
HydroMentia Taylor Cr. ATS	flow-way	none	periphyton	14,521	0.6	36	1.5	324.6	0.005	447.9	378	374	1%
SFWMD STA-3/4 PSTA Project	field-scale cell	Peat removed to expose limestone caprock	periphyton, *Eleocharis*, *Utricularia, Typha*	410,400	3.2	120	43	6.5	6.6	0.38	16.2	10.4	36%
USACE Flying Cow Mesocosms	mesocosm	Lime sludge (2.5 cm) on Riviera sand (30 cm)	periphyton (EAV not described)	93	10.0	29	32	5.0	6.4	0.49	27.0	17.0	37%
USACE Flying Cow Mesocosms	mesocosm	Ft. Thompson limestone (30 cm)	periphyton (EAV not described)	93	10.0	29	32	2.9	11.0	0.25	24.0	13.0	46%
USACE Flying Cow Mesocosms	mesocosm	Local limestone (15 cm) on Riviera sand (15 cm)	periphyton (EAV not described)	93	10.0	29	32	6.0	5.3	0.57	26.0	9.0	65%
USACE Flying Cow Mesocosms	mesocosm	Ft. Thompson (15 cm) limestone on Riviera sand (15 cm)	periphyton (EAV not described)	93	10.0	29	32	5.1	6.3	0.45	24.0	14.0	42%
USACE STA-1E Field-scale Cells	field-scale cell	Lime sludge (2.5 cm) on Riviera sand (13 cm)	*Panicum,* periphyton	188,176	8.1	14	31	11.4	2.7	0.33	7.9	10.2	-29%
USACE STA-1E Field-scale Cells	field-scale cell	Miami (5 cm) limestone on local limestone (10 cm)	*Panicum, Typha,* periphyton	188,176	8.1	14	26	6.5	4.0	0.23	9.6	9.6	0%
USACE STA-1E Field-scale Cells	field-scale cell	Local limestone (15 cm)	periphyton	188,176	8.1	14	28	6.5	4.3	0.23	9.9	8.2	17%

* Values are mean TP concentrations at the ATS outflow before the effluent was filtered through a 10 µg microscreen.