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Restoration Strategies Regional Water Quality Plan – Science Plan for the Everglades Stormwater Treatment Areas:

Soil Amendments/Management to Control P Flux

Phase I Summary Report for the Use of Soil Amendments/Management to Control P Flux Study

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Study Plan Summary

Anaerobic wetland soils mobilize forms of phosphorus (P) that are usually retained in well-drained terrestrial soils. As a result, P moves much more readily through wetland soils and can flux (i.e., diffuse) upward into the water column provided there is a decreasing concentration gradient between the soil porewater and the overlying water column (Reddy and DeLaune 2008, Kadlec and Wallace 2009, Ballantine and Tanner 2010). The objective of the Use of Soil Amendments/ Management Techniques to Control P Flux Study is to investigate whether internal loading of P in the STAs (i.e., the flux of soluble P from the soil to the overlying water column) can be reduced by application of soil amendments and/or soil management techniques and thereby lower outflow total P (TP) concentrations. The Detailed Study Plan (DSP) for this project specifies that work will be conducted in three phases with a STOP/GO decision made at the conclusion of the first two phases. Phase I comprised three tasks:

- Task 1 - Expansion of an existing literature review on technologies for controlling soil-P flux in wetlands or lakes,
- Task 2 - Data mining and/or synthesis of past South Florida Water Management District (District or SFWMD) supported projects relevant to this study and
- Task 3 - To the extent practicable, assess the feasibility of implementing any of these technologies at full-scale in the STAs.

If a decision is made to continue with the study after Phase I, subsequent efforts will involve bench-scale experiments (Phase II) followed by large-scale field trials conducted in the STAs (Phase III) to document the treatment efficacy of select soil amendments and/or soil management techniques. This report summarizes the results of Phase I activities for the abovementioned tasks. Short descriptions of the Phase II and III portions of the study are provided in the Conclusions & Recommendations section and Appendix 1 of this report. Appendix I also has provisional time-lines for the start date and duration of Phase III data collection.

Task 1 - Literature Review

The Phase I literature review started with the initial set of papers and project reports compiled during the development of the Restoration Strategies Science Plan. This list was augmented with additional reference found using the web-based search engine Google Scholar[1]. The focus of this effort was to generate a list of materials proven effective at sequestering P and soil management techniques that may reduce soil-P flux and potentially could be used in the STAs. This review was not intended to be a compilation of all research conducted on these materials/techniques nor to describe the biogeochemical mechanisms involved in the sequestration of P in detail. The summary provided herein relied heavily on subject matter reviews by

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[1] Keywords searched in Google Scholar included "treatment wetland" AND "soil amendment", "wetland amendment", wetland AND "soil amendment", wetland AND "soil capping", wetland AND "wood chips".

CH2M Hill (2002), Douglas et al. (2004), Johansson Westholm (2006), Penn et al. (2007), Bottcher et al. (2009), Cucarella and Renman (2009), Ballantine and Tanner (2010), Ippolito et al. (2011), Vohla et al. (2011), Buda et al. (2012), and additional information found online. Reference information for journal articles, project reports and other publications was compiled into an EndNote library specific to this project (version X7, Thomas Reuters, Philadelphia, PA).

Soil Amendments

A "soil amendment" is defined for this study as any material that sorbs soluble P and includes (a) liquids, slurries or fine-grained particulate materials that can be incorporated into or broadcast on top of the soil [e.g., lime, drinking water treatment residuals (DWTRs), Phoslock™] and (b) course-grained materials that typically are used as the substrate in horizontal subsurface/vertical flow wetlands or in-ground/in-stream filter systems (e.g., crushed mollusk shells, various slags). Particulate materials used as soil amendments are typically rich in metal cations, primarily aluminum (Al), calcium (Ca), iron (Fe) or magnesium (Mg), that readily bond with dissolved P (Douglas et al. 2004, Johansson Westholm 2006, Penn et al. 2007, Vohla et al. 2011, Buda et al. 2012). The term "sorption" refers to adsorption and precipitation mechanisms that either separately or in combination remove dissolved constituents from solution (Penn et al. 2007, Cucarella and Renman 2009). The mode of action for Al and Fe components in particulate soil amendments is primarily through direct adsorption of P onto the particle surface whereas Ca and Mg components usually go into solution where they form P precipitates (Penn et al. 2007). The sources of soil amendments include natural materials (e.g., apatite, aragonite, gypsum, limestone, zeolite), man-made products (e.g., ferric chloride, Phoslock™, soda ash, ViroPhos™) and waste by-products derived primarily from manufacturing, other industrial processes or electric power generation (e.g., coal fly ash, DWTRs, Reclime®, slags). Desirable characteristics in a soil amendment to be used in a treatment wetland include low cost, local availability in large quantities, high affinity for P, high retention of sorbed P under low redox conditions and low toxicity to flora and fauna (Penn et al. 2007, Ballantine and Tanner 2010, Vohla et al. 2011, Buda et al. 2012). Calcium and Al-based soil amendments generally are less sensitive to changes in redox conditions and thus are less likely to release bound P under the anaerobic conditions typically found in wetland soils (Ballantine and Tanner 2010).

Over 100 different materials that sorb P and have been tested for use as a soil amendment were identified during the literature review with approximately equal numbers of natural, man-made and waste by-product materials (**Table 1**). Treatment efficacy for these materials was reported as either percent P removed or sorption capacity (i.e., mass P removed/mass soil amendment). Because of marked differences in experimental methodology and study conditions that influence P sorption (e.g., water temperature and pH, amendment particle size and porosity, amendment mass to solution volume ratio, contact time of amendment with water, time required to saturate the amendment with P, initial P concentration, concentration of dissolved organic material and other anions that compete for P binding sites), it is not possible to normalize results from different studies and directly compare their sorption capacities (Johansson Westholm 2006, Cucarella and Renman 2009, Vohla et al. 2011, Buda et al. 2012). Furthermore, the majority of soil amendments have been studied only in laboratory experiments (Vohla et al. 2011, Buda et al. 2012). It is difficult to predict how these materials would perform long-term under field conditions as P retention in the laboratory can be much higher compared to rates obtained in the field (Johansson Westholm 2006, Vohla et al. 2011, Buda et al. 2012). Only long-term field trials can characterize real-world performance or reveal unforeseen management issues for a soil amendment or soil management technique.

Based solely on the ability to sorb P, there appears to be a wide range of soil amendments that could potentially be used in the STAs (**Table 1**). However, many of these materials do not meet one or more of the other criteria desirable in a soil amendment, most notably: low cost, local availability in sufficient quantities needed for use in the STAs or no impact to downstream flora and fauna. In addition, the P removal capacity of any soil amendment is finite and once the material becomes saturated with P, the material must be replaced to restore treatment (Johansson Westholm 2006, Ballantine and Tanner 2010, Buda et al. 2012). Furthermore, the duration of most laboratory and field experiments has been too short (< 1 year) to extrapolate their results to long-term treatment efficacy. The few long-term data that are available suggest that soil amendments become saturated and lose their effectiveness within a few years after deployment and that five years may be the maximum treatment period that reasonably can be expected (Vohla et al. 2011).

Soil amendments have almost universally been tested only with domestic wastewater or agricultural runoff that had P concentrations orders of magnitude greater than STA inflow levels. Furthermore, most of the studies conducted in wetlands have been in horizontal subsurface or vertical flow systems where the soil amendment constituted most, if not all, of the substrate[2]. Only a few studies (see CH2M Hill 2003a, Hoge et al. 2003) have attempted to use soil amendments in a fashion similar to what is proposed for the STAs, i.e., as a soil application to reduce soil-P flux thus lowering water-column TP concentrations in a free water surface wetland. Hoge et al. (2003) treated 2-ac impoundments built on organic-soil farmland with surface applications of three different soil amendments (an alum-based DWTR, gypsum and slaked lime) and monitored water-column TP concentrations in the impoundments for 16 weeks after the cells were flooded. They found that only the DWTR treatment substantially reduced water-column TP concentrations compared to the control. However, their water-column TP levels were one to two orders of magnitude greater than TP concentrations commonly observed at the outflow of the STAs. CH2M Hill (2003a) conducted a 4-month study in which they amended mesocosms

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[2] The STAs, in contrast, are free water surface wetlands. See Kadlec and Wallace (2009) for details on the operating differences in horizontal subsurface flow, vertical flow and free water surface treatment wetlands.

filled with peat collected from STA-2 with polyaluminum chloride, ferric chloride and slaked lime. They concluded that these soil amendments were not effective in reducing the initial flux of soil P to the water column, but speculated that the short duration and small scale of the experiment may have contributed to these results.

There was discussion during the development of the Restoration Strategies Science Plan on the merits of adding wood chips in the STAs as a supplemental carbon source to enhance nutrient removal. Wood chips have been investigated in a few studies for their ability to promote nutrient removal in bioreactors and subsurface flow wetlands, but the focus of this work was on nitrogen (N) removal and not P (Christianson et al. 2009, Hopes 2010, Schipper et al. 2010, Hart 2012). The rate of denitrification in wetlands is dependent on the amount of organic carbon (C) in the soil (Reddy and DeLaune 2008). Ballantine and Tanner (2010) suggested adding wood chips in treatment wetlands where the surface layer of soil had been removed (to reduce soil-P flux) to provide a C source and promote microbial denitrification.

Soil Management Techniques

Three soil management techniques were discussed during the development of the Restoration Strategies Science Plan for reducing soil-P flux in the STAs: soil capping, soil inversion and topsoil removal. Soil capping involves placing a chemically reactive or inert material on top of the soil surface to inhibit the upward flux of P into the water column. This technique has been investigated for use in both freshwater and marine systems (e.g., Yamada et al. 1987, Jacobs and Förstner 1999, Berg et al. 2004, Ye et al. 2006, Chimney et al. 2007, Hickey and Gibbs 2009, Lin et al. 2011, Ding et al. 2012, Meis 2012, Meis et al. 2012, Xu et al. 2012). One spoil-capping approach, alum application, has been widely used to inactivate sediment P in the hypolimnion of shallow eutrophic lakes (Welch et al. 1988, Welch and Cooke 1999, Cooke et al. 2005). As noted in the previous section, Hoge et al. (2003) applied soil amendments to the soil surface in test impoundments to inhibit soil-P flux. Soil inversion, which involves plowing or disking the nutrient-rich topsoil layer so that it is replaced with the underlying nutrient-poor subsurface soil horizon, has been proposed as a way to manage nutrient export in agricultural systems (Daniel et al. 1998, Pekrun et al. 2003). Soil removal is a practice used in lake restoration to reduce internal nutrient loading (Cooke et al. 2005). Removal of the nutrient-rich surface soil layer, thereby exposing the lower-nutrient subsoil (or limestone caprock), has been suggested as a method to eliminate a source of internal P loading in treatment wetlands (Ballantine and Tanner 2010, Lindstrom and White 2011).

Task 2 – Relevant District-supported Projects

The District has carried out a number of projects that are relevant to this study. Chimney et al. (2007) performed short-term laboratory experiments that found broadcasting a soil amendment (Reclime®) on top of sediment cores (peat collected from the footprint of STA-3/4) was much more effective at reducing soil-P flux to the overlying water column immediately after the cores were flooded versus the inhibition of soil-P flux achieved with mixing Reclime® into the soil. The District has evaluated the effectiveness of soil capping. In the largest platform tested to date, a 5-ac wetland cell capped with limerock at the Field-scale PSTA Research Site achieved a flow-weighted mean (FMW) outflow TP concentration of 18 µg L^{-1} during a 9-month period of optimal performance (CH2M Hill 2003b). The District has investigated the potential benefits of soil removal to reduce the internal P loading (Reddy et al. 2002) and has tested the effectiveness of this approach in the field with two different platforms. In the first study, another 5-ac cell at the Field-scale PSTA Research Site was scraped down to the limestone caprock and achieved a FWM outflow TP concentration of 16 µg L^{-1} during the same operational period noted above (CH2M Hill 2003b). In the second study, the 100-ac PSTA cell in the STA-3/4 PSTA Project also was scraped down to the limestone caprock and had annual FWM outflow TP concentrations that ranged from 8 to 12 µg L^{-1} for six consecutive operational years (Zamorano et al. 2014). The District has conducted a number of pilot projects that demonstrated the utility of inverting the topsoil with the subsurface soil horizon to reduce copper concentrations at the soil surface (Environmental Consulting & Technology 2003, 2006, Shaw Environmental 2007, Water and Soil Solutions 2009, WRScompass 2009, South Florida Water Management District and URS 2014) or to reduce the flux of soil-P to the water column (South Florida Water Management District 2009).

Task 3 - Feasibility Assessment

The feasibility of using soil amendments or soil management techniques to reduce outflow TP concentrations in the STAs can be evaluated from several different perspectives: constructability, treatment efficacy, operations/regulatory issues and economics. Not all these areas can be fully addressed in Phase I of this study.

Constructability

The District has experience with the large-scale engineering and construction practices that would be required to employ soil amendments or soil management techniques in the STAs. For example, during the rehabilitation of STA-1W and STA-5, a number of treatment cells were dewatered while the remainder of the STA remained in operation, the vegetation and accrued sediment in the dewatered cells were removed, or the cell topography was recontoured, and the aquatic plant communities reestablished after the cells were reflooded. The District also has experience with soil capping[3], topsoil removal[4] and soil inversion projects[5] at a large scale. Therefore, there is no reason from a constructability perspective that soil amendments or soil management techniques could not be employed at full-scale in the STAs.

Treatment Efficacy

Despite the number of studies focused on soil amendments and soil management techniques (see **Table 1**), no published data were found that demonstrated the long-term efficacy of using these approaches to reduce outflow P concentrations in free water surface treatment wetlands. While soil amendments and soil management techniques, in theory, may enhance STA treatment performance, field trials will be necessary to verify their long-term usefulness. Therefore, a meaningful assessment of the treatment efficacy of any of these approaches in the STAs cannot be made at this time.

Operations & Regulatory Issues

There are a number of potential operations and regulatory issues related to using soil amendments or soil management techniques in the STAs that need to be addressed. These issues and associated questions are presented in **Table 2**. The ramifications of using soil amendments and/or soil management techniques in the STAs must be considered to help guide the STOP/GO decision for this study after the completion of Phase I, and determine if the study team should continue with further investigation and decide whether there will be any constraints on conducting this research.

Economics

Cost were estimated for: (a) the construction and infrastructure associated with large-scale test facilities (LSTFs) needed to conduct field trials in the STAs and (b) implementing soil amendments and soil management techniques at full-scale in the STAs. The original conceptual design for the LSTFs has been revised and now includes an option that utilizes two cells in the STA-1W Expansion Area (EA) to test the efficacy of soil inversion (Field-trial Option #1) and a second option that calls for building four sub-cells in each of four STAs (STA-1E, STA-1W, STA-3/4 and STA-5/6) to test several different technologies (Field-trial Option #2; see **Appendix 1** for details).

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[3] District field-station personnel built two 5-ac limerock pads (12 and 24 inches thick) within Cell 3 of STA-2 and a 5-ac limerock-capped cell (24 inches thick) at the Field-scale PSTA Research Site adjacent to STA-2. This later site was decommissioned and is now part of STA-2 Cell 4.

[4] The District, or its contractors, removed all soil down to the caprock in another 5-ac cell located at the Field-scale PSTA Research Site and in the 100-ac PSTA Cell located at the STA-3/4 PSTA Project.

[5] Soil inversion pilot projects were conducted by Environmental Consulting & Technology (2003, 2006), Shaw Environmental (2007), South Florida Water Management District (2009), Water and Soil Solutions (2009), WRScompass (2009), South Florida Water Management District and URS (2014).

Costs for Field-trial Option #1 would only entail installing autosamplers at the inflow and outflow water control structure of Cells 7 and 8 should this equipment not be part of the STA-1W EA design ($178K, **Table 3**). In Field-trial Option #2, the application of one soil amendment, limerock capping and soil inversion in the sub-cells in each abovementioned STA[6] will be tested. The cost of the soil amendment was derived from the range of prices for hydrated lime (calcium hydroxide [$Ca(OH)_2$]) found online and a field application rate of 3 t/ac (**Table 4**). The other costs for this option were developed with the assistance of Mr. Jack Ismalon, Principle Cost Estimator, Engineering and Construction Bureau, SFWMD.

Estimated construction and infrastructure costs for the LSTFs in Field-trial Option #2 ranged from a low of $3.7M in STA-1W to a high of $24.8M in STA-5/6; the total estimated construction cost for all four STAs is $57.5M (**Table 4**). The estimated costs to apply a soil amendment, install a 6-inch thick limerock cap or invert the surface layer of soil to a depth of 2 ft over the entire STA surface area dominated by SAV (31,284 ac) are $99.1M, $876.4M and $85.6M, respectively (**Table 5**). As noted above, soil amendments eventually become saturated with P and will need to be replaced on a periodic basis[7]. A limerock cap may require periodic maintenance at some indeterminate frequency to remove the new sediment, which may be P rich, that accrues on the limerock cap surface. Reapplication of a soil amendment or maintaining a limerock cap will be additional costs that recur throughout the operational life of an STA; note that these additional costs are not captured in **Table 5**. The cost estimates in **Tables 4** and **5** are preliminary and there is uncertainty in the assumptions used to generate them. As such, all costs should be regarded as order of magnitude estimates and that a wide range of values could be generated by varying one or more of the scenario assumptions. The cost threshold at which any soil amendment or soil management technique becomes economically infeasible for the District to implement in the STAs is outside the scope of this report.

Conclusions & Recommendations

Our conclusions and recommendations for this Phase I portion of the study are as follows:

1. While all of the soil amendments listed in **Table 1** sorb P to varying degrees, many of them are not suitable for use in the STAs primarily because they are either not available locally, or if available, could not be supplied in sufficient quantities to meet our needs. A secondary consideration is potential negative impacts to downstream Everglades flora and fauna, which are unknown for most of these materials. For Field-trial Option #2 (**Appendix 1**), our recommendation is to test one or more agricultural

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[6] One sub-cell in each STA will be operated as a control and will not be manipulated. We elected not to test adding wood chips because there is no evidence in the literature that this technique is effective at reducing P. We elected not to test topsoil removal because any significant lowering of the bottom elevation in the STAs likely would adversely affect system hydraulics.

[7] The frequency of soil amendment refurbishment is unknown at this time; our best estimate is that it will be required every 3 to 5 years.

products that are known to sorb P (e.g., aragonite or Reclime®), are available in sufficient quantities for use in the STAs and have low potential for negative impacts to downstream flora or fauna.

2. All of the operations and regulatory issues raised in **Table 2** should be considered before a decision to proceed with the next phase of this study is made. This study should continue beyond Phase I only if the District is reasonably certain that the use of soil amendments or soil management techniques would be acceptable in the STAs and the receiving Everglades water bodies.
3. The DSP for this project specifies that it will be conducted in three sequentially ordered phases: Phase I → Phase II → Phase III. Phase II was to consist of small-scale experiments that screen a variety of soil amendments and/or soil management techniques identified in Phase I for their ability to inhibit soil-P flux. Phase III field trials would then test the most promising of these soil amendments/management techniques at large scale. However, based on what was learned in Phase I about the P sorption capabilities of various materials and the limitations of transferring laboratory results to the field, coupled with the SFWMD's recent experience testing soil amendments (Chimney et al. 2007, Chimney et al. 2013), there is no longer a need to conduct a large number of experiments with multiple soil amendments. Instead, if a GO decision to continue with the study after Phase I is reached, a modified Phase II to identify the optimum application rate(s) for a few select soil amendments (e.g., aragonite and Reclime®) will be conducted. Concurrent with the start of Phase II work, Phase III will be initiated and design of the LSTFs that are described in **Appendix I** will begin. Limerock capping and soil inversion also will be tested in these LSTFs. Given the substantial cost of implementing a soil amendment or soil management technique at full-scale in the STAs, and the inherent biogeochemical variability among STAs (see **Table 5**), it is recommended that the field trials be conducted in the four STAs specified in **Appendix 1** to demonstrate that these technologies will work across all the STAs.

STOP/GO Decision

This Phase I Summary Report was reviewed by the Restoration Strategies (RS) Science Plan Management Team (Team). Considering the uncertainties in treatment efficacy, potential impacts to STA operations and the economics associated with conducting large-scale field trails and implementing any of these technologies at full-scale in the STAs, the Team recommended that (a) the study move forward with planning associated with Field-trial Option #1 in the STA-1W EA and (b) not to proceed with study Phases II and III for Field-trial Option #2 at this time. Cells in the STA-1W EA are scheduled to be flow-capable on December 31, 2018. The RS Steering Committee on October 6, 2015 agreed with these STOP/GO recommendations.

Table 1. Soil amendments and soil management techniques identified in a literature review conducted for Phase I of the Use of Soil Amendments/Management Techniques to Control P Flux Study.

Soil Amendment/ Management Technique	Type	Description/Composition/Characteristics	References§
acid mine drainage residuals	by-product	A waste product generated during the neutralization of acid mine drainage	47
AlgalBLOCK	man-made	A precipitated form of surface activated calcium carbonate	19
allophane	natural	An aluminum silicate clay mineraloid [$Al_2O_3 \cdot (SiO_2)_{1.3\text{-}2} \cdot (2.5\text{-}3)H_2O$] that contains alumina; found in volcanic and non-volcanic derived soils	5, 20
alum/aluminum sulfate	man-made	$Al_2(SO_4)_3 \cdot 14\ H_20$; alkaline - highly caustic & reactive; low solubility	2, 4, 5, 6, 9,14, 17, 25, 36, 37, 39, 40, 47, 48, 62
alumina	natural	Aluminum oxide [Al_2O_3]	35
alumina-activated	man-made	Aluminum oxide [Al_2O_3]	20
alumina-coke mixture	by-product	A waste material produced during aluminum ore processing; contains a mixture of Ca, Al, Fe and Al-coke	35
aluminum chloride	man-made	$AlCl_3$	6, 47
alunite	man-made	Hydrated aluminum potassium, sulfate mineral [$KAl_3(SO_4)_2(OH)_6$]	58
apatite/phosphate rock	natural	A calcium phosphate mineral [$Ca_{10}(PO_4)_6(OH, F, Cl)_2$] with high concentrations of Ca, OH, F and Cl	5, 58
aragonite	natural	A calcium carbonate mineral precipitated from sea water; evaluated during the New Alternative Technology Assessment (NATA) Program (see Chimney et al. 2013)	12
Baraclear®	man-made	A proprietary mixture of alum and other non-toxic earthen materials; manufactured as nodules with a diameter of 1/4" to 3/8"	5
bauxite	natural	An aluminum ore rich in hydrated Al and Fe oxides	16, 21, 32, 58
bauxite mine waste	by-product	A waste material produced during the processing of bauxite ore	47
Bauxsol™	by-product	Neutralized bauxite residuals	58
bentonite	natural	An absorbent aluminum phyllosilicate clay; contains Ca, Mg, Fe, Al and Si oxides	16
black oxide	by-product	A waste material derived from mineral sands processing	16
bone char	man-made	A granular material produced by charring animal bones	44
brick (Fe-coated)	man-made		16
calcareous rock (crushed)	natural		3
calcium carbonate/calcite	by-product	A carbonate mineral; the most stable form [$CaCO_3$]; residual precipitated during drinking water treatment	2, 9, 17, 20, 36, 48, 62
calcium chloride	man-made	$CaCl_2$; produced from limestone or during the manufacture of soda ash	37, 47
calcium silicate slag	by-product		47
cement kiln dust	by-product	A fine dust-sized material resulting from cement production; composed primarily of CaO and SiO_2	44, 47
coal fly ash	by-product	A waste product from burning coal; contains silica dioxide, alumina and ferric oxides	5, 16, 20, 21, 32, 46, 47, 58
coal fly ash (anthracite)	by-product	A waste product from burning anthracite coal; contains amorphous ferric hydroxide [$Fe(OH)_2$]	8

Table 1. (continued).

Soil Amendment/ Management Technique	Type	Description/Composition/Characteristics	References§
coal fly ash (bituminous)	by-product	A waste product from burning bituminous coal; contains calcium hydroxide [$Ca(OH)_2$] and calcium sulfate [$CaSO_4 \cdot 2H_2O$]	8
copperas	man-made	a.k.a. ferrous sulfate or iron(II) sulfate [$FeSO_4 \cdot 7H_2O$]; available in granular form	6
Damolin (new product)	man-made	A processed calcium carbonate product	3
Damolin (old product)	man-made	A processed calcium carbonate product	3
dinoSoil	natural	A leonardite containing humic and fulvic acids, montmorillonite clay, Fe & Al oxides and other minerals; from Texas	46, 57
dolomite/dolomite sand	natural	Calcium magnesium carbonate [$CaMg(CO_3)_2$]; see lime (agricultural/limerock)	2, 32, 58
DWTR	by-product	Drinking water treatment residuals derived from aluminum, calcium or iron salts; also may have some polymers	5, 9, 17, 47, 62
DWTR-Al	by-product	The residuals of Al salts used in the treatment of drinking water	1, 6, 8, 24, 29, 31, 38, 39, 44, 45, 46, 48
DWTR-Ca	by-product	The residuals of Ca salts used in the treatment of drinking water	24, 35, 46
DWTR-Fe	by-product	The residuals of Fe salts used in the treatment of drinking water	6, 24, 31, 35, 38, 46
ferric chloride	man-made	Iron(III) chloride [$FeCl_3 \cdot 6H_2O$]; strong acid	2, 6, 9, 10, 17, 33, 37, 47, 62
ferric oxide	natural		20
ferric sulfate	man-made	Iron(III) sulfate [$Fe_2(SO_4)_3 \cdot 3H_2O$]; strong acid	6, 9, 47
Filtra P	man-made	Produced by heating limestone, gypsum and Fe oxides; high calcium hydroxide content	58
Filtralite-P™	man-made	An amended clay material developed for P removal by sorption to Al, Ca, Mg and Fe oxides	3, 5, 16, 20, 32, 58
GAC	man-made	Granular activated charcoal	44
gravel	natural	Trace amounts of Ca, Mg, Fe and Al oxides	16, 20, 58
gypsum	natural	Hydrated calcium sulfate[$CaSO_4 \cdot (2H_2O)$]; neutral pH	8, 9, 15, 16, 29, 46, 47, 55
gypsum (waste)	by-product	A waste product produced during the processing of gypsum	47
HeloFIR®	man-made	A dark granular material specific for P removal	3
HiClay® alumina	by-product	A proprietary material generated during alum production & other bauxite-based processes	9
humate product	by-product	A dried waste material produce during titanium mining	35
hydrotalcite	natural	A layered double hydroxide soil mineral of the general formula ($Mg_6Al_2(CO_3)(OH)_{16} \cdot 4(H_2O)$)	20
Hyper+ion 1090	man-made	A polyaluminum hydroxychloride solution	6
imogolite	natural	An aluminum silicate clay mineral [$Al_2SiO_3(OH)_4$]; occurs in soils formed from volcanic ash	20
iron ore	natural		58
iron oxides/steel wool	man-made	Materials added to peat and sand to enhance P removal	5
lanthanum	natural	A rare earth element	20
laterite	natural	A soil type rich in Fe and Al; formed in hot and wet tropical areas; derived from decomposition of bauxite rock	32, 58

Table 1. (continued).

Soil Amendment/ Management Technique	Type	Description/Composition/Characteristics	References[§]
LECA®	man-made	Light-Expanded Clay Aggregates; an amended clay material developed for removing P by sorption to Al, Ca, Mg and Fe oxides	5, 16, 20, 21, 32, 58
Lehigh cement	man-made	Contains Ca, Mg, Fe and Al	16
lime			6, 46
lime (agricultural/ limerock)	natural	a.k.a. dolomite [$CaMg(CO_3)_2$]; weakly alkaline	9
lime (mixed)	by-product	A mixture of CaO, $Ca(OH)_2$ and $CaCO_3$; spent material generated during sugar refining	34
lime (quick/burnt)	man-made	Calcium oxide [CaO]; strongly alkaline and reactive	9, 34, 47
lime (slaked/hydrated)	man-made	Calcium hydroxide [$Ca(OH)_2$]; alkaline with low solubility	2, 4, 9, 10, 29, 47, 48
lime (sugarbeet)	by-product	A waste material produced from sugarbeets during sugar production	62
limestone/limerock	natural	A sedimentary rock composed largely (> 50%) of calcium carbonate [CaCO3]	5, 16, 17, 18, 21, 28, 32, 41, 44, 47, 56, 58
LWA	man-made	Light-weight aggregates; an amended clay material developed for P removal by sorption to Al, Ca, Mg and Fe oxides	58
maerl	natural	Collective name for deposits of calcareous red algae; dredged from the sea floor; high $CaCO_3$ content	26, 32, 58
mag dust	by-product	A waste product derived from building practices	55
marble	natural	A non-foliated metamorphic rock composed of recrystallized carbonate minerals, most commonly calcite (limestone) or dolomite	58
marl gravel	natural	A solidified soil consisting of clay and fine particles of limestone	32, 58
Nclear®	man-made	A proprietary mixture of calcium silicate hydroxides; evaluated during the NATA Program	12
Norlite	man-made	A lightweight course aggregate made from fired shale	28, 58
ochre	by-product	A waste product from treatment of abandoned mine waters containing hydrated iron oxide [Fe(OH)3 & FeO(OH)]	5, 58
ochre (black)	by-product	A waste product from treatment of abandoned mine waters; has a high Al content	55
ochre (red)	by-product	A waste product from treatment of abandoned mine waters; has a high Al content	55
oil shale (burnt)	by-product	A waste product from heating oil shale to produce mineral oil	21, 32, 58
oil shale ash	by-product	Residue remaining after the combustion of oil shale in Estonian thermal power plants	58
opoka	natural	An amorphous calcareous sedimentary rock found in south-eastern Poland; contains Ca, Mg, Fe, Al and Si oxides	16, 32, 58
PACL	man-made	Polyaluminum chloride (polyaluminum hydroxychloride) [$Al_2(OH)_nCl_{6-n}\cdot nH_2O$)]; mildly acidic	6, 9, 10, 33, 39
PAM	man-made	Polyacrylamide (PAM) polymer: anionic or cationic; neutral pH	6
paper mill lime	by-product	A by-product of paper production; contains Ca	47

Table 1. (continued).

Soil Amendment/ Management Technique	Type	Description/Composition/Characteristics	References§
paper mill sludge	by-product	A by-product of paper production; contains Al and Ca	47
peat	natural	A soil that has high organic matter content; accumulation of partially decayed vegetation or organic matter	18, 58
Phoslock™	man-made	A bentonite clay amended with lanthanum developed for P sorption; forms rhabdophane [$LaPO_4$·H2O]; evaluated during the NATA Program	5, 12, 19, 42, 43
PNAS	man-made	Partially neutralized aluminum sulfate	39
polonite	man-made	Manufactured by heating opoka to 900 °C; consists mainly of reactive lime and wollastonite phases	58
polymers	man-made	This category includes a number of different anionic, cationic and non-ionic products	9, 25
Pro-Sil	by-product	A silica slag containing Ca, Ma, Si and other micronutrients	46
pumice	natural	A porous, low-density rock produced when volcanic lava with a high water and gas content cools and hardens	5
pumice soil	natural	A light, porous soil of volcanic origin with high levels of Al, Fe, Ca and Mg; can have varying amounts of allophane	5
Reclime®	by-product	A Ca-Mg silicate with impurities; by-product of steel production; alkaline	9, 11
red mud	by-product	A waste material generated during alumina refining from bauxite	20, 58
sand	natural	This category encompasses a wide variety of sand types with differing physico-chemical properties	5, 16, 20, 58
sand (Al/Fe-coated)	man-made		16, 35
sand (concrete)	natural		35
sand (foundry)	by-product	A waste material from sand molds used in metal casting	47
sand (masonry)	natural		35
sand (organic)	natural		35
sand (quartz)	natural		18, 58
sandblast grit	by-product	A waste product from sandblasting	35
sander dust	by-product	A waste product from building practices	55
serpentinite	natural	A magnesium-rich silicate mineral associated with igneous rocks [$H_4Mg_3Si_2O_9$]	5
shale	natural	An argillaceous, fine-grained sedimentary rock derived from limestone	5, 16, 21, 58
shells			
shells (crushed blue mussel)	by-product	Waste shells produced by aquaculture; high Ca content	3
shells (crushed seashells)	by-product		3, 5, 32
shells (oyster)	by-product	Waste shells produced in oyster culture; high Ca content	58
shellsand	natural	A natural calcareous material formed mainly from crushed shells, snails and coral algae	5, 32, 58
siderite	natural	A mineral composed of iron(II) [ferrous] carbonate [$FeCO_3$]	8
slag	by-product	By-product of steel and iron production containing varying amounts of Ca, Mg, Al, Si and Fe oxides	5, 8, 16, 20, 32, 41, 44, 58
soda ash	man-made	Sodium carbonate [Na_2CO_3]	6
sodium aluminate	man-made	$Na_2Al_2O_4$; weakly alkaline and extremely reactive	6, 9, 14, 50
sodium bicarbonate	man-made	$NaHCO_3$	6

Table 1. (continued).

Soil Amendment/ Management Technique	Type	Description/Composition/Characteristics	References[§]
sodium hydroxide	man-made	a.k.a. caustic soda or lye [NaOH]	6
sodium nitrate	natural	a.k.a. saltpeter; $NaNO_3$	37
soil	natural	P retention is related to the mineral content of Fe and Al compounds	20, 58
soil (calcareous)	natural	A soil with a high $CaCO_3$ content	16
soil (glossic hapludalf)	natural	A fine loamy, mixed soil formed from calcareous and sulfur-rich glacial till	28
soil (spodosol)	natural	Ashy gray, acidic soils with a strongly leached surface layer; the B horizon of a forest soil; contains Fe and Al oxides	16, 32, 58
soil capping	-	Cover existing soil with a layer of material with low P content to reduce P flux from the soil to the water column	19, 42, 43, 61
soil inversion	-	Disc/plow so as to place the high nutrient/contaminate topsoil layer underneath the deeper sub-soil layer	22, 23, 52, 53, 54, 59, 60
soil removal	-	Remove topsoil containing the highest nutrient/contaminate concentrations; may restrict N removal due to initial lack of organic matter	5, 36, 49
STI	man-made	Simtec triad ionate; a proprietary clay-like mineral product that contains Al, Fe, Ca and Mg; evaluated during the NATA Program	12
SuperMag	by-product	A magnesium-based fertilizer by product	35
Tennessee slag	by-product	A Ca-Mg silicate with impurities; by-product from electric furnace production of P; alkaline	9, 11
tephra	natural	The fragmented material explosively erupted from a volcano; may contain large amounts of allophane	5
titanium mine waste	by-product	A waste material produced during the processing of titanium ore	46
utelite	man-made	A lightweight expanded shale aggregate	16
vermiculite	natural	A hydrous, silicate mineral classified as a phyllosilicate; $(Mg^{+2}, Fe^{+2}, Fe^{+3})_3 [(AlSi)_4O_{10}] \cdot(OH)_2\cdot 4H_2O]$	55
ViroPhos™	man-made	Proprietary mixture of hematite ($Fe2O_3$), alumina ($Al(OH)_3$), sodalite ($Na_4(Al_6Si_6O_{24})Cl_2$) and quartz (SiO_2); evaluated during the NATA Program	12
wollastonite	natural	A calcium inosilicate (metasilicate) mineral composed of calcium oxide and silicon dioxide [$CaSiO_3$]	5, 7, 8, 9, 18, 28, 32, 58
wood (ash)	by-product		47
wood (chips)	natural	Investigated for N removal or neutralization of acid mine drainage	13, 27, 30, 51
wood (treebark)	natural		5
woodchip biochar	man-made	Investigated for N removal	27
WP-1™	man-made	A proprietary mixture of mineral compounds; evaluated during the NATA Program	12
zeolite	natural	Microporous aluminosilicate minerals with low bulk density and high porosity; can contain Ca and Mg	5, 16, 21, 32, 58
zeolites (amended)	man-made	Zeolite pre-treated with cationic surfactants to enhance anion retention	5

Table 1. (continued).

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§Reference key: [1] Agyin-Birikorang et al. (2009), [2] Ann et al. (2000), [3] Arias & Brix (2004), [4] Babin et al. (1992), [5] Ballantine & Tanner (2010), [6] Bottcher et al. (2009), [7] Brooks et al. (2000), [8] Callahan et al. (2002), [9] CH2M Hill (2002), [10] CH2M Hill (2003a), [11] Chimney et al. (2007), [12] Chimney et al. (2013), [13] Christianson et al. (2009), [14] Cooke et al. (1981), [15] Cox et al. (2005), [16] Cucarella & Renman (2009), [17] DB Environmental, Inc. (2013), [18] DeBusk et al. (1997), [19] Ding et al. (2012), [20] Douglas et al. (2004), [21] Drizo et al. (1999), [22] ECT, Inc. (2003), [23] ECT, Inc. (2006), [24] Elliott et al. (2002), [25] Florida Department of Environmental Protection (2011), [26] Gray et al. (2000), [27] Hart (2012), [28] Hill et al. (2000), [29] Hoge et al. (2003), [30] Hopes (2010), [31] Ippolito et al. (2011), [32] Johansson Westholm (2006), [33] Jorge et al. (2002), [34] Kirkkala et al. (2012), [35] Leader et al. (2008), [36] Lindstrom & White (2011), [37] Liu et al. (2009), [38] Makris et al. (2005), [39] Malecki-Brown & White (2009), [40] Malecki-Brown et al. (2009), [41] Mara et al. (2007), [42] Meis (2012), [43] Meis et al. (2012), [44] Mortula et al. (2007), [45] Novak & Watts (2005), [46] O'Connor et al. (2005), [47] Penn et al. (2007), [48] Reddy et al. (1998), [49] Reddy et al. (2002), [50] Sanville et al. (1976), [51] Schipper et al. (2010), [52] South Florida Water Management District & URS (2014), [53] SFWMD (2009), [54] Shaw (2007), [55] Spears et al. (2013), [56] Strang & Wareham (2006), [57] Struve & Zhou (undated), [58] Vohla et al. (2011), [59] Water and Soil Solutions, LLC (2009), [60] WRScompass, Inc. (2009), [61] Xu et al. (2012), [62] Zvomuya et al. (2006).

Table 2. Feasibility issues, questions and comments generated during Phase I of the Use of Soil Amendments/Management Techniques to Control P Flux Study that require consideration before the study moves to the next phase.

	Feasibility Issue/Question/Comment	Response/Resolution*
1	**Limerock capping** involves adding a layer of crushed limerock (i.e., limestone) on top of the existing soil in the downstream treatment cells of the STAs. The depth of the limerock layer that will be required to provide treatment is unknown at this time, but may range from several inches to more than one foot. Adding limerock will reduce a cell's storage capacity and may incur a hydraulic penalty, i.e., the increase in surface elevation will impede flow as water coming from upstream treatment cells would have to move "uphill" as it enters capped cells. Two operational issues that may constrain the thickness of the limerock layer need to be addressed: a. How much loss of storage capacity in a cell due to capping can be tolerated? b. How much of a hydraulic impediment to flow in a cell due to capping can be tolerated?	*While the loss of cell storage capacity and flow restriction associated with limerock capping were recognized as problems in the STAs, an upper tolerance limit for either issue that would preclude the use of this technology was not identified. However, due to the high projected cost of installing a limerock cap, this approach is the least attractive of the treatment technologies included in this study.*
2	Applying a **soil amendment** or installing a **limerock cap** in the STAs will require that treatment cells be dewatered and the vegetation removed before the work is done. These cells would then be reflooded and the wetland plant community allowed to reestablish itself before flow-through operations could resume. This process will take at least one year (and possibly longer) during which time the entire flow-way would be offline. Any soil amendment eventually will become saturated with P and have to be replaced. New soil will accrue on top of a limerock cap over time; if this soil is P rich, it may have to be removed to prevent P flux back to the water column. Removing this soil will likely disturb the upper portion of the limerock cap and necessitate that it be repaired. Reapplication of a soil amendment or maintenance of a limerock cap will be required throughout the operational life of a STA at some yet undetermined frequency and require that cells again be taken offline for a least on year while the work is done and the plant community becomes reestablished. Consider that every STA flow-way may need treatment to achieve the WQBEL criteria. Some issues that need to be addressed concerning using soil amendments or a limerock cap in the STAs include: a. Can STA flow-ways be taken off-line for one year (or longer) for the initial application of a soil amendment or installation of a limerock cap? b. Based on the operating scenario assumed for the STAs during the design of the Restoration Strategies projects, how frequently can a flow-way be taken offline in subsequent years to reapply the soil amendment or perform maintenance on the limerock cap?	*Restoration Strategies assumes that each STA will be taken offline entirely for maintenance activities once every 20 years. While taking STA flow-ways offline more frequently would not be ideal, doing so for the initial installation of a soil amendment or limerock cap and subsequent reapplication of the soil amendment or maintenance activities on the limerock cap at a shorter time interval in future years could be tolerated.*
3	Applying a **soil amendment** or **limerock cap** has been criticized as not economically feasible to implement at full-scale in the STAs due to their size. However, the dollar threshold above which these technologies become cost prohibitive is undefined. The affordability of any of these technologies ultimately is a policy issue.	*This is just a comment; no input was elicited from the focus group.*

Table 2. (continued).

	Feasibility Issue/Question/Comment	Response/Resolution
4	Application of a **soil amendment** in the STAs more than likely will require enormous quantities of material, i.e., many tens of thousands of tons per application. A consideration in selecting any particular product for testing is the availability of sufficient quantity needed for use over the operational life of the STAs.	*Our inclination at this time is to test an agricultural product that is 1) widely used in the EAA, 2) available locally in quantities that will meet our future needs for use in the STAs and 3) has no toxicity issues for downstream Everglades flora and fauna*
5	The application of a **limerock cap** or a **soil amendment** in the STAs may have regulatory implications: a. Would using either of these approaches in the STAs require a change to the current STA operating permit? b. If so, what would USEPA and FDEP require from the District in order to authorize their use in the in the STAs? Will the District have to demonstrate that outflow from a cell treated in either fashion is "marsh ready"? c. Will the District be allowed to divert water around the STAs when flow-ways are off-line for soil amendment reapplication or maintenance of the limerock cap?	*All regulatory issues will need to be addressed with USEPA and FDEP prior to implementing any of the technologies that are part of this study. However, none of the issues raised here is seen as prohibiting the use of limerock capping or soil amendment in the STAs.*
6	Phase III of this study calls for conducting field trials of candidate technologies in the STAs. Our initial proposal to construct large enclosures (~ 10 ac) within the STAs for this work was criticized by the Technical Representatives as being too small and subject to experimental artifacts. There is agreement (in part) with their assessment. Alternate suggestions have been to use entire treatment cells for testing. One approach would involve constructing new longitudinal internal levees to partition existing cells and conduct tests within these new sub-cells. Issues that need to be addressed concerning this approach include: a. Is such an approach feasible from an operations or regulatory perspective, i.e., can the entire treatment cells be used for testing? b. There is no guarantee that any soil amendment/management technique shown to work in one STA will necessarily work when applied to the other STAs. Ideally, tests would be conducted in every STA. Is there enough operational flexibility in the STAs to allow us to conduct tests in one flow-way of a number of STAs? c. Conducting experiments in entire cells has risks. There is no guarantee that treatment performance in cells after they are manipulated will improve relative to pre-testing performance and there is a possibility that post-manipulation performance may be worse than pre-testing performance, i.e., one or more cells could "break" during testing. There also may be other unanticipated negative impacts. In addition, returning manipulated cells to their original condition after the study may require restarting the cell (i.e., removing the new levees and the amended soil or limerock cap and reestablishing vegetation) or will not be possible in the case of soil inversion.	*It is recognized that there is potential risk in conducting research on these technologies at a large-scale in the STAs. Nevertheless, these concerns would not preclude conducting large-scale field trials to test these technologies.*

Table 2. (continued).

	Feasibility Issue/Question/Comment	Response/Resolution
7	How will success be judged in this study, i.e., what level of treatment performance will the field trials have to achieve to be judged as having been successful? Will it be sufficient for treated cells to produce an outflow TP concentration that is only measurably lower than the control cell or will the treated cells have to achieve outflow TP levels that meet the WQBEL criteria?	*Implementing one of these technologies ideally would enable the STAs to achieve the WQBEL. However, enhanced treatment performance that falls short of the WQBEL may be acceptable under some circumstances.*
8	If a **soil amendment** or a **soil management technique** were to be implemented in the STA-1W Expansion Area or in the A-1 Flow Equalization Basin (FEB), it would be easier to install the technology during construction when the work can be done in the dry. However, based on the anticipated construction schedule for the STA-1W Expansion Area and the A-1 FEB, there may not be sufficient time to finish the field-trial phase of this study, and validate that the technology works, before installation of the technology would have to start. • Would the District want to commit to implementing a technology in the STA-1W Expansion Area or the A-1 FEB before the final phase of this study has been completed?	*Implementing any of the technologies that are part of this study throughout the entire STA-1W Expansion Area is not being considered at this time.*
9	One **soil management technique** that has been proposed for treatment wetlands is topsoil removal. The idea is to remove a source of P that can flux back to the water column. However, topsoil removal would lower the wetland floor and may affect system operation. • If topsoil is removed from the STAs, how much material can be taken out before system hydrology and hydraulics are compromised, i.e., how far below the original soil elevation can excavation occur before there would be problems moving water through and maintaining a target stage in the STAs?	*Due to hydraulic issues associated with lowering the ground elevation in the STAs, topsoil removal has been excluded from the technologies that will be studied as part of this study.*

* Input to these issues and questions was provided by a focus group that consisted of Lawrence Gerry, Susan Gray, Delia Ivanoff, Jill King, Jennifer Leeds, Jeremy McBryan, Kim O'Dell and Larry Schwartz.

Table 3. Estimated infrastructure costs for conducting field trials in the STA-1W Expansion Area during the Use of Soil Amendments/Management Techniques to Control P Flux Study.

	Cell 7	Cell 8	TOTAL
Surface area (ac)	1,323	1,231	2,554
Autosamplers (6)[1]	$ 88,860	$ 88,860	$ 177,720

[1] Autosampler unit cost = $29,620

Table 4. Estimated infrastructure and construction costs for a conceptual design of large-scale test facilities in select SAV cells of the STAs to be used in field trials during the Use of Soil Amendments/Management Techniques to Control P Flux Study.

	STA-1E	**STA-1W**	**STA-3/4**	**STA-5/6**	**TOTALS**
Candidate SAV treatment cells	4N & 2	2B	3B	1B & 2B	-
Soil-amendment sub-cell (ac)	318	48	325	612	1,303
Limerock-cap sub-cell (ac)	318	48	325	612	1,303
Soil-Inversion sub-cell (ac)	257	48	325	612	1,242
New levees (mi)	4	2	4	4	14
Boat ramps (#)	4	4	4	4	16
Stage recorders (#)	8	8	8	8	32
Autosamplers (#)	8	8	8	8	32
Soil amendment (t/ac)	3	3	3	3	-
Limerock cap (cu. yd.)	256,520	38,720	262,167	493,680	1,051,087
DIRECT COSTS					
Land preparation[1]	$ 803,700	$ 129,600	$ 877,500	$ 1,652,400	$ 3,463,200
New levee construction[2]	$ 1,791,440	$ 895,720	$ 1,791,440	$ 1,791,440	$ 6,270,040
Boat ramps[3]	$ 80,000	$ 80,000	$ 80,000	$ 80,000	$ 320,000
Stage recorders[4]	$ 140,000	$ 140,000	$ 140,000	$ 140,000	$ 560,000
Autosamplers[5]	$ 236,960	$ 236,960	$ 236,960	$ 236,960	$ 947,840
Limerock cap[6]	$ 5,899,960	$ 890,560	$ 6,029,833	$ 11,354,640	$ 24,174,993
Soil amendment[7]	$ 413,400	$ 62,400	$ 422,500	$ 795,600	$ 1,693,900
Soil inversion[8]	$ 257,000	$ 48,000	$ 325,000	$ 612,000	$ 1,242,000
	$ 9,622,460	$ 2,483,240	$ 9,903,233	$ 16,663,040	$ 38,671,974
OVERHEAD COSTS[9]					
Mobilization/demob. (10.0%)	$ 962,246	$ 248,324	$ 990,323	$ 1,666,304	$ 3,867,197
Field office overhead (6.0%)	$ 577,348	$ 148,994	$ 594,194	$ 999,782	$ 2,320,318
Home office overhead (3.0%)	$ 288,674	$ 74,497	$ 297,097	$ 499,891	$ 1,160,159
OTHER COSTS[10]					
Sales tax (6.5%)	$ 148,859	$ 38,416	$ 153,203	$ 257,777	$ 598,255
Profit (6.0%)	$ 687,044	$ 177,303	$ 707,091	$ 1,189,741	$ 2,761,179
Bonds (1.5%)	$ 184,299	$ 47,562	$ 189,677	$ 319,148	$ 740,686
Contingency (15.0%)	$ 1,842,995	$ 475,616	$ 1,896,771	$ 3,191,480	$ 7,406,862
TOTAL COSTS	**$ 14,313,925**	**$ 3,693,953**	**$ 14,731,590**	**$ 24,787,165**	**$ 57,526,632**
Low Range -5%	$ 13,598,229	$ 3,509,255	$ 13,995,011	$ 23,547,806	$ 54,650,300
High Range +5%	$ 15,029,621	$ 3,878,650	$ 15,468,170	$ 26,026,523	$ 60,402,964

[1] Unit cost to clear and grub existing wetland vegetation in the three experimental sub-cells = $900/ac; [2] Unit cost for construction of new levees = $447,860/mi; [3] Boat ramp unit cost = $20,000; [4] Stage recorder unit cost = $17,500; [5] Autosampler unit cost = $29,620; [6] Unit cost to purchase, transport to site and install a 6-inch layer of limerock over the entire surface area of the limerock-cap sub-cell = $23/cu. yd.; [7] Unit cost to purchase and transport soil amendment to site = $400/t + unit cost to apply soil amendment over entire surface area of the soil-amendment sub-cell = $100/ac; [8] Unit cost to invert the surface layer of soil to a depth of 2 ft over the entire surface area of the soil-inversion sub-cell = $1,000/ac; [9] Overhead costs calculated as a percentage of total direct costs; [10] Other costs calculated as a percentage of total direct costs + overhead costs.

Table 5. Estimated costs to apply a soil amendment, install a limerock cap or invert the surface soil over the surface area of STA treatment cells dominated by submerged aquatic vegetation (SAV). Cost estimates based on applying these measures to the entire surface area dominated by SAV.

Total surface area dominated by SAV in the STAs (ac)[1] =	31,284
SOIL AMENDMENT	
Mass of soil amendment applied over total SAV surface area (t)[2] =	93,851
Cost to purchase, transport and apply soil amendment[3] =	$ 40,668,680
Cost of land preparation[4] =	$ 28,155,240
Overhead costs[5] =	$ 13,076,545
Other costs[6] =	$ 17,209,077
	$ 99,109,542
LIMEROCK CAP	
Volume of limerock applied over total SAV surface area (cu. yd.)[7] =	25,235,437
Cost to purchase, transport to site and install limerock cap[8] =	$ 580,415,059
Cost of land preparation[4] =	$ 28,155,240
Overhead costs[5] =	$ 115,628,357
Other costs[6] =	$ 152,169,960
	$ 876,368,616
SOIL INVERSION	
Cost of soil inversion over total SAV surface area[9] =	$ 31,283,600
Cost of land preparation[4] =	$ 28,155,240
Overhead costs[5] =	$ 11,293,380
Other costs[6] =	$ 14,862,385
	$ 85,594,604

[1]This area includes the entire surface area of treatment cells designated as "SAV cells" and the portion of the surface area of STA-2 Cells 2, 5 and 6 that is dominated by SAV; [2]Mass calculation based on an application rate of 3 t/ac; [3]Based on a unit cost of $400/t to purchase and transport material to the site and $100/ac to apply it; [4]Based on a unit cost of $900/ac to clear and grub existing wetland vegetation; [5]Overhead costs calculated as a 19% markup of direct costs – see **Table 3** for details; [6]Other costs calculated as a 25.0045% markup of direct costs – See **Table 3** for details; [7]Volume of limerock based on installing a 6-inch thick layer of material over the entire SAV surface area; [8]Based on a unit cost of $23/cu. yd. to purchase, transport to the site and install material; [9]Based on a unit cost of $1,000/ac to invert the surface layer of soil down to a depth of 2 ft.

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Appendix 1 – Revised Conceptual Design for Conducting Field Trials in the STAs as Part of the Use of Soil Amendments/Management Techniques to Control P Flux Study

Based on review comments received from the Technical Representatives on the Detailed Study Plan (DSP)[8] and additional direction provided by District management, the conceptual design for the large-scale test facilities (LSTFs) in the STAs has been revised and we now propose two different options for conducting field trials. The first option is to use Cells 7 and 8 of the STA-1W Expansion Area (EA) to investigate the efficacy of soil inversion[9]. The second option is to partition several existing SAV treatment cells into a number of "sub-cells" and conduct 6field trials of different technologies within these experimental units.

Field-trial Option #1 - STA-1W Expansion Area

The STA-1W EA will consist of three new cells, Cell 6, 7 and 8, located immediately west of the existing STA-1W facility (**Appendix Fig. 1**). All the soil in Cell 7 will be inverted to a depth of 2 ft while all the soil in Cell 8 will be left undisturbed[10]. The treatment performance of Cell 7 (1,323 ac, the experimental unit) will be compared to that of Cell 8 (1,231 ac, the control) to evaluate the efficacy of soil inversion to reduce outflow TP concentrations. The only new infrastructure that may be needed for this option is to install autosamplers at the inflow and outflow water-control structures in Cells 7 and 8 if autosamplers at these locations are not already part of the STA-1W EA design. We do not anticipate that any other modifications will be required to utilize these cells.

The current construction schedule calls for all STA-1W EA cells to be flow-capable by December 31, 2018. It is estimated that it will take 12 to 18 months for the aquatic vegetation community to become established after the facility is flooded and the cells to meet their phosphorus start-up criterion. Data collection can begin as soon as flow-through operation in the STA-1W EA is permitted, which may be as soon as January 2020 and will last 4 to 5 years.

Field-trial Option #2 - LSTFs in existing SAV cells

Treatment cells to be employed in this option were selected based on their configuration, which allows for the construction of a number of rectangular sub-cells arranged in parallel within each STA; candidate treatment cells include STA-1E Cells 4N and 2, STA-1W Cell 2B, STA-3/4

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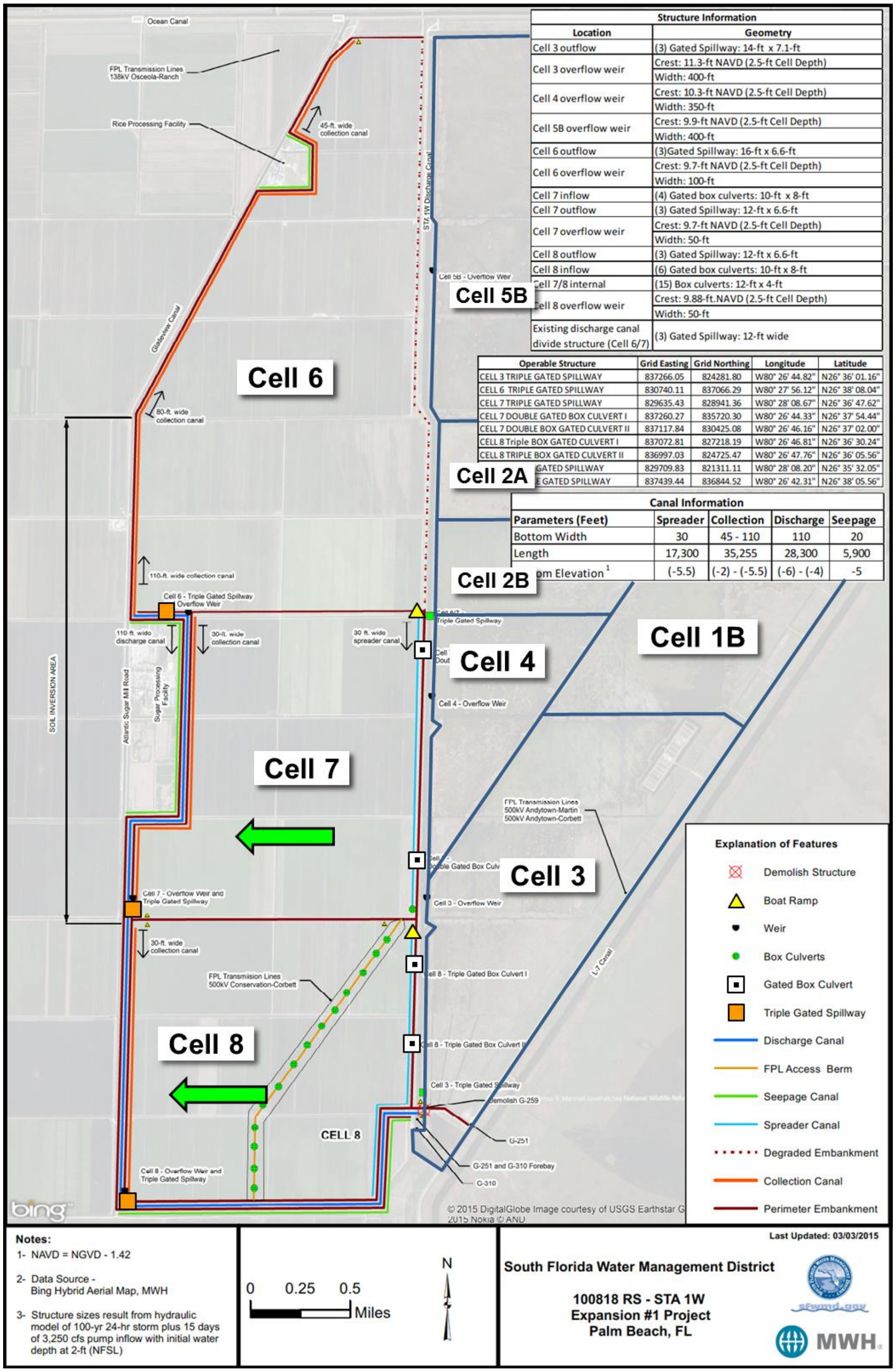
[8] The Technical Representatives expressed concerns that the 10-ac experimental cells originally proposed for the field trials in the DSP would have performance artifacts due to their relatively small size and not be representative of the full-scale STAs. There also were issues related to achieving desired hydraulic retention times and how to mimic the hydrology of the STAs, especially peak flows during storm events, in the 10-ac experimental cells.

[9] Surface soil in portions of the STA-1W Expansion Area will be inverted during construction to bury its high copper concentrations. We would take advantage of this situation to investigate whether soil inversion can reduce outflow TP concentrations.

[10] Approximately one-half of the soil in Cell 6 will be inverted while the remaining soil will be left undisturbed. Water that flows over each of these areas will mix within the cell. Because these waters cannot be sampled separately, Cell 6 is not suitable for conducting an experiment on the influence of soil inversion on treatment performance.

Cell 3B and STA-5/6 Cells 5-1B and 5-2B (**Appendix Fig. 2**). The plant community in all these cells is dominated by SAV. This new design has much larger experimental units (the sub-cells range in size from 48 to 612 ac, depending on the STA) and utilizes existing water control structures for water delivery rather than relying on small pumps to manage inflow and outflow as originally proposed in the DSP. New levees will be constructed that together with existing levees will create four sub-cells within each of the above-mentioned treatment cells. Each sub-cell will have dedicated head- and tailwater stage recorders and inflow and outflow autosamplers. Our intent is to operate the candidate treatment cells the same as the other treatment cells in each respective STA during the study and to apply the same hydraulic load to each sub-cell within a treatment cell. One sub-cell will be used as a control, i.e., it will receive no experimental manipulation, while the other sub-cells will be manipulated. The sub-cells will be cleared of all wetland vegetation before treatments are applied and the aquatic plant communities reestablished before conducting the experiment.

It is estimated that the design and construction of the new levees plus application of the experimental treatments within the sub-cells (a soil amendment, a limerock cap and soil inversion) will require 18 to 24 months followed by an additional 6 to 12 months for aquatic vegetation to grow in. Data collection could start 24 to 36 months after a GO decision is made to proceed with Phase III of the study and will continue for 4 to 5 years.



Structure Information	
Location	**Geometry**
Cell 3 outflow	(3) Gated Spillway: 14-ft x 7.1-ft
Cell 3 overflow weir	Crest: 11.3-ft NAVD (2.5-ft Cell Depth)
	Width: 400-ft
Cell 4 overflow weir	Crest: 10.3-ft NAVD (2.5-ft Cell Depth)
	Width: 350-ft
Cell 5B overflow weir	Crest: 9.9-ft NAVD (2.5-ft Cell Depth)
	Width: 400-ft
Cell 6 outflow	(3)Gated Spillway: 16-ft x 6.6-ft
Cell 6 overflow weir	Crest: 9.7-ft NAVD (2.5-ft Cell Depth)
	Width: 100-ft
Cell 7 inflow	(4) Gated box culverts: 10-ft x 8-ft
Cell 7 outflow	(3) Gated Spillway: 12-ft x 6.6-ft
Cell 7 overflow weir	Crest: 9.7-ft NAVD (2.5-ft Cell Depth)
	Width: 50-ft
Cell 8 outflow	(3) Gated Spillway: 12-ft x 6.6-ft
Cell 8 inflow	(6) Gated box culverts: 10-ft x 8-ft
Cell 7/8 internal	(15) Box culverts: 12-ft x 4-ft
Cell 8 overflow weir	Crest: 9.88-ft.NAVD (2.5-ft Cell Depth)
	Width: 50-ft
Existing discharge canal divide structure (Cell 6/7)	(3) Gated Spillway: 12-ft wide

Operable Structure	Grid Easting	Grid Northing	Longitude	Latitude
CELL 3 TRIPLE GATED SPILLWAY	837266.05	824281.80	W80° 26' 44.82"	N26° 36' 01.16"
CELL 6 TRIPLE GATED SPILLWAY	830740.11	837066.29	W80° 27' 56.12"	N26° 38' 08.04"
CELL 7 TRIPLE GATED SPILLWAY	829635.43	828941.36	W80° 28' 08.67"	N26° 36' 47.62"
CELL 7 DOUBLE GATED BOX CULVERT I	837260.27	835720.30	W80° 26' 44.33"	N26° 37' 54.44"
CELL 7 DOUBLE BOX GATED CULVERT II	837117.84	830425.08	W80° 26' 46.16"	N26° 37' 02.00"
CELL 8 Triple BOX GATED CULVERT I	837072.81	827218.19	W80° 26' 46.81"	N26° 36' 30.24"
CELL 8 TRIPLE BOX GATED CULVERT II	836997.03	824725.47	W80° 26' 47.76"	N26° 36' 05.56"
GATED SPILLWAY	829709.83	821311.11	W80° 28' 08.20"	N26° 35' 32.05"
E GATED SPILLWAY	837439.44	836844.52	W80° 26' 42.31"	N26° 38' 05.56"

Canal Information				
Parameters (Feet)	**Spreader**	**Collection**	**Discharge**	**Seepage**
Bottom Width	30	45 - 110	110	20
Length	17,300	35,255	28,300	5,900
om Elevation [1]	(-5.5)	(-2) - (-5.5)	(-6) - (-4)	-5

Explanation of Features

☒	Demolish Structure
△	Boat Ramp
●	Weir
●	Box Culverts
▣	Gated Box Culvert
■	Triple Gated Spillway
—	Discharge Canal
—	FPL Access Berm
—	Seepage Canal
—	Spreader Canal
······	Degraded Embankment
—	Collection Canal
—	Perimeter Embankment

Notes:

1- NAVD = NGVD - 1.42

2- Data Source -
Bing Hybrid Aerial Map, MWH

3- Structure sizes result from hydraulic model of 100-yr 24-hr storm plus 15 days of 3,250 cfs pump inflow with initial water depth at 2-ft (NFSL)

Last Updated: 03/03/2015

South Florida Water Management District

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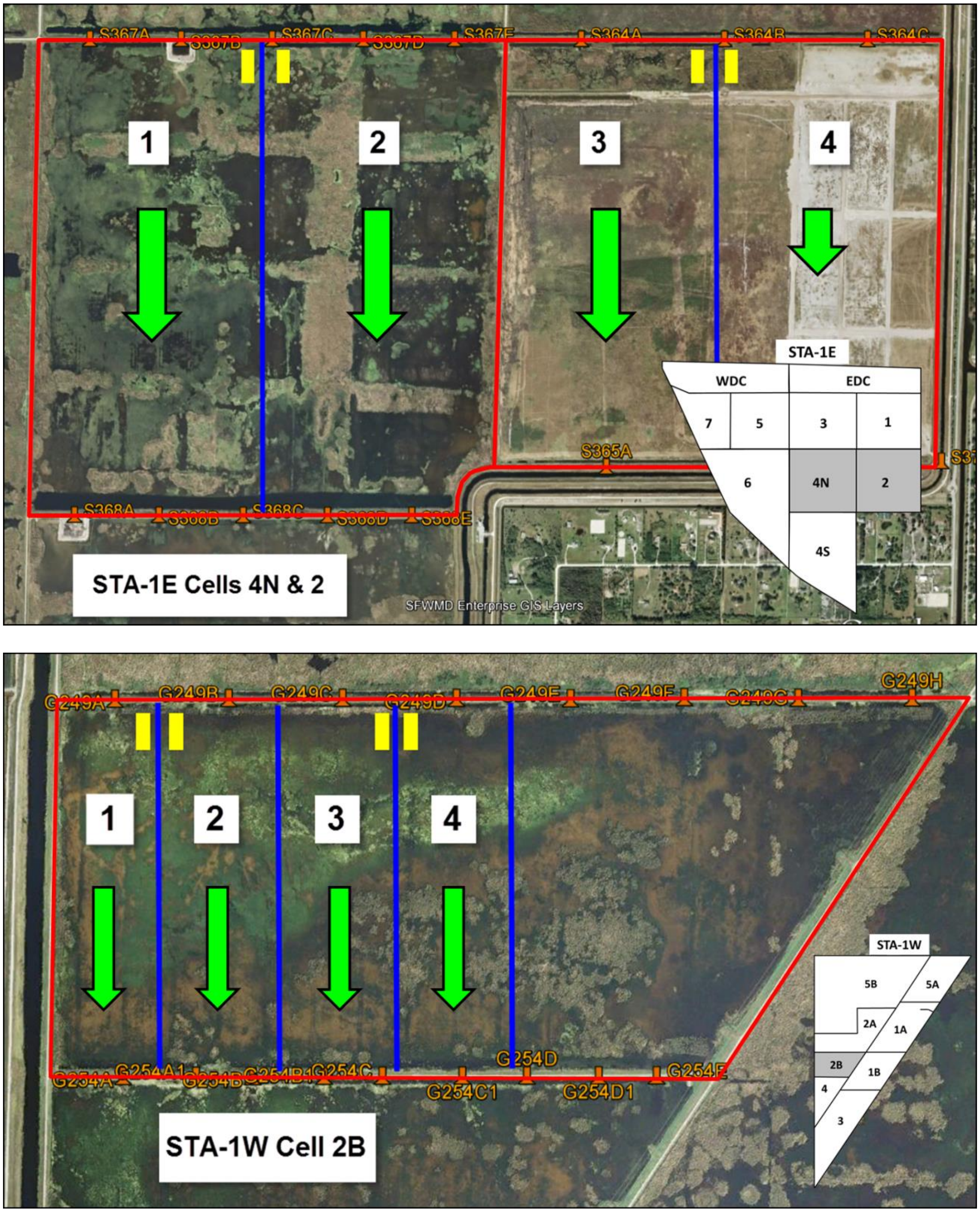
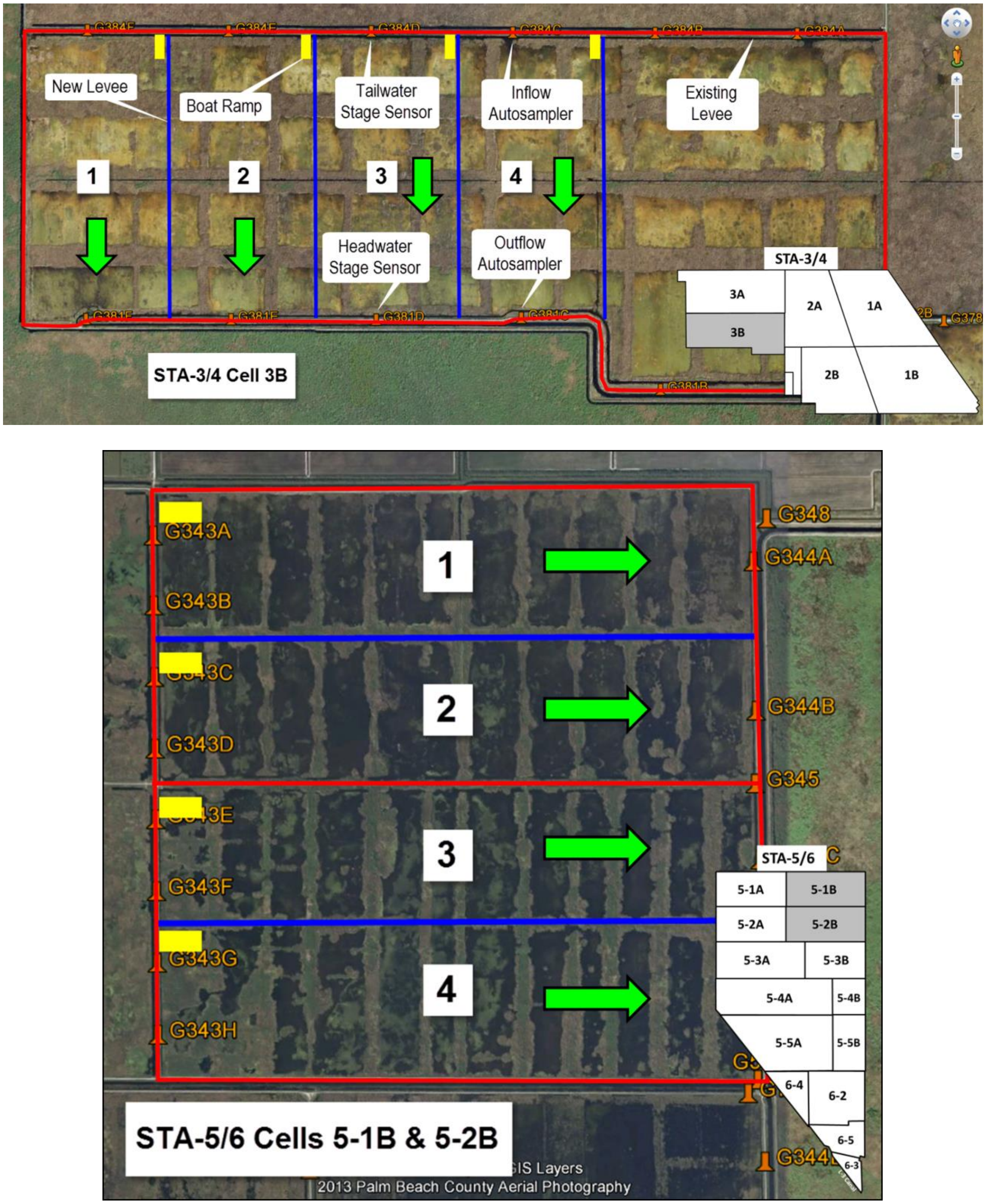
Appendix Figure 1. Schematic of the STA-1W Expansion Area showing Cells 7 and 8 that are proposed for use as large-scale test facilities in the Use of Soil Amendments/Management Techniques to Control P Flux Study. Yellow triangles indicate existing boat ramps; white and orange squares indicate existing inflow and outflow water control structures, respectively; green arrows indicate the direction of flow in Cells 7 and 8.



Appendix Figure 2. Schematics of proposed large-scale test facilities in candidate STA Treatment Cells (STA-E Cells 4N and 2, STA-1W Cell 2B, STA-3/4 Cell 3B and STA-5/6 Cells 5B-1B and 5B-2B) for the Use of Soil Amendments/Management Techniques to Control P Flux Study. Red lines indicate existing levees; blue lines indicate new levees to be constructed; yellow rectangles represent new boat ramps; orange symbols show locations of existing water control structures; green arrows indicate the direction of flow. Numbers identify the new sub-cells within each treatment cell. Map inserts show the location of the candidate treatment cell (shaded gray) within its respective STA.



Appendix Figure 2. (Continued).