# Restoration Strategies Science Plan

# Detailed Study Plan

# Evaluation of Factors Contributing to the Formation of Floating Tussocks in the STAs

## OVERALL STUDY PLAN SUMMARY

The Everglades Stormwater Treatment Areas (STAs) are highly dynamic managed systems subject to variations in hydrology, hydraulic loading, and topography. As a result, water levels in the STAs often go above or below the optimal depth range for the emergent aquatic vegetation (EAV) community. Deepwater conditions in STAs may affect cattail (*Typha sp.*) health and coverage. Floating cattails and cattail tussocks may in part be the result of prolonged deep-water conditions. Tussock formation in the STAs could be aggravated by other factors such as, vegetation type, sediment characteristics, physical and chemical processes. This study aims to characterize and compare conditions between areas of good cattail health and growth without floating tussocks to areas prone to chronic floating tussock formation. The information derived from this study could aid in (adaptive) management decisions aimed to prevent the formation of floating tussocks in the STAs.

**The project will address the following key SFWMD Restoration Science Strategies Plan (RSSP) Question:**

- What measures can be taken to enhance vegetation-based treatment in the STAs?

**and sub-question:**

- What are the effects and interactions between water depth, duration, rate of depth change, and soil characteristics on sustainability of dominant vegetation?

## BACKGROUND/LITERATURE REVIEW

Wetlands are water saturated areas that are periodically or continuously flooded throughout the year (Kadlec and Wallace, 2009). Wetland systems are easily characterized and classified (as swamps, marshes, bogs, fens, or sloughs) based on geographic location, soil type, vegetation community, and hydrologic conditions (Kadlec and Wallace, 2009). Within these water saturated areas, there are naturally occurring floating wetlands that have been commonly referred as floating sudds (Thompson, 1985; Ellery et al., 1990), floating marshes (Sasser, 1994), floating tussocks (Alam et al., 1996; Lawrence and Zedler, 2011), floating islands (Cherry and Gough, 2006), floating soils (Gantes et al., 2005) and floating mats (Glasser, 1996; Azza et al., 2006; Chen and Vaughan, 2014). These natural floating wetlands or tussocks occur globally (Lawrence and Zedler, 2011). They have been observed and described around the world in Africa (Ellery et al., 1990; Azza et al., 2006), Europe (van Diggelen et al., 1996; Mueller et al., 1996), South America (Gantes et al., 2005) and largely in the continental US (Mitsch and Gosselink, 1993; Sasser, 1994; Fechner-Levy and Hemond, 1996; Alam et al., 1996; Cherry and Gough, 2006; Chen and Vaughan, 2014). In addition, artificially created floating wetlands, like naturally occurring floating wetlands, have been designed and widely implemented for the reduction of nutrients in urban stormwater runoff (Headley and Tanner, 2012; Nichols et al., 2016).

Naturally occurring floating wetlands are ecosystems characterized by a floating mat of decomposing organic and mineral sediment, and decaying plant detritus that is held together by the live and dead roots of emergent macrophytes growing on top of the rarely inundated mat (Sasser et al., 1991). A depth driven variable zone of open and clear water is often found between the floating mat and the benthic sediments (Sasser et al., 1994; Headley and Tanner, 2012). Hydrology of a system affects the movement of these naturally formed tussocks (Swarzenski et al., 1991). Most floating tussocks move vertically in response to water level fluctuations (Almendinger and Glaser, 1986; Swarzenski et al., 1991). But, they can also move horizontally and break away in response to water flow and wind action (Azza et al., 2006). Similar mobility characteristics are observed in artificially created floating tussocks, using artificial substrates to increase buoyancy and encourage the growth of macrophytes. In some cases, anchoring devices are also used to fix tussocks in place (Headley and Tanner, 2012).

The size, thickness, and composition of a floating tussock mat are primarily dependent on the growth and productivity of the dominant vegetative species (Headley and Tanner, 2012). While floating tussock mats can range from a few square meters ($m^2$) up to 100,000 (hectares) ha in size (Sasser et al., 1996), the thickness of these floating mats ranges from approximately 20 to 120 cm (Sasser et al., 1996; Headley and Tanner, 2006). The width and strength of the floating mat are dependent on the rooting system of the floating tussock vegetative community (Sasser et al., 1995).

Clark (2000), proposes three mechanisms for the initial formation of natural floating tussocks about buoyancy. The first mechanism entails the delamination of organic substrates in unvegetated areas, likely resulting from an increase in gas production within sediments. The second mechanism occurs in areas densely vegetated by plants that have adapted physically to thrive under floating conditions once they are detached from the substrate. The detached floating plants consolidate in low energy areas to form an organic substrate for other plants to grow. The third mechanism combines the two previous mechanisms with sediments and rooted vegetation detaching simultaneously to form the floating tussock mass. This mechanism is linked to the increase of water levels, but may include other factors or processes occurring in the wetland.

As indicated above, floating tussock formation in wetlands can be caused by simultaneous factors that include hydro-pattern, vegetation and sediment type, and physico-chemical processes. The hydropattern of a wetland plays an important role in the formation of floating tussocks. As defined by Gunderson (1989), the hydropattern of a wetland refers to two components dealing with the duration of flooding, and the depth of flooding. In wetlands, prolonged inundation has been associated with the formation of floating tussocks (Kadlec and Bevis, 2009; Lawrence and Zedler, 2011). Increased flooding and stable water levels helped certain plants to form floating tussocks (Zeddler and Kerchner, 2004). In the Florida Everglades, sawgrass tussocks can form under continuous deep-water conditions (Olmsted and Armentano, 1997). In the Everglades Stormwater Treatment Areas (STAs), prolonged deep-water conditions may be responsible for the formation of large cattail floating tussocks (Chen and Vaughan, 2014). Lawrence and Zedler (2011), found that sedges subjected to high water depths and continuous inundation developed certain plant features associated with floating tussocks. Emergent wetland plant species such as cattail, while adapted to live under continuous flooding have appeared susceptible to prolonged high water depths (Grace, 1989; Kadlec and Wallace, 2009). Under deep water conditions, cattail plants will stress and float to the surface (Chen and Vaughan, 2014). In time and under continuous flooding, large stands of floating cattails will develop into a floating decaying mat or tussock (Chen and Vaughan, 2014). In floating tussocks primarily composed of cattail plants, rhizomes have appeared to contribute the most to the buoyancy of the mat (Hogg and Wein, 1988). These cattail tussocks appeared to be less buoyant and likely to sink during early spring while becoming more buoyant later in the summer season (Hogg and Wein, 1988). Moreover, free-floating macrophytes (e.g. Water Lettuce) are known to trap organic matter in their stems and root structures, aided by accumulated anaerobic gasses, these plants can float and form into a floating tussock (Hoyer et al., 2008). From this point, the decomposition of organic material at the surface of the floating tussock further contributes to the consolidation of the vegetation mat creating suitable conditions for other macrophytes to grow (Mallison et al., 2001; Azza et al., 2006; Kadlec and Wallace, 2009; Headley and Tanner, 2012).

Sediments of most organic soils are characterized by bulk densities of $<0.3$ g cm$^{-3}$, and contain at least 20-30% organic matter (Reddy and DeLaune, 2008). However, for floating tussocks to form and float, their substrate or sediment composition must be primarily made of organic matter (Kadlec and Wallace, 2009). Sasser et al. (1996), reported extremely low bulk densities ranging from 0.029 to 0.074 g cm$^{-3}$, and high organic matter content (64% to 90%) in large floating mats (tussocks) in Louisiana.

In general, wetlands are large contributors of methane ($CH_4$) emissions (Shipper and Reddy, 1994). Prolonged inundation in wetland systems promotes anaerobic conditions resulting in highly reduced environments which drives up decomposition rates and the production of gases (Kadlec and Wallace, 2009). Extreme anaerobic and reduced environments can induce methanogenesis (Kadlec and Wallace, 2009). In South Florida, prolonged and deep-water conditions in wetlands are often observed during the summer months, coinciding with the rainy season. As a result, the occurrence of tussocks increases during the summer months, where temperature, decomposition rate, and gas production is at its highest (Altor and Mitsch, 2006; Cherry and Gough, 2006). Fluxes of $CH_4$ from wetlands increase as soil temperatures increase (Altor and Mitsch, 2006; Altor and Mitsch, 2008). The anaerobic decomposition process in the wetland drives the production of $CH_4$, and carbon dioxide ($CO_2$) gases (Kadlec and Wallace, 2009). Altor and Mitsch (2006) demonstrated in continuously flooded wetlands that $CH_4$ fluxes can be over three times higher than areas that are intermittently flooded. These fluxes have a diel component with higher productions in the afternoon hours. Under continuous flooding the overproduction of $CH_4$ gas and its accumulation beneath the benthic sediments creates conditions for large gas releases that can drive detachment of sediments and vegetation (**Figure 1**), and encourage the formation of floating tussocks (Azza et al., 2006; Cherry and Gough, 2006). These gases (bubbles) can remain trapped beneath the decomposing organic material to further generate a lift that contributes to the buoyancy of the floating tussock (Hogg and Wein, 1988). Moreover, plants play a role in the release of accumulated $CH_4$ gases. Floating tussocks composed of cattail (*Typha latifolia*) and sedges (*Carex* spp.) can have a higher production and release of $CO_2$ and $CH_4$ gases than other wetland plant species (Minke et al., 2015). In a study, Kao-Kniffin et al. (2010), found that certain wetland plants (*Scirpus cyperinus, Glyceria striata, and Juncus effuses*) \ transport and release $CH_4$ gases more effectively than other species (*Phalaris arundinacea and Typha angustifolia*). More important, it is possible that a greater accumulation of gases will occur beneath wetlands primarily colonized by plants that are inefficient in the release of gases. The magnitude of $CH_4$ fluxes may be controlled by the duration of inundation, drawdown periods and water depth, coupled with vegetation growth

(**Figure 1**), and seasonality (Altor and Mitsch, 2006; Altor and Mitsch, 2008). Other stress factors such as wave action, windstorm, and flow velocities in conjunction with sustained deep-water conditions may contribute to the uprooting of plants and formation of floating tussocks.

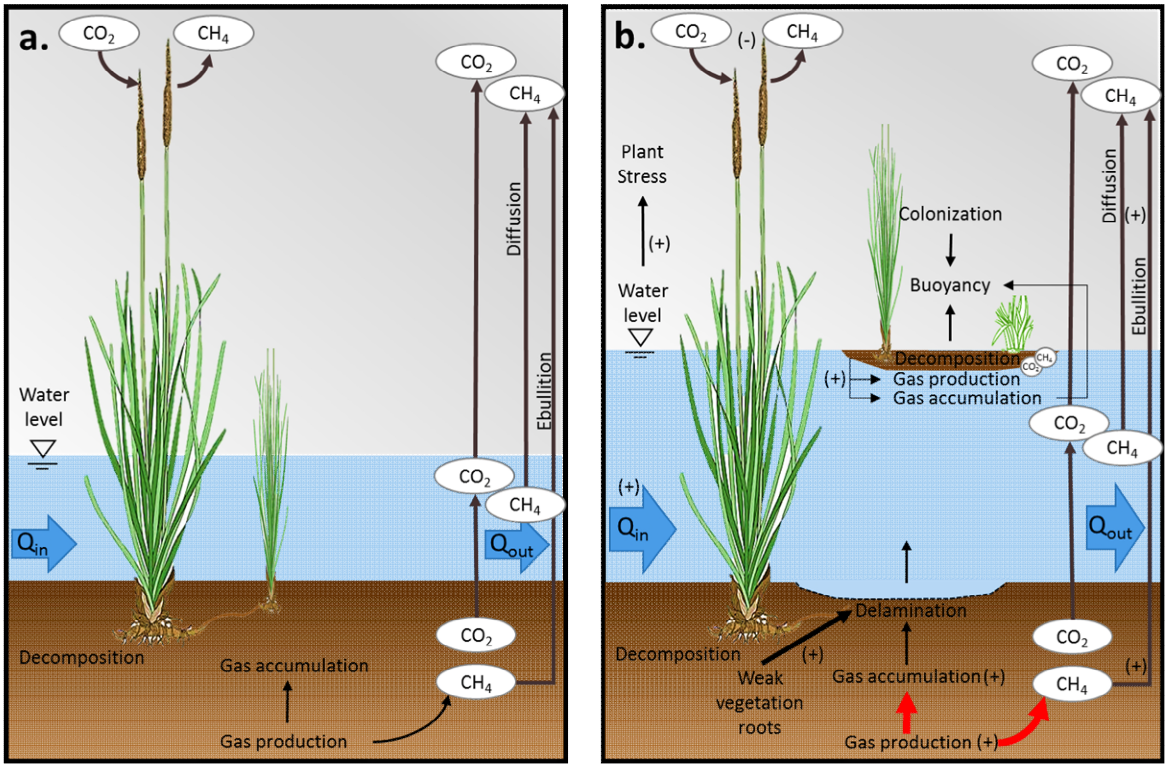


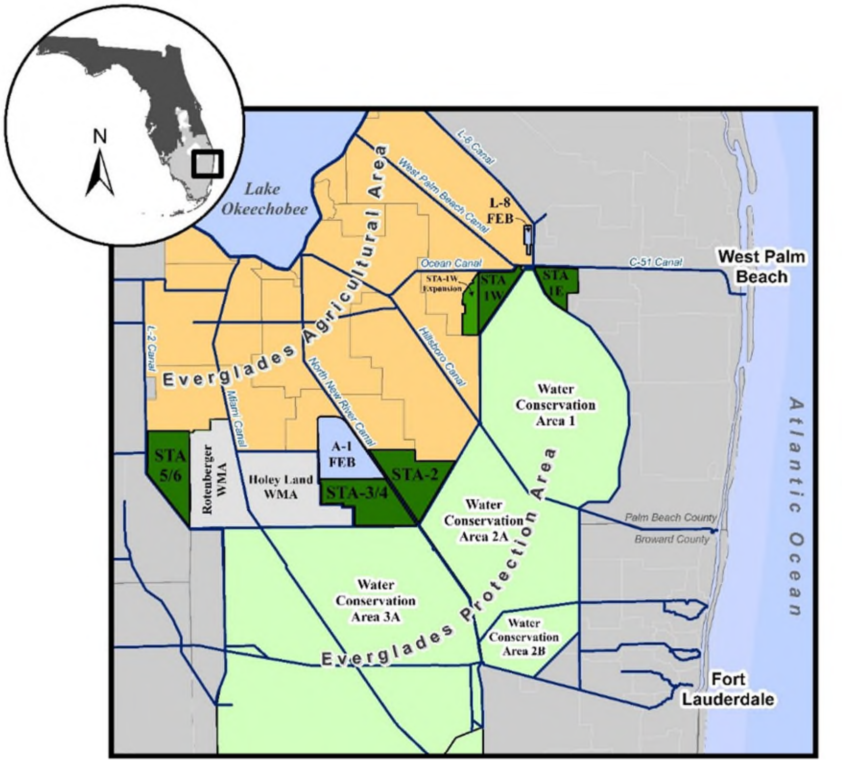
**Figure 1**. Simplified conceptual model for floating tussock formation in treatment wetlands under high flow and prolonged deep water conditions, change (increase and decrease) from normal conditions are indicated by positive (+) and negative (–) signs; a) normal shallow water levels (w/ expected seasonal drawdown), healthy vegetation stands, stable decomposition rates and gas exchanges, and b) prolonged deep water conditions with stressed vegetation, reduced plant gas exchange, higher decomposition rates, overproduction and accumulation of gases in the soils, and the detachment of plants and delamination of soils.

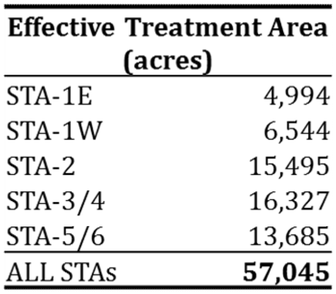
In some cases, the formation of these natural floating tussocks is beneficial to the environment. For instance, floating tussocks may improve plant species richness (Cherry and Gough, 2006) increase biodiversity (Lawrence and Zeddler, 2011), and aid emergent plants to colonize deeper areas (Azza et al., 2006). While implementation of artificially created floating mats or tussocks as treatment wetlands can assist nutrient reduction in runoff, the undesired natural formation of floating tussocks can be problematic and difficult to control. Serious economic and environmental consequences can arise due to the formation of undesired floating tussocks (Azza et al., 2006). For instance, the drifting and accumulation of large floating tussocks can impede navigation in waterways, and reduce accessibility to shorelines, docks, and boat ramps (Mallison et al., 2001), and interfering with fishing and recreational activities (Alam et al., 1996; Headley and Tanner, 2006). In addition, floating tussocks can impede the flow of water by clogging drainage canals and structures.

Floating tussocks or mats can potentially reduce productivity and diversity of marsh communities (Alam et al., 1996), precluding the establishment of rooted EAV and submerged aquatic vegetation (SAV) species. Cherry and Gough (2006), indicated that floating tussocks "floating islands" resulted in localized hydrologic changes that affected the cover of water lily and favored the recruitment of other species. In open water systems, floating tussocks could shade the water column, thereby affecting the growth of underlying SAV. The increase in organic matter (OM) and low dissolved oxygen concentrations beneath floating tussocks can reduce fish habitat (Alam et al., 1996; Hoyer et al., 2008).

In one cattail (*Typha sp.*) dominated floating marsh, the floating tussock mat growth was driven primarily by the accumulation of the internal belowground biomass rather than the accumulation of the aboveground biomass (Hogg and Wein, 1987). Headley and Tanner (2012), suggests that OM will likely start to detach from the bottom of floating tussock once the tussock mat reaches its maximum thickness. The erosion of these floating tussocks will likely be exacerbated during high flows, and by other factors such as wave and wind action. Chen and Vaughan (2014), suggested that floating cattail mats found in the STAs likely will result in reduced or loss of nutrient uptake by plants. In addition, decomposing floating mats likely will result in nutrient releases (PP and DOP) back to the water column thus reducing the treatment performance of the STAs (Chen and Vaughan, 2014). This is consistent with Gantes et al. (2005), that showed certain floating tussocks will function as a source rather than a sink of particulate matter. In the STAs, moving floating cattail tussocks have scoured the bottom of the wetland (Chimney et al., 2000). The formation of floating tussocks in the STAs, and the potential negative effect this may have on treatment performance is of concern to the restoration efforts of the South Florida Water Management District (SFWMD or District).

The STAs play an important role in Everglades Restoration. Constructed within the Everglades Agricultural Area (EAA), the STAs primary purpose is to reduce TP concentrations in agricultural runoff and other sources before this water is released to the Everglades Protection Area (Chimney and Goforth, 2001; Sklar et al., 2005). The District currently manages six STAs (STA-1E, STA-1W, STA-2, STA-3/4, STA-5, and STA-6) comprising approximately 57,045 acres of effective treatment area, and is in the process of completing construction of an additional 4,300 acres of effective treatment area in STA-1W (**Figure 2**). To provide optimal P removal, the STAs are generally subdivided into cells and are designed to control the water flow (Kadlec and Newman, 1992). STA Cells are usually set up sequentially to maintain EAV closer to the inflow followed by SAV near the outflow (Goforth, 2005). This configuration is based on the concept that different vegetation types removes P at different rates, and is often controlled by inflow concentrations (Kadlec and Newman, 1992; Dierberg et al., 2002). As of FY2017, approximately half of the STAs footprint have been designated for EAV and SAV respectively (**Table 1**).





| Effective Treatment Area (acres) | |
|---|---:|
| STA-1E | 4,994 |
| STA-1W | 6,544 |
| STA-2 | 15,495 |
| STA-3/4 | 16,327 |
| STA-5/6 | 13,685 |
| ALL STAs | **57,045** |

**Figure 2**. Location of the Everglades Stormwater Treatment Areas (STAs) 1 East (1E), 1 West (1W), 2, 3/4, and 5/6 in relation to the Everglades Agricultural Area and the Everglades Protection Area.

**Table 1.** Number of SAV and EAV cells and effective treatment coverage in the STAs.

| # Cells | Designated | Effective Treatment Areas (acres) |
|---|---|---|
| 21 | EAV | 26,335 |
| 23 | SAV | 30,710 |

The STAs are highly dynamic managed systems, which are subject to variations in hydrology, hydraulic loading, and topography. As a result, the STAs' operation fluctuates outside of optimal water depth range for the EAV vegetation community within treatment cells. Short term depth variation within an acceptable range may not alter vegetative communities; however, the average water depth of the wetland is a factor that can dictate changes in vegetative communities (Kadlec and Wallace, 2009).

Extended periods of deep flooding affect the physiology of plants due to changes in "oxygen concentration, soil pH, dissolved and chelated micro and macronutrients, and toxic chemical concentrations" (Kadlec and Wallace, 2009). Deep water conditions in the STAs have the potential to negatively affect cattail (*Typha sp.*) health and coverage. Studies have shown that periods of deep water sometimes are associated with cattail stress and mortality (Grace, 1989; Chen et al., 2010; Miao and Zou, 2012; Chen et al., 2013). For example, extreme storm events may result in high water depths that affect the EAV. Prolonged and repeated instances of deep water conditions are believed to have affected cattail stands in the STAs, and resulted in decreased coverage and poor growth. It is also believed that prolonged deep-water conditions result in floating cattail mats, and tussocks.

Isolated floating cattail tussocks were initially reported in STA-1W Cells 1 and 2 in the year 2000 (Chimney et al., 2000). At that time, the formation of tussocks was attributed to the combined effect of windstorm uprooting of cattail plants and sustained water depth conditions (Chimney et al., 2000). The uprooting of cattail and formation of floating tussocks in Cell 2 was subsequently attributed to operational changes leading to sustained (6 years) deep water conditions (Kadlec and Wallace, 2009). In 2004, vegetation coverage in both EAV and SAV cells of STA-1W declined and floating cattail tussocks appeared; this condition was attributed to high hydraulic and TP loading rates (Pietro et al., 2009). The decline and uprooting of cattail was further exacerbated by three major hurricanes that passed through the area in 2004 and 2005 (Pietro et al., 2009).

Like STA-1W, low cattail coverage and floating tussocks have been observed and reported in the EAV cells of STA-1E over the years of operation (Germain and Pietro, 2011). In the STA-1E EAV Cells, prevalent deep-water conditions are common due to construction issues related to the topography of the STA. It is believed that the deep-water conditions in STA-1E EAV Cells is partly responsible for stressing the cattail community and encouraging the formation of tussocks (**Figure 2**). In 2013, STA-1E Cell 7 was covered primarily by a large floating tussock (Ivanoff et al., 2013). In STA-3/4 Cell 1A, frequent deep-water conditions have been attributed to reduced cattail coverage and increased floating tussocks in areas near the inflow of the cell (Germain and Pietro, 2011). Similar observations have been made in EAV Cells of STA-1W (Cell 1A and 2A), and in STA-3/4 (Cells 2A and 3A) (**Figure 3**). In the STAs, most of the floating tussocks are primarily cattail, sedges, and grasses growing on the detritus material of the same species (Chen and Vaughan, 2014). These floating mats are rarely flooded, therefore the vegetation growing on them is not subjected to deep water conditions. STAs are regularly invaded by free-floating macrophytes such as water lettuce (*Pistia stratiotes*), water hyacinth (*Eichhornia crassipes*), and pennywort (*Hydrocotyle* spp). These plants, if left untreated, tend to form large vegetation mats that can provide substrate for other emergent plants. Currently, the presence of floating tussocks of all sizes have been reported in more than half of the STA EAV Cells (**Figure 4**) and in few SAV Cells (**Table 2**).

Floating tussocks found in EAV Cells of the STAs with during the past three water years (WY2014-WY2016) occurred when there was 100% inundation, with a water depth of 1.5 feet for the dry months and about 2 feet during the wet months. To date, few EAV Cells in the STAs benefit from drawdowns, and only one of these continuous flooded cells with slightly lower inundation depths (STA-2 Cell 1) did not show signs of floating tussocks (**Figure 5**).

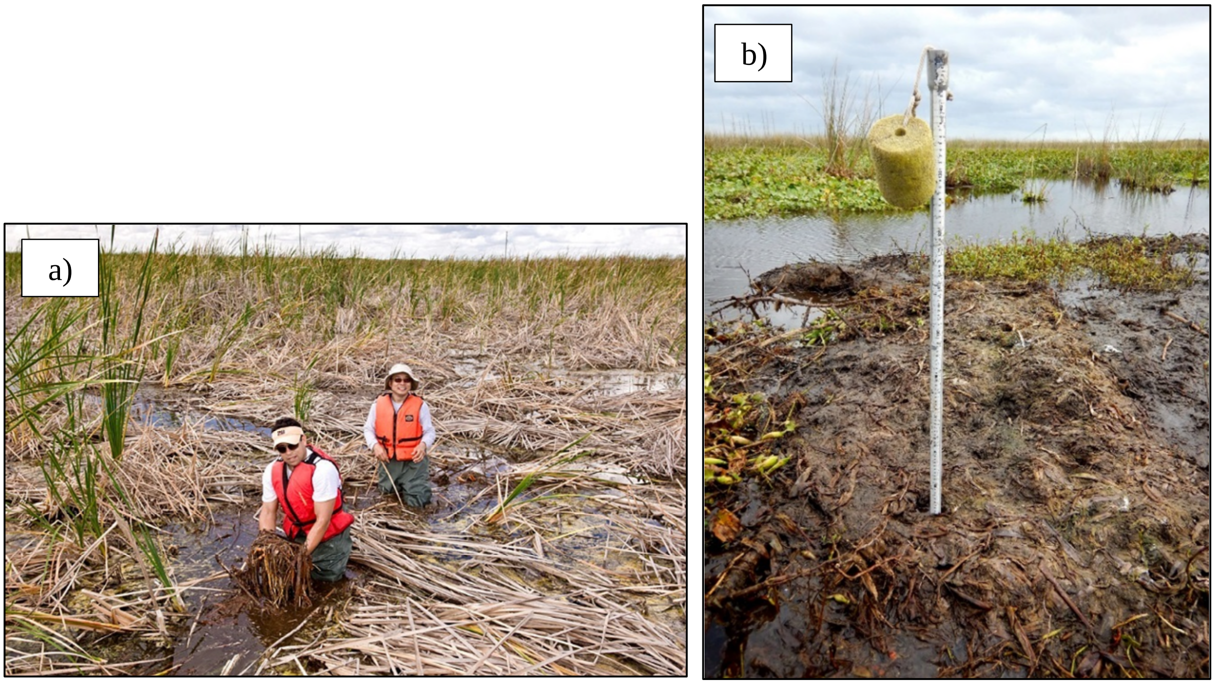


**Figure 2**. Large areas of dead floating cattail plants observed in STA-1E Cell 7 in May 2009 (photo a) and February 2016 (photo b).

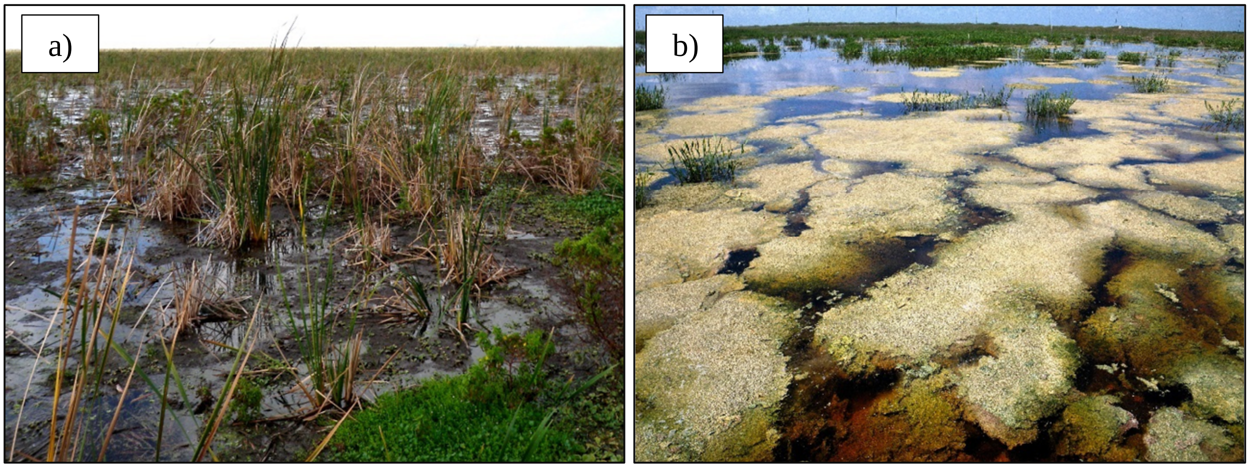


**Figure 3**. Floating tussocks observed in STA-1W, EAV Cell 2A in June 2016 (photo a); and, STA-3/4, SAV Cell 3B in June 2011 (photo b).

**Table 2**. 2017 list of reported STA Cells with floating cattail plants and floating tussocks.

| ***STA-Cell*** | **Floating cattails** | **Floating tussock - mats** |
|---|---|---|
| *STA-1E Cell 3* | X | X |
| *STA-1E Cell 5* | X | |
| *STA-1E Cell 7* | X | X |
| *STA-1W Cell 1A (rehabilitated in 2015)* | X | X |
| *STA-1W Cell 2A* | X | X |
| *STA-2 Cell 5 (SAV Cell)* | X | X |
| *STA-2 Cell 6 (SAV Cell)* | X | |
| *STA-3/4 (all A Cells)* | X | |
| *STA-5 (all A Cells)* | X | X |

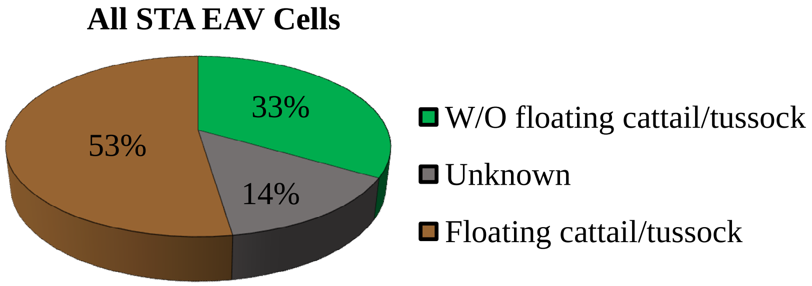


**Figure 4**. Percentage of EAV Cells affected by floating cattail and tussocks in the STAs.

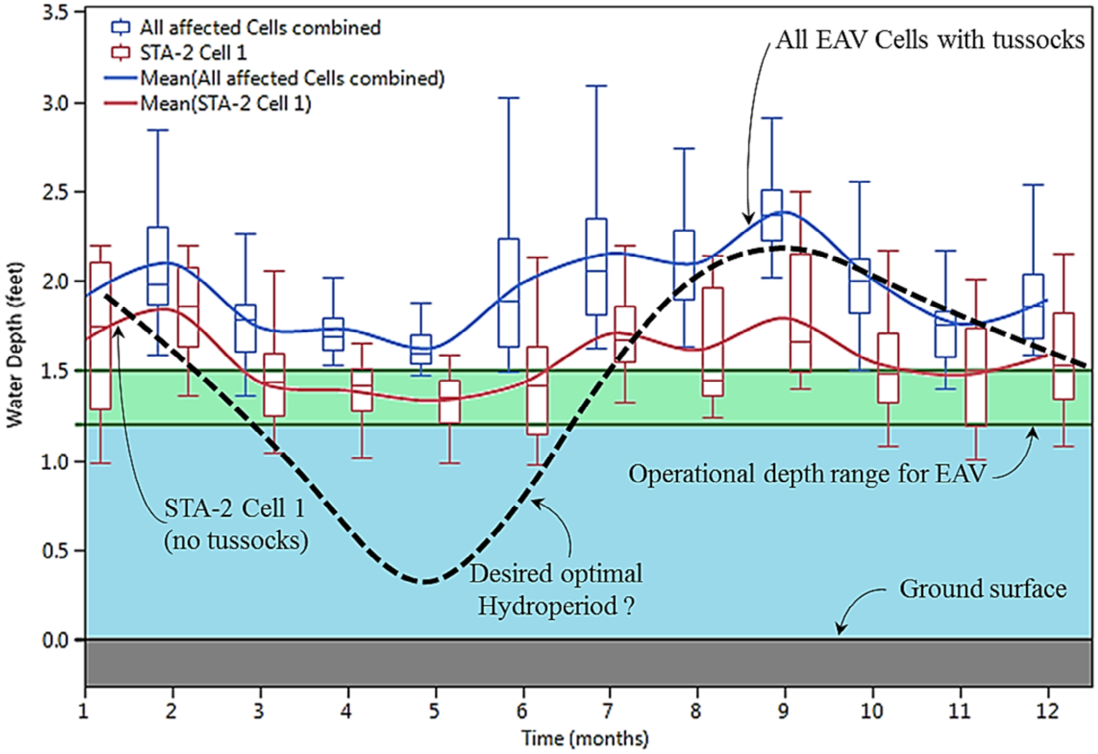


**Figure 5**. Hydroperiod and water regime in the STA EAV Cells for WY2014 – WY2016; lines represent mean values, and box plots show median and interquartile values.

Floating tussocks in the STAs have been problematic and hard to control. Floating tussocks have been associated with the reduced capacity of some STAs to produce the required ultra-low outflow phosphorus concentrations. Floating tussocks are also responsible for the scouring of large areas, the resuspension of sediments, and the destruction of established EAV and SAV communities (Chimney et al., 2000; Pietro et al., 2010).

To eliminate and prevent floating tussocks in the STAs, the District is actively removing floating cattail mats and tussocks, encouraging the growth of deep water tolerant macrophytes such as giant bulrush (*Scirpus californicus*) (**Figure 6**), mechanically harvesting floating tussocks in larger areas (**Figure 7**), and treating floating tussocks with herbicide in efforts that they will break apart and disintegrate on their own (Ivanoff et al., 2013; Chimney, 2014). However, some of the removal techniques currently used may negatively affects the performance of the STAs. For instance, removal of floating tussocks through harvesting can result in increases of TP and turbidity levels in the water column associated with the physical breakdown of biomass (Alam et al., 1996). And while turbidity levels will decrease after tussock removal, TP may remain elevated until new vegetation growth is established (Alam et al., 1996). Another effective practice is the application of herbicide to the floating tussocks to kill the colonizing vegetation in hope that the tussock will eventually fall apart. Nevertheless, this is a lengthy process that could take several months and could require multiple herbicide applications. Furthermore, large rehabilitation efforts require the affected cell to be placed off line for several months or years, affecting entire flow-ways and reducing the treatment capacity of the STA (Pietro, 2012). Some of these larger efforts require the drawdown of water levels for extended periods of time to allow for the colonization of seedlings, clonal expansion of plants, elimination of floating tussocks (Germain and Pietro, 2011), and re-planting the area with deep water tolerant macrophytes.

Finally, rehabilitation and tussock removal activities can be extremely costly. In most cases, more than one approach (herbicide spraying and removal of tussocks, drawdown and planting) is needed to rehabilitate larger areas resulting in even higher costs. Current rates for herbicide application range from $100 to over $1000 per acre depending on herbicide type, and site accessibility. Harvesting of tussocks can be a laborious and expensive task with costs greater than $4,000 per acre. In severe cases, a complete drawdown of the wetland followed by earthwork may be necessary to manage the problem, while further increasing the cost of the rehabilitation. Other more affordable approaches aimed at preventing the formation of floating tussocks require the planting of macrophytes that are more tolerant of different hydroperiods and can thrive in a wide range of water depths. Finally, in the STAs and in other areas, the control of floating tussocks in affected areas has been proven beneficial for the reestablishment of desired wetland plant species and improved habitat for fish and waterfowl (Mallison et al., 2010).

**Figure 6**. Bulrush planting in STA-1E Cell 7, areas previously dominated by floating tussocks.

**Figure 7**. Decaying vegetation harvesting in STA-1W Cell 3 on July 1, 2008.

## STUDY PLAN OBJECTIVES

The overall objective of this study is to determine the key factors that cause floating cattail plants and tussocks in the STAs. Specifically, the study would characterize and compare conditions between areas of healthy cattail coverage (without signs of floating cattail plants or floating tussocks) versus areas prone to chronic floating tussock formation in the STAs. In addition, the study would assess the effects of floating tussocks on STA treatment performance.

Finally, results from this study should provide an understanding of the factors that contribute to the formation of floating tussocks in the STAs. The information derived from this study could aid in (adaptive) management decisions aimed to prevent the formation of floating tussocks in the STAs.

## STUDY QUESTIONS AND HYPOTHESES

To achieve the primary objective of this study, several research questions and corresponding hypotheses were formulated as listed below:

1. ***What are the factors (vegetation type, sediment type, and chemical processes) driving the formation of floating tussocks in the STAs?***

   Hypothesis 1: The formation of floating tussocks is driven by soil type, soil gas ebullition, and soil bulk density.

   Hypothesis 2: Cattail is prone to floating due to its naturally buoyant structure and relatively shallow root/rhizome morphology.

   Sub-questions:

   a) What are the type and characteristics of soils in the STAs that are associated with floating tussocks?

b) What are the vegetative types or species in the STAs that are more susceptible to form floating tussocks?
c) How are soils and vegetative types in chronic floating tussock areas different from areas without tussocks?

2. ***What are the operational ranges (water depth, hydroperiod, hydraulic loading rate, velocity) that promote the formation of floating tussocks in the STAs?***

Hypothesis 3: Prolonged deep-water conditions result in tussock formation.

Sub-questions:

a) What are the STA hydrological conditions (depth and duration) in the cells with floating tussocks?
b) How is the hydrology in chronic floating tussock areas different from areas without tussocks?

3. ***What is the magnitude of influence of dissolved gas ebullition on floating tussock formation in the STAs?***

Hypothesis 4: Higher production and release of gases in the soil layer of the STAs will occur in prolonged deep-water areas than in shallow areas with intermittent drawdowns.

Sub-questions:

a) How is the gas ebullition in chronic floating tussock areas different from areas without tussocks?
b) How is gas ebullition affected by hydrologic condition?
c) Is there an optimal hydrologic condition to minimize gas ebullition impacts on cattails?
d) Will drawdown be effective in controlling tussock formation?

4. ***What are the effects of floating tussocks on the adjacent cattail community, and on the performance of affected STA Cell?***

Hypothesis 5: Over time, floating tussocks will destroy the adjacent vegetation community, and affect the treatment performance of affected STA EAV Cells.

## STUDY PLAN DESCRIPTION

The proposed study will be conducted in two phases. Phase 1 consists of several tasks that include: 1) a comprehensive literature search and review of the biology and chemistry of floating tussocks; 2) the survey and assessment of STA EAV Cells currently containing floating tussocks; 3) the evaluation of data available (hydrology, vegetation, and sediments) to evaluate possible factors driving the formation of tussocks in the STAs. Phase 2 will entail the development of an in-depth study plan, including experimental design and study methods. Selection of study sites (STA EAV Cells) in areas with healthy cattail coverage without signs of floating cattail plants or floating tussocks, and sites compared with areas containing floating tussocks. the characterization of vegetative community, sediment type, hydrology, and physico-chemical processes at each study site. The information and data collected will be evaluated, and comparisons between sites will be conducted. The possible effects of floating tussocks on the adjacent vegetation and on treatment performance will be evaluated.

## Phase 1

### Task 1: Literature search and review

A preliminary review of previous research and existing information on floating tussocks, causal factors, and management strategies will be conducted and summarized.

### Task 2: Assessment of floating tussock coverage in STA EAV Cells

This task will consist of conducting a comprehensive spatial survey (ground and aerial) assessment of each STA EAV Cells to determine the current coverage and extent of floating cattails and floating tussocks. Affected areas will be mapped and the approximate coverage and type of floating mat or tussock (based on vegetative community) will be determined.

### Task 3: Data mining

This task consists of the evaluation of operational ranges, including hydrologic conditions, patterns in selected affected areas based on findings from Task 2. Available data (vegetation, sediment, water quality, stage, and flow) will be examined to determine if there are patterns or commonalities among affected areas.

### Task 4: Evaluation of findings / report

This task will consist on summarizing all findings from previous tasks and the preparation of a comprehensive report indicating recommendations (stop/go) for further evaluation and the development of Phase 2.

## Phase 2

### Development of study method and study plan

Field evaluation of potential methodologies will be conducted to gather information that would be used to determine the best measurement and sampling methods to address the key questions for the study. If the initial information gathered from the tasks listed above indicates the need for further in-depth study, a study plan, including experimental design and study methods, will be developed. This phase will include the selection of study areas and study sites in the STAs for evaluation.

## DATA MANAGEMENT AND DOCUMENTATION

This study will follow the overall data management protocol described in the Restoration Strategies Science Plan and the SFWMD's scientific data management SOP (SFWMD, 2012a). All data collected from this study will be loaded into the different SFWMD databases:

DBHYDRO – water quality data from the inflow and outflow structures; flow data; stage data.

ERDP – all ecological data and groundwater well data collected by the SFWMD.

MORPHO – all study files, including data deliverables, photos, and drawings.

Data loading into the databases will be coordinated with the assigned data steward for the study. All data will be accompanied by clear metadata that would allow reconstruction and understanding of the datasets.

## QUALITY ASSURANCE AND QUALITY CONTROL

This study will follow the general QA/QC guidelines specified in the Restoration Strategies Science Plan and the SFWMD's Field and Laboratory Quality Manuals.

The SFWMD's quality system is outlined in the Quality Management Plan (SFWMD, 2012c), and supported by the Field Sampling Quality Manual (SFWMD, 2015), Chemistry Laboratory Quality Manual (SFWMD, 2012b), and SFWMD Enterprise Scientific Data Management Policies and Procedures (SFWMD, 2007; 2009). The Study Plan Leader will review all data and ensure the accuracy, precision, and completeness of collected data/information prior to loading into the databases. Any data that does not meet the SFWMD's data validation criteria will be qualified using standard SFWMD/FDEP data qualifier codes.

## REPORTING

Quarterly reports will be required from each of the component leads and the contractors. The Study Plan Leader will summarize the findings and status on a quarterly basis and provide quarterly progress report to management. Presentations about the study will also be delivered when requested, e.g. for the SFWMD's Science Plan team, Restoration Strategies workshops, and Long-Term Plan public communication meetings.

On an annual basis, the Study Plan Leader, in coordination with the study team, will prepare a write-up for the South Florida Environmental Report (SFER). This will include progress and findings that are available at the time of SFER chapter preparation.

## SCHEDULE

This Study Plan includes the implementation of various components (field sampling and monitoring, laboratory analysis, and laboratory studies), reports, and deliverables.

**Schedule for Phase 1 Implementation:**

| Task # | Description | FY18 | | | | FY19 |
|---|---|---|---|---|---|---|
| | | Q1 | Q2 | Q3 | Q4 | Q1 |
| 1 | Literature search and review | X | | | | |
| 2 | Assessment of floating tussock coverage in STA EAV Cells | X | X | X | | |
| 3 | Data mining | X | X | X | X | |
| 4 | Evaluation of findings / report | | | | | X |

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