APPENDIX C – SCIENCE PLAN

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The Decomp Physical Model (DPM) Science Plan: The Effects of Year-Round Sheetflow and Canal Backfilling

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Part 1. Overview of Lessons Learned and Monitoring Priorities for Year-Round Testing of the Decomp Physical Model

Part 1 of this document is an overview of lessons learned from the first 4 flow events of Decomp Physical Model (DPM), the remaining uncertainties, and a justification for proposed year-round testing to address those uncertainties. The proposed monitoring plan focuses on three topics: effects of sheetflow and associated nutrient loading on biological and physical processes in the ridge and slough landscape; interactions of canal-backfilling effects and sheetflow on sediment and phosphorus dynamics in and around the L-67C canal; and landscape-scale responses of enhanced hydrologic connectivity in WCA-3B.

I. Lessons learned from Dry Season Flows 1-4

In the ridge and slough portion of DPM, each flow event continued to support previous findings that sustained flow of at least 8-10 weeks is needed to maximize slough velocities, sediment transport and sediment redistribution, critical steps for landscape restoration. The study also confirmed previous flow events showing that the combined SAV/periphyton responses in the slough are ultimately responsible for creating higher velocities and sediment transport observed during sustained flows. However, flows rapidly diminished beyond 500 m of the structure, and tended to move preferentially eastward. The rate of "slough clearing" by natural processes (sediment redistribution to ridges), and the extent to which active management (reconnecting, enlarging sloughs) can increase the extent of sheetflow restoration of sloughs, and potentially redirect more flow south (rather than east), remains a critical uncertainty for large-scale sheetflow restoration.

Elevated flow velocities led to changes in fauna and foodwebs in the marsh interior. Because high flows led to nutrient loading (increase P concentration in heterotrophic bacteria and algae/cyanobacteria), the algal species composition in sloughs also changed, as did food quality (based on fatty acid analysis). These changes were tracked into small fish, suggesting that flow also fundamentally changes food web function. Inspection of the horizontal sediment traps from ridge and slough sites also indicated that some smaller-sized macroinvertebrate taxa were more abundant in high-flowing sloughs, suggesting they are drifting like macroinvertebrates in a stream ecosystem.

In the L-67C canal backfill area, DPM monitoring showed elevated canal velocities in the L-67C, particularly during flow. Canal sediment accumulation and sediment chemistry varied across the canal backfill treatments. However, because one to two thirds of the S-152 discharge enters the L-67C north of the canal backfill treatments, sediment and P load into the treatments varies substantially (i.e., the no backfill treatment conveys most of the flow). Within-treatment velocities also vary several-fold, requiring more spatially explicit information to provide appropriate comparisons among treatments. Quantifying sediment and P loading and retention or source effects in the canal and backfill area remains an important component of the canal study. In addition, the impacts of vegetation change within the canal and of active management (described above) in redirecting S-152 flow toward the backfill area (with consequences for sediment and P loading) also present uncertainties that must be addressed in DPM.

Canal fill and levee removal changed the way fish move across the landscape. Largemouth bass, bowfin, and Florida gar moved from the Pocket into WCA 3B once the levee was removed. Fish used the fill treatments in similar density and species composition as the littoral zone of unfilled habitat. This indicates that canal backfill treatments increased the area of preferred habitat for fish within the canal; however, the quality of these habitats this is uncertain over the long term because canal vegetation continues to change in the partial and filled areas. Small marsh fish responded to the DPM modifications by changing their movement and habitat use as water levels rose and dropped.

II. Remaining uncertainties, priorities for understanding the ecological effects of year-round flow and canal backfilling

1. Biological (algal & foodweb) responses to and feedbacks on flow

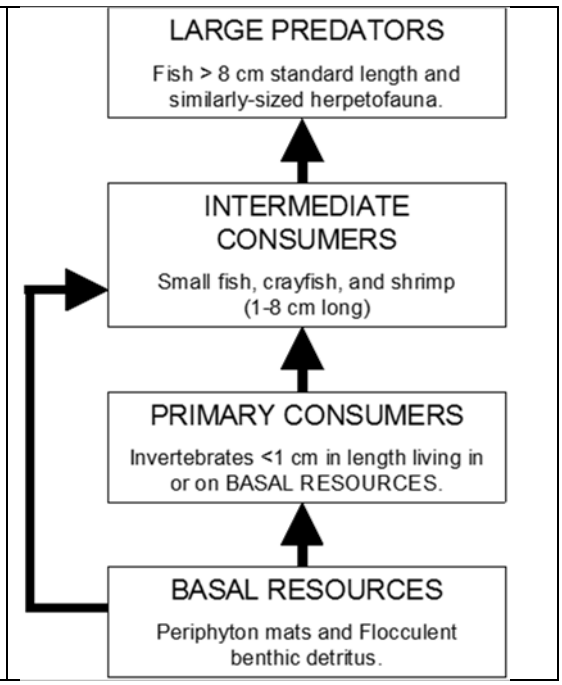
As described in previous reporting, sheetflow events have consistently "cleared out" sloughs of floating periphyton, further accelerating flow and sediment redistribution. Additionally, changes in the properties of floc (erodibility and decomposition) and a reduction in standing floc with sustained flows also act to increase flow. Based on these findings, DPM monitoring in subsequent flow events must address how rapidly and how far changes in slough periphyton and floc can occur, ultimately enabling larger-scale landscape restoration to occur.

While enhanced flow may be desirable for redistributing sediments, monitoring will also address whether loading of nutrients (due to higher velocities) may lead to long-term changes in slough vegetation and function. Short-term studies demonstrated that periphyton community composition and P cycling are directly affected by increased flow, even when surface water concentrations average ≤ 10 µg/L. The greatest changes were stimulation of filamentous green algae, higher cell TP content and reduced phosphatase activity (indicative of decreased P limitation). These effects generally decreased with increasing distance from inflow, though elevated algal TP was observed even 800 m from the S-152. Interestingly, several of the observed responses to increased P supply were still evident along the flowpath gradient 1 month post flow cessation. Longer-term studies are needed to examine if the flow/nutrient stimulus penetrates to a greater distance over a longer period of time and to what extent these areas may recover following flow cessation.

Macroinvertebrates are a diverse group of consumers ranging from primary consumers to predators right in the center of the food web (**Figure 1-1**). Predicting the net effects of flow on macroinvertebrate communities (i.e., mostly primary consumers plus detritivores) is complicated by at least three opposing mechanisms: 1) physical stress of flow, 2) flow-related vegetation/structural changes and 3) flow-related changes to algal food quality. While macroinvertebrates may be predicted to rise with moderate nutrient loading (e.g., King and Richardson 2007, Trexler and Loftus 2016) the effects of flow correlated with loading is less clear and some enhanced productivity may quickly move up to larger organisms (**Figure 1-1**). Drifting macroinvertebrates might provision fishes and larger macroinvertebrates while macroinvertebrate taxa resistant to flow/drift could experience enhanced growth and densities following flow-mediated changes to the algal resources. Repeated quantitative observations in flowing and non-flowing sloughs (i.e., along the gradient) will provide a basic understanding of the net impacts of

flow, but mechanistic understanding of both macroinvertebrate communities and comprehensive food web responses will also require experimental studies to test various food web and stress-related hypotheses.

Figure 1-1. Simple diagram of aquatic food web in the Everglades (redrawn from Dorn et al. 2006). Understanding food web responses to flow and flow-mediated nutrient loading requires monitoring responses in multiple trophic levels.



Small fish (<8cm standard length) density and species composition was changed by implementation of elevated flows and canal removal when compared to control sites outside of the DPM study area. In the marsh on the east side of the Gap, it is difficult to separate the direct effects of flowing water from the effects of canal filling and levee removal. Following canal filling, levee removal, and flow implementation, the density of small fishes that serve as prey for apex predators was increased by over 2-fold in the marsh west of the L-67C canal compared to control sites. Changes in the relative abundance of these species was linked to movements toward and away from the canal-fill treatments. Thus, at least some of the DPM effects were to change the use of habitats in the study area and change the way small fish aggregate in the landscape as water levels rise and drop.

We also obtained evidence that elevating water flow velocity has the potential to affect small fish population growth by improving the edibility of biofilms (**Figure 1-2**). We documented that water flow in year 3 of the project led to loading of P in biofilms growing on plastic substrates placed in experimental cages in a high-flow area compared to similar substrates in the month before, during the pre-flow period. These biofilms had high relative abundance of nutrient exploiting *Mougeotia* species (green algae) compared to biofilms produced in the pre-flow period. The also had high relative abundance of fatty acid markers for algae and low relative abundance of markers for heterotrophic bacteria. Collectively, flowing water favored a more edible biofilm, dominated by algae high in essential fatty acids compared to biofilms produced in periods of low water flow. Herbivorous fish benefitted from this more edible food source by storing more fat, accumulating relatively more P in their tissues and more essential fatty acids, including those in the family

including omeg-3 fatty acids. These results suggest fish would be a higher quality prey item for apex predators like wading birds, similar to results by Hagerthey et al. (2014) from the Cattail Habitat Improvement Project (CHIP).

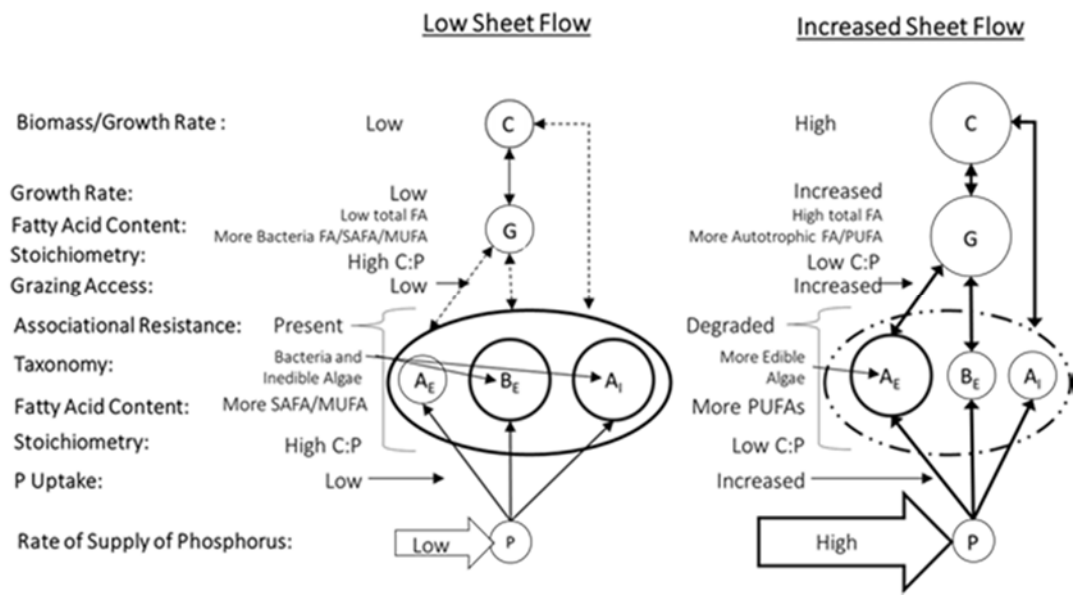


Figure 1-2. Conceptual model of impacts of flow on experimental food web. C – secondary consumer/omnivore; G – primary consumer; AE – edible algae; BE – heterotrophic bacteria; Ai – inedible algae; P – Phosphorus. Re-drawn from Trexler et al. (2015). Many of these predictions were supported by our study.

Large fish (>8cm standard length) catch-per-unit-effort (CPUE), an index of density, was greatly changed by the DPM experimental manipulations, with some species increasing others decreasing. Largemouth Bass doubled CPUE in canal fill treatments, where sunfish also increased. Other species decreased in CPUE in the partial or complete fill areas, or both areas, compared to the control areas and before-fill sampling, notably Florida gar and Lake Chubsuckers. Largemouth Bass and Bowfin with surgically implanted radio transmitters moved throughout the study area and crossed from the L-67C canal and Gap area into WCA 3B once the levee was degraded. Bowfin averaged 15% closer proximity to the canal treatment areas after filling and levee removal compared to before treatment, but were 150% farther away from the canal in the untreated (control) areas compared to before treatment. Largemouth Bass tended to stay closer to the canal after the DPM modifications were implemented, but the same change was observed in the treatment and control areas.

The canal-fill areas became filled with emergent vegetation that appeared to be treated by fish similar to the vegetated littoral zone of the unmodified canal. By providing attractive habitat across the entire width of the canal, the fill treatments increased the aerial coverage of high CPUE habitat. Our movement results suggest that this change arose from fishes moving from adjacent marshes, particularly in the dry season, causing the canal-fill areas to act as fish concentrators. This suggests the possibility of canal partial fills as a fishing enhancement, if submerged aquatic vegetation like *Hydrilla* can be kept from filling the space.

2. Hydrologic limitations of sheetflow restoration and the role of active management

The effectiveness of the S-152 in restoring large areas still remains a key unknown. DPM results suggest three potential trajectories for restoration within the study area: (1) sheetflow generated by the S-152 will only restore small areas (500-m radius from inflow); (2) sheetflow impacts may eventually "spread" across the landscape, involving feedbacks between sheetflow and biogeochemical responses; or (3) an intermediate combination of the two resulting in very slow expansion of sloughs and sheetflow restoration. Additional flow events are needed to determine whether sheetflow benefits spread at a snail's pace (e.g., a few meters per decade) or something more substantial (100-1000's of meters per year). The former would indicate the need for active management to "kick start" restoration by removing sawgrass that resists flow along some of the historic (predrainage) slough pathways.

A large-scale active management study was initiated in the fourth flow event to reconnect sloughs (up to 2-km from the S-152) that have been encroached by sawgrass. Continued monitoring in these managed areas will be implemented to test how effectively the footprint of sheetflow may be expanded. Whether high velocities can be expanded, with or without active management, likely depends on how slough SAV and periphyton change with P loading resulting from high velocities. For instance, should SAV and periphyton continue to "clear" farther from the S-152 with successive flow events (reducing vegetative resistance to flow), then it may be expected that the footprint of sheetflow will expand in tandem with slough clearing.

3. The impact of sediment and P resuspension in the L-67C canal and evaluating the ecological effects of canal backfilling

Because canal sediments are enriched (typically above 800 mg P/kg), potential impacts of sediment resuspension on water quality in the canal, gap and DB sites in WCA3B are of great concern. In the first 2 flow events, elevated velocities of 7-8 cm s^{-1} measured in the canal under high flows suggest entrainment is likely. Biomarker analyses and accumulation rates suggested sediments either in or around the canal were mobilized during high flow, much of which was redirected toward a ~3 km stretch of the L-67C north of the backfill area. As a result, flows into and out of the canal treatments and levee gap were unevenly distributed. Two-thirds of the S-152 discharge enters the open canal treatment via the canal itself, rather than the marsh. To evaluate the uneven load of water, sediment and P into the canal backfill, year-round monitoring will include spatially intensive surveys of paired water velocities and water quality sampling through the canal and downstream (the DB area), as initiated in the fourth flow event. Such surveys address two important remaining unknowns: (1) the location and extent to which sediment and P are being resuspended and impacts on loading downstream and (2) the location of areas within existing treatments where sediment and P loading conditions are still comparable and may provide valid treatment comparisons. Also to be tested is the potential importance of groundwater discharge with high TP concentration to phosphorus movement. Similarly, to test the potential impacts of sediment resuspension, a comprehensive core sediment survey will be carried along the L-67C canal within the DPM foot print.

Three years after construction was completed, submerged and emergent vegetation in the partial and complete fill treatments continues to change. Canal vegetation alters both the habitat quality

(for fauna) and hydrology of the treatments. Because vegetation has not stabilized in the canal, monitoring vegetation impacts and their interactions with backfill type on both biological (fauna) and biogeochemical (sediments and P) will be needed during subsequent flow events. *Hydrilla* invasion is a concern for the fill areas. Active management of this invasive plant should be considered. Future work should evaluate the possibility that active submerged aquatic vegetation management will be required to fully realize positive habitat enhancements that are possible by partial canal filling.

4. The impact of connectivity and year-round flow on landscape hydrology and tree island responses in WCA-3B.

We anticipate that longer duration, wet season flows will increase hydrologic connectivity between the pocket and WCA-3B. Introducing more flow and water into 3B affords the opportunity to understand their effects on different landscape habitats and at larger scale. As a result, monitoring hydrologic and ecological at a larger spatial scale will be required, including tree islands in WCA-3B and basin-wide flow patterns. However, since 3B has been over-drained, sawgrass encroachment has reduced the area of hydrologically connected sloughs. To evaluate flow effects at the basin-level, we anticipate that active vegetation management will be necessary to restore open-water sloughs and natural flow paths in this portion of what was historically Shark River Slough. Because additional flows into the DPM study area and WCA-3B will alter hydrology around tree islands in those areas, monitoring will aim to characterize hydraulic pattern and hydrogeochemical processes on one or more tree islands located in WCA-3B. The objective of this study is to understand how biochemical patterns are affected or influenced by increasing hydrologic connectivity between the pocket and WCA-3B. To accomplish this objective, we will monitor and characterize spatial and temporal evapotranspiration patterns along with the hydrology variability within the tree island.

Part 2. Hydrologic and ecological monitoring in the ridge and slough landscape

I. Statement of issue and study objective: Task 1: Hydrologic monitoring and associated ecological measurements

The DECOMP Physical Model (DPM) is a large-scale field test designed to address uncertainties associated with the Comprehensive Everglades Restoration Project (CERP) Water Conservation Area (WCA) 3 Decompartmentalization and Sheet Flow Enhancement Project (DECOMP), specifically to reduce the environmental risks and aid alternative selections associated with Project Implementation Reports (PIR) 2 and 3. The project couples the operation of hydrologic features (the S-152 culverts on the L-67A and canal backfilling and levee removal on the L-67C) and design alternatives with a comprehensive hydrological and ecological monitoring plan. The project entails coordinating the operation of the hydraulic features with the collection of monitoring data in a statistically robust manner to reduce uncertainty associated with canal backfilling and velocity thresholds for restoring ecological attributes of the historic ridge and slough landscape, including microtopography, patterning and loads that maintain oligotrophic aspects of the system.

The DPM utilizes structural features that generate a range of surface water velocities to occur in a marginally degraded portion of the natural system in order to verify the critical velocity threshold necessary to entrain and redistribute particles and nutrients in the landscape, which is thought to be a fundamental process needed to maintain the historic ridge and slough pattern. The creation of this "flow field" allows evaluation of the spatial variability of particle and nutrient transport. During the first 4 flow events, the primary objectives of the DPM study were to assess the benefits of sheet flow study by evaluating surface flows, vegetation interactions, and particle entrainment and redistribution along a spatial and temporal gradient of surface flow velocities. During the baseline period and first 4 flow events (spanning 2010-2017), field monitoring was prioritized to address the hypotheses related to physical responses, such as velocities and sediment transport, the primary mechanisms thought to underlie sediment and nutrient redistribution.

The original DPM science plan listed 13 flow hypotheses to determine the role of flow in structuring and maintaining ridge and slough landscape pattern (DPMST 2010). While findings from these flow events confirmed and quantified physical impacts of flow, DPM testing also showed that biological responses (by periphyton and small fauna) to flow were substantial and in some cases regulated flow itself. In addition, pilot studies to enhance flow by reconnecting historic sloughs showed that active management approaches may be needed to achieve sheetflow restoration over larger areas. As a result of these findings, the next phase of DPM prioritizes monitoring that addresses hypotheses related to how biological responses respond to and feedback on flow and the extent to which active management can be utilized to expand the areal extent of flow (DPMST 2010).

II. Statement of work (abbreviated)

This SOW describes the design of a field based hydrological, sedimentological, and biological experimental and monitoring program to address uncertainties associated with flow thresholds and associated material loading effects on hydrologic and ecological functions in the ridge and slough landscape. The design utilizes the physical features and structures of the DPM, including the S-152 gated culvert structure on the L-67A levee and a 3000-ft gap on the L-67C levee, 4.5 km south of the S-152. To the extent possible, flows will be conducted whenever water quality conditions at the S-152, the hydrologic gradient between L-67A and the pocket, and other operational constraints are acceptable for flow, as permitted by the Florida Department of Environmental Protection (FDEP). Since the original project began, the additional 7 years of L-67A canal water TP data has enabled more robust statistical analyses for forecasting when canal water TP is sufficiently low (and flow can occur), as needed to maintain the oligotrophic conditions in the downstream marshes. Whereas the original operational window ran from October through January (DPMST 2010), communications among DPM scientists, FDEP and US Army Corps of Engineers (USACE) are currently being pursued to develop new operational rules that may expand the operational window to include any month when flow conditions are acceptable, including wet season months when biological activities such as aquatic production is greatest.
This SOW focuses on the contributions of scientists from the United States Geological Survey (USGS), South Florida Water Management District (SFWMD), Florida International University (FIU), Florida Atlantic University (FAU), and University of Hawaii to the DPM. The specific units of USGS that are involved include the USGS National Research Program (NRP) in Reston,

VA and the USGS Caribbean-Florida Water Science Center (CFL-WSC) in Davie, FL. The lead USGS personnel for the study are Drs. Judson Harvey and Jay CHoi from the NRP in Reston and Mark Dickman from the CFL-WSC. The lead SFWMD personnel include Drs. Fred Sklar, Sue Newman, Carlos Coronado-Molina, Erik Tate-Boldt, Christa Zweig, Michael Manna, Eric Cline and Colin Saunders of the Everglades Systems Assessment Section. The lead scientist at Florida International University is Dr. Joel Trexler. The lead scientist at Florida Atlantic University is Dr. Nathan Dorn. The lead scientist at University of Hawaii is Dr. David Ho.

Individual agencies are responsible for design and coordination of all assigned activities, including instrument selection and acquisition, site design and field activities, as well as oversight and coordination of data acquisition, QA/QC, and data interpretation. Field activities and reporting will be coordinated among agencies through cooperation between USGS and SFWMD. Representatives of the USGS and SFWMD will also actively participate with the USACE regarding the operations of the S-152 structure in order to ensure that data collection coincides with operations (USACE, 2012). SFWMD will be responsible for installation and removal of sampling platforms. In addition, USGS-Reston will coordinate with the CFL-WSC which are responsible for assistance and leadership in the installation of the hydrologic monitoring stations (including airboat support) and maintenance of the monitoring sites, including troubleshooting and instrument servicing on an as-needed basis. The CFL-WSC will take the lead in acquiring data by downloading at hydrologic monitoring stations and they will also take the lead in QA/QC and post processing of the data. The CFL-WSC will also assist the USGS-Reston in hydrologic data interpretation. The CFL-WSC will work alongside and support the activities of the USGS-Reston during the annual, two-to-three-week intensive field investigations. When it becomes necessary the CFL-WSC will take the lead in replacing equipment at field sites using equipment provided by USGS-Reston and will remove equipment from hydrologic monitoring stations that have been discontinued. Finally, the CFL-WSC will assist the USGS-Reston in removing all equipment and decommissioning the hydrologic monitoring sites that remain at the end of the study.

The DPM tasks for Hydrologic Monitoring, Biological Monitoring, Sedimentological Monitoring and Geomorphological (topography and patterning) Monitoring (described below) involve the following key components: a) operation and maintenance of field instrumentation for the collection of water level and environmental data; b) processing of hydrologic stage records; c) local- and large-scale water velocity and tracer studies; d) assessment of biological (primary producers and foodweb) responses to flow and loading; f) sediment biogeochemical characteristics and fluxes; g) active management and geomorphological environmental assessment; and h) quality assurance, quality control, data release and publication.

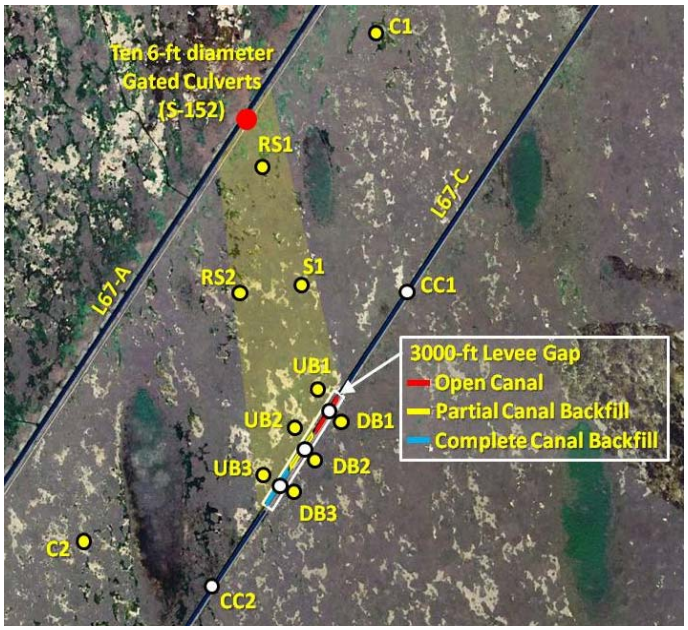
Data will continue to be collected by a BACI (before, after, control, impact) sampling design and a spatially stratified design, implemented during the previous flow events. Associated with each sampling design, there are two categories of stations within the DPM: **sentinel** stations (shown in **Figure 2-1A**) associated with the BACI design, and **temporary stations** (**Figure 2-1B**) associated primarily with spatially stratified sampling or less frequent, focused sampling. The BACI design involves sample collection before and after experimental flow releases at locations affected by the flow release as well as control sites outside the footprint of the flow release. The original BACI design described in the DPM Science Plan (DPMST 2010) was to include 2 years of pre-impact and 2 years of impact sampling, with an option for a 3rd year of impact sampling. Due to the

delayed installation of the culvert structure (S-152), the design now includes 3 years of pre-impact sampling and four years of impact (flow) sampling. As flows move to year-round testing, the BACI design may be applied to evaluate before and after flows (i.e., baseline vs flow), as well as before and after year-round flows (i.e., short-term (2-3 months) dry-season flows vs extended (expected 3-6 months) year-round flows). At sentinel stations, associated with the BACI design, a long-term suite of multiparameter data is collected, including water depth, velocity, suspended sediment concentration, dissolved oxygen, conductivity, temperature, and pH.

A spatially stratified sampling design was generated to quantify and understand spatial gradients in biogeochemical processes across the entire DPM footprint and how those gradients are modified by flow (**Figure 2-1B)**. Floc and periphyton chemistry observed over the initial baseline period (June-2010 to January-2012) indicated substantial variation and gradients in nutrient standing stocks, bioavailability, sediment type (peat or marl) and vegetation type with distance from canals or landscape features such as tree islands. Understanding these gradients was deemed critical due to their potential interactive effects with the high-flow and canal backfill treatments on ecosystem response variables such as biogeochemical cycling and sediment entrainment and transport, among others. For spatial gradient design, sampling locations were generated as part of the MAP-RECOVER system-wide landscape sampling and mapping project (PI: Dr. Michael Ross, Florida International Univ.).

At the **temporary** stations, associated with the spatially stratified design and other short-term focused measurements, the suite of parameters listed above for **sentinel** stations will also be sampled during specific times of interest (flow releases, pre-operational window, etc.) or at less frequent sampling times. Dr. Ross and colleagues have conducted vegetation sampling at all sites in **Figure 2-1B** in 2012. At a subset of these sites, other physical and biogeochemical processes are also measured, as described in the following 5 sections and in greater detail in section **III. Sampling Design**. For the forthcoming year-round flows, monitoring at both and sentinel and temporary stations will also be coordinated to evaluate the role of active management, specifically, reconnecting historic sloughs now largely invaded by sawgrass. Maps and photos provided in **Figures 2-1C** and **2-1D** show the location and extent of actively managed areas in the DPM study area, and historic and current imagery which shows the reduced areal coverage of sloughs, relative to historic imagery.

A



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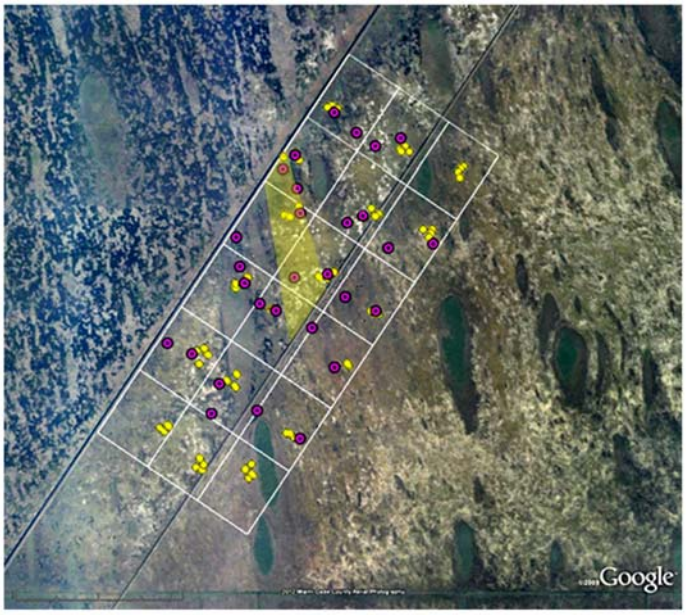

Figure 2-1 (A). Map of the DECOMP Physical Model (DPM) experimental site, located in "the pocket" between the L-67A and L-67C canal/levee structures. Hydrologic and biological response variables are measured at 12 marsh sentinel sites (site Z5-1, not shown, is near S-152 outflow) and 5 canal sentinel sites using a Before-After-Control-Impact (BACI) experimental design. Abbreviations are as follows: C = control; RS = ridge/slough; S = slough; UB = upstream backfill; DB = downstream backfill; CB = canal backfill; CC = canal control. Walkways are located at all stations except the canal stations. **(B).** Map of temporary stations with less frequent and/or more focused sampling and generated from a spatially stratified sampling design. The latter design was generated by Dr. Michael Ross and colleagues (FIU) as part of the RECOVER-MAP in order to quantify vegetation, topography and (at a smaller subset of points) other biogeochemical response variables. Yellow symbols represent the 216 subplots used to survey standing vegetation in each of 18 zones. The purple symbols represent the subplots used to sample floc and soil (in 14 of the 18 zones, 28 subplots total). Shaded polygon indicates flowpath highlighted in **A**.

Figure 2-1 continued. C). View of DPM study area from 1940 (left) and present aerial imagery (right), the yellow area showing general location for active management of sheetflow by reconnecting historic sloughs (evident as dark areas in the 1940 image) and increasing the overall flow footprint. Tree island boundary shown for visual reference**. D)**. (left) Map of areas proposed for herbicide application along two historic flowpaths and (right) helicopter view of actively managed areas (treated sawgrass patches indicated by brown patches) Photo from Dr. C. Zweig (SFWMD). 1940 aerial imagery provided by USGS, SOFIA database: https://sofia.usgs.gov/publications/ofr/02-327/ (PI, Dr. Tom Smith, USGS).

C

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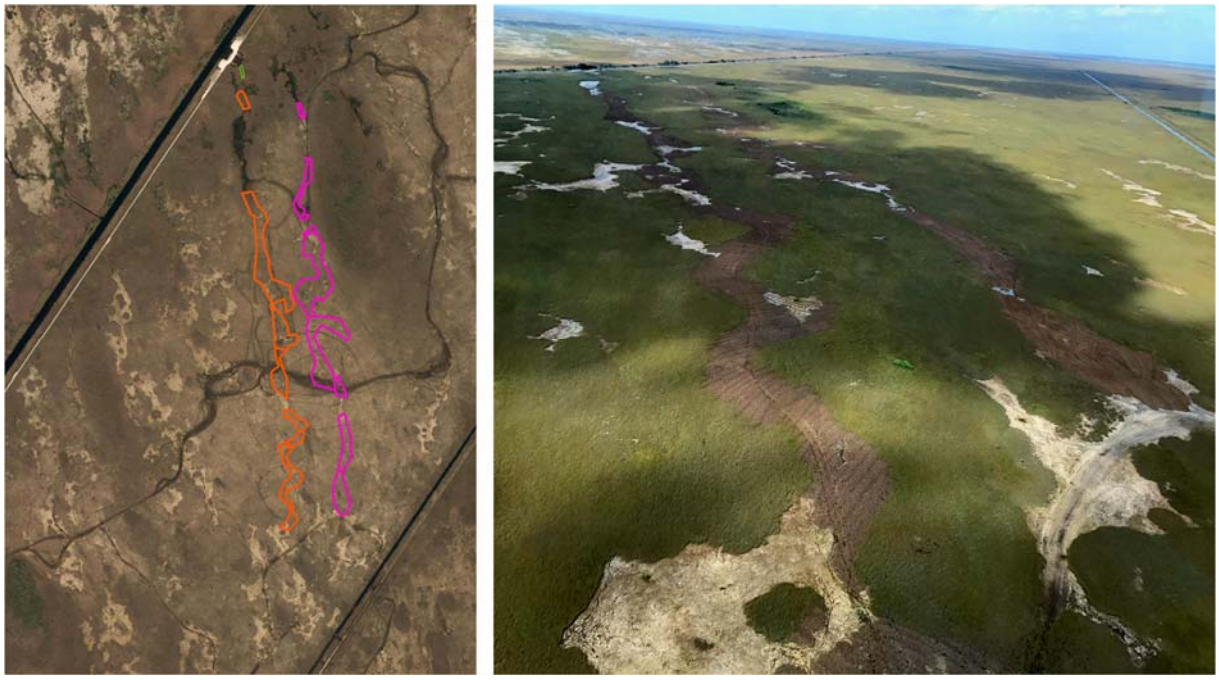

1. Monitoring

The hydrodynamics of surface water flow before and during flow releases will be assessed by quantifying surface-flow velocities and hydraulic gradient across the DPM experimental footprint. Results will be expressed as "flow fields" that describe the speed and direction of water movement in relation to the driving force for flow (i.e., energy slope or, as measured, the water surface slope). Surface-water flows and energy slope will be quantified using data collected at (1) a grid with 7 or more stations where water level is measured continuously with KPSI pressure transducers to assess water depth and water surface slope that describes the driving force and direction of water flow, (2) a selected number (5 or more) sites collecting continuous point velocity measurements using SONTEK acoustic doppler velocimeters (ADV) describing local patterns of flow speed and direction in ridge and slough areas, (3) large-scale SF-6 tracer releases to describe kilometer-scale hydrologic transport pathways.

Water-level and velocity instrumentation will be routinely visited and calibrated for quality assurance and linked to a common elevation datum through high-precision GPS surveying. The hydrologic monitoring will serve as a framework for conducting a large number of location-specific measurements on flow field dynamics, particle sources, physical characteristics of particles, particle mass-balance relationships, and associated vegetation characterizations, as described below. As noted in the S-152 Operational Strategy (USACE, 2012), headwater, tailwater, and flow data at the S-152 will be frequently monitored (e.g., one reading per fifteen to 60 minutes) and made available online. Data can be viewed and downloaded at the following website:

http://nwis.waterdata.usgs.gov/nwis/uv?cb_00065=on&cb_63160=on&cb_00095=on&cb_00095=on&cb_63158=on&cb_63158=on&format=gif_default&site_no=255154080371300&period=&begin_date=2013-10-29&end_date=2014-05-01

2. Algal and primary producer community responses to flow and loading

Many of the sheetflow hypotheses involve modeling that explicitly accounts for interactions with vegetation community structure such as the "flow resistance" that causes feedback between flow and vegetation communities though the effect of flow resistance on water depth, i.e. a major physical factor that determines which plant communities thrive and which fade away. Of course a change in plant communities changes flow resistance with further resets water depth and feeds back to plant communities (Larsen et al., 2010). Therefore, vegetation community composition, biomass (bio volume, including separate analysis of periphyton), and stem densities will be determined through state-of-the-art methods involving harvesting of vegetation in 0.25-m^2 clip plots followed by physiognomic analysis (Harvey et al., 2009; Lightbody and Nepf, 2006) to determine the distribution of stem diameters and frontal areas in the water column. The vegetation quadrats will be measured using a stratified random sampling scheme at ridge, slough, and transition zones at all sites within the hydrologic monitoring network. These measurements will be taken repeatedly during the years of experimentation to establish a record of temporal variation related to seasonal and interannual variations in vegetation architecture. Vegetation-flow relationships will then be used to verify empirical predictive relationships between flow and biological responses. In addition, changes in key ecological processes like ecosystem primary production, decomposition, and nutrient cycling will be made as they respond to increased flow.

After enough data are collected we will refocus efforts toward quantifying relationships between the flow resistance parameters frontal area and stem density and potentially simpler to acquire metrics such as biomass, leaf area index, and remotely sensed measures such as NDVI, etc.

Intensive sampling events will also be conducted within sloughs with varying flow velocities (to be determined by the DPM science team) specifically aimed at evaluating slough algal and submerged aquatic vegetation (SAV) responses to flow. Routine (monthly or continuous) water quality, sediment and hydrology data will be collected to provide information on seasonal and interannual differences in algal responses, and as needed for overall data synthesis.
Dependent on the specific mechanisms being studied, monitoring to capture the effects of year-round flow will entail:

- ~6 week deployments of artificial substrates for periphyton growth and community response
- Spatially intensive surveys of flow (pre- and during) within sloughs to evaluate spatial variation and deployment sites (Flowtracker, some dye deployments)
- Incubations of periphyton biomass (from substrates or *in situ* biomass) for estimating metabolic rates (GPP/R)
- Incubations of benthic floc for estimating metabolic rates (GPP/R)
- Continuous ADV deployments (pre- to post-flow) at each site to determine velocity profile and shear stress changes with time (due to "periphyton clearing" in sloughs) during the flow event
- Deployments of Hydrolab (5-d) for ecosystem GPP/R estimates), with *in situ* estimation of O2 dynamics in floc and gas exchange experiments
- Vegetation and metaphyton characterization of frontal area and physical (grain size) and P content and fractionation of epiphyton and floc
- Lab analysis of periphyton and floc chemistry (TC, TP, TN)
- Lab analysis of periphyton, epiphyton and floc for algal community composition
- Lab analysis of surface water and/or periphyton (and floc) for phosphatase activity
- Aerial imagery of select sloughs to evaluate periphyton die-off/slough clearing
- "Phytoplankton" samples and quantitative analyses collected from the sloughs before and during the sloughing events
- Throw-trap sampling of aquatic consumers along the nutrient enrichment gradient
- Field enclosure experiments to document aquatic consumer responses to nutrient loading.

3. Foodweb responses to flow and loading

Prior studies of nutrient gradients indicate that nutrient loading can enhance faunal biomass in Everglades wetlands, however food web responses depend on functional or taxonomic groups, trophic position, exact loading rates and correlated changes to macrophytes (King and Richardson 2007, Hagerthey et al. 2014). Expectations for the DPM experiment are further complicated by the direct and indirect effects of flow itself. The net effects of flow on the macroinvertebrate

assemblages were not studied in DPM 1. In DPM 2 macroinvertebrate communities will be repeatedly sampled in sloughs in the gap with sweep nets (King and Richardson 2007) or another sampling device (Turner and Trexler 2007) to quantify the changes to the macroinvertebrate community. Multiple flowing and non-flowing sloughs will be sampled and each slough will be sampled at multiple randomized locations (~10 m^2) with multiple sweeps. Sampling events will occur in both flow and post-flow periods each year. During DPM 2 the macroinvertebrates collected in sediment traps during flow events will also be enumerated and identified in a subset of the monitored sloughs to compare the taxa of the extant communities to the composition of drifting macroinvertebrates. Work to document macroinvertebrate responses to flow will include:

- Repeated sampling events in multiple sloughs along the flow gradient to quantify macroinvertebrate communities (i.e., mostly primary consumer taxa 0.2-2 cm).
- Lab analysis of the composition of macroinvertebrates collected during sampling events.
- Lab analysis of macroinvertebrates in sediment traps for a subset of sloughs during flowing and non-flowing periods.

4. Sediment biogeochemical characteristics and fluxes

One of the leading hypotheses regarding the formation and maintenance of the ridge and slough landscape concerns the role of particle transport and redistribution of entrained sediments. To determine the importance of particle transport, a variety of parameters will be measured to characterize sediment properties and trace particle movement. Suspended sediment concentrations, size distributions, and particulate phosphorus measurements will be obtained through grab sampling at all sites in the hydrologic monitoring network. Potential sources for suspended sediment (bed floc, epiphyton coatings on vegetation stems) will be sampled for the same parameters. At select sites throughout the network, these characteristics will be monitored prior to and during the period of the flow release through both *in situ* instrumentation and regular sample collection. Transport will continue to be measured using sediment traps and biochemical analyses of trapped sediment (to evaluate sediment source, nutrient loads).

5. Active Marsh Improvement (AMI) and geomorphological assessments

A large-scale (1-2 km) effort to clear sawgrass biomass that has invaded sloughs was initiated in the summer of 2016 (**Figure 2-1C and D)**. Sloughs along the southern flowpath will be connected to a distance of 1-2 km from the S-152. With this study, there is the potential for high flows to be extended well beyond the current limit of 500-m, and also for flows to be redirected south, counter to the current eastern flowpath. Activities will entail the following:

- Application of herbicide along pathways connecting remnant sloughs along the southern flowpath
- Sampling of flow velocities (Flowtracker and/or ADV) across adjacent ridge, treated ridge and slough habitats, and associated water depth and floc depth measurements

- Associated sampling of water quality parameters (same parameters as for routine monthly samples)

One of the defining features of high-functioning ridge and slough landscapes is the bimodal distribution of ground-surface elevations with each mode associated with a distinct plant community. We will measure ground-surface elevation (top of floc and peat) as it varies spatially at fine (m-scale) and coarse (100-m) spatial scales, from which microtopographic-vegetation probability density functions and water depth probability density functions can be determined. This monitoring will be coordinated to the extent possible with the AMI study and other sentinel and spatial survey monitoring.

III. Sampling Design

1. Schedule

A schedule of tasks to be completed for addressing the Ridge and Slough hypotheses as part of year-round testing is provided in **Table 2-1**, including schedules for previous baseline and dry-season flow years. Sampling tasks are organized by vegetation, hydrology, biogeochemistry and sediment characteristics and fluxes. Flow releases are expected to be initiated in the months spanning July to October, earlier in relatively wet years and later in drier years. As the flow will likely correspond to seasonal rainfall and stage conditions in WCA3, flow years are organized by water year. As required for the BACI statistical design, sampling in each study year will include pre-flow (before) and during/after flow (impact) months. For some biologically controlled parameters with fast response times (e.g., diel oxygen concentrations), sampling occurring during months preceding the flow will technically include "before" sampling, while longer term parameters (e.g., soil or floc chemistry) will utilize previous year's data as the "before" period.

Monitoring stations (deployments and real-time), once functioning, are expected to provide 36-48 months of monitoring (depending on the parameter) spanning pre-, during and post-flow conditions in forthcoming water years. A matrix describing, in detail, the coordinated sampling among the different research groups, and current sites, is provided in an electronic appendix to this document (see file "DPM_Sampling_Matrix.xlsx"). The matrix was developed following a site visit by all the Principal Investigators (PI) in June 2010 and is updated yearly by DPM PIs. As sampling is coordinated to more closely co-located and couple parallel studies (e.g., algal responses tied to faunal growth studies), site locations and specific activities may change slightly.

*Note: In the event that operation of the S-152 is not possible in a designated flow year, sampling as outlined above should continue as part of the baseline or no-flow monitoring. This monitoring is necessary in order to quantify and explain variability in years with and without high-sheetflow, maintaining the statistical power of the BACI analysis.

Table 2-1. Schedule of tasks to be completed for addressing the Ridge and Slough hypothesis, including baseline (no flow) years, dry season flow years (2013-2017), and year-round testing years (latter organized by water year). ** A fourth year-round flow year is included as a contingency in the event flow is not possible in one of the previous years or additional data are required for statistical power.

(i) = installed	Baseline Years	Dry Season Flow Years			Year-Round Flow1			Year-Round Flow2			Year-Round Flow3			Year-Round Flow4 **		
	Jun10- Aug13	(Aug2013 - Apr2017)			(May17-Apr18)			(May18-Apr19)			(May19-Apr20)			(May20-Apr21)		
Sampling tasks - Ridge and Slough	Aug - Apr	pre-	flow	post	pre-	flow	post	pre-	flow	post	pre-	flow	post	pre-	flow	post
vegetation structure																
microtopography	x	x	x	x	x (month to be determined)			x (month to be determined)			x (month to be determined)			x (month to be determined)		
vegetation frontal area	x															
vegetation surveys (landscape survey, imagery, or site-specific surveys)	x	x	x		x (month to be determined)			x (month to be determined)			x (month to be determined)			x (month to be determined)		
hydrology																
pressure transducers	(i) x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
acoustic doppler profilers	(i) x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
water depths	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
flow velocity & direction	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
SF6 tracer release	x	x	x			x			x			x			x	
Dye tracer release			x			x			x			x			x	
Biogeochemistry - processes & attributes																
Water Quality Monitoring (incl. TSS & Partic-P)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Ecosystem metabolism	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Periphyton processes			x	x	x	x	x	x	x	x	x	x	x	x	x	x
Periphyton-algal taxonomy			x	x	x	x	x	x	x	x	x	x	x	x	x	x
Phosphatase enzyme activity	x		x		x	x	x	x	x	x	x	x	x	x	x	x
Fish responses	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Invertebrate responses					x	x	x	x	x	x	x	x	x	x	x	x
Decomposition (discont.2015)	x	x	x	x												

Table 2-1. *continued*

	(i) = installed	Baseline Years	Dry Season Flow Years			Year-Round Flow1			Year-Round Flow2			Year-Round Flow3			Year-Round Flow4 **		
		Jun10- Aug13	(Aug2013 - Apr2017)			(May17-Apr18)			(May18-Apr19)			(May19-Apr20)			(May20-Apr21)		
Sampling tasks - Ridge and Slough		Aug - Apr	pre-	flow	post	pre-	flow	post	pre-	flow	post	pre-	flow	post	pre-	flow	post
Sediment Chars & Fluxes																	
	suspended sediment concentration & size characterization (grabs)	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x
	in situ monitoring of SSC & size (single station)	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x
	sample collection particulate-P	x	x	x	x	n/a (see Biogeochem.)			n/a (see Biogeochem.)			n/a (see Biogeochem.)			n/a (see Biogeochem.)		
	floc, soil & epiphyton collection for biogeochemical characterization, size distribution	x		x		x	x	x	x	x	x	x	x	x	x	x	x
	Sediment settling (vertical traps)	n/a	n/a	n/a	n/a	x	x	x	x	x	x	x	x	x	x	x	x
	Sediment transport (horizontal traps)	(i) x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Molecular biomarker analysis (sediment, veg.), paired with traps (discontin. Mar2016)	x	x	x	x												
	Floc collection & chemical analysis, paired with traps	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Algal taxonomy of floc & sediment, paired with traps	x	x	x	x	x	x		x	x		x	x		x	x	
	Critical Entrainment Thresholds	x	x		x	x		x	x		x	x		x	x		x
	DST tracer releases & synoptic sampling	x		x			x			x			x			x	

2. Site Selection

Measurements will be obtained from a network of up to 17 **sentinel** stations within the DPM footprint (see **Figure 2-1A**). These stations were selected to address the ridge and slough and canal backfilling uncertainties, to satisfy the requirements of the BACI experimental design, and to fully sample the range of flow velocities expected during operations. With the exception of the canal sentinel stations, each sentinel station has a walkway that was constructed to support long-term measurement equipment and to minimize disturbance to local vegetation communities while sampling. Each walkway accesses one or two sampling sites, depending on whether it spans one or two vegetation communities. For the purposes of this work plan, a site is defined as a location with a distinct vegetation community (distinguished by changes in species composition and physiognomy which are known to have unique effects on the fluid dynamics of flowing waters (Larsen et al. 2009b), from which an independent set of data will be collected.

Sampling sites for the spatial survey (**Figure 2-1B**) were generated as part of the MAP-RECOVER system-wide landscape sampling and mapping project (PI: Dr. Michael Ross, Florida International Univ.). The sampling design entailed stratifying the DPM footprint (a 3-km x 7.5-km area, oriented parallel to the L-67A and C levees) into a grid of 18 1-km x 1.25-km zones. Within each zone one random location was selected. This location represents the center of a cluster of four additional points, or nodes, randomly selected within a given distance from the center of each cluster. At each node, three subplots are generated for a total 216 subplots. One of the subplots is the center node and the other two are at a random distance (3-23 m) north and east of the center node. Vegetation and topography was surveyed by Dr. Ross and colleagues at all 216 subplots in October 2012. Soil, floc, sediment transport and other biological and biogeochemical response variables are also monitored intermittently at a subset of these sites.

Sentinel Stations for Ridge and Slough Hypothesis Testing

RS1_U – Upstream platform (30 ft long) directly downstream of L-67A culverts that accesses monitoring sites UTR and UTS (ridge and slough tracer release sites, respectively).

RS1_D – Downstream monitoring platform (60 ft long) that accesses monitoring sites UR and US (ridge and slough, respectively).

RS2 – About midway through the DPM footprint, location of the second ridge and slough walkway (30 ft long). The platform accesses monitoring sites MR2 and MS2 (ridge and slough, respectively).

C2 - Location of the southwestern control site consisting of a ridge and slough with a 30 ft platform spanning both. This is on the southwest side of the DPM footprint, outside of any potential flow impacts. The platform accesses monitoring sites CR2 and CS2 (ridge and slough, respectively).

S1 – Location of central slough (10 ft platform). The platform accesses the monitoring site MS1. In 2015, this site was discontinued due to disturbance. Note that due to site disturbance this site was discontinued in July 2014, and replaced with a near-inflow site, Z5-1.

C1 – Location of the northeastern control site. The platform accesses the monitoring sites CR1 and CS1 (ridge and slough, respectively).

UB1 – Location just upstream of the complete backfill treatment. This will consist of a 10 ft walkway in a slough. The platform accesses monitoring site DS1.

UB2 – Location just upstream of the partial backfill treatment. This will consist of a 10 ft walkway in a slough. The platform accesses monitoring site DS2.

UB3 – Location just upstream of the no backfill treatment. This will consist of a 10 ft walkway in a slough. The platform accesses monitoring site DS3.

Z5-1 – Added 2015. Location ca. 150-200 m downstream of S-152. The platform accesses the monitoring site Z5-1R.

Sentinel Stations for Canal Backfilling Hypothesis Testing

CB1 (syn. with MB1) – This is the canal sampling location of the no backfill treatment. Vertical sediment accumulation and canal temperature and turbidity are monitored in the central portion of the canal. We will install a monitoring station here, to be operated during a flow release. Pre-release data included flow velocities measured with an Argonaut.

CB2 (syn. with MB2) – This is the canal sampling location of the partial backfill treatment. Vertical sediment accumulation and canal temperature and turbidity are monitored in the central portion of the canal. The current plan is to install a monitoring station here, to be operated during a flow release. Pre-release data included flow velocities measured with an Argonaut and water levels measured with a KPSI.

CB3 (syn. with MB3) – This is the canal sampling location of the complete backfill treatment. Vertical sediment accumulation and canal temperature and turbidity are monitored in the central portion of the canal. Although it is unclear how the backfill treatment will permit sampling, the current plan is to install a monitoring station here, to be operated during a flow release. Pre-release data included flow velocities measured with an Argonaut.

CC1N -- This is the canal sampling location of the north canal control station. Vertical sediment accumulation and canal temperature and turbidity are monitored in the central portion of the canal.

CC2S -- This is the canal sampling location of the south canal control station. Vertical sediment accumulation and canal temperature and turbidity are monitored in the central portion of the canal.

DB1, DB2, DB3 – 10 ft platforms downstream of the canals in sloughs. DB2 has a KPSI to measure water levels and a staff gage. There is no plan to make long term flow monitoring measurements although flow velocities were measured overnight using Vectrino ADVs at these locations.

Sites for spatially stratified and short-term focused sampling

Sites for the spatially stratified sampling design are listed in the electronic appendix "DPM_Sampling_Matrix.xlsx" and displayed in **Figure 2-1B**. Vegetation surveys were conducted at all 216 subplots, across the 18 zones shown in **Figure 2-1B**. At 28 of these subplots (purple symbols, **Figure 2-1B**), benthic floc samples are collected annually for C, N, P and organic matter content in representative sloughs at or nearest to each site. At a subset of those 28 sites, located at varying distances due south or due east of the S-152, other physical and biological parameters are also measured, along with hydrologic parameters, at varying frequency, depending on the parameter. This information quantifies the landscape gradients in sediment chemistry and biogeochemical properties, and changes in those properties over time, providing context and quantitative covariates for the BACI design.

3. Experimental Approach

The before-after-control-impact (BACI) approach is used to determine how pulsed-flow events impact response variables. In this approach, the effects are analyzed by measuring conditions *before* a planned activity (i.e., the opening of the L-67A culverts) and then comparing the findings to those conditions measured *after* the event. A BACI design also requires the concomitant *before* and *after* measurements of response variables at sites not affected by the impact (i.e., control). Assuming operations will continue again in November of 2015, the *before* and *after* monitoring periods will consist of 36 and 36 months, respectively. At this time, a third year impact flow is expected to occur starting in November 2015. A third flow was deemed essential to provide sufficient statistical power for testing effects on several hydrological and ecological parameters. The BACI approach will be applied to both the Backfilling and Ridge & Slough Sheet flow experiment designs.

Multiple representative ridge & slough habitats have been selected for detailed measurements within the flow-way where surface flow velocities at certain times and places are likely to exceed 3 cm/sec. An additional two sites located outside of the flow-way serve as low-velocity controls. To minimize disturbance, a network of aluminum walkways and staging platforms will be constructed to access sampling sites. Stations will be accessed by airboats using established routes or by a float helicopter. Hydrodynamic measurements at the sites will focus on the physics of flow and particle transport. Ecological measurements will focus on biological attributes that affect hydrodynamics as well as those that respond to increased nutrient supply associated with increased flow. Biogeochemical measurements will address how nutrient transport and cycling may change with increased sheet flow. Sampling frequencies and locations will vary depending upon the parameter, and are explicitly described in the next section of this document.

Spatially stratified sampling approach is also used to determine how flow events impact response variables, but specifically aimed at evaluating how flow responses occur over shorter gradients. This approach was necessitated by observations of floc and periphyton chemistry in pre-flow years (2010-2012) which indicated substantial variation among sites and suggested large-scale gradients in nutrient standing stocks, bioavailability, sediment type (peat or marl) and vegetation type with distance from canals or landscape features such as tree islands. In addition, observations from the first 4 flow events that flow was greatly reduced within ~500-m of the S-152 structure necessitated additional monitoring at shorter distances from the S-152. Understanding these gradients was deemed critical due to their potential interactive effects with the high-flow and canal backfill

treatments on ecosystem response variables such as biogeochemical cycling and sediment entrainment and transport, among others. Therefore, a spatially explicit sampling design was generated to quantify and understand these spatial gradients across the entire DPM footprint. Sampling sites for the spatial survey (**Figure 2-1B**) were generated as part of the MAP-RECOVER system-wide landscape sampling and mapping project (PI: Dr. Michael Ross, Florida International Univ.).

4. Field Methods/Lab Methods – Hydrologic & ecological monitoring in the ridge and slough landscape

A. Continuous measurements

- **Flow velocity and direction (PIs Harvey and Choi):** Methods follow the operating procedure outlined in Harvey et al. (2009). At each equipment location flow velocity and direction will be measured at a fixed depth in the water column using 10 megahertz (MHz) down-looking acoustic Doppler velocimeters (ADV) manufactured by SonTek/YSI and Nortek. The ADV approach can measure flow velocity to a resolution of 0.01 cm s^{-1} with an accuracy of 1% of measured velocity (SonTek, 2001). Velocities will be sampled at a frequency of 10 Hz in one minute bursts collected every 30 min. Velocity datasets will be filtered and edited according to standard criteria suggested by the instrument manufacturer (SonTek, 2001) as well as specific criteria that were developed and refined in a prior Everglades study (Riscassi and Schaffranek, 2002). A minimum statistical correlation of 70% per sample and a minimum of 200 valid samples per burst will be used as quantitative filters. Data with an acoustic signal-to-noise ratio (SNR) of 5 dB or less will be discarded. The resulting quality assured data set of 30-min point velocities will be averaged to produce daily values. Through modeling, point velocities will be converted to depth-averaged velocities using the model of Lightbody and Nepf (2007), as described in Harvey et al. (2009).

  ADVs will be serviced regularly, during which data will be downloaded, batteries replaced, and compass calibration and diagnostics performed on the instrument. Between site visits, the height of the ADV sensor will be adjusted based on the need to keep the sensor submerged until the next site visit. The height of each ADV sensor will be adjusted to keep column anticipated for the deployment period. Instruments will be deployed for sixth months out of each year of the experiment, centered on the operational window.

  Previously, velocity profiles were obtained as described in Harvey et al. (2009), using the same ADV sensors deployed for continuous monitoring. For the profiles, velocities were measured at 10 Hz in 1 or 2 min bursts yielding 600 or 1200 samples, respectively, at each depth increment. Flow velocities were measured at 1.5, 3, or 6 cm depth increments throughout the water column, depending on total water depth, apparent vertical variability in vegetation architecture, and overall favorability of measurement conditions and time constraints. Sufficient velocity profile data has been collected and those measurements have been discontinued.

Criteria for editing the velocity profile data are an extension of those used in the editing of the continuous point velocity data. In addition to using the same minimum 70% correlation filter used previously for point velocity data, a phase space threshold despiking process will also be applied to the profile data (Goring and Nikora, 2002;Wahl, 2003). Signal-to-noise-ratios will be monitored continuously during collection of the vertical velocity profiles to determine if the ADV sample volume was obstructed by vegetation and as an indicator of the vertical location of the top of the floc. The large number of samples averaged for each burst and the filtering and quality assurance procedures used to edit and process the data provide confidence that the maximum possible resolution (0.01 cm s-1) reported for this instrumentation [SonTek, 2001] is achieved in these measurements.

In the canal treatments, acoustic Doppler profilers (Sontek phase-coherent acoustic Doppler profilers and an Argonaut-SW) will be deployed to provide continuous records of velocity profiles. Profilers will be deployed in an up-looking configuration and will sample vertical profiles of flow velocity and direction in one-minute bursts collected every 30 minutes. Post-processing QA/QC will follow the procedures described above for the ADVs. Depth-averaged flow velocities will be computed directly from the profiles.

- **Water level (PIs Harvey and Choi):** Water level will be obtained according to USGS Office of Surface Water standards. At ridge and slough sites, pressure transducers (KPSI water-level sensors) will be deployed in 1.5-inch PVC wells. The pressure transducers have an accuracy of +/- 0.15 cm and will record water level at 15-minute intervals. Data will be downloaded and instrument diagnostics performed at monthly intervals. Data will be QA/QC'd and corrected for drift according to USGS Office of Surface Water procedures (Kenney, 2010). Unlike the KPSI transducers, these transducers have no internal compensation for atmospheric pressure, so a fourth HOBO transducer will be installed above-ground to monitor variation in atmospheric pressure. The HOBO instruments will monitor water level at the same interval as the KPSI instruments, will be downloaded and serviced approximately monthly, and resulting data will be QA/QC'd and corrected for drift according to the same USGS procedures referenced above. The elevation of pressure transducer wells will be surveyed into a common datum so that the slope of the water surface can be evaluated by fitting a plane through the network of monitored sites. Transducers will remain deployed for the duration of the DPM project, starting in October 2010.

- **Suspended sediment size distributions (PIs Harvey and Choi):** Continuous records of suspended sediment size distributions will be obtained from a single site during flow releases using a laser diffraction particle size analyzer (LISST-FLOC, Sequoia Scientific) according to the methods of Noe et al. (2010) and Harvey et al. (2011). Because the instrument is subject to biofouling, it will be deployed for periods of up to three days before, at the start of, and after DPM operations. The LISST-FLOC measures diffraction of a laser to estimate the in situ volume concentration and size distribution of suspended sediment. The particle size measurement range is 7.5-1500 microns, divided into 32 logarithmically spaced size-class bins. The instrument will be suspended horizontally so that the optical path is located at mid water column or slightly below and programmed to collect data in 5-second bursts every 10 minutes.

- **Suspended sediment concentrations (PIs Larsen and Harvey):** The LISST-FLOC (see above) provides continuous measurements of volumetric suspended sediment concentrations. Volumetric concentrations will be converted to mass concentrations using the floc density vs. floc size relationship provided in Larsen et al. (2009), which was developed for the Everglades. In addition, we will monitor several suspended sediment concentration surrogates as a relative measure of differences in suspended sediment concentrations between sites. One surrogate is turbidity, determined with an optical probe on a sonde (YSI 600-OMS V2). During the experimental flow release, three or more turbidity sondes will be deployed at mid water column at across the ridge-to-slough transition and with distance downstream to determine the extent to which floc transport is attenuated with distance into the ridge.

  A second surrogate is the signal-to-noise ratio obtained from the ADVs. ADVs operate by the Doppler shift of sound waves caused by particles in the flow, and the signal-to-noise ratio of the instrument increases in flows with more particles. The ADV's signal-to-noise ratio will be related to suspended sediment concentration using regression that takes differences in water temperature and particle size into account, as described in Elci et al. (2009). This surrogate was tested and found to be ineffective for the DPM and these analyses will be discontinued.

B. Discrete Sampling

- **Flow velocity and direction**:
  - **Large Scale Patterns (PI Ho):** The large-scale patterns of hydrologic transport between the L-67A and L-67C levees will be assessed using sulfur hexafluoride (SF_6) tracer methodology modified for the low-gradient Everglades (Ho et al. 2009; Variano et al. 2009). The tracer will be released immediately downstream of the L-67A culverts and the daily fate of the plume followed by making continuous measurements of SF_6 concentrations using a GC mounted to an airboat. The plume will be followed for 5-10 days depending on dispersal rates. The results of the tracer tests, when compared with available aerial photography to delineate landscape features will be used to assess flow dynamics within the ridge and slough landscape, including vegetation interactions.
  - **Meso Scale Patterns (PI Cline, Zweig):** Tracer studies using Fluorescein dye will be used to assess the meso-scale effect (within and between ridges and sloughs and across canals) of flow during periods of pulsed and no-pulsed flow. Dye will be introduced upstream of canals and in 5-10 sloughs and aerial observations will be made at regular intervals (hourly) to ascertain flow patterns. In addition, water samples for dye detection will be collected from sentinel sites at 15-min intervals.
  - **Local Patterns (Harvey and Choi):** Velocity profiles using ADVs as well as Nortek Vectrino ADVs will be obtained as described in Harvey et al. (2009). For the profiles, velocities will be measured at 10 Hz in 1 or 2 min bursts yielding 600 or 1200 samples, respectively, at each depth increment. Flow velocities will be measured at 1.5, 3, or 6 cm depth increments throughout the water column,

depending on total water depth, apparent vertical variability in vegetation architecture, and overall favorability of measurement conditions and time constraints. These data will be subjected to the same QA/QC and filtering processes described in the "Flow velocity and direction" section above**.**

- **Aerial Imagery (PI Zweig)**. Flow patterns and periphyton collapse will be monitored with the Box on an Aircraft (BOA), an aerial imagery system that provides georeferenced images at < 6 cm resolution.

- **Active Management (PI Zweig).** Active management will be used to create historic slough flow paths through the DPM footprint and into 3B. Before and after flow directions will be measured with a handheld FlowTracker ADV.

- **Critical Entrainment Threshold (CET) of sediments (PI Newman, Manna):** A Critical Entrainment Threshold (CET) describes the flow velocity at which a sediment particle is first suspended in the flow field; thus, is analogous to when erosion begins. CET of sediments within the DPM footprint will be determined *in situ* using an annular benthic flume constructed of two cylinders that form a 0.1 m annular channel (Partrac 2005, 2006, 2008). Benthic annular flumes have a history of use extending back to the mid-1980's and have been chiefly used previously on intertidal and shallow sub-tidal cohesive sedimentary environments (Black and Paterson 1997). The inner cylinder (radius 0.35 m), outer cylinder (radius 0.55m), and watertight lid are constructed of Perspex™. Bed shear stress is created via a rotating lid affixed to the channel top. Lid rotation is by a geared DC motor controlled directly via software on a portable laptop computer with a specialized interface box. The software allows for control of the operational variables, start velocity, end velocity, step-wise rotation frequency increments, increment duration, and ramping rate between increments. An optical backscatter turbidity sensor (OBS) is fixed at 5 cm above the sediment water interface such that the sensing zone is directed across the channel. Turbidity was recorded at 1 Hz. The flume was calibrated to derive the relationship between lid rotation and flow velocity at 0.05m above the sediment-water interface. CET is obtained by the relationship between flow velocity and turbidity. Upon completion of a CET experiment, estimates of particle settling velocities will be made by continuing to log turbidity after rotation of the lid has stopped. Flume deployments will be made among the sediment types (minimum n=5) located with the DPM footprint.

- **Suspended sediment size distributions (PIs Harvey and Choi):** Whereas the laser diffraction particle size analyzer (LISST-FLOC, Sequoia Scientific) will be used to capture dynamics at key locations, we will supplement those measurements with the LISST-Portable benchtop laser diffraction particle size analyzer (Sequoia Scientific). The latter is a field instrument that allows measurements at the site or in the laboratory a few hours later in order to minimize the disruption of organic cohesive sediment as a result of sample handling and ageing. In addition, the LISST-Portable benchtop laser diffraction particle size analyzer (Sequoia Scientific) can be used to analyze floc and epiphyton sources of particles. Prior to and after operation of the DPM, the floc bed will be sampled by coring the surficial sediment to a depth of at least 10 cm using a 2.5-inch core tube. Two representative cores per site will be removed for analysis on the LISST-Portable

instrument. Epiphyton will be collected with a wet-dry vacuum as described in Larsen et al. (2009b). The intake of the vacuum will be placed against vegetation stems and moved up and downward in the water column while sampling in order to obtain a depth-integrated sample. Suspended solids samples from floc and epiphyton will be collected using a 500 µm Nitex mesh as described in Noe et al. (2007). For the water column sample a 1 L of sample will also be collected from mid water column at each site by pumping through a size-16 Masterflex tube fixed in place via a rod. A pre-filter at the end of the water column tube (500 µm) will exclude large vegetation pieces; the size distribution of remaining particulates suspended in the water will be analyzed using the LISST-Portable.

- **Suspended sediment concentrations (PIs Harvey and Choi):** Suspended sediment collected as described above will also be analyzed for mass concentration for direct determination of suspended sediment concentration (SSC). Ideally those measurements are made in discrete size bins in order to convert volumetric concentrations reported by the LISST to mass concentrations consistent with Harvey et al. (2011). Within 24 hours of sample collection, each sequential size filtration sample is sequentially filtered through 100 µm, 10 µm, 2.7 µm, 0.45 µm, and 0.2 µm filters by vacuum filtration. The mass concentration of suspended sediment in each size class (0.2 – 0.45 µm, 0.45 – 2.7 µm, 2.7 – 10 µm, 10 – 100 µm, and > 100 µm) is determined by drying and weighing each filter on a microbalance before and after filtration. Our measurements thus far have determined that that pairing total SSC concentrations with grain size estimates made using the LISST-Portable instrument provides the best dataset considering all factors.

- **Vegetation characterization (PIs Choi and Harvey):** Vegetation community composition, biomass (biovolume, including separate analysis of periphyton mass per unit area), and stem densities will be determined through state-of-the-art methods involving harvesting of vegetation in 0.25-m^2 clip plots followed by physiognomic analysis (Harvey et al., 2009; Lightbody and Nepf, 2006) to directly measure the distribution of stem diameters and frontal areas. The vegetation quadrats will be measured using a stratified random sampling scheme at ridge, slough, and transition zones at all sites within the hydrologic monitoring network. These measurements will be made repeatedly over the course of the study to establish any seasonal and interannual variations in vegetation architecture. Additionally, these measurements will be used in ongoing efforts to verify empirical predictive relationships between biomass and flow resistance parameters detailed in Harvey et al. (2009). Sufficient vegetation data has been collected and these measurements have been discontinued in favor of estimation techniques involving easier to measure variables that relate biomass for given species with on the ground and remotely sensed quantities such as leaf area index and NDVI.

- **Ecosystem metabolism (PIs Tate-Boldt, Choi):** Ecosystem metabolism (aquatic gross primary production, ecosystem respiration, and net ecosystem production) will be estimated from high-frequency measurements (30 min) of dissolved oxygen obtained over a 5-day deployment interval from calibrated and maintained Hydrolab multiparameter sondes suspended in the water column. Calculation of net ecosystem production and respiration estimates will be obtained following Staer et al. (2010), Hagerthey et al. (2010),

Bott (1996), and Hall (2016). Deployments will be conducted quarterly and pre-post flow operations. To verify and strengthen these finding the USGS-Reston team will conduct long term (wet season) deployments of sondes and they will also conduct gas tracer tests to verify reaeration rates to be used in metabolism calculations. They will also measure net respiration directly in floc using oxygen balance measurements before and after flow releases.

- **Algae/Cyanobacterial Response to Water Flow-Community Changes in Periphyton and Dispersion of the Periphyton Mat (PIs Rosen, Newman):** Artificial substrates will be deployed monthly to capture the seasonal variation algal/cyanobacteria community structure. Samples will be preserved (Lugol's) and the organisms quantified microscopically (calculated as number/biovolume per cm^2). Natural periphyton collections will also be collected for comparison. Colonization of the artificial substrates as a function of distance (250, 400, 500 and 800 meters) from the S-152 will also be examine before, during and after flow events. In addition, 1-L water samples from the slough before, during and after the introduction of flow will collected and analyzed for the type, size and quantity of organisms that are derived for the degradation of the periphyton mat. For epiphyton and floc studies the relative abundance of organisms present will be determined microscopically from scraped stems or sediment samples, repectively.

- **Biological Response to Pulsed Water Flows: Phosphatase Enzyme Activity (PI Newman):** Phosphatase activity will be used to indicate the relative degree of phosphorus limitation of the floc, water, and periphyton community in the sloughs during low and high flow conditions. Phosphatase activity will be measured fluorometrically using a standardized substrate; methylumbelliferyl phosphate. To ensure that the periphyton community is of known age, periphyton phosphatase activity and biomass will be determined from periphyton that is allowed to colonize dowels suspended within the water column. Data will be expressed per unit area (Newman et al. 2003). Periphyton structure and function (community assemblages, P cycling rates, and tissue P content) can be highly variable temporally, with substantial changes occurring on the order of days to weeks. Because of this variability, comparisons of enzyme activities across years is less informative than understanding the variability on shorter, weekly to monthly, time scales. Therefore, the optimal sampling schedule for measuring phosphatase activity in the DPM is to conduct sampling during the high-flow event, rather than comparing phosphatase activity measured within the operational window of pre- versus flow-impact years.

- **Water quality monitoring (PI Tate-Boldt, Newman):** Water column samples will be collected monthly, October through January, from slough habitat at each of the DPM sentinel stations and in the L-67A canal. Samples are collected mid-water column using a peristaltic pump, preserved and analyzed following standard District protocols. Water samples will be analyzed for alkalinity, calcium, chloride, dissolved organic carbon, hardness, potassium, magnesium, sodium, ammonium, nitrate + nitrite, ortho P, sulfate, total N and Total P.

- **Preparation of solid samples for biogeochemical analysis (PIs Choi, Newman, Harvey, Saunders):** Biogeochemical analyses (total particulate phosphorus (TPP), microbially bound P, labile P, loss on ignition, and total nitrogen) will be performed on three types of solid samples: bed floc, epiphyton from vegetation stems, and suspended solids from 2 depths within the water column. Bed floc will be collected by inserting a 20-cm acrylic core tube into the peat, capping, and withdrawing the intact core. After the floc settles, the clear overlying surface water will be poured off. Floc will then be poured off and collected in 1-L plastic Nalgene bottles. Epiphyton will be collected with a wet-dry vacuum as described in Larsen et al. (2009b). The intake of the vacuum will be placed against vegetation stems and moved up and downward in the water column while sampling in order to obtain a depth-integrated sample. Suspended solids samples will be collected as described in Noe et al. (2007). To obtain more detailed information on particle chemistry, water column total particulate phosphorus (TPP), labile (i.e., bicarbonate extractable) P and microbial (chloroform extractable minus bicarbonate extractable) P will be obtained from water samples collected in November of each year. Samples collected for water column suspended sediments are passed through 500 µm Nitex mesh prior to being stored on ice and brought to the laboratory for processing. Immediately upon return to the laboratory, samples are filtered through a 0.2 µm Pall membrane filter. The filters are extracted, digested and analyzed for TPP, microbial and labile P as described below. Particulate mass is recorded on two filters per sample

    - **Total particulate P (TPP):** TPP will be obtained from bed floc and epiphyton samples for all ridge and slough sites during the pre-operation period. During the operations period, this set of samples will again be collected immediately prior to the flow release. In addition, suspended particles within the water column will be sampled from a single depth (mid water column) at sentinel sites, with an additional sample collected at a depth of 5 cm above the floc layer at 5 sentinel sites during pre-, operational and post-operational periods. Total P will be determined on particles collected on 0.2 µm filters.

    - **Chemical fractionation for particulate P:** Chemical fractionation will be performed on bed floc, epiphyton, and suspended solids within the water column to determine the microbial and labile fractions of P. A complete set of samples for chemical fractionation will be obtained from all ridge and slough sites once during the pre-operation period and once during the operational period immediately prior to the first flow release. During the flow release, chemical fractionation will be performed on one set of samples for each site.

      Phosphorus fractionation will be performed using a modified Hedley procedure (Hedley et al., 1982). For each fractionation, replicate filters will be collected. The labile P fraction will be extracted from one of the filters by the addition of 0.5 M $NaHCO_3$, followed by shaking, centrifugation, and digestion of the supernatant. The microbial+labile fraction will be extracted from the suspended particles on the other filter by the addition of $CHCl_3$ followed by overnight incubation and then by the addition of $NaHCO_3$ as described above. The microbial fraction will be estimated by differencing the microbial+labile fraction and the labile fraction.

- **Total particulate nitrogen:** Replicate filters from samples collected for chemical fractionation for particulate P will be analyzed for total particulate nitrogen. Analyses will be performed using standard procedures.

- **Spatial survey of floc and soil:** Spatial surveys of slough floc and vegetation community are conducted during the wet season to quantify gradients in floc biogeochemistry across the study site, to evaluate how flow changes these gradients. 28 sites are sampled and in slough habitats within the RECOVER-MAP subplots (see site selection). The sites for these measurements are provided in the sampling matrix file "DPM_Sampling_Matrix.xlsx". A subsample of these sites are selected to measure the spatial gradient in sediment transport as a function of distance from the S-152.

- **Particle Transport (PIs Choi, Saunders, Harvey, Newman, and Tate-Boldt):** Particle transport will be studied in a three-tiered approach that utilizes 1) *in situ* transport of natural particles (SFWMD, Saunders), 2) a complementary study of the tracking of natural particle mobilization during the flow-release (USGS, Choi and Harvey), and 3) the release and tracking of artificial tracers (SFWMD, Tate-Boldt and Saunders). The complementary studies provide a powerful approach to understand the transport and fate of particles by exploiting the advantages of each method and minimizing the disadvantages. Both the *in situ* natural particle study and the natural particle mobilization study during flow releases incorporate measurements of physical characteristics of entrained sediments along with phosphorus concentrations and additional chemical markers unique to natural particles from epiphyton compared with bed floc. The artificial tracer experiment uses a dual signature tracer (DST) particle that is hydraulically matched to natural particles. While the DST tracers are only detectable over short spatial and temporal scales, they offer the best means to quantify particle interception on vegetation stems during transport. Thus, the two natural particle experiments will serve for long and short-range validation of particle transport and contribute independent information about the role of vegetation stem interception in sediment deposition.

  - ***In situ* natural particle tracers (PI Saunders):** The transport and deposition rate of floc particles among adjacent ridge-and-slough habitats under baseline and high-flow conditions are measured using a combination of 1) horizontal transport of floc (using horizontal traps); 2) vertical deposition of floc; 3) floc standing stocks; and 4) chemical analyses of advected sediment and standing floc to quantify the biogenic contributions to floc deposition, transport, and standing stocks.

    Vertical deposition of particles in the marsh will be captured following Leonard et al., (2006). Deposition rates are estimated as grams per ground area per time, where ground area is measured from the diameter of trap inlet. Horizontal transport of floc will be measured employing methods described in Philips et al., (2000), in which a PVC/polyethylene sediment sampler (approx. 10 cm ID x 1 m) captures suspended sediments moving in the direction of water flow and induces sedimentation by settling. Samplers may be deployed within the water column or

within the floc layer to collect time-integrated samples of sediment transport in the water column and as bed load, respectively. Loading rates are estimated as grams per frontal area per time, where frontal area was measured from the diameter of the inlet and outlet tubes. Loading rates per frontal area are then converted to loading per ground area based on measured water depths

Floc standing stocks will be estimated using methods described in Neto et al. (2005), in which Aluminum corers (8 cm ID) are used to collect floc samples, subsequently subsampled for standard chemical constituents (TC, TN, TP, LOI, total dry weight).

The sampling design for the natural tracer study is aligned with the sampling plan of larger Ridge-Slough DPM work plan. Collections of floc for vertical accumulation, horizontal transport and standing stocks will involve simultaneous measurements along ridge-to-slough transects at each of the ridge-slough boardwalk sites (nominally: RS1, RS2, C1, C2 and a subset of spatial "Z" sites). Deployments will occur before, during and after the impact time windows. Vertical and horizontal traps are to be deployed nominally at six week intervals before, during and after the S-152 operational window.

- **Natural particle mobilization during flow release study (Choi, Harvey, Saunders and Newman)**: Particle transport will be studied by measuring the dynamics of mobilization of natural particles during the flow release using a combination of LISST and direct sampling by pumping (Harvey et al., 2011). Natural particle mobilization experiments will determine the bulk entrainment threshold and particulate phosphorus fluxes of natural particles of different sizes and from different source areas (e.g. epiphyton on rooted aquatics versus floating periphyton versus bed floc) through physical and chemical characteristics of sediment (Harvey et al., 2011) and natural biomarkers (described above). Through the natural particle mobilization experiment, mass fluxes of material from various sources areas will be quantified as will the standing stock of entrainable particles using the methods of Harvey et al. (2011).

  The natural particle mobilization experiment is unique in automating particle size detection using the LISST and also quantifying source areas (epiphyton vs. floating periphyton vs. bed floc). Complementary Dual Synthetic Tracers (DST, see next section) are more accurate tracers of particle movement over a defined flow path but as synthetic tracers lack information about source of sediment and fluxes of particulate nutrients. Both of the tracers provide complementary information for quantifying floc transport distances and interception by vegetation. Thus, combining the two approaches provides the most comprehensive information about particulate material sources, fluxes, and transport distances.

  Two questions addressed by the combination of DST tracers and natural particle mobilization experiments are 1) what fraction of mobilized particles are captured by the ridge, and 2) what the distance that slough particles are transported into the

ridge—an important quantity to which ridge spreading rates are expected to be sensitive. Furthermore cooperation between natural particle mobilization and DST tracing can reveal the extent to which enhanced settling of particles within vegetation canopies serves as a permanent sink for sediment and associated particulate phosphorus within ridges and sloughs. Present-day sloughs are more densely populated by emergent vegetation than under historic conditions (Bernhardt and Willard, 2010), but the role of that vegetation in enhancing sedimentation (possibly leading to loss of sloughs) is not well understood. In this way the natural particle mobilization experiment operating in parallel with the DST tracing will address two critical uncertainties in understanding how the ridge and slough landscape evolved, has degraded, and may be restored. These data can be compared with results of ongoing modeling work (Larsen and Harvey, 2010), which suggests that redistribution of floc from sloughs to ridges is essential to maintaining distinct ridges and sloughs.

- **Dual Signature Tracer (DST) Studies (PI Tate-Boldt, Saunders):** Particle transport will be evaluated using a dual signature tracer (DST) that is hydraulically matched (i.e., representative) of the mean particle size and settling velocity of sediment collected from the study region. The DST particle is made of an inert fluorescent material in which magnetite inclusions are imbedded (Partrac 2005, 2006, 2008). The tracer will be "dropped" as frozen blocks at each site to ensure minimal contamination. A "drop" typically consists of 20-40 kg of tracer with a unique fluorescent signature per treatment. Tracer will be retrieved using magnetic rods in a sentinel and synoptic design in order to provide adequate temporal and spatial resolution. The sentinel study (moderate spatial but high temporal frequency) will consist of five 30,000 gauss magnets deployed perpendicular to the flow path 3 m downstream and upstream from the drop zone. Magnets will be continuously suspended in the water column and visited monthly to collect any adhering tracer. The tracer will be dried and weighed (g dw/pole) and summed for each magnet (g dw/magnet). Given the 5 cm effective capture radius of the magnet (i.e., any tracer passing within 5 cm of the magnet will be captured), the mass of tracer on each magnet can be expressed per unit area. When combined with the cross-sectional area of the channel (determined from microtopography measurements of the slough), we can estimate the downstream mass flux of tracer (g of tracer/day). Additionally, the vertical distribution of tracer on the magnet provides information of the vertical transport of particles (i.e., are particles suspended in the water column or transported as bed load?). To assess the redistribution of particles, synoptic maps (high spatial but low temporal frequency) of tracer will be obtained by probing sediment beds and vegetation beds with a magnet and determining tracer mass. Synoptic measurements will be made at six-month intervals. To aid in the determination of tracer flux and re-distribution before (low flow) and after (high flow), two tracer drops of different color will be scheduled per treatment.

- **Description of animal/foodweb responses to nutrient loading (PIs Trexler, Dorn, Hansen).** DPM phase 1 created a zone of nutrient enriched marsh immediately downstream from the culverts.

In addition to changes in the periphyton, small fish density is clearly elevated in the area typical of nutrient enriched sites (Turner et al 1999; Trexler and Loftus 2015). DPM phase 2 will include characterization of aquatic communities across the DPM study area and in reference/control transects. Throw-trap sampling, as used in DPM phase 1, will be conducted at 14 sites in addition to 15 sites already sampled in this way and continued in phase 2. Three samples will be collected at each site three times per year (early and late in the flow event and once late in the dry season); the exact locations of the sites will be coordinated with other DPM research groups to avoid impacts on hydrologic and biogeochemical data gathering, but leverage those data for interpretation of throw-trap data to the extent possible. Slough sites for macroinvertebrate sampling will also be coordinated with DPM researchers and fauna sampling described above. Throw-trap and sweep-net sampling sites will be co-located with algal and fauna sampling to the extent feasible.

- **Food-web linkages (PIs Trexler, Dorn, Hansen).** In DPM phase 1 we conducted a pilot experiment demonstrating the use of field enclosures to document food-web transfers of nutrient loading to biofilms growing in the DPM into consumers. In DPM phase 2, we will apply results from that study to establish food web linkages of biogeochemical effects of flow that have direct influence on the production of food for apex predators like wading birds and alligators. We will hold selected fish and macroinvertebrates in field cages placed in and out of the Physical Model flowpath where they can feed on algal and bacterial mats and invertebrates to document the effects of flow on food-webs. We will use 1-m^2 cages to hold consumers that have been previously maintained in the laboratory on diets selected to standardize their fatty acid (FA) and stoichiometric tissue composition. Work from DPM phase 1 demonstrated that FA profiles are powerful markers of diet that are in equilibrium with diet changes within a three-week period. In our phase 1 experiment, we demonstrated that an herbivorous fish, Sailfin Mollies, but not an omnivorous fish (Eastern Mosquitofish) or an omnivorous invertebrate (Riverine Grass Shrimp), demonstrated marked change in FA and stoichiometric tissue composition when placed in high-flow velocity conditions compared to one in low-flow conditions. This work will be extended by running six-week experiments and sampling periphyton-mat inhabiting invertebrates, in addition to fish, to document the impacts of nutrient loading on food-web function across 3 trophic levels. We will place cages in the DPM flow path and outside of it to provide flow enhanced and not-enhanced treatments. This experiment will be repeated in the late dry season, when water is not flowing, and in November-December when water is flowing.

5. Modeling and Data Synthesis

After success in increasing and redirecting flows through small-scale slough creation, hydrologic models have been developed to determine the feasibility of active management on a landscape scale. The Environmental Fluid Dynamics Code (EFDC) hydrologic model (through the program EFDC Explore) has been calibrated and validated for the DPM footprint within the pocket and used it to provide an initial assessment on whether removal of emergent vegetation (sawgrass) could theoretically redirect and increase flow on a large scale. Modeling results suggested such vegetation removal could strongly alter flows. Using the modeling as a proof of concept, field manipulations have been initiated to connect and expand remnant sloughs, using historical imagery (1940's) to determine where herbicide should be applied to areas invaded by sawgrass. Scaling up the basin-level, we have also created an EFDC-based model of WCA-3B to determine the extent

to which removing dense emergent vegetation can change direction of flows from the DPM levee gap south, along the historic Shark River Slough flow path, to the S-355 structure.
Field results from the DPM will be compared with published and ongoing modeling outcomes from other funded studies. Physically-based modeling of water flow, sediment transport, and the influence of vegetation flow resistance are being assessed though one dimensional (radial) simulations with matching between modeled and measured flow velocities, water depths, vegetation imparted flow resistance, and resulting water and sediment exchange between ridges and sloughs (Choi, Gomez-Velez, and Harvey, in prep.).

To understand how internal cycling and flow-driven transport impact P cycling and water TP over the landscape, the Ribbon model (Saunders et al. in prep) summarizes the major ecosystem P stocks (plants, fauna, detritus, floc and soil), P fluxes (ecosystem P retention and cycling rates) and water-column P concentration (TP) for conceptual hydrologically linked landscape "ribbons". This approach includes both the construction of a static budget for representative ridge and slough communities and a dynamic model (using STELLA modeling software) that simulates P cycling within and exchanges between landscape "ribbons" connected by flow. These budgets and models have been parameterized with *in situ* measurements (from 2000 to present) of plant community composition, above- and below-ground biomass and production, periphyton uptake, detritus decomposition, nutrient mineralization/immobilization, sedimentation, water residence, and floc metabolism provided through the Florida Coastal Everglades Long-term Ecological Research (FCE LTER) program. Previous applications of the Ribbon model in oligotrophic and canal-impacted wetlands of Shark Slough showed the highest sensitivity of water TP and ecosystem P stocks and fluxes to habitat exchanges of water and floc P and to floc cycling rates. For the DPM, a similar approach is being used to generate static and dynamic sediment and P budgets for ridge and slough habitats in different, contrasting landscape zones of the DPM footprint (e.g., marshes near canal/levee structures; interior marshes; open-water canal habitat). These budgets, linked by sheetflow and sediment transport, help highlight the ecosystem processes driving landscape P cycling, summarize the observed spatial propagation of P loading effects, and identify key uncertainties when P budgets reveal inconsistencies (e.g., missing sinks/sources) within habitats or between landscape features or zones. The data synthesis used to generate sediment and P budgets may be used for calibrating or comparing with other ecosystem modeling described above and sedimentological RASCAL model (described below).

A complementary USGS effort funded through the PES program is the ongoing development, validation, and adaptation of the RASCAL (Ridge and Slough Cellular Automata Landscape) model (Larsen and Harvey 2010, 2011) to better address restoration uncertainties. RASCAL simulates the in-place sediment accretion and sediment redistribution feedbacks thought to be essential for maintaining a patterned ridge and slough landscape; global sensitivity analyses of the model suggest the combinations of flow velocities, water depths, and water surface slopes needed for long-term preservation of this landscape. However, given the low ambient flow conditions, it has not been possible to validate the model's predictions of flow and sediment transport processes under landscape-forming conditions. The flow releases scheduled for the operational period of the DPM will provide a unique and unprecedented opportunity to validate model predictions and refine the simulation of processes if necessary.

Measurements obtained through DPM monitoring will also provide critical information to further refine RASCAL by explicitly testing the "sediment redistribution hypothesis" and furthering that test to understand the role of redistribution of sediment associated particulate phosphorus transport into the simulation (Larsen et al., 2015). The model currently assumes that refractory carbon in sediment is of primary import in landscape-building processes through the augmentation of topography. However, recent work (Harvey et al., 2011; Noe et al., 2010) shows that bed and epiphyton floc may also contain substantial quantities of phosphorus, which could indirectly influence topographic evolution through stimulation of primary productivity and/or decomposition. Incorporating particulate phosphorus transport into the model will allow us to compare the effects of these different mechanisms of landscape development on landscape morphology and sensitivity to altered concentrations of phosphorus and/or altered hydrology. These comparisons will inform the development of restoration targets.

6. Maps or schematic of sampling sites/design

See **Figure 2-1** for an enlarged view of the DPM footprint and locations of the monitoring stations. Station name abbreviations are as follows:

C = control

RS = ridge/slough

S = slough

UB = upstream backfill

DB = downstream backfill

CB = canal backfill (synonymous with "MB")

CC = canal control

Z = zone (1-18) for spatially stratified sampling design

IV. Quality Assurance and Control (QA/QC)

a. Quality Control Requirements and Procedures

Data, including a summary index, derived from the project will be provided to the project manager with the submission of each Annual Report as hard copies (e.g., CD) and via email or FTP site. All data formatting, analysis, and delivery will meet the CERP data standards. In addition, the metadata template provided in the SOW as Attachment 3 will be submitted for EACH data set.

Quality Assurance and Quality Control (QA/QC): Many of the methodologies used to address the DECOMP uncertainties are considered state-of-the-art or require sampling specifically suited to DPM objectives. Therefore, the DPM science team has worked closely with the QAOT to develop the appropriate Standard Operating Procedure documentation. Sampling methods in DPM follow those procedures described in the QAOT-approved (SOPs) specific to individual DPM sampling tasks, rather than general sampling methods (e.g., CERP Quality Assurance Systems Requirements Plan (QASR), www.evergladesplan.org/pm/program_docs/qasr.aspx. ; FDEP Standard Operating Procedures for Field Activities (DEP-SOP-001/01), www.dep.state.fl.us/labs/qa/sops.htm; FDEP Standard Operating Procedures for Laboratory Activities (DEP-SOP-002/01), www.dep.state.fl.us/labs/qa/sops.htm,; New and Alternative Analytical Laboratory Methods (DEP-QA-001/01), ftp://ftp.dep.state.fl.us/pub/labs/assessment/sopdoc/2004sops/newalt.pdf). The primary investigators are listed next to the field method as the primary contact person.

Instrumentation, including the hydrologic monitoring network, are calibrated and maintained before use and deployment. This will include complete sensor assessment and calibration, firmware, and software upgrades, real-time data collection, and simulated deployments to assess data quality. After the equipment has been deployed, data from long-term autonomous deployments will be collected and downloaded monthly. For the hydrologic monitoring network, portable equipment will be QA/QC'd in real time by USGS personnel (CFL-WSC, USGS Reston).

b. Corrective Action

According to the Quality Assurance Systems Requirements manual, corrective action is any measure taken to rectify conditions adverse to quality and, where possible, to prevent recurrence. For the hydrologic monitoring network, any data that does not meet QA/QC requirements the corrective action will be documented. For the case of sensor data this may include the removal of data from further analysis and consideration.

V. Data Management

a. Data Review (Verification, Validation, Assessment)

The quality of data generated during technical activities must be assessed both in real time and retrospectively. Thus, data generators (participating field and laboratory groups) are responsible for data verification. This involves reviewing instrument calibration, raw data, and quality control results in real time to ensure it meets QAOT reporting requirements. This will be done in real-time for the portable data collection and done monthly for the autonomous deployments.

Individual principal investigators assume the responsibility of providing valid data; thus, are responsible for validating data according to standard operating procedures and/or prescribed procedures. They will maintain documentation of validation findings, add validation qualifiers to denote data quality failures, and prepare reports that summarize issues that could limit data usability. Data review (Verification, Validation, and Assessment) will be performed by a minimum of two scientists familiar with the methodology by examining the data through graphical

means and the pre and post calibration sheets. The five steps of the Data Quality Assessment Process, according to EPA QA/G-9R will be followed.

b. Data Maintenance and Integrity Assurance

Our intent is to store raw data within each agencies database: ERDP maintained by the Everglades Division at the South Florida Water Management District and SOFIA, the USGS database. These databases have a long and well-established history that will ensure data maintenance and assure integrity. We will comply with the data maintenance requirements of CERP. As CERPzone, the CERP RECOVER database is currently online, DPM data will be provided following the guidelines provided by CERPzone. In addition, there is an effort at the South Florida Water Management District to develop an Ecology Database similar to DBHYDRO, if this product comes on line, raw data from the DPM could be migrated to that database. Metadata Tables will be completed to ensure that CERP data guideline requirements are met.

VI. Schedule of Deliverables

Annual report of data and preliminary analysis are due September of each year, starting 2018. Data derived from all sampling processes described in the annual work plan will be archived and affirmed for quality.

Status and preliminary findings will be summarized in the semi-annual reporting of results due March of each year, starting 2018.

VII. Literature Cited

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Part 3. Hydrologic and ecological monitoring of the Canal Backfill treatments

I. Statement of issue and study objective: Task 2: Biological Monitoring

The DECOMP Physical Model (DPM) is a large-scale field test designed to address uncertainties associated with the CERP DECOMP project, specifically to reduce the environmental risks and aid alternative selections associated with PIR 2 and PIR 3. The project couples the construction and operation of hydrologic features and design alternatives with a comprehensive hydrological and ecological monitoring plan. The intent is to coordinate the operation of the hydraulic features with the collection of monitoring data in a statistically robust manner to reduce uncertainty.

The conceptual proposal for sheet flow restoration in the central Everglades, not including the Miami Canal, calls for the degradation of approximately 75 mi (121 km) of levees and the complete backfilling of 84 mi (135 km) of canals (USACE and SFWMD 1999). While the need for levee degradation to re-establish sheetflow is well established, there remains uncertainty and controversy over the need to backfill canals to marsh grade (complete backfill), particularly in canals that are oriented perpendicular to the direction of flow, to minimize hydraulic short-circuiting to marsh flow. This is primarily because it is not known if a physical surface connection is an absolute necessity to restore the ecological function of the ridge & slough system or ecosystem connectivity. There are two primary reasons (arguments) against completely backfilling the canals thus warranting the investigation of alternatives. First, the existing network of canals supports a highly prized and valued sport fishery. Second, the complete backfill of all the canals may not be economically viable.

The first objective of this study is to characterize the resident fish and invertebrate assemblages within the L-67C that has been engineered to include a breech in the levee and a complete canal backfill, partial backfill, and no-backfill treatment. Data collection focuses on use of the adjacent marsh by these organisms. Included in the assessment is the determination of habitat quality (e.g., temperature regimes, dissolved oxygen profiles) and assessment of canals as refugia should the environmental opportunity present itself (i.e., droughts). The study will test nine hypotheses related to canal backfilling and levee removal, as outlined in the Science Plan (DPMST 2010).

The second objective of this study is to quantify the effect of backfilling treatments and interactions with sheetflow on hydrology, sediment and nutrient dynamics in and around the L-67C canal and levee gap. The USGS and SFWMD sub-teams are addressing the need for mass balance information about sources of water, sediment, and phosphorus crossing the L-67C breach. This includes determining the effect of increasing flow velocities, along the canal, and its potential role to entrain sediments. Particularly, we will evaluate the role of backfilling in maintaining low-nutrient sediment redistribution and determine the canal role as a nutrient sink or source. Four years post-construction, vegetation communities continue to change in the backfill treatments in the L-67C. Vegetation surveys will be conducted to understand the role vegetation plays in shaping hydrology, sediment and nutrient dynamics.

II. Statement of work (abbreviated)

This work plan addresses research activities seeking to evaluate the response of aquatic communities, particularly fishes, and canal physiochemical environments to a landscape-scale manipulation of water flow accomplished by breaching a levee, introducing enhanced water flow velocities, and altering canal depths adjacent to Everglades marshes. These manipulations have the potential to alter seasonal use of habitats by fish and alter population and community dynamics in the canal and adjacent marshes, with possible implications for ecosystem function. These changes have the potential to improve Everglades fisheries and alter the role of top-down controls on ecosystem function by changing habitat connectivity and seasonal community dynamics. To address these uncertainties, hypotheses related to aquatic communities were included in the DECOMP Science Plan (DPMST 2010) that serve as the key motivating statements for the research proposed here:

The USGS-Reston sub-team is quantifying the contributions to flows crossing the L-67C levee breach including canal flows approaching from the northeast or southwest, flow contributions crossing over the breached canal section from the DPM experimental area, and flows from groundwater. Principal components for the work include acoustic Doppler profilers (Sontek acoustic Doppler profilers referred to as Argonaut-SWs) which will be deployed at several locations in the L-67C canal to provide continuous records of canal flow by sampling vertical profiles of flow velocity and direction in one-minute bursts collected every 30 minutes. Those data will be combined with flows computed from the UB and DB sites and occasional Sontek Flowtracker surveys (coordinated with SFWMD) for measuring flows across the L-67C levee breach, and occasional sampling of groundwater. In order to extend the mass balance analysis, flow information will be combined with sampling of suspended sediment concentration and total phosphorus concentration. Phosphorus concentrations in benthic canal sediments (from sediment cores) along the L-67C canal will provide information needed to determine the potential effect of nutrient source during the high flow events. This new data along with our continuous record of sediment (and associated nutrient) accumulation rates will provide a better understanding on distribution and remobilization of sediments and nutrients within the treatment sites during high flow events.

Conceptual model for effects of compartmentalization on faunal communities

Aquatic community responses to decompartmentalization of WCA-3B and 3A will occur at multiple trophic levels and have the potential to be complex. Two strong ecological drivers will generate these changes: connectivity across the wetland landscape, including to canals that act as dry-season aquatic refuges; and hydrological modification of water flow with implications for microtopographic relief, vascular plant cover, floc dynamics, and biogeochemistry of phosphorus. Other effects will be a spatial re-distribution of hydroperiods across the landscape that will shift core population areas geographically. These changes are likely to alter patterns of density, standing crop, and relative abundance of fishes and macroinvertebrates at the local and landscape scale with implications for community function and energy dynamics (**Figure 3-1**). Changes in the hydroscape, such as canal filling and levee removal, have direct effects on fish populations and

communities by affecting their demography (survival, mortality, and reproductive rates,) but also have indirect effects by affecting their behavior (movement rates and habitat choice). Everglades aquatic animal populations are spatially structured by the annual expansion and contraction of the flooded landscape, which is responsible for the creation of high-quality prey patches for apex predators such as wading birds and alligators. The DPM provides an experimental framework for analyses of this dynamic.

Increased rates of wet-season water flow are anticipated to re-distribute floc in space. Though the benthic macroinvertebrate community has lower density than is found in floating mats, this is the habitat of crayfish and grass shrimp that are important food items for wading birds and aquatic predatory species. In addition to the direct effects of re-distribution of floc by increased wet-season flow rates, changes in energy flow are certain to have implications up the food web that are not currently appreciated. Changes in microtopography will probably affect patterns of concentration of fish and macroinverbrates in dry season, with implications for the availability of food to wading birds during nesting.

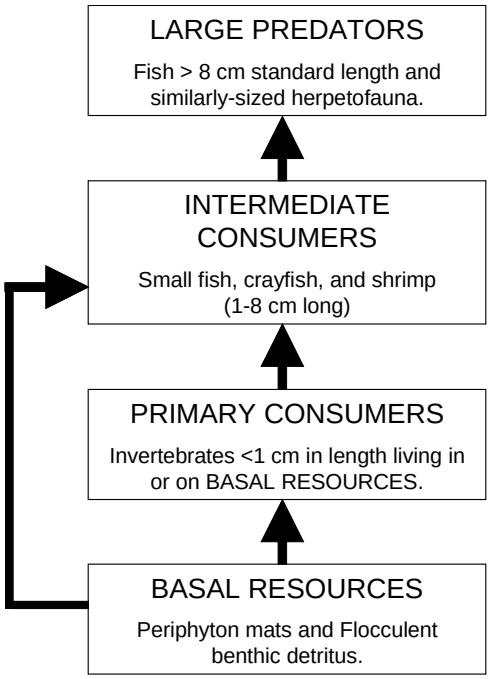

Figure 3-1. Simple diagram of aquatic food web in the Everglades. With access to canals (or very long hydroperiods as seen in WCA-3A), the top box has more animals and decreases the density of intermediate consumers Predator exclusion studies indicate that this changes patterns of grazing on basal resources. It probably also increases primary consumers, but we haven't found evidence of that yet (redrawn from Dorn et al. 2006).

Canals currently effect fish populations by acting as conduits for movement across the landscape. This is supported by genetic analysis of spotted sunfish (*Lepomis punctatus*) indicating that canal populations are more homogeneous than those in marshes (McElroy et al 2003). Furthermore, tracking of Florida gar (*Lepisosteus platyrhincus*), Mayan cichlids (*Cichlasoma uropthalmus*), and largemouth bass with surgically implanted radio transmitters indicates that these fish at times move long distances across the marsh, often ending in canals in the dry season (unpublished data).

Other potential effects of decompartmentalization may come from changing habitat use by alligators and fish. Alligators are critical environmental engineers in Everglades wetlands. When access is available, alligators tend to use canals for habitat instead of marsh ponds. This leads to fewer alligator ponds in the marsh near canals and affects the size and age structure of alligator populations. Alligator holes are a refuge for survival through drought by fishes and other aquatic animals when they are present. The loss of this habitat, or its re-distribution in space, is certain to have important cascading effects on aquatic animals in the marshes, though no studies have addressed this issue directly. In fact, recent analyses indicate that alligator ponds near canals in

the Southern Everglades hold fewer fish in the dry season than ponds distant from canals (Parkos and Trexler, unpublished ms). Thus, canals appear to affect the seasonal dynamic and dry-season refuge use of top trophic levels in the Everglades, with as yet poorly understood implications for ecosystem function in marshes or at the landscape scale.

Decompartmentalization seems likely to affect Everglades fisheries by increasing the flux of prey fishes into deep-water habitats and increasing access of juvenile game species to marshes. Largemouth bass are the primary native species targeted by anglers in Everglades interior canals. Our tracking data indicate that these fishes move from canals into marshes during the wet season, presumably to feed and possibly to escape their predators. They move back to canals during the dry season, presumably to find refuge from drying marshes and possibly to take advantage of concentrated prey; it is this dry-season concentration that supports widely praised Everglades fisheries. Understanding this dynamic has the potential to contribute to DECOMP engineering plans that serve both ecosystem function and fisheries productivity. Canal backfilling alternatives included in the DECOMP (DPM), and the response of game fishes to them, will be an important contribution of this effort.

III. Sampling Design

1. Schedule

A schedule of tasks to be completed for addressing the L-67C levee gap and backfilling hypotheses as part of year-round testing is provided in **Table 3-1**, including schedules for previous baseline and dry-season flow years. Sampling tasks are organized by vegetation, hydrology, biogeochemistry and sediment characteristics and fluxes. Flow releases are expected to be initiated in the months spanning July to October, earlier in relatively wet years and later in drier years. Monitoring will be conducted at intervals that bridge the operational window, with special efforts focused during the operational window.

A matrix describing, in detail, the coordinated sampling among the different research groups is provided in an electronic appendix to this document ("DPM_Sampling_Matrix.xlsx").

Table 3-1. Schedule of tasks to be completed for addressing the Canal Backfill hypotheses, including baseline (no flow) years, dry season flow years (2013-2017), and year-round testing years (latter organized by water year). ** A fourth year-round flow year is included as a contingency in the event flow is not possible in one of the previous years or additional data are required for statistical power.

(i) = installed					Year-Round Flow1			Year-Round Flow2			Year-Round Flow3			Year-Round Flow4 **		
	Baseline	Dry Season Flow Years			(May17-Apr18)			(May18-Apr19)			(May19-Apr20)			(May20-Apr21)		
Sampling tasks - L67C monitoring	Years	pre-	flow	post	pre-	flow	post	pre-	flow	post	pre-	flow	post	pre-	flow	post
Vegetation structure																
microtopography	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
vegetation frontal area	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
vegetation surveys (landscape survey, imagery, or site-specific surveys)	x	x	x		x (month to be determined)			x (month t.b.d)			x (month t.b.d)			x (month t.b.d)		
Hydrology																
pressure transducers	(i) x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
acoustic doppler profilers	(i) x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
water depths	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
flow velocity & direction	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Water tracer releases (SF6, Dye)			x			x			x			x			x	
Biogeochemistry - processes & attributes																
Water Quality Monitoring (incl. TSS & Partic-P)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Ecosystem metabolism	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Fish responses	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Invertebrate responses		x	x													
Sediment Chars & Fluxes																
suspended sediment concentration & size characterization (grabs)	x		x		x	x	x	x	x	x	x	x	x	x	x	x
in situ monitoring of SSC & size (single station)	x		x		x	x	x	x	x	x	x	x	x	x	x	x
sample collection particulate-P	x		x		n/a (see Biogeochem.)			n/a (see Biogeochem.)			n/a (see Biogeochem.)			n/a (see Biogeochem.)		
floc, soil & epiphyton collection for biogeochemistry & size distribution	x		x		x	x	x	x	x	x	x	x	x	x	x	x
Sediment settling (vertical traps)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Sediment transport (horizontal traps)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Biomarker analysis (sediment, veg.), paired w. traps (discontin. Mar2016)	x	x	x	x												
Floc collection & chemical analysis, paired with traps	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
DST tracer releases & synoptic sampling						x			x			x			x	

2. Site Selection

Three sites will be located within each treatment on the L-67C canal coordinated with monitoring of the physical environmental parameters. Sites will be designated as NCC and SCC (control canal, north and south, respectively), CB1 (open canal), CB2 (partial backfill canal), and CB3 (complete backfill canal) followed by the replicate number (1, 2, and 3) to match sample identifications used by other groups at the same sites. Exact locations for sampling will be coordinated in order to avoid interference with other sampling protocols. Sites are described previously in Part 2 (**Part 2. III. Sampling Design**) of this document and in **Figure 2-1**.

3. Experimental/Spatial Design

Statistical methods: A Before-After Control-Impact (BACI) design will be used to assess differences among treatments in response to increased flow.

4. Field Methods/Lab Methods

A. Fish and Invertebrate Monitoring

DPM phase 1 research documented significant effects of canal and levee alternation on small and large fish populations and communities. Small fish density was increased in the immediate vicinity of the canal fill treatments, probably by a combination of demographic and behavioral effects. Large fish populations were also affected by the canal manipulations, most clearly through habitat choices re-sorting the fish across the landscape and creating new and attractive habitat in the canal-fill areas; most changes in the large-fish community documented to date resulted from behavior and especially movement. Levee removal definitively re-connected formerly isolated areas of the Everglades, with several radio-tagged Largemouth Bass, Bowfin, and Florida Gar moving from the Gap into WCA 3B. All three of these species were shown to traverse areas far exceeding the DPM study area, traveling miles north and south within the Gap, passing from through a degraded levee area 6 miles north of the DPM canal treatments, as well as through the DPM degraded levee to access WCA 3B. Within WCA 3B, a few individual fish moved to the southeastern extreme end and back within a several-month period. One tagged Largemouth Bass was caught by a fisherman, released at the L-67C boatramp, and within one week swam several miles north to the general area where it was caught in the DPM study area. These large fish provide a mechanism to integrate impacts of marsh restoration over large areas through increased connectivity caused by levee removals.

It is clear that changes in the aquatic communities in response to canal filling and levee removal are still ongoing. For example, small fish communities east of the L-67C canal and levee in WCA 3B were changed by its removal, but have not yet converged on compositions similar to the Gap or areas distant from the canal. Continued tracking of these communities is needed to evaluate if, and over what timeframe, canal/levee manipulations can restore ecological function. Therefore, DPM phase 2 work should include some continuation of data gathering from phase 1 and some new activities addressing questions arising from phase 1 results.

- **Canal Fishes (PI Trexler):** To determine if fish assemblage structure differs among canal treatments, each treatment will be surveyed using electro-shocking at most five times per year (Chick et al. 1999; Chick et al. 2004). Because electrofishing is non-destructive, sampling will be conducted immediately before and after flows are manipulated. Additionally, dual frequency identification sonar (DIDSON; http://www.soundmetrics.com) will be used to estimate fish density in the canal backfilling treatment areas (Holmes et al. 2006). This methodology is complementary to electrofishing, which is limited in its usefulness because cichlids are not equally susceptible as native centrarchids and most electrofishing applications target surface fishes. DIDSON can be used to provide supplemental evidence in the form of 'sonic videos' of fishes in canals when vegetation density is relatively low, as in the open canal treatment area.

- **Marsh Fishes (PI Trexler):** To assess fish use of the canal treatments and the importance of connectivity, throw-trap samples will be taken adjacent to the canal treatments and at two distances downstream. Three 1-m^2 throw-trap samples will be taken at each canal treatment at each of the three distances from the canal, as well as at reference/control sites to the north and south of the DPM study area, for a total of 45 samples per sampling event.

- **Fish Movement (PI Trexler):** To capture fish movement, up to 20 large fish each of two species (largemouth bass and bowfin) will be tagged with radio transmitters and their positions determined at weekly intervals, again with extra intensity immediately before and after flow manipulations (Winter 1996). Species choices will be determined by data gathered on the relative abundance of species at the collection site. Fish must be large enough that transmitters weigh no more than 5% of the fish mass, setting a minimum size for the target study species.

  Unlike large fish that can be tracked directly, movement of fish too small for transmitters must be documented by indirect means. Drift fences will be established at all sites where throw-trap samples are collected to capture the directionality and biomass of fishes moving across the landscape. Drift fences will function similarly to fyke nets and will be fitted with minnow traps to capture small fishes. Drift fences provide data on the 'encounter rate' of the trap as fishes move across the landscape. These data will be supplemented with density and biomass estimates of small fishes obtained using throw traps (Jordan et al. 1997). Obaza (2009) has recently demonstrated that data from encounter samples, such as drift fences, and density samples, as from drift fences, can be combined to yield estimates of small fish speed and direction (see also DeAngelis et al. 2010). As implied by hypothesis ***BH08*** (DPMST 2010), opening connections to canals may alter small fish movement patterns in the marshes, with implications for ecosystem

function in the donor and recipient habitats, for example related to local grazing impacts and food production for higher consumers such as wading birds.

B. Canal Sediment and Nutrient Dynamics Monitoring

- **Water quality monitoring (PI Tate-Boldt, Newman):** Water column samples will be collected monthly, October through January, from slough habitat at each of the DPM sentinel stations upstream and downstream of the L-67C canal/levee gap. Sampling will include the same parameters and methods listed for the ridge and slough monitoring (see **Part 2. III. Sampling Design. Section 4. Field Methods/Lab Methods**).

- **Canal Sediment Traps (PI Coronado-Molina):** To capture vertical particle fluxes, three sets of vertical sediment traps per treatment will be suspended 1 m above the sediment-water interface. For canals, a set of vertical sediment traps consisting of three vertically oriented tubes with an aspect ratio (length:width) of 8:1 (Kerfoot et al. 2004) will be deployed. After the canal has been completely backfilled, sediment dynamics will be monitored in the shallow water marshes upstream and downstream of the canal using horizontal traps (Phillips et al., 2000) and vertical traps (Leonard et al. 2006). Shallow water traps samples will be coded with an additional modifier: M (marsh, upstream) and DB (i.e., DB-1, 2 and 3 sloughs). Sediment traps will be deployed continuously with canal vertical trap collections every 3 weeks (Nov-Dec) and every 6 weeks (Jan-Mar). To develop a more complete sediment budget for the canal locations, horizontal sediment traps (see description Part 1, above) may be deployed in slough habitats downstream of the L-67C gap at the DB sites. The deployment and retrieval frequency follows that of the canal traps. Sampling may also be coordinated with relevant construction milestones (breaching of the L-67C levee).

  Upon retrieval, the collected material (from sediment traps or standing sediment) will be processed for dry weight determination and molecular organic biomarker ("biomarker") analyses. For dry weight determination, samples will be sieved through 1-mm sized screens, and the fine (<1-mm) fraction will be dried to constant weight at 80ºC. Samples will be combusted for 2 hrs at 550 ºC for determination of organic matter content. Vertical mass flux (g/m2/d) will then be calculated Biomarkers will be used to identify the source of sediment organic matter (from ridge and slough vegetation and detritus) that is accumulating in traps and in standing sediment. These analyses will follow standard organic geochemical methods previously used to characterize biogenic sources of floc organic matter (Saunders et al., 2006; Neto et al., 2006; Gao et al., 2007).

- **Continuous temperature depth profiles (PI Coronado-Molina):** Temperature data loggers (e.g., Tidbit or HOBO, Onset Computer Corporation, Pocasset, MA) will be suspended at 1m intervals on the vertical sediment trap suspension cables. Temperature will be recorded at 30-minute intervals. The resulting depth profiles will be used to determining if thermal stratification occurs.

- **Physicochemical depth profiles (PI Coronado-Molina):** Depth profiles at 0.5 m intervals for dissolved oxygen, temperature, pH, and specific conductivity will be obtained at a minimum of quarterly and pre-post flow operations using a calibrated and maintained Hydrolab multiparameter sonde (Hach, Loveland CO).

- **Ecosystem metabolism (PI Tate-Boldt, Coronado-Molina):** Ecosystem metabolism (gross primary production, ecosystem respiration, and net ecosystem production) will be estimated from high-frequency measurements (30 min) of dissolved oxygen obtained over a 5-day deployment interval from calibrated and maintained Hydrolab multiparameter sondes at mid-water column above the sediments at each sediment trap site. Calculation of estimates will be obtained following Staer et al. (2010). Deployments will be conducted quarterly and pre-post flow operations.

- **Groundwater TP (PI Choi and Harvey);** Groundwater contributions to flow and phosphorus loading to the L-67 levee breach will be assessed though installation of drivepoints for sampling groundwater concentrations of dissolved phosphorus in porewater at the base of peat but directly above the underlying limestone that demarcates the top of the surficial aquifer.

- **Dual Signature Tracer (DST) Studies (PI Tate-Boldt, Saunders):** A dual signature tracer (DST), manufactured by Partrac Ltd., Glasgow, UK, will be used determine the extent to which canals alter the movement and fate of ridge-and-slough sediments and canal-derived sediments. The DST is a novel technology utilizing magnetic inclusions in a sediment tracer, matched to the properties of Everglades sediment and is hydraulically matched (i.e., representative) of the mean particle size and settling velocity of floc collected from the study region. Sediment movement within three backfill treatments (complete backfill, partial backfill, and no backfill) will be evaluated within the L-67C canal and levee gap. The objective of the DST canal backfill treatment study will be to test for particle entrainment and advective transport across the canal; and the potential of the canal treatments to act as a particle sink.

- **Canal vegetation survey and biomass estimation (PI Manna, Coronado-Molina):** Biological and physical properties of vegetation in backfill and control canal sites will be monitored to determine their effects on the hydrologic and biogeochemical processes in the L-67C canal. SAV and emergent vegetation in the canal treatments (full, part, no and control) will be sampled after summer peak growth (august-sept), annually for species presence and in a randomly stratified approach, comparing treatment vegetation at sampling times to control site(s). Vegetation biomass, aerial cover, species presence, and tissue nutrients will be assessed with sampling events using a combination of destructive harvests and non-destructive surveying methods. This information will be paired with aerial imagery from the BOA method in order to scale field measurements to entire treatment areas, as required for evaluating relationships between vegetation abundance and spatially intensive surveys of canal hydrology (**Part C**, below) and hydraulic and material budgets of the canal backfill area.

C. Canal Hydrology Monitoring Tasks

Results from the previous 3 flow events demonstrated the need for a more spatially intensive sampling of water velocities and water quality in and around the L-67C canal and levee/gap feature. Numerous preferential flowpaths were observed resulting in highly uneven flow into canal treatments and DB sites, with implications for potential "hotspots" of sediment or Phosphorus mobilization in the canal.

To address this uncertainty for future flow events, spatially intensive sampling will be conducted in and around the canal backfill treatments. Routine (monthly or continuous) water quality, sediment and hydrology data will be collected to provide information on seasonal and interannual differences and overall data synthesis. A brief description of all monitoring tasks is as follows:

- **Continuous canal velocity and stage monitoring (Harvey, Choi)**: Monitoring setup with two continuously recording XR Argonauts in canal, stage monitoring, and continuous velocity measurements at key sites wetlands upstream and downstream.

- **Point-velocity profiles within edge vegetation bordering L-67C in FB, PB, and NB treatments (PI Soderqvist):** Point-velocity profiles (0.2 and 0.6 of depth) will be conducted within the upstream (NW) and downstream (SE) edge vegetation bordering all three treatments to provide velocity vectors and approximate discharge for water entering and leaving the L-67C canal. Geo-referenced velocity and discharge vector tables will be made available for mapping purposes.

- **Point-velocity transects across L-67C in FB and PB treatments (PI Soderqvist):** Point-velocity profiles (0.2, 0.6, and 0.8 of depth) will be conducted at various cross-sections within the FB and PB treatments (including either side of the plugs) to provide velocity vectors and approximate discharge for water flowing down the L-67C canal. Geo-referenced velocity and discharge vector tables will be made available for mapping purposes.

- **ADCP transects across L-67C in NB treatment (PI Soderqvist):** Velocity profiles will be conducted at various cross-sections within the NB treatment to provide velocity vectors and discharge for water flowing down the L-67C canal. Geo-referenced velocity and discharge vector tables will be made available for mapping purposes. Contour and planview imagery of data will be provided from USGS VMT software processing package.

IV. Quality Assurance and Control (QA/QC)

a. Quality Control Requirements and Procedures

Standard Operating Procedures (SOP) have been developed for the fish and macroinvertebrate sampling in the RECOVER program (CERP Quality Assurance Systems Requirements (QASR)). These are available for download from the CERP webpage:

Fish:

http://www.evergladesplan.org/pm/pm_docs/qasr/qasr_2007_archive/qasr_app_m.pdf

Macroinvertebrates:
http://www.evergladesplan.org/pm/pm_docs/qasr/qasr_2007_archive/qasr_app_l.pdf

A QA/QC plan has not been developed for sonar sampling by DIDSON device because this is a recent and novel method for use in Everglades research. We will develop an SOP with quality assurance plan as part of the baseline monitoring of the initial year of this project. An SOP has been developed for the maintenance, calibration, deployment, and data QA/QC for the Hydrolab multiparameter sondes and ecosystem metabolism calculations. The SOP includes corrective actions and data qualifiers. These are available for review by contacting Dr. Colin Saunders (CSaunder@sfwmd.gov). An SOP will be developed for vertical sediment traps; however, the method is based on established practices in the scientific literature and standard chemical analyses (dry weight determination and loss on ignition).

V. **Data Management**

b. Data Review (Verification, Validation, Assessment)

Data review (Verification, Validation, and Assessment) will be performed by a minimum of two scientists familiar with the methodology by comparing the electronic and raw data sheets. This will be followed by an automated analysis through graphical means.

c. Data Maintenance and Integrity Assurance

The initial plan is to house the data in the NSF-LTER database maintained by the Florida Coastal Everglades program at Florida International University, Miami, Florida (http://fcelter.fiu.edu/). All Metadata will comply with the LTER network-wide Ecological Metadata Language (EML 2.0.1) standard developed at the National Center for Ecological Analysis and Synthesis (NCEAS). Details are available at http://fcelter.fiu.edu/research/information_management/documents/. All metadata will also comply with CERP data requirements.

Environmental data will be stored in the ERDP database maintained by the Everglades Division at the South Florida Water Management District. There is an effort at the South Florida Water Management District to develop an Ecology Database similar to DBHYDRO, if this product comes on line, data from the DPM will be migrated to that database. We will comply with the data maintenance requirements of CERP. As CERPzone, the CERP RECOVER database, comes online, DPM data will be provided following the guidelines provided by CERPzone.

VI. Schedule of Deliverables

Annual report of data and preliminary analysis are due September of each year, starting 2018. Data derived from all sampling processes described in the annual work plan will be archived and affirmed for quality.

Status and preliminary findings will be summarized in the semi-annual reporting of results due March of each year, starting 2018.

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Part 4. WCA-3B Hydrologic Connectivity Study

I. Statement of issue and study objective: Task 3: WCA-3B Hydrologic Connectivity Montioring

The objective of this study is to characterize the ecological and hydrologic impacts of increased flow into WCA-3B via the S-152 inflow culverts and the L-67C levee gap and how active management can ameliorate and enhance increased depth and flow for landscape connectivity improvement.

II. Statement of work (abbreviated)

This work plan addresses research activities seeking to evaluate the response of WCA-3B landscape to enhanced flow accomplished by breaching a levee, introducing enhanced water flow velocities, and altering canal depths adjacent to Everglades marshes and tree islands.

It is not likely that recreating historic hydrology alone will restore the DPM over-drained landscape. Sawgrass is resilient to varied water depths as evidenced by its diminished, but widespread presence in southern WCA 3A South that has been ponded for the past 30 years. The lack of open water sloughs in the DPM footprint likely affects the ability of flow to penetrate further into the environment, so our hypothesis was that active management (slough creation by biomass removal) could restore both the ridge and slough (RSL) pattern and its processes, allowing flow to propagate further into DPM and beyond into 3B. After successful testing on a local, scale, we used modeling to determine the probability of success at a landscape scale before initiating a large active management project. Specifically, our questions were: 1) Can we create faster flows and propagate it further into the DPM footprint and beyond? 2) Can we change flow direction? 3) Can we create microtopography? 4) Can we create differential flows between ridges and sloughs? 4) What is the best option for active management of an over-drained RSL? 5) Can we restore pattern and flow direction on a landscape scale?

Increasing landscape connectivity in DPM and 3B through the historic Shark River Slough flow path to the S-355 structure through active management could eliminate the need, or modify the structural design criteria, for a new levee to create the Blue Shanty Flow way, as part of CEPP. This would be a significant cost savings and recreate the natural flow way with the least amount of disturbance to the landscape.

Tree islands are hypothesized to be an active sink of P in the landscape that contributes to the P balance of Everglades Ridge-Slough-Tree island system, promoting an otherwise oligotrophic wetland landscape. Thus, understanding the complex feedback mechanisms that regulate plant-groundwater-surface interactions, and nutrient dynamics is necessary to understand the effect of increased water flow in a region that has been hydrologic unconnected for more than 60 years. The purpose of the tree island monitoring project is to better understand the mechanisms leading to the restoration of the Ridge-Slough-tree island system in WCA-3B.

III. Sampling Design

1. Schedule

Biological and hydrologic monitoring will be conducted at intervals that bridge the year-round operational window. Hydrologic monitoring in tree island habitats will be conducted every two months, with special efforts focused during the operational window. A maximum of 6 sampling events, to collect surface and porewater samples, will be conducted per year.

2. Site Selection

Sites will be located both in the DPM footprint and in the western side of 3B (**Figure 4-1**). Exact locations for sampling will be coordinated in order to avoid interference with other sampling protocols.

Tree island sites are located within a tree island named Twin Heads (3BS-10) (approximately 1-km south of the L-67C gap; **Figure 4-1**). Currently, there are 16 shallow wells that will be part of the hydrologic and porewater nutrient monitoring. Wells locations are shown in the map below.

3. Experimental/Spatial Design

Statistical methods: For the active management, flow speed and direction will be compared before and after treatment. For tree island studies, sampling before during and after flow tests will also be used to assess the effect of increased flow and water level on the spatial temporal pattern in groundwater levels, surface water levels, hydroperiod and nutrient water quality

4. Field Methods/Lab Methods

A. Active Marsh Improve to enhance sheetflow basin-wide

- **Active management of ridge and slough patterning (PI Zweig):** To explore the possibility of removing sawgrass at a large-scale (i.e., > 10 x 10 km^2) to restore landscape pattern and direction in the DPM footprint and 3B, we modeled flow direction and speed using EFDC Explorer (ver. 8.0, Dynamic Solutions International LLC, Edmonds, WA, USA). EFDC Explorer is a graphical user interface for the Environmental Fluid Dynamics Code model developed by the U.S. Environmental Protection Agency to model

hydrodynamics and contaminant/sediment transport in flowing systems. Model results were favorable to the idea that removing vegetation resistance would allow flow direction and speed to be enhanced. Large sloughs will be recreated (according to historic imagery) by herbicide application (and possible prescribed fire) to remove resistance and we will monitor flow speed and direction with FlowTracker ADVs.

- **Landscape flow monitoring (PI Zweig, Cline, Ho):** To assess landscape velocities in WCA-3B, using a combination of ADVs and water tracers. At different flow rates during the year, Fluorescein dye will be injected into the marsh and monitored with georeferenced aerial imagery from a helicopter.

C. Tree Island Monitoring

- **Tree island hydrologic and nutrient monitoring (PI Coronado-Molina).** Maintain and service all piezometers and pressure transducers deployed on tree island (3BS10, **Figure 4-1**) located within the DPM footprint. Piezometers and pressure transducers will be maintained and serviced on a monthly basis. Collect surface, porewater, and groundwater samples for nutrients, ions, and alkalinity

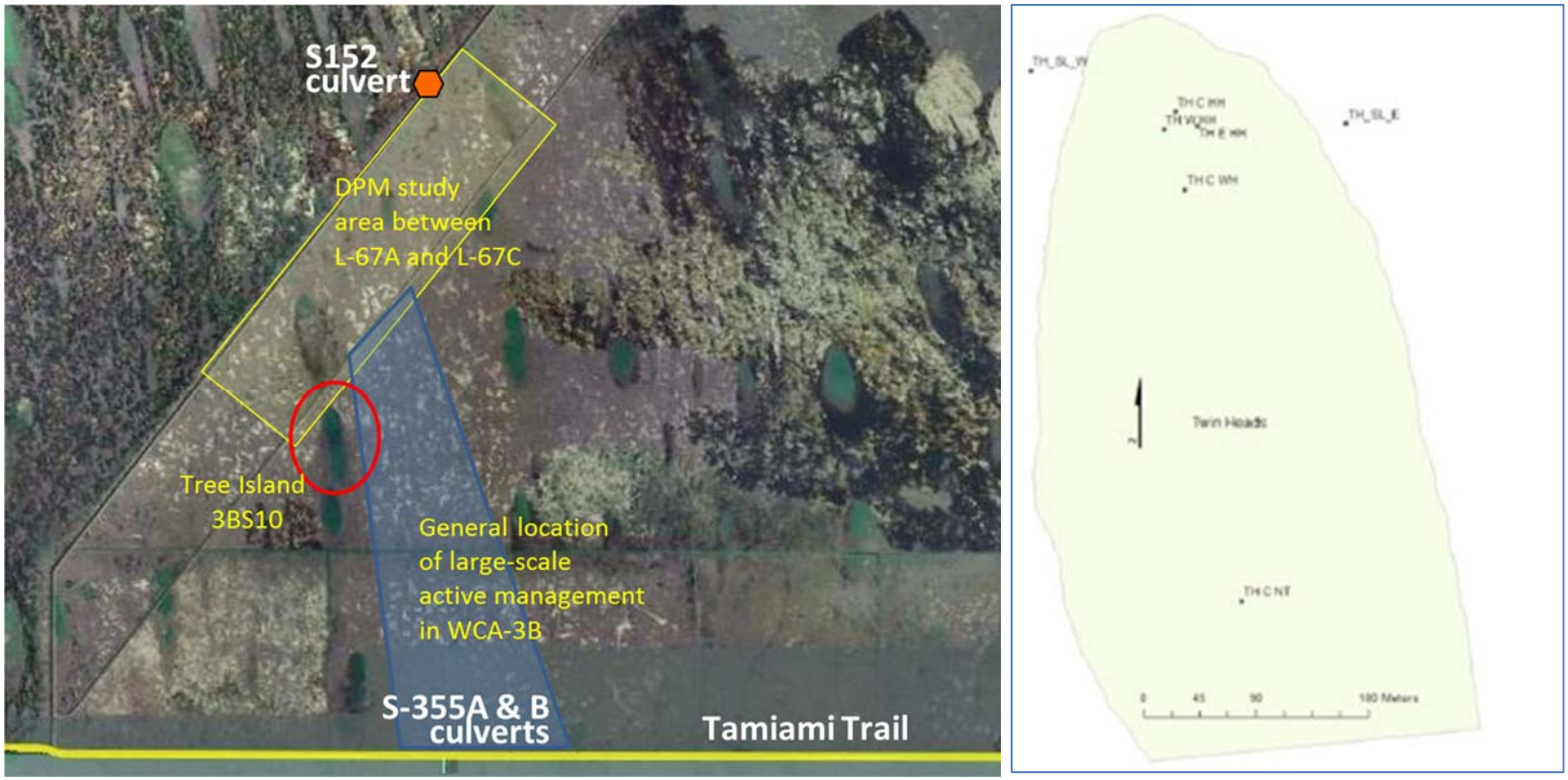

Figure 4-1. (Left) Map of the DPM study area, including location of active management area (blue shaded area) in WCA-3B and tree island 3BS10 (circled in red), downstream of L-67C gap, for focused tree island monitoring. (Right) Map of tree island 3BS10 showing the location of the wells in the head (northern-most portion of map) and near-tail (southern-most portion of map) portions of the tree island.

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