

# **Preliminary Results of the South Florida Canal Aquatic Life Study**

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*October 7, 2019*



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# South Florida Canal Aquatic Life Study

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## Background and Introduction

### Purpose of Document

The purpose of this report is to give a general summary of the water quality and biological data collected during the South Florida Canal Aquatic Life Study and to provide the results of the initial analyses of the relationships between water quality and biological parameters. The biological data presented in this report are limited to the macroinvertebrate community. The macroinvertebrate data were chosen as the focus of this initial effort because there is an accepted index (i.e., SCI) that could be used to assess the canals and compare differences among canals even though it has not been calibrated for the Everglades bioregion or the South Florida canals. Additionally, the habitat assessment (HA) method provides an assessment of the amount and quality of habitat available for the macroinvertebrates and can be used in conjunction with the SCI. Further, cursory evaluations of the data for other communities suggested limited populations or lack of response to differences in canal conditions. It should also be noted that, due to the considerable lag-time between sample collection and completion of the taxonomic analysis of the biological samples, not all of the results for the biological samples were available at the time of this report. Once all of the biological data are available, more extensive analyses will be conducted using the macroinvertebrate data as well as being expanded to include the other biological communities (phytoplankton, zooplankton, fish, LVS, and RPS) with the results being provided in future reports.

### Background

The landscape in South Florida has changed in numerous ways over the last century and these changes have resulted in a highly managed system often dominated by water conveyances and control structures. The Central & Southern Florida (C&SF) Project, which was initially authorized by Congress in 1948, dramatically altered the waters of south Florida and continues to impact this region through current water management-based projects. The current C&SF Project includes 2,600 miles of canals, over 1,300 water control structures, and 64 pump stations (SFWMD 2010). The C&SF Project, which is operated by the South Florida Water Management District (SFWMD), provides water supply, flood control, navigation, water management, and recreational benefits to South Florida. As a part of the C&SF, there are four major canals running from Lake Okeechobee to the lower east coast - the West Palm Beach Canal (42 miles), Hillsboro Canal (51 miles), North New River Canal (58 miles), and Miami canal (85 miles). In addition, there are many more miles of primary, secondary, and tertiary canals operated as a part of or in conjunction with the C&SF or as a part of other water management facilities within the SFWMD. Other entities operating associated canals include counties and special drainage districts.

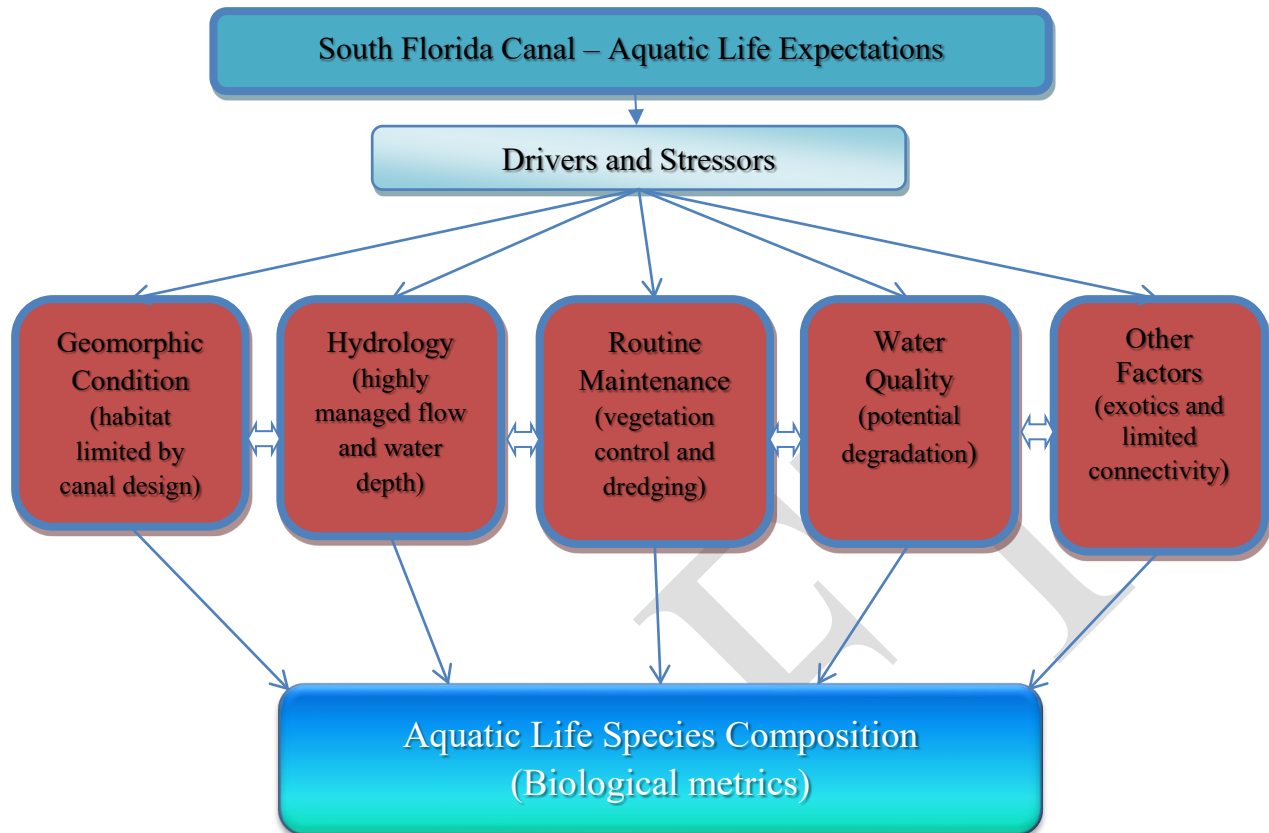
There is a great deal of diversity in the design, construction, and operation of these canals. The hydrology of the canals is highly manipulated by a series of water control structures and levees that have altered the natural hydroperiods and flows of the South Florida watershed on local and regional

scales. Freshwater and estuarine reaches of waterbodies are delineated by coastal salinity structures operated by the SFWMD. Thus, freshwater and estuarine connectivity is highly altered. During the wet season (approximately June thru October), discharges to tide through coastal salinity structures may be frequent and large, while during the dry season (approximately November through May) discharges are less frequent and may be of smaller volume.

Not only are the flow of the canals extremely managed, but a great deal of vegetation management is necessary to maintain water flow in the canals, since dense vegetation greatly decreases the hydraulic conductivity of the canal system. Each year, these highly managed systems require millions of dollars for plant management. Methods used to control aquatic vegetation in canals include mechanical harvesting, biocontrol methods such as grass carp, and herbicide application. Additionally, the various canal locations and surrounding land uses impact the water quality, soil type, and topography of the canals.

### **Conceptual Model**

Flowing waters in present day South Florida primarily include anthropogenically created canals that were constructed from uplands, wetlands, or existing transverse glades and built primarily for flood control, navigation, or water supply. Due to the physical nature of canals, their hydrology, the aquatic vegetation maintenance activities, and the resultant effects on dissolved oxygen (DO) and other chemical constituents of the canals, the aquatic life in canals cannot be expected to be the same as that of natural, flowing waters. Drivers and stressors influencing biological expectations for canal systems include geomorphic condition (physical canal design, which is different from the natural system), hydrology (highly managed flow regime), routine canal management activities (vegetation/habitat removal), water quality, and other factors (exotic taxa, limited connectivity) (**Figure 1**). Fauna that are most directly affected by these stressors include periphyton, phytoplankton, zooplankton, aquatic plant communities, epibenthic invertebrates, and fish.



**Figure 1. Conceptual model of the biological expectations for the aquatic life in the South Florida canals.**

Consistent with this conceptual model, aquatic life expectations for canals are different from those for natural, flowing waters. The existing biological expectations for natural streams [e.g., as measured by the Stream Condition Index (SCI)] are likely inappropriate and unachievable for most canals, predominantly due to the habitat and hydrologic modifications in canals.

Because the canals do not provide optimal habitat for aquatic organisms generally found in natural streams, the species of aquatic organisms present in canals tend to be indicative of the stressful physical conditions resulting from canal construction (morphology and hydrology) and ongoing maintenance (routine habitat removal and water management practices). Therefore, of the ten individual metrics comprising the SCI, ones that are indicative of sensitive taxa (e.g., number sensitive taxa, % long-lived taxa) may yield limited information for the canals due to the limited ability of these organisms to survive the harsh environment in the canals. However, other SCI metrics (e.g., taxa richness, filter-feeders, % tolerant taxa) may provide more useful information concerning the relative health of the canals. To

make the SCI a useful tool for the canals, the important metrics need to be identified and the expectations for these metrics must be better defined.

## South Florida Canal Aquatic Life Study Design

To perform a comprehensive assessment of South Florida canals and the aquatic life associated with those canals, the Florida Department of Environmental Protection (department) initiated planning for the South Florida Canal Aquatic Life Study in January 2012. The focus of the study was limited to the freshwater portions of South Florida canals (i.e., all monitoring stations are upstream of any salinity control structures). The objectives associated with the study are:

- a) Assess aquatic life in South Florida canals;
- b) Evaluate the physical, management, and biogeochemical differences among South Florida canals;
- c) Determine interrelationships between aquatic life in canals and other physical, hydrologic, and chemical variables (e.g., water quality, flow, management activities) that affect the aquatic life; and
- d) Collect information that can be used to guide management decisions.

The department developed and implemented this study through a collaborative approach, with input and assistance from a variety of stakeholders with expertise on the assessment of aquatic life in South Florida canals and/or responsibility for their operation and maintenance (e.g., SFWMD, Palm Beach, Broward, Miami/Dade, Lee, Collier Counties, the City of Cape Coral, and the Conservancy of SW Florida).

## Overall Study Approach

The department collected physical, biological, and water quality data periodically over a four-year period at multiple sites in numerous South Florida canals to better define aquatic life use expectations for the canals. The canals sampled were selected to represent a wide range of physical, hydrologic, water quality, management, and land use conditions. To help determine the range of physical and water quality conditions that could be expected across South Florida canals and to aid in the development of the scope of the study and site selection, a synoptic sampling event was conducted during the planning stage of the study. Details concerning the pre-study sampling along with a brief summary of the results are provided below.

## Pre-Study Synoptic Sampling in South Florida Canals

In February and March of 2012, department field staff conducted a synoptic sampling exercise at single sites on 29 randomly-selected canals (**Table 1**) in southeastern Florida to ensure that a range of water quality conditions would be captured (**Figure 2**).

**Table 1. Summary of sites sampled during the pre-study synoptic sampling conducted in February and March 2012.**

| Station Nickname | Station Description               | STORET | WBID   | Sample Date | Latitude | Longitude | Habitat Score |
|------------------|-----------------------------------|--------|--------|-------------|----------|-----------|---------------|
| Z6CN6002         | L-29 (Tamiami Canal)              | 41344  | 3289J  | 3/20/12     | 25.76224 | -80.70803 | 85            |
| Z6CN6003         | Lake O Rim Canal                  | 41345  | 3213C  | 2/7/12      | 26.99633 | -80.62214 | 57            |
| Z6CN6004         | L-13 (Ocean Canal)                | 41346  | 3252A  | 2/8/12      | 26.67848 | -80.46465 | 36            |
| Z6CN6005         | L-35 Canal                        | 41347  | 3279   | 3/7/12      | 26.1329  | -80.38718 | 53            |
| Z6CN6006         | L-31E Canal                       | 41348  | 3298   | 3/6/12      | 25.56185 | -80.3317  | 16            |
| Z6CN6007         | Holeyland Seepage Canal           | 41349  | STA3   | 2/27/12     | 26.33717 | -80.63617 | 77            |
| Z6CN6008         | C-51 (WPB Canal)                  | 41350  | STA1E  | 2/21/12     | 26.6838  | -80.33351 | 39            |
| Z6CN6009         | N New River Canal                 | 41351  | 3277C  | 3/7/12      | 26.11628 | -80.31785 | 46            |
| Z6CN6011         | L-3 Canal                         | 41352  | 3256C  | 2/22/12     | 26.58    | -80.13027 | 23            |
| Z6CN6012         | L-1E (West Canal off Miami Canal) | 41353  | 3251   | 2/9/12      | 26.65297 | -80.82983 | 39            |
| Z6CN6013         | C-8 (Biscayne Canal)              | 41354  | 3285   | 3/6/12      | 25.91581 | -80.20517 | 55            |
| Z6CN6014         | Loxahatchee River                 | 41355  | 3230   | 2/21/12     | 26.91912 | -80.17572 | 60            |
| Z6CN6015         | E-4 Canal                         | 41356  | 3262   | 2/22/12     | 26.4653  | -80.09544 | 47            |
| Z6CN6016         | L-24 (Miami Canal)                | 41357  | 3260   | 2/9/12      | 26.42329 | -80.80856 | 46            |
| Z6CN6017         | I-75 Canal                        | 41358  | 3268G  | 3/21/12     | 26.146   | -80.70088 | 98            |
| Z6CN6019         | C-23 Canal                        | 41359  | 3200   | 3/8/12      | 27.20628 | -80.46559 | 34            |
| Z6CN6020         | C-51 (WPB Canal)                  | 41360  | 3238E  | 2/8/12      | 26.68493 | -80.3773  | 22            |
| Z6CN6023         | L-5 Canal                         | 41361  | 3263   | 2/27/12     | 26.33343 | -80.6019  | 54            |
| Z6CN6024         | C-17 Canal                        | 41362  | 3242A  | 2/21/12     | 26.80415 | -80.08736 | 40            |
| Z6CN6025         | C-14 Canal                        | 41363  | 3270   | 3/21/12     | 26.22878 | -80.17067 | 44            |
| Z6CN6026         | L-31N Canal                       | 41364  | 3303A  | 3/7/12      | 25.48081 | -80.5627  | 45            |
| Z6CN6027         | L-30 Canal                        | 41365  | 3262   | 2/27/12     | 26.48376 | -80.09632 | 62            |
| Z6CN6029         | N Fork Snake Creek Canal          | 41366  | 3283   | 3/6/12      | 25.98638 | -80.31168 | 48            |
| Z6CN6030         | Belcher Canal                     | 41367  | 3163B  | 2/7/12      | 27.4698  | -80.3876  | 31            |
| Z6CN6031         | E-1WN Canal                       | 41368  | 3262B1 | 3/21/12     | 26.48545 | -80.20443 | 36            |
| Z6CN6034         | C-304 Canal                       | 41369  | 3268I  | 3/21/12     | 26.01278 | -80.51133 | 96            |
| Z6CN6035         | L-64 Canal                        | 41370  | 3213C  | 3/22/12     | 27.13951 | -80.6553  | 36            |
| Z6CN6036         | Unknown Name Canal                | 41371  | 3244   | 3/22/12     | 26.81559 | -80.65944 | 54            |
| Z6CN6037         | L-35B Canal                       | 41372  | 3265H  | 3/22/12     | 26.21956 | -80.38814 | 98            |

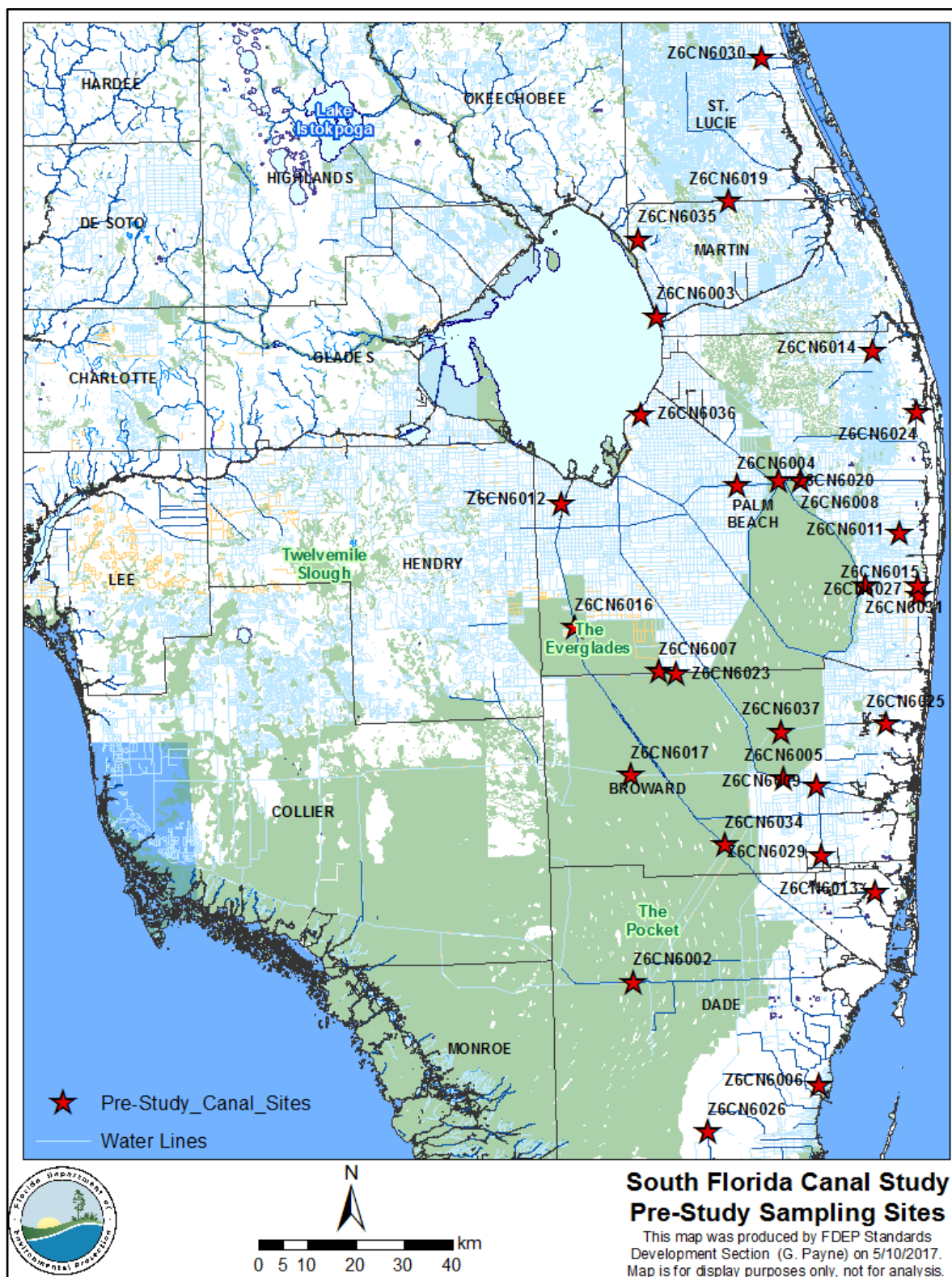


Figure 2. Locations of the pre-study synoptic samplings conducted in February and March 2012.

Grab samples were collected and analyzed for alkalinity, hardness, specific conductance, dissolved oxygen, transparency (Secchi depth), turbidity, color, chlorophyll *a*, nitrogen species, and total phosphorus. Water depths in the sampled canals ranged from less than 1 meter (m) to nearly 8 m. The 50<sup>th</sup> percentile depth was approximately 3 m.

Alkalinity is the measure of water's acid neutralization capacity and provides a measure of the water's buffering capacity. Canal waters are often comprised of mineral-rich agricultural runoff and groundwater, which results in higher levels of alkalinity in these waters. Values ranged from ~120 to 380 mg/L of CaCO<sub>3</sub>, with most of the values greater than 200 mg/L of CaCO<sub>3</sub>, which would be characterized as very hard water.

Specific conductance is a measure of water's ability to conduct an electrical current. Specific conductance ranged from ~400 micromhos per centimeter (µmhos/cm) to ~1,400 µmhos/cm, with the 50<sup>th</sup> percentile at ~650 µmhos/cm. Elevated levels of specific conductance may be linked to groundwater intrusion (connate seawater) into canal surface waters, potentially associated with water management activities and agricultural irrigation.

Dissolved oxygen (DO) levels varied widely between ~4 milligrams per liter (mg/L) to ~13 mg/L. DO levels were generally high because the sampling was conducted in February and March when water temperatures were low. DO concentrations are expected to be seasonally dependent as they are affected by factors such as temperature and water velocity.

Chlorophyll-*a* levels ranged from close to < 0.5 µg/L to ~70 µg/L. These concentrations are expected to vary seasonally as algae populations fluctuate with changes in temperature and water residence time, as well as changes in the availability of nitrogen and phosphorus. An analysis of chlorophyll-*a* and transparency data revealed that there may be a relationship ( $R^2 = 0.3036$ ) between the two parameters. The data suggest that as chlorophyll-*a* concentrations increase, the transparency decreases. This may be due, in part, to the fact that when chlorophyll levels are higher, there is an increase in algal-derived turbidity (shading), which can decrease the transparency. As expected, a strong relationship between transparency and turbidity (algal plus inorganic particles) exists ( $R^2 = 0.75$ ).

Nitrogen species—ammonia, nitrate + nitrite (NO<sub>x</sub>), and total Kjeldahl nitrogen (TKN)—were all analyzed, and values of total nitrogen ranged from < 0.5 mg/L to ~2.5 mg/L. The largest fraction of nitrogen at all of the sites was TKN with much lower levels of ammonia and NO<sub>x</sub> (**Figure 3**), indicating that most of the nitrogen present is in organic or particulate form. TKN concentrations averaged 1.24 mg/L with ammonia and NO<sub>x</sub> concentrations averaging .077 and 0.067 mg/L, respectively. A regression of TKN versus color (**Figure 4**) suggests that a significant amount of the nitrogen may be attributable to tannic and/or humic substances, which naturally occur in canals due to the presence of adjacent wetlands.

Total phosphorus (TP) concentrations ranged from 4 to 320 µg/L, with an average and median of 49 and 26 µg/L, respectively. All but two sites had TP concentrations below 100 µg/L, with 17 of the 29 sites exhibiting TP concentrations below 50 µg/L.

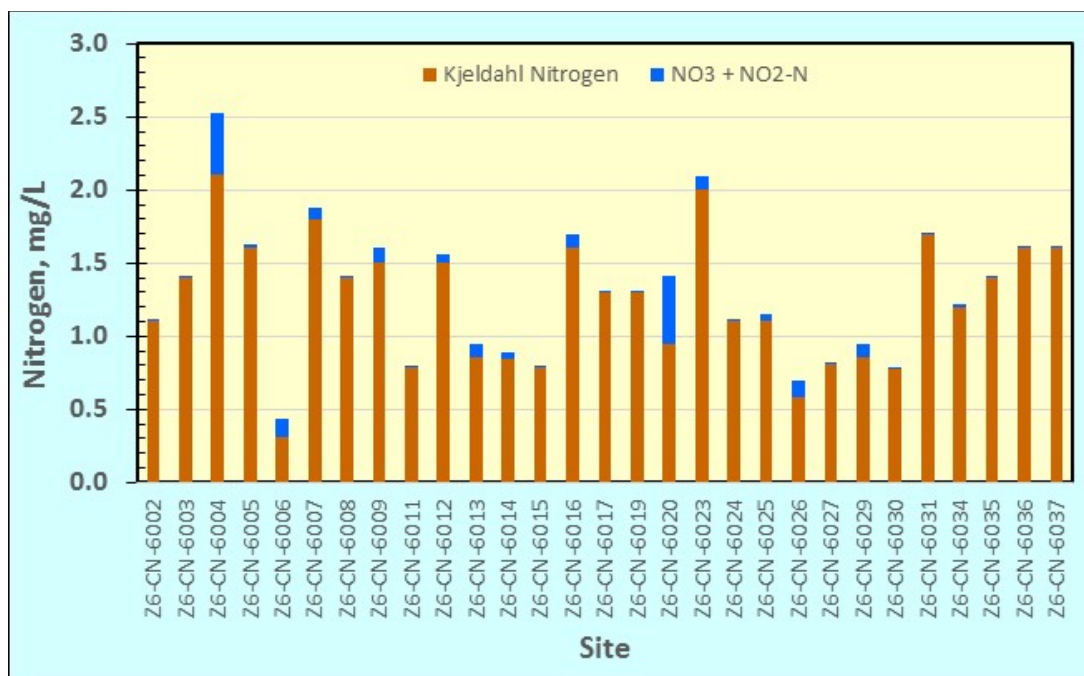


Figure 3. Nitrogen species in samples collected during the pre-study sampling conducted in February and March 2012.

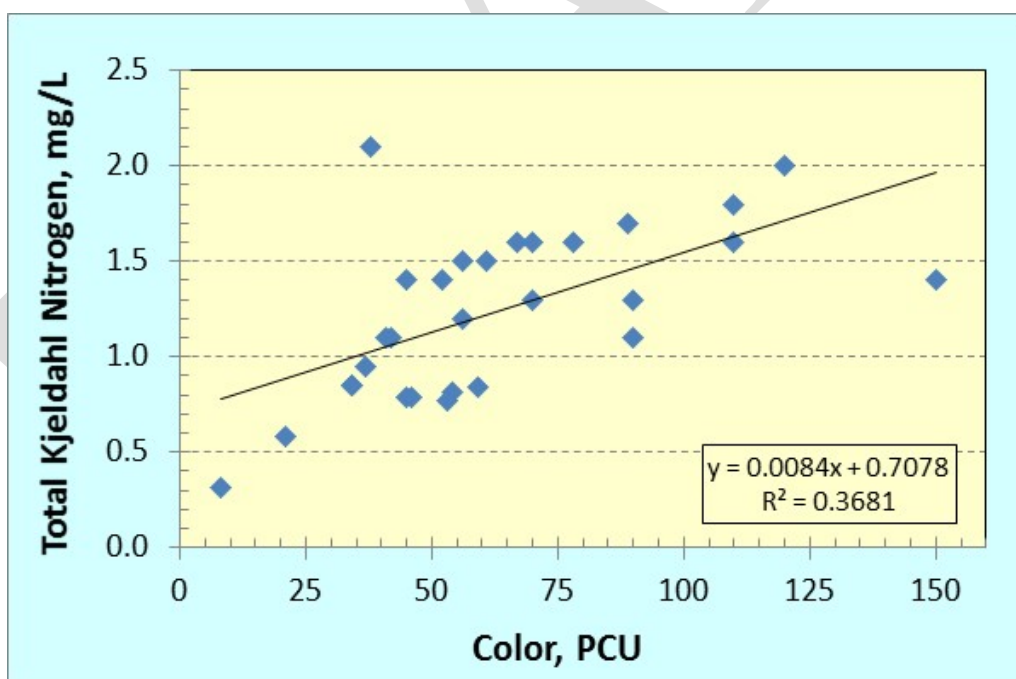


Figure 4. Relationship between total Kjeldahl nitrogen (TKN) and color for samples collected during the pre-study sampling conducted in February and March 2012.

## South Florida Canal Study Scope

The primary South Florida Canal Study was conducted over a four-year period from November 2012 through October 2016 and included the major components listed below.

- Established sites that are representative of the range of conditions present in specific canals and regional influences, selected as described below;
- Conducted periodic sampling of the water quality conditions and biological communities at the representative sites to determine the range of conditions that can be expected in the canals and factors influencing the biological communities;
- Established sites for a “Before-After-Control-Impact” (BACI) Study to evaluate the relative effect of management practices (vegetation control) on biological expectations, including biological recovery time from stress associated with routine maintenance of canals;
- Used data collected during the study to develop and calibrate the conceptual model described above that can be used to help guide management decisions concerning the canals.

The study was conducted in a regionally phased approach. During the first year of the study (i.e., Phase I), canals in St. Lucie, Martin, and West Palm Beach counties were targeted for sample collection. During the second year (i.e., Phase II), canals in Broward and Miami-Dade counties were selected with a reduced number of Phase I sites continuing to be sampled at a reduced frequency to provide a longer period of record. Reduced numbers of both Phase I and Phase II sites continued to be sampled during the third year of the study with no new sites added. During the fourth and final year of the study (i.e., Phase III) canals in southwestern Florida (i.e., Lee, Collier, and Hendry counties) were targeted with the sampling conducted at the Phase I and II sites during year three continuing during the final year of the study.

Within each region, canals and sampling sites were initially selected to capture the expected range of canal types and conditions, including Landscape Development Intensity (LDI) index values and land uses, water quality, habitat conditions, and to provide a relatively even geographic distribution within the area. Generally, two to four sites were located within each canal to characterize the variability within the canal, compare variability between canals, and capture any localized effects. To allow the maximum use of data from existing monitoring programs, many of the sites selected for the study were co-located with sites monitored by other entities (e.g., SFWMD, Broward, Miami-Dade, Lee and Collier Counties, and City of Cape Coral). Prior to finalizing the location of monitoring sites within each region, a site reconnaissance visit was made to all of the potential sites. Additionally, during the finalization of the site locations, sampling logistics (i.e., accessibility of the sites, locations of boat ramps) were also considered.

For the Phase I area, 40 monitoring sites located within 13 canals were selected in the northern portion of southeastern Florida (St. Lucie, Martin, and West Palm Beach counties) where monitoring was started in November 2012. During the second year of the study, 14 canals containing 38 sites were located in the Phase II area (Broward, Miami-Dade Counties). The Phase III area was monitored at 35 sites in 16 canals during the final year of the study. **Figure 5** shows the location of the monitoring sites sampled during the study with a description of the sites being provided in **Table 2**.

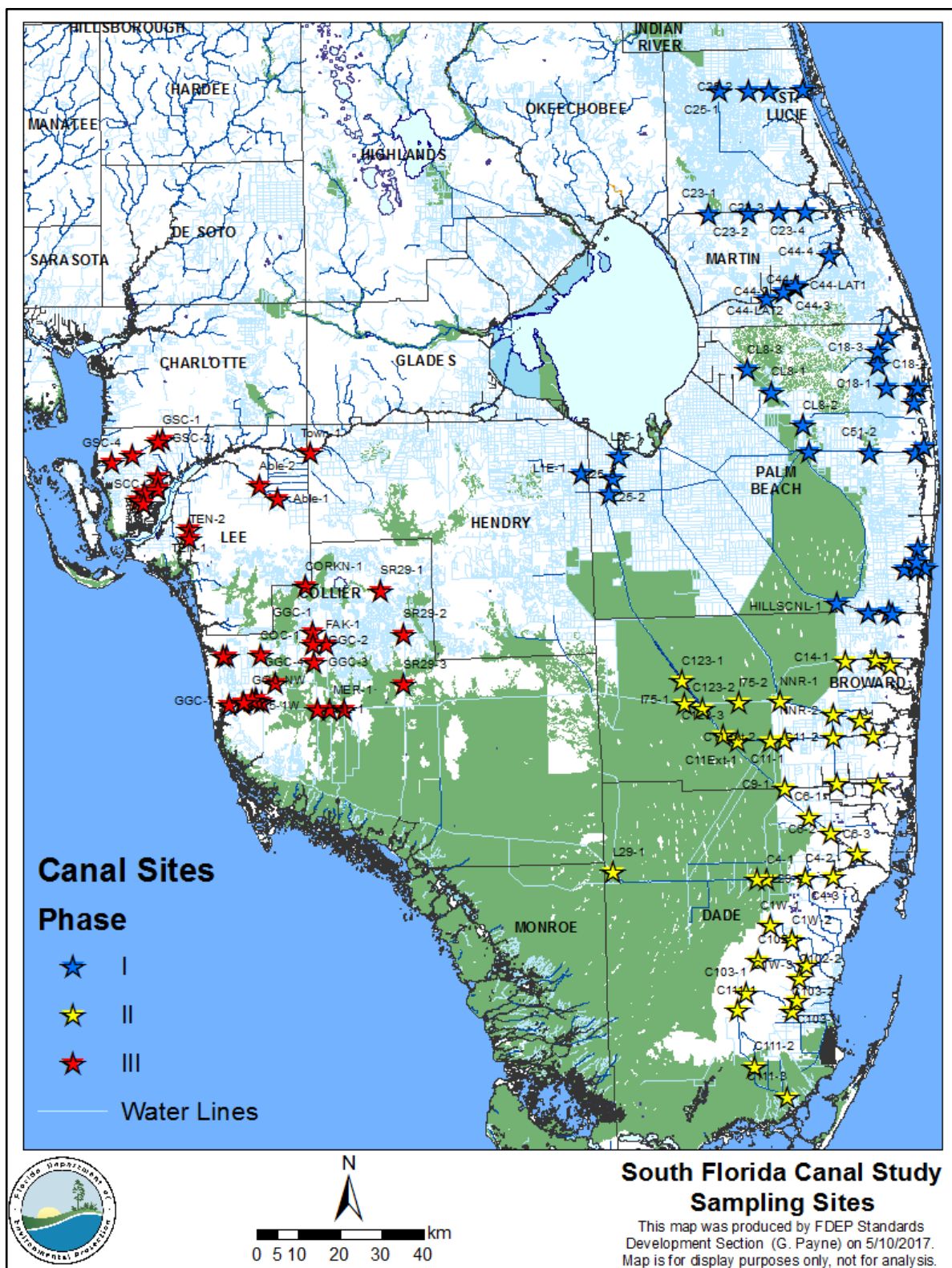


Figure 5. Location of monitoring sites sampled during the South Florida Canal Study.

**Table 2. Description of sampling stations selected for the South Florida Canal Study.**

| Phase          | Canal                              | General Canal Location                                         | Approximate Surrounding Land use                                                                                                  | Station Descriptions                                                                                                                                                                                             |
|----------------|------------------------------------|----------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Phase I</b> | <b>C-25</b>                        | N St. Lucie County                                             | Mix of ag (54%), urban (24%), and natural (16%) - ag is predominantly tree crops (citrus) and improved pasture.                   | 1*. W end of C-25, @ junction of C-25 extension<br>2. Center of C-25, upstream of S-99<br>3. Center of C-25 canal, east of I-95<br>4*. E end of C-25, upstream of S-50                                           |
|                | <b>C-23</b>                        | St. Lucie/Martin County line                                   | Mostly Ag (76% - mix of improved pasture and some probable citrus), some natural (19%), and 3% urban                              | 1*. W segment of C-23, downstream of the railroad tracks<br>2. Center of C-23, east of SW Allapatah Rd<br>3. Center of C-23, west of I-95<br>4*. E end of C-23, upstream of S-97                                 |
|                | <b>C-44</b>                        | Central Martin County                                          | Mix of ag (57 %), urban (9%), and natural (32%) - ag is predominantly improved pasture, tree crops (citrus), and open rural lands | 1*. W end of C-44, downstream of Beeline Highway<br>2.Center of C-44<br>3. Center of C-44<br>4*. E end of C-44, upstream of S-80<br>Lateral 1. Lateral canal located at the center of C-44, downstream of site 3 |
|                | <b>C-17</b>                        | E Central Palm Beach County                                    | Mostly urban (69%) - LDI > 6                                                                                                      | 1*. S end of C-17, downstream of Blue Heron Blvd<br>2. Lateral branch of C-17, downstream of Lighthouse Dr.<br>3*. N end of C-17, upstream of S-44                                                               |
|                | <b>C-18</b>                        | Palm Beach Gardens to Jupiter                                  | Mostly natural (77 %) - LDI ~2                                                                                                    | 1*. S end of C-18, downstream of Beeline Highway<br>2*. Center of C-18, upstream of G-160<br>3*. Center of C-18, downstream of G-160<br>4*. N end of C-18, upstream of S-46                                      |
|                | <b>Miami (L-25) Canal</b>          | L-25, northern most stretch of canal, south of Lake Okeechobee | Predominantly ag (98%) - western EAA                                                                                              | 1*. N end of L-25, south of Railroad tracks south of Lake Okeechobee<br>2. Center of L-25, south of L-1E and L-25 intersection<br>3*. S end of L-25, south of L-21, L-26, and L-25 intersection                  |
|                | <b>West Palm Beach c-51) Canal</b> | C-51, C Palm Beach County - runs along S of Southern Blvd.     | Heavily urbanized (70-79%)                                                                                                        | 1*. W end of canal, downstream of S-5AE<br>2. Center of canal, upstream of S-1553. E end of canal, upstream of Congress Ave                                                                                      |

|                 |                              |                                                        |                                                 |                                                                                                                                                                                                                       |
|-----------------|------------------------------|--------------------------------------------------------|-------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                 |                              |                                                        |                                                 | Flyover*. Lateral Canal off E end of C-51, north of Pine Lake                                                                                                                                                         |
|                 | <b>Hillsboro (g-8) Canal</b> | G-8, Palm Beach/Hillsboro County line                  | Mostly urban (75%)                              | 1*. W end of canal, downstream of WCAs<br>2. E end of canal, near juncture with E-4<br>3*. Center of canal, near juncture with E-2W<br>4. E-1 lateral canal, N or S of Hillsboro<br>5. E-3 canal, N or S of Hillsboro |
|                 | <b>L-8</b>                   | W Palm Beach County, borders Corbett and Dupuis tracks | Mix of ag and natural                           | 1. Center of L-8, alongside Corbett track<br>2*. S end of L-8, upstream of the M-1 and L-8 intersection<br>3*. N end of L-8, alongside Dupuis track                                                                   |
|                 | <b>L-1E</b>                  | NE Hendry County                                       | Predominantly ag (98%) - western EAA            | 1*. Center of L-1E, upstream of Rogers Rd. bridge                                                                                                                                                                     |
|                 | <b>C-15</b>                  | SE Palm Beach County                                   | Mostly urbanized (80%)- LDI > 7                 | 1*. W end of C-15, downstream of LWDD Pump station 12<br>2. Center of C-15, at the intersection of C-15 and E-4<br>3*. E end of C-15, upstream of S-40                                                                |
|                 | <b>E-4</b>                   | E Palm Beach County                                    | Mostly urbanized (70%)- LDI > 6                 | 1. Center of E-4, downstream of Lake Ida<br>2*. S end of E-4, upstream of Linton Blvd                                                                                                                                 |
|                 | <b>E-2W</b>                  | E Palm Beach County                                    | Mix of ag (30%) and urban (70%)                 | 1*. S end of E-2W, upstream of SW 18 <sup>th</sup> St and the Hillsboro Canal intersection                                                                                                                            |
| <b>Phase II</b> | <b>C-111</b>                 | S Dade County                                          | Mix of ag (40%) and natural (60%)               | 1**. N end of C-111, downstream of S-176<br>2. Center of C-111, downstream of C-111E intersect<br>3**. S end of C-111, upstream of S-197                                                                              |
|                 | <b>C-103</b>                 | S Dade County                                          | Mix of ag (50%), urban (40%), and natural (10%) | 1*. W end of C-103, downstream of SW 217 <sup>th</sup> Ave bridge<br>2**. E end of C-103, upstream of S-179<br>3. Center of N lateral C-103, upstream of Turnpike bridge                                              |
|                 | <b>C-102</b>                 | S Dade County                                          | Mix of ag (60%), urban (30%), and natural (10%) | 1**. NW end of C-102, downstream of SW 197 <sup>th</sup> Ave.                                                                                                                                                         |

|  |                            |                                                               |                                      |                                                                                                                                                 |
|--|----------------------------|---------------------------------------------------------------|--------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|
|  |                            |                                                               |                                      | 2**. Center of C-102, upstream of S-165                                                                                                         |
|  | <b>C-1W</b>                | S Dade County                                                 | Mix of ag (30%) and urban (70%)      | 1**. NW end of C-1W, downstream of S-338<br>2**. Center of C-1W, upstream of SW 152 <sup>nd</sup> St.<br>3**. SE end of C-1W, upstream of S-148 |
|  | <b>C-4</b>                 | Central Dade County                                           | Mix of natural (15%) and urban (75%) | 1**. W end of C-4, downstream of S-336<br>2. Center of C-4, upstream of Turnpike<br>3**. E end of C-4, upstream of Palmetto Expressway          |
|  | <b>Miami (C-6) Canal</b>   | C-6, southern stretch of canal, central Dade County           | Mostly urbanized (85%)               | 1**. NW end of C-6, downstream of Turnpike<br>2. Center of C-6, upstream of Palmetto Expressway<br>3**. SE end of C-6, upstream of S-26         |
|  | <b>C-9</b>                 | Dade-Broward Border                                           | Mix of urban (85%) and natural (15%) | 1**. W end of C-9, upstream of S-30<br>2. Center of C-9, downstream of NW 67 <sup>th</sup> Ave.<br>3**. Center of C-9, upstream of US 441       |
|  | <b>L-29</b>                | W Central Dade County                                         | Mostly natural (85%)                 | 1. W end of L-29, downstream of S-343A<br>2. E end of L-29, upstream of S-334                                                                   |
|  | <b>C-11</b>                | Central Broward County                                        | Mostly urbanized (80%)               | 1. W end of C-11, upstream of S-381<br>2. Center of C-11, upstream of S-13AW<br>3. E end of C-11, upstream of S-13                              |
|  | <b>C-11 EXT</b>            | Central Broward County                                        | Mostly natural (95%)                 | 1**. W end of C11-EXT<br>2**. E end of C-11 EXT, upstream of L-68A intersection                                                                 |
|  | <b>Miami (C-123) Canal</b> | C-123, central stretch of the canal, W central Broward County | Mostly natural (98%)                 | 1**. NW end of C-123, downstream of S-339<br>2. Center of C-123, upstream of S-340.<br>3**. Center of C-123, downstream of S-340                |
|  | <b>I-75</b>                | W Central Broward County                                      | Mostly natural (90%)                 | 1**. E end of I-75, upstream of C-123 intersection<br>2. E end of I-75, downstream of C-123 intersection                                        |

|                  |                                        |                                                                      |                                                 |                                                                                                                                                                                                                                                         |
|------------------|----------------------------------------|----------------------------------------------------------------------|-------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                  | <b>North New River (L-35 and G-15)</b> | L-35 and G-15, southern stretch of the canal, central Broward County | Mostly urbanized (80%)                          | 1**. W end of L-35, downstream of G-123<br>2**. W end of G-15, downstream of Flamingo Rd.<br>3**. Center of G-15, upstream of G-54                                                                                                                      |
|                  | <b>C-14</b>                            | N Broward County                                                     | Mostly urbanized (95%)                          | 1. W end of C-14, downstream of Coral Ridge Dr. /Nob Hill Rd.<br>2. Center of C-14, upstream of US 441<br>3. Center of C-14, downstream of S-37B                                                                                                        |
| <b>Phase III</b> | <b>Able Canal</b>                      | W Lee County                                                         | Mostly urbanized (70%)                          | 1. At Connecticut Rd. bridge<br>2. At Sunshine Blvd N bridge                                                                                                                                                                                            |
|                  | <b>Cleveland Canal</b>                 | Central Lee County                                                   | Highly urbanized (98%)                          | 1. Parallel to NW 6 <sup>th</sup> St.                                                                                                                                                                                                                   |
|                  | <b>Corkscrew Sanctuary</b>             | Lee/ Collier County border                                           | Highly natural (99%)                            | 1. NE section of the Corkscrew Sanctuary                                                                                                                                                                                                                |
|                  | <b>Escapade Canal</b>                  | Central Lee County                                                   | Highly urbanized (98%)                          | 1. S of SW 20 <sup>th</sup> St.                                                                                                                                                                                                                         |
|                  | <b>Gator Slough Canal</b>              | N Lee County                                                         | Mix of urban (60%) and natural (40%)            | 1**. NE end of Gator Slough Canal, downstream of US 41<br>2. Center of Gator Slough Canal, downstream of Garden Blvd.<br>3**. Center of Gator Slough Canal, weir at Nelson Rd N<br>4. SW end of Gator Slough Canal, upstream of weir at Burnt Store Rd. |
|                  | <b>Meade Canal</b>                     | Central Lee County                                                   | Highly urbanized (98%)                          | 1. Upstream of Viscaya Pkwy                                                                                                                                                                                                                             |
|                  | <b>San Carlos Canal</b>                | Central Lee County                                                   | Highly urbanized (98%)                          | 1. Parallel to Nicholas Pkwy E<br>2. Upstream of Veterans Memorial Pkwy                                                                                                                                                                                 |
|                  | <b>Ten Mile Canal</b>                  | Central Lee County                                                   | Highly urbanized (75%)                          | 1. Upstream of weir at Daniels Pkwy<br>2. Downstream of Ben C Pratt/6 Mile Cypress Pkwy                                                                                                                                                                 |
|                  | <b>Townsend Canal</b>                  | W Hendry County                                                      | Mix of ag (75%), natural (10%), and urban (15%) | 1. At SR-80 bridge                                                                                                                                                                                                                                      |
|                  | <b>Airport Road North Canal</b>        | NW Collier County                                                    | Highly urbanized (85%)                          | 1. N end of Airport Road North Canal                                                                                                                                                                                                                    |
|                  | <b>Cocohatchee River</b>               | NW Collier County                                                    | Highly urbanized (70%)                          | 1. Upstream of Collier Blvd bridge<br>2. Upstream of SFWMD spillway, COCO-1                                                                                                                                                                             |
|                  | <b>Faka Union Canal</b>                | Central Collier County                                               | Highly natural (80%)                            | 1. Upstream of Oil Well Rd. bridge<br>2. At I-75 bridge                                                                                                                                                                                                 |

|  |                               |                        |                                                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|--|-------------------------------|------------------------|-------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|  | <b>Golden Gate Main Canal</b> | Central Collier County | Mix of urban (55%) and natural (45%)            | <ol style="list-style-type: none"> <li>1. At NE 47<sup>th</sup> Ave</li> <li>2. Upstream of Oil Well Rd.</li> <li>3. At NE 10<sup>th</sup> Ave.</li> <li>4. Upstream of White Blvd.</li> <li>5. Downstream of SFWMD Weir, GG-3</li> <li>6. Upstream of SFWMD Weir, GG-2</li> <li>7. Upstream of SFWMD Weir, GG-1</li> <li>NE1. Downstream of the intersection of SW 47<sup>th</sup> St. and SW 25<sup>th</sup> Ct.</li> <li>NE2. Upstream of Tropicana Blvd.</li> <li>NW. Downstream of Golden Gate Pkwy</li> </ol> |
|  | <b>I-75 Canal</b>             | E Collier County       | Mix of natural (60%) and urban (40%)            | <ol style="list-style-type: none"> <li>1. Upstream of SFWMD weir, D2-7</li> </ol>                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|  | <b>Miller Canal</b>           | S Collier County       | Highly natural (90%)                            | <ol style="list-style-type: none"> <li>1. A I-75 bridge</li> </ol>                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|  | <b>SR29 Canal</b>             | W Collier County       | Mix of ag (40%), natural (40%), and urban (20%) | <ol style="list-style-type: none"> <li>1. NW end of SR29 Canal, downstream of Seminole Crossing Trail</li> <li>2. Center of SR29 Canal, upstream, of Oil Well Rd.</li> <li>3. S end of SR29 Canal</li> </ol>                                                                                                                                                                                                                                                                                                        |

\*Water quality and biological monitoring at Phase I site was continued on a semi-annual basis during year 2 and quarterly during years 3 and 4 of the study.

\*\*Water quality and biological monitoring at Phase II site was continued on a quarterly basis during years 3 and 4 of the study.

Water quality and biological sampling was conducted periodically at each site during the study. During the initial year for each phase of the study, water quality sampling was conducted monthly with biological monitoring being performed on a quarterly basis. For Phase I and II sites where monitoring was continued beyond the initial year for that Phase, the sampling frequency was reduced to semi-annually or quarterly as footnoted in **Table 2**. All of the sampling was performed in accordance with department SOPs, with the exception that some of the biological sampling methods were modified slightly to account for the differences in the physical nature of the canals compared to natural streams. Additionally, the SCI was utilized as an assessment tool to evaluate the macroinvertebrate community present even though it has not been calibrated to the Everglades bioregion or the South Florida canals. The water quality and biological parameters monitored during the study are:

**Water Quality Parameters**

- Turbidity
- Color
- NOx
- TP
- TKN
- TOC
- Chlorophyll a
- Dissolved Oxygen
- Percent DO Saturation
- pH
- Specific Conductance
- Water Temperature

**Biological Monitoring**

- Phytoplankton
- Zooplankton
- Stream Condition Index (SCI)  
(Quantitative macroinvertebrate)
- Rapid Periphyton Survey
- Linear Vegetation Survey
- Habitat Assessment

In addition to the water quality and biological sampling, the department worked with the SFWMD and other interested parties to assemble additional information that could be used to help explain difference in the biological communities among the canals. This additional information included location of monitoring stations and flow gages monitored by other entities, and land use information. Study staff also assembled site-specific information including canal cross-sections, vegetation maintenance records, locations of connections to surrounding wetlands, presence of armored banks, presence of a wadable littoral zones, and the types of habitats present.

**“Before-After-Control-Impact” (BACI) Study**

To quantitatively assess the influence of routine canal maintenance, including factors such as water level manipulations and aquatic vegetation removal (both in-canal habitat and the riparian zone), a Before-After-Control-Impact” (BACI) Study was conducted as part of the overall South Florida Canal Study. In this type of study, a representative system is monitored both before and after a controlled treatment is applied (i.e., vegetation management in this case). The BACI study is intended to provide information on the magnitude and duration of effect that vegetation management by herbicide application has on the biological assemblages of the canals.

The study was conducted in the C-18 canal starting in August 2014. The C-18 canal was selected for the study because no vegetation control activities had been performed in the canal for at least a year prior to the study and due to the relatively high SCI and HA scores observed for the C-18 sites indicating a relatively healthy macroinvertebrate community. The lack of previous vegetation maintenance activities helped ensure that biological succession related to prior disturbance within the canal would not affect the results. Three sites within the treatment area were sampled immediately prior to the vegetation management and one, three, and six months after the treatment. The three monitoring sites were located within the treatment area and separated by a minimum of approximately 300 m. Ideally, there would have been a site located outside the treatment area to act as a control; however, due to the SFWMD’s need to maintain the flow capacity within the canal, it was not possible for them to leave any portion of the canal untreated. Because all of the canal was treated to remove vegetation, the pre-treatment sampling served as the control.

The initial pre-treatment sampling was conducted on August 19, 2014, with the vegetation control treatment being applied the following day, August 20, 2014. The treatment consisted of using clippers and applying the herbicide Diquat mainly to control the submersed aquatic plant, *Cabomba caroliniana*. All of the stations were resampled again on September 16, 2014 approximately one-month after the treatment. Additional post-treatment monitoring events were conducted on November 25, 2014 and February 25, 2015, approximately three and six months after the treatment, respectively. During each of the four monitoring events conducted for the BACI study, all of the parameters that were being measured for the main canal study were also monitored at each site.

DRAFT

## Results and Discussion

The purpose of this report is to give a general summary of the water quality and biological data collected during the South Florida Canal Aquatic Life Study and to provide the results of the initial analyses of the relationships between water quality and biological parameters. While the study included the monitoring of many aspects of the various biological communities present [macroinvertebrate, phytoplankton, zooplankton, aquatic plants (LVS), and algae (RPS)], this report focused on the macroinvertebrate community. The macroinvertebrate data was chosen for this initial effort because there is an accepted index (i.e., SCI) that could be used to assess the canals and compare differences among canals even though it has not been calibrated for the Everglades bioregion or the South Florida canals. Additionally, the habitat assessment (HA) method provides an assessment of the amount and quality of habitat available for the macroinvertebrates and can be used in conjunction with the SCI. Further, preliminary evaluations of phytoplankton and zooplankton communities indicated limited populations or lack of response to differences in canal conditions. Additionally, data collected from the fish community at selected sites indicated that most canals were dominated by the same limited number of non-sensitive species.

Results from the study indicate considerable variation in water quality and biological (macroinvertebrate) communities regionally, among canals within a region (Phase), and even among sites within the same canal. The water quality data collected during the study are summarized by canal in **Appendix 1**, with the habitat assessment and macroinvertebrate data summarized in **Appendix 2**. As expected, data collected during the study indicate that the canals often do not meet applicable Class III WQ criteria [DO, pH, specific conductance, and chlorophyll (assessment target of 20 µg/L)], and the biological expectations of natural streams in the Peninsula (i.e., Peninsula SCI) (**Table 3**). It should be noted that the analysis of the exceedances of the DO, specific conductance, turbidity, and pH criteria did not consider the natural background provisions of these criteria due to the difficulty in defining natural background conditions for man-made, highly managed waterbodies. Additionally, although the SCI has not been calibrated to the canals in the Everglades bioregion, the Peninsula SCI was calculated for the macroinvertebrate data collected during the canal study for this initial evaluation to allow a comparison between canals and to evaluate how the macroinvertebrate communities in the canals compared to the expectation for natural streams in the Peninsula.

Percent DO saturation was the most commonly exceeded water quality criteria with 21.8 percent of all measurements being below the applicable 38% saturation criteria and over half of the canals having more than 10% of the measured values being below the criteria. Most (92.9%) of the canals in the Phase II area exhibit more than 10% of the measurements below the criteria. The high exceedance rate in the Phase II area is likely related to the greater inputs of low DO water from the surrounding marsh and groundwater combined with relatively low rates of primary production as evidenced by low chlorophyll-*a* levels. The lowest DO exceedance rate was observed for the Phase I area where many of the canals receive nutrient rich water from Lake Okeechobee and the agricultural areas such as the EAA and where there is more photosynthetic production resulting in higher DO levels.

Exceedances of the 20 µg/L chlorophyll-*a* assessment threshold followed the opposite spatial trend from that described for DO. The highest chlorophyll-*a* exceedance rate (73.3 %) was observed for the Phase I area where primary production is greater due to the higher nutrient levels originating from Lake Okeechobee and the EAA. The lowest chlorophyll-*a* exceedance rate was found in the Phase II area where nutrient levels are lower and there is less production.

Exceedances of the numeric specific conductance and turbidity criteria were restricted to the Phase I area and are probably related to the source of water (i.e., drainage from agricultural areas and discharge from Lake Okeechobee) for the canals in this area. It should be noted that the criteria for specific conductance and turbidity (as well as pH and DO) include natural background provisions that allow an acceptable deviation from natural background conditions. However, the data from the canal study were only assessed against the numeric portion of these criteria because of the difficulty in establishing natural background conditions in highly managed man-made waterbodies. Twenty percent of the canals in the Phase I area exceeded the specific conductance criterion in more than 10% of the samples, with 6.7% of the canals greater than 29 NTUs in more than 10% of the samples. Infrequent exceedances of the 6 to 8.5 units pH criteria occurred in all study areas; however, all of the canals had an exceedance rate less than 10%.

Additionally, the SCI scores for the vast majority of the macroinvertebrate samples collected did not achieve the minimum expectations for natural streams in the Peninsula. From 72.2 to 92.2 % of the sites in the three areas failed to achieve a passing average SCI score of 40 or greater, with 68.4% of all individual samples scoring less than the minimum acceptable score of 35 for natural streams (**Table 1**). In general, lower SCI scores are expected in the canals compared to natural streams due to the harsh conditions and lack of habitat suitable for more sensitive macroinvertebrates. However, differences in habitat quality and abundance among the canals did not help explain variations in SCI scores across the canals. Possible explanations for the differences in the macroinvertebrate communities among the canals are discussed later in this report.

Water quality and biological results and relationships between parameters are discussed in greater detail below by parameter.

**Table 3. Summary of exceedances of applicable water quality criteria.**

| Parameter                         | Percent of all Samples Exceeding Criteria | Percent of All Canals with > 10% Exceedance | Percent of Canals with > 10% Exceedance by Phase |                   |                   |
|-----------------------------------|-------------------------------------------|---------------------------------------------|--------------------------------------------------|-------------------|-------------------|
|                                   |                                           |                                             | I                                                | II                | III               |
| % DO Saturation <sup>1</sup>      | 21.8                                      | 51.1                                        | 26.7                                             | 92.9              | 45                |
| pH <sup>1</sup>                   | 0.5                                       | 0                                           | 0                                                | 0                 | 0                 |
| Specific Conductance <sup>1</sup> | 2.7                                       | 6.4                                         | 20                                               | 0                 | 0                 |
| Chlorophyll-a                     | 11.9                                      | 36.2                                        | 73.3                                             | 7.1               | 30                |
| Turbidity <sup>1</sup>            | 2.2                                       | 2.2                                         | 6.7                                              | 0                 | 0                 |
| SCI                               | 68.4 <sup>2</sup>                         | 83.2 <sup>3</sup>                           | 92.5 <sup>3</sup>                                | 86.8 <sup>3</sup> | 68.6 <sup>3</sup> |

<sup>1</sup>Natural background provisions in DO, pH, specific conductance, and turbidity criteria were not considered.

<sup>2</sup>SCI analysis based on percent of individual samples with Peninsula SCI scores <35.

<sup>3</sup>SCI analysis was based on percent of sites with average Peninsula SCI scores <40.

## Water Quality

### Corrected Chlorophyll-*a*

Corrected chlorophyll-*a* concentrations in samples collected during the South Florida Canal Study averaged 9.7 µg/L and ranged from less than 0.5 µg/L to 330 µg/L. The canals in the Phase I area exhibited the highest chlorophyll levels with an average of 16.2 µg/L. The higher chlorophyll levels appear to be associated with areas with higher nutrient (TP and/or TN) concentrations such as in canals draining Lake Okeechobee and agricultural areas (e.g., EAA). The lowest average chlorophyll-*a* level of 3.6 µg/L was found for the Phase II canals, which ranged from less than 0.5 µg/L to 42 µg/L. Many of the Phase II canals flow through and have significant inflow from the Everglades marsh, which is highly oligotrophic and phosphorus limited and does not support higher chlorophyll-*a* growth. The Phase III sites exhibited intermediate chlorophyll-*a* levels, averaging 7.8 µg/L and ranging from 0.5 µg/L to 140 µg/L. A more detailed depiction of the spatial distribution of average chlorophyll-*a* levels by site is provided in **Figure 6**. Chlorophyll-*a* concentrations did not exhibit strong correlations with nutrient levels, except in the Phase II area where there was a linear relationship with TP concentrations (**Figure 7**). As described above, many of the Phase II canals have significant inflow from the Everglades marsh, which is a highly oligotrophic, phosphorus-limited system; therefore, a response to increased TP levels would be expected.

### Total Phosphorus

Total phosphorus concentrations exhibit the same general spatial pattern as described for chlorophyll, with the highest levels found in the Phase I canals, and the lowest values recorded for the Phase II sites, with the Phase III canals having intermediate levels. The same north to south gradient in TP levels has been documented in the Everglades (Payne et.al., 2009). This observed gradient results from the major

sources of phosphorus occurring in the north (i.e., Lake Okeechobee, EAA, and other agricultural areas) and the Everglades being a highly oligotrophic, phosphorus-limited system; the phosphorus is quickly assimilated as it is transported to the south.

The Phase I canals, which are generally closer to the phosphorus sources, exhibit TP concentrations averaging 0.121 mg/L and ranging from 0.007 to 1.1 mg/L. In contrast, the TP concentrations in the Phase II canals, many of which drain from the Everglades marsh, are nearly an order of magnitude lower averaging 0.013 mg/L and ranging from less than 0.002 to 0.081 mg/L. Phase III canals exhibited intermediate TP levels, averaging 0.0868 mg/L and ranging from 0.005 to 0.76 mg/L. A map providing a more detailed illustration of the spatial distribution of average TP concentrations by site is shown in **Figure 8**.

### Total Nitrogen and Nitrate + Nitrite

The concentration of total nitrogen (TN) in surface waters is not measured directly, but is calculated as the sum of total Kjeldahl nitrogen (TKN; organic nitrogen plus ammonia) and nitrite plus nitrate ( $\text{NO}_3 + \text{NO}_2$ ). For this report, TN values were calculated only for samples for which both TKN and  $\text{NO}_3 + \text{NO}_2$  results were available.

Moderate levels of TN can be found in many of the South Florida canals with less of a discernable spatial pattern observed. Higher concentrations were found in more localized areas such as the canals in the EAA and those near the outflows from Lake Okeechobee (**Figure 9**). The Phase II canals exhibited a slightly higher average TN than for the other two areas. TN concentrations in the Phase II area averaged 1.54 mg/L and ranged from 0.31 to 4.79 mg/L. TN levels in the Phase I and II areas averaged 1.36 and 0.96 mg/L, respectively.

While most sites in the Phase II area have TN concentrations comparable to those found in the other areas, there is a localized area of high TN concentrations found in the south-eastern portion of the region in the C1W, C102, and C103 canals. This peak in TN levels is being driven by elevated  $\text{NO}_3 + \text{NO}_2$  concentrations ranging up to 4.5 mg/L (**Figure 10**). For comparison, the  $\text{NO}_3 + \text{NO}_2$  concentrations in other areas average 0.13 mg/L or less. The cause of the elevated  $\text{NO}_3 + \text{NO}_2$  concentrations is unknown but is likely related to the agricultural activities and the high level of urbanization in the surrounding area. More detailed depictions of the spatial distributions of average TN and  $\text{NO}_3 + \text{NO}_2$  levels by site are provided in **Figures 9** and **10**, respectively.

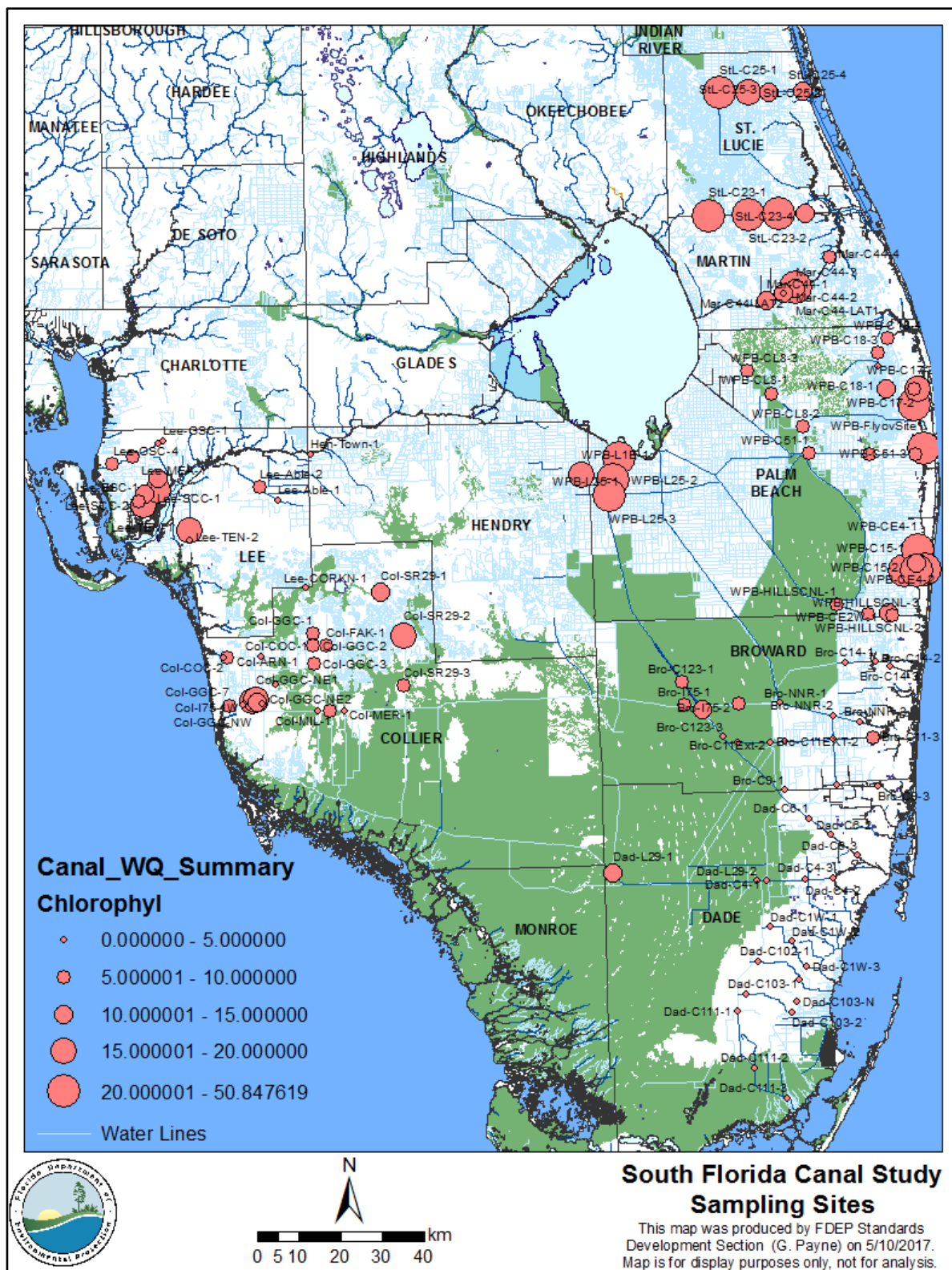


Figure 6. Spatial distribution of average chlorophyll-*a* concentrations for sites sampled during the South Florida Canal Aquatic Life Study.

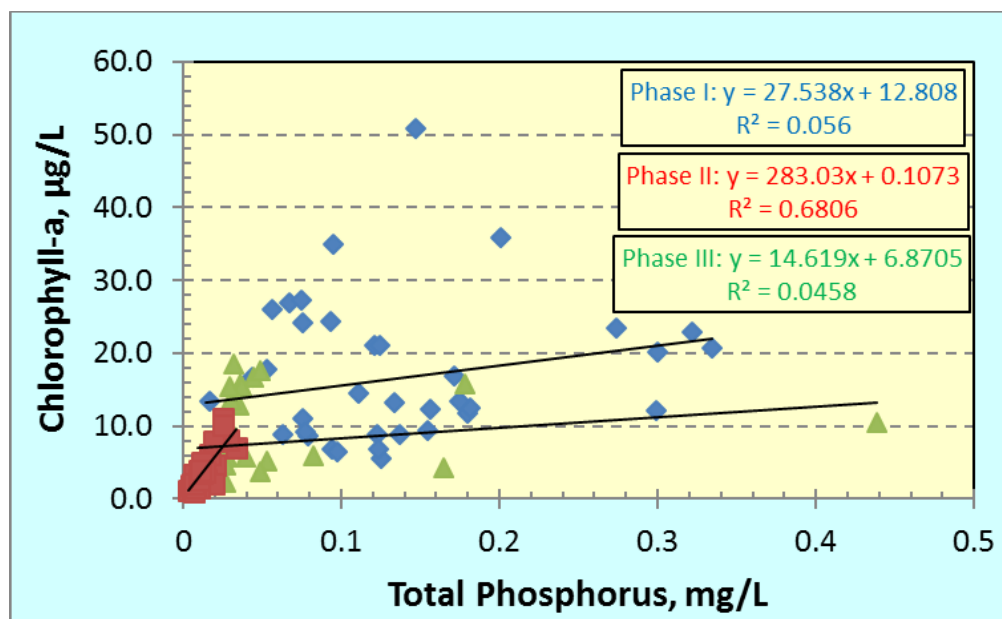


Figure 7. Relationship between total phosphorus and chlorophyll-*a* concentrations by Phase for samples collected during the South Florida Canal Aquatic Life Study.

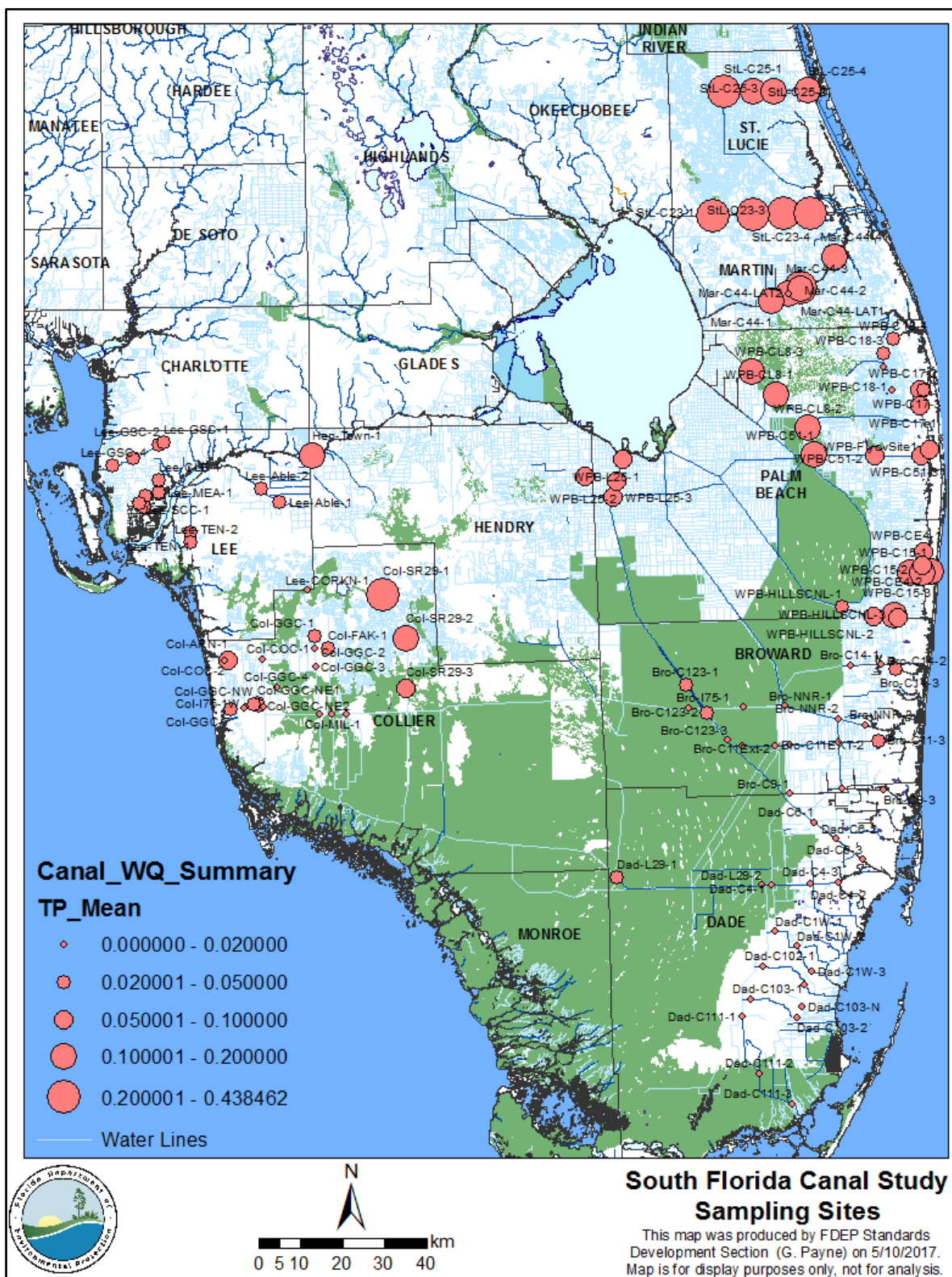


Figure 8. Spatial distribution of average total phosphorus concentrations for sites sampled during the South Florida Canal Aquatic Life Study.

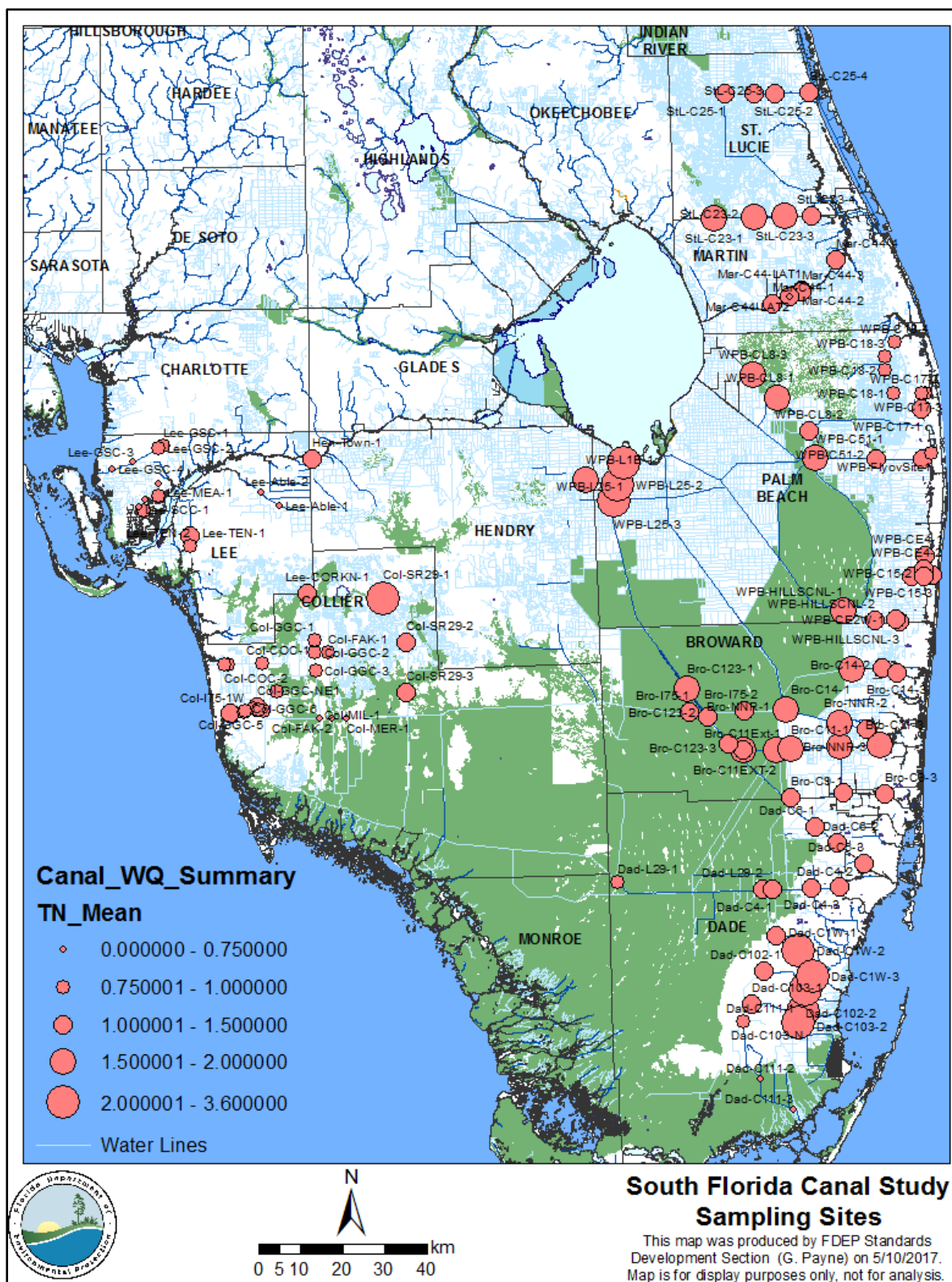


Figure 9. Spatial distribution of average total nitrogen concentrations for sites sampled during the South Florida Canal Aquatic Life Study.

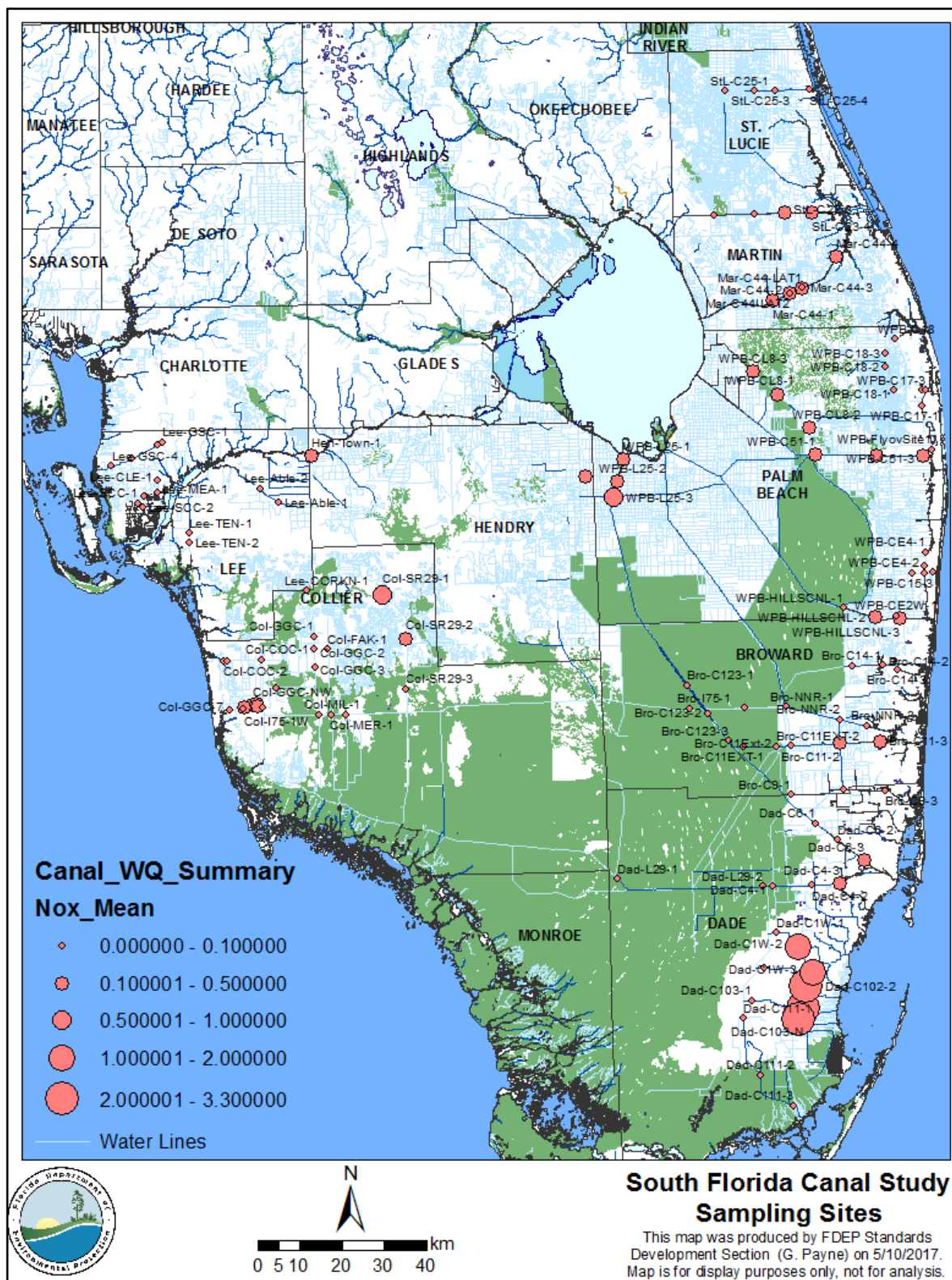


Figure 10. Spatial distribution of average nitrate + nitrite nitrogen concentrations for sites sampled during the South Florida Canal Aquatic Life Study.

### Color and Organic Carbon

Organic carbon and color are typically highly related parameters in aquatic systems because much of the color in waterbodies is derived from the quantity and nature of the organic material present. Because of this relationship, color and organic carbon exhibit similar spatial patterns.

During the study, organic carbon in the South Florida canals averaged 15.0 mg/L and exhibited a range from less than 0.5 to 44 mg/L. All three areas exhibited similar average organic carbon concentrations of 16.2, 15.7, and 12.3 mg/L, at the Phase I, II, and III sites, respectively. A map providing a detailed illustration of the spatial distribution of average organic carbon concentrations by site is shown in **Figure 11**.

Color averaged 64.5 PCU and exhibited a wide range from less than 5 PCU to 415 PCU in the South Florida canals. In contrast to organic carbon, average color levels exhibited more of a spatial pattern, with Phase I sites exhibiting the highest average of 81.5 PCU and Phase II sites exhibiting the lowest average of 45.3 PCU. Phase III sites exhibited an intermediate average color level of 60.7 PCU. A map providing a more detailed illustration of the spatial distribution of average color levels by site is provided in **Figure 12**. This spatial pattern appears to be dependent on both the concentration and nature of organic matter present.

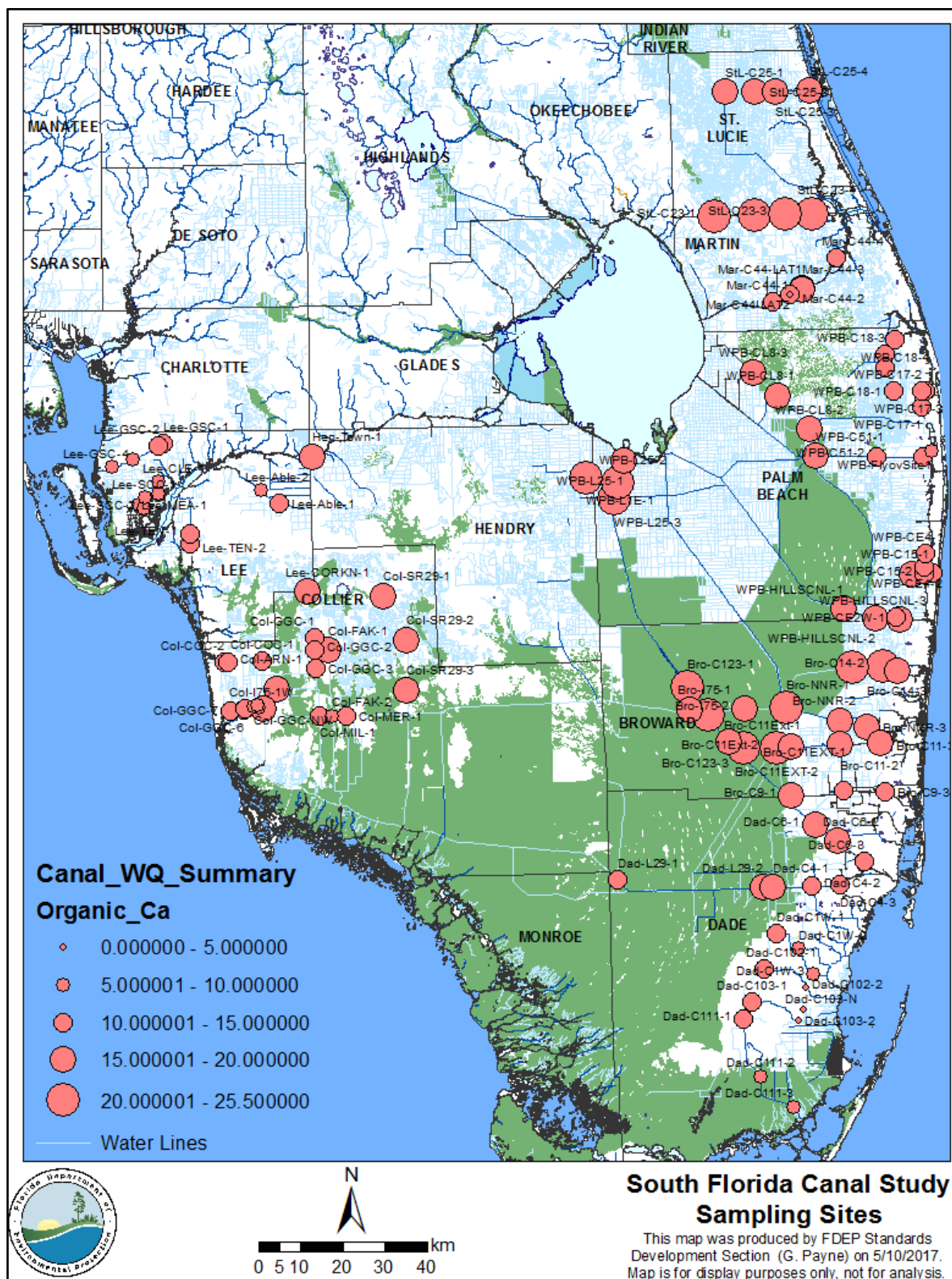
As typically observed for natural streams, a relationship was found between organic carbon and color in the South Florida canals as shown in **Figure 13**. However, unlike the consistent relationship typically observed for natural streams, the relationship between organic carbon and color for the canal sites appears to be bifurcated, with some sites exhibiting a stronger color response to organic carbon than others. To better understand the reason for the bifurcation, the relationship between organic carbon concentrations and color levels was examined by area/Phase as provided in **Figure 14**. This analysis indicates that organic carbon inputs to the Phase II canals elicits less of a color response than in the other two areas. This difference appears to stem from the fact that many of the Phase II canals drain from the Everglades marsh where nutrient levels are low and much of the organic matter present is older and has been degraded to some extent and is therefore more refractory. In contrast, many of the canals in the Phase I area drain from Lake Okeechobee or agricultural areas where nutrient and chlorophyll levels are higher and provide a continuous supply of “fresh” algae as the source of the organic matter. Inputs of this “fresh” organic matter would be expected to exhibit a greater color response.

This hypothesis is further supported by the same bifurcated organic carbon – color relationship observed for the Phase I area, which has a combination of sites that drain from Lake Okeechobee, while others drain from the Everglades. Canals draining Lake Okeechobee and agricultural areas (e.g., C-44, C-23) exhibit a greater color response to organic carbon inputs than do those receiving water from the Everglades marsh (e.g., Hillsborough Canal). Additionally, the same type of bifurcated relationship was observed between organic carbon and TP concentrations for the Phase I area (**Figure 15**). Phosphorus forms complexes with organic matter; however, much of the phosphorus bound in newer organic material is readily released as the organics decompose or are oxidized, whereas, much of the

phosphorus in older more refractory organic material has been lost with the remaining phosphorus being more resistant to release.

In contrast, a stronger linear relationship was observed between total Kjeldahl nitrogen and organic carbon concentrations (**Figure 16**). Nitrogen does not form complexes with organic matter in the same manner as phosphorus. Instead most of the nitrogen in organic matter is contained within the structures of proteins, peptides, nucleic acids, and urea, which are more resistant to loss. Therefore, nitrogen is released more evenly during the decomposition of the organic matter.

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**Figure 11. Spatial distribution of average organic carbon concentrations for sites sampled during the South Florida Canal Aquatic Life Study.**

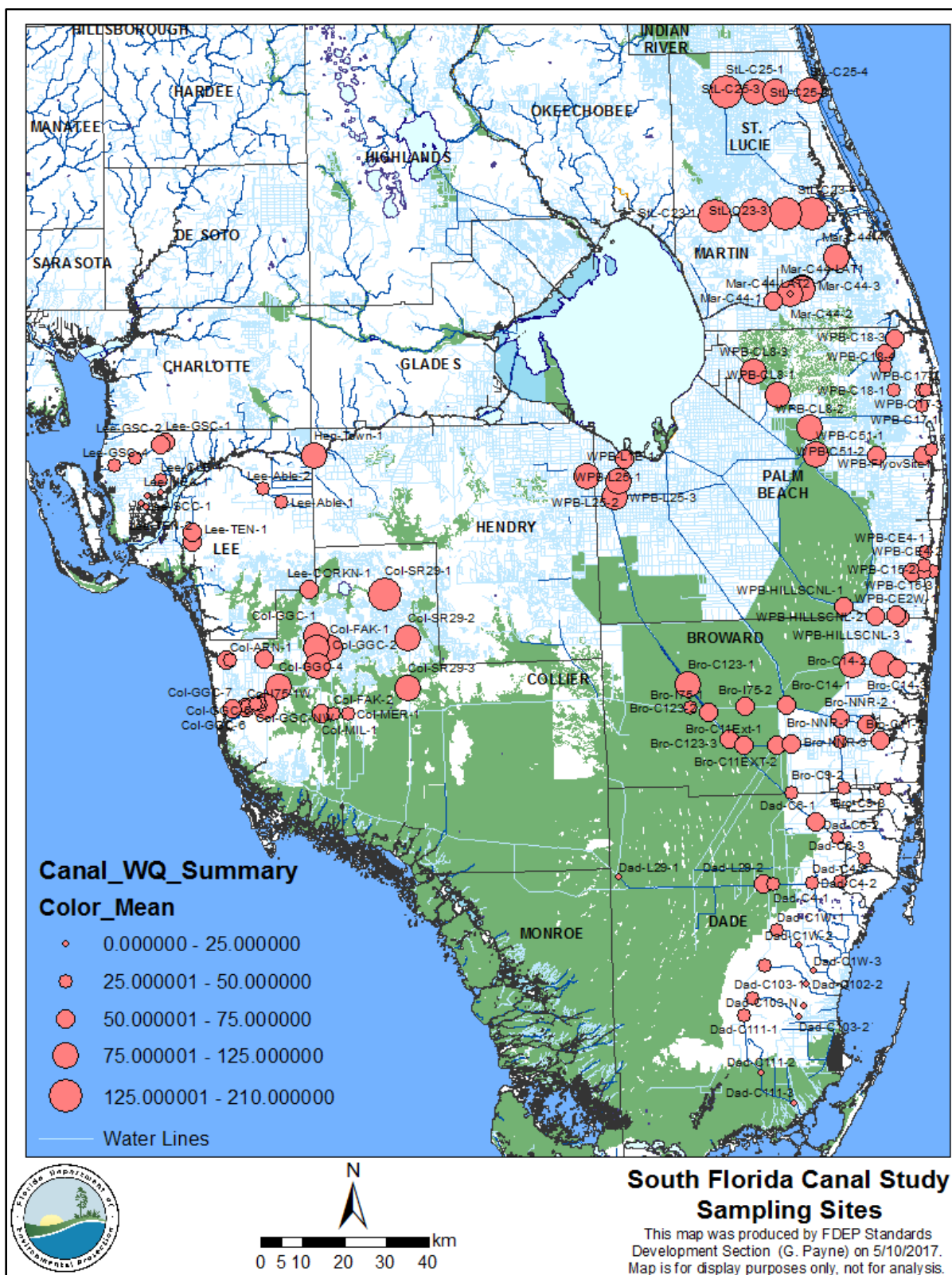


Figure 12. Spatial distribution of average color levels for sites sampled during the South Florida Canal Aquatic Life Study.

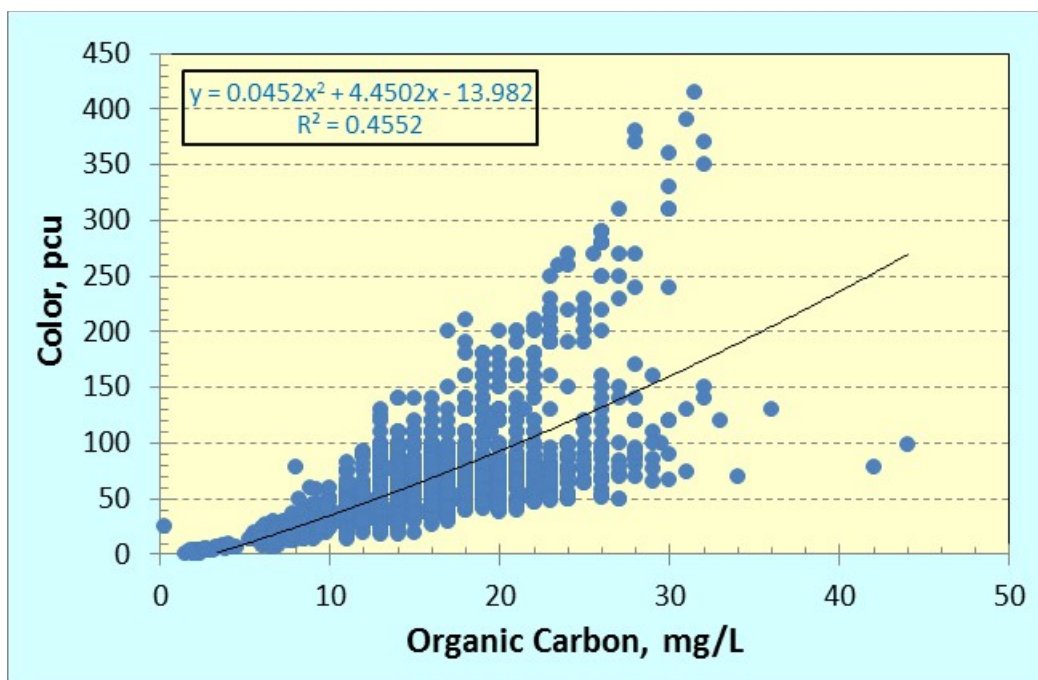


Figure 13. Relationship between organic carbon concentration and color levels for all samples collected during the South Florida Canal Aquatic Life Study.

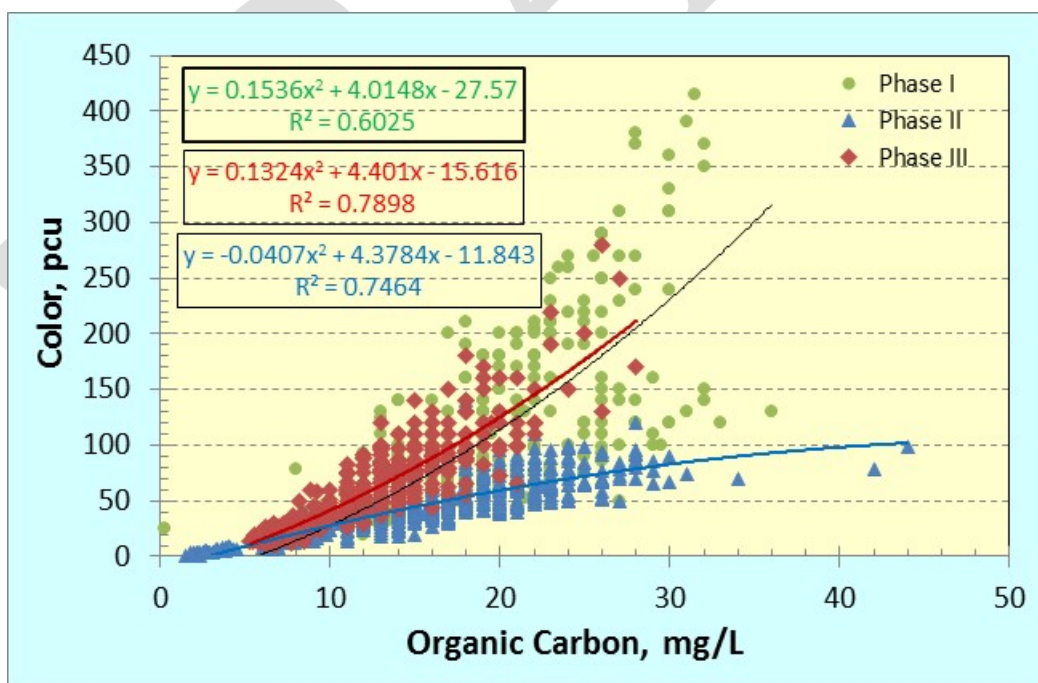


Figure 14. Relationship between organic carbon concentration and color levels by Phase for samples collected during the South Florida Canal Aquatic Life Study.

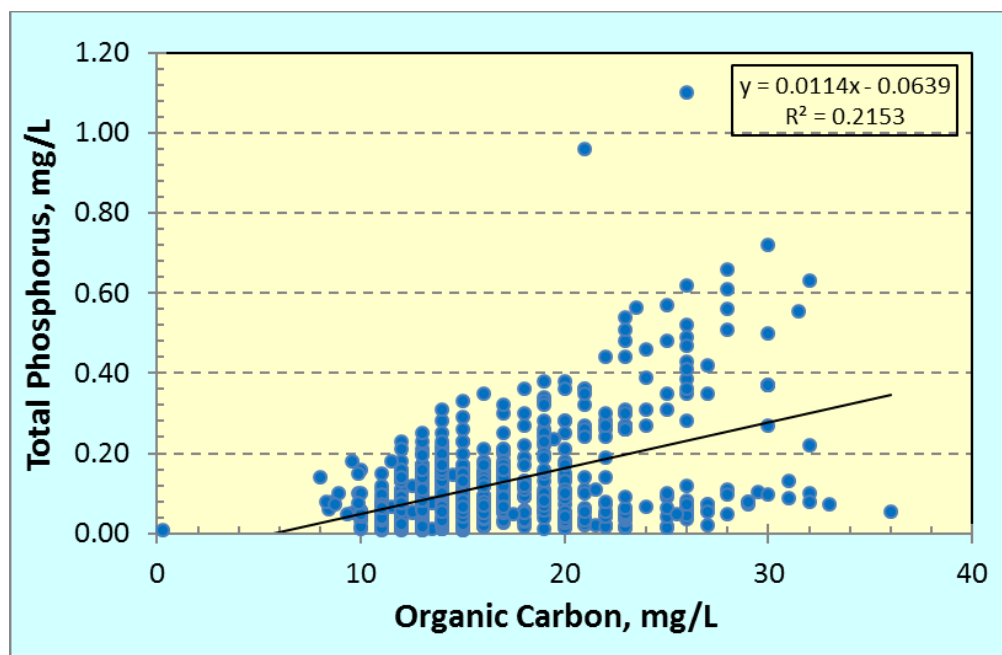


Figure 15. Relationship between organic carbon and total phosphorus concentrations for samples collected for the Phase I sites during the South Florida Canal Aquatic Life Study.

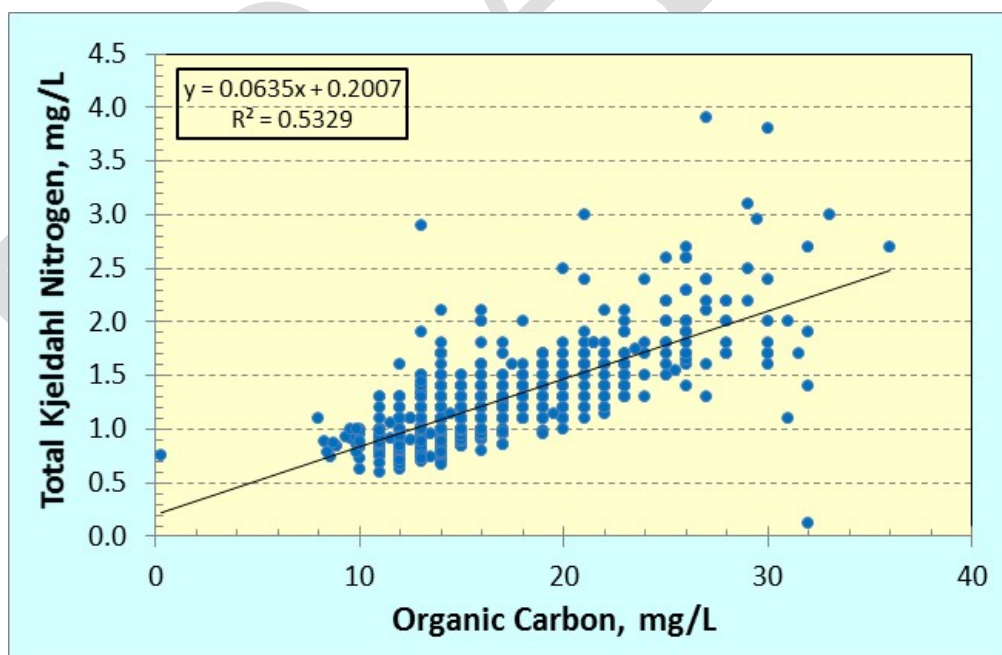


Figure 16. Relationship between organic carbon and total Kjeldahl nitrogen concentrations for samples collected for the Phase I sites during the South Florida Canal Aquatic Life Study.

### Turbidity

Turbidity levels were generally low in all canals sampled during the study, with infrequent higher values probably associated with high flow or rainfall events. Overall, turbidity levels averaged 4.1 NTU and ranged from less than 0.5 to 90 NTU. Phase I canals exhibited a slightly higher average turbidity level (6.7 NTU) compared to Phase III (2.9 NTU) and Phase II (1.6 NTU) canals. Infrequent turbidity measurements above the 29 NTU criterion were isolated to the Phase I sites. **Figure 17** provides detailed depictions of the spatial distributions of average turbidity levels by site.

### DO Saturation

Oxygen gas dissolved in water is vital to the existence of most aquatic organisms. The concentration of DO in an aquatic environment is an important indicator of that environment's quality. In any biologically active aquatic system, the actual concentration of DO within the water column is regulated by the balance between a variety of sources (e.g., photosynthetic production during the day, reaeration) and sinks [e.g., respiration and sediment oxygen demand (SOD)].

As discussed previously, DO levels in the canals were frequently below the applicable 38 % saturation criterion. In general, DO saturation levels averaged 61.7% and ranged from 2.3 to 182 %. The Phase I and III sites had the highest average DO levels (71.3% and 69.2% saturation), but also exhibited the widest range from 2.3 to 182 %. Sites with the highest DO levels were typically associated with greater nutrient and chlorophyll-*a* levels, which are indicative of higher photosynthetic rates. The lowest average DO levels (47.4% saturation) were found for the Phase II sites, many of which drained from the Everglades marsh. Wetlands in general and specifically the Everglades marsh is known to have low DO levels due to lower production and increased demand (Weaver, 2004). To acknowledge the naturally low DO levels in the Everglades, a SSAC for DO in the Everglades Protection Area was adopted by the Department on January 26, 2004 and was subsequently approved by USEPA as a revision to Florida Water Quality Standards. The DO levels allowed by the SSAC depend on water temperature and time-of-day to take into account the effect of water temperature on DO solubility and natural diel fluctuations. The Everglades DO SSAC can allow DO concentrations in the marsh as low as 1.0 mg/L or less during early morning hours when water temperatures are high. However, the SSAC does not apply to the South Florida canals. A more detailed depiction of the spatial distribution of average DO saturation levels by site is provided in **Figure 18**.

### Specific Conductance

Specific conductance (conductivity) is a measure of water's ability to conduct an electrical current and is an indirect measure of the total concentration of ionized substances (e.g.,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{Cl}^-$ ,  $\text{HCO}_3^-$ , and  $\text{SO}_4^{2-}$ ) in the water. Conductivity will vary with the number and type of these ions in solution. In some cases, it can be used to differentiate among various water sources, such as groundwater, rainwater, agricultural runoff, and municipal wastewater. Changes in conductivity beyond natural background variability can result in potentially deleterious effects to aquatic life. For example, very high conductivities would be detected under conditions of saltwater intrusion.

Overall, specific conductance averaged 611  $\mu\text{mhos/cm}$ , with similar average levels for all three areas. Conductance averaged 639, 607, and 571 for Phase I, II, and III areas, respectively. However, there were

significant variation between the canals and sites within each area likely due to differences in source water and groundwater inputs (**Figure 19**). Sites with the highest specific conductance levels (i.e., near or greater than 1,000  $\mu\text{mhos/cm}$ ) were found in the most northern canals in the Phase I area (i.e., Canals C-25 and C-23). These canals are also the only ones that exceeded the applicable 1275  $\mu\text{mhos/cm}$  criteria in more than 10% of the samples collected (**Table 3**). Some of the canals with the lowest conductance levels were also located in the Phase I area (i.e., canals C17 and C18). Most of the canals in the Phase II area exhibited moderate conductance levels ranging from 494 to 708  $\mu\text{mhos/cm}$ . Canals in the Phase III area exhibited a wider range in average conductance levels, with values ranging from 356 to 925  $\mu\text{mhos/cm}$ . Sites nearer the coast tended to have the highest conductance levels, with lower levels found at more inland sites

### pH

The pH value is defined as the negative log(base 10) of the hydrogen ( $\text{H}^+$ ) ion activity. In low ionic-strength freshwaters, the activity of the  $\text{H}^+$  ion is approximately equal to the concentration of  $\text{H}^+$  ions. Since pH is based on a log scale, each pH unit change represents a tenfold change in the concentration of  $\text{H}^+$  ions (acidity). Most living organisms, especially aquatic life, function best in a pH range of 6.0 to 9.0, although individual species have specific ideal ranges. The current Class III criterion for pH specifies that this parameter shall not be lowered below 6.0 units or raised above 8.5 units in predominately fresh waters.

There are a number of interrelationships among pH, photosynthesis, and carbon dioxide ( $\text{CO}_2$ ) in water. When  $\text{CO}_2$  enters fresh water, small amounts of carbonic acid are formed, which then dissociate into  $\text{H}^+$  and  $\text{CO}_3^{2-}$  ions, thereby resulting in a lowering of pH. Since photosynthesis and respiration alter  $\text{CO}_2$  concentration in the water, these processes exert an influence on pH. During the day, while photosynthetic processes are consuming  $\text{CO}_2$ , the concentration of carbonic acid declines and pH rises. The addition of  $\text{CO}_2$  by respiration at night reverses the reactions and lowers pH.

Canal pH levels averaged 7.5 units, with individual sites averaging from 6.7 to 8.0 units. Infrequent pH levels exceeding the 6.0 to 8.5 unit applicable criteria occurred throughout the study area and were likely associated with periods of high photosynthetic activity (**Table 3**). The three areas exhibited similar pH levels, averaging 7.6 units for the Phase I area and 7.4 units for the Phase II and III areas. Due to the narrow pH range exhibited by the canal sites and the similarity between regions, no spatial pattern was apparent with variations being highly localized.

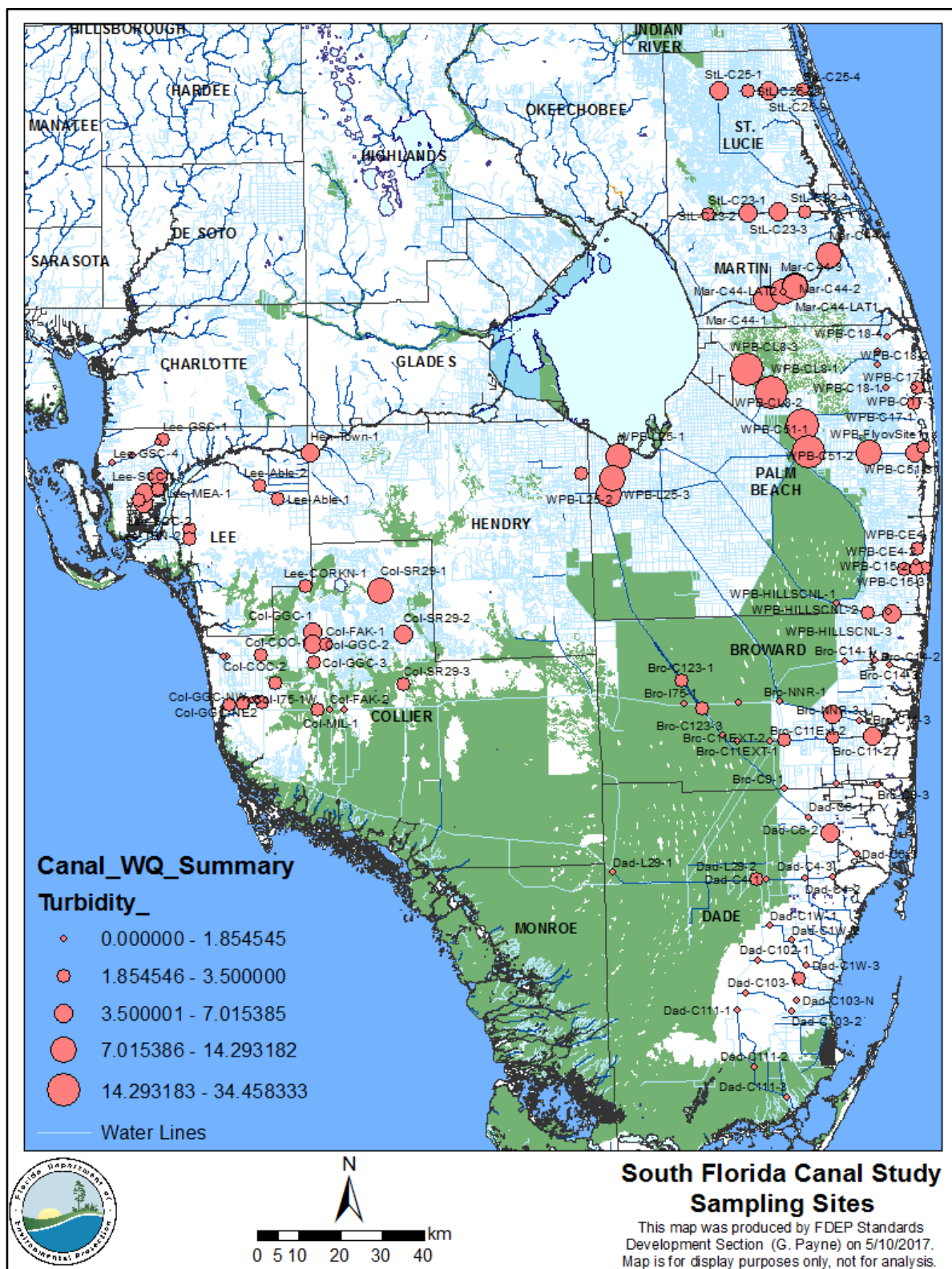


Figure 17. Spatial distribution of average turbidity levels for sites sampled during the South Florida Canal Aquatic Life Study.

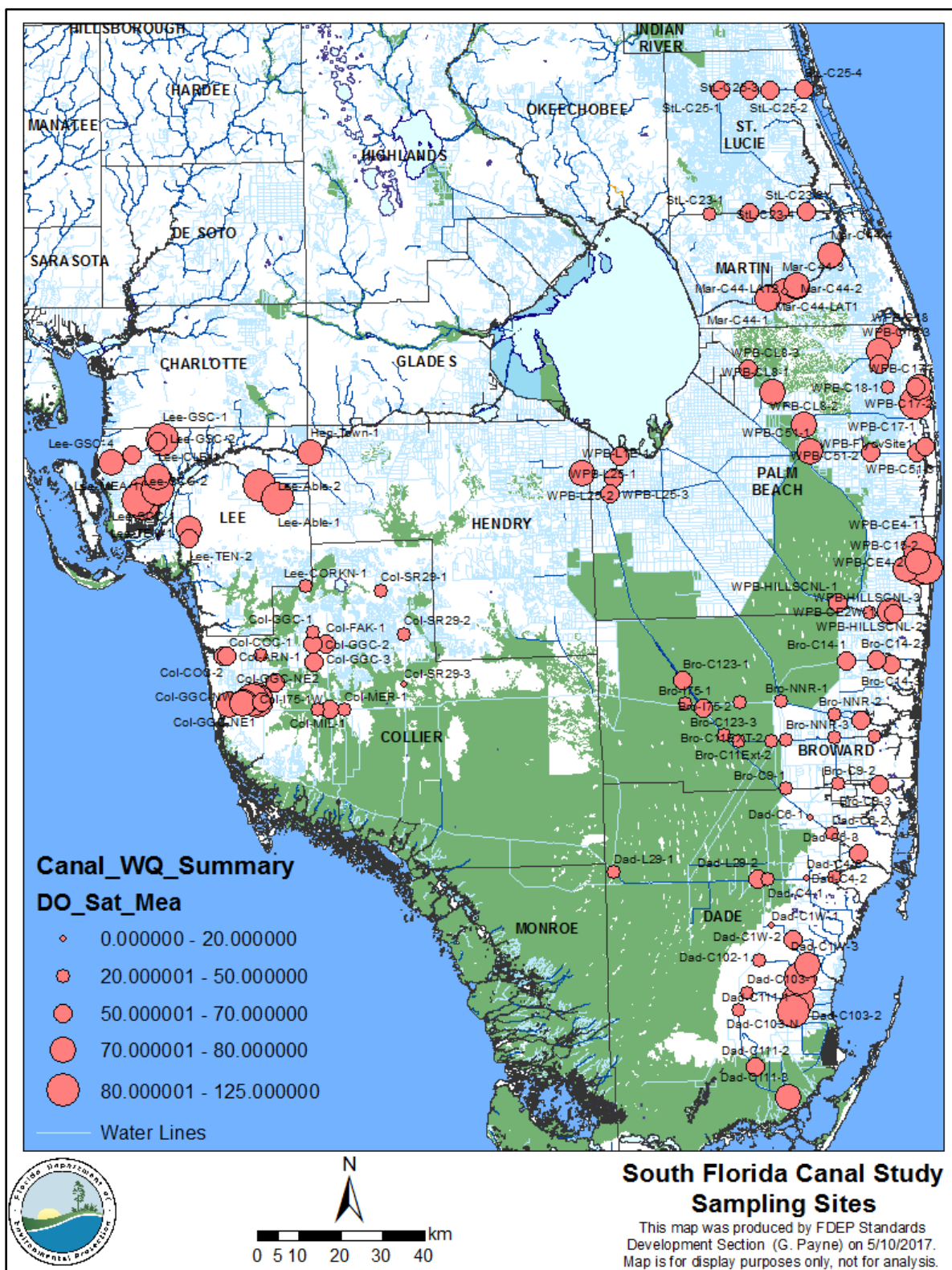


Figure 18. Spatial distribution of average DO saturation levels for sites sampled during the South Florida Canal Aquatic Life Study.

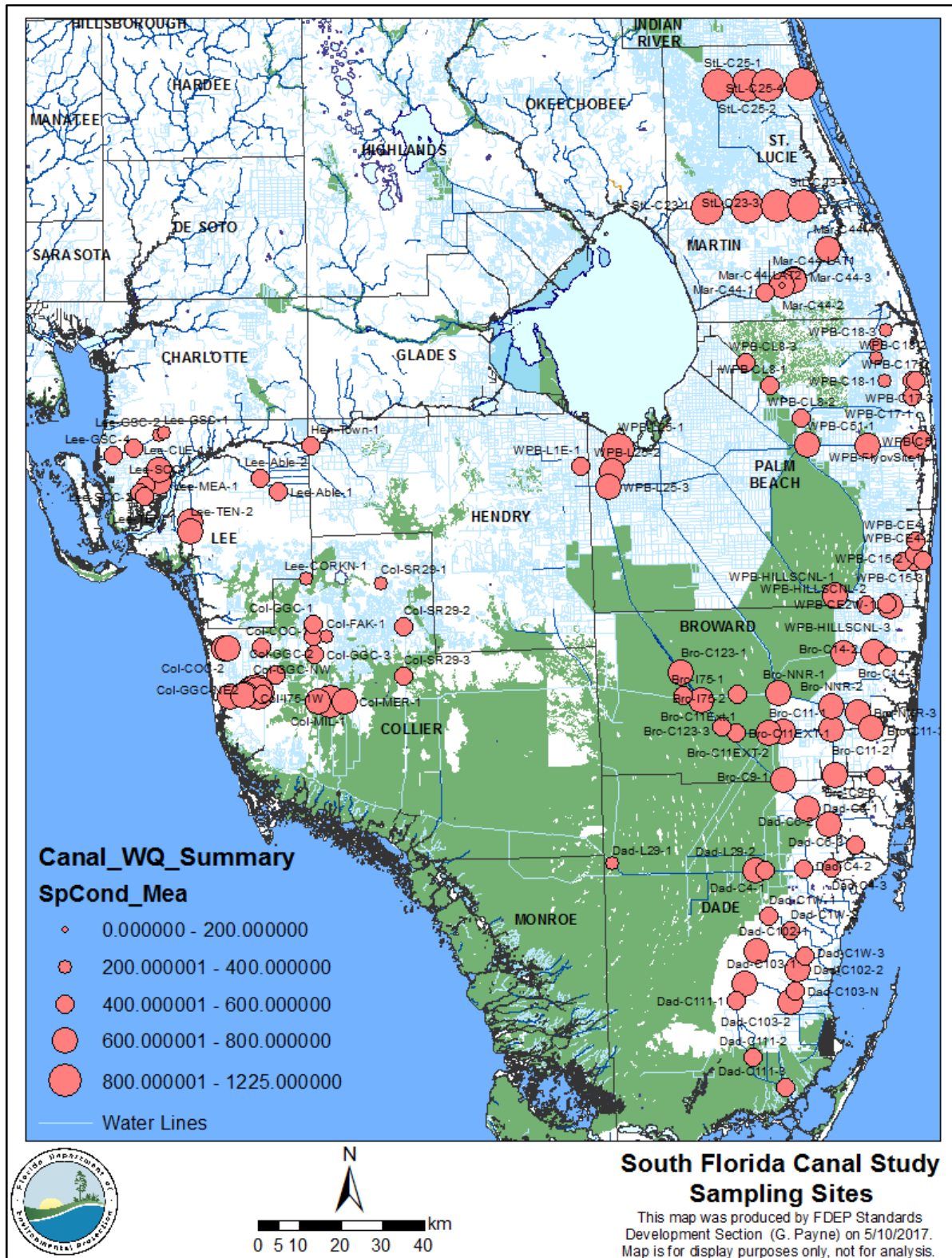


Figure 19. Spatial distribution of average specific conductance levels for sites sampled during the South Florida Canal Aquatic Life Study.

## Macroinvertebrates

### Habitat Assessment

The Habitat Assessment (HA) is a rapid field method used to evaluate the physical structure and extent of disturbance in a waterbody. Eight in-stream and riparian components of the biological habitat are scored (0 to 20 points) to estimate the influence of habitat factors on the resident aquatic organisms. The Habitat Assessment includes types and amounts of benthic substrates, water velocity, amount of sand and silt accumulation, extent of artificial channelization, bank stability, and riparian zone width and vegetation type. Habitat Assessment scores range from 11 to 160 and overall habitat quality is assigned to one of four categories: Optimal (120 to 160 points), Suboptimal (80 to 119 points), Marginal (40 to 79 points), and Poor (11 to 39 points).

As expected, most of the South Florida canals were found to be habitat limited due to the physical and hydrologic characteristics of the canals as well as their periodic maintenance. Most of the canals are characterized by deep box-cut channels with limited or no riparian zone and vegetation controlled by periodic maintenance activities. Overall, HA scores averaged 49 points (marginal) and ranged from 14 points (poor) to 111 points (suboptimal), with no scores in the optimal category.

The highest HA scores were found for the Phase II sites, which averaged 56 points, with 79% of the sites with average HA scores in the marginal category, 15% in the suboptimal category, and 5% in the poor category (**Figure 20**). The highest scoring sites were located in canals within the Everglades marsh (i.e., Water Conservation Area 3, WCA-3) where the canals are open to the marsh and there was more vegetation and more natural riparian zones. Sites outside of the Everglades scored lower due to the loss of connection to the marsh. HA scores for Phase III sites were only slightly lower, averaging 55 points with 89% of the sites being in the marginal range, 6% of the sites being in the suboptimal category, and 6% in the poor category. Within the Phase III area, the highest HA scores were recorded for sites in canals within more natural areas with less routine vegetation maintenance (e.g., Corkscrew Swamp Canal and State Road 29 Canal). Canals within more urbanized areas with greater levels of bank armament typically scored lower. In general, the lowest HA scores were found in the Phase I area where there were no sites scoring in the suboptimal category. 55% of the Phase I sites scored in the marginal category with the remaining 45% being in the poor category. The lower HA scores in the Phase I area result from most of the canals sampled being larger canals with limited or no riparian zone, highly variable flow conditions, and vegetation controlled by more frequent maintenance activities.

### SCI

The Stream Condition Index (SCI) is a biological assessment procedure that measures the degree to which flowing fresh waters support a healthy, well-balanced biological community, as indicated by benthic macroinvertebrates. The SCI is comprised of ten individual metrics selected to: a) represent as many attribute categories as possible; b) provide meaningful and predictable assessment of human effects; and c) avoid redundancy so that correlated metrics do not provide similar information. The ten-metrics used to calculate the SCI are:

1. Percent Tanytarsini
2. Number of Sensitive Taxa
3. Percent Very Tolerant Taxa
4. Number of Total Taxa

- |                                           |                                                                                               |
|-------------------------------------------|-----------------------------------------------------------------------------------------------|
| 5. Number of Ephemeroptera (mayfly) Taxa  | 8. Percent Filterers or Suspension Feeders                                                    |
| 6. Number of Trichoptera (Caddisfly) Taxa | 9. Number of Long-Lived Taxa (taxa requiring more than one year to complete their life cycle) |
| 7. Percent Dominant Taxon                 | 10. Number of Clinger Taxa                                                                    |

While the SCI was developed to assess the biological health of natural waters, it was applied to the macroinvertebrate data collected from the South Florida canals during this study to allow for comparisons among the canals and between the canals and the expectations for natural streams. For streams, average SCI scores for a minimum of two temporally independent samples of 40 or greater are considered “Healthy” (provided that neither of the last two samples have SCI scores less than 35). SCI scores of 64 or greater are considered “Exceptional.” For natural streams, average scores of less than 40 are considered indicative of biological impairment.

As predicted, most of the SCI scores for the South Florida canals were low and failed to meet the biological expectations for natural streams in the Peninsula. Overall, SCI scores averaged 29 points and ranged from 3 to 60 points, with less than a third of the samples scoring 35 points or more. Additionally, only 16.8 % of the sites sampled during the study achieved the minimum acceptable average score of 40 defined for natural streams. Regionally, the mean SCI scores for the three areas were similar, averaging 29 points for Phase I and II areas and 33 points for sites in the Phase III area.

Even though the average SCI scores were similar across the areas, there were regional differences in the percentage of sites with passing SCI scores. The Phase III area had the highest percentage of sites with average scores above 40 points, with 34% above 40 compared to 16% for Phase II sites and 7.5% for Phase I (**Figure 21**).

Interestingly, SCI scores did not appear to be influenced by variations in HA scores among canals (**Figure 22**) as conceptually expected. While not expected, the lack of relationship between SCI and HA scores is consistent with the finding of a previous study a smaller group of southwest Florida canals that found no difference in SCI scores between sites with low HA scores and those with higher scores (FDEP, 2001). While the macroinvertebrate community found in canals is likely restricted by the generally limited habitat compared to natural streams, the macroinvertebrate population surviving in the canals is not highly influenced by variation in habitat quality or quantity across the canals. This may be the result of other factors being more limiting than habitat to the remaining macroinvertebrates found in the canals. Also interesting is the finding that the sites located in canals traversing the Everglades marsh exhibited some of the lowest SCI scores despite having the best HA scores and some of the best water quality (i.e., low conductance, nutrient, and chlorophyll levels).

The relationships between the 10-individual metrics that comprise the SCI and the SCI scores were also evaluated to determine which metric or group of organisms had the greatest influence on the SCI scores. The results indicate the SCI scores were most highly correlated to the total number of taxa in the sample (**Figure 23**) and the percent dominant taxa (**Figure 24**). The results also showed very similar

relationships between the SCI scores and the metrics for all three areas. SCI scores were least influenced by the numbers of sensitive taxa, long-lived taxa, clinger taxa, and ephemeroptera taxa. The lack of correlation between the SCI scores and these metrics is due to the limited number of organisms in these groups.

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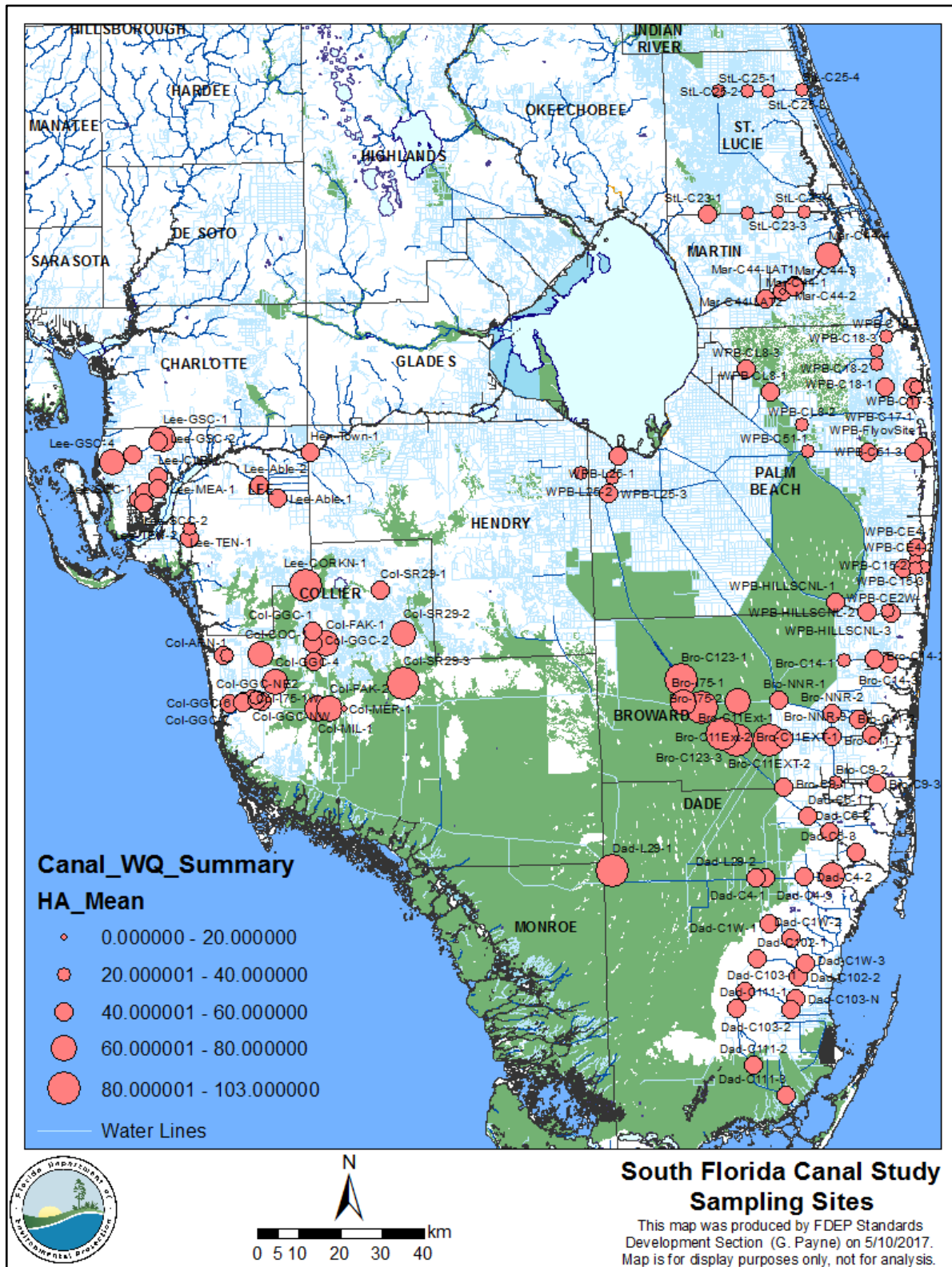
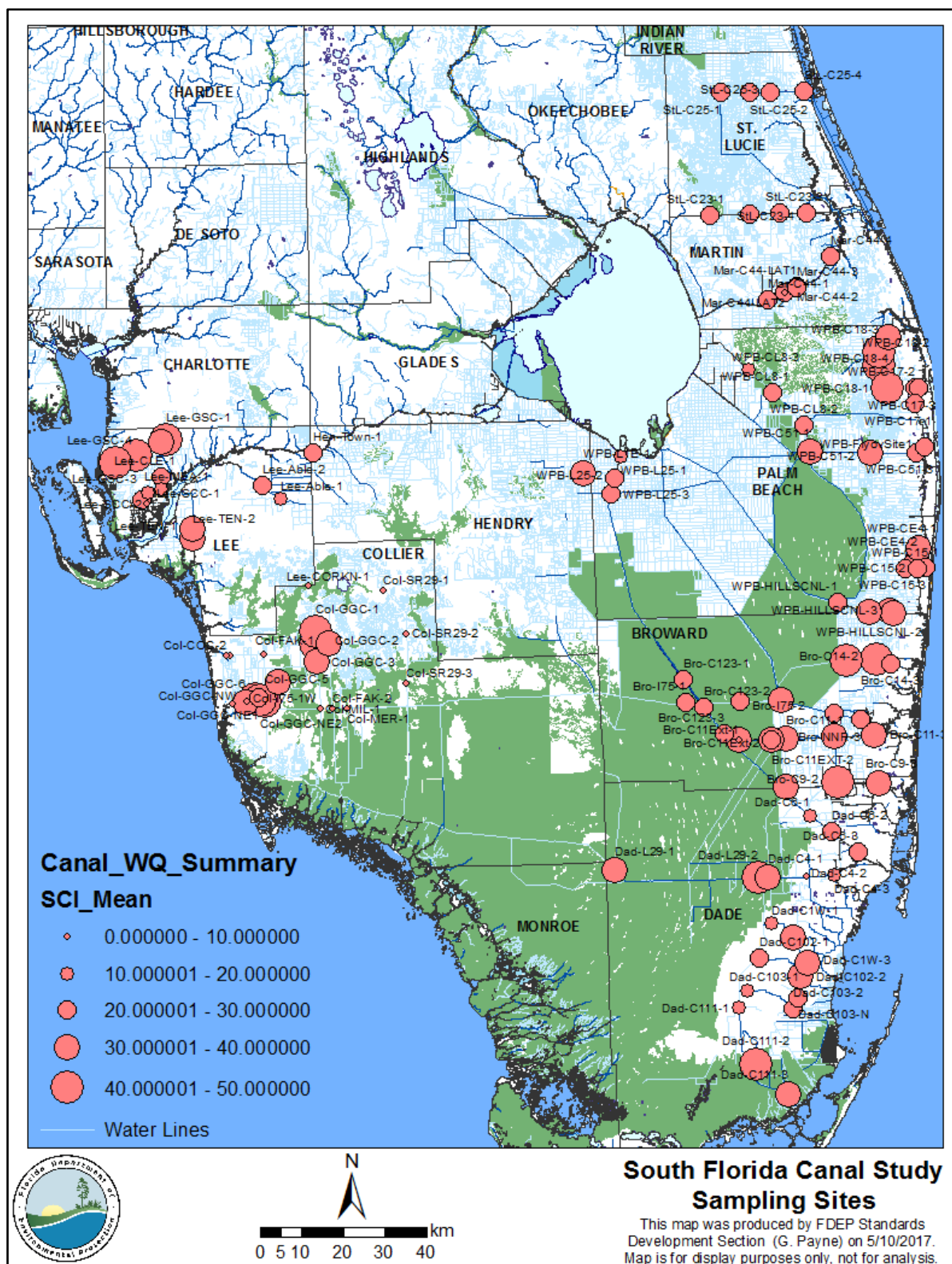


Figure 20. Spatial distribution of average Habitat Assessment (HA) scores for sites sampled during the South Florida Canal Aquatic Life Study.



**Figure 21. Spatial distribution of average Stream Condition Index (SCI) scores for sites sampled during the South Florida Canal Aquatic Life Study.**

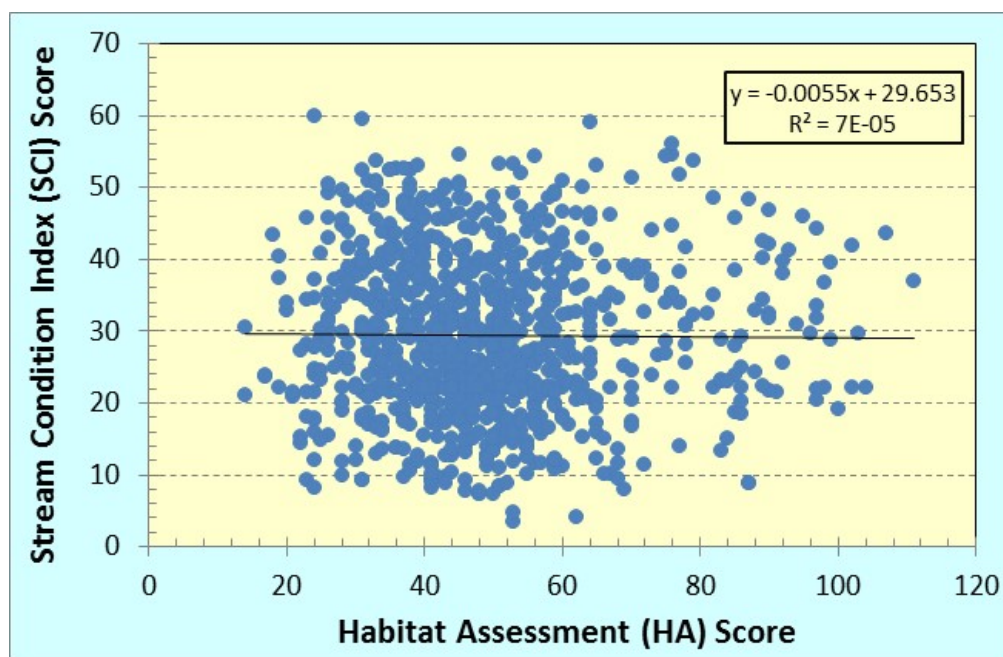


Figure 22. Relationship between Habitat Assessment (HA) and Stream Condition Index (SCI) scores for samples collected during the South Florida Canal Aquatic Life Study.

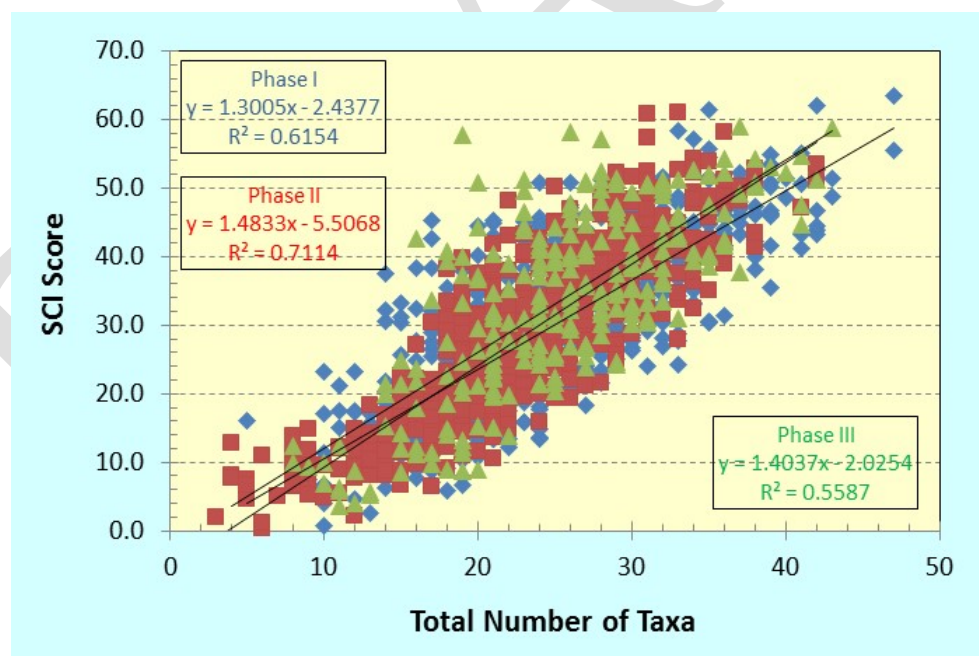
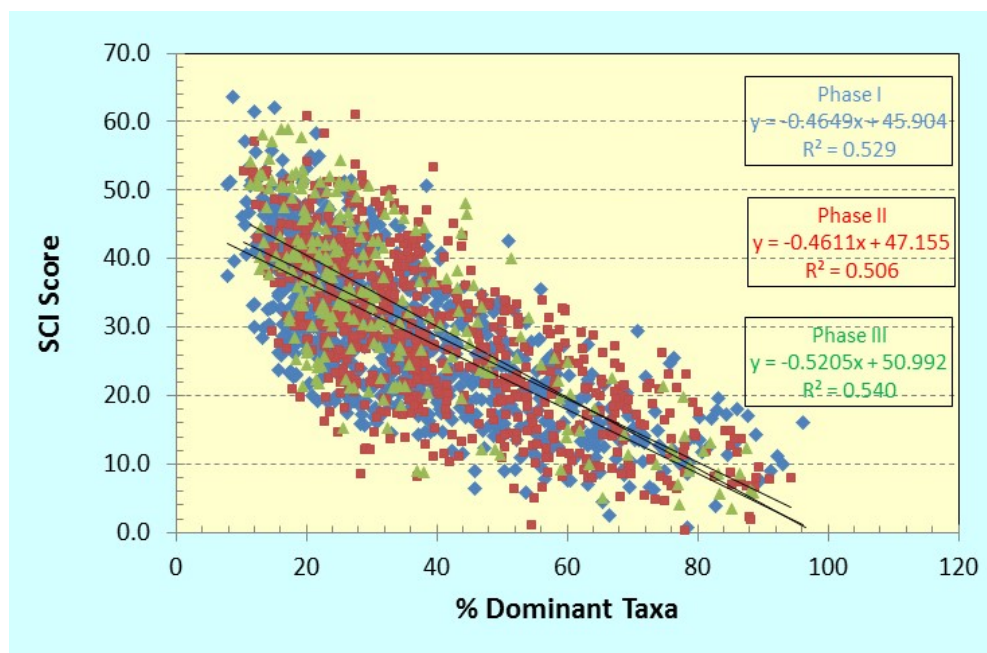


Figure 23. Relationship between Stream Condition Index (SCI) scores and the total number of macroinvertebrate taxa for samples collected during the South Florida Canal Aquatic Life Study.



**Figure 24. Relationship between Stream Condition Index (SCI) scores and the percent dominant taxa for samples collected during the South Florida Canal Aquatic Life Study.**

### Relationships between SCI Scores and Other Factors

As in natural streams, the health and composition of biological communities in the South Florida canals are controlled by a number of drivers and stressors as described earlier and illustrated in the conceptual model for this study (**Figure 1**). The factors controlling the biological communities include both natural and anthropogenic influences and range from habitat availability to geomorphic and hydrologic conditions to water quality and management activities. These factors can influence the biological communities directly or through complex interrelationships.

Numerous preliminary analyses of the data collected during the Canal Study have been conducted previously to determine the factors controlling or influencing the biological communities found in the South Florida canals. These previous evaluations include extensive statistical analyses conducted by Dr. Curt Pollman (Pollman, 2017) that yielded little explanatory information about the macroinvertebrate community or SCI response in the canals. Most of these previous analyses attempted to group all of the South Florida canals together assuming that all of the canals would respond to the same factors in a similar and predictable manner. For example, because macroinvertebrates require dissolved oxygen to survive, it is reasonable to expect a relationship between the SCI scores and DO. However, when the average SCI scores for all canal sites are plotted with the average DO (**Figure 25**), no relationship is apparent. The lack of relationships between the biological communities and expected influencing

factors found during these analyses suggests that all of the canals are not responding to the same factors or at least not in the same manner. Therefore, the same type of analysis was not repeated here.

Instead, the South Florida canals were separated by region (project phase) and health of the macroinvertebrate community as indicated by the SCI score. That is sites performing well based on the average SCI score ( $SCI \geq 40$ ) were separated from sites with lower SCI scores ( $SCI < 40$ ) for each project area/phase. Differences in water quality and habitat conditions between SCI groups were then examined for each area. Results of this evaluation are presented in **Table 4**. This analysis provided more insight into the localized site-specific nature of the factors influencing the biological communities. For example, as described previously, the Phase II sites located in canals traversing the Everglades marsh exhibited some of the best HA scores along with the best water quality (i.e., low nutrients and chlorophyll concentrations, and lower conductance levels) that would be expected to support a healthier more balanced macroinvertebrate community; however, the SCI scores for these sites were much lower than expected and among the lowest reported for the Phase II area (**Figure 21**). After examining the differences between the sites with low SCI scores to those with higher scores (**Table 4**), one of the primary differences is that the sites passing the SCI have higher DO levels compared to sites with lower SCI scores. This observation is supported by **Figure 18**, which shows that the sites within WCA-3 exhibited some of the lowest DO levels. Since macroinvertebrates need sufficient DO levels to survive, it can be concluded that the biological communities at sites within WCA-3 are limited by DO levels despite other factors being near optimal levels. This hypothesis was further tested by replotting the SCI scores and DO levels only for sites in which DO could be limiting (i.e., sites with average DO saturation of ~50% or less) (**Figure 26**). By limiting the analysis to only low DO sites, a significant positive SCI response to increasing DO levels is observed as expected. By including all sites in the analysis (**Figure 25**) as was done in previous analyses (Pollman, 2017), the relationship between SCI scores and DO levels was obscured by the sites which were responding to factors other than DO (i.e., DO levels not limiting the macroinvertebrate community).

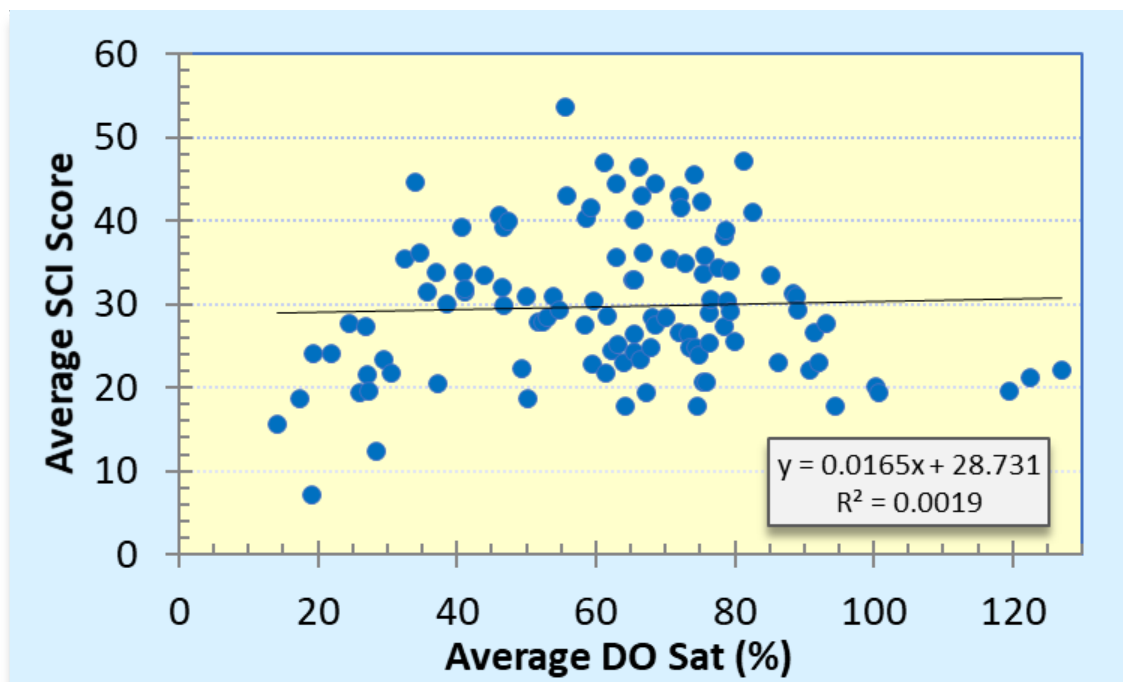


Figure 25. Relationship between average SCI scores and average DO saturation levels for all canal sites.

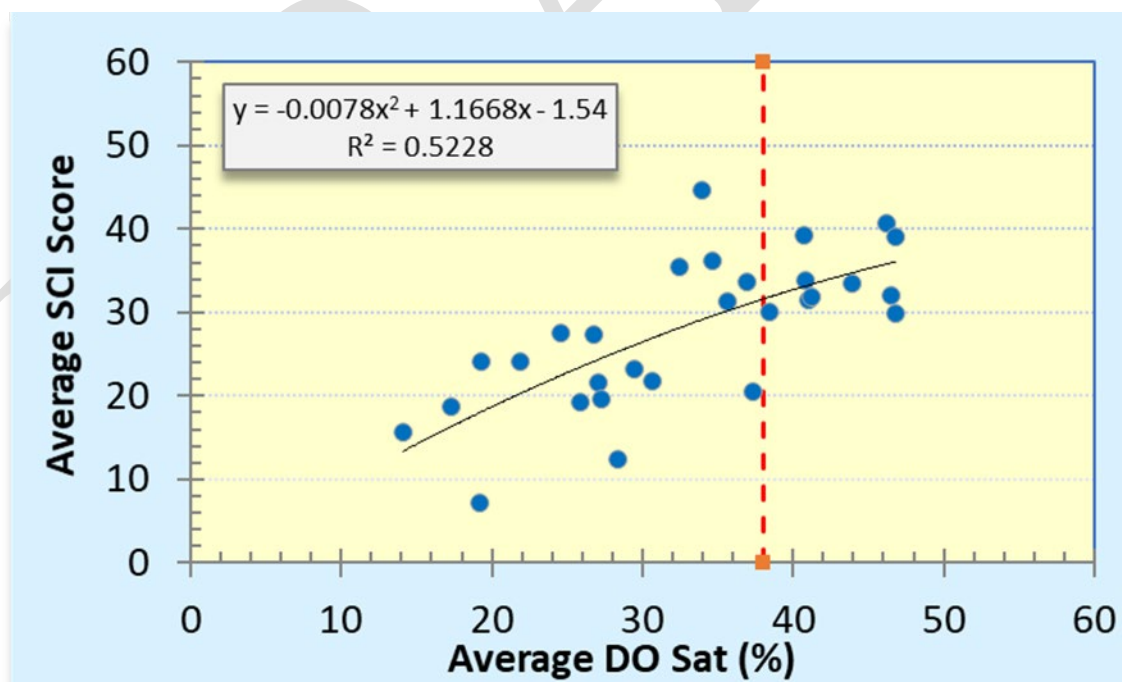


Figure 26. Relationship between average SCI scores and average DO saturation levels for canal sites with DO levels of less than 50% saturation.

In contrast, for the Phase I sites where DO levels are higher, the macroinvertebrate community does not appear to be limited by DO. Instead the, the primary factors that are different between sites passing the SCI and those with failing scores are specific conductance and nutrients (including chlorophyll). The specific conductance levels at sites passing the SCI is approximately half of that for sites with failing SCI scores (334 versus 677  $\mu\text{mhos/cm}$ ). Likewise, levels of TP, TN, and chlorophyll concentrations are all much lower for sites passing the SCI compared to sites passing the SCI (**Table 4**). By comparing **Figures 6, 8, 9, and 19**, the TP, TN, and chlorophyll concentrations and conductance levels appear to be interrelated, with high levels occurring at the same sites. Many of the sites exhibiting high levels of these factors drain agricultural areas or receive drainage from Lake Okeechobee, which is known to be eutrophic. The mechanism for a direct adverse effect of high nutrients and chlorophyll levels on the macroinvertebrate community is unknown, but may be associated with wider diel DO fluctuations (very low DO levels occurring at night), algal smothering, or presence of toxic algae. It is also possible that the high nutrients and chlorophyll levels are surrogates for some other factor for which data are not available.

The differences in the passing and failing SCI sites in the Phase III area appear to also be related to nutrient and chlorophyll levels but is less clear (**Table 4**). The less clear nature of the differences in the Phase III area may be due to the broader range of canal types, source water, and management activities for the canals in this area. This may suggest the need to repeat the analyses based on different grouping of sites, possibly based on water source.

The findings of this analysis also help understand why extensive analyses conducted previously have failed to provide significant information concerning the factors influencing the biological communities. The previous analyses have assumed that the biological community responds to a controlling factor in a linear or other predictable manner regardless of the levels of other factors. The current analyses suggest that the biological response in the canals may follow more of the conceptual model provided by Liebig's Law of the Minimum that was first developed to describe the response of agricultural plants to nutrients and other growth/yield factors, but has more recently been applied to biological populations and ecosystem models. Liebig's Law states that biological response (e.g., plant growth, biological community health) is not controlled by the total amount of resources available, but by the scarcest resource (most limiting factor) as is often simplistically depicted by a barrel (Liebig's barrel) where the staves of the barrel represent the various growth factors and the capacity of a barrel (i.e. plant growth or other biological response) is limited by the shortest stave (i.e., factor in shortest supply) regardless of the height of the other staves (other factors) as shown in **Figure 27**. Applying Liebig's conceptual model to the SCI response for the canal sites in the Everglades, the lowest stave in the barrel would represent low DO levels that limit the biological community despite more optimal levels of other parameters (e.g., habitat, water quality) (**Figure 27**).

Based on the results from these preliminary analyses of the macroinvertebrate community, it is suggested that future analyses of the biological communities in the South Florida canals follow this conceptual model instead of the linear predictable response model that has not been successful in previous attempts.

### Before-After-Control-Impact (BACI) Study Results

The BACI study was conducted to quantitatively assess the influence of routine canal maintenance (aquatic vegetation removal) on the biological communities found in the canals. The study was conducted in the C-18 canal starting in August 2014. The C-18 canal was selected for the study due to its relatively high SCI and HA scores. Three sites within the treatment area were sampled immediately prior to the vegetation management and at one, three, and six months after the treatment. The results of the study indicate that, prior to the vegetation treatment, the average HA score was 72 points (**Figure 28**). One month after the maintenance, the average HA score dropped to 52 points and remained at lower levels for the duration of the study. The initial drop in HA score appears to be related to a decrease in the amount and diversity of habitat due to the removal of the vegetation. Other factors, such as differences in flow, may have contributed to the scores remaining low.

The SCI scores obtained during the BACI study averaged 41.7 points for the pre-treatment sampling event. The scores decreased slightly to an average of 35.0 points for the samples collected one month after treatment (**Figure 29**). Results for the samples collected at three and six months after treatment indicate that the macroinvertebrate community fully recovered from any treatment effect, with SCI scores slightly higher than the pre-treatment samples. Average SCI scores for the three and six months after treatment sampling events were 48.7 and 47.5, respectively. It should be noted that the 6.7-point difference in SCI scores between the pre-treatment and one-month post-treatment sampling events and the ~ 6.4-point difference between the pre-treatment and three and six-month post-treatment sampling events is likely within the expected error for the SCI methodology.

In contrast to the original hypothesis that periodic vegetation management activities conducted in the canals resulted in a significant limitation on the biological communities present, the results of the BACI study indicate that the macroinvertebrate community is not strongly affected by canal vegetation maintenance activities, with any effect being short-lived. These results also support the previous finding that habitat is not a primary factor influencing the macroinvertebrate community.

### Conclusions and Path Forward

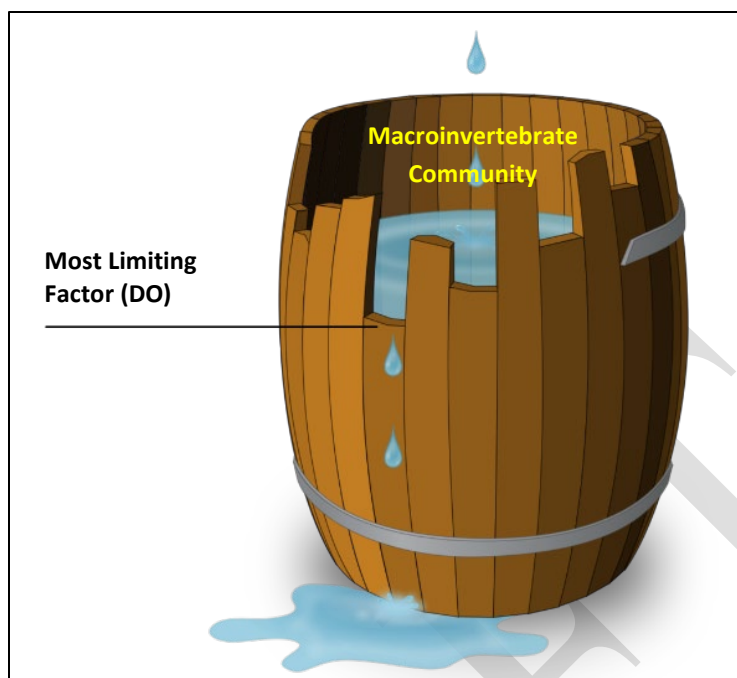
The results from the South Florida Canal Study have demonstrated a wide range of water quality and biological conditions exist across the canals in South Florida. Additionally, the macroinvertebrate community in the canals is highly limited due to the low habitat quantity, quality, and diversity compared to natural streams. The macroinvertebrate community is dominated by taxa that tolerate the harsh environment found in the canals, with a general lack of more sensitive organisms. While the limited habitat may help explain the differences between the canals and natural streams, variation in habitat does not appear to be a significant factor explaining biological differences among canals. Additionally, results from the BACI Study indicate that maintenance activities (i.e., physical and chemical vegetation removal) and the resulting loss of habitat do not have a strong influence on the macroinvertebrate community in the canals.

Additional analyses could be conducted using the macroinvertebrate data as well as being expanded to include the other biological communities (phytoplankton, zooplankton, fish, LVS, and RPS). However, due to the limited number of organisms and diversity observed during preliminary evaluations, more

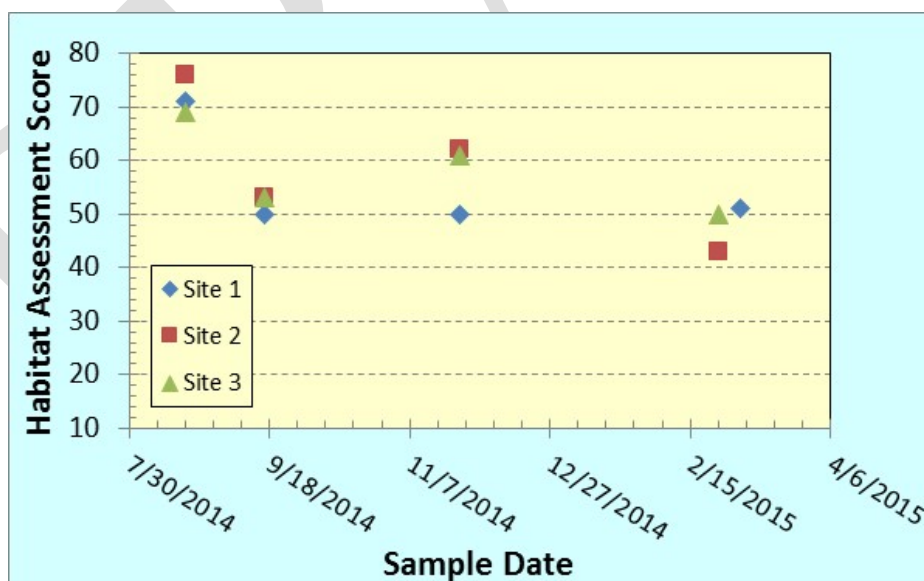
extensive analyses of the other population are not expected to provide a better understanding of the canals. The results from the analyses of the macroinvertebrate community presented herein suggest that for any additional analyses, the canal sites should be regrouped based on source water characteristics (i.e., Lake Okeechobee and agricultural drainage versus Everglades inputs versus highly urban inputs, etc.) to more fully evaluate potential drivers and influences on the biological communities. Additionally, it is suggested that future analyses of the biological communities incorporate the Liebig's Law conceptual model instead of the linear predictable response model that has been unsuccessful in previous attempts to understand and interpret data collected in the canals.

**Table 4. Comparison of average habitat and water quality results for sites passing the SCI (average SCI  $\geq 40$ ) to average results for sites with failing the SCI scores (average SCI  $< 40$ ).**

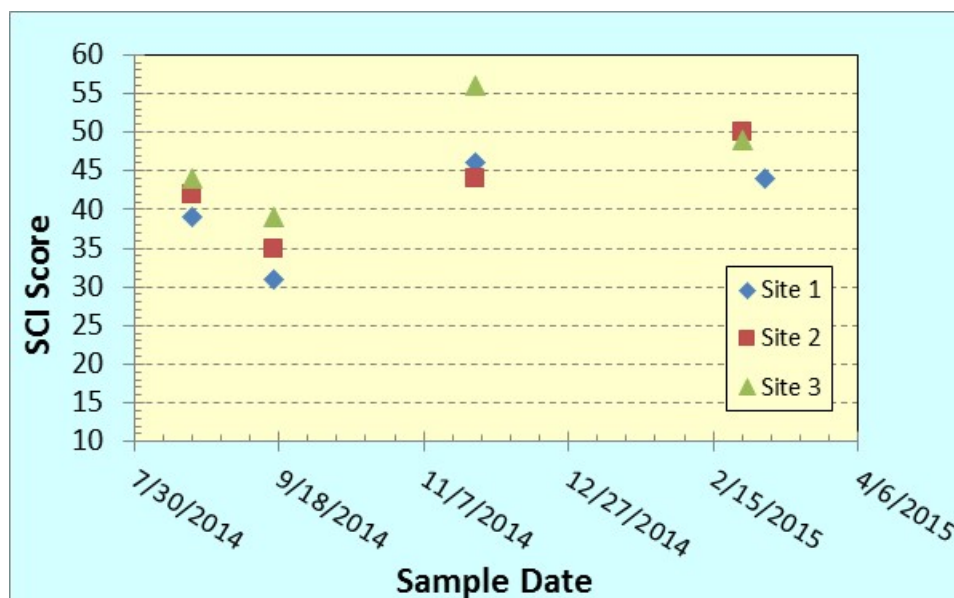
| Phase      | SCI Result | N   | SCI Score<br>Unitless | Habitat Assessment Score<br>Unitless | DO Saturation<br>% | Specific Conductance<br>$\mu\text{mhos/cm}$ | Color (true)<br>PCU | Chlorophyll-a, Corrected<br>$\mu\text{g/L}$ | Total Kjeldahl Nitrogen<br>mg/L | Nitrate + Nitrite Nitrogen<br>mg/L | Total Nitrogen<br>mg/L | Total Phosphorus<br>mg/L | Organic Carbon<br>mg/L | Turbidity<br>NTU |
|------------|------------|-----|-----------------------|--------------------------------------|--------------------|---------------------------------------------|---------------------|---------------------------------------------|---------------------------------|------------------------------------|------------------------|--------------------------|------------------------|------------------|
| Phase I    | SCI Pass   | 3   | 42.7                  | 40.4                                 | 62.2               | 333.9                                       | 47.9                | 8.9                                         | 0.88                            | 0.01                               | 0.89                   | 0.02                     | 13.2                   | 1.2              |
| Phase I    | SCI Fail   | 37  | 26.7                  | 41.1                                 | 70.0               | 676.5                                       | 85.3                | 16.9                                        | 1.26                            | 0.13                               | 1.39                   | 0.13                     | 16.4                   | 7.3              |
| Phase I    | All        | 40  | 27.9                  | 41.1                                 | 69.4               | 650.8                                       | 82.5                | 16.3                                        | 1.23                            | 0.13                               | 1.36                   | 0.13                     | 16.2                   | 6.9              |
| Phase II   | SCI Pass   | 5   | 44.1                  | 39.5                                 | 54.6               | 631.0                                       | 51.9                | 3.3                                         | 1.21                            | 0.04                               | 1.25                   | 0.010                    | 18.1                   | 1.4              |
| Phase II   | SCI Fail   | 33  | 26.7                  | 58.9                                 | 46.7               | 603.5                                       | 43.5                | 3.7                                         | 1.15                            | 0.39                               | 1.54                   | 0.013                    | 15.2                   | 1.7              |
| Phase II   | All        | 38  | 29.0                  | 56.3                                 | 47.7               | 607.2                                       | 44.6                | 3.6                                         | 1.16                            | 0.34                               | 1.50                   | 0.012                    | 15.6                   | 1.6              |
| Phase III  | SCI Pass   | 10  | 44.1                  | 60.6                                 | 69.8               | 532.3                                       | 66.3                | 4.2                                         | 0.77                            | 0.06                               | 0.83                   | 0.02                     | 12.6                   | 2.3              |
| Phase III  | SCI Fail   | 25  | 28.2                  | 53.4                                 | 70.0               | 588.7                                       | 58.0                | 8.8                                         | 0.90                            | 0.09                               | 1.00                   | 0.06                     | 12.1                   | 3.0              |
| Phase III  | All        | 35  | 32.7                  | 55.5                                 | 70.0               | 573.1                                       | 60.3                | 7.6                                         | 0.87                            | 0.08                               | 0.95                   | 0.05                     | 12.3                   | 2.9              |
| All Phases | SCI Pass   | 18  | 43.9                  | 51.4                                 | 64.3               | 526.7                                       | 59.3                | 4.7                                         | 0.91                            | 0.05                               | 0.96                   | 0.02                     | 14.2                   | 1.9              |
| All Phases | SCI Fail   | 95  | 27.1                  | 50.5                                 | 62.0               | 627.7                                       | 63.5                | 10.2                                        | 1.13                            | 0.21                               | 1.34                   | 0.07                     | 14.8                   | 4.2              |
| All Phases | All        | 113 | 29.8                  | 50.7                                 | 62.4               | 611.7                                       | 62.9                | 9.3                                         | 1.09                            | 0.19                               | 1.28                   | 0.06                     | 14.7                   | 3.8              |



**Figure 25.** Example application of Liebig's Law of the minimum for the macroinvertebrate community (SCI scores) in the Phase II area of South Florida Canal Study. Biological community (SCI) is being controlled by most limiting factor (DO) not consistent linear relationships between the community and the influencing factors.



**Figure 26.** Habitat Assessment results from the Before-After-Control-Impact (BACI) Study conducted as part of the South Florida Canal Study. Initial sampling event was conducted immediately prior to canal vegetation maintenance with subsequent events conducted approximately one, three, and six months after treatment.



**Figure 27.** Stream Condition Index (SCI) results from the Before-After-Control-Impact (BACI) Study conducted as part of the South Florida Canal Study. Initial sampling event was conducted immediately prior to canal vegetation maintenance with subsequent events conducted approximately one, three, and six months after treatment.

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