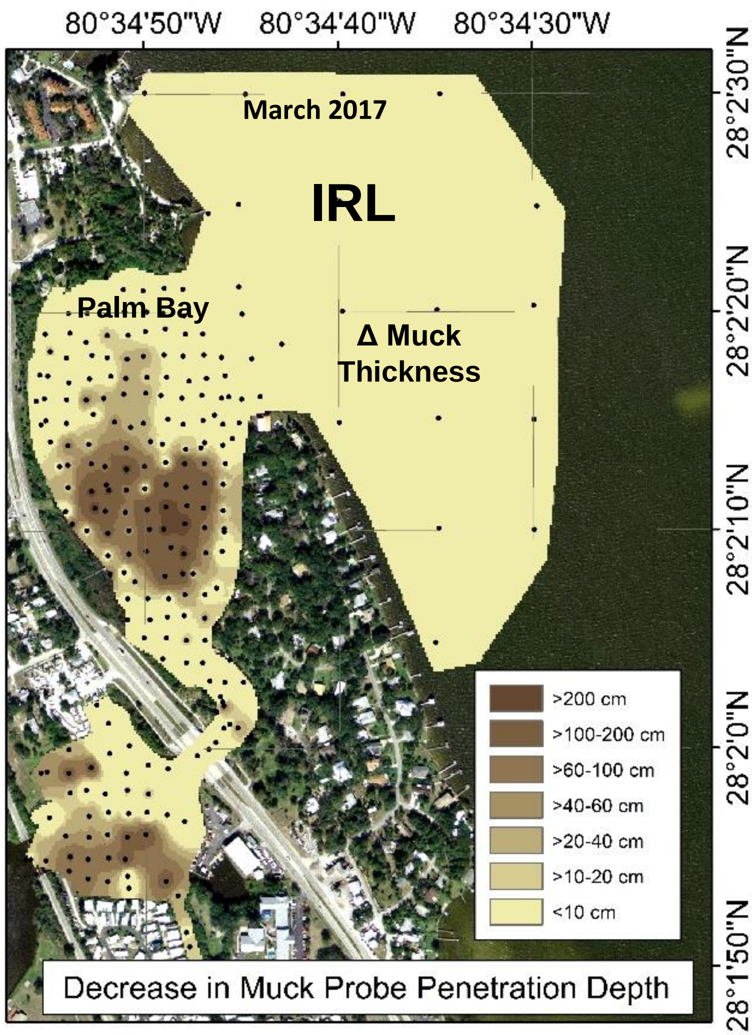
Impacts of Environmental Muck Dredging 2017-2018

Muck Dredging Research Project Management (Subtask 1)

Final Project Report to Brevard County Natural Resources Management Department
Funding provided by the Florida Legislature as part of
DEP Grant Agreement No. NS005 – Brevard County Muck Dredging



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February 2021

Cover Image: Contour map of muck thickness in Turkey Creek from the adjacent Indian River Lagoon (IRL) to the Florida East Coast (FEC) railroad bridge. (Courtesy of Robert Trocine)

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Final Project Report Submitted to
Brevard County Natural Resources Management Department
2725 Judge Fran Jamieson Way, Building A, Room 219
Viera, Florida 32940

Funding provided by the Florida Legislature as part of
DEP Grant Agreement No. NS005 – Brevard County Muck Dredging

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February 2021

Muck Dredging Research Project Management (Subtask 1)

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Executive Summary

In order to address serious water quality issues associated with muck sediment in the Indian River Lagoon, the Florida Legislature in the 2016 session directed $1.5 million to the Florida Institute of Technology through Brevard County to investigate the effects of environmental muck dredging in the Indian River Lagoon (IRL). Six interdisciplinary projects (Subtasks) developed by the Indian River Lagoon Research Institute (IRLRI) at Florida Institute of Technology were coordinated through the muck dredging research project management office: (1) Muck Dredging Research Project Management, (2) Muck Removal Efficiency plus Biological and Chemical Responses/Improvements after Muck Dredging, (3) Trends for Inputs of Muck Components from Rivers, Creeks and Outfalls to the Indian River Lagoon, (4) Lagoon-Wide Application of the Quick-Flux Technique to Determine Sediment N and P Fluxes, (5) Optimizing Selection of Sites for Environmental Dredging in the Indian River Lagoon System, and (6) Hydrologic and Water Quality Model for Management and Forecasting within Brevard County Waters. Executive summaries from the peer reviewed final project reports for these subtasks are reproduced at the end of this report. Regular meetings of the Florida Institute of Technology Environmental Muck Dredging (FIT-EMD) research principal investigators with representatives from Brevard County Natural Resource Management Department were used to optimize research outcomes. Progress reports were regularly shared with Florida Department of Environmental Protection and a team of external scientific consultants and other stakeholders. Florida Institute of Technology Environmental Muck Dredging research progress, reported through monthly meetings, written reports and public presentations, is summarized in this report.

In addition to the work summarized, key findings and recommendations from legislatively funded FIT Environmental Muck Dredging Research is presented here.

Important Findings and Recommendations from FIT EMD Research Final Reports

With funding provided by the Florida Legislature as part of DEP Grant Agreement Nos. S0714 and NS005 and administered by Brevard County, environmental muck dredging research was conducted by the Indian River Lagoon Research Institute (IRLRI) at Florida Institute of Technology. Important findings and recommendations from peer-reviewed final reports are listed below. ***Numbers after findings or recommendations refer to report titles on pages v-vi of this report.

Findings: Lagoon-wide Muck Investigations

MK.1. All major and many minor muck deposits in the IRL and Banana River Lagoon (BRL) were likely sampled during this study, excluding the northern BRL near NASA property, where access is limited. **19, 20*

MK.2. A rapid technique called Quick Flux was developed to collect sediment pore water to determine fluxes of N and P from muck to the overlying water. The method was validated against an accepted method that used detailed interstitial water samples. More than 400 Quick Flux determinations of benthic fluxes of N and P were obtained to provide a robust data set that complements biological and geochemical studies. **9, 19*

MK.3. A Grand Survey of 53 sites, followed by detailed geochemical and biological study of the top 20 (of 53) sites in the IRL and BRL (Brevard County), was carried out; it greatly enhanced available data and perspectives on the lagoon-wide distribution of muck. The top 20 sites were prioritized for muck projects by first using a geochemical ranking and then confirming choices using biological indices for benthic fauna and seagrasses. **19, 20*

MK.4. Baseline biological (seagrass and infauna) and geochemical data were obtained for the IRL near Mims, for Sykes Creek and nearby comparison sites prior to dredging. **17*

MK.5. Dredging of sand and shells can be precluded using a newly designed prototype with variable intake and shrouded dredging suction head. Treatment with ferrate (a very reactive iron oxide) removed nutrients. Field testing of the coupled system confirmed the feasibility of small-scale muck sump operations along canals and rivers that flow into the IRL. An autonomous scaled-up system could be developed and installed at permanent locations in canals to manage muck removal prior to entering the Lagoon. **14*

Findings: Turkey Creek Muck Removal

TC.1. Environmental dredging of 160,000 m^3 of muck from Turkey Creek removed about 300 metric tons of nitrogen (N) and 70 metric tons of phosphorus (P). **9, 17*

TC.2. Dredging reduced the volume and surface area of muck in the dredged area by >60% and <20%, respectively; slumping and redistribution of adjacent muck sediments following dredging limited the surface area dredged. **17*

TC.3. Water volume in the dredged area increased by 160,000 m^3 after dredging, a direct result of the volume of sediment removed from Turkey Creek. Concentrations of dissolved oxygen in the creek increased after dredging in proportion to a deeper basin and larger volume of water. **7, 17*

TC.4. N and P fluxes from muck sediments were >50% lower 3 months after dredging. **17, 19*

TC.5. >99.9% of the solids pumped from Turkey Creek were retained in a Dredge Material Management Area (DMMA) at US1 and Robert J. Conlan Boulevard in Palm Bay until trucked to central Florida for use as a soil amendment. Chemical treatments effectively controlled concentrations of dissolved phosphate in the DMMA. Concentrations of nutrients in water discharged from the DMMA were not identifiable at 100 m from the outfall. **9, 17*

TC.6. Despite significant environmental variability and muck removal activities in Turkey Creek, the habitat supported an abundant and diverse assemblage of fishes. **8*

TC.7. Muck sediments in Turkey Creek likely contribute to, and may be the primary reason for, seagrasses struggling in what would otherwise appear to be an ideal location in Turkey Creek. **2*

TC.8. Infauna which live in nearby sediments with a modest organic matter content can benefit from dredging muck that has a very high organic matter content and little or no infaunal life because the new conditions will likely be an improvement and infaunal life will migrate by tracking improved sediment composition. Seagrasses and fishes, in contrast, are populations we expect to respond to longer term, general improvements in regional estuarine water quality, but were not observed to respond directly to local dredging. **2, 7, 17*

TC.9. A new method for capturing near-bottom moving fluid mud with suspended particulate matter showed a reduction in fluid mud and muck near the bottom after dredging in Turkey Creek. Overall, it appears that the basin near the mouth of the creek may be acting like a muck trap. Both the IRL and Turkey Creek (west of railroad bridge) appear to be acting as muck sources. **4, 12*

Findings: Tributary and Groundwater Inputs of Nutrients and Suspended Sediments to IRL

TR.1. Mean concentrations of total N (TN) for the four tributaries studied (St. Sebastian River, Turkey Creek, Crane Creek and Eau Gallie River) were 30–50% lower than the USEPA standard of 1540 µg N/L for Florida inland waters. However, two of the four tributaries (the St. Sebastian and Eau Gallie rivers) had mean concentrations of total P (TP) that were 80% and 100% higher than USEPA criteria of 120 µg P/L. **10, 18*

TR.2. Dissolved organic N (DON) made up more than half of the TN in IRL tributaries. The more biologically available forms of N (ammonium, nitrate and nitrite) made up only ~25% of the TN. In contrast, phosphate, the more biologically available form of P, made up about half of the TP. Understanding harmful algal blooms requires knowing concentrations of specific forms of N and P (e.g., nitrate or organic nitrogen) not just TN or TP. **10, 18*

TR.3. About 60% of TN and TP fluxes from tributaries to the IRL were carried during the wet season in 2016 (June 1–October 31). During 2017, >50% of the various chemical forms of N and P were delivered to the IRL during a 7-week period of rain and flooding following Hurricane Irma in mid-September. These results support the present fertilizer ordinance. **18*

TR.4. Estimated fluxes of TN (300–400 metric tons of N/y) and TP (30–80 metric tons of P/y) from major tributaries were at the same order-of-magnitude as benthic muck fluxes from the north IRL (300 metric tons N/y and 45 metric tons P/y). **18*

TR.5. Concentrations of total suspended solids, dissolved organic carbon, TN, ammonium and phosphate were not significantly different in water samples collected from Turkey Creek during 2016–17 relative to 1988–89. In contrast, significant increases over three decades were identified for TP (+82%), particulate P (+90%), particulate N (+300%) and nitrate + nitrite (+400%). Only dissolved organic N showed a significant decrease (-25%). Increased urbanization and residential property, plus decreased natural lands, supported the trends observed. **18*

TR.6. After 10 months of groundwater sampling, the three communities (septic, sewer, and sewer with reclaimed irrigation) had significantly higher groundwater total nitrogen concentrations than the natural area, but they were not significantly different from each other. Organic forms of N (TKN and NH4+) were significantly higher in the sewer community than the community receiving reclaimed irrigation water. But the reclaimed community had significantly higher inorganic nitrogen (NOx) than the septic or sewer communities. In surface water, the organic forms of N comprise ~90% of the total dissolved N in the water column. The organic forms of P comprise ~70% of the total dissolved P in the water column. In groundwater, organic forms of N were the dominant form in septic and sewer communities, but inorganic forms of N were found in the community receiving reclaimed water for irrigation. **15*

TR.7. Based on measured groundwater data, modeled TN loading to groundwater in the Turkey Creek area was at least 2100 kg N/year or 6 kg N/year for each household. Furthermore, N plumes extended well beyond the 20–60 m previously reported, indicating that distance from an Onsite Sewage Treatment & Disposal System to the receiving waterway should not be the only indicator used to predict loading. **15*

Findings: Modeling Water Quality Related to Muck Deposits and Dredging

ML.1. Modeling of muck zones shows that muck dredging has the potential to reduce N concentrations in the water column within dredged areas as well as up to 8 km away from dredged areas. The impact of muck dredging in all areas was detectable in model results which show a post-dredging reduction of TN. However, the impact of dredging was less for zones influenced by strong freshwater inflows, particularly during the wet season. **21*

ML.2. The IRL hydrodynamic and water quality model continues to be developed through updated boundary conditions and inclusion of additional muck zones. As more information is acquired on the extent of muck deposits in the IRL, these areas can be incorporated into the model and tested for the potential benefits of muck dredging at other locations. **5, 11, 21*

ML.3. Using a wind gust approach, an assessment of published estimates for surface roughness at the three ASOS (Automated Surface Observing System) sites was performed. Results for the Fort Pierce and Vero Beach systems, but not for Melbourne, were consistent with the data. For some flow directions, published roughness estimates at the Melbourne ASOS were too low due to difficulties in accurately determining low-end roughness values; this is a possible issue if one chooses to adjust roughness values from land to water. Such discrepancies have important implications and thus ASOS wind direction should be considered when using National Weather Service data to represent IRL locations. **13*

Recommendations

RE.1. Successful management plans for controlling muck and nutrients in the IRL require continuing assessment of external and internal inputs of substances that are precursors to algal blooms and future muck deposits. Therefore, more data are needed for (i) major tributaries to the IRL during regular and storm flow, (ii) atmospheric inputs, (iii) direct runoff from hundreds of outfalls along the lagoon and (iv) fluxes of nutrients from IRL muck to the overlying water. **10, 18, 19*

RE.2. Continuous chemical data for tributaries and the IRL are needed to better assess nutrient inputs, especially during extreme water flows that accompany hurricanes. The fertilizer ban is worth continuing with a possible shift to both start and end one month later, this shift better incorporates recent tropical storms in September and October. Decreases in the N and P content of reclaimed water is recommended. More data are needed to identify the specific components that make up dissolved organic N and dissolved organic P. Furthermore, wherever possible, isotope data for specific chemical forms of N are needed to help better identify nutrient sources. But, most of all, we need to work to restrict or treat nutrient runoff during periods of extreme water flow. **18*

RE.3. We encourage, where possible, that muck remediation efforts be carried out in the top 20 sites prioritized for muck projects. We also recommend increased focus on closely-spaced areas and those noted for the onset of major algal blooms. Moreover, geochemical and biological rankings from this study must be considered in context with other pertinent variables including cost, proximity to a DMMA, assessments of likely muck migration, benefits of formation of a trap for future muck accumulation, project constructability and other factors as applicable. **19*

RE.4. Muck management efforts should focus on projects that reduce areal coverage of muck deposits more than muck volumes. **20*

RE.5. Cost effective strategies should be employed to reduce nutrient levels in water from settled muck before release to the IRL. **17*

RE.6. Baseline data for seagrass and drift algae are critical to future evaluation of potential environmental improvements. **7*

RE.7. Although residential communities along Turkey Creek appear to be equally polluting with nutrients, this can only be confirmed by repeating the study design in different areas. **15*

RE.8. The distance from an Onsite Sewage Treatment and Disposal Systems to the receiving waterway should not be the only indicator used to predict nutrient loading potential. Nitrogen plumes in our study extended well beyond the 20 to 60 m reported in the literature. **15*

Florida Institute of Technology Environmental Muck Dredging Research Reports*

FIT EMD Year 1 peer-reviewed final research reports are found in:
Impacts of environmental muck dredging 2014–2015. Final Project Report to Brevard County Natural Resources Management Dept., J.G. Windsor, Jr. (Ed.), July 2016

1. *Muck Dredging Research Project Management (Subtask 1)*, John Windsor
2. *Biological Responses to Muck Removal (Subtask 2), Kevin Johnson and John Shenker*
3. *The Efficiency of Muck Removal from the IRL and Water Quality after Muck Removal (Subtask 3), John Trefry*
4. *Movement Measurements of Muck and Fluidized Mud at Dredge Sites (Subtask 4), Charles Bostater*
5. *Hydrologic and Water Quality Model for Management and Forecasting within Brevard County Waters of the IRL (Subtask 5), Gary Zarillo*

FIT EMD Year 2 peer-reviewed final research reports are found in:

6. *Muck Dredging Research Project Management (Subtask 1)*, John Windsor, June 2019
7. *Biological Responses to Muck Dredging in the Indian River Lagoon, Part I. Seagrass Monitoring and Infaunal Surveys (Subtask 2)*, Kevin Johnson, September 2017
8. *Biological Responses to Muck Dredging in the Indian River Lagoon, Part II: Fish Populations and Sea Grass Restoration (Subtask 3)*, Jonathan Shenker, March 2018

9. *Determining the Effectiveness of Muck Removal on Sediment and Water Quality in the Indian River Lagoon, Florida (Subtask 4A)*, Austin L. Fox, John H. Trefry, Robert P. Trocine, Stacey L. Fox, Jessica E. Voelker, December 2017
10. *Inputs of Nitrogen and Phosphorus from Major Tributaries to the Indian River Lagoon (Subtask 4B)*, John H. Trefry, Austin L. Fox, Robert P. Trocine, Stacey L. Fox, Jessica E. Voelker, Katherine M. Beckett, October 2017
11. *Hydrologic and Water Quality Model for Management and Forecasting within Brevard County Waters (Subtask 5)*, Gary Zarillo, April 2018
12. *Moving Muck & Fluidized Mud & Tributary Bedload Measurements at Dredge Sites (Subtask 6)*, Charles Bostater, May 2018
13. *Wind and microclimate analysis for application to fetch-limited wind wave growth analysis at IRL dredging locations (Subtask 7)*, Steven Lazarus, November 2017
14. *Feasibility of muck removal at fixed locations in the IRL watershed and subsequent ferrate treatment to remove nutrients and contaminants (Subtask 8)*, Robert J. Weaver and Thomas D. Waite, January 2018
15. *Source to Slime Study in Indian River Lagoon (Subtask 9)*, Leesa Souto, May 2019

<u>*FIT EMD Year 3 peer-reviewed final research reports are found in:*</u>

16. *Muck Dredging Research Project Management (Subtask 1)*, John Windsor, February 2021
17. *Muck Removal Efficiency plus Biological and Chemical Responses/Improvements after Muck Dredging (Subtask 2)*, Kevin Johnson, Jon Shenker, and John Trefry, June 2020.
18. *Trends for Inputs of Muck Components from Rivers, Creeks and Outfalls to the Indian River Lagoon (Subtask 3)*, John Trefry and Austin Fox, December 2019
19. *Lagoon-Wide Application of the Quick-Flux Technique to Determine Sediment N and P Fluxes (Subtask 4)*, Austin L. Fox and John H. Trefry, June 2019
20. *Optimizing Selection of Sites for Environmental Dredging in the Indian River Lagoon System (Subtask 5)*, John H. Trefry and Kevin B. Johnson, November 2019
21. *Sediment & Water Quality Modeling for Nutrients, Muck and Water Clarity Scenario Assessments (Subtask 6)*, Gary A. Zarillo and Claudia Listopad, January 2021

***Funding through DEP Grant Agreement Nos. S0714 and NS005 administered by Brevard County**

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Funds for these investigations were provided by the Florida Legislature as part of DEP Grant Agreement No. NS005 – Brevard County Muck Dredging.

Valuable guidance and feedback throughout the yearlong investigation was given by Matt Culver, Virginia Barker and Mike Mcgarry of the Brevard County Natural Resources Management Department. Other inputs throughout the year from external reviewers and comments on the draft final reports also improved the project and the final report. Those external reviewers included Robert Virnstein, Joel Steward, Charles Jacoby and Dennis Hanisak.

These studies are contributing to the effective restoration of Indian River Lagoon. The work would not have been brought to a successful conclusion without the dedication of my research colleagues. These principal investigators deserve my thanks and are Charles R. Bostater, Austin L. Fox, Kevin B. Johnson, Steven M. Lazarus, Claudia Listopad, Jonathan Shenker, Leesa Souto, John H. Trefry, Robert J. Weaver, Thomas D. Waite, and Gary A. Zarillo.

Muck Dredging Research Project Management (Subtask 1)

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February 2021

Summary

In order to address serious water quality issues associated with muck sediment in the Indian River Lagoon, the Florida Legislature in the 2016 session directed $1.5 million to the Florida Institute of Technology through Brevard County to investigate the effects of environmental muck dredging in the Indian River Lagoon (IRL). Six interdisciplinary projects (Subtasks) developed by the Indian River Lagoon Research Institute (IRLRI) at Florida Institute of Technology were coordinated through the muck dredging research project management office: (1) Muck Dredging Research Project Management, (2) Muck Removal Efficiency plus Biological and Chemical Responses/Improvements after Muck Dredging, (3) Trends for Inputs of Muck Components from Rivers, Creeks and Outfalls to the Indian River Lagoon, (4) Lagoon-Wide Application of the Quick-Flux Technique to Determine Sediment N and P Fluxes, (5) Optimizing Selection of Sites for Environmental Dredging in the Indian River Lagoon System, and (6) Hydrologic and Water Quality Model for Management and Forecasting within Brevard County Waters. Executive summaries from the peer reviewed final project reports for these subtasks are reproduced at the end of this report (page 19). Regular meetings of the Florida Institute of Technology Environmental Muck Dredging (FIT-EMD) research principal investigators with representatives from Brevard County Natural Resource Management Department were used to optimize the research outcomes. Progress reports were regularly shared with Florida Department of Environmental Protection and a team of external scientific consultants and other stakeholders. Florida Institute of Technology Environmental Muck Dredging research progress, reported through monthly meetings, written reports and public presentations, is summarized in this report.

Introduction

In order to address serious water quality issues associated with muck sediment in the Indian River Lagoon, the Florida Legislature in the 2016 session directed $1.5 million to the Florida Institute of Technology through Brevard County to investigate the effects of environmental muck dredging in the Indian River Lagoon (IRL). A collaborative, interdisciplinary effort, through the Indian River Lagoon Research Institute (IRLRI), developed the following projects to help better guide future muck removal efforts throughout the state. A list of each of the projects (subtasks) with a brief description is shown in Table 1.

Table 1. FIT EMD Research Year 3 Subtasks

1. *Muck Dredging Research Project Management,* John Windsor (PI) FIT EMD Research Project Management coordinates effective communications of research plans and results between principal investigators, Brevard County Department of Natural Resources Management, other agencies, external reviewers and the public.

2. *Muck Removal Efficiency plus Biological and Chemical Responses/Improvements after Muck Dredging,* Kevin B. Johnson (PI); Jonathan M. Shenker and John H. Trefry (Co-PIs) Extensive surveys of sediment and water biogeochemistry, seagrass, benthic infauna and fisheries in Turkey Creek were carried out before dredging (April 2015–January 2016), during two separate phases of dredging (Phase I, February 20, 2016–April, 22, 2016 and Phase II, September 6, 2016–January 11, 2017), and after dredging during May 2016–April 2017. The goals of the Turkey Creek study were to track changes in (1) the distribution and composition of muck, (2) benthic fluxes of N and P from muck to the overlying water column, (3) sediment and water quality, (4) seagrass distribution and growth, (5) abundance, diversity and richness of benthic infauna, (6) abundance, diversity and microhabitat use of juvenile fishes and (7) feeding habits of fishes that could be impacted by dredging. Additional surveys were started before and during dredging at the Mims Boat Ramp and before dredging in Sykes Creek.

3. *Trends for Inputs of Muck Components from Rivers, Creeks and Outfalls to the Indian River Lagoon*, John H. Trefry and Austin L. Fox (Co-PIs) Successful management plans for controlling muck in the Indian River Lagoon (IRL) require continuing assessment of external and internal inputs of nutrients and other substances that are precursors to algal blooms and muck deposits. Runoff from tributaries to the IRL provide one major pathway for external inputs. Atmospheric deposition, direct runoff from hundreds of outfalls and groundwater seepage also are important external sources. Benthic fluxes from IRL muck are the main internal source of nutrients. This study focused on runoff to the IRL from large tributaries by obtaining and interpreting data for concentrations and chemical forms of dissolved and particulate nitrogen (N) and phosphorus (P) as well as calculating nutrient fluxes to the IRL. Surveys were carried out monthly, as well as episodically during rain events, from December 2015 to March 2018. Sampling locations, all with U.S. Geological Survey (USGS) flow gauges, included St. Sebastian River, Turkey Creek, Crane Creek and Eau Gallie River.

4. *Lagoon-Wide Application of the Quick-Flux Technique to Determine Sediment N and P Fluxes,* Austin L. Fox and John H. Trefry (Co-PIs) Releases of dissolved nitrogen (N) and phosphorus (P) from Indian River Lagoon (IRL) muck to the overlying water contribute >30% of all nutrient inputs to the lagoon. Other major pathways for nutrient additions to the IRL include stormwater runoff, atmospheric deposition and groundwater/baseflow. Nutrients carried along these various pathways are predominantly introduced on land via fertilizers, wastewater, leaking septic systems, biomass burning, fossil-fuel combustion as well as agricultural and other human activities. To achieve the fundamental goal of decreasing N and P concentrations in the lagoon, adequate knowledge about each source is needed to implement effective remediation techniques. Muck is one of the less obvious and less understood sources of dissolved N and P to the IRL, largely due to insufficient data and an incomplete understanding of what controls these nutrient releases. This study was designed to (1) improve and validate a more rapid technique for estimating nutrient fluxes from muck and then (2) use that information to better understand and decrease N and P releases from muck.

Table 1. FIT EMD Research Year 3 Subtasks (*Continued*)

5. *Optimizing Selection of Sites for Environmental Dredging in the Indian River Lagoon System,* John H. Trefry and Kevin B. Johnson (PIs) To earn continued public support, funds from "Save Our Lagoon" and other sources must be successfully used to help restore portions of the Indian River Lagoon (IRL). Yet, even if hundreds of millions of mitigation dollars are available, it is critical to target locations that hold the greatest promise for lasting recovery. Therefore, scientifically-sound criteria based on biological, geochemical and physical metrics are needed to help identify optimal dredging sites. In addition, choosing sites in proximity to seed/source biota and the presence of certain organisms or habitats may greatly improve the return on investment per dredging effort. This project (1) refined the metrics for prioritizing dredge sites using data for geochemical and biological parameters obtained during this study and (2) generated a prioritized list of the 20 most promising dredging sites using data from this study. The two main questions being addressed during this research are the following: What metrics should be used to select muck dredging sites? Which potential IRL dredging sites show the most promise?

6. *Hydrologic and Water Quality Model for Management and Forecasting within Brevard County Waters,* Gary A. Zarillo. Ph.D. (PI), PG: Claudia Listopad, Ph.D., GISP (Co-PI) Water quality and hydrologic, and hydrodynamic process data are integrated into a model of the Indian River Lagoon (IRL) for long-term calibrated and validated predictions of water quality. The overall goal was to combine model simulations with measured data to assess the impact of muck dredging on local and regional water quality. Questions addressed include: 1) to determine whether muck dredging will improve local water quality in the vicinity of Turkey Creek and other localities that are to be dredged over the next several years, 2) to determine whether improved model calibration by measured *in situ* data and modeled watershed data will allow the relative effects of watershed inputs and nutrient flux from muck sediments to be resolved, and 3) to determine if muck dredging either locally or regionally can result in a lasting improvement of IRL water quality.

The executive summaries from each of the FIT EMD Year 3 peer-reviewed Final Project reports are reproduced at the end of this report.

Approach

Each of the six subtasks was coordinated through the research project management office. Regular meetings of the Florida Institute of Technology Environmental Muck Dredging (FIT-EMD) research principal investigators facilitated the exchange of scientific findings among all the investigators. Results of field and lab work as well as logistics discussions were shared with all interested parties. The project management office assembled and distributed written monthly, quarterly and final project reports and updated Brevard County Natural Resources Management Department on research findings by sending email updates, holding monthly scientific roundtable discussions with interested agencies and organizations, conducting quarterly scientific presentations and project review meetings, and obtaining and incorporating peer review by external scientists. In addition, the project office engaged the public about muck dredging research through presentations open to the public.

Results

Project design and research updates were discussed at monthly and quarterly meetings throughout the year with Brevard County Natural Resources Management Department. Written progress reports were shared with anyone who requested regular updates. In addition to monthly discussion of results, logistics and sampling strategies, a few other noteworthy items are shown with the monthly meeting dates in Table 2. External scientific review is important for the ongoing work. An external review panel provided comments, criticisms and recommendations for projects. At least three external reviewers provided comments on draft and revised final reports. Peer reviewed final reports for all FIT EMD funded research subtasks are shown below:

FIT EMD Year 1 peer reviewed final research report

- *Impacts of environmental muck dredging 2014–2015. Final Project Report to Brevard County Natural Resources Management Dept.*, J.G. Windsor, Jr. (Ed.), July 2016

FIT EMD Year 2 peer reviewed final research reports

- *Muck Dredging Research Project Management (Subtask 1)*, John Windsor, June 2019
- *Biological Responses to Muck Dredging in the Indian River Lagoon, Part I. Seagrass Monitoring and Infaunal Surveys (Subtask 2)*, Kevin Johnson, September 2017
- *Biological Responses to Muck Dredging in the Indian River Lagoon, Part II: Fish Populations and Sea Grass Restoration (Subtask 3)*, Jonathan Shenker, March 2018
- *Determining the Effectiveness of Muck Removal on Sediment and Water Quality in the Indian River Lagoon, Florida (Subtask 4A)*, Austin L. Fox, John H. Trefry, Robert P. Trocine, Stacey L. Fox, Jessica E. Voelker, December 2017
- *Inputs of Nitrogen and Phosphorus from Major Tributaries to the Indian River Lagoon (Subtask 4B)*, John H. Trefry, Austin L. Fox, Robert P. Trocine, Stacey L. Fox, Jessica E. Voelker, Katherine M. Beckett, October 2017
- *Hydrologic and Water Quality Model for Management and Forecasting within Brevard County Waters (Subtask 5)*, Gary Zarillo, April 2018
- *Moving Muck & Fluidized Mud & Tributary Bedload Measurements at Dredge Sites (Subtask 6)*, Charles Bostater, May 2018
- *Wind and microclimate analysis for application to fetch limited wind wave growth analysis at IRL dredging locations (Subtask 7)*, Steven Lazarus, November 2017
- *Feasibility of muck removal at fixed locations in the IRL watershed and subsequent ferrate treatment to remove nutrients and contaminants (Subtask 8)*, Robert J. Weaver, Thomas D. Waite, January 2018
- *Source to Slime Study in Indian River Lagoon (Subtask 9)*, Leesa Souto, May 2019

FIT EMD Year 3 peer reviewed final research reports

- *Muck Dredging Research Project Management (Subtask 1)*, John Windsor, February 2020
- *Muck Removal Efficiency plus Biological and Chemical Responses/Improvements after Muck Dredging (Subtask 2)*, Kevin Johnson, Jon Shenker, John Trefry, June 2020.
- *Trends for Inputs of Muck Components from Rivers, Creeks and Outfalls to the Indian River Lagoon (Subtask 3)*, John Trefry, Austin Fox, December 2019
- *Lagoon-Wide Application of the Quick-Flux Technique to Determine Sediment N and P Fluxes (Subtask 4)*, Austin L. Fox, John H. Trefry, June 2019
- *Optimizing Selection of Sites for Environmental Dredging in the Indian River Lagoon System (Subtask 5)*, John H. Trefry, Kevin B. Johnson, November 2019

- *Sediment & Water Quality Modeling for Nutrients, Muck and Water Clarity Scenario Assessments (Subtask 6)*, Gary A. Zarillo, Claudia Listopad, January 2020

In addition to coordinating the research efforts, reaching out to the local stakeholders was important to explain the impacts of IRL muck and the potential benefits associated with muck removal in the overall context of IRL restoration. Presenting research results is an important component of informing stakeholders. Research presentation titles by the FIT EMD Year 3 Principal Investigators are summarized in Table 3. Social media continued to be a source for public discussion of muck dredging and IRL restoration issues. FIT EMD attempted to provide muck basics, describe muck concerns, address muck misconceptions, update ongoing research relevant to muck, explain the need for muck removal, provide progress on muck removal, and share public presentations by the FIT EMD Research Team. An important element captured from all research and dredging activities to date is "What Lessons Are We Learning?" Recommendations informed by FIT EMD research are now being implemented in Indian River Lagoon restoration efforts. Lessons learned from the Florida Institute of Technology IRL muck dredging research will be of value to coastal environmental muck dredging projects, not just for the entire IRL, but also throughout the state of Florida. Included below (page 14) is a summary of key findings recommendations from all FIT EMD Research final reports.

<u>Table 2. FIT EMD Research Year 3 Meetings</u>

Florida Institute of Technology Environmental Muck Dredging Principal Investigators met with Brevard County staff monthly to discuss progress on continuation and new projects. In addition to monthly discussion of results, logistics, including muck dredging project updates, and sampling strategies, other noteworthy highlights are summarized here.

- August 14, 2017 Notice to proceed issued in July 2017. Monthly meetings focused on the transition and integration of Years 1 and 2 results to the Year 3 work plan. Dr. Weaver summarized findings from optimizing dredge head performance (Y2 Subtask 8). Most of this work was conducted in the laboratory due to difficulties encountered at the Melbourne Tillman Canal field location. Some discussion centered on potential further funding (Y3) of the engineering portion of this project. Dr. Waite presented a detailed overview of the ferrate treatment work for DMMAs. Suggestions were made to promote the technology with the dredging companies and see if they were ready to include this approach in DMMA management. Y3 PIs shared preliminary ongoing studies throughout the Lagoon, including pre-dredging measurements at Mims Boat Ramp and Sykes Creek. Discussions with County staff led to the decision to indicate in each upcoming subtask monthly report that QA Plans submitted to Brevard County for Year 2 work would continue in Year 3.

- September 11, 2017 Meeting cancelled due to Hurricane Irma. The written monthly progress report was substituted for this meeting.

- October 2, 2017 Drs. Souto and Listopad shared groundwater sampling and preliminary analysis results for samples from the Turkey Creek/Palm Bay area (Y2 Subtask 9). Increasing the number of sampling locations and additional analytes were recommended by the group. Unallocated Y2 funds were transferred to this subtask. During discussion of FIT EMD Y3 subtasks, potential parameters to be used for optimizing the selection of locations for muck removal were discussed.

- November 13, 2017 Dr. Shenker reviewed progress on dredging impacts on fish and sea grass (Y2 Subtask 2). Dr. Trefry and Dr. Fox presented results for Trends for Inputs of Muck Components from Rivers, Creeks and Outfalls to the Indian River Lagoon (Subtask 3) and Lagoon-Wide Application of the Quick-Flux Technique to Determine Sediment N and P Fluxes (Subtask 4). Preliminary discussions of Optimizing Selection of Sites for Environmental Dredging in the Indian River Lagoon System (Subtask 5) were led by Dr. Trefry and Dr. Johnson. Muck research related presentations at the American Shore and Beach Preservation Association (ASBPA) 2017 were reviewed.

- December 11, 2017 Drs. Souto and Listopad shared results for Source to Slime in Indian River Lagoon (Y2 Subtask 9). Year 3 Project Updates focused on Sediment & Water Quality Modeling for Nutrients, Muck and Water Clarity Scenario Assessments, Gary A. Zarillo and Claudia Listopad. Questions addressed by all included: How can modeling help us better understand bigger pictures in Indian River Lagoon? What conclusions will be presented at the end of the project? What is missing from the model? What other modeling needs do we have? What can be done in a short time frame, less than a year?

- January 8, 2018 A County proposed grass clipping campaign was reviewed. The benefits for reducing precursors to muck, including grass clippings, were listed. The FIT EMD team decided that monthly meetings will now attempt to integrate discussions of results across the subtasks. Drs. Fox and Trefry volunteered to lead the first discussions among all the FIT EMD PIs. The goal was

Table 2. FIT EMD Research Year 3 Meetings (*Continued*)

to help all PIs think more broadly about our combined results and their implications. All attendees came prepared to add any relevant information that fit the following topics: Turkey Creek Dredging: Past results, lessons learned, the next step! (Dr. Fox) and Tributaries in the context of nutrient sources to the IRL (Dr. Trefry).

- February 12, 2018 Drs. Johnson and Shenker took the lead for a round table discussion on: What makes a good restoration site, and how do we define success in restoration?

- March 12, 2018 The muck dredging research team responded to a memo from Anthony Gubler: To What Extent is Dissimilatory Nitrate Reduction to Ammonium (DNRA) influencing the Indian River Lagoon? Research papers were distributed to all prior to the meeting to support the discussion. Next, Drs. Listopad, Souto and Zarillo presented some of their results as we all discussed the topic: Can we put the pieces of the water quality puzzle together? Modeled watershed baseflow and runoff loads, measured baseflow and storm conditions, and measured groundwater quality. How do these data fit together? Are we missing something? The team continued the discussion of integrating these datasets. The PIs were encouraged to share Sykes Creek results so that dredging prioritization for Sykes Creek could move forward. Short updates on the IRL circulation modeling (IRLNEP) for the impact of 520 and 528 causeways, fish kill response scenarios, and other related research opportunities.

- April 9, 2018 The meeting focused on the Palm Bay groundwater study and identifying sources of nitrogen to the Indian River Lagoon. Questions addressed included: How are we using stable isotopes to tell a story and how should they be used? Dr. Leesa Souto and Dr. Austin Fox led that discussion which transitioned to a critical review/discussion by all of: *Widespread sewage pollution of the Indian River Lagoon system, Florida. (USA) resolved by spatial analyses of macroalgal biogeochemistry* by Peter J. Barile. Marine Pollution Bulletin 128 (2018) 557-574. The meeting concluded with an interactive presentation of Flux of nutrients from muck sediments in the north central Indian River Lagoon from Drs. Fox and Trefry.

- May 14, 2018 Meeting cancelled

- June 11, 2018 Brief updates on Indian River Forum sponsored by Florida Today (May 9, 2018), the Brevard IRL Coalition Call to Action (May 14, 2018), and Biosolids Symposium (June 8, 2018). Walker Dawson queried the team about siting considerations for ORCA Kilroy sensor stations near Grand Canal to identify flow velocities and nutrient concentrations leaving canals entering the BRL. Research presentations followed. Dr. Trefry led a discussion on IRL Tributaries, Large and Small: Global and Local Perspectives; Dr. Shenker updated the team on Fish Recruitment and Habitats in the IRL: Natural Variation and Anthropogenic Impacts; and Dr. Johnson concluded with Pre- and Post-dredging Surveys of Infauna and Seagrasses. Before the meeting ended, Brevard County staff reviewed a proposed Septic Ordinance.

- July 9, 2018 Development of the strategy for prioritizing future dredging projects in Brevard County continued today with a tag team approach Dr. Fox, Dr. Trefry and Dr. Johnson.

- August 13, 2018 Research topics addressed included an update on modelling results that are part of Y3 muck dredging research from Dr. Zarillo and Dr. Listopad and recent enhanced circulation model runs for Port Canaveral and the IRLNEP by Dr. Zarillo. Dr. Souto and Dr. Listopad listed key points learned from their research, how these findings should be applied to IRL restoration and whether they recommend additions or revisions to the SOIRL Project Plan.

Table 2. FIT EMD Research Year 3 Meetings (*Continued*)

- September 10, 2018 Dr. Johnson, Dr. Shenker, Dr. Trefry, and Dr. Fox listed key points learned from their research, how these findings should be applied to IRL restoration and whether they recommend additions or revisions to the SOIRL Project Plan.

- October 1, 2018 Dr. Zarillo listed key points learned from his research, how these findings should be applied to IRL restoration and whether he recommends additions or revisions to the SOIRL Project Plan. Dr. Trefry updated the team on tributary contributions to the Indian River Lagoon.

- November 12, 2018 Meeting cancelled.

- December 10, 2018 A roundtable discussion on optimizing muck dredging locations in Indian River Lagoon was led by Drs. Fox, Ma, Johnson and Trefry. Summary of a survey completed in the last few weeks about the SOIRL Project Plan was given by Holly Abeels, Florida Sea Grant Extension Agent, University of Florida IFAS Extension Brevard County. Comments were offered by FIT EMD PIs/IRLRI (IR Lagoon Research Institute).

- January 14, 2019 Updates from Modeling the Benefits of Environmental Muck Dredging at FIT were given by Dr. Gary Zarillo and Dr. Claudia Listopad. Questions from the discussion on optimizing the selection of muck dredging locations (December 2018) were addressed by Xiao Ma, with contributions from Kevin Johnson Austin Fox, focusing on which index to use.

- February 11, 2019 Recent research findings were from: Source to Slime in IRL by Dr. Souto and Dr. Listopad and Muck Removal Efficiency plus Biological and Chemical Responses/ Improvements after Muck Dredging by Dr. Johnson, Dr. Trefry and Dr. Shenker.

- March 11, 2019 Research updates included Environmental Muck Dredging modeling by Dr. and Trends in concentrations and forms of N and P during Aureoumbra bloom of 2018 from Dr. Trefry and Dr. Fox. A detailed message distributed to all included: The last monthly meeting between the FIT EMD research team and Brevard County staff was held on March 11, 2019. We are nearing a conclusion for all tasks. Brevard County has contracted with the Indian River Lagoon Research Institute to continue research collaboration meetings quarterly.

Table 3. FIT EMD Research Year 3 Presentations

Peer Reviewed Journal Articles

2018

- Bostater, C., Rotkiske, T., and Oney, T., 2018, Marine Bottom Boundary Layer Sediment Flux Measurement of Fluidized Mud and Muck Using Vertical and Horizontal Sonde Arrays, Proceedings International Society of Ocean & Polar Engineering, (ISOPE), ISBN 978-1-880653-87-6, pp. 1374-1378.
- Bostater, C., Yang, B., and Rotkiske T., 2018, Video Measurements and Analysis of Surface Gravity Waves in Shallow Water, In: Surface Waves - New Trends and Developments, F. Ebrahimi (ed.), InTech, ISBN 978-953-51-5733-5, pp. 127-143.
- Colvin, J., **Lazarus**, S., Splitt, M., Weaver, R., and Taeb, P. 2018: Wind driven setup in east central Florida's Indian River Lagoon: Forcings and parameterizations. *Estuarine, Coastal and Shelf Science*, https://doi.org/10.1016/j.ecss.2018.08.004. Note that the operational product is still up and running real time… https://fit-winds.github.io/IRLSetup/
- Cox, A., Hope, D., Zamura-Duran, M.A. and Johnson, K. 2018. Environmental Factors Influencing Benthic Polychaete Distributions in a Subtropical Lagoon, Marine Technology Society Journal 52(4), 58-74, 2018.
- Fox, A.L. and Trefry, J. 2018. Environmental Dredging to Remove Fine-Grained, Organic-Rich Sediments and Reduce Inputs of Nitrogen and Phosphorus to a Subtropical Estuary, Marine Technology Society Journal 52(4), 42-57, 2018.
- Provost, L.A., Weaver, R.J., Waite, T.D. and Grisanti, H.C. 2018. Fabrication and Testing of a Variable Area Dredge Coupled with an Inline Slurry Treatment System for Concurrent Muck and Nutrient Removal, Marine Technology Society Journal 52(4), 75-80, 2018.
- Weaver, R.J., and Hunsucker, K.Z. 2018. Coastal Water Quality: From Science to Solutions, Marine Technology Society Journal 52(4), 5, 2018.

2017

- Holman, B., **Lazarus**, S., and Splitt, M. 2017: A fetch-based statistical method to bias correct and downscale wind speed over unresolved water bodies, *Wea. Forecasting*, **32**, 1637-1657. https://doi.org/10.1175/WAF-D-17-0016.1.

2016

- Bostater, C., and Rotkiske, T., 2016, Fluid mud sondes & acoustic imaging methods for coastal dredging, Proceedings International Society of Ocean & Polar Engineering, (ISOPE), ISBN 978-1-880653-88-3, pp. 1561-1567.
- Bostater, C., 2016, A new multispectral instrument for *in-situ* characterization of flocs & colloidal aggregates in natural water, SPIE Vol.9862, doi: 10.1117/12.2230386, pp. 98620K1-10.
- Bostater, C., Rotkiske, T., and Oney, T., 2016, Hyperspectral reflectance signature protocol for predicting subsurface bottom reflectance in water: *in-situ* and analytical methods, SPIE Vol. 9999, pp. 9990N1-12.
- Rotkiske, T., and Bostater, C., 2016, GIS Mapping of fluid mud transport pre-, during-, and post dredging agitation by using engineered novel instrumentation, Proceedings International Society of Ocean & Polar Engineering, Proceedings International Society of Ocean & Polar Engineering, (ISOPE), ISBN 978-1-880653-88-3, pp. 1542-1547.
- Bostater, C., and Rotkiske, T., 2015, Moving fluid mud sondes, optical and acoustic sensing methods in support of coastal waterway dredging, SPIE Vol. 9623, doi: 10.1117/12.2195829, pp. 96380F1-17.

Table 3. FIT EMD Research Year 3 Presentations *(Continued)*

Journal Articles in Preparation

- Kachouie, N.N., Provost, L.A. and Weaver, R.J. Statistical Modeling of Fine Sediments Dredged Using a Variable Area Dredging Suction Head (In prep)
- Trefry, J.H. and Fox, A.L. Tracking Runoff Fluxes of Nitrogen and Phosphorus Species to Harmful Algal Blooms in a Barrier Island Lagoon, (In prep for *Frontiers of Marine Science*)
- Fox, A.L. and Trefry, J.H. Benthic Nutrient Fluxes in a Subtropical, Barrier Island Lagoon, (In prep for *Frontiers of Marine Science*)

ANNUAL Indian River Lagoon Symposium Research Presentations at HBOI at FAU

Indian River Lagoon Symposium 2018: *Restoration of the Indian River Lagoon;* Harbor Branch Oceanographic Institute at Florida Atlantic University, Fort Pierce, Florida, February 8, 2018

- Impacts of Dredging, Hurricanes and Seasonality on Fluxes of Nitrogen and Phosphorus from IRL Sediments Austin L. Fox, John H. Trefry, and Stacey L. Fox Florida Institute of Technology, Melbourne, FL
- Highlights from a Two-Year Time Series for Chemical Forms of Nitrogen and Phosphorus in Tributaries to the Northern Indian River Lagoon (IRL) John H. Trefry, Austin L. Fox, and Stacey L. Fox Florida Institute of Technology, Melbourne, FL
- Living Shoreline Designs for Lagoon-front Residents: Living Shoreline Demonstration Site & Wave Tank Modeling Jake Zehnder, Robert J. Weaver, Jody B. Palmer, and Virginia Barker Brevard Zoo, Melbourne, FL; Florida Institute of Technology, Melbourne, FL; Brevard County Natural Resources Management, Melbourne, FL
- Living Docks: Promoting the Growth of Benthic Communities for Improved Water Quality Ryan P. Christiansen, Kelli Z. Hunsucker, and Robert J. Weaver Florida Institute of Technology, Melbourne, FL

Indian River Lagoon Symposium 2019: *Quo Vadis*, Johnson Education Center, FAU Harbor Branch, Fort Pierce, Florida, February 7-8, 2019

- Biological Responses to Aeration in an Estuarine Canal with Fine-Grained Organic-Rich Sediments, Xiao Ma, Kevin B. Johnson, Austin Fox, and John Trefry, Florida Institute of Technology, Melbourne, FL
- Abundance and Community Richness of Benthic Amphipods in a Shallow Subtropical Estuary, Nayan Mallick and Kevin B. Johnson, Florida Institute of Technology, Melbourne, FL
- Options for Remediation of Fine-Grained, Organic-Rich Sediments in the IRL System, Austin L. Fox and John H. Trefry, Florida Institute of Technology, Melbourne, FL
- Comparing Groundwater Nutrient Concentrations in Turkey Creek Neighborhoods with Septic Tanks, Sewer, and Reclaimed Irrigation, Kayleigh Douglass, Danielle Huffner, Claudia Listopad, and Leesa Souto, Applied Ecology, Inc., Indialantic, FL; Florida Institute of Technology, Melbourne, FL; Marine, Resources Council, Melbourne, FL

Indian River Lagoon Symposium 2020: Reassessing IRL Biodiversity, Johnson Education Center, FAU Harbor Branch, Fort Pierce, Florida, February 13-14, 2020

- A Proposed Study of Organic Sediment Impacts on Seagrasses and their Association with Benthic Infauna, Sean Crowley and Kevin B. Johnson, Florida Institute of Technology, Melbourne, FL

Table 3. FIT EMD Research Year 3 Presentations (Continued)

- Stoichiometry of Nutrient Fluxes in Sediments, Iulia Bibire, Austin Fox, Tyler Provoncha, Abigail Gering, and Maria Fernanda Hernandez Garcia, Florida Institute of Technology, Melbourne, FL
- Benthic Foraging Fish Prey Selectivity in Dredged Sediments, Danielle Juzwick, Kevin B. Johnson, and Jonathan Shenker, Florida Institute of Technology, Melbourne, FL
- Spatial Distribution of Oxygen in the Indian River Lagoon, Tyler Provoncha, Austin Fox, Stacey Fox, Iulia Bibire, Maria Fernanda Hernandez Garcia, and Abigail Gering, Florida Institute of Technology, Melbourne, FL
- Spatial Variation of Sediment Oxygen Demand in a Subtropical Estuary, the Indian River Lagoon, Abigail Gering, Austin Fox, Stacey Fox, Iulia Bibire, Tyler Provoncha, and Maria Fernanda Hernandez Garcia, Florida Institute of Technology, Melbourne, FL
- An Introduction to Restoring Lagoon Inflow Research Phase I, Gary Zarillo, Robert Weaver, Ashtok Pandit, Kevin Johnson, Ralph Turingan, Austin Fox, and Jeff Eble, Florida Institute of Technology, Melbourne, FL
- Is Sediment Aeration an Effective Strategy for Muck Management in the IRL? Austin Fox, Maria Hernandez, Abigail Gering, Iulia Bibire, Stacey Fox, and Tyler Provoncha, Florida Institute of Technology, Melbourne, FL

Annual Indian River Lagoon TechCon Research Presentations at Florida Institute of Technology

TechCon 2017: Indian River Lagoon Technical Conference on Coastal Water Quality: From Science to Solutions, Florida Institute of Technology, Melbourne, Florida, September 29, 2017.

- Muck Removal in the IRL: Dredging? Aeration? Other Approaches? John H. Trefry and Austin L. Fox; Florida Institute of Technology, Melbourne, FL
- Detection of Anthropogenic chemical and biological contaminants in IRL muck, Andrew G. Palmer, Florida Tech, Melbourne, FL, Beth Falls, ORCA, and Thiara Bento, FIT
- Controlled Intake Area Dredging in Combination with Rapid Sediment Separation and Ferrate Treatment for Water Quality Improvement in the Indian River Lagoon, H. C. Grisanti and L. A. Provost; Florida Institute of Technology, Melbourne, FL
- Living Docks: Promoting the growth of benthic communities for improved water quality, Kelli Z. Hunsucker and Robert J. Weaver; Florida Institute of Technology, Melbourne, FL
- Utilizing Citizen Science as a Tool for Muck Mapping in the IRL, Jared McNally; Marine Resources Council
- Controlled Intake Area Dredging in Combination with Rapid Sediment Separation and Ferrate Treatment for Water Quality Improvement in the Indian River Lagoon, H. C. Grisanti and L. A. Provost; Florida Institute of Technology, Melbourne, FL
- The impact of wind forcing uncertainty in coastal flow modeling, Vanessa Haley, Dr. Steven Lazarus, Dr. Gary Zarillo; Florida Institute of Technology, Melbourne, FL

TechCon 2018: Technical Conference on Coastal Water Quality, Indian River Lagoon Research Institute, Florida Institute of Technology, Melbourne, Florida, September 28, 2018.

- Environmental Muck Dredging, Austin L. Fox, PhD, John H. Trefry, PhD, Florida Institute of Technology, Melbourne, FL
- Effectiveness, Efficiency, and Improvements of a Variable Area Suction Head for Muck Removal in Indian River Lagoon, Leigh Provost, Robert J. Weaver, PhD, Hannah Grisanti, Florida Institute of Technology, Melbourne, FL
- Defining indicators and assessing the health of the Indian River Lagoon, a diverse, coastal estuary in Central Florida, U.S.A., Leesa Souto, PhD, Claudia Listopad, PhD, Danielle Huffner, MRC / Applied Ecology

Table 3. FIT EMD Research Year 3 Presentations *(Continued)*

- Comparing groundwater nutrient concentrations in Turkey Creek neighborhoods with septic tanks, sewer, and reclaimed irrigation, Kayleigh Douglass, Danielle Huffner, Claudia Listopad, PhD, Leesa Souto, PhD, Applied Ecology and MRC
- Generation of an ensemble high resolution wave height climatology for the Indian River Lagoon shoreline, Vanessa Haley, Steven Lazarus, PhD, Florida Institute of Technology, Melbourne, FL

TechCon 2019: Conference on Coastal Water Quality and Technical Showcase, Indian River Lagoon Research Institute, Florida Institute of Technology, Melbourne, Florida, September 27, 2019.

- Hidden Sources: Measuring Groundwater Loads to the Indian River Lagoon, Leesa Souto, Executive Director of Marine Resources Council and Claudia Listopad, Applied Ecology
- Gut Content Analysis of Benthic Foraging Fish Compared to Available Prey in Dredged Sediments, D. Juzwick, K.B. Johnson, J. Shenker, Florida Institute of Technology, Melbourne, FL
- Benthic Infauna Associations with Seagrasses in a Shallow Subtropical Estuary, S. Crowley and K.B. Johnson, Florida Institute of Technology, Melbourne, FL

OTHER public presentations, meetings and participation by FIT EMD Principal Investigators

- National Estuaries Day Panel Discussion on IRL Restoration at the Marine Resources Council, September 30, 2017, Palm Bay Florida. A panel of the IRL experts, Dr. Duane DeFreese (IRLNEP), MRC Executive Director Dr. Leesa Souto, Dr. John Windsor, Dr. John Trefry, Dr. Kelli Hunsucker, and Dr. Robert Weaver of Florida Institute of Technology, spoke about lagoon research and restoration plans. The focus was on audience participation, discussing questions and concerns, as well as presenting potential solutions for IRL restoration. The event was free, open to the public, and well attended.

- John Trefry, Florida Institute of Technology, Melbourne, FL, presented *"Internal Loading of Nutrients to the Northern Indian River Lagoon River Lagoon"* at the Inaugural Florida Marine Science Symposium on October 25, 2017 in St. Petersburg. The paper, co-authored by Austin L. Fox, described how the FIT EMD tributaries study is being used to compare differences in the magnitude and chemical forms of nitrogen and phosphorus that are diffusing from interstitial water versus inputs via the IRL tributaries.

- Fox, A. 2017. The Challenges of Environmental Dredging in a Coastal Lagoon. American Shore and Beach Preservation Association Meeting, Fort Lauderdale, Florida, 24-27 October 2017.

- Hope, D., A. Cox, A. Zamora-Duran, K.B. Johnson. 2017. Biological Monitoring in Response to Muck Removal in a Tributary Creek of the Indian River Lagoon. American Shore and Beach Preservation Association Meeting, Fort Lauderdale, Florida, 24-27 October 2017.

- What Are Likely Sources and Chemical Forms of N and P added to Indian River Lagoon Waters? John Trefry, Ph.D., Florida Institute of Technology and Austin Fox, Ph.D., Florida Institute of Technology, SOIRL Citizens Oversight Committee, February 15, 2019, Viera, Florida.

- Straight Talk: Sewage Systems, Septics and Muck in Our Lagoon. Florida Tech IRLRI, WFIT and IRL Coalition public meeting, February 26, 2019, Melbourne, Florida. Muck presentation and panel discussion by Dr. John Trefry, Florida Institute of Technology, Melbourne, FL.

- Marine Resources Council Communications Assembly, August 15-16, 2017, Palm Bay, Florida.

Table 3. FIT EMD Research Year 3 Presentations *(Continued)*

- Monitoring Performance and Measuring Success: Muck Removal, John Trefry, SOIRL Citizens Oversight Committee, September 15, 2017, Viera, Florida.

- Florida Tech Documentary Camera Crew accompanied the FIT EMD sea grass and infauna sampling team in March. The video documentary focused on what it is like to be a Florida Tech graduate researcher working on IRL https://www.youtube.com/watch?v=sW6kktg0gw4

- Save Our Indian River Lagoon Plan: A Marathon not a Sprint, John Windsor, Marine Resources Council, April 21, 2018, Palm Bay, Florida.

- Florida Today IRL Lagoon Meet the Experts, John Windsor, May 9, 2018, Viera, Florida.

- IRL Coalition Call to Action Meeting, John Windsor, May 14, 2018, Melbourne, Florida.

- Are Bottom Sediments an Important Source of Nutrients to the Northern Indian River Lagoon (IRL)? Dr. John H. Trefry and Dr. L. Austin Fox, Lunch Briefing, Rayburn 2325 (SST Committee Room), June 15, 2018, Washington, DC.

- The IRL Restoration, John Windsor, June 21, 2018, Buena Vida Estates, W. Melbourne, Florida

- Save Our Indian River Lagoon Project Plan 2019 Update, Comments by Dr. John Windsor, Board of County Commissioner Meeting, February 26, 2019, Viera Florida.

- Brevard County Commission Workshop on Utilities and Indian River Lagoon, Public comment by John Windsor, April 18, 2019, Viera, Florida.

- Straight Talk on the IRL Public Forum, John Windsor, May 31, 2019, Titusville, Florida.

- IRLNEP Communications Workshop, John Windsor, June 14, 2019, Sebastian, Florida.

- Florida Ocean Alliance Stakeholder Workshop, Strategic Plan Development, Kevin Johnson, Robert Weaver, John Windsor, November 20, 2019, Port Canaveral Florida.

- Save Our IRL Citizens Oversight Committee meetings, Viera, Florida. August 16, September 15, October 20, November 17, and December 15, 2017; January 19, February 16, March 16, April 20, May 18, June 15, July 20, September 21, October 19, November 16, and December 14, 2018; January 18, February 15, March 15, April 19, May 17, May 31, July 19, August 16, September 19, October 18, November 21, December 13, 2019; and January 17, February 21, April 17, May 15, July 17, August 21, September 18, October 16, and November 20, 2020.

- IRLNEP Meetings: IRL NEP Council Board of Directors, August 11, 2017, October 13, 2017, December 8, 2017 and January 12, 2018, July 13, 2018, December 14, 2018, February 8, 2019, May 10, 2019, August 9, 2019, November 8, 2019, February 7, 2020, May 8, 2020, July 31, 2020, November 6, 2020; IRL NEP Management Advisory Board August 8, 2017, October 10, 2017, December 5, 2017, April 10, 2018, July 10, 2018, February 5, 2019, May 7, 2019, August 6, 2019, November 5, 2019, February 4, 2020, May 5, 2020, July 28, 2020; IRLNEP STEM Advisory Committee Meeting, November 28, 2017, March 20, 2018, July 10, 2018, February 5, 2019, May 7, 2019, August 6, 2019, November 5, 2019, February 4, 2020, May 5, 2020, July 28, 2020.

Important Findings and Recommendations from FIT EMD Research Final Reports

With funding provided by the Florida Legislature as part of DEP Grant Agreement Nos. S0714 and NS005 and administered by Brevard County, environmental muck dredging research was conducted by the Indian River Lagoon Research Institute (IRLRI) at Florida Institute of Technology. Important findings and recommendations from peer-reviewed final reports are listed below. *****Numbers after findings or recommendations refer to report titles on page 18.

Findings: Lagoon-wide Muck Investigations

MK.1. All major and many minor muck deposits in the IRL and Banana River Lagoon (BRL) were likely sampled during this study, excluding the northern BRL near NASA property, where access is limited. **19, 20*

MK.2. A rapid technique called Quick Flux was developed to collect sediment pore water to determine fluxes of N and P from muck to the overlying water. The method was validated against an accepted method that used detailed interstitial water samples. More than 400 Quick Flux determinations of benthic fluxes of N and P were obtained to provide a robust data set that complements biological and geochemical studies. **9, 19*

MK.3. A Grand Survey of 53 sites, followed by detailed geochemical and biological study of the top 20 (of 53) sites in the IRL and BRL (Brevard County), was carried out; it greatly enhanced available data and perspectives on the lagoon-wide distribution of muck. The top 20 sites were prioritized for muck projects by first using a geochemical ranking and then confirming choices using biological indices for benthic fauna and seagrasses. **19, 20*

MK.4. Baseline biological (seagrass and infauna) and geochemical data were obtained for the IRL near Mims, for Sykes Creek and nearby comparison sites prior to dredging. **17*

MK.5. Dredging of sand and shells can be precluded using a newly designed prototype with variable intake and shrouded dredging suction head. Treatment with ferrate (a very reactive iron oxide) removed nutrients. Field testing of the coupled system confirmed the feasibility of small-scale muck sump operations along canals and rivers that flow into the IRL. An autonomous scaled-up system could be developed and installed at permanent locations in canals to manage muck removal prior to entering the Lagoon. **14*

Findings: Turkey Creek Muck Removal

TC.1. Environmental dredging of 160,000 m^3 of muck from Turkey Creek removed about 300 metric tons of nitrogen (N) and 70 metric tons of phosphorus (P). **9, 17*

TC.2. Dredging reduced the volume and surface area of muck in the dredged area by >60% and <20%, respectively; slumping and redistribution of adjacent muck sediments following dredging limited the surface area dredged. **17*

TC.3. Water volume in the dredged area increased by 160,000 m^3 after dredging, a direct result of the volume of sediment removed from Turkey Creek. Concentrations of dissolved oxygen in the creek increased after dredging in proportion to a deeper basin and larger volume of water. **7, 17*

TC.4. N and P fluxes from muck sediments were >50% lower 3 months after dredging. **17, 19*

TC.5. >99.9% of the solids pumped from Turkey Creek were retained in a Dredge Material Management Area (DMMA) at US1 and Robert J. Conlan Boulevard in Palm Bay until trucked to central Florida for use as a soil amendment. Chemical treatments effectively controlled concentrations of dissolved phosphate in the DMMA. Concentrations of nutrients in water discharged from the DMMA were not identifiable at 100 m from the outfall. **9, 17*

TC.6. Despite significant environmental variability and muck removal activities in Turkey Creek, the habitat supported an abundant and diverse assemblage of fishes. **8*

TC.7. Muck sediments in Turkey Creek likely contribute to, and may be the primary reason for, seagrasses struggling in what would otherwise appear to be an ideal location in Turkey Creek. **2*

TC.8. Infauna which live in nearby sediments with a modest organic matter content can benefit from dredging muck that has a very high organic matter content and little or no infaunal life because the new conditions will likely be an improvement and infaunal life will migrate by tracking improved sediment composition. Seagrasses and fishes, in contrast, are populations we expect to respond to longer term, general improvements in regional estuarine water quality, but were not observed to respond directly to local dredging. **2, 7, 17*

TC.9. A new method for capturing near-bottom moving fluid mud with suspended particulate matter showed a reduction in fluid mud and muck near the bottom after dredging in Turkey Creek. Overall, it appears that the basin near the mouth of the creek may be acting like a muck trap. Both the IRL and Turkey Creek (west of railroad bridge) appear to be acting as muck sources. **4, 12*

Findings: Tributary and Groundwater Inputs of Nutrients and Suspended Sediments to IRL

TR.1. Mean concentrations of total N (TN) for the four tributaries studied (St. Sebastian River, Turkey Creek, Crane Creek and Eau Gallie River) were 30–50% lower than the USEPA standard of 1540 µg N/L for Florida inland waters. However, two of the four tributaries (the St. Sebastian and Eau Gallie rivers) had mean concentrations of total P (TP) that were 80% and 100% higher than USEPA criteria of 120 µg P/L. **10, 18*

TR.2. Dissolved organic N (DON) made up more than half of the TN in IRL tributaries. The more biologically available forms of N (ammonium, nitrate and nitrite) made up only ~25% of the TN. In contrast, phosphate, the more biologically available form of P, made up about half of the TP. Understanding harmful algal blooms requires knowing concentrations of specific forms of N and P (e.g., nitrate or organic nitrogen) not just TN or TP. **10, 18*

TR.3. About 60% of TN and TP fluxes from tributaries to the IRL were carried during the wet season in 2016 (June 1–October 31). During 2017, >50% of the various chemical forms of N and P were delivered to the IRL during a 7-week period of rain and flooding following Hurricane Irma in mid-September. These results support the present fertilizer ordinance. **18*

TR.4. Estimated fluxes of TN (300–400 metric tons of N/y) and TP (30–80 metric tons of P/y) from major tributaries were at the same order-of-magnitude as benthic muck fluxes from the north IRL (300 metric tons N/y and 45 metric tons P/y). **18*

TR.5. Concentrations of total suspended solids, dissolved organic carbon, TN, ammonium and phosphate were not significantly different in water samples collected from Turkey Creek during 2016–17 relative to 1988–89. In contrast, significant increases over three decades were identified for TP (+82%), particulate P (+90%), particulate N (+300%) and nitrate + nitrite (+400%). Only dissolved organic N showed a significant decrease (-25%). Increased urbanization and residential property, plus decreased natural lands, supported the trends observed. **18*

TR.6. After 10 months of groundwater sampling, the three communities (septic, sewer, and sewer with reclaimed irrigation) had significantly higher groundwater total nitrogen concentrations than the natural area, but they were not significantly different from each other. Organic forms of N (TKN and NH4+) were significantly higher in the sewer community than the community receiving reclaimed irrigation water. But the reclaimed community had significantly higher inorganic nitrogen (NOx) than the septic or sewer communities. In surface water, the organic forms of N comprise ~90% of the total dissolved N in the water column. The organic forms of P comprise ~70% of the total dissolved P in the water column. In groundwater, organic forms of N were the dominant form in septic and sewer communities, but inorganic forms of N were found in the community receiving reclaimed water for irrigation. **15*

TR.7. Based on measured groundwater data, modeled TN loading to groundwater in the Turkey Creek area was at least 2100 kg N/year or 6 kg N/year for each household. Furthermore, N plumes extended well beyond the 20–60 m previously reported, indicating that distance from an Onsite Sewage Treatment & Disposal System to the receiving waterway should not be the only indicator used to predict loading. **15*

Findings: Modeling Water Quality Related to Muck Deposits and Dredging

ML.1. Modeling of muck zones shows that muck dredging has the potential to reduce N concentrations in the water column within dredged areas as well as up to 8 km away from dredged areas. The impact of muck dredging in all areas was detectable in model results which show a post-dredging reduction of TN. However, the impact of dredging was less for zones influenced by strong freshwater inflows, particularly during the wet season. **21*

ML.2. The IRL hydrodynamic and water quality model continues to be developed through updated boundary conditions and inclusion of additional muck zones. As more information is acquired on the extent of muck deposits in the IRL, these areas can be incorporated into the model and tested for the potential benefits of muck dredging at other locations. **5, 11, 21*

ML.3. Using a wind gust approach, an assessment of published estimates for surface roughness at the three ASOS (Automated Surface Observing System) sites was performed. Results for the Fort Pierce and Vero Beach systems, but not for Melbourne, were consistent with the data. For some flow directions, published roughness estimates at the Melbourne ASOS were too low due to difficulties in accurately determining low-end roughness values; this is a possible issue if one chooses to adjust roughness values from land to water. Such discrepancies have important implications and thus ASOS wind direction should be considered when using National Weather Service data to represent IRL locations. **13*

Recommendations

RE.1. Successful management plans for controlling muck and nutrients in the IRL require continuing assessment of external and internal inputs of substances that are precursors to algal blooms and future muck deposits. Therefore, more data are needed for (i) major tributaries to the IRL during regular and storm flow, (ii) atmospheric inputs, (iii) direct runoff from hundreds of outfalls along the lagoon and (iv) fluxes of nutrients from IRL muck to the overlying water. **10, 18, 19*

RE.2. Continuous chemical data for tributaries and the IRL are needed to better assess nutrient inputs, especially during extreme water flows that accompany hurricanes. The fertilizer ban is worth continuing with a possible shift to both start and end one month later, this shift better incorporates recent tropical storms in September and October. Decreases in the N and P content of reclaimed water is recommended. More data are needed to identify the specific components that make up dissolved organic N and dissolved organic P. Furthermore, wherever possible, isotope data for specific chemical forms of N are needed to help better identify nutrient sources. But, most of all, we need to work to restrict or treat nutrient runoff during periods of extreme water flow. **18*

RE.3. We encourage, where possible, that muck remediation efforts be carried out in the top 20 sites prioritized for muck projects. We also recommend increased focus on closely spaced areas and those noted for the onset of major algal blooms. Moreover, geochemical and biological rankings from this study must be considered in context with other pertinent variables including cost, proximity to a DMMA, assessments of likely muck migration, benefits of formation of a trap for future muck accumulation, project constructability and other factors as applicable. **19*

RE.4. Muck management efforts should focus on projects that reduce areal coverage of muck deposits more than muck volumes. **20*

RE.5. Cost effective strategies should be employed to reduce nutrient levels in water from settled muck before release to the IRL. **17*

RE.6. Baseline data for seagrass and drift algae are critical to future evaluation of potential environmental improvements. **7*

RE.7. Although residential communities along Turkey Creek appear to be equally polluting with nutrients, this can only be confirmed by repeating the study design in different areas. **15*

RE.8. The distance from an Onsite Sewage Treatment and Disposal Systems to the receiving waterway should not be the only indicator used to predict nutrient loading potential. Nitrogen plumes in our study extended well beyond the 20 to 60 m reported in the literature. **15*

Florida Institute of Technology Environmental Muck Dredging Research Reports*

FIT EMD Year 1 peer-reviewed final research reports are found in:
Impacts of environmental muck dredging 2014–2015. Final Project Report to Brevard County Natural Resources Management Dept., J.G. Windsor, Jr. (Ed.), July 2016

1. *Muck Dredging Research Project Management (Subtask 1)*, John Windsor
2. *Biological Responses to Muck Removal (Subtask 2), Kevin Johnson and John Shenker*
3. *The Efficiency of Muck Removal from the IRL and Water Quality after Muck Removal (Subtask 3), John Trefry*
4. *Movement Measurements of Muck and Fluidized Mud at Dredge Sites (Subtask 4), Charles Bostater*
5. *Hydrologic and Water Quality Model for Management and Forecasting within Brevard County Waters of the IRL (Subtask 5), Gary Zarillo*

FIT EMD Year 2 peer-reviewed final research reports are found in:

6. *Muck Dredging Research Project Management (Subtask 1)*, John Windsor, June 2019
7. *Biological Responses to Muck Dredging in the Indian River Lagoon, Part I. Seagrass Monitoring and Infaunal Surveys (Subtask 2)*, Kevin Johnson, September 2017
8. *Biological Responses to Muck Dredging in the Indian River Lagoon, Part II: Fish Populations and Sea Grass Restoration (Subtask 3)*, Jonathan Shenker, March 2018
9. *Determining the Effectiveness of Muck Removal on Sediment and Water Quality in the Indian River Lagoon, Florida (Subtask 4A)*, Austin L. Fox, John H. Trefry, Robert P. Trocine, Stacey L. Fox, Jessica E. Voelker, December 2017
10. *Inputs of Nitrogen and Phosphorus from Major Tributaries to the Indian River Lagoon (Subtask 4B)*, John H. Trefry, Austin L. Fox, Robert P. Trocine, Stacey L. Fox, Jessica E. Voelker, Katherine M. Beckett, October 2017
11. *Hydrologic and Water Quality Model for Management and Forecasting within Brevard County Waters (Subtask 5)*, Gary Zarillo, April 2018
12. *Moving Muck & Fluidized Mud & Tributary Bedload Measurements at Dredge Sites (Subtask 6)*, Charles Bostater, May 2018
13. *Wind and microclimate analysis for application to fetch-limited wind wave growth analysis at IRL dredging locations (Subtask 7)*, Steven Lazarus, November 2017
14. *Feasibility of muck removal at fixed locations in the IRL watershed and subsequent ferrate treatment to remove nutrients and contaminants (Subtask 8)*, Robert J. Weaver and Thomas D. Waite, January 2018
15. *Source to Slime Study in Indian River Lagoon (Subtask 9)*, Leesa Souto, May 2019

FIT EMD Year 3 peer-reviewed final research reports are found in:

16. *Muck Dredging Research Project Management (Subtask 1)*, John Windsor, February 2021
17. *Muck Removal Efficiency plus Biological and Chemical Responses/Improvements after Muck Dredging (Subtask 2)*, Kevin Johnson, Jon Shenker, and John Trefry, June 2020.
18. *Trends for Inputs of Muck Components from Rivers, Creeks and Outfalls to the Indian River Lagoon (Subtask 3)*, John Trefry and Austin Fox, December 2019
19. *Lagoon-Wide Application of the Quick-Flux Technique to Determine Sediment N and P Fluxes (Subtask 4)*, Austin L. Fox and John H. Trefry, June 2019
20. *Optimizing Selection of Sites for Environmental Dredging in the Indian River Lagoon System (Subtask 5)*, John H. Trefry and Kevin B. Johnson, November 2019
21. *Sediment & Water Quality Modeling for Nutrients, Muck and Water Clarity Scenario Assessments (Subtask 6)*, Gary A. Zarillo and Claudia Listopad, January 2021

***Funding through DEP Grant Agreement Nos. S0714 and NS005 administered by Brevard County**

Impacts of Environmental Muck Dredging 2017-2018 at Florida Institute of Technology Year 3 Final Report - Titles and Executive Summaries

In order to address serious water quality issues associated with muck sediment in the Indian River Lagoon, the Florida Legislature in the 2016 session directed $1.5 million through Brevard County to the Florida Institute of Technology (Year 3 Projects) to investigate the effects of environmental muck dredging in the Indian River Lagoon. A collaborative University effort, through the Indian River Lagoon Research Institute, developed the following projects (subtasks) to help better manage future muck removal efforts throughout the state:

1. *Muck Dredging Research Project Management*, John Windsor (PI)
2. *Muck Removal Efficiency plus Biological and Chemical Responses/Improvements after Muck Dredging,* Kevin B. Johnson (PI); Jonathan M. Shenker and John H. Trefry (Co-PIs)
3. *Trends for Inputs of Muck Components from Rivers, Creeks and Outfalls to the Indian River Lagoon,* John H. Trefry and Austin L. Fox (Co-PIs)
4. *Lagoon-Wide Application of the Quick-Flux Technique to Determine Sediment N and P Fluxes,* Austin L. Fox and John H. Trefry (Co-PIs)
5. *Optimizing Selection of Sites for Environmental Dredging in the Indian River Lagoon System*, John H. Trefry and Kevin B. Johnson (PIs)
6. *Hydrologic and Water Quality Model for Management and Forecasting within Brevard County Waters,* Gary A. Zarillo (PI) and Claudia Listopad (Co-PI)

Muck Dredging Research Project Management (Subtask 1)

John G. Windsor
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February 2021

Executive Summary

In order to address serious water quality issues associated with muck sediment in the Indian River Lagoon, the Florida Legislature in the 2016 session directed $1.5 million to the Florida Institute of Technology through Brevard County to investigate the effects of environmental muck dredging in the Indian River Lagoon (IRL). Six interdisciplinary projects (Subtasks) developed by the Indian River Lagoon Research Institute (IRLRI) at Florida Institute of Technology were coordinated through the muck dredging research project management office: (1) Muck Dredging Research Project Management, (2) Muck Removal Efficiency plus Biological and Chemical Responses/Improvements after Muck Dredging, (3) Trends for Inputs of Muck Components from Rivers, Creeks and Outfalls to the Indian River Lagoon, (4) Lagoon-Wide Application of the Quick-Flux Technique to Determine Sediment N and P Fluxes, (5) Optimizing Selection of Sites for Environmental Dredging in the Indian River Lagoon System, and (6) Hydrologic and Water Quality Model for Management and Forecasting within Brevard County Waters. Executive summaries from the peer reviewed final project reports for these subtasks are reproduced at the end of this report. Regular meetings of the Florida Institute of Technology Environmental Muck Dredging (FIT-EMD) research principal investigators with representatives from Brevard County Natural Resource Management Department were used to optimize the outcomes of these research investigations. Progress reports were regularly shared with Florida Department of Environmental Protection and a team of external scientific consultants and other stakeholders. Florida Institute of Technology Environmental Muck Dredging research progress, reported through monthly meetings, written reports and public presentations, is summarized in this report.

In addition to the work summarized, key findings and recommendations from legislatively funded FIT Environmental Muck Dredging Research is presented here.

Muck Removal Efficiency plus Biological and Chemical Responses/Improvements after Dredging (Subtask 2)

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July 2020

Executive Summary

Removal of fine-grained, organic-rich sediments is an integral part of restoring the Indian River Lagoon (IRL) to a healthy ecosystem. This sediment, often referred to as IRL muck, is a concern because it can increase turbidity, consume oxygen, create an inhospitable benthic habitat and is an internal source of dissolved nitrogen (N) and phosphorus (P) that diffuse from muck into the overlying water of the lagoon. Dredging is being used as a method for removing large reservoirs of muck with associated N and P; however, there are challenges to dredging and few data are available to quantify the efficacy of environmental dredging in the IRL or elsewhere.

As the primary emphasis of this study, extensive surveys of sediment and water biogeochemistry, seagrass, benthic infauna and fisheries in Turkey Creek were carried out before dredging (April 2015–January 2016), during two separate phases of dredging (Phase I, February 20, 2016–April, 22, 2016 and Phase II, September 6, 2016–January 11, 2017), and after dredging during May 2016–April 2017. The goals of the Turkey Creek study were to track changes in (1) the distribution and composition of muck, (2) benthic fluxes of N and P from muck to the overlying water column, (3) sediment and water quality, (4) seagrass distribution and growth, (5) abundance, diversity and richness of benthic infauna and (6) abundance, diversity and microhabitat use of juvenile fishes and (7) feeding habits of fishes that could be impacted by dredging. Additional surveys were started before and during dredging at the Mims Boat Ramp and before dredging in Sykes Creek.

Pre-dredging surveys in Turkey Creek (February 2015) identified up to 3 m of muck in the study area between the Florida East Coast Railroad Bridge and the mouth of Turkey Creek with little to no muck in the adjacent IRL. Within the established dredge area, the efficacy of muck removal by conventional hydraulic dredging was ~63% based on removal of 52,000 of 83,000 m^3 of muck, which contained ~300 metric tons of N and ~70 metric tons of P. Dredging increased water depth and bay volume, a potential benefit to fishes, benthic fauna and seagrass. Benthic fluxes of N and P were ~50% lower at 3 months after dredging, which if continued would decrease annual releases of dissolved N and P from IRL muck by ~3 tons and ~1 ton, respectively, within the ~0.10 km^2 of Turkey Creek that were dredged. Monthly water quality surveys in Turkey Creek (April 2015 to April 2017) showed that the 1- to 2-m deeper water column after dredging contained twice the dissolved oxygen. Increase in oxygen may enhance resiliency to oxygen depletion events. Before, during and after dredging, values for dissolved ammonium and phosphate were highest in bottom water, consistent with sediments as a continuing source of these nutrients to the overlying water.

Surveys for seagrasses, drift algae and benthic infauna were conducted quarterly in Turkey Creek during the time period of muck removal listed above. Data for the occurrence of seagrasses (primarily *Halodule wrightii*) and drift algae (DA), included % cover, canopy heights, %

occurrence, and biomass. *H. wrightii* was not present within transects sampled in Turkey Creek nearest the dredge site. *H. wrightii* was most abundant (32% coverage), when present, in the shallower nearshore portions of transects (40–70 cm depth) within the adjacent IRL; abundance generally declined in winter to 0-5% visual percent cover. In contrast, drift algae, mainly *Gracilaria* spp. plus one or two other species, were more abundant in Turkey Creek than in the adjacent IRL. During 2017, lesser amounts of drift algae were observed in the IRL; however, large amounts were seen in Turkey Creek during winter and spring of 2017 and summer 2018. No statistically significant impact from dredging or muck removal was found in the abundance of seagrasses and drift algae. Rather, the small population changes observed in seagrass communities were more likely tied to simple seasonal changes, with winter months having the least abundances. Seagrasses are populations we expect to respond to longer term, general improvements in regional estuarine water quality, but not necessarily to local dredging.

The abundances and distributions of 83 species of invertebrate benthic infauna were determined via sediment grabs, and community parameters correlated with sediment geochemistry, especially percent organic matter. Richness and diversity of infaunal invertebrate communities were greatest at sandier IRL sites, almost nil within muck, and intermediate in Turkey Creek (TC) adjacent to where dredging occurred. Sediments in these areas displayed a gradient of fine-grained, organic-rich sediment characteristics, which co-varied with the occurrence of certain species and with diversity and richness patterns. Infaunal diversity and abundance were greater in sandier sediments. Dredged muck sites showed increases in infauna diversity, richness, and abundances in the months following dredging. Dredged sites with mixed sand and muck sometimes showed a decrease in these same metrics during 2017, likely from dredge-removal of infauna. A year later, however, infauna abundances and diversity at dredged intermediate stations were more like undredged intermediate stations.

Sampling with a 17-m seine net within the Turkey Creek region captured 59 taxa. These samples were dominated by small pelagic and demersal fishes, and did not include larger predatory fishes moving through the area. Catches were heavily dominated by schools of small pelagic fishes, particularly anchovies (*Anchoa* spp.), whose distributions reflected rapid movement of schools in and around the region without any direct association with dredging activities. Of the demersal fishes, the most abundant taxa were juvenile mojarras (*Eucinostomus* spp. and *Diapterus* spp.) and juvenile drums (Atlantic croaker, silver perch, red drum, juvenile seatrout and kingfish). All of these taxa showed large variations in abundance that reflected seasonal patterns in reproduction and interannual variation in lagoon-wide recruitment as well as responses to environmental perturbations in Turkey Creek such as periods of high freshwater discharge through the creek following major rain events. These taxa also exhibited variable patterns of microhabitat utilization: juvenile mojarras were most abundant in the hard sandy habitat along the western edge of the Turkey Creek embayment, silver perch and red drum were most common in the northern portion of the habitat characterized by oyster shells and softer sediments, and sea trout and kingfish were most common in the hard sandy habitat outside the mouth of Turkey Creek. Gut content analysis of these juveniles showed that most fed on epibenthic and infaunal crustaceans, mollusks and polychaetes. Although dredging did not have a detectable impact on the distribution and abundance of these juveniles, removal of muck appeared to have increased the abundance of some of these prey taxa. An increase in the prey base of these fishes indicates that the region could support increased numbers of juvenile fish, but the lack of complex habitat structure (e.g. seagrasses and oyster beds) that provides small fish with some protection against predators may mitigate against positive impacts of increasing food resources for the fish.

Dredged material from Turkey Creek was transported ~2 km north to a Dredge Material Management Area (DMMA) for settling and dewatering. Clarified water was discharged into the adjacent IRL. The overall retention efficiency for solids in the DMMA was >99.9%. Values for Total Suspended Solids (TSS) in the outfall from the DMMA to the IRL averaged ~28 mg/L during Phase I and 12 mg/L during Phase II, with four brief episodes of higher values. Background TSS values were 10–20 mg/L in the adjacent IRL. Chemical treatments effectively reduced concentrations of dissolved phosphate from as high as 10,000 µg P/L in the incoming dredged material to <40 µg P/L in clarified water released to the lagoon during Phase II, relative to <50 µg P/L in the lagoon. Total dissolved nitrogen in water released from the DMMA to the IRL was >5 mg N/L throughout the dredging process, relative to <0.8 mg/L in the lagoon. Additional efforts are now underway to decrease concentrations of dissolved nitrogen, mostly as ammonium, during future uses of DMMAs. Nutrient concentrations were at baseline values for the IRL at ~100 m from the outfall. We estimate that ~6 tons of N (~90% dissolved) and ~0.1 ton of P (~30% dissolved) were released from the DMMA during this one-year dredging project. Although unique to this particular IRL area, freshwater discharges annually release ~80 and ~5 tons of N and P, respectively, to Turkey Creek, far more than released from the DMMA.

Monitoring at the Mims Boat Ramp and Sykes Creek was initiated during 2017 and 2018, respectively. Dredging at the Mims Boat Ramp was carried out from April 23, 2018 to June 26, 2018 and then from August 29, 2018 to the conclusion on December 4, 2018. About 27,000 m^3 of wet muck sediment were removed from the Mims area in dredging that was completed in December 2018. About 80% of the muck, at thicknesses of 1–2 m, was found in a small basin at the southern end of the Mims dredge area. Benthic fluxes of N and P before dredging at the Mims area were 20–30% greater than in Turkey Creek. Mims seagrasses were primarily *Halodule wrightii* and had some of the densest populations observed in IRL during this study for the Environmental Muck Dredging (EMD) Project, but were absent from the densest muck areas of Mims. In adjacent sandier areas in summer, the high growth season, seagrass coverage reached as high as 100% and seagrass blades reached a length of 16.8 cm. Mims also had some of the highest observations of drift algae towards the end of the sandy transects, in the summer of 2018.

Regarding infauna, 45 species of benthic fauna, mostly sediment infauna of the phyla Arthropoda, Mollusca and Annelida, were observed at Mims. In the summer, infauna abundances reached a high of 2.5×10^4 animals per m^2 and richness was as great as 17 species per sample. Fishes were less abundant than in Turkey Creek, but the populations were again dominated by small pelagic species. Demersal juveniles were primarily species that spawn inside the lagoon, unlike at Turkey Creek where off-shore spawned larvae that recruit through Sebastian Inlet are dominant members of the community. At the completion of the third year of sampling (EMD3), Mims dredging was still underway. For this reason, before and after dredging comparisons of seagrasses and infauna,

respectively, were not possible for Mims and associated sites. Biological sampling at Mims will continue for the near future, and the data herein will serve as baselines for comparison with post-dredging data yet to be collected.
At Sykes Creek, where dredging has not yet occurred, pre-dredging data provide a baseline for water/sediment quality and biological health (seagrasses, infauna, and fishes) for future comparisons after dredging occurs.

Measured Turkey Creek dredging outcomes during the timeframe of this study were as follows:

- Muck volume reduced by >60%
- Muck surface area reduced by ~20%
- Water volume increase due to increased column depth, of 160,000 m^3, accompanied by increased DO
- Composition of persistent muck was unchanged
- N and P fluxes reduced by 50% within 3 months after dredging
- Variable seagrass trends were indistinguishable from seasonal trends at control sites during the course of this study. Seagrasses are slow responding and should continue to be followed for possible long-term dredging responses, as it is hoped they will still respond to more general, regional improvements in water quality
- Some infauna indicators improved when dredging was carried out on muck sediments with the highest organic content, where metazoan life was largely absent prior to dredging. With intermediate sediments, however, dredging activity reduced some infauna
- In cases where infauna community indicators responded to dredging in the short term, continued monitoring showed that the biological community tracked sediment conditions, even in cases where they reverted to a pre-dredging state
- Fish captured in Turkey Creek seining were dominated by pelagic fishes (e.g., anchovies) and some small benthic species (e.g., juvenile mojarras and juvenile drums), whose occurrence is likely a function of typical, regional spawning cycles and microhabitat use.
- In summary, most chemical and biological factors improved after muck dredging; however, results were compounded/confounded by natural seasonal and yearly variation.

Recommendations include continued monitoring and refinement of muck removal techniques. Continued monitoring of seagrasses at Turkey Creek, Mims, Sykes Creek and associated sites on a quarterly schedule will allow comparison with historical data in different annual growth phases, and will be useful because seagrasses are expected to eventually respond to general regional improvements, though this may take some years. Quarterly monitoring of benthic invertebrates and sediment conditions at the same sites is important because these are the first environmentally dredged sites of many planned under the SOIRLPP; successes and failures related to environmental muck dredging have only begun to be observed and measured. Future dredging stands to benefit from a more full knowledge of early outcomes, including long-term effects. Improvement in the completeness of muck removal, or a softening of the angle of repose of dredged borders, could help rehabilitated sediments keep low organic content and host diverse and abundant benthic communities for longer after dredging.

Trends for Inputs of Muck Components from Rivers, Creeks and Outfalls to the Indian River Lagoon (Subtask 3)

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December 2019

Executive Summary

Successful management plans for controlling muck in the Indian River Lagoon (IRL) require continuing assessment of external and internal inputs of nutrients and other substances that are precursors to algal blooms and muck deposits. Runoff from tributaries to the IRL provide one major pathway for external inputs. Atmospheric deposition, direct runoff from hundreds of outfalls and groundwater seepage also are important external sources. Benthic fluxes from IRL muck are the main internal source of nutrients. This study focused on runoff to the IRL from large tributaries by obtaining and interpreting data for concentrations and chemical forms of dissolved and particulate nitrogen (N) and phosphorus (P) as well as calculating nutrient fluxes to the IRL. Surveys were carried out monthly, as well as episodically during rain events, from December 2015 to March 2018. Sampling locations, all with U.S. Geological Survey (USGS) flow gauges, included St. Sebastian River, Turkey Creek, Crane Creek and Eau Gallie River.

Vertical profiles for conductivity, temperature, dissolved oxygen and pH, along with discrete water samples, were obtained from each tributary. Water samples were analyzed for total dissolved and suspended solids, total nitrogen, ammonium, nitrate + nitrite, dissolved and particulate organic nitrogen, total phosphorus, phosphate, dissolved organic phosphorus, particulate phosphorus, dissolved iron, sulfate, calcium, chloride, silica, alkalinity, plus particulate organic carbon, iron, aluminum and silicon. The two-year study yielded a wealth of data and interpretations that are presented in the four sections of *Results and Discussion* summarized below.

The first section, ***Overview of Water Flow and Chemical Composition***, takes a big-picture look at the four tributaries. The largest tributary, Turkey Creek, has an average water flow of 158 ft^3/sec (CFS; 0.13 km^3/y) and an area of 254 km^2 relative to 20 million CFS (16,500 km^3/y) and 3.3 million km^2 for the Mississippi River. Yet, despite their small sizes and water flow, the four IRL tributaries have annual water runoff (water flow/basin area) that is greater than mean estimated values for all continents except South America. This above-average runoff flows into a poorly flushed IRL that is vulnerable to rapid inputs of freshwater and nutrients which can promote extensive algal blooms. Management solutions for reducing nutrient inputs to the IRL depend on robust and continuous data for all nutrient sources, including major tributaries.

Concentrations of total dissolved solids (TDS) for all four tributaries (n = 104) averaged 740 mg/L, relative to 110 mg/L for world rivers. TDS inversely tracked flow with highest values during low flow. Chloride and sodium from seawater intrusion into groundwater made up 75% of the TDS. Average values for total nitrogen (TN) in all four tributaries (920 ± 250 µg/L) were 30–50% lower than the U.S. Environmental Protection Agency (USEPA) standard for Florida (1540 µg/L). In contrast, three tributaries had mean values for total phosphorus (TP) that were higher than the Florida criteria (120 µg/L); the highest mean value was 244 µg/L for the Eau Gallie River. Only Turkey Creek had mean TP values (63 µg/L) below the USEPA standard.

Concentrations of the various forms of N and P also were determined (Figure ES1). Such information is important because each form of N and P is used at a different rate and biological efficiency during the onset and sustained growth of large algal blooms. Dissolved organic nitrogen (DON) made up more than half of the TN for all four tributaries (Figure ES1). Phosphate, the more biologically available and only inorganic form of P, comprised about half of the TP for the four tributaries. In contrast, more biologically available N (NH_4^+ and N+N) made up only ~25% of TN.

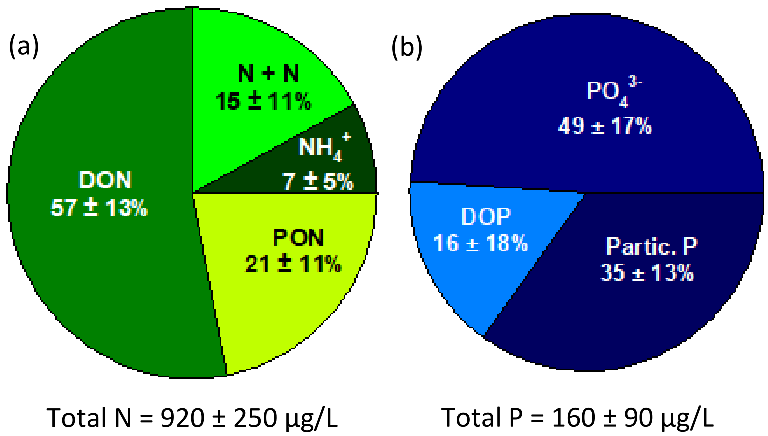

Figure ES1. Chemical forms of (a) nitrogen where DON = dissolved organic nitrogen, N+N = nitrate + nitrite, NH_4^+ = ammonium, and PON = particulate organic nitrogen and (b) phosphorus where PO_4^{3-} = phosphate, DOP = dissolved organic phosphorus, and Partic. P = particulate phosphorus for monthly samples from all four major tributaries (n =104).

In the second section, ***Trends in Concentrations of Chemicals as a Function of Water Flow***, one hypothesis was tested regarding the significance of water flow in controlling concentrations of TDS, total suspended solids (TSS), as well as the various chemical forms of N and P. Equations for each chemical parameter versus log water flow were written, where possible, for each tributary to calculate fluxes to the IRL (e.g., Figure ES2a, b). Our data for IRL tributaries yielded acceptable equations for calculating fluxes (i.e., $r \geq 0.6$ and $p < 0.05$) for 9 of 13 chemical parameters in the St. Sebastian River. However, flux equations for only 3–5 chemical parameters versus flow met our criteria in the other three tributaries. In these other cases, median values, rather than equations, were used to calculate chemical fluxes. Equations and medians were less successful in adequately calculating fluxes when chemical concentrations followed complex patterns versus water flow. These complexities included (i) large enrichment or dilution of chemicals during high flow, (ii) low values for NH_4^+ and N+N during the June–September fertilizer ban and (iii) increased concentrations of NH_4^+ and N+N after the ban (e.g., Figure ES2c, d). Recycling of ~8 million liters (2.2 million gallons) of reclaimed wastewater per day in the Melbourne area was another example of human activity that was identified in Crane Creek.

Phosphate concentrations tended to be greater during very high flow, including instances of 10–40 times higher PO_4^{3-} concentrations following Hurricanes Matthew (October 2016) and Irma (September 2017). Very low ratios for $[(N+N) + (NH_4^+)] / (PO_4^{3-})$ during higher flow indicated release of phosphate from soil minerals. In contrast, concentrations of N+N were often diluted below median values during peak flow, then slowly returned to median values as flow decreased.

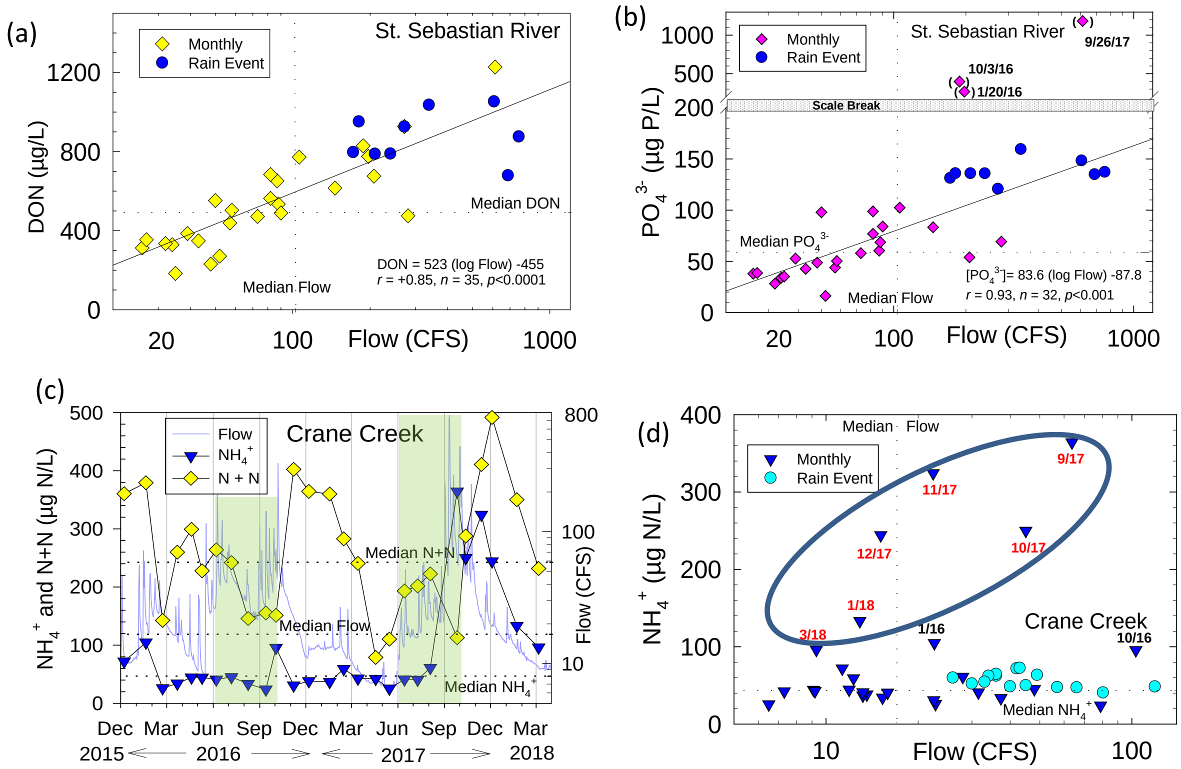

Figure ES2. Concentrations of (a) dissolved organic N (DON) and (b) phosphate (PO_4^{3-}) versus water flow at St. Sebastian River; (c) ammonium (NH_4^+), nitrate + nitrite (N+N) and water flow and (d) NH_4^+ versus water flow at Crane Creek. Green shading on (c) shows period of fertilizer restriction in Brevard and Indian River Counties. Oval on (d) shows NH_4^+ from September 2017–March 2018. Details in full report.

In the third section, ***Tributary Fluxes of Dissolved and Particulate Chemicals to the Indian River Lagoon***, annual fluxes of total N and P for the four major tributaries for 2016 and 2017 were calculated based on daily flows and tributary-specific equations or medians (Table ES1).

Table ES1. Fluxes of total nitrogen (N) and total phosphorus (P) from major tributaries of the Indian River Lagoon.

Tributary	Total N (tons/y)		Total P (tons/y)		Mean Flow (CFS)		Drainage Area (km^2)
	2016	2017	2016	2017	2016	2017	
Eau Gallie River (EG)	10	14	2.5	3.7	11	17	24
Crane Creek (CC)	24	27	3.4	3.8	32	35	48
Turkey Creek (TC)	164	162	11	11	211	210	254
St. Sebastian River So. Prong (SR)	108	184	19	57	111	165	91
Total	306	387	36	76	365	427	417

Mean annual inputs of total N and P (2016, 2017) from the four major tributaries were within 25% of estimated benthic fluxes of N (300 tons) and P (45 tons) from muck sediments in the North IRL (north of Melbourne Causeway, State Road 192). Very high PO_4^{3-} fluxes, concurrent with low N+N and NH_4^+ fluxes, were observed in the St. Sebastian River (South Prong) during large rain events when pH was < 7; this observation is likely due to remobilization of phosphate minerals. In most cases, >70% of the TN and TP were delivered to the IRL during above-median flow that occurred on ~120 days per year. These results confirm the importance of continuing a fertilizer ban during the June–September period of higher water flow and nutrient transport. To further improve estimates of nutrient loading, continuous data for nutrients are needed to match available continuous water flow data.

Turkey Creek: Then (1988–89) and Now (2016–2017) uses data from the present study and an earlier Florida Institute of Technology study to test the hypothesis that concentrations and fluxes of N and P have increased over a three-decade period in Turkey Creek (TC) due to increased urban development. We estimate that urban land use increased from 36% in 1988–89 to 64% in 2016–17. Accompanying that change were several increases in nutrient concentrations in TC including an 82% increase in total P plus 400% and 500% increases in PON and N+N, respectively (Table ES2). Decreased Al and Si in Turkey Creek particles (as a % of TSS) for 2016–17 relative to 1988–89 (Table ES2) suggested that erosion and transport of soil inorganic minerals (i.e., Si and Al) may have decreased due to improvements in soil retention in upland basins of TC. In contrast, an increased organic matter (OM) fraction may yield future muck deposits that are more organic rich.

Table ES2. Changes in concentrations of chemical parameters for Turkey Creek from 1988–89 to 2016–17.

Chemical Parameter	**Significant Change from 1988-89 to 2016-17[a]**
Particulate Organic C (mg C/L)	76% increase, $p<0.0001$
Dissolved Organic N (µg N/L)	25% decrease, $p=0.0018$
Nitrate + Nitrite (µg N/L)	500% increase, $p<0.0001$
Particulate Organic N (µg N/L)	400% increase, $p=0.0024$
Total P (µg P/L)	82% increase, $p=0.0100$
Particulate P (µg P/L)	90% increase, $p=0.0125$
Particulate Al (as % of TSS)	37% decrease, $p=0.0012$
Particulate Si (as % of TSS)	24% decrease, $p=0.0051$
TDS, TSS, DOC, TN, NH_4^+, PO_4^{3-}, DOP;	No significant change, $p>0.05$

[a]t-test, two-tailed, equal variance; mean values were statistically different when $p\leq0.05$.

Our data for the IRL, along with results from this and other studies, support renewed focus on studies of P, and continuing assessment of N, including their various chemical forms. Recent studies globally project increased river flow during extreme events at mid-latitudes. Data from Hurricanes Matthew (2016) and Irma (2017) along the IRL support that projection and encourage enhanced evaluation of phosphate and other chemical releases during these large-scale events. Once again, we confirm previous conclusions that the main fuel for enhanced algal blooms is large, rapid inputs of nutrients to areas of the IRL where lagoon water has a long residence time.

Lagoon-Wide Application of the Quick-Flux Technique to Determine Sediment Nitrogen and Phosphorus Fluxes (Task 4)

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June 2019

Executive Summary

Releases of dissolved nitrogen (N) and phosphorus (P) from Indian River Lagoon (IRL) muck to the overlying water contribute >30% of all nutrient inputs to the lagoon. Other major pathways for nutrient additions to the IRL include stormwater runoff, atmospheric deposition and groundwater/baseflow. Nutrients carried along these various pathways are predominantly introduced on land via fertilizers, wastewater, leaking septic systems, biomass burning, fossil-fuel combustion as well as agricultural and other human activities. To achieve the fundamental goal of decreasing N and P concentrations in the lagoon, adequate knowledge about each source is needed to implement effective remediation techniques. Muck is one of the less obvious and less understood sources of dissolved N and P to the IRL, largely due to insufficient data and an incomplete understanding of what controls these nutrient releases. This study was designed to (1) improve and validate a more rapid technique for estimating nutrient fluxes from muck and then (2) use that information to better understand and decrease N and P releases from muck.

The Quick-Flux technique was used to determine benthic fluxes of N and P from sediments collected at >400 stations in the IRL and Banana River Lagoon (BRL). This method was successfully validated by comparison with results using whole-core squeezers. Sediment samples also were analyzed for water content, Loss on Ignition (LOI) at 550°C, organic C and N, and other chemical and physical properties. The large Quick-Flux data set acquired was used as a valuable and planned component of reports for Task 2 (Muck Removal Efficiency plus Biological and Chemical Responses/Improvements after Muck Dredging, Johnson et al., 2019) and Task 5 (Optimizing Selection of Sites for Environmental Dredging in the Indian River Lagoon System, Trefry et al., 2019).

Results from our one-year research effort with Quick-Flux include the following:

- Muck locations from acoustic surveys, LIDAR and past probing were confirmed via probing. Some sites identified as containing muck were found to have accumulated high-water-content sand and shell or abundant benthic algae, not muck. Twenty large muck areas were probed at multiple locations to determine water depths, muck thicknesses and the spatial distribution of these deposits.

- N and P fluxes determined using the Quick-Flux technique were strongly correlated with values determined from detailed interstitial water profiles (r = 0.92 for N and 0.77 for P).

- The best predictors of benthic N fluxes were water content by volume (porosity) and organic matter content as Loss on Ignition (LOI). Porosity and log[LOI] were strongly correlated (r = 0.99).

- Fluxes of nitrogen and phosphorus followed seasonal temperature fluctuations with a 2 to 25-fold increase in fluxes as sediment temperatures increased from 16 to >30°C. Equations were developed to standardize benthic fluxes to a sediment temperature of 25°C.

- The molar N:P ratio for interstitial water varied temporally and spatially from <10 to >50; these variations were likely a response to redox conditions in sediments and overlying water.

Optimizing Selection of Sites for Environmental Dredging in the Indian River Lagoon System (Subtask 5)

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November 2019

Executive Summary

Fine-grained, organic-rich sediments, locally called Indian River Lagoon (IRL) muck, are anoxic and uninhabitable to benthic fauna and seagrasses. At the same time, rich bacterial communities thrive on the organic matter in IRL muck to produce large amounts of dissolved nitrogen (N) and phosphorus (P) that are released to the overlying water. These nutrient releases (fluxes) account for 30–40% of the N and P added to the lagoon from all sources including runoff, direct discharges and atmospheric deposition. Muck management has thus become an important part of restoration plans for the lagoon system. To date, dredging has been the dominant mechanism for removing IRL muck; however, sand capping, aeration and other techniques are being evaluated. Irrespective of the technique used for muck management, selection of optimal sites for mitigation is a priority.

The goal of this project was to choose and rank 20 optimal sites in the IRL and Banana River Lagoon (BRL) in Brevard County for muck projects, ostensibly from the standpoint of muck removal. Metrics for optimization presented here were based on geochemical and biological data for samples collected during this study. Initially, 53 sites were chosen for geochemical investigation during a Grand Survey. These sites included previously identified muck deposits, as well as locations near upland sources and deeper water; both settings favor muck accumulation. Twenty sites were chosen for further investigation based on organic matter content (>10%), maximum muck thickness (>0.8 m) and muck surface area (>20,000 m^2).

Data from detailed geochemical and biological surveys of the 20 sites were used to create independent rankings of sites for muck management. These rankings described below provide a scientific perspective for selecting muck projects that are intended to be applied in concert with other considerations. Additional factors include, but are not limited to, the following: cost, proximity to a dredged material management area, potential for muck to spread out from a site, formation of a sump (trap) for future inputs, and project constructability.

Geochemical data for sediment fluxes of dissolved N from several locations in each site were used to rank sites from highest (#1) to lowest (#20) fluxes (Table ES1; Figures ES1 and ES2). Overall, 15 of 20 sites were in the IRL; however, the five sites in the BRL contained 37% of the total muck volume (4.3 million m^3) and 52% of the total sediment flux of N (123 tons/y) for the top 20 sites.

Data also were collected from biological studies of the top 20 sites. Ranking was based on the Shannon Wiener diversity index for benthic fauna and a combined seagrass index

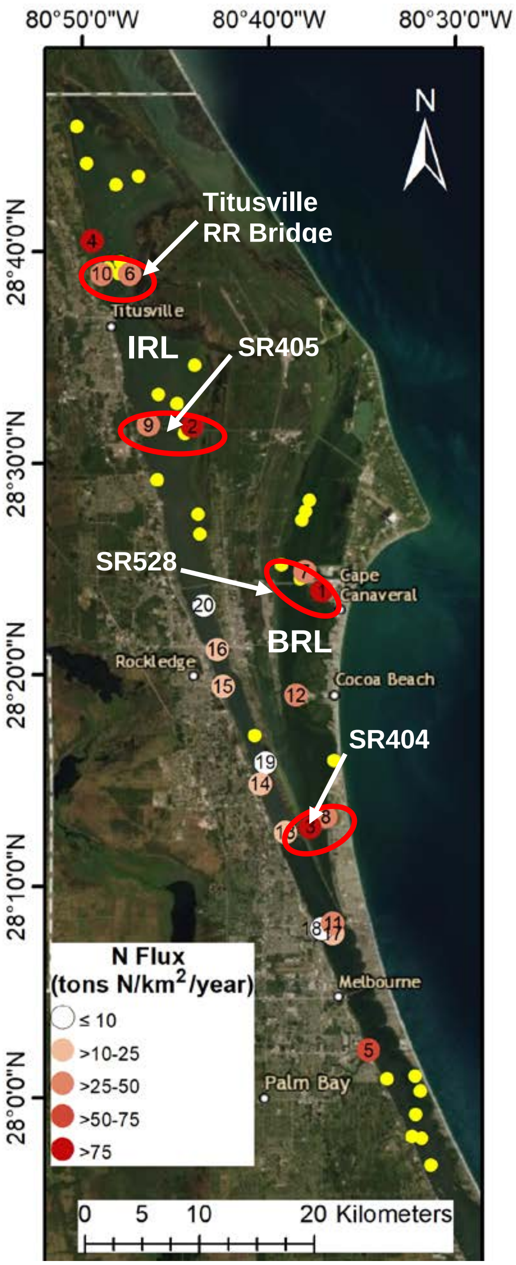

Figure ES1. Map of Indian River Lagoon (IRL) and Banana River Lagoon (BRL) showing sites ranked from 1–20 for muck projects based on sediment nitrogen (N) flux (color-coded, numbered circles). The highest ranked site (#1) had the highest N flux. Numbers on map correspond with data by rank in Table ES1. Yellow circles show additional 33 sites from the Grand Survey. Red ovals identify eight optimal sites that cluster within areas noted for the onset of algal blooms and large benthic fluxes of N.

Table ES1. Ranking of sites in Banana River Lagoon (BRL) and Indian River Lagoon (IRL) based on the geochemical property of sediment nitrogen (N) fluxes in metric tons/km^2/y. Station rankings match locations on Figure ES1.

Rank	Site ID	Site Identification	Mean N Flux (t/km^2/y)
1	BRL8-399	SR528 SE (Beachline Exprwy)	101
2	IRL8-529	SR405 NE (NASA Cswy)	100
3	BRL8-213	SR404 NW (Pineda Cswy)	83
4	IRL8-675	Mims Boat Ramp	77
5	IRL8-037	Turkey Creek	69
6	IRL8-649B	Titusville RR SE	42
7	BRL8-414	SR528 NE (Beachline Exprwy)	41
8	BRL8-221	SR404 NE (Pineda Cswy)	38
9	IRL8-530	SR405 NW (NASA Cswy)	32
10	IRL8-649A	Titusville RR SW	30
11	IRL8-137	SR518 NE (Eau Gallie Cswy)	29
12	BRL8-317	Cocoa Beach Country Club	27
13	IRL8-209	SR404 NE (Pineda Cswy)	20
14	IRL8-247	Rockledge A	16
15	IRL8-324	Cocoa South	13
16	IRL8-353	SR520 South (Merritt Is. Cswy)	11
17	IRL8-129	SR518 South (Eau Gallie Cswy)	10
18	IRL8-133	SR518 NW (Eau Gallie Cswy)	7.5
19	IRL8-264	Rockledge B	6.4
20	IRL8-388	SR 520–528	6.2

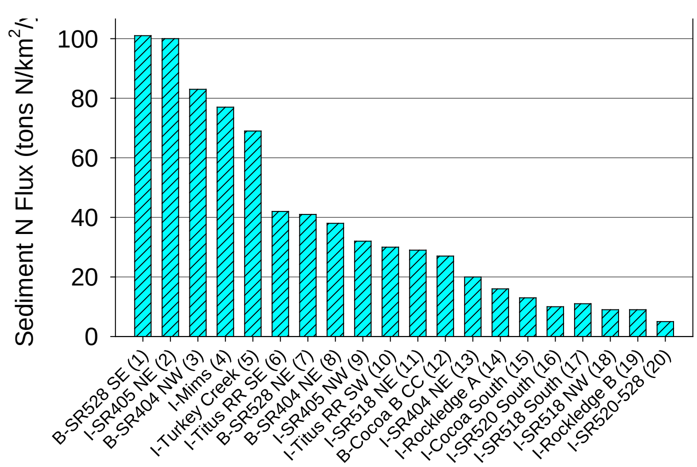

Figure ES2. Rankings for top 20 sites based on sediment nitrogen (N) flux. Numbers in parentheses on x-axis show rank where #1 is for site with highest N flux. Site rankings match listing on Table ES1. (I = Indian River Lagoon; B = Banana River Lagoon)

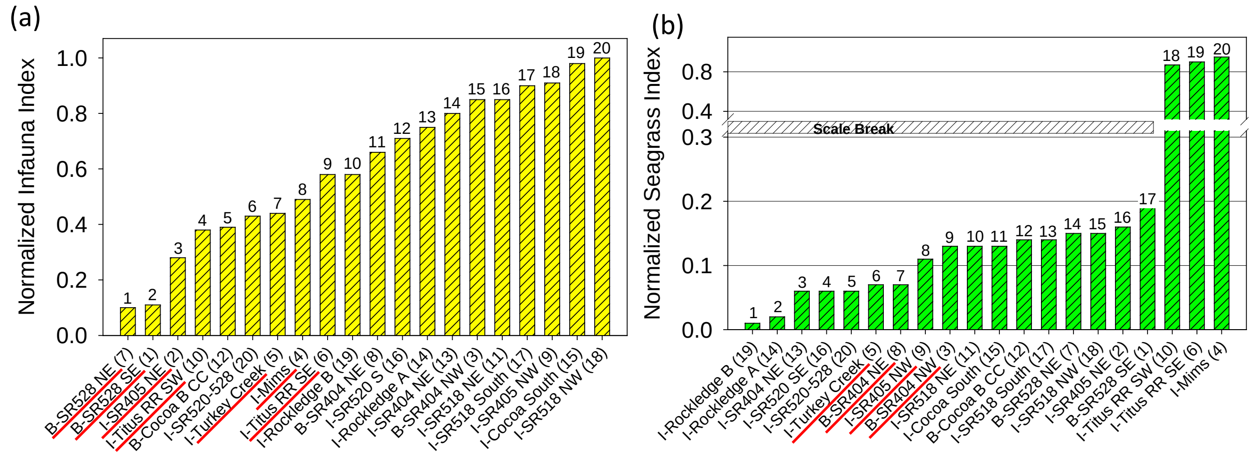

Figure ES3. Rankings for normalized (a) diversity index for benthic fauna and (b) seagrass index. The highest ranked site (#1 above bars on each graph.) had the lowest index value (y-axis) and thus the least viable ecological environment. Numbers in parentheses on x-axes show rankings based on sediment nitrogen flux as identified in Table ES1. Underlined site identifications among top 10 biological indicators also were among top 10 sites based on sediment nitrogen fluxes (Figure ES2). (I = Indian River Lagoon; B = Banana River Lagoon)

(% seagrass cover and distance from muck to nearest seagrass bed). The highest ranked site (#1) for benthic fauna and seagrasses had the lowest index values (lowest abundance and diversity) and thus were considered the least viable ecological environments (Figure ES3). Such sites will likely benefit from muck projects.

When biological rankings for benthic fauna and seagrasses were each juxtaposed with geochemical rankings based on sediment N flux, the top 10 sites based on geochemistry also were ranked among the top 10 sites for benthic fauna and/or seagrasses (low abundance and diversity; Figure ES3). Four of the top 10 sites were in the BRL between State Road (SR) 404 (Pineda Causeway) and SR 528 (Beachline Expressway) plus the adjacent IRL to the west (Figure ES1). An additional four of the top 10 sites were located in the IRL between SR 405 (NASA Causeway) and the Titusville Railroad Bridge (Figure ES1). These optimal areas for muck projects cluster within key zones for the onset of algal blooms (Figure ES1). The other two top 10 sites based on sediment N flux (#4, Mims and #5 Turkey Creek) were known muck deposits that were recently dredged.

The geochemical and biological rankings discussed in this report provide scientific evidence to guide management decisions regarding key sites for muck projects, including dredging. We encourage, where possible, that muck remediation efforts be carried out in optimal areas as ranked here, especially when they are noted for the onset of major algal blooms. A combined effort for muck projects at closely spaced sites also may yield a greater degree of success. Moreover, the geochemical and biological rankings from this study must be considered in context with other pertinent variables (e.g., cost and project constructability as listed above).

Hydrologic and Water Quality Model for Management and Forecasting within Brevard County Waters of the Indian River Lagoon

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January 2021

Executive Summary

This project integrates water quality and hydrologic, and hydrodynamic process data into the model of the Indian River Lagoon. The overall goal is to combine model simulations with measured data to assess the impact of muck dredging on local and regional water quality. Water quality modeling in the final year of the project benefited from the expansion of muck zone assessment from Turkey Creek to the additional areas. Model experiments in all muck zones show that muck dredging has the potential to reduce nitrogen based nutrient concentration in the water column outside the dredged area, as well as within the dredged areas. Model experiments also demonstrate the potential for reducing phosphorus based nutrient concentrations. The impact of muck dredging in all areas was detectable in the model results, which show a post dredging reduction of total nitrogen concentration. Muck zones tested in this project can be broadly divided into two groups, those directly influenced by seasonally strong freshwater inflows and other zones not directly influenced by inflow due to their location at some distance from tributaries mouths. Muck zones in this study most influenced by inflows are Turkey Creek and the Eau Gallie NE zone. The predicted benefits of muck dredging in both these areas were detectible, particularly during the dryer season. Freshwater inflows from Turkey Creek and the Eau Gallie River partially masked predicted dredging produced reductions in water column total nitrogen (TN) concentrations due nitrogen loading from the inflow. The model-predicted principal form of nitrogen for both the Turkey Creek area and the Eau Gallie area is dissolved organic nitrogen (DON) with lesser contributions from nitrate + nitrite (NOX) and ammonium (NH4). In addition to predicted reductions of total nitrogen (TN), another predicted corresponding benefit of muck dredging is increased dissolved oxygen (DO) levels. In other areas where muck zones are less directly influenced by freshwater inflows, the predicted total nitrogen (TN) concentrations are dominated by nitrate + nitrite (NOX). The predicted benefit from muck dredging in these areas is more persistent over the model runs and the magnitude of total nitrogen (TN) reduction after dredging is larger.

Overall, the ongoing muck dredging program is predicted to have significant benefits in all muck zones investigated in this study. These are gauged by predicted reductions in total nitrogen concentration in the water column above the dredged muck deposits and in areas beyond the immediate footprint of the dredged zone. With respect to the Turkey Creek dredged muck zone, predicted reductions in total nitrogen (TN) and increases in DO were predicted to extend to at least 8 km from the entrance of Turkey Creek. Total phosphorus concentrations were also predicted to decline in the vicinity of some of the muck zones investigated, but not in others. More spatial and temporal samples of nutrient flux from sediments are required to constrain the water quality model calculations, particularly with respect to the forms of phosphorus, which generally occur at lower concentrations in the water column compared to forms of nitrogen. Never-the-less, comparisons between model data and measured data for nitrogen, phosphorus and dissolved oxygen demonstrate that the EFDC/HEM3D model applied to the Indian River Lagoon system to evaluate

the impacts of muck dredging is performing with good accuracy despite the lack of spatially and temporally extensive sediment nutrient flux data to constrain the model calculations.

As of this writing the IRL hydrodynamic and water quality model continues to be developed through updates of model boundary conditions and inclusion of additional muck zones in the model grid. As more information is developed on the extent of muck deposits in the IRL system the model can be adjusted to include these zones.