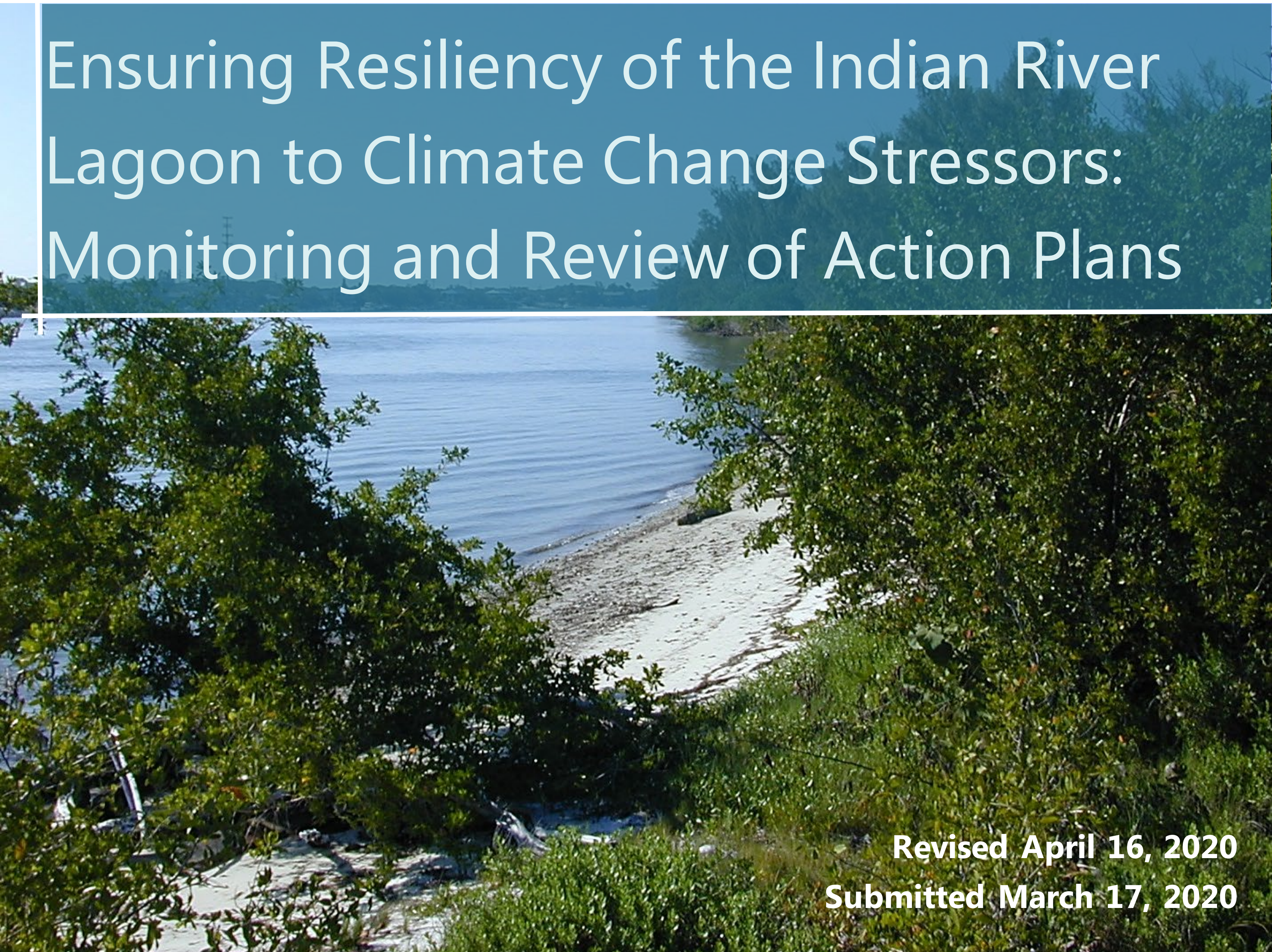
ONE LAGOON
ONE COMMUNITY • ONE VOICE

Establishing an Action Plan for Adaptation Planning

Ensuring Resiliency of the Indian River Lagoon to Climate Change Stressors: Monitoring and Review of Action Plans



Revised April 16, 2020

Submitted March 17, 2020

Prepared for: Indian River Lagoon Council

Prepared by:

RWParkinson Consulting, Inc., The Balmoral Group & Stetson Universit

RWParkinson Consulting, Inc.

The Balmoral Group

Stetson University · Pro Deo et Veritate · 1883 · Florida

Ensuring Resiliency the Indian River Lagoon to Climate Change Stressors: Monitoring and Review of Action Plans

Prepared by: Randall W. Parkinson, Ph.D., P.G.
RWParkinson Consulting, Inc.
Melbourne, Florida, 32935

Valerie Seidel
The Balmoral Group
Winter Park, Florida, 32789

Clay Henderson
Stetson University
Deland, Florida, 32723

Prepared for: Indian River Lagoon National Estuary Program
Sebastian, Florida, 32958

Corresponding Author:
Randall W. Parkinson, Ph.G., P.G.
RWParkinson Consulting, Inc.
Melbourne, Florida
(321) 373-0976
rwparkinson.inc@gmail.com

Suggested Citation:
Parkinson, R.W., Seidel, V., and Henderson, C., 2020. Ensuring Resiliency the Indian River Lagoon to Climate Change Stressors: Monitoring and Review of Action Plans. Final Report prepared for the Indian River Lagoon Council, Sebastian, Florida, 26 pages.

Introduction

This project is being undertaken to identify specific adaptation actions (outputs) to decrease the vulnerability of the Indian River Lagoon to five climate change stressors: warming temperatures, changing patterns of precipitation, increasing storminess, acidification, and sea level rise. The project Scope of Work is based upon the EPA (EPA 2014) workbook 'Being Prepared for Climate Change' and consists of two Phases and ten steps (Figure 1).

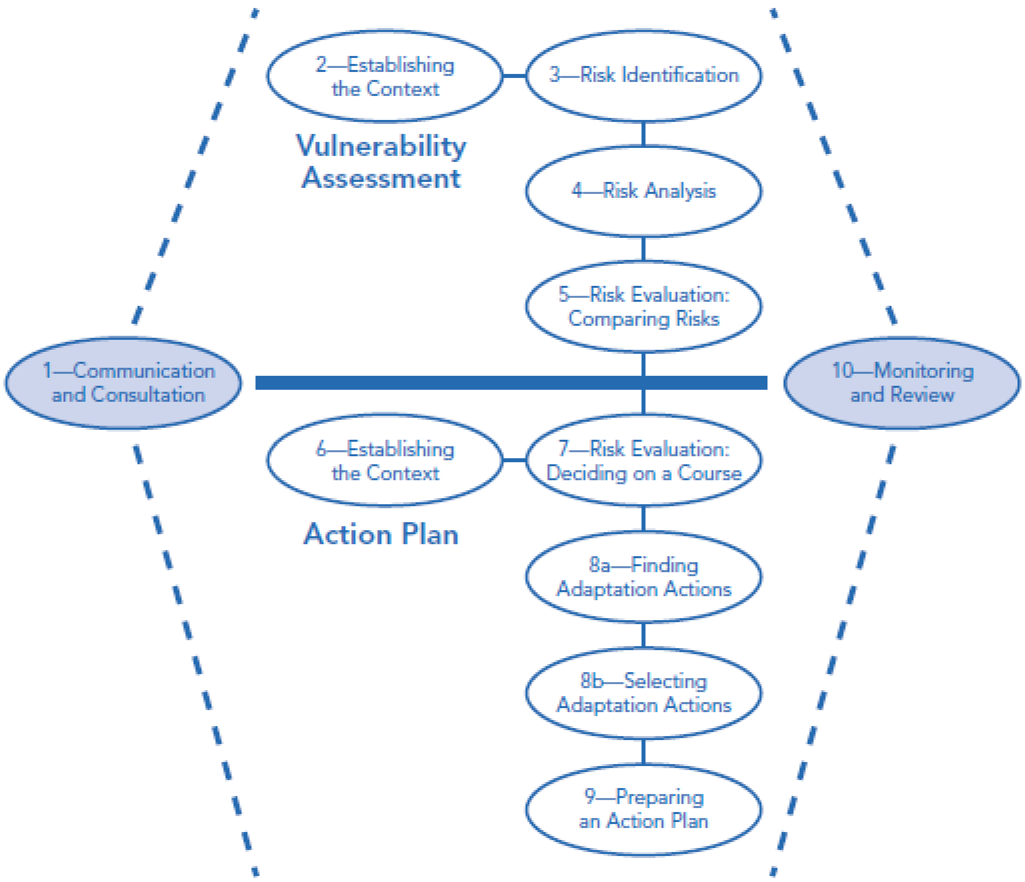


Figure 1. Steps to completion of a vulnerability assessment and action plan. EPA 2014.

In Phase I (Parkinson and Seidel 2018), a vulnerability assessment was completed in which specific risks to the 2008 Comprehensive Conservation and Management Plan (CCMP) goals and related action plans were identified. The outcome of Phase II (ongoing/herein), is the identification of a suite of risk-reducing (aka resilience enhancing) adaptation actions and plans formatted to facilitate seamless integration into the revised CCMP (Indian River Lagoon National Estuary Program 2019). Phase II consists of five deliverables associated with Steps 6-10:

1. Step 6: Identification of potential partners to address risks identified in Phase I
2. Step 7: Prioritization of risks and likely management strategies
3. Step 8: Ranking of adaptation actions to reduce priority risks

4. Step 9: Preparation of action plans to implement adaption actions
5. Step 10: Development of protocol to monitor and review plan effectiveness

Deliverables 1 - 4 were completed previously and submitted under separate cover. Herein, we report on Workbook Step 10/Project Deliverable 5.

Step 10/Deliverable 5. Monitoring and Review

> The objective of this step is to construct a framework to efficiently monitor and review the implementation and effectiveness of the IRL Climate Ready Estuary Action Plans

The results of the vulnerability analysis (Step 8) indicate Impaired Waters is the most vulnerable key indicator or vital sign to climate change stressors with regards to both the number of at risk CCMP action plans and level of risk. Two other vital signs in the same category as Impaired Waters (i.e., Water Quality), also scored high: Wastewater and Storm/Surface water. These observations are not surprising given water quality impairment is measured using Total Maximum Daily Loads (TMDLs), which are a measure of the content of N and P in the basin and primarily derived from Wastewater Treatment Plants and On Site Treatment and Disposal Systems (WWTP, OSTDS) and surface water (i.e. storm and surface water storage and conveyance systems; SWSC).

The most frequent stressors to all vital signs are changes in precipitation, storminess, and SLR. Based upon these results, nine adaptation actions have been formulated to reduce impairment from anthropogenic pollutant loading caused by these three stressors (Figure 2). A majority of the other 32 vital signs and related action plans are also expected to benefit from the pursuit of these adaptation actions given they are interconnected by biological, chemical, and physical processes operating within the IRL watershed.

Nine Action Plans are proposed as an initial step towards reducing risks to the IRL watershed caused by increased pollutant loadings from WWTP, OSTDS, and SWSC systems compromised by the three predominant climate stressors. Each plan consists of the following five steps:

1. Construct a georeferenced map of all WWTP, OSTDS, and SWSC systems, including (invert)elevations, proximity to groundwater table and IRL shoreline, and service area.
2. Evaluate integrity of all WWTP, OSTDS, and SWSC systems (age, design life, service history).
3. Evaluate the vulnerability of all WWTP, OSTDS, and SWSC systems to the three predominant climate change stressors.
4. Prioritize risks to all WWTP, OSTDS, SWSC systems based upon information generated in Steps 1 - 3. Consider prioritizing risks by generating a numerical score based upon an assessment of the consequences, spatial scale, likelihood, and urgency.
5. Prepare a Climate Change Adaptation Strategy (CCAS) containing a comprehensive set of goals and objectives to mitigate the risks to prioritize at risk WWTP, OSTDS, SWSC systems.

A document describing the rationale and details of the proposed action plans is included as Addendum 1 to this report.

Elevated pollutant loadings caused by climate change will likely complicate the ability of existing state programs (i.e., Basin Management Action Plans or BMAPs and Reasonable Assurance Plans or RAPs) to meet their respective water quality targets or TMDLs within the IRL watershed. Therefore, a partnership between IRLNEP and Florida Department of Environmental Protection (FDEP) should be established specifically to collaborate on the monitoring and review of mitigative strategies (i.e., FDEP BMAP, IRL Climate Ready Estuary Action Plans) designed to reduce water quality impairment caused by excessive nutrient loading within the IRL watershed (Figure 3). Both programs have a dedicated leadership structure, common goals and related action plans to improve water quality through nutrient reduction. There also exists an established stakeholder network (Addendum 1 Appendix A), funding stream, and monitoring / reporting protocol that could be strengthened through collaboration.

To ensure the mitigation strategies associated with this partnership reflect current field conditions and state of knowledge, their periodic (5 and/or 10 yr) review and revision is recommended. Topics to consider include an evaluation of: (1) progress towards reduction nutrients, (2) climate change stressors, (3) population growth and related changes in land use, and the (4) ecological response of the estuary to natural and anthropogenic forces (Figure 3).

In summary, to significantly reduce IRL water quality impairment caused by changes in historical / future land use changes and climate change stressors, the input of nutrient pollution (i.e., nitrogen and phosphorous) from OSTDS, WWTP, and SWSC infrastructure must be reduced. This will improve water quality, reduce impairment, and stimulate the recovery of a more resilient, climate-ready estuary.

Reference Cited

EPA. 2014. “Being Prepared for Climate Change A Workbook for Developing Risk-Based Adaptation Plans.” Wshington, D.C.: EPA Climate Ready Estuaries.

Indian River Lagoon National Estuary Program. 2019. “Looking Ahead to 2030 - A 10-Year Comprehensive Conservation and Management Plan for the Indian River Lagoon.” Sebastian, Florida. http://www.irlcouncil.com/uploads/7/9/2/7/79276172/irlnep_preliminary_final_draft_ccmp_revision_2018-11-01_low.pdf.

Parkinson, Randall W, and Valerie Seidel. 2018. “Climate Change Vulnerability Assessment of the Indian River Lagoon National Estuary Program’s Comprehensive Conservation and Management Plan.” Final Report. Sebastian, Florida: Indian River Lagoon National Estuary Program.

Stressor	Adaptation Action
PPt	Reduce pollutant loadings from WWTP durng high rainfall events
	Reduce pollutant loadings from OSTDS during high rainfall events
	Reduce pollutant loadings from surface water storage and conveyance infrastructure during high rainfall events
Storms	Reduce pollutant loadings from WWTP due to more frequent and intense storms
	Reduce pollutant loadings from OSTDS due to more frequent and intense storms
	Reduce pollutant loadings from surface water storage and conveyance infrastructure due to more frequent and intense storms
SLR	Reduce pollutant loadings from WWTP caused by rising water table and sea level (inundation, erosion)
	Reduce pollutant loadings from OSTDS caused by rising water table and sea level (inundation, erosion)
	Reduce pollutant loadings from surface water storage and conveyance infrastructure caused by rising water table and sea level (inundation, erosion)

Figure 2. Summary of adaptation actions to reduce risks to Water Quality caused by the most significant climate change stressors. No priority implied.

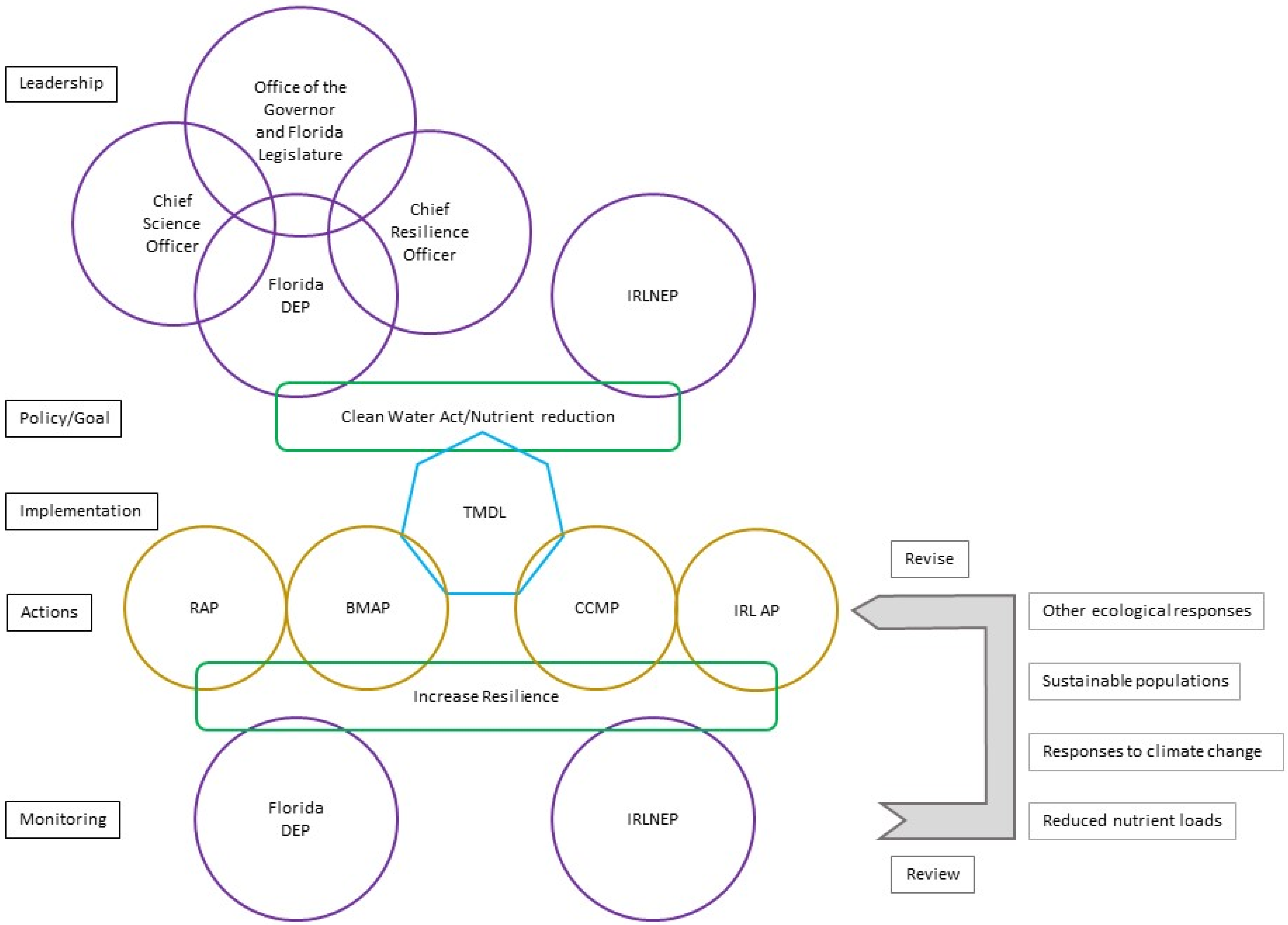


Figure 3. Integrated delivery system for a climate ready Indian River Lagoon. IRL BMAP = IRL basin management action plan, CCMP = Comprehensive conservation and management plan, CRE-VA = Climate ready estuary - vulnerability assessment, CRE-AP = Climate ready estuary - action plan, IRL NEP = Indian River Lagoon National Estuary Program, ML RAP = Mosquito Lagoon reasonable assurance plan, TMDL = total maximum daily loads

Addendum 1: Climate Ready Estuary Action Plan

ONE LAGOON

LIVING RESOURCES & HEALTHY COMMUNITIES

Climate Ready Estuary Action Plans

ACTIONS: RESEARCH IRL risk-based vulnerabilities to climate change. RESPOND to priority risks by formulating climate change adaption actions and undertaking related action plans designed to generate a Climate Change Adaptation Strategy (CCAS) containing a comprehensive set of goals and objectives to mitigate the risks to each system the requisite information to make informed adaption decisions to mitigate risks to the built and natural environment caused by climate change. IMPLIMENT CCASs to optimize IRL resilience to climate change. REPORT findings and scientific advancements to IRLNEP Management Conference community partners.

Figure 1. Nuisance flooding in Martin County, Florida.

ISSUE SUMMARY: The IRL is vulnerable to the impacts of climate change stressors including rising temperatures (temperature), changes in precipitation patterns (precipitation)(Figure 1), increasing frequency and intensity of storms (storminess), ocean acidification (acidification), and sea level rise (SLR). These will change the IRL in ways that will challenge resource management and stewardship. Most scientists agree that these impacts are already occurring. However, in most cases there are management actions that can be undertaken to adapt or mitigate these stressors and in so doing reduce risk and build resiliency.

The USEPA Climate Ready Estuaries Program identified ten steps to help NEPs identify, analyze, prioritize, and reduce their climate change risks. These steps fall into two activity categories: (1) risk-based vulnerability assessment, and (2) formulate an action plan to reduce risks[1]. The vulnerability of the goals and objectives of the IRLNEP CCMP (2008)[2] to the five climate change stressors was assessed in 2018[3]. One hundred and fifty-four risks were identified and ranked according to the level of threat. The results of that vulnerability assessment were reorganized in 2019 to be consistent with the new organization and terminology of the revised CCMP[4].

These results indicate *Impaired Waters* is the most vulnerable key indicator or *vital sign* to climate change stressors with regards to both the number of at risk CCMP action plans and level of risk (Table 1). Two other vital signs in the same category as Impaired Waters (i.e., Water Quality), also scored high: Wastewater and Storm/Surface water. These observations are not surprising given water quality impairment is measured using TMDLs, which are a measure of the content of N and P in the basin and primarily derived from wastewater (WWTP, OSTDS) and surface water (i.e. storm and surface water storage and conveyance systems; SWSC).

The most frequent stressors to all vital signs are changes in precipitation, storminess, and SLR (Table 1). Based upon these results, nine adaptation actions have been formulated to reduce impairment from anthropogenic pollutant loading caused by these three stressors (Table 2). A majority of the other 32 vital signs and related action plans are also expected to benefit from the pursuit of these adaptation actions given they are interconnected by biological, chemical, and physical processes operating within the IRL watershed.

Category and Vital Sign	Stressor						Accept	Level of Risk			
	Temp	PPt	Storms	pH	SLR	**Sum**		Higher	High	Moderate	**Sum**
Water Quality											
Impaired waters (IW)	5	54	57	0	55	**171**	5	162	4	0	**166**
Wastewater (WW)	1	10	10	1	10	**32**	2	30		0	**30**
Stormwater and surface water (SW)	5	8	8	1	9	**31**	3	24	2	2	**28**
Hydrology and hydrodynamics (HH)	3	3	0	0	3	**9**	0	3	6	0	**9**
Legacy loads and healthy sediments (LL)	0	0	1	0	0	**1**	0	0	1	0	**1**
Atmospheric deposition (AD)	1	1	1	0	0	**3**	3	0	0	0	**0**
Sum	15	76	77	2	77	**247**	13	219	13	2	**234**
Habitats											
Seagrass (S)	6	16	15	1	14	**52**	5	47	0	0	**47**
Living shorelines (LS)	1	1	2	1	2	**7**	3	0	4	0	**4**
Wetlands and impounded/altered marshes (W)	3	1	0	0	2	**6**	5	1	0	0	**1**
Sum	10	18	17	2	18	**65**	13	48	4	0	**52**
Living Resources											
Biodiversity (B)	3	16	11	1	17	**48**	5	33	10	0	**43**
Species of concern (SoC)	10	15	18	1	19	**63**	4	47	12	0	**59**
Invasive species (InS)	2	15	14	0	14	**45**	3	14	28	0	**42**
Commercial and recreational fisheries (CRF)	3	15	19	1	14	**52**	4	42	6	0	**48**
Sum	15	45	51	2	47	**160**	11	103	46	0	**149**
Grand Total	**40**	**139**	**145**	**6**	**142**	**472**	**37**	**370**	**63**	**2**	**435**

Table 1. Summary of number and level of risks to IRL vital signs caused by climate change.

Risk-based vulnerabilities to climate change extend beyond the IRL's water quality, habitats, and living resources. The economy and quality of life in the IRL watershed is closely linked to both its natural and built assets. The vitality of both will be evermore challenged by climate change stressors. In the natural environment, these include but are not limited to sea grass, commercial and recreational fisheries, wetlands, and biodiversity. Within the built environment, these include but are not limited to emergency shelters, airports, ports, power plants, transportation corridors, evacuation routes, integrity of traditional supply chains for goods and services, human health, communication networks, and homeland security.

To build resiliency against climate change, local governments have begun to plan and prepare[5–7]. When discussing future climate change scenarios, both built and natural assets need to be considered by scientists, decision makers, and practitioners as one interdependent and integrated coastal system[8–10]. Equally important is the input from local communities, given what transpires over the duration of this century will surely challenge community values, aspirations, and quality of life. For these reasons, adaptive management will require significant community engagement and a process for implementing and monitoring the progress of adaptation action plans designed specifically to mitigate risks to the built and natural environment.

Stressor	Adaptation Action
PPt	Reduce pollutant loadings from WWTP durng high rainfall events
	Reduce pollutant loadings from OSTDS during high rainfall events
	Reduce pollutant loadings from surface water storage and conveyance infrastructure during high rainfall events
Storms	Reduce pollutant loadings from WWTP due to more frequent and intense storms
	Reduce pollutant loadings from OSTDS due to more frequent and intense storms
	Reduce pollutant loadings from surface water storage and conveyance infrastructure due to more frequent and intense storms
SLR	Reduce pollutant loadings from WWTP caused by rising water table and sea level (inundation, erosion)
	Reduce pollutant loadings from OSTDS caused by rising water table and sea level (inundation, erosion)
	Reduce pollutant loadings from surface water storage and conveyance infrastructure caused by rising water table and sea level (inundation, erosion)

Table 2. Summary of adaptation actions to reduce risks to Water Quality caused by the most significant climate change stressors. No priority implied.

STRATEGIES:

To reduce the risk of increased pollutant loadings into the IRL watershed caused by caused by the three predominant climate change stressors, nine Adaptation Actions have been identified and are described in the following sections. Nine Action Plans, designed to facilitate the implementation each Adaptation Action, are described thereafter.

ADAPTATION ACTIONS

- ### Reduce risk to water quality caused by increased pollutant loadings from WWTP and conveyance systems during high rainfall events

More frequent and intense rainfall events can cause a temporary increase in both inflow (i.e., manhole) and infiltration (i.e., broken lateral) into the WWTP conveyance system (Figure 2). These increases can quickly overwhelm the capacity of the system to effectively transport and prosses the incoming wastewater. Untreated material can outflow into surface and groundwater systems along the conveyance pathway or be deliberately discharged into canals or waterways as an emergency response decision made by plant managers. More frequent and intense rainfall events can also result in plant failure[11]. A typical WWTP contains numerous structures and above ground piping that are be vulnerable to flooding (Figure 3). These too can be compromised during high rainfall events and result in the contamination of surface and groundwater in the IRL watershed.

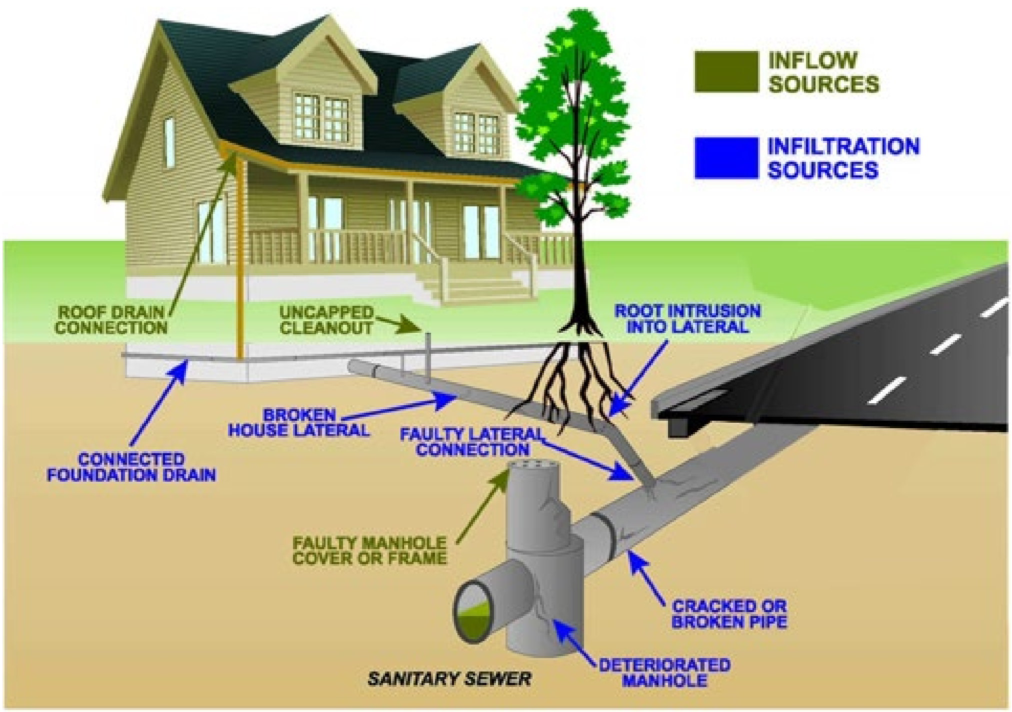


Figure 2. Schematic of wastewater flow from a residential property towards a WWTP. Modified from City of Bryant, Texas.

Figure 3. Typical layout of WWTPs in Brevard (left) and St. Lucie (right) County. Credit Google Earth.

- Reduce risk to water quality caused by increased pollutant loadings from OSTDS during high rainfall events

More frequent and intense rainfall events can cause a temporary increase pollutant loading from OSTDS by enhancing the rate of downward percolation of leachate. Rainfall events can temporarily elevate the groundwater table and saturate the leach field. In either case, the effectiveness of soil absorption and biological treatment of leachate is compromised and this can result in an increase in pollutant loadings into the groundwater system or proximal waterway (Figure 4).

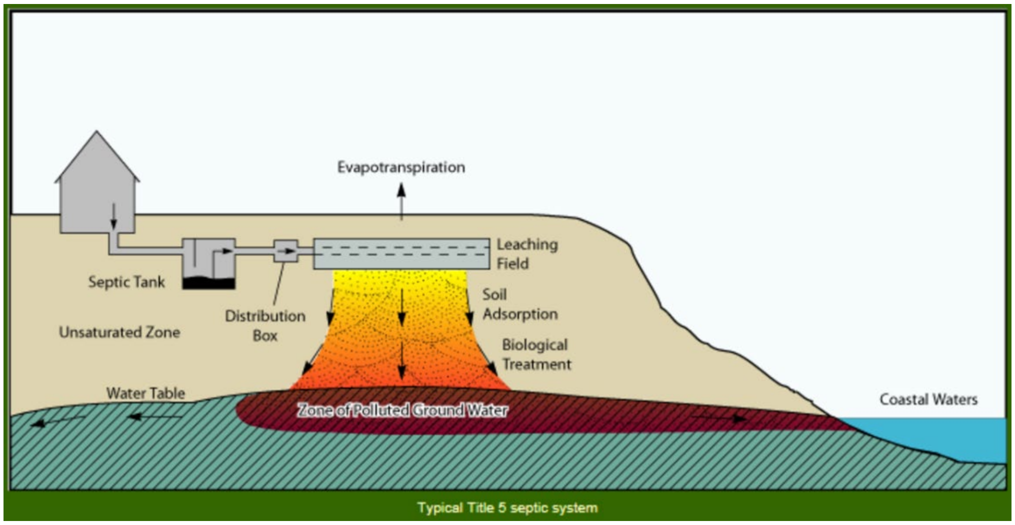


Figure 4. Schematic of typical OSDS. Credit Mass.gov.

- Reduce risk to water quality caused by increased pollutant loadings from SWSC systems during high rainfall events

More frequent and intense rainfall events can temporarily increase the volume and elevation of surface water managed in SWSC. Some events are likely to exceed the system's capacity and result in localized flooding. During such an event, surface water will likely mix with untreated or partially treated wastewater from the concomitant failing of WWTP and/or OSTDS, and increased flux of fertilizers and other chemical contaminants within the system's domain. This can result in a surge of pollutant laden water into the IRL watershed.

- Reduce risk to water quality caused by increased pollutant loadings from WWTP and conveyance systems compromised by more frequent and intense storms

Heaving rainfall during more frequent and intense storms can cause a temporary increase in both inflow (i.e., manhole) and infiltration (i.e., broken lateral) into the WWTP conveyance system (Figure 2). These increases can quickly overwhelm the capacity of system to effectively transport and prosses the incoming wastewater. Untreated material can outflow into surface and groundwater systems along the conveyance pathway or be deliberately discharged into canals or waterways as an emergency response decision made by plant managers.

A typical WWTP contains numerous structures and above ground piping that are vulnerable to flooding and wind damage (Figure 3). More frequent and intense storms can also result in plant failure, causing the unintended release of untreated or partially treated wastewater into surface and groundwater systems.

More frequent and intense storms can cause substrate erosion, resulting in the destabilization of footers and foundations. This in turn can cause physical damage to both above and below ground elements of the conveyance system and physical plant and the release of pollutants into the IRL watershed.

- ### Reduce risk to water quality caused by increased pollutant loadings from OSTDS compromised by more frequent and intense storms

Precipitation associated with more frequent and intense storms can cause a temporary increase pollutant loading from OSTDS by enhancing the rate of downward percolation of leachate towards the ground water table. Heavy rainfall and storm surge can temporarily elevate the groundwater table or completely submerge the leach field. In either case, the effectiveness of soil absorption and biological treatment of leachate is compromised, and this can result in an increase in pollutant loadings into the IRL watershed.

Landfall of more frequent and intense storms can also result in substrate erosion and associated physical damage to OSTDS located proximal to the IRL shoreline (Figure 5). This in turn can result in system failures and an increase in pollutant loadings.

Figure 5. Septic tank exposed by coastal erosion. Credit Miami-Dade County.

- ### Reduce risk to water quality caused by increased pollutant loadings from SWSC systems compromised by more frequent and intense storms

Precipitation during more frequent and intense storms can temporarily increase the volume and elevation of surface water managed by SWSC systems. The capacity of conveyance and storage basins can be exceeded during these events, resulting in a surge of surface water onto the surrounding landscape (Figure 6). During such an event, surface water will likely mix with untreated or partially treated wastewater from the concomitant failing of WWTP and/or OSTDS, and introduction of fertilizers and other chemical contaminants within the system's domain. This can result in a surge of pollutant laden water into the IRL watershed.

Figure 6. Surface water storage and conveyance (SWSC) system in the St. Lucie Estuary Watershed. Credit Google Earth.

Landfall of more frequent and intense storms can result in substrate erosion, physical damage, and corrosion of floodgates, weirs, pumps, and other water control structures (Figure 7). This in turn can result in an increase in the failure rate of WWTP, OSTDS, and outfalls within the system's domain, leading to a temporary surge in pollutant loadings to surface and ground water within the IRL watershed.

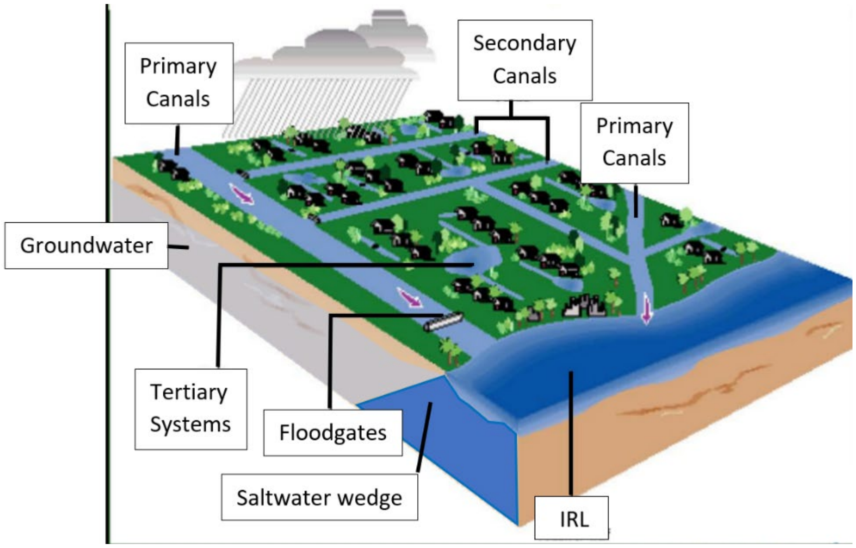


Figure 7. Schematic of typical surface water conveyance system. Modified from Southeast Florida Regional Climate Compact.

- Reduce risk to water quality caused by increased pollutant loadings from WWTP and conveyance systems compromised by rising water table and sea level (inundation, erosion)

Rising water table and sea level will cause disruption to WWTP as they are intermittently flooded at increasing frequencies[12]. This can result in an increase in the inflow and infiltration into the conveyance system and may result in the release of untreated or partially treated Plant wastewater into the IRL watershed. Many of these systems will also be disrupted by changing base level and associated hydraulic head, wherein those relying upon gravity flow will no longer perform as designed. Above ground structures, piping, and other (infra)structure (Figure 3) will also suffer chemical (i.e., corrosion) degradation as more saline surface- and ground-water (i.e., the saltwater wedge) migrates landward. During flooding events, physical damage is anticipated due to water waves and currents.

- Reduce risk to water quality caused by increased pollutant loadings from OSTDS compromised by rising water table and sea level (inundation, erosion)

Rising ground water and sea level, as well as saltwater intrusion (Figure 8), can cause a permanent increase in pollutant loading from OSTDS by reducing the effectiveness of the leachate field as it becomes increasingly compressed (Figure 8) and/or compromised by increasing salinity. Substrate erosion caused by water waves and currents associated with a landward migrating shoreline will likely cause disruption or failure of OSTDS located proximal to the IRL shoreline.

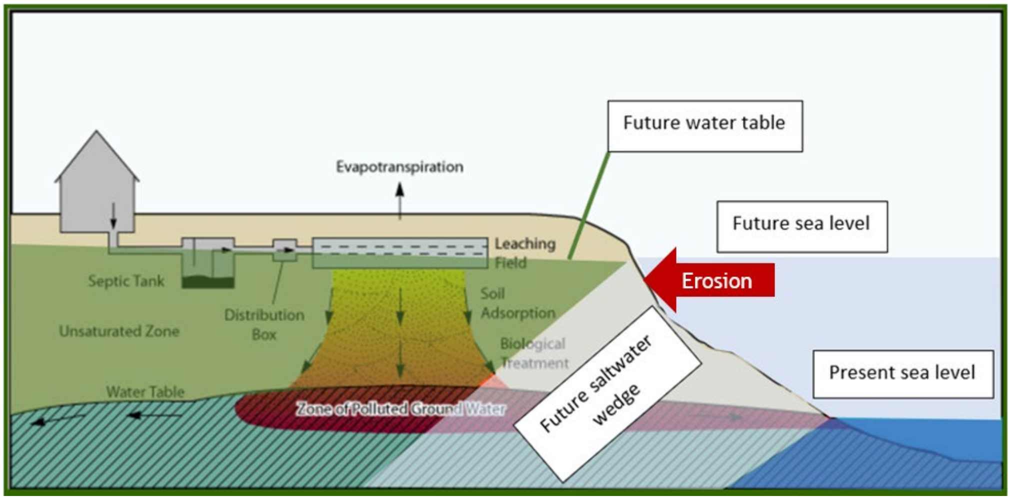


Figure 8. Effects of rising sea level on OSTDS located close to the IRL include saturation of leaching field, saltwater intrusion into polluted zone, and shoreline erosion (see Figure 5). Modified from Mass.gov.

- ## Reduce risk to water quality caused by increased pollutant loadings from SWSC systems compromised by rising water table and sea level (inundation, erosion)

Rising ground water and sea level can cause a permanent increase in pollutant loading from SWSC systems by reducing or eliminating the effectiveness of retention-detention basins to scrub pollutants as the distance between the basin floor and water table becomes increasingly compressed. Many of these systems will also be disrupted by changing base level and associated hydraulic head, wherein those relying upon gravity flow will no longer perform as designed. Plants, pump stations, outfalls and other (infra)structure can also suffer chemical (i.e., corrosion) degradation as more saline surface and ground water (i.e., the saltwater wedge) migrates landward. These systems can also be subject to physical damage caused by substrate erosion associate with water waves and currents (Figure 9).

Figure 9. Newly constructed baffle boxes along the IRL shoreline in Jensen Beach. Credit Florida Division of Water Resources Management.

ACTION PLANS

Nine Action Plans are proposed as an initial step towards reducing risks to the IRL watershed caused by increased pollutant loadings from WWTP, OSTDS, and SWSC systems compromised by the three predominant climate stressors (Table 3-5). Each plan consists of the following five steps:

1. Construct a georeferenced map of all WWTP, OSTDS, and SWSC systems, including (invert)elevations, proximity to groundwater table and IRL shoreline, and service area.
2. Evaluate integrity of all WWTP, OSTDS, and SWSC systems (age, design life, service history).
3. Evaluate the vulnerability of all WWTP, OSTDS, and SWSC systems to the three predominant climate change stressors.
4. Prioritize risks to all WWTP, OSTDS, SWSC systems based upon information generated in Steps 1 - 3. Consider prioritizing risks by generating a numerical score based upon an assessment of the consequences, spatial scale, likelihood, and urgency (Table 6).
5. Prepare a Climate Change Adaptation Strategy (CCAS) containing a comprehensive set of goals and objectives to mitigate the risks to priority at risk WWTP, OSTDS, SWSC systems.

Adaptation Action	Action Plan Output	Lead Agencies	Partner Agencies	IRLNEP Role
Reduce risk to water quality caused by increased pollutant loadings from WWTP and conveyance systems during high rainfall events	CCAS to mitigate risk to WWTP systems during high rainfall events	See Appendix A	See Appendix A	Conduct, collaborate, and coordinate
Reduce risk to water quality caused by increased pollutant loadings from OSTDS during high rainfall events	CCAS to mitigate risk to OSTDS during high rainfall events	See Appendix A	See Appendix A	Conduct, collaborate, and coordinate
Reduce risk to water quality caused by increased pollutant loadings from SWSC systems during high rainfall events	CCAS to mitigate risk to SWSC systems during high rainfall events	See Appendix A	See Appendix A	Conduct, collaborate, and coordinate

Table 3. Adaptation Actions, Action Plans, and partners to address risks caused by changes in precipitation.

Adaptation Action	Action Plan Output	Lead Agencies	Partner Agencies	IRLNEP Role
Reduce risk to water quality caused by increased pollutant loadings from WWTP and conveyance systems compromised by more frequent and intense storms	CCAS to mitigate risk to WWTP and conveyance systems compromised by more frequent and intense storms	See Appendix A	See Appendix A	Conduct, collaborate, and coordinate
Reduce risk to water quality caused by increased pollutant loadings from OSTDS compromised by more frequent and intense storms	CCAS to mitigate risk to OSTDS compromised by more frequent and intense storms	See Appendix A	See Appendix A	Conduct, collaborate, and coordinate
Reduce risk to water quality caused by increased pollutant loadings from SWSC systems compromised by more frequent and intense storms	CCAS to mitigate risk to SWSC systems compromised by more frequent and intense storms	See Appendix A	See Appendix A	Conduct, collaborate, and coordinate

Table 4. Adaptation Actions, Action Plans, and partners to address risks caused by increasing storminess.

Adaptation Action	Action Plan Output	Lead Agencies	Partner Agencies	IRLNEP Role
Reduce risk to water quality caused by increased pollutant loadings from WWTP and conveyance systems compromised by rising water table and sea level (inundation, erosion)	CCAS to mitigate risk to WWTP systems compromised by rising water table and sea level (inundation, erosion)	See Appendix A	See Appendix A	Conduct, collaborate, and coordinate
Reduce risk to water quality caused by increased pollutant loadings from OSTDS compromised by rising water table and sea level (inundation, erosion)	CCAS to mitigate risk to OSTDS compromised by rising water table and sea level (inundation, erosion)	See Appendix A	See Appendix A	Conduct, collaborate, and coordinate
Reduce risk to water quality caused by increased pollutant loadings from SWSC systems compromised by rising water table and sea level (inundation, erosion)	CCAS to mitigate risk to SWSC systems compromised by rising water table and sea level (inundation, erosion).	See Appendix A	See Appendix A	Conduct, collaborate, and coordinate

Table 5. Adaptation Actions, Action Plans, and partners to address risks caused by rising water table and sea level.

Consequence	Spatial extent of impact
1. Low (could adjust, life will go on)	1. Site (bridge, stormwater outflow)
2. Medium	2. Place (wildlife refuge)
3. High (catastrophic, major disruption)	3. Region (watershed)

Likelihood	Time horizon
1. Low	1. > 10 years
2. Medium	2. 5-10 years
3. High (very likely, predictable)	3. Already occurring or < 5 years

Table 6. Risk analysis scoring matrix.

OUTCOMES:

- **Short-term (1 – 2 years):** IRLC approves nine Adaptation Action Plans to mitigate risks to WWTP, OSTDS, and SWSC systems caused by three predominant climate change stressors.
- **Medium-term (3 – 4 years):** IRLC collaborates with partners complete each of the nine Action Plans.
- **Long-term (5 – 10+ years):** Significant progress is made by IRLC and its partners towards implementing and tracking the progress of each of the nine Action Plan CCASs, perhaps using the existing TMDL programs operating within the IRL watershed. This will establish the IRL as a Climate Ready Estuary. Monitoring of progress continues until the waterbody is removed from the Impaired Waters designation list and thereafter if deemed necessary by the IRLC and its partners.

BARRIERS TO SUCCESS:

- Lack of technical and financial resources.
- Legal and regulatory impediments

REFERENCES CITED

1. EPA. *Being Prepared for Climate Change A Workbook for Developing Risk-Based Adaptation Plans*. 128 (EPA Climate Ready Estuaries, 2014).
2. Indian River Lagoon National Estuary Program. *Indian River Lagoon Comprehensive Conservation and Management Plan Update 2008*. 120 (2008).
3. Indian River Lagoon National Estuary Program. *Looking ahead to 2030 - A 10-year Comprehensive Conservation and Management Plan for the Indian River Lagoon*. 90 (2019).
4. Parkinson, R. W. & Seidel, V. *Climate Change Vulnerability Assessment of the Indian River Lagoon National Estuary Program's Comprehensive Conservation and Management Plan*. 110 (Indian River Lagoon National Estuary Program, 2018).

5. Florida Department of Environmental Protection. Sea Level Rise Case Study for Evacuation Routes in Martin and St. Lucie Counties. (2017). Available at: https://floridadep.gov/rcp/florida-resilient-coastlines-program/documents/sea-level-rise-case-study-evacuation-routes. (Accessed: 25th July 2019)
6. Brevard County. *Brevard County Emergency Management Hazard Summaries*. 13 (2016).
7. East Central Florida Regional Planning Council. *Resilient Volusia County*. 139 (2017).
8. Nicholls, R. Planning for the Impacts of Sea Level Rise. *Oceanog.* **24**, 144–157 (2011).
9. Lawrence, J., Bell, R., Blackett, P., Stephens, S. & Allan, S. National guidance for adapting to coastal hazards and sea-level rise: Anticipating change, when and how to change pathway. *Environmental Science & Policy* **82**, 100–107 (2018).
10. *Climate Change and Adaptation Planning for Ports: 1st Edition (Hardback) - Routledge*. (2016).
11. McMahan, E. K. Impacts of Rainfall Events on Wastewater Treatment Processes. (University of South Florida, 2006).
12. Hummel, M. A., Berry, M. S. & Stacey, M. T. Sea Level Rise Impacts on Wastewater Treatment Systems Along the U.S. Coasts. *Earth's Future* e312 (2018). doi:10.1002/2017EF000805

APPENDIX A: ORGANIZATIONAL NETWORK OF RAP (MOSQUITO LAGOON) AND BMAP PARTNERS IN IRL WATERSHED

Basin	Allocation Entities	Agencies
Mosquito Lagoon	City of Edgewater City of New Smyrna Beach City of Oak Hill Volusia County	Florida DOT
Northern Indian River Lagoon	Agricultural Producers Brevard County Volusia County City of Cocoa City of Edgewater City of Indian Harbour Beach City of Melbourne City of Oak Hill City of Rockledge City of Titusville Florida Department of Transportation District 5 Kennedy Space Center Town of Indialantic Town of Palm Shores Town of Melbourne Village Florida Power and Light – Cape Canaveral Power Plant Reliant Energy – Indian River Power Plant	Florida Department of Agriculture and Consumer Services Florida Department of Environmental Protection Florida Farm Bureau Federation Indian River Lagoon National Estuary Program St. Johns River Water Management District
Banana River	Agricultural Producers Brevard County City of Cape Canaveral City of Cocoa Beach City of Indian Harbour Beach City of Satellite Beach Cape Canaveral Air Force Station Florida Department of Transportation, District 5 Kennedy Space Center Patrick Air Force Base	Florida Department of Agriculture and Consumer Services Florida Department of Environmental Protection Indian River Lagoon National Estuary Program St. Johns River Water Management District

Basin	Allocation Entities	Agencies
	Agricultural Producers	Florida Department of Agriculture and Consumer Services
	Brevard County	Florida Department of Environmental Protection
	Indian River County	Florida Fruit and Vegetable Association
	St. Lucie County	Indian River Lagoon National Estuary Program
	City of Fellsmere	St. Johns River Water Management District
	City of Fort Pierce	South Florida Water Management District
	City of Melbourne	
	City of Palm Bay	
	City of Sebastian	
	City of Vero Beach	
	City of West Melbourne	
	Town of Grant-Valkaria	
	Town of Indialantic	
	Town of Indian River Shores	
Central Indian River Lagoon	Town of Malabar	
	Indian River Land Trust	
	Town of Melbourne Beach	
	Town of Melbourne Village	
	Town of Orchid	
	Town of St. Lucie Village	
	Florida Department of Transportation District 4	
	Florida Department of Transportation District 5	
	Turnpike Enterprise	
	Fellsmere Water Control District	
	Fort Pierce Farms Water Control District	
	Indian River Farms Water Control District	
	Melbourne-Tillman Water Control District	
	Sebastian River Improvement District	
	Vero Lakes Water Control District	
	Agricultural Producers	Florida Department of Agriculture and Consumer Services
	Martin County	Florida Department of Environmental Protection
	Okeechobee County	South Florida Water Management District
	St. Lucie County	
	City of Fort Pierce	
	City of Port St. Lucie	
	City of Stuart	
	Copper Creek Community Development District	
St. Lucie Estuary	Florida Department of Transportation – District 4	
	Florida Turnpike	
	Hobe St. Lucie Conservancy District	
	North St. Lucie River Water Control District	
	Pal Mar Water Control District	
	Town of Sewall's Point	
	Tradition Community Development District	
	Troup-Indiantown Water Control District	
	Verano Community Development Distric	