Appendix H

Long-Term Hydrometeorological Conditions Assessment (LHCA)

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H CLIMATE CHANGE VULNERABILITY ASSESSMENT ON INDIAN RIVER LAGOON SOUTH PROJECT

This appendix discusses the climate change vulnerability assessment performed for the Indian River Lagoon South (IRL-S) Project in support to the 2021 Validation Report. USACE established an overarching USACE Climate Change Adaptation Policy Statement to support climate preparedness and resilience in 2011. In 2014, the policy was updated, and the Climate Preparedness and Resilience (CPR) Community of Practice (CoP) was established. CPR policy states that climate change assessments should be considered for all phases of the project life cycle, for both existing and proposed projects where decision documents are required. In order to determine the risk and resiliency of the project to climate change, the IRL-S Validation Report was evaluated in accordance with USACE climate guidance. Two primary climate assessments are evaluated for this project: potential impacts from future sea level change and, trends and projected future for hydrology affecting the scope of the project area.

Previously, USACE completed a CCVA for the IRL-S C-23/24 STA Project in February 2021 (USACE, 2021a). The IRL-S C23/24 CCVA applied current USACE CPR guidance and will be an appendix to all subsequent IRL-S C23/C24 project Design Documentation Reports (DDR). In addition, technical and policy reviews of the Final IRL-S Project Implementation Report (PIR) and all appendices and annexes were completed by February 2014. At the time, recent requirements and tools to consider Climate Change were not available.

In this appendix, all elevations are in feet and with North American Vertical Datum of 1988 (NAVD88) unless otherwise indicated.

H.1 Indian River Lagoon South Project Description

The southern Indian River Lagoon (IRL) includes the portion of the lagoon from the St. Lucie-Indian River County line south to the Martin-Palm Beach County line (approximately 41 miles, north to south). The contributing basins include both the St. Lucie Estuary (SLE) watershed and the C-25 basin, both of which drain directly to the IRL near the Ft. Pierce Inlet on the north end of the study area (**Figure H-1**). The western portion of the study area is predominantly agricultural with most urbanization within the coastal area. There are seven municipalities in the planning area, including Fort Pierce, Port St. Lucie, St. Lucie Village, Stuart, Sewalls Point, Jupiter Island, and Ocean Breeze Park. The SLE, IRL, and Atlantic Ocean are a source of aesthetic beauty, recreation, and livelihood that have drawn people to the area for many years and serve as the economic foundation of the community.

The IRL is an estuary of national significance, recognized by the U.S. Environmental Protection Agency National Estuary Program and designated a Florida Aquatic Preserve and Outstanding Florida Water. The lagoon ecosystem, however, is suffering from unnaturally large, poorly located and poorly timed freshwater discharges arriving through the St. Lucie Canal and other elements of the Central and Southern Florida (C&SF) Project. A consequence of rapid delivery of freshwater runoff to the lagoon is the accumulation of muck on the bottom of the estuary, reducing water transparency and eliminating many original estuarine bottom communities such as seagrasses and oyster flats. The large freshwater discharges and existing muck deposits interact to stress estuary bottom communities and prevent their natural regeneration, resulting in a severely degraded ecological system.

The Comprehensive Everglades Restoration Plan (CERP) was documented in the 1999 C&SF Project Comprehensive Review Study Final Integrated Feasibility Report and Programmatic Environmental Impact Statement, a.k.a. Restudy (USACE, 1999). CERP was approved by Congress as a framework for the restoration of the natural system under Section 601 of the Water Resources Development Act (WRDA) of 2000 (Title VI, P.L. 106-541). The purpose of the CERP is to modify structural and operational components of the C&SF Project to achieve restoration of the Everglades and the south Florida ecosystem, while providing for other water-related needs such as urban and agricultural water supply and flood protection.

The IRL-S study builds on the work done in the Restudy to address water resources problems in the Upper East Coast Region by providing a much finer level of detail gained through area-specific hydrologic modeling, environmental analysis and a detailed problem definition and solution analysis process. The study was completed in August 2002 with a Division Engineers Notice issued in September 2002 and the final Environmental Impact Statement (EIS), filed in the Federal Register, in October 2002. The IRL-S Final Project Implementation Report (PIR) and EIS was completed in 2004 and authorized in the WRDA of 2007.

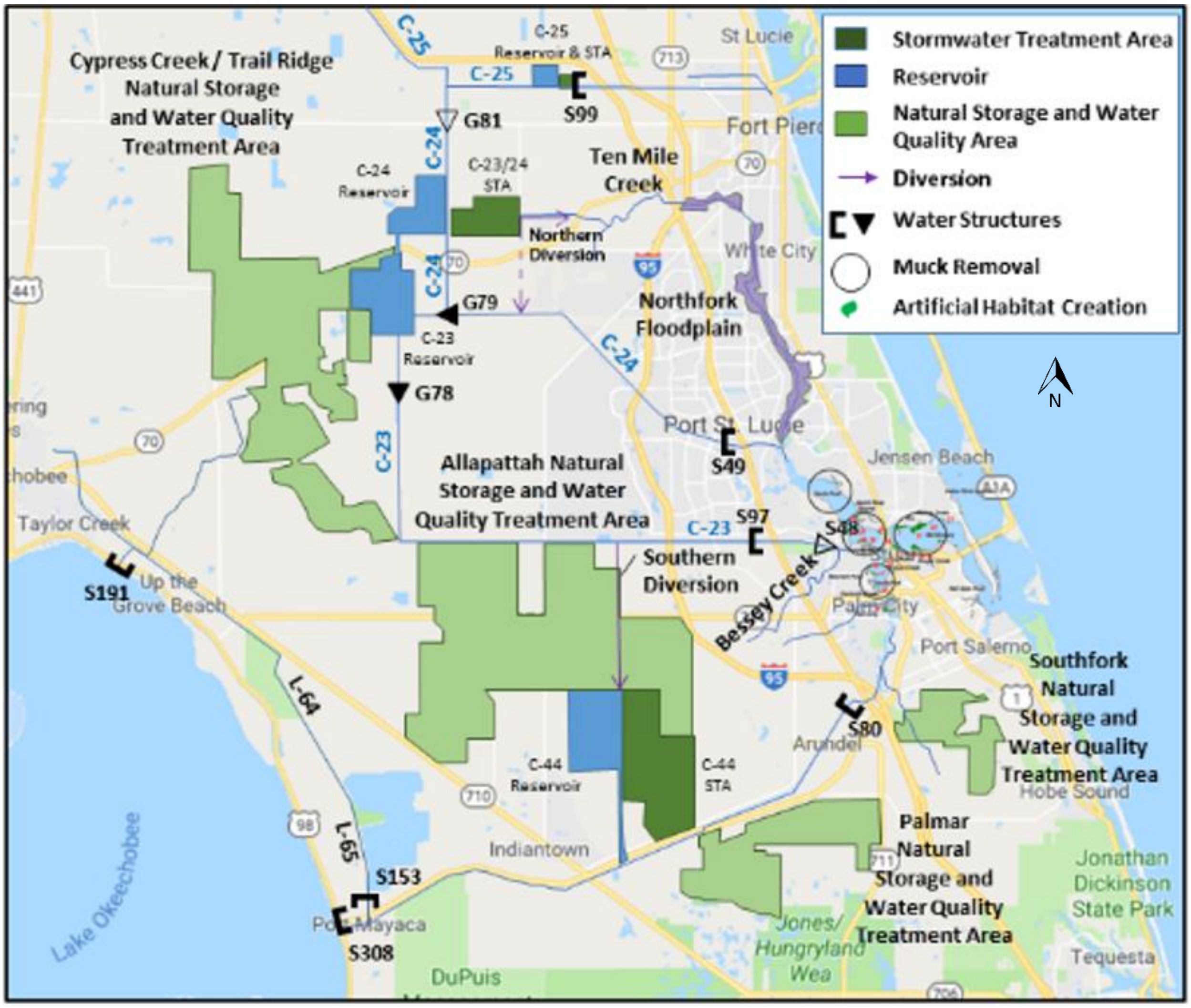


Figure H-1. Map of Study Area

The IRL-S Project features were split into two Phases in the 2010 IRL-S Project Partnership Agreement (PPA). Phase 1 contains the proposed reservoirs and Stormwater Treatment Area (STA)s. Phase 2 contains the natural storage areas, muck removal, and creation of artificial habitat. The status of all IRL-S Project features is provided below.

Phase 1, features in multiple status:

- C-44 Reservoir feature is at the end of construction
- C 44 STA feature construction is complete
- C-23/24 North and South Reservoirs features currently under design,
- C-23/24 STA feature construction contract has been awarded,
- C-25 Reservoir and STA features have not initiated design and/or construction.

Phase 2, all features have not initiated design and/or construction:

- Palmar Complexes (includes South Fork Complex) Natural Storage and Water Quality Areas,
- Allapattah Complexes Natural Storage and Water Quality Areas,
- Cypress Creek/Trail Ride Complexes Natural Storage and Water Quality Areas,
- North Fork Natural Floodplain Restoration,
- Muck removal and
- Artificial habitat

H.1.1 Project Features

The IRL-S Project includes reservoirs, stormwater treatment areas, natural areas and floodplain restoration components for the C-44, C-23/24, C-25, North Fork and South Fork watersheds (**Figure H-2**). Most of the project features (**Figure H-1**) listed below were described from the IRL-S 2014 PIR/EIS.

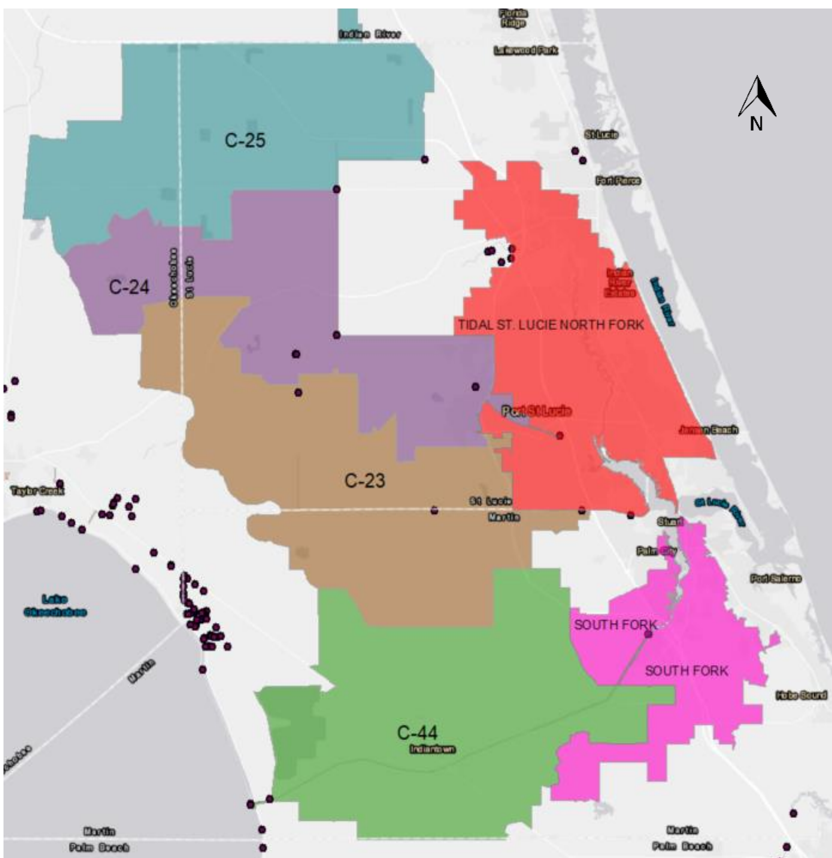


Figure H-2. Location of watersheds within IRL-S project area

C-44 Watershed
The recommended plan includes four components within the C-44 watershed. These components include the C-44 Reservoir, the C-44 STA (west and east) and the Palmar Complex - Natural Storage and Water Quality Treatment Area (West of I-95 and East of I-95, later also called South Fork Natural Storage).

The C-44 Reservoir is a 3,400-acres storage feature to be operated at 15 feet (50,600 acre-feet capacity). The C-44 STA is 6,300-acres. Both features are currently under construction. The Palmar Complex - Natural Storage and Water Quality Treatment Area is an approximately 17,143-acres facility to provide phosphorus and nitrogen reduction in the St. Lucie River and Estuary and Indian River Lagoon prior to runoff into east coast canals. This project feature has been deferred to a later phase (Phase II) of implementation.

C-23/24 Watershed
The recommended plan includes five components within the C-23/24 watershed. These components are the C-23/24 North Reservoir, C-23/24 South Reservoir, C-23/24 Stormwater Treatment Area, Cypress Creek Complex - Natural Storage and Water Quality Treatment Area, and Allapattah Complex - Natural Storage and Water Quality Treatment Area.

The C-23/24 North Reservoir is a 2,000-acre storage feature to be operated at 16.5 feet (about 33,000 acre-feet capacity) and the C-23/24 South Reservoir is 3,500-acre storage feature to be operated at 16.5 feet (about 58,000 acre-feet capacity). Both reservoirs are currently under design. The C-23/24 STA is an approximately 2,500-acre facility (1,970 acres of effective treatment area) to be operated at a maximum depth of two feet. The STA will be designed to remove phosphorus from stormwater entering the C-23/24 North and South reservoirs. This feature is currently under acquisition procurement for construction contract award. The Cypress Creek Complex and Allapattah Complex- Natural Storage and Water Quality Treatment Areas are approximately 32,639-acres and 42,348-acres respectively. These facilities were recommended to provide phosphorus and nitrogen reduction in the St. Lucie River and Estuary and Indian River Lagoon prior to runoff into east coast canals. These project features have been deferred to a later phase (Phase 2) of implementation.

C-25 Watershed
The recommended plan includes two components within the C-25 watershed. These components are the C-25 Reservoir and Stormwater Treatment Area.

The C-25 Reservoir is a 750-acres storage feature to be operated at eight feet (5,928 acre-feet capacity). The C-25 STA is 160-acre feature to be operated at a maximum depth of two feet. The STA will be designed to remove phosphorus load entering the STA from the reservoir. Both features have not initiated design and/or construction.

North Fork and South Fork Watersheds
The recommended plan includes three components within the North Fork and South Fork Watersheds. These components include Muck Remediation, Artificial Habitat, and North Fork Floodplain Restoration.

The Muck remediation involves the removal of accumulated muck within the SLE from areas that are effectively “dead zones.” Muck accumulation has covered substrate that once supported a healthy submerged aquatic vegetation (SAV) and oyster community. Removal of this sediment would greatly improve estuarine conditions by exposing this substrate making it suitable for colonization by target species. Removing the muck would also improve water quality conditions for target species by improving the clarity of the water and reducing sunlight attenuation, especially critical for re-colonization and growth of SAV. The Artificial Habitat will include a total of 90 acres created (60 acres of oyster shell hash, 24 acres of prefabricated reef balls, and 6 acres of artificial submerged aquatic vegetation). The North Fork Floodplain Restoration feature includes acquisition and preservation of approximately 3,100 acres of floodplain and adjacent lands, which will receive an additional 64,500 acre-feet of flow via the northern diversion efforts. All these project features have been deferred to a later phase (Phase 2) of implementation.

H.2 Sea-level Change

The climate assessment for Sea Level Change (SLC) follows the USACE guidance of Engineer Regulation (ER) 1100-2-8162, "Incorporating Sea Level Change in Civil Works Programs" (USACE, 2013) and Engineer Pamphlet (EP) 1100-2-1, "Procedures to Evaluate Sea Level Change: Impacts, Responses, and Adaptation" (USACE, 2019). ER 1100-2-8162 and EP 1100-2-1 provide guidance for incorporating the direct and indirect physical effects of projected future SLC across the project life cycle in managing, planning, engineering, designing, constructing, operating, and maintaining USACE projects and systems of projects.

To better support data-driven and risk-informed decision-making, the USACE has developed online tools that are accessible at CPR CoP Applications Portal (USACE, 2021b). Two of these web-based tools are used in this section to assess the effects of sea level change: Sea Level Change Curve Calculator (SLCC) (USACE, 2021c) and the Sea Level Tracker (SLT) (USACE, 2021d). Both tools provide a consistent and repeatable method to visualize the dynamic nature and variability of coastal water levels at tide gauges, allow comparison to USACE projected SLC scenarios, and support simple exploration of how SLC has or will intersect with local elevation thresholds related to infrastructure (e.g., roads, power generating facilities, dunes), and buildings. Taken together, decision-makers can align various SLC scenarios with existing and planned engineering efforts, estimating when and how the sea level may impact critical infrastructure and planned development activities (USACE, 2018b). These tools are designed to help with the application of the guidance found in ER 1100-2-8162 and EP 1100-2-1. The tools use equations in the regulation to produce tables and graphs for the following three SLC scenarios:

1) Baseline (or "low") estimate, which is based on historic SLC and represents the minimum expected SLC.
2) Intermediate estimate.
3) High estimate, representing the maximum expected SLC.

The calculator accepts user input—including project start date, selection of an appropriate NOAA long-term tide gauge, and project life span—to calculate projected SLCs for the respective project. The SLT has more functionality for quantifying and visualizing observed water levels and SLC trends and projections against existing threshold elevations for critical infrastructure and other local elevations of interest (USACE, 2021d). The start date used by the calculator is 1992, which corresponds to the midpoint of the current National Tidal Datum Epoch of 1983-2001.

The IRL-S most project features are located approximately 15 miles inland from the eastern coast of Florida. The project is protected from SLC to the east at the Atlantic Ocean by the water control structures S-48, S-49, S-50, and S-80. These structures are operated to maintain the optimum water levels in the upstream areas for flood risk management and prevent saltwater intrusion. Because of this protection, existing or future sea levels to the east are not expected to impact the hydrologic boundaries, including coastal surge, and groundwater impacts, governing the performance and operation of the project features. However, SLC impacts most likely could occur downstream of the controlling structures. Refer to **Section H.2.2** for detailed information.

H.2.1 Sea-level Change Existing Conditions

The tide gauge selected for this analysis was the NOAA Lake Worth Pier, FL (8722670) gauge (**Figure H-3**). The gauge is approximately 30 miles south of the nearest IRL-S Project feature, Southfork Natural Storage and Water Quality area. Available sea level trend data for the gauge can be found at NOAA's website at tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8722670#tabscenario. Lake Worth Pier gauge, with records since 1984, has only recently become compliant for USACE SLC analysis in the SLCC. The relative linear sea level trend was estimated by NOAA as 3.81 millimeters/year (0.0125 feet/year) with a 95% confidence interval of +/- 0.54 millimeters /year based on monthly mean sea level data from years 1970 to 2020 (**Figure H-4** and **Figure H-5**). This gauge was selected due to its proximity to the IRL-S project and has a more conservative relative linear sea level trend compared to other gauges on the east coast of Florida. The linear trend at the NOAA Virginia Key, FL (8723214) gauge near Miami is 0.0097 feet/year, which is a smaller trend than the Lake Worth Pier gauge. The plotted data for the Lake Worth Pier gauge can be found at NOAA's Tides and Currents website (NOAA, 2021b).

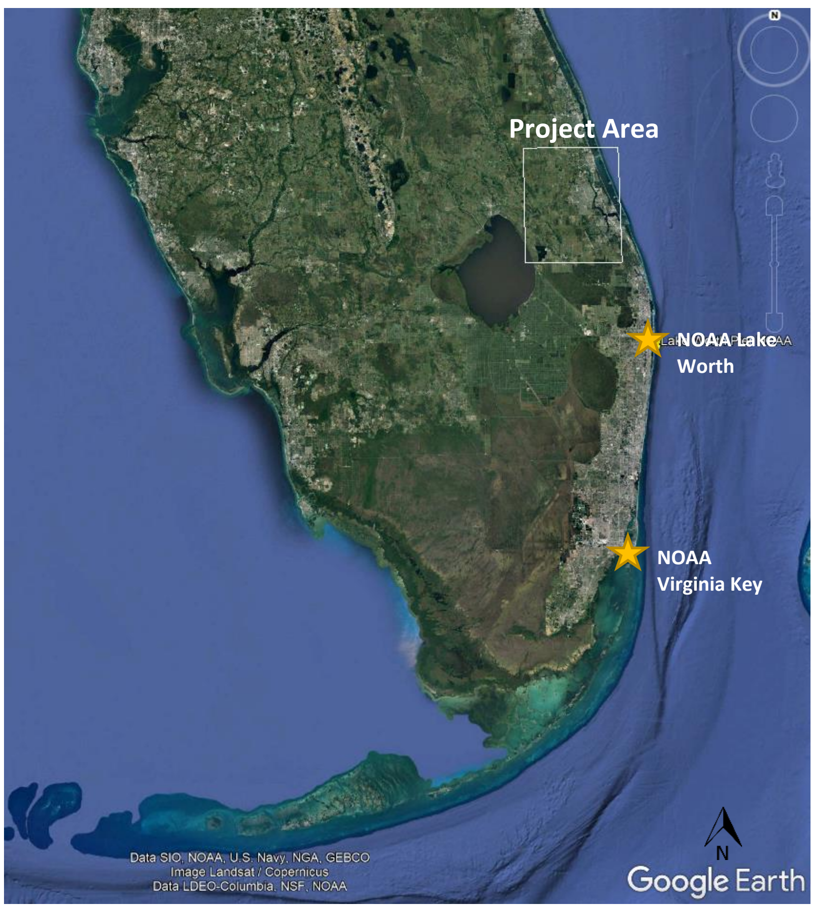


Figure H-3. Location Map of NOAA Lake Worth Pier Tide Gauge (8722670) used for the IRL-S Sea Level Change Analysis in relationship with the Project Area and NOAA Virginia Key Tide Gauge (8723214).

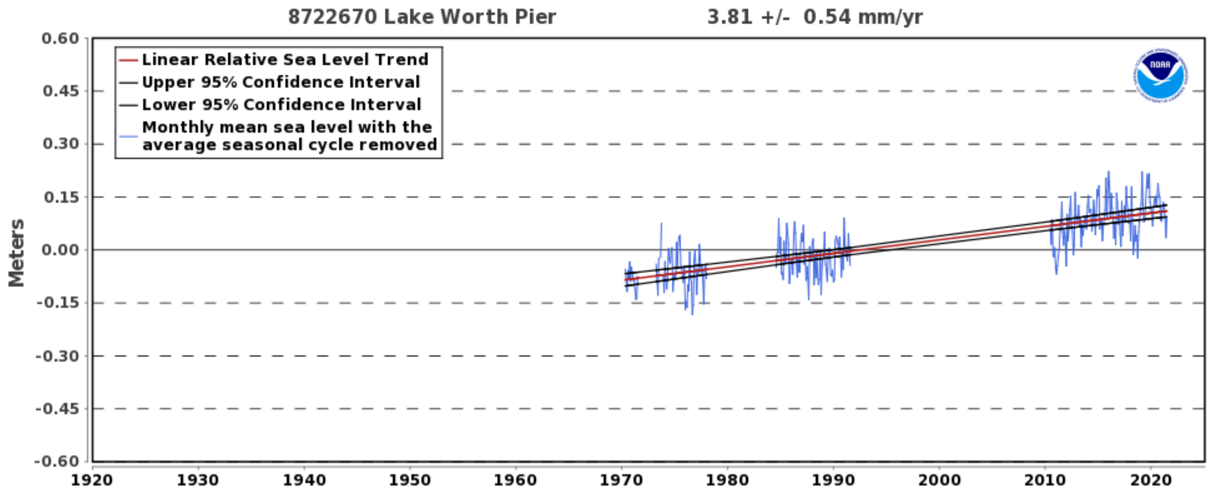


Figure H-4. Available tide gauge data and relative sea level trend for NOAA Lake Worth Pier Tide Gauge (8722670) in meters

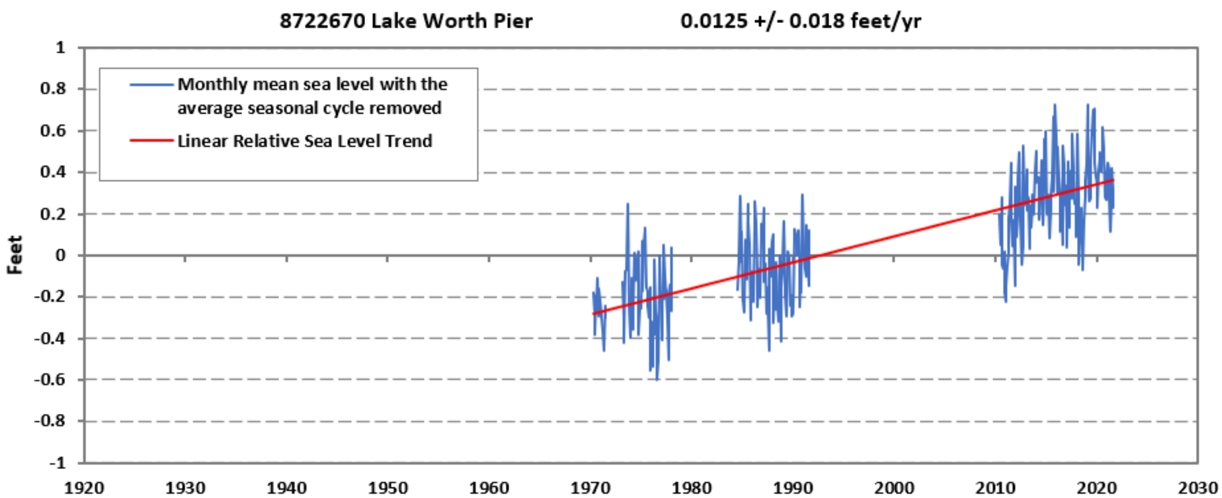


Figure H-5. Available tide gauge data and relative sea level trend for NOAA Lake Worth Pier Tide Gauge (8722670) in feet.

The tidal datums obtained from SLCC tool (USACE, 2021c) for the Lake Worth Pier Gauge are provided in **Figure H-6** illustrating the estimated tide phases based on the observed gauge data. The datums can be used as a reference to assist the interpretation of SLC projections. Obtained tidal datums are provided in tabular form in **Table H-1** in feet NAVD88.

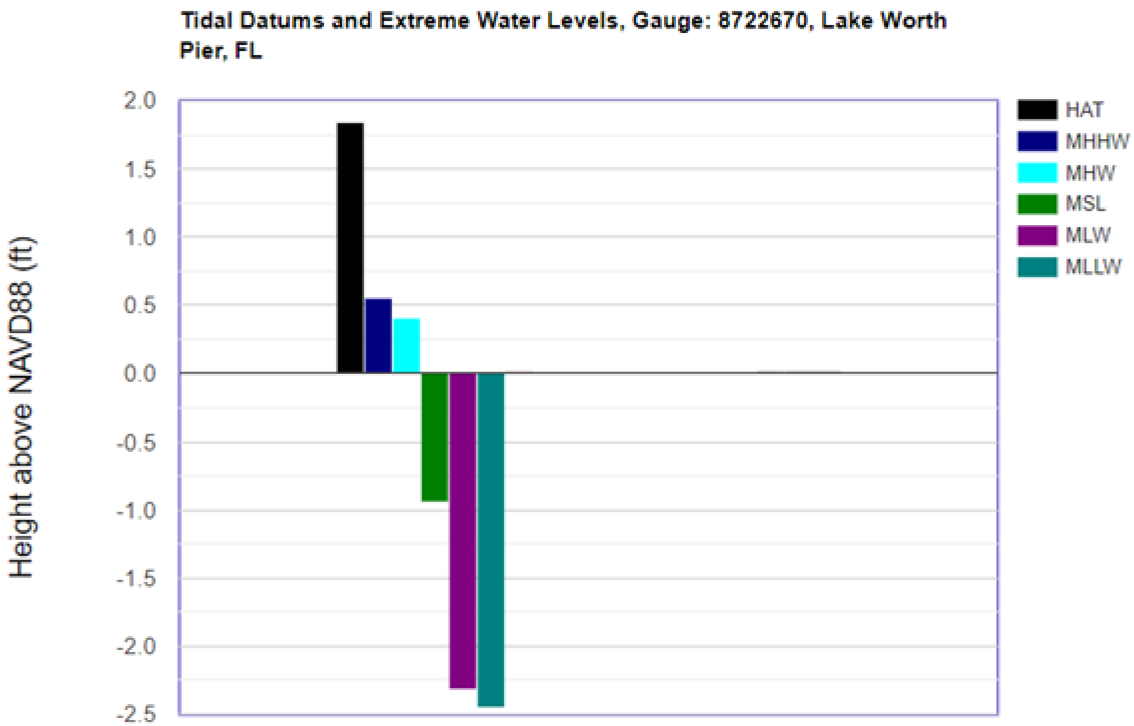


Figure H-6. NOAA Lake Worth Pier Gauge (8722670) Tidal Datums.

Table H-1. Tidal Datums for NOAA Lake Worth Pier Gauge (8722670).

Tidal Datums	Elevations in feet NAVD88
Highest Astronomical Tide, HAT	1.84
Mean Higher High Water, MHHW	0.55
Mean High Water, MHW	0.41
Mean Sea Level, MSL	-0.94
Mean Low Water, MLW	-2.32
Mean Lower Low Water, MLLW	-2.45

H.2.2 Potential Impacts to the Project from Future Sea-level Change

The following analysis evaluates potential effects on operation of IRL-S Project features and anticipated benefits. For the purpose of this analysis, the following years are evaluated:

- 2030 (Completion of construction for IRL-S Phase 1, as per the 2020 South Florida Ecosystem Restoration Integrated Delivery Schedule; Phase 2 implementation schedules have not been developed)
- 2080 (50 years into the future, representing the mid-point of the IRL-S project life cycle)
- 2130 (100 years into the future, representing the end of the IRL-S project life cycle)

Climate for which the project is designed can change over its life cycle and may impact its performance, and/or operation and maintenance activities. Given these factors, USACE guidance from ECB 2018-14, suggests that the project life cycle should be up to 100 years. For most projects, the project life cycle starts when construction is complete which typically corresponds to the time when the project starts accruing benefits. For some cases, however, the project life cycle starts before construction completion, typically because these projects start getting benefits during construction. For IRL-S, the project life cycle begins in 2030, when construction is planned to be complete. The SLC projections for IRL-S were evaluated for USACE Low, Intermediate, and High curves relative to the 1992 tidal epoch mid-point (Epoch: 1983 to 2001) **(Figure H-7)**. The SLC projected elevations for the years 2030, 2080, and 2130 in 5-year intervals are provided and summarized in **Table H-2.** For IRL-S during the year 2030, SLC projections range from -0.47 to -0.07 feet NAVD88; for the year 2080, SLC projections range from 0.16 to 3.03 feet NAVD88; for the year 2130, SLC projections range from 0.79 to 7.85 feet NAVD88.

Potential impacts to the project from future SLC were evaluated qualitatively using two approaches:

- Identify and evaluate critical threshold elevations at which SLC impacts may impact the performance or operation (including backwater effects from SLC at hydrologic boundaries) of the project.
- Map future SLC elevations using NOAA's Sea Level Rise Viewer (NOAA, 2021a) to determine if the inundation footprint due to SLC would encroach on the IRL-S Project footprint during the assumed 100-year project life cycle.

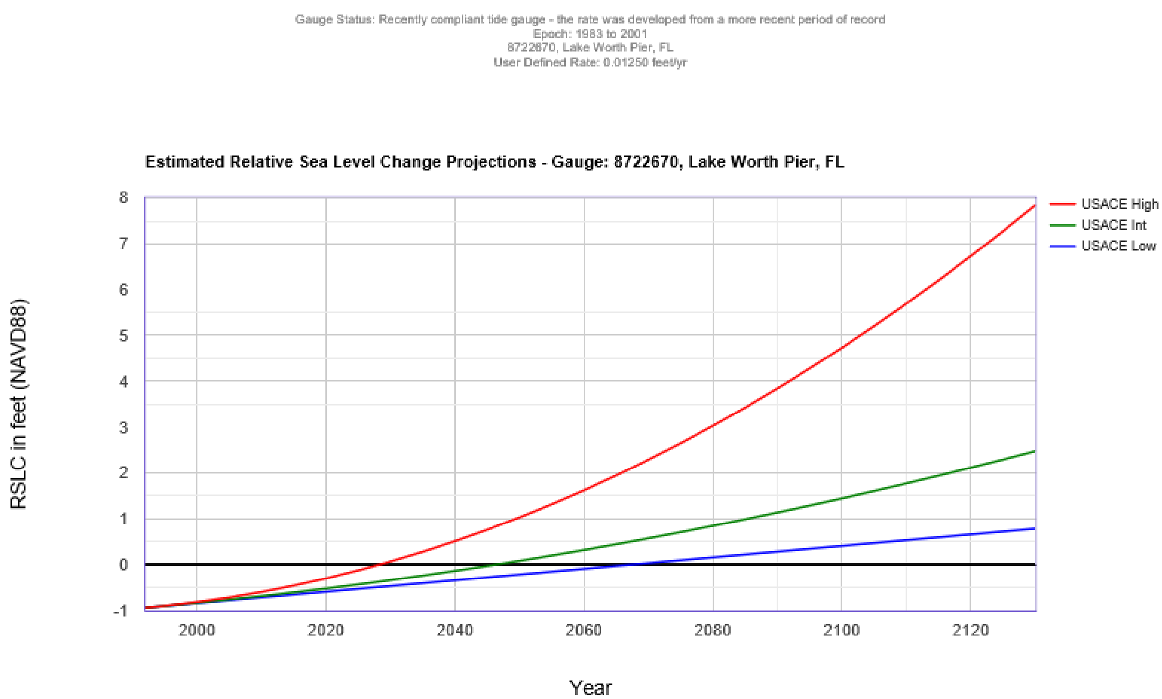


Figure H-7. Estimated Relative Sea Level Change Projections at NOAA Lake Worth Pier Gauge (8722670) for USACE Low, Intermediate, and High Curves

Table H-2 Estimated USACE Low, Intermediate, and High SLC projections at Lake Worth Pier Gauge for years 1992 through 2130.

Year	USACE Low (feet NAVD88)	USACE Int (feet NAVD88)	USACE High (feet NAVD88)
1992	**-0.94**	**-0.94**	**-0.94**
2030	**-0.47**	**-0.34**	**0.07**
2035	-0.4	-0.24	0.28
2040	-0.34	-0.14	0.51
2045	-0.28	-0.03	0.76
2050	-0.22	0.08	1.03
2055	-0.15	0.2	1.32
2060	-0.09	0.32	1.62
2065	-0.03	0.45	1.95
2070	0.04	0.58	2.29
2075	0.1	0.71	2.65
2080	**0.16**	**0.85**	**3.03**
2085	0.22	0.99	3.43
2090	0.28	1.14	3.85
2095	0.35	1.29	4.28
2100	0.41	1.45	4.73
2105	0.47	1.61	5.21
2110	0.54	1.77	5.7
2115	0.6	1.94	6.21
2120	0.66	2.12	6.73
2125	0.72	2.3	7.28
2130	**0.79**	**2.48**	**7.85**

H.2.2.1 Critical Elevation Thresholds for Project Features

Water levels in the vicinity of IRL-S Project features are regulated by four tidal structures S-50, S-49, S-48, and S-80, located on the C-25, C-24, C-23, and C-44 Canals, respectively (**Figure H-8**). These structures' main purposes are to discharge the flood runoff from the tributary basins, prevent overdrainage by maintaining optimum water levels, and prevent saltwater intrusion. The S-80 Lock also provides a means for passing boat traffic through the St. Lucie Canal.

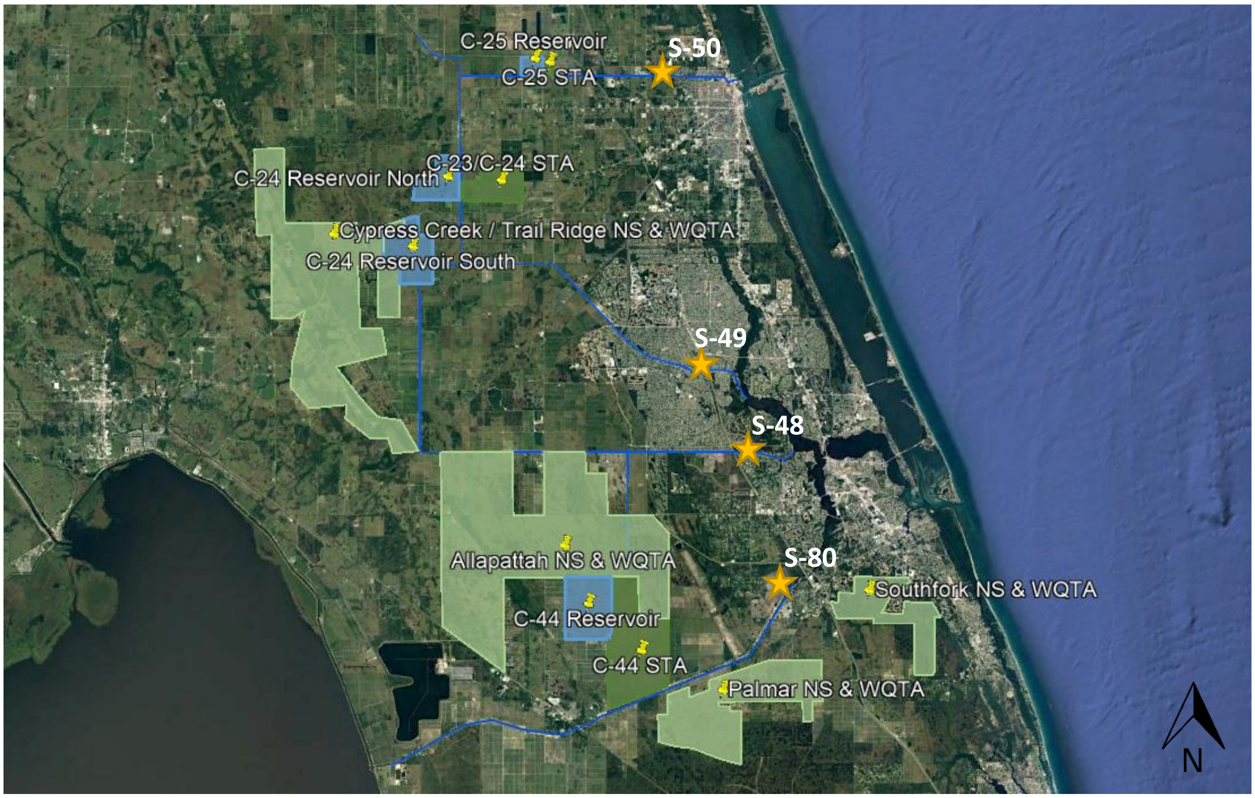


Figure H-8. Location of tidal structures regulating the canal water levels in the vicinity of IRL-S Project features

For the S-50, S-49, and S-48, the geometry of the structure was used to estimate when the sea level change in tailwater is expected to impact the discharge capacity of the structure. The performance of features located upstream of fixed-crest weirs, the S-50 and S-48, will be protected from the downstream impacts due to increased sea levels until the crest elevation is exceeded. For the S-49 Gated Spillway, the effect of the increased downstream elevations will propagate upstream when the tailwater elevations exceed the spillway crest and structure gates are open. The S-80 Spillway has a crest elevation of 2.04 feet NAVD88, which indicates that submerged flow conditions can occur at the structure with current conditions. However, a lower critical elevation value of 1.5 feet NAVD88 was established for Climate Change Assessment for Lake Okeechobee Watershed Restoration Project (LOWRP, USACE 2020b) and Herbert Hoover Dike (HHD) due to expected impacts to a downstream community. Both LOWRP and HHD are connected to Lake Okeechobee, which is the headwaters of the C-44 Canal. The critical elevations and basis for their selections are summarized in **Table H-3**. **Figure H-9** shows the estimated relative SLC from years 2030 to 2130, calculated with the USACE Sea Level Change Curve Calculator (USACE, 2021c) for NOAA Lake Worth Pier Gauge, considering the lowest thresholds for the project which are the S-49 and S-80 critical elevations of 5.88 and 1.5 feet NAVD88 respectively.

Table H-3. Critical elevations for the coastal structures for IRL-S Project

Structure	Canal	Type of Structure	Critical Elevation Type	Critical Elevation (feet NAVD88)
S-50	C-25	Fixed-Crest Weir	Weir Crest	13.48
S-49	C-24	Gated Spillway	Spillway Crest	5.88
S-48	C-23	Fixed-Crest Weir	Weir Crest	9.48
S-80	C-44	Gated Spillway and Lock	Impacts to Downstream Community	1.5

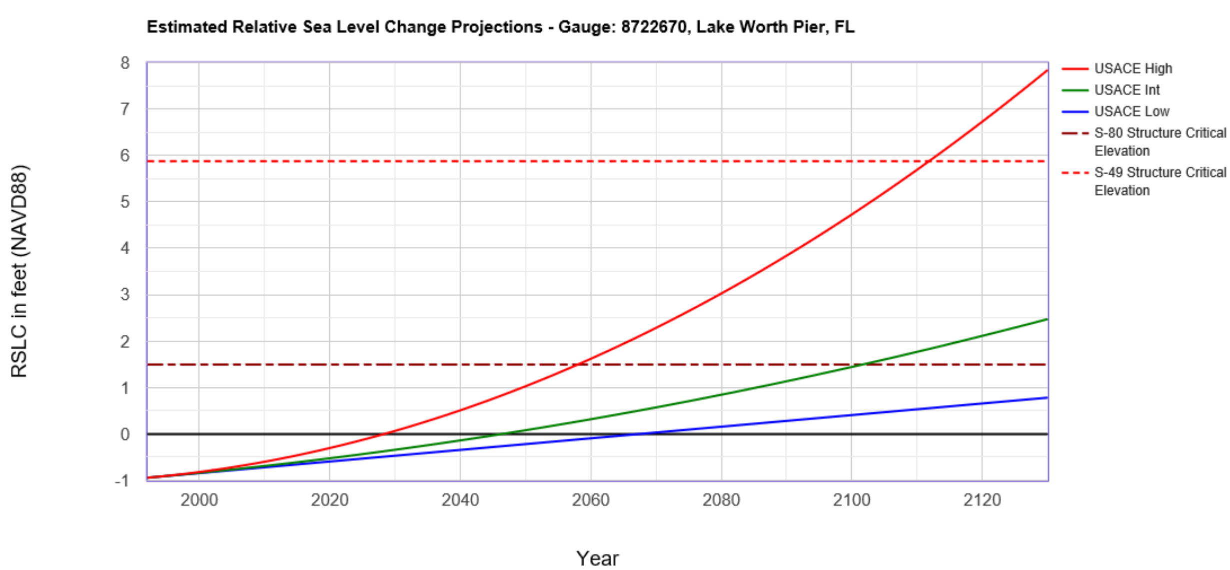


Figure H-9. Estimated Relative Sea Level Change Projections at NOAA Lake Worth Pier Gauge (8722670) for USACE Low, Intermediate, and High Curves compared to lowest critical elevations.

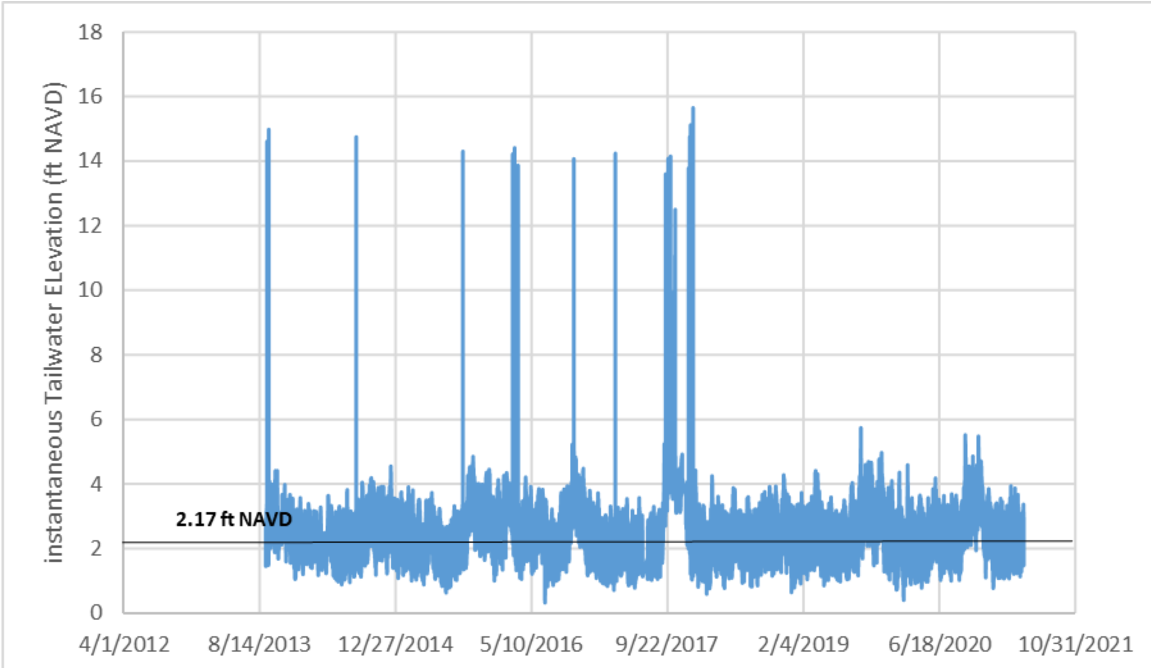


Figure H-10. Instantaneous tailwater stage elevations for S-80 Structure.

The S-80 structure is directly connected to the Atlantic Ocean via meandering, 15-mile stretch of the St. Lucie River. The record of instantaneous tailwater stages shown in **Figure H-10** were time-averaged for the available period between September 5, 2013 to April 4, 2021 to calculate the current mean tailwater stage value as 2.17 feet NAVD88. Considering this value is higher than the established critical elevation for this structure, 1.5 feet NAVD88, the structure's discharge capacity may have already been impacted by rising sea levels. Since S-80 is also utilized for regulatory releases from Lake Okeechobee, potential capacity limitations would need to be incorporated into future Lake Okeechobee regulation schedule analyses. Considering the average tailwater elevation for this structure (2.17 feet NAVD88) is higher than the mean sea level at Lake Worth Pier Gauge (-0.94 feet NAVD88), it can be concluded that the water stages at this site is affected by the elements of inland hydrology, such as upstream discharge influences and head losses throughout the channel. Due to the complexity of a thorough analysis and its potential impact on other ongoing, larger-scale studies, consistent with previous ecosystem restoration projects, the curves provided in **Figure H-9** were assumed to be applicable at the location of the structure while estimating the critical threshold exceedance years provided in **Table H-4**.

The years that critical thresholds are expected to be reached for each tidal structure are summarized in **Table H-4**. It should be noted that the provided projection curves were developed for the mean sea levels assuming that sea level projections for Lake Worth Gauge are applicable at the structure locations. Therefore, the structure thresholds can be exceeded before the years reported in the table, when local and/or instantaneous water levels exceed the structure thresholds.

Table H-4. Years in which critical thresholds are expected to be reached.

Structure	Critical Elevation (feet NAVD88)	Year of Critical Threshold Reached USACE Low	Year of Critical Threshold Reached USACE Intermediate	Year of Critical Threshold Reached USACE High
S-50	13.48	3145	2330	2173
S-49	5.88	2537	2207	2111
S-48	9.48	2825	2271	2143
S-80	1.5	2187	2101	2058

H.2.2.2 Inundation Maps

The IRL-S project features are protected from the direct influence of SLC by water control structures located on canals regulating the upstream local water levels. NOAA's Sea Level Rise Viewer (NOAA, 2021a) was used to visualize regional impacts from coastal seal level rise and provided in **Figure H-2.** NOAA's inundation maps are based on mean higher high water (MHHW) and provided in 1-feet increments. In absence of a detailed analysis, it is assumed that future projections for MHHW will follow a similar trend as the MSL projection curves provided in **Figure H-9.** The obtained future MHHW levels are rounded up to the next full feet of elevation to develop the maps shown in **Figure H-11** and **Figure H-12.** Since the current MHHW for the Lake Worth Pier gauge is 0.55 feet NAVD88 (**Table H-1**), this value was added to the projection curves to convert them from feet NAVD88 to "difference over current in feet". It needs to be noted that the "current" datums presented in the **Table H-1** are developed using the 1983-2001 Epoch, which is referred at the mid-point of this range as 1992 Epoch.

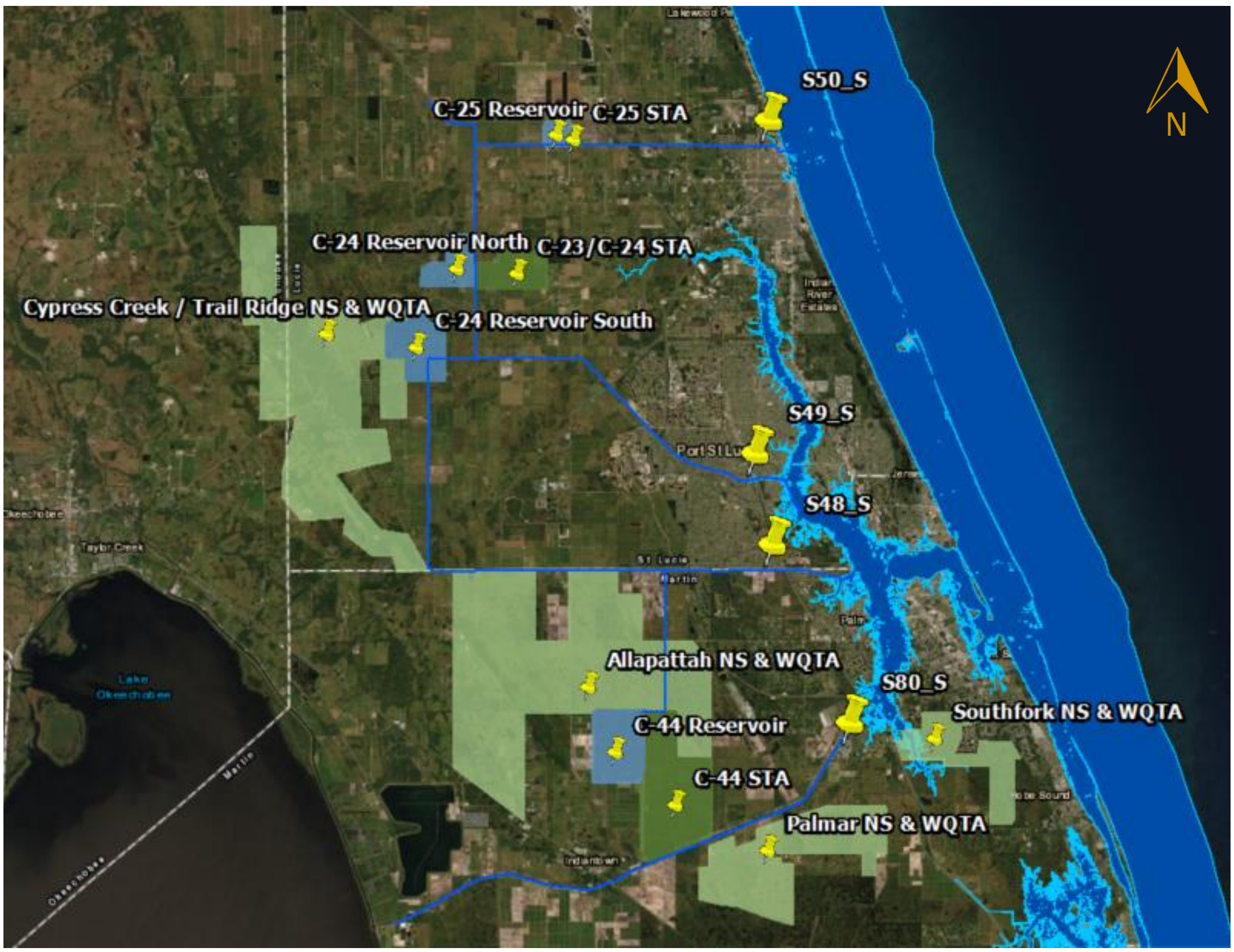


Figure H-11. Approximate High Curve SLC Inundation Scenario for year 2130 for IRL-S project (9 feet increase over 1992 Epoch MHHW).

As seen in the figure, the SLC inundation is not expected to propagate upstream of all four tidal structures affecting the main project's features. The S-50 and S-48 have critical elevations high enough to not be impacted by the SLC within project analysis timeframe (2030-2130). The S-49 and S-80 are equipped with gates, which provide additional operational flexibility while providing protection from potential adverse impacts of rising sea levels. Even though the structures' discharge capacity can be adversely impacted by the increased tailwater elevation, the inundation does not propagate upstream due to the gates. The features that will be directly impacted by the increased sea level are those located downstream of tidal structures. Inundation maps focusing on areas downstream of coastal structures for the IRL-S project are shown in **Figure H-12** for years 2030, 2080, and 2130.

Despite sea levels not being able to physically reach and impact IRL-S features relative to the year 2080 projections, there could still be tailwater effects that could cause a backwater effect propagating upstream towards IRL-S features.

Evaluation of the tidal structure critical elevations showed that, while the year 2130 Low and Intermediate projections (0.79 and 2.48 feet NAVD88, respectively) will not directly impact IRL-S features, the USACE High (7.85 feet NAVD88) for the year 2130 may adversely impact the project features. The performance and operation of S-80 may be vulnerable to the high SLC curve as early as year 2058. S-49 gated spillway is also directly connected to the Atlantic Ocean via approximately 17-mile stretch of North Fork of St. Lucie River. Since this structure operates in free controlled mode, tailwater elevation data is not available since only headwater data is used in discharge calculations. Due to the high crest elevation (5.88 feet NAVD88), the structure's performance is not expected to be impacted until year 2111 by the raising tailwater elevation under the High SLC curve scenario. All other structures are not vulnerable to SLC until after year 2100.

SLC appears likely to impact the IRL-S project downstream of S-80, therefore future resiliency and adaptive management measures for the IRL-S project may need to be considered. The C&SF water management system will likely need to make changes to infrastructure and operations in the future in order to manage rising sea levels. Therefore, infrastructure and operational changes to the C&SF Project will likely be necessary to address adverse effects from rising sea level.

Due to the regional impact of SLC, non-IRL-S C&SF Project features and infrastructure along the coastline may be impacted sooner than IRL-S Projects features. Other studies in the region (such as Lake Okeechobee Watershed Restoration Project and Lake Okeechobee Regulation Schedule updates) will help inform indirect effects of SLC to IRL-S. This indirect SLC effect may prompt the need for a more detailed regional SLC analysis of the entire C&SF Project. Future resiliency and adaptative measures for the IRL-S Project features may need to be considered due to a more accelerated potential impact of SLC. Although this is a less probable scenario, the likelihood and potential impact of this risk has been considered during the evaluation of the project contingency.

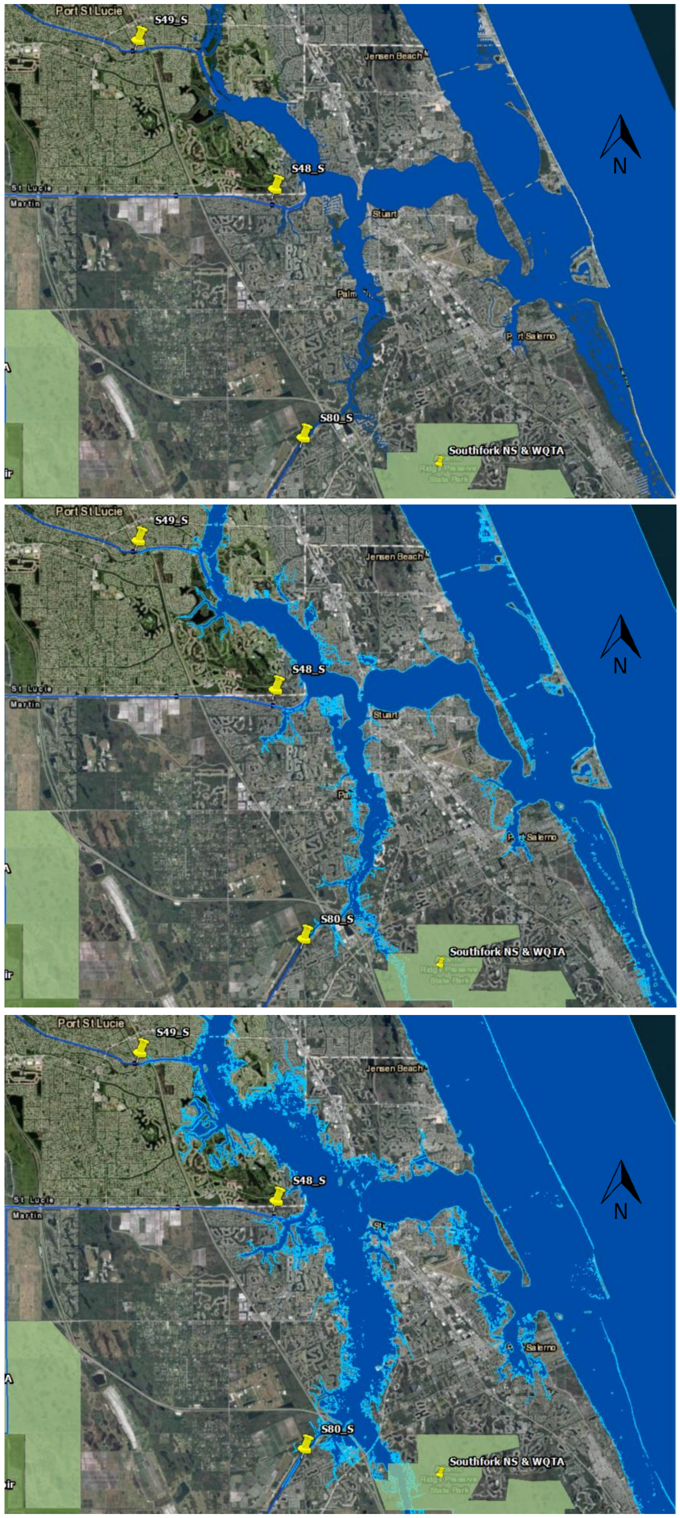


Figure H-12. Approximate High Curve SLC Inundation Scenarios for (a) Year 2030 (+1 feet); (b) Year 2080 (+4 feet), (c) and Year 2130 (+9 feet over 1992 Epoch MHHW)
https://coast.noaa.gov/slr/#/layer/sce/3/-8943868.75677375/3146036.894439393/12/satellite/54/0.8/2050/interHigh/midAccretion

H.2.3 Impacts on the IRL-S Benefits due to Sea Level Change

Since IRL-S project authorization in 2004, many of the USACE guidelines have changed as more scientific knowledge of climate change factors have been studied and understood. Therefore, this section will describe the potential impact to the IRL-S project benefits considering a very important factor in climate change which is SLC. This analysis has been performed qualitatively but supported by reliable scientific data and knowledge of the project area.

Sections below compare the changes in benefits between 2004 Final PIR/EIS and 2021 Validation Report included in **Section 9** of the Main Validation Report in contrast with future SLC up to year 2130.

H.2.3.1 Reservoirs: C-44, C-23/24N, C-23/24S and C-25

2004 Final PIR/EIS Description of Benefits: Reduction in frequency and duration of damaging discharges to receiving water bodies and retention of watershed flows in the natural system; water quality treatment is an ancillary benefit of reservoirs. In addition, reservoirs will provide agricultural water supply thereby reducing dependency on the Florida aquifer. Ancillary benefits from reductions in pesticides and other pollutants contained in runoff currently discharged to the estuary.

2021 Validation Report Confirmation of Benefits: Increase in expected benefits above those stated in 2004 Final PIR/EIS due to significant decline in IRL since 2004 (Refer to **Section 9.1.1** of the Main Report for full details).

2030-2130 Potential Impact to Benefits: All four reservoirs are more than 10 miles inland from the east coast of Florida. Therefore, negative impacts to proposed reservoirs performance due to SLC is unlikely. However, as frequency and duration of headwater discharges most likely will decrease, it is expected that this water will be available more often for storage and to be managed within the watersheds. This could potentially result in an increase of project benefits due to the additional operational flexibility reservoirs will provide in the future to the area. Also, an increase in water available for the reservoirs, might increase the potential for settling of particulates (i.e. minor increase in water quality) along with increased opportunity for groundwater recharge. There may also be the added benefit of holding water longer in the dry season for distribution when it is most needed by the ecosystem.

H.2.3.2 Stormwater Treatment Areas: C-44, C-23/24 and C-25

2004 Final PIR/EIS Description of Benefits: Water quality treatment, reduction in nutrient loads (phosphorus/nitrogen) and sediment transport to estuary. Ancillary benefits from reductions in pesticides and other pollutants contained in runoff currently discharged to the estuary.

2021 Validation Report Confirmation of Benefits: Increase in expected benefits above those stated in 2004 Final PIR/EIS due to significant decline in IRL since 2004 (Refer to **Section 9.1.1** of the Main Report for full details).

2030-2130 Potential Impact to Benefits: All three STAs are more than 10 miles inland from the east coast of Florida. Therefore, negative impacts to proposed STAs performance due to SLC is unlikely. However, as frequency and duration of headwater discharges most likely will decrease, it is expected that more water will be available for water quality treatment, reducing nutrient loads and sediment transport to the estuary, and allowing water with better quality to be distributed within the watersheds. In the future, this could potentially result in an increase in project benefits.

H.2.3.3 Natural Storage and Water Quality Treatment Areas: Palmar, Cypress Creek, Allapattah Complexes

2004 Final PIR/EIS Description of Benefits: Preservation, protection, and increase in the spatial extent of wetlands; increase in habitat of focal species; water storage, water quality treatment.

2021 Validation Report Confirmation of Benefits: Increase in expected benefits above those stated in 2004 Final PIR/EIS due to continued loss of natural areas and increases in human development within the IRL-S watershed since 2004. Due to the combination of these two elements, stressors such as polluted stormwater runoff, increased flow and increased sedimentation have further degraded the SLE and IRL. Natural storage and treatment areas are also considered habitat-based climate change adaptation measures as they increase the spatial extent of the existing network of conservation lands (Watson et al. 2014) and establish high quality habitat corridors to enhance connectivity between protected areas (Nunez et al. 2013).

2030-2130 Potential Impact to Benefits: Cypress Creek and Allapattah Complexes are located more than 10 miles from the east coastline of Florida, while Palmar Complex (which includes South Fork Complex) is about 4 miles away from the coastline. As explained in the 2021 Validation Report Confirmation of Benefits for this feature, loss of natural areas and increases in human development continues to happen within the project area. Therefore, keeping the natural areas whole as much as we can, will continue to provide same or more valuable project benefits in the future, not only due to the continued development pressures within the IRL-S Project area but due to the need of plant and animal species to have the ability to adapt and migrate due to climate and SLC. These features increase the resiliency of the south Florida ecosystem and represent habitat-based climate change adaptation measures. These benefits were not captured in the original 2004 Final PIR/EIS and thus represent an overall increase in project benefits.

H.2.3.4 Muck Remediation

2004 Final PIR/EIS Description of Benefits: Improvements in water quality, improvements in habitat quality and increase in extent of substrate available for oyster and seagrass colonization.

2021 Validation Report Confirmation of Benefits: Increase in benefits above those stated in 2004 Final PIR/EIS due to the continued decline of water quality within the project area as well as an increase in frequency and extent of harmful algae blooms. Removal of existing muck will reduce legacy nutrients within the estuary that can be stirred up during large storm events or hurricanes. Muck removal will also increase spatial extent of oysters and seagrass by providing suitable substrates for recolonization, further assisting to reduce nutrients within the water body and providing food for native wildlife, including the threatened manatee.

2030-2130 Potential Impact to Benefits: Although this feature is very close to the coastline and thus, is likely to be directly influenced by SLC it is expected that project benefits will remain or increase above those presented in the 2004 Final PIR/EIS. The reason for this assumption is that the depth and spatial extent of muck removal for oysters and seagrass is adjustable, allowing this concept to be adaptable to future scenarios.

H.2.3.5 Artificial Habitat

2004 Final PIR/EIS Description of Benefits: Approximately 90 acres of habitat for oysters and submerged aquatic vegetation created in areas where muck removal will occur to accelerate recolonization process of these targeted species.

2021 Validation Report Confirmation of Benefits: Artificial or created habitat will provide a variety of benefits to a myriad of wildlife within the IRL-S project area. Artificial substrate will allow for recruitment and colonization of oysters, which provide an abundance of benefits through their filtering abilities. Oyster colonization will increase transparency, visibility and allow sunlight to penetrate assisting with growth and development of native seagrass and SAV communities. This in turn will also allow colonization of other benthic organisms providing direct benefits to essential fish habitat and the species that rely upon this area for foraging and reproduction (Refer to **Section 9.1.1** of the Main Report for full details).

2030-2130 Potential Impact to Benefits: Although this feature is very close to the coastline and thus, is likely to be directly influenced by SLC, it is expected that project benefits will remain or increase above those presented in the 2004 Final PIR/EIS. The reason for this assumption is that the depth and spatial extent of artificial habitat is adjustable and adaptable to future scenarios while allowing a variety of organisms to flourish in the area.

H.2.3.6 North Fork Floodplain Restoration

Based on the 2014 IRL-S PIR/EIS, the 3,089 acres considered for the North Fork Floodplain Restoration were not part of the quantitative analysis performed on the estuary and watershed components. However, this component has critical habitat that it is important to the recruitment and early life history stages of several important commercial and recreational species such as snook. In addition, this area has a unique flora and fauna. If these areas are not acquired, they will continue to be degraded, developed and additional fragmentation will occur. The diversions to the North Fork combined with this component would restore a large amount of this currently over-drained habitat.

The most significant uncertainties associated with the sea level change impact projections provided in this assessment are: 1) the lag time between when freshwater wetlands become significantly impaired due to salinity impacts and when replacement estuarine habitat becomes fully productive, and 2) the degree to which project related water reservations will protect natural system water supplies given SLR related demand from the developed areas.

The risk assessment of this Climate Change Vulnerability Assessment can be found in **Section H.3.3** of this Appendix.

H.2.4 Sea Level Change Summary

The effects of SLC have been analyzed per ER 1100-2-8162 and EP 1100-2-1. Most of the project features are located inland and not directly affected by the SLC. However, the preceding analysis shows that the critical elevation of 1.5 feet NAVD88 (S-80) and 5.88 feet NAVD88 (S-49) will be intersected by the high SLC projected curve in year 2058 and 2111, respectively. Therefore, operational changes may be needed to compensate for the increased tailwater elevations at water control structures. This could lead to operational limitations at these structures, depending on the land use, social and environmental changes at the year of analysis. Project features located south of water control structures, would require an adaptable design to further handle the future impact of sea level rise.

As described in Section 9.1 of the main validation report, conditions within the St. Lucie Estuary and Indian River Lagoon have continued to deteriorate due to unnatural volumes and timing of nutrient-laden freshwater inflows. Due to the additional storage, water quality treatment areas and water management provided by the proposed IRL-S Project features, the project is expected to provide substantially higher habitat functionality when compared to the future without project. The proposed volume of storage and treatment features will reduce the number, duration, and severity of large volumes of nutrient-laden freshwater inflows during dry periods. Also, these proposed features are expected to boost resiliency of the project area from potential adverse effects related to excess runoff and saltwater intrusion caused by SLC. Although regional SLC impacts may decrease freshwater habitat in the future due to increased sea levels, the freshwater flows IRL-S is expected to provide could potentially help smooth the transition from freshwater ecosystem to estuarine and eventually to marine in some extreme SLC scenarios.

Therefore, it is expected that IRL-S Project benefits considered within the period of analysis will remain or increase above those presented in the 2004 Final PIR/EIS due to the higher habitat functionality the project will provide. It needs to be noted here that there are uncertainties in the estimation of effects to project related ecosystem benefits due to the qualitative nature of the assessment.

SLC will be an important factor to monitor in throughout the life of the project to ensure IRL-S benefits can be maintained as long as possible into the future. Since IRL-S is part of a much larger water management system, other parts of the system may begin to feel the impacts of SLC earlier than IRL-S, which could have a cascading effect, potentially impacting the operations of IRL-S features. Additionally, IRL-S features may become impacted sooner than SLC projections predict due to the combination of more frequent tropical cyclone events. This indirect SLC effect may prompt the need for a more detailed regional SLC analysis on the entire C&SF Project.

H.3 Inland Hydrology Overview

The climate assessment for inland hydrology follows the USACE guidance of Engineering and Construction Bulletin (ECB) 2018-14, Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects (USACE, 2020a). ECB 2018-14 provides guidance for incorporating climate change information in the hydrologic analyses in accordance with the USACE climate preparedness and resilience policy and ER 1105-2-101, Risk Assessment for Flood Risk Management Studies (USACE, 2017). The vulnerability and risk to this project associated with inland hydrology climate change was assessed qualitatively as outlined in ECB 2018-14. The vulnerability assessment covers a literature review of current climate including observed and projected climate trends and application of climate tools used to provide information on observed and projected climate trends relevant to the project area.

H.3.1 Literature Review

As required by ECB 2018-14, a hydrologic literature review was conducted to summarize peer reviewed literature on current climate and observed climate trends and projected climate trends in the project area. The literature review includes sources specific to Florida and also the surrounding region:

1) Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions – South Atlantic-Gulf Region 03 (USACE, 2015)
2) Climate Change Indicators in the United States (EPA, 2016)
3) Climate Science Special Report: Fourth National Climate Assessment, Volume I (USGCRP, 2017) and II (USGCRP, 2018)
4) NOAA State Climate Summaries (Runkle, 2017)
5) USACE Jacksonville District Report on Climate Change, Comprehensive Everglades Restoration Plan Central Everglades Planning Project Final Integrated Project Implementation Report and Environmental Impact Statement (USACE, 2014)

The literature focuses on the following climate variables, which are consistent with those identified for the project:

1) Precipitation
2) Temperature
3) Streamflow

A synthesis of USACE peer-reviewed climate literature is available for the South Atlantic-Gulf Region and is referenced as one of the primary sources of information in this literature review. This USACE report summarizes observed and projected climate and hydrological patterns cited in reputable peer-reviewed literature, authoritative national and regional reports, and characterizes climate threats to USACE business lines (USACE, 2015). The project watershed falls within the South Atlantic-Gulf Region, which is also referred to as Water Resources Region 03 (2-digit hydrologic unit code, or HUC03) as shown in **Figure H-13**.

Additional national and regional reports from the United States Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA)—including the United States Global Change Research Program (USGCRP) report *Climate Science Special Report: Fourth National Climate Assessment, Volume I and II* (USGCRP, 2017 and USGCRP, 2018)—are cited to further identify observed changes in climate variables and assess projected, future changes in climate variables for the study area. Finally, in order to report on climate trends specific to central and south Florida, a USACE Jacksonville District report on climate is referenced. This report summarizes observed and projected climate patterns cited in various Florida reports and studies.

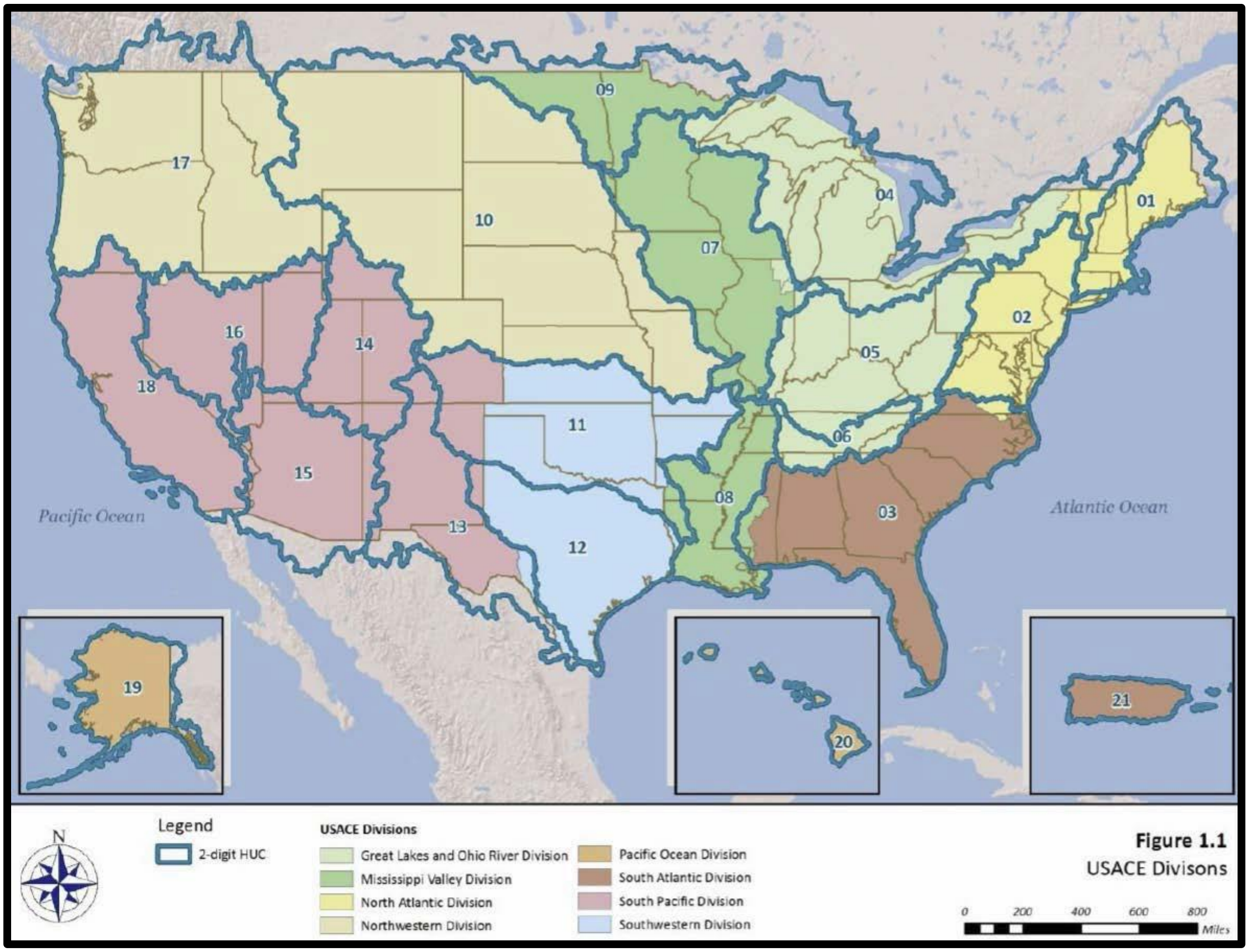


Figure H-13. Map of 2-digit hydrologic unit code boundaries for the Continental United States, Alaska, Hawaii, and Puerto Rico (USACE, 2015).

The literature review summarizes available resources discussing observed and projected hydroclimatic trends in the project area. There is evidence of changes to global climate patterns that will likely have an impact on central and south Florida in terms of rainfall and air temperature. A summary of the literature reviewed as part of the USACE *Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions – South Atlantic-Gulf Region 03* (USACE, 2015) is displayed in **Figure H-14**. The figure represents observed and projected trends for climate variables in the South Atlantic-Gulf region which includes Florida. The literature however found an increasing number of one-day extreme maximum temperatures in Florida, whereas there was no overall observed maximum temperature trend for the South Atlantic-Gulf region.

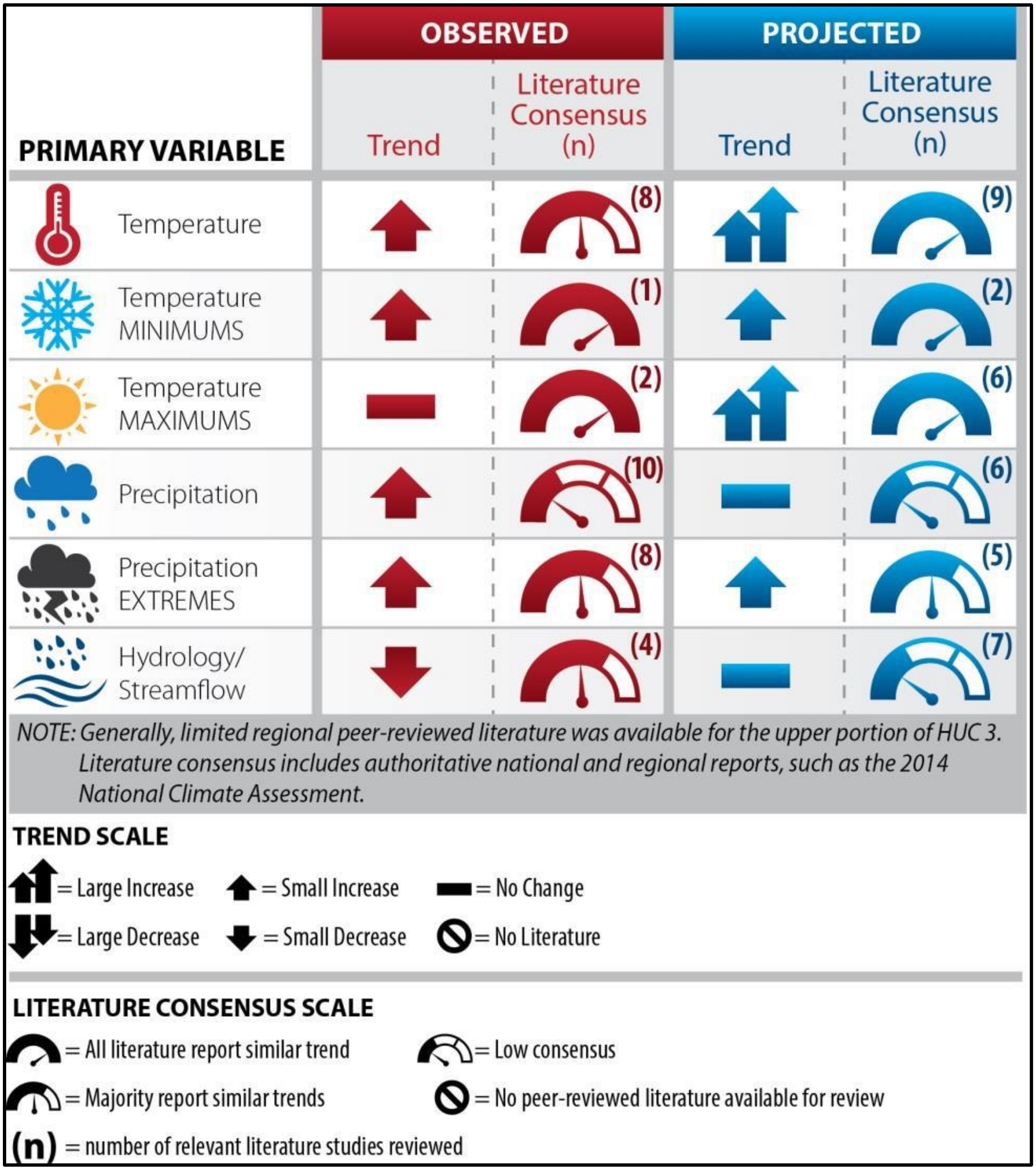


Figure H-14. Summary Figure from USACE Literature Synopsis of South Atlantic-Gulf Region- 03.

Based on the references reviewed, there is an overall increasing trend in observed, annual/seasonal air temperature, as well as temperature extremes. This literature review indicates that observed precipitation shows no discernible trends in annual/seasonal precipitation but shows an increase in the frequency and intensity of extreme precipitation events. The annual frequency of hurricanes has remained relatively stable throughout the 20th and early 21st centuries; however, hurricane rainfall is expected to increase for Florida as the climate continues to warm. SFWMD data indicate that there has been an increase in heavy downpours in many parts of the region, while the percentage of the region experiencing moderate to severe drought increased over the past three decades. Rising air and water temperatures and in precipitation are intensifying droughts and increasing heavy downpours. No trend in observed streamflow was found. A summary of the observed trends can be found in **Table H-5.**

Projected air temperature trends among the five peer-reviewed literature sources show an increase in in air temperature minimums and maximums. The studies reviewed generally agree on an increase in mean annual air temperature for the South Atlantic-Gulf Region of approximately 2° to 4° C by the latter half of the 21st century. The largest increases are projected for the summer months, with extreme temperatures expected to increase even more than average temperatures. Projected precipitation shows no discernible trend in annual/seasonal precipitation but does show an increase in the frequency and intensity of extreme precipitation events. Research shows that there is strong evidence that increased water vapor resulting from higher temperatures will likely be the primary cause of the projected increases. The frequency of seasonal hourly precipitation extremes is expected to increase in all regions of the United States. In addition, future projections of extreme events, including droughts, are the subject of the literature. Drought is a consistent climate threat for Florida resulting in reductions in water supplies, disruptions to agriculture, and increased risk of wildfires. The literature projects an increase in the severity of future droughts for the region, as projected temperature and evapotranspiration (ET) increases outweigh the increases in precipitation. There is no consensus on an increase or decrease in projected streamflow. A summary of the projected trends can be found in **Table H-6**.

Table H-5. Observed trends of the climate variables reviewed in the literature

Literature Source	Temperature (annual/seasonal)	Temperature Minimums	Temperature Maximums	Precipitation (annual/seasonal)	Precipitation Extremes	Streamflow
Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions – South Atlantic-Gulf Region 03 (USACE, 2015)	Increase	Increase	Increase	Increase, but low consensus	Increase	Decreasing Trend, but low consensus
Climate Change Indicators in the United States (EPA, 2016)	Increase	Increase	Increase	No Trend	Increase	No Trend
Climate Science Special Report: Fourth National Climate Assessment, Volume I and II (USGCRP, 2017; USGCRP, 2018)	Increase	Increase	Increase	Decreases in Spring Precipitation & Increases in Winter Precipitation; no trend in summer or fall precipitation	Increase	No Trend
NOAA State Climate Summaries (Runkle et al., 2017)	Increase	Increase	No Trend	No Trend	No Trend	Not Addressed
USACE Jacksonville District studies	Not Addressed	Not Addressed	Not Addressed	No trend	Not Addressed	Not Addressed

Table H-6. Projected trends of the climate variables reviewed in the literature.

Literature Source	Temperature (annual/seasonal)	Temperature Minimums	Temperature Maximums	Precipitation (annual/seasonal)	Precipitation Extremes	Streamflow
Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions – South Atlantic-Gulf Region 03 (USACE, 2015)	Increase	Increase	Increase	No Trend	Increase	No Trend
Climate Change Indicators in the United States (EPA, 2016)	Not Addressed	Not Addressed	Not Addressed	Not Addressed	Not Addressed	Not Addressed
Climate Science Special Report: Fourth National Climate Assessment, Volume I and II (USGCRP, 2017; USGCRP, 2018)	Increase	Increase	Increase	No Trend	Increase	No Trend
NOAA State Climate Summaries (Runkle et al., 2017)	Increase	Not Addressed	Increase	No Trend	Increase	Not Addressed
USACE Jacksonville District studies (USACE, 2014)	Increase	Not Addressed	Not Addressed	Not Addressed	Increase	Not Addressed

H.3.2 Climate Hydrology Vulnerability Assessment

In addition to a literature review, the vulnerability assessment includes the application of climate tools to provide information on observed and projected climate trends relevant to the project area.
The following USACE CPR web-based tools were used in the analysis:

1. Climate Hydrology Assessment Tool (CHAT) – evaluate historic and projected climate trends.
2. Nonstationarity Detection Tool (NSD) – evaluate historic climate trends.
3. Vulnerability Assessment Tool (VA) – provide qualitative information on projected climate conditions.
4. Time Series Toolbox

H.3.2.1 Climate Hydrology Assessment Tool (CHAT)

The CHAT allows users to assess trends in both observed and projected hydrometeorological data to support consistent analyses and to develop reliable, qualitative projections of climate changes for USACE projects. The tool can be accessed at https://corpsmapz.usace.army.mil/apex/f?p=313:10:0::NO.

The CHAT projects future changes in streamflow using general circulation models (GCMs) at the watershed scale designated as HUC04, a spatial scale consistent with the spatial and temporal precision of downscaled modeling climate-hydrology datasets. **Figure H-15** shows the HUC04 basins for the South Atlantic-Gulf Region. The IRL-S project is located within the southernmost basin in Florida designated as HUC 0309.

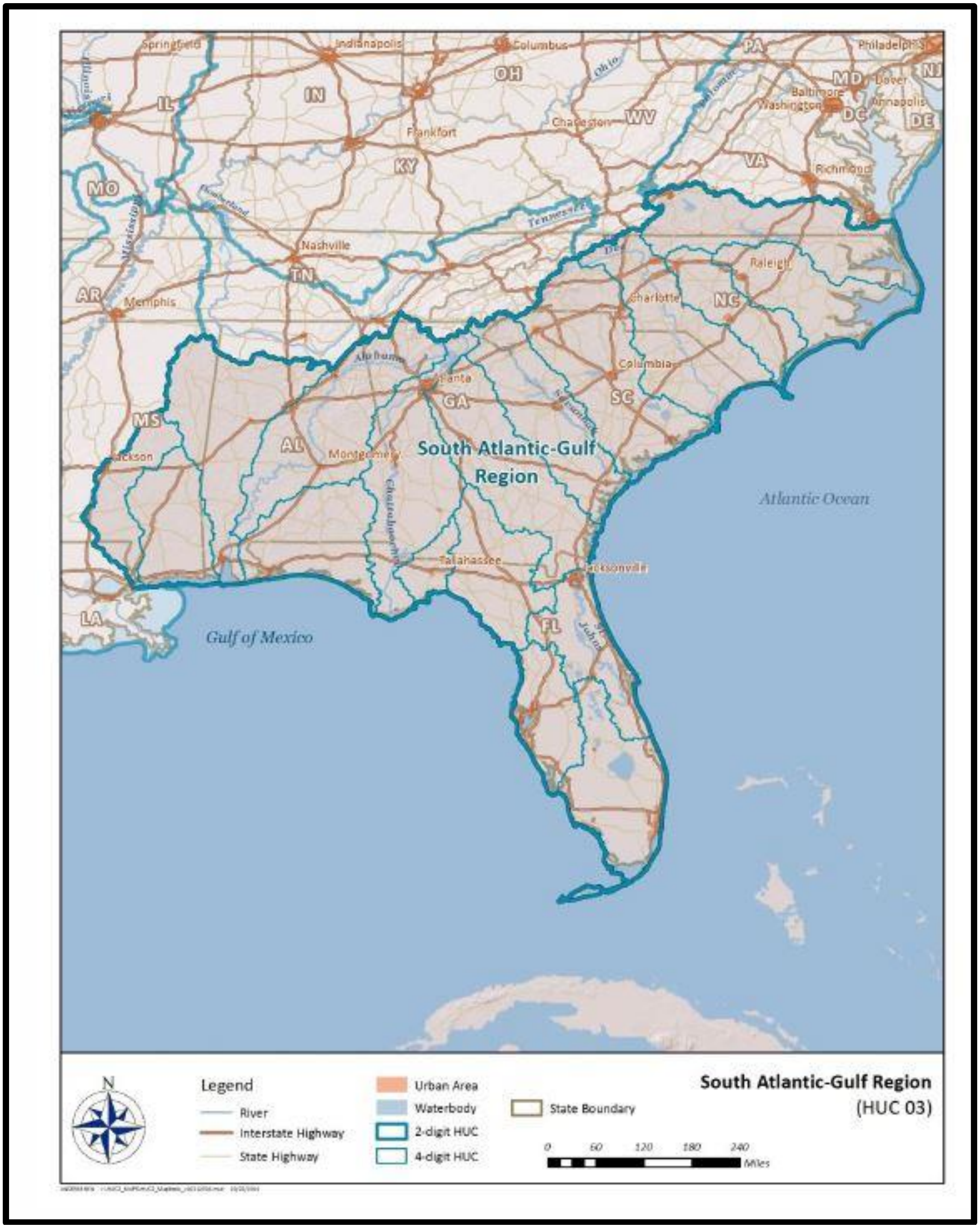


Figure H-15. Water Resources Region 03: South Atlantic-Gulf Region boundary (USACE, 2015).

H.3.2.1.1 Observed Trends in Streamflow Peaks

Because the Fisheating Creek gauge has the longest unregulated period of record (see **Figure H-17**) of any streamflow gauge within the Lake Okeechobee watershed, it is used in the climate hydrology assessment to identify trends and potential nonstationarities within the period of record. There are other long-term gauges in the Lake Okeechobee watershed, but these gauges were not selected because they are not influenced by climate change but by human activity that could affect the frequency and magnitude of flood flows – for example, water management activities, agricultural practices, changes in land use, and water control structure operations. The drainage area for Fisheating Creek has largely remained a natural basin and unchanged over time with little change to land use, drainage, and flood control infrastructure.

Trends in peak streamflow may provide supporting evidence of climate change. The analysis focuses on high flows because the purpose of the IRL-S project is to improve the quantity, timing, and distribution of water flows to Lake Okeechobee and the estuaries by capturing high flows into Lake Okeechobee and releasing the flows in a manner that will provide optimal benefits to the downstream system. Because Lake Okeechobee stages and inflows, the lake are highly regulated, other variables relevant to the study purpose, such as reservoir elevations and flow durations, are highly influenced by water management decisions for Lake Okeechobee and the contributing watershed. Peak streamflow may also impact flood risk reduction and ecosystem restoration projects, making it important to the Flood Risk Reduction and Ecosystem Restoration USACE business lines.

Using the CHAT, a first-order statistical analysis of trends in observed, peak streamflow data was conducted using data from Fisheating Creek U.S. Geological Survey (USGS) gauge 2256500 at Palmdale, Florida (see **Figure H-16**). The tool applies a linear regression analysis to the observed data to estimate the probability values and goodness of fit.

Figure H-16. Location of the Fisheating Creek at Palmdale Gauge (USGS 02256500).

The p-value associated with trendline of the streamflow data is estimated as 0.053 by the CHAT tool (**Figure H-18)**, which is slightly higher than the accepted threshold for significance of 0.05. The 0.05 threshold indicates that the trendline has a statistically significant trend. This result shows evidence that there might be a decreasing trend in the historically observed peak flow data over the period of record 1932-2014.

02256500 FISHEATING CREEK AT PALMDALE, FL

LOCATION - Lat 26°55'56", long 81°18'54" referenced to North American Datum of 1927, in SW 1/4 sec.03, T.41 S., R.30 E., Glades County, FL, Hydrologic Unit 03090103, near right bank on downstream side of southbound bridge on U.S. Highway 27, 1.0 mi south of Palmdale, and 16 mi upstream from Lake Okeechobee.

DRAINAGE AREA - 311 mi².

SURFACE-WATER RECORDS

PERIOD OF RECORD - April 1931 to current year.

REVISED RECORDS - WRD FL-66-2: Drainage area.

GAGE - Water-stage recorder and data-collection platform. Datum of gage is 27.19 ft above NGVD of 1929 and 25.91 ft below NAVD of 1988. Prior to Mar. 16, 1949, nonrecording gage and Mar. 16, 1949, to Jan. 23, 1956, water-stage recorder, at site 450 ft upstream at same datum.

COOPERATION - This gage is monitored in cooperation with the US Army Corps of Engineers Jacksonville District and the Florida Department of Agriculture and Consumer Services.

Figure H-17. Pertinent data from USGS for Fisheating Creek at Palmdale gauge 02256500.

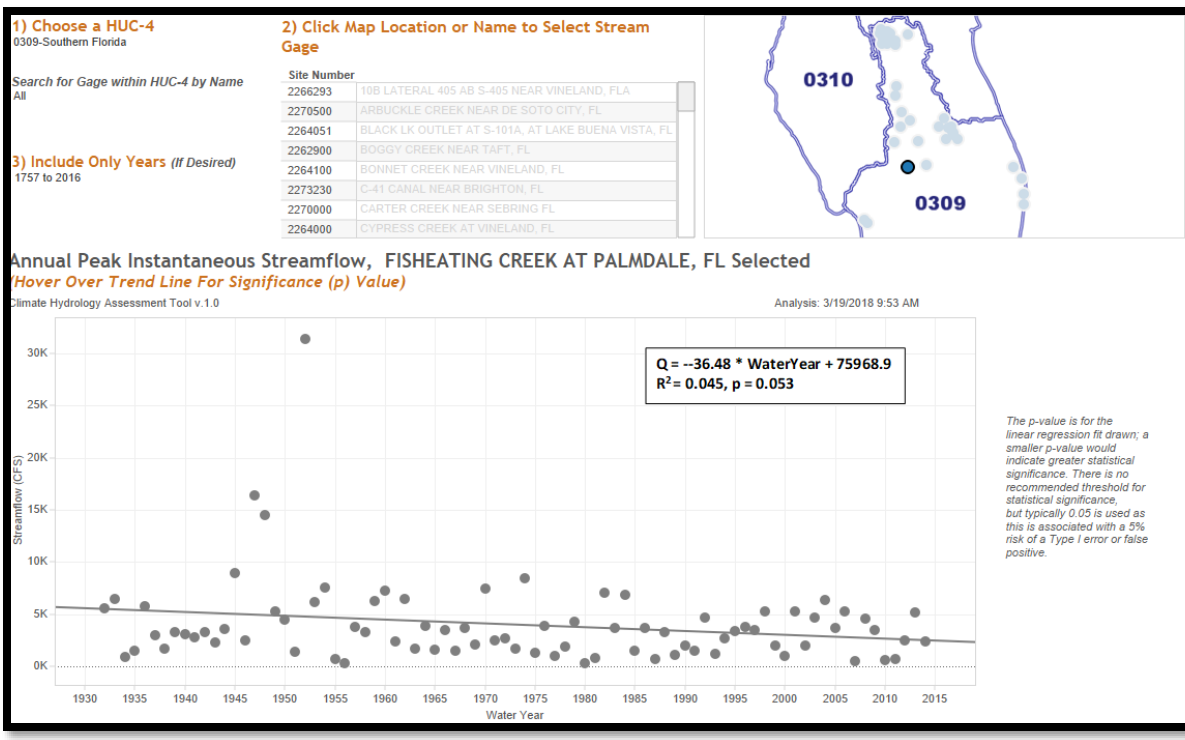


Figure H-18. Climate Hydrology Assessment Tool output using annual instantaneous peak discharge at Fisheating Creek gauge; HUC04 Southern Florida Basin (HUC 0309).

H.3.2.1.2 Projected Trends

Projected, future streamflow datasets are identified at a HUC04 watershed scale. The IRL-S project is located within the HUC04 southern Florida Basin 0309 (HUC 0309). **Figure H-19** displays the range of projected, unregulated, annual maximum monthly flows computed by 93 different combinations of GCM outputs generated using different concentration pathways of greenhouse gas emissions. Climate-changed hydrology is generated for a period of 2000-2099 for the HUC044 Basin 0309 (Southern Florida). There is a consistent range in the projected annual maximum monthly flows in **Figure H-19**. This range is representative of the uncertainty, such as future rainfall, evapotranspiration, and groundwater levels associated with climate-changed hydrology. Because of Florida's unique hydrology, with streamflow highly influenced by surface water and groundwater interactions, the uncertainty in projected streamflow is high.

The CHAT also provides the graphical representation of projected annual maximum monthly range based on the used models. The graph in **Figure H-19** displays the range of projected, unregulated annual maximum monthly flows for the HUC04 southern Florida Basin 0309 (HUC 0309). In the figure, the range of variations for the 93 projections of the annual maximum flows is represented by yellow polygons, while the mean of all 93 projections is shown in blue line. In addition to the uncertainties in the modeled hydrometeorological variables, the estimated ranges by the CHAT are subject to many uncertainties including errors in temporal downscaling, spatial downscaling, hydrologic modeling, emissions scenarios, and GCMs themselves.

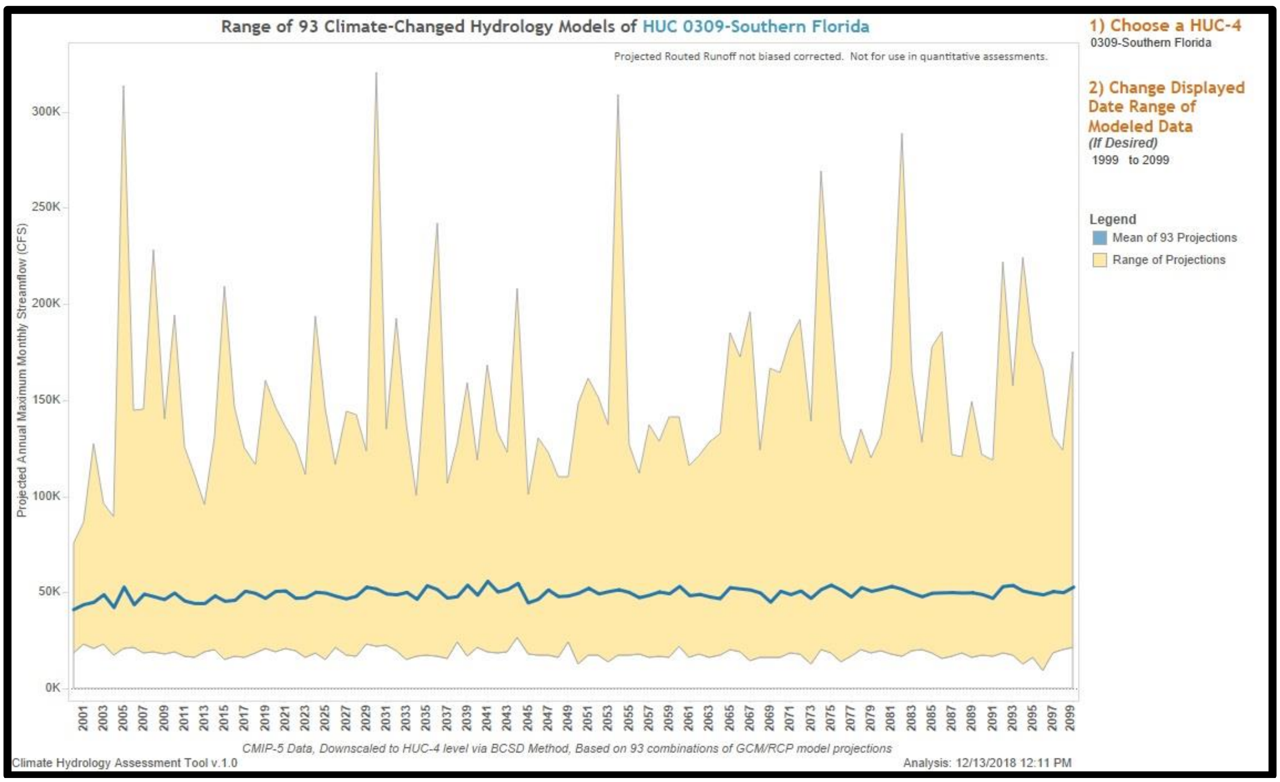


Figure H-19. Range of projected annual maximum monthly streamflow in HUC04 Southern Florida Basin HUC0309.

A statistical analysis of the projected hydrology for 2000-2099 indicates a statistically significant linear trend of increasing average annual maximum monthly flows (**Figure H-20**). This increase is statistically significant (p-value < 0.05) and suggests the potential for future increases in streamflow relative to current conditions. This trend is not consistent with the literature as the literature projects no change in streamflow.

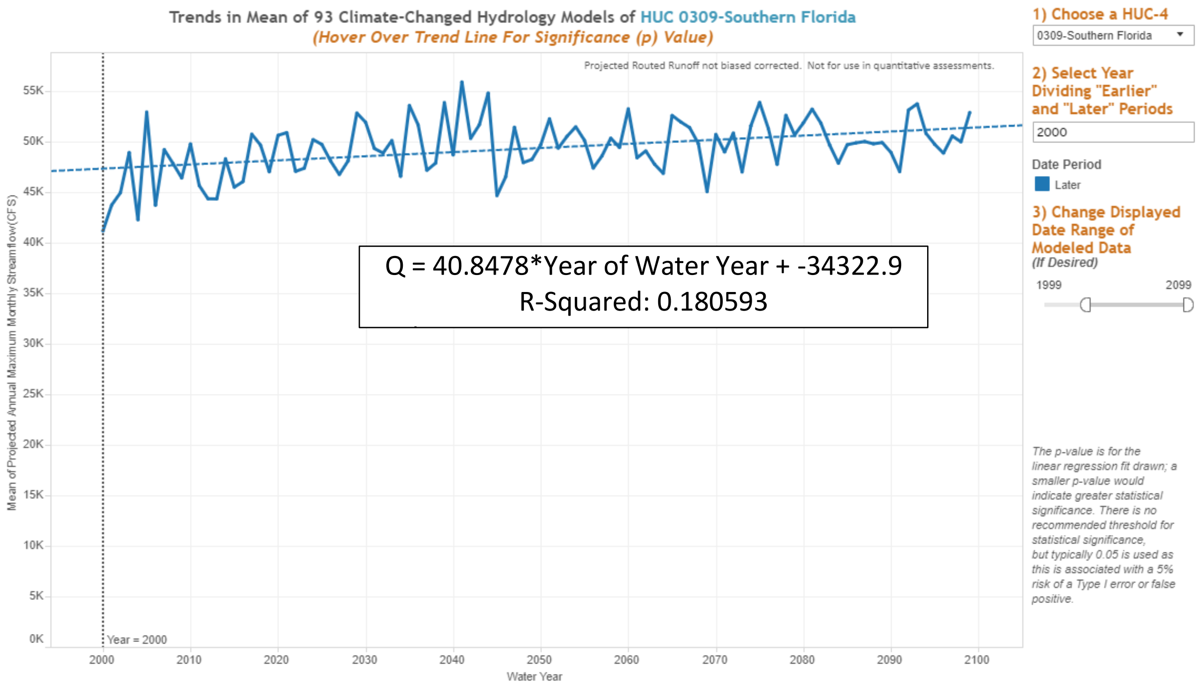


Figure H-20. Trends in projected mean annual maximum monthly streamflow in Southern Florida Basin (HUC04 0309).

H.3.2.2 Nonstationarity Detection (NSD) Tool

The Nonstationarity Detection Tool (NSD) was developed to support ETL 1100-2-3. The USACE developed the tool to enable users to detect abrupt and slowly varying changes (nonstationarities) in observed, annual instantaneous peak discharges at USGS streamflow gauges with over 30 years of record. The tool allows users to conduct monotonic trend analysis on the data and any resulting subsets of stationary flow records identified. The tool can be accessed at https://corpsmapz.usace.army.mil/apex/f?p=257:10:0::NO.

The NSD was utilized for the Fisheating Creek USGS gage 2256500 at Palmdale, FL in accordance with ECB 2018-14. The tool analyzes whether the assumption of stationarity, which is the assumption that statistical characteristics of time-series data are constant over the period of record, is valid for a given hydrologic time-series data set. Similar to the CHAT analysis, the Fisheating Creek gage was selected because it has the longest unregulated period of record of any streamflow gage within the Lake Okeechobee watershed. Similar to the observed CHAT assessment, an assessment of observed streamflow data is conducted to determine if there is supporting evidence of climate change at this gauge.

Figure H-21 shows the results from the tool's period of record 1932-2014. The statistical methods collectively identified nonstationarities in two different years: 1953 and 1963, for the period of record 1932-2014. The nonstationarities were identified using the Energy Divisive Method for 1963 and the Lombard Wilcoxon Method for 1953. The Energy Divisive Method detected a change in the underlying distribution of the data. The Lombard Wilcoxon Method detected a change in the average value, or mean, of the data. None of the statistical methods detected abrupt or smooth changes in the data.

A “strong” nonstationarity is one for which there is a consensus among a minimum of three nonstationarity detection methods (more than one test flagging a nonstationarity targeted at the same statistical property), robustness in detection of changes in statistical properties (tests flagging nonstationarities targeted at different statistical properties), and relatively large change in the magnitude of a dataset’s statistical properties (mean or standard deviation). Based on these criteria, neither the 1953 nor 1963 event is considered a strong change point. They do not meet the criteria for consensus, robustness, and magnitude, and are not considered statistically significant.

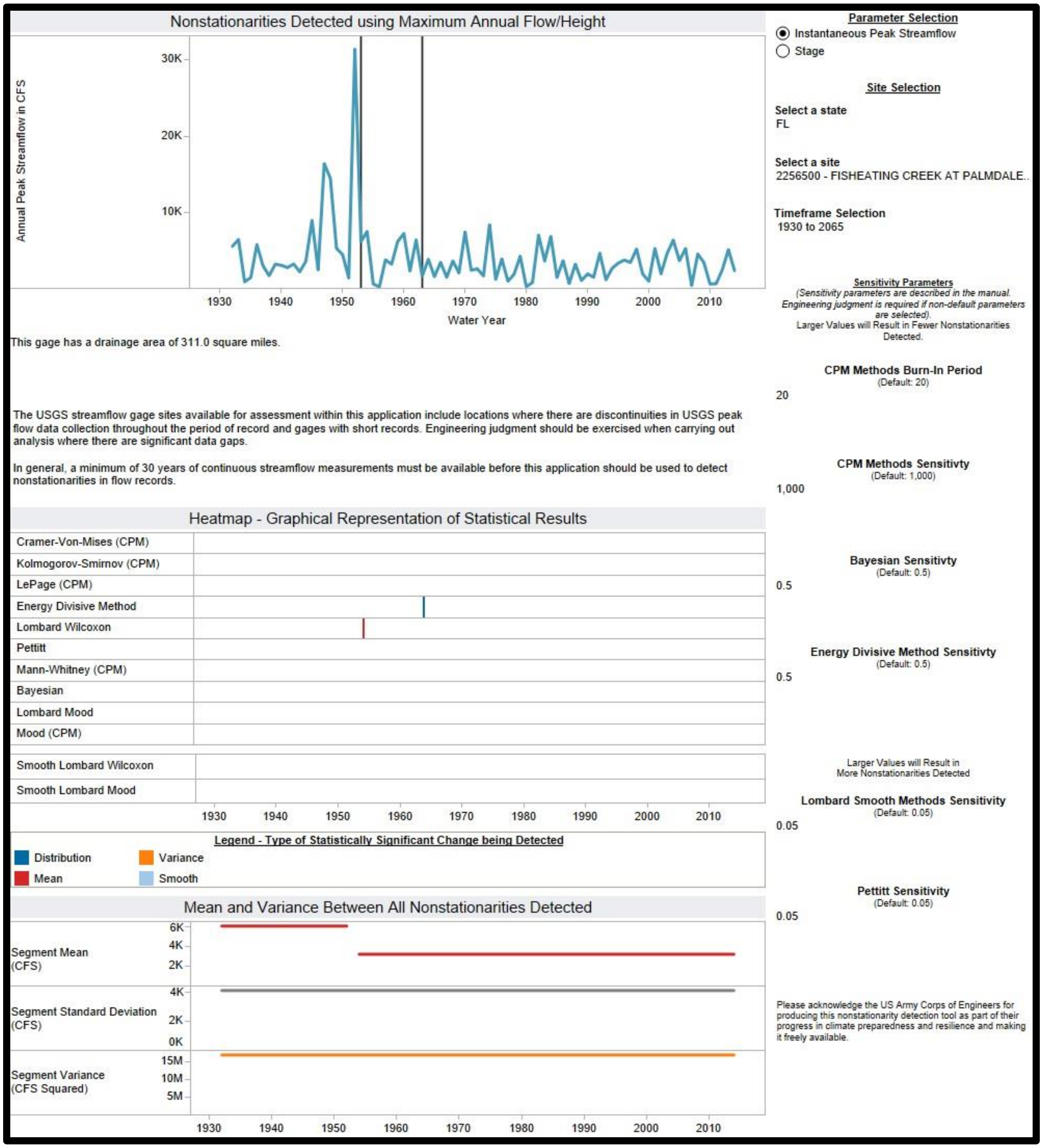


Figure H-21. Output from Nonstationarity Detection tool – Fisheating Creek at Palmdale.

H.3.2.2.1 Monotonic Trend Analysis

A monotonic trend analysis was conducted to identify statistically significant trends in peak streamflow. Detected nonstationarities are used to subdivide the period of record into stationary subsets, each of which were tested for the presence of monotonic trends. If no statistically significant nonstationarities are identified within an annual instantaneous peak streamflow dataset, then the entire period of record could be assessed for monotonic trends. Because the nonstationarities identified are not considered statistically significant, the entire period of record of 1932-2014 was assessed. **Figure H-22** shows a monotonic trend analysis using the Mann-Kendall Test and Spearman Rank Order test for time period 1932-2014. No statistically significant trend in annual peak streamflow was detected for the period of record.

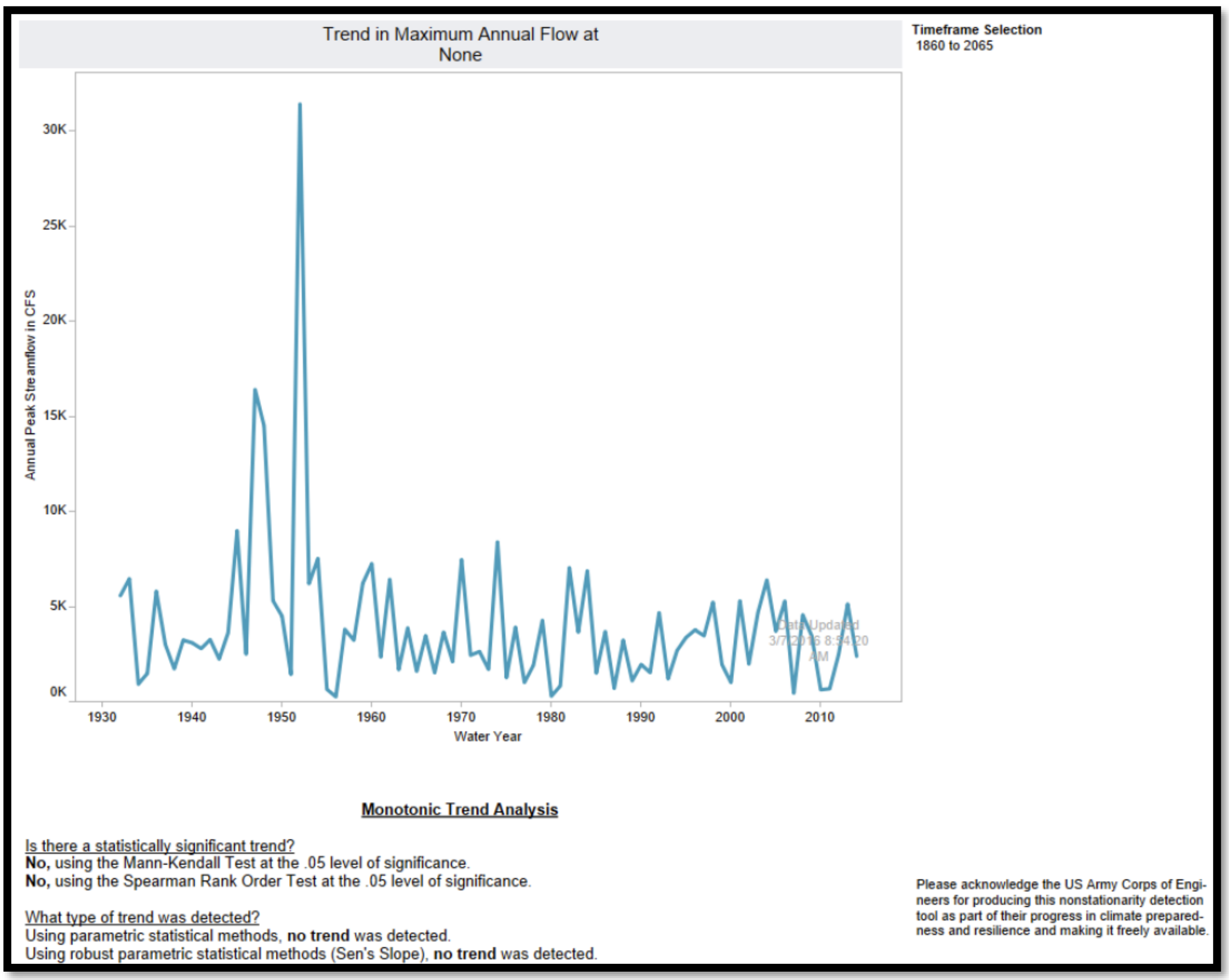


Figure H-22. Monotonic trend analysis results.

H.3.2.3 The USACE Watershed Vulnerability Assessment Tool

The USACE Watershed Vulnerability Assessment (VA) Tool provides a nationwide, screening-level assessment of climate change vulnerability relating to USACE mission, operations, programs, and projects. Indicators are used to develop vulnerability scores specific to each of the 200 watersheds within the contiguous United States and to each USACE business line. The Weighted Order Weighted Average (WOWA) method is used to aggregate individual vulnerability indicators and their associated datasets into the watershed-scale vulnerability scores. The WOWA score combines indicators using a weighting technique to control how much an indicator with a small value can average out an indicator with a large value, thereby affecting perceived vulnerability. The VA Tool is based on downscaled climate information and hydrology aggregated at the watershed level for selected indicator variables. The tool supports a qualitative identification of potential vulnerabilities for more detailed study (USACE, 2016).

The VA Tool examines the vulnerability of projects within all USACE business lines using data for two scenarios and three epochs. The epochs include the current time period as the base period and two future 30-year periods centered on the years 2050 (2035-2065) and 2085 (2070-2099). Within each future epoch, GCMs are sorted by cumulative runoff projections and divided into two equal-sized groups that represent a Dry scenario and a Wet scenario. All results are thus given for each combination of scenario and future epoch: Dry-2050, Dry-2085, Wet-2050, and Wet-2085. The VA Tool allows the user to explore dominant indicators and summarize vulnerability in several different ways for each scenario/epoch combination. The current study will use the VA Tool to perform such an analysis on southern Florida (HUC 0309), which includes the IRL-S project, with emphasis on the indicators of vulnerability for the primary business line, Flood Risk Reduction. Additional analysis was also performed relative to the project’s secondary business line, Emergency Management. It is recognized that other USACE business lines such as Ecosystem Restoration are important to the project, however, Flood Risk Reduction and Emergency Management are the only business lines with indicators that drive vulnerability within the VA Tool (USACE, 2016).

Table H-7 provides the number and name of selected indicators for the Flood Risk Reduction business line within the Vulnerability Assessment Tool within a National Standard View, along with a brief description of each.

Table H-7. Number, name, and description of selected indicators for the Flood Risk Reduction Business Line within the Vulnerability Assessment Tool.

Number	Name	Description
175C	ANNUAL_COV	Long-term variability in hydrology: ratio of the standard deviation of annual runoff to the annual runoff mean. Includes upstream freshwater inputs (cumulative).
277	RUNOFF_PRECIP	Percent change in runoff divided by percent change in precipitation.
568C	FLOOD_MAGNIFICATION	Change in flood runoff: ratio of indicator 571C (monthly runoff exceeded 10% of the time, including upstream freshwater inputs) to 571C in base period.
568L	FLOOD_MAGNIFICATION	Change in flood runoff: Ratio of indicator 571L (monthly runoff exceeded 10% of the time, excluding upstream freshwater inputs) to 571L in base period.
590	90PERC_EXCEEDANCE	Acres of urban area within 500-year floodplain.

To set the context of this watershed nationally, within the USACE South Atlantic Division (SAD), and within the Jacksonville District (SAJ), **Table H-8** lists the vulnerability scores for the Flood Risk Reduction business line for HUC 0309 as well the range of scores nationally and for SAD and SAJ for all scenario-epoch combinations in the form of the Weighted Order Weighted Average (WOWA). Vulnerability of the Flood Risk Reduction business line within HUC 0309 for the Dry scenarios appears to be ranked near the top in all cases; in fact, HUC 0309 is ranked highest within its district and division. When looking at the Wet scenario for the same business line, HUC 0309 is slightly above average for both epochs when compared to the rest of the nation. **Figure H-23** reveals that the VA tool classifies HUC 0309 as vulnerable for all scenario-epoch combinations for the Flood Risk Reduction business line when compared to the rest of the nation (top 20%). These results suggest that climate change impacts must be considered in the planning and design of flood risk reduction within HUC 0309, including the IRL-S.

Table H-8. Vulnerability Scores for HUC 0309 (Column 3) for the Flood Risk Reduction business line for each scenario-epoch combination nationally, SAD and SAJ.

Business Line	Scenario - Epoch	WOWA Score	National Range	Range in SAD	Range in SAJ
Flood Risk Reduction	Dry – 2050	67.07	35.15 – 70.08	41.53 – 68.18	44.88 – 68.18
	Dry – 2085	68.18	35.15 – 70.08	41.53 – 68.18	44.88 – 68.18
	Wet – 2050	70.46	39.80 – 92.85	46.76 – 71.78	49.40 – 71.18
	Wet – 2085	71.78	39.80 – 92.85	46.76 – 71.78	49.40 – 71.18

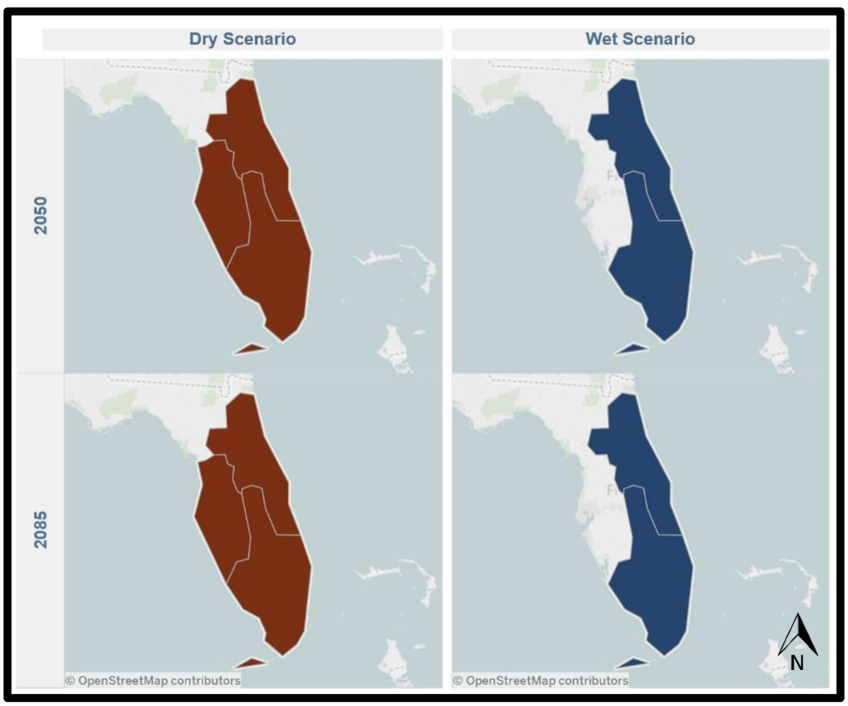


Figure H-23. SAD watersheds identified as vulnerable for the Flood Risk Reduction business line for all scenario-epoch combinations (Dry-2050, Dry-2085, Wet-2050, and Wet-2085).

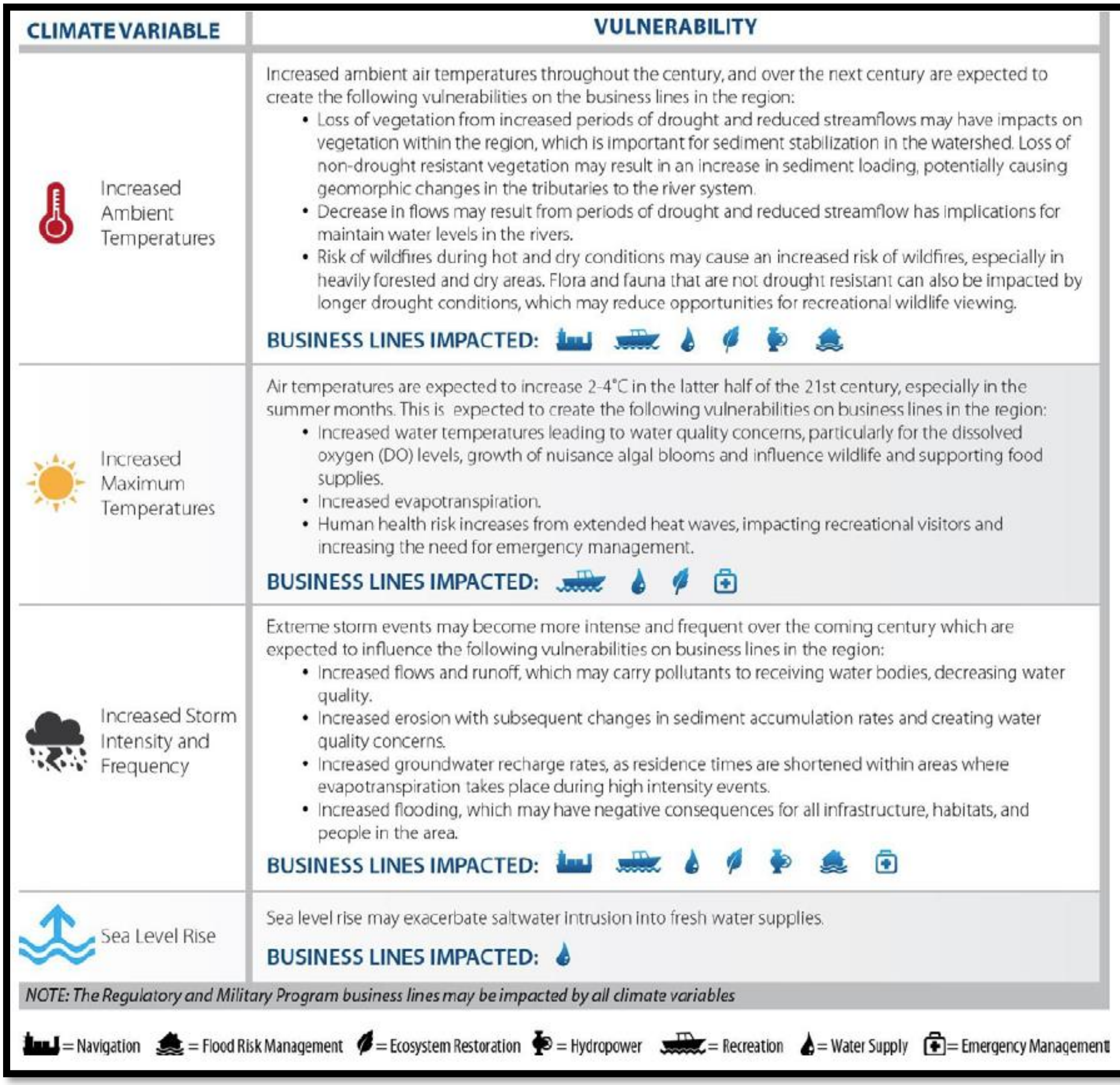
The next step of the vulnerability assessment is to understand which indicators drive the vulnerability of the IRL-S in HUC 0309 in terms of the Flood Risk Reduction business line and how their individual values are projected to change between epochs. **Table H-9** provides the absolute values of each indicator for both scenarios and epochs, along with their percent contribution to the overall vulnerability score of each scenario-epoch combination. The indicator that dominates vulnerability in both scenarios is Indicator #590 (area of the 500-year floodplain), which contributes near 61% for both epochs in the Dry scenario and near 57% for both epochs in the Wet scenario. See **Table H-7** for more detailed indicator definitions. Note that, in all cases, Indicators #568C and #568L have values greater than 1 (1.03 and 1.02 in the Dry scenario and 1.28 and 1.27 in the Wet scenario for the 2050 and 2085 epochs, respectively), which indicates positive increases in future flood flows for both the dry and wet scenarios.

Table H-9. The values/percent contribution to vulnerability of each indicator associated with the Flood Risk Reduction business line for all scenario-epoch combinations along with the percent change between epochs for each scenario.

Number	Dry-2050	Dry-2085	Percent Change	Wet-2050	Wet-2085	Percent Change
175C	0.34/2.97	0.33/2.86	-2.21	0.31/2.58	0.32/2.63	4.47
277	2.00/10.65	1.99/10.44	-0.62	2.04/6.57	2.12/6.60	3.99
568C	1.03/19.45	1.02/19.98	-0.78	1.28/22.63	1.27/22.07	-0.66
568L	1.03/6.38	1.02/6.23	-0.78	1.28/11.44	1.27/11.15	-0.66
590	687.6/60.55	849.4/61.48	23.54	687.6/56.78	849.4/57.54	23.54

Indicator #590 suggests that consideration should be given to devising the steps in the planning and design phases of the IRL-S project that will reduce the vulnerability of the project to a growing urban 500-year floodplain. Further discussion on increased population trends is discussed in Appendix G, Section 6 of this report.

USACE projects are varied, complex, and often encompass multiple business lines. The relationships among these business lines, with respect to impacts from climate change, are complicated, with cascading effects. Such interrelationships must be recognized as an essential component of future planning efforts when considering the best methods or strategies to adapt. Flood Risk Reduction and Emergency Management are the only business lines with indicators that drive vulnerability within the VA Tool (USACE, 2016). There are, however, other business lines that may be impacted by changes in climate variables in central and south Florida: Ecosystem Restoration, Navigation, Water Supply, and Recreation. **Figure H-24** summarizes the projected climate trends and impacts on each of the USACE business lines (USACE, 2015).



CLIMATE VARIABLE	VULNERABILITY
Increased Ambient Temperatures	Increased ambient air temperatures throughout the century, and over the next century are expected to create the following vulnerabilities on the business lines in the region: • Loss of vegetation from increased periods of drought and reduced streamflows may have impacts on vegetation within the region, which is important for sediment stabilization in the watershed. Loss of non-drought resistant vegetation may result in an increase in sediment loading, potentially causing geomorphic changes in the tributaries to the river system. • Decrease in flows may result from periods of drought and reduced streamflow has implications for maintain water levels in the rivers. • Risk of wildfires during hot and dry conditions may cause an increased risk of wildfires, especially in heavily forested and dry areas. Flora and fauna that are not drought resistant can also be impacted by longer drought conditions, which may reduce opportunities for recreational wildlife viewing. **BUSINESS LINES IMPACTED:**
Increased Maximum Temperatures	Air temperatures are expected to increase 2-4°C in the latter half of the 21st century, especially in the summer months. This is expected to create the following vulnerabilities on business lines in the region: • Increased water temperatures leading to water quality concerns, particularly for the dissolved oxygen (DO) levels, growth of nuisance algal blooms and influence wildlife and supporting food supplies. • Increased evapotranspiration. • Human health risk increases from extended heat waves, impacting recreational visitors and increasing the need for emergency management. **BUSINESS LINES IMPACTED:**
Increased Storm Intensity and Frequency	Extreme storm events may become more intense and frequent over the coming century which are expected to influence the following vulnerabilities on business lines in the region: • Increased flows and runoff, which may carry pollutants to receiving water bodies, decreasing water quality. • Increased erosion with subsequent changes in sediment accumulation rates and creating water quality concerns. • Increased groundwater recharge rates, as residence times are shortened within areas where evapotranspiration takes place during high intensity events. • Increased flooding, which may have negative consequences for all infrastructure, habitats, and people in the area. **BUSINESS LINES IMPACTED:**
Sea Level Rise	Sea level rise may exacerbate saltwater intrusion into fresh water supplies. **BUSINESS LINES IMPACTED:**

NOTE: The Regulatory and Military Program business lines may be impacted by all climate variables

= Navigation = Flood Risk Management = Ecosystem Restoration = Hydropower = Recreation = Water Supply = Emergency Management

Figure H-24. Summary of projected climate trends and impacts on USACE business lines (USACE, 2015).

H.3.3 Risk Assessment

The climate hydrology vulnerability assessment results for the project indicate that it is in a relatively susceptible watershed. There are some observed and projected climate trends based on the literature review and the statistical analysis conducted using the hydrologic tools. The watershed is most vulnerable to increases in extreme storm frequency and intensity and increases in air temperature. There is statistical evidence that suggests the potential for future increases in streamflow relative to current conditions; however, no significant nonstationarities were detected for observed flow records.

The vulnerability assessment tool identified the USACE Flood Risk Management Business line as the most vulnerable. There are however other business lines that may be impacted by changes in climate variables. These changes could have an impact on Ecosystem Restoration, Navigation, Water Supply, Recreation, and Emergency Management business lines in central and south Florida.

Per guidance in ECB 2018-14, **Table H-10** identifies risk resulting from changed climate conditions in the future. The table shows the major project feature, the trigger event (climate variable that causes the risk), the hazard (resulting dangerous environmental condition), the harms (potential damage to the project or changed project output), and qualitative assessment of the likelihood and uncertainty of this harm. Note that not all impacts of climate change will result in increased risk, as there may be enhanced project benefits.

Increases in extreme storm frequency and intensity and increases in temperatures present risks to the project features. Increased precipitation may lead to increased flows and larger flood volumes and potential risk to the project's levees and higher likelihood of increased freshwater discharges to the estuaries. Increased temperatures may lead to decreased flows, drought, reduced benefits to IRL-S and restored wetlands.

Based on the vulnerability assessment, it is recommended that the project account for risk in climate change by including resiliency and adaptation measures in the project design cost to account for the risk associated with the impact of climate change for the duration of the project life cycle. This includes the design and operations to handle extreme wet and dry conditions, including floods and droughts. This will ensure that the plan selected is robust enough to accommodate changing climatic conditions. However, for the planning phase, climate change and resilience are incorporated as conservative assumptions considered during planning level design.

If sea level rise trends increase significantly, or if an increase in the frequency of extreme storm events increases the design events used for IRL-S design efforts prior to IRL-S full implementation, or if drought conditions increase, then future resiliency and adaptation measures to the area served by the project could include:

1. Modification of operations of project structures, especially during the wet/dry season.
2. Additional water control structures/pump stations may be added to provide increased flexibility to maintain design capacity.

Although this is a less probable scenario, the likelihood and potential impact of this risk has been considered during the evaluation of the project contingency.

Table H-10. Risk assessment.

Feature or Measure	Trigger	Hazard	Harm	Qualitative Likelihood
Reservoirs & STAs	Increased Sea Level	Future sea-level elevation may be greater than present.	Hydraulic structure capacities may be reduced due to higher water levels in the canals located upstream of tidal structures.	Somewhat Likely
Reservoirs & STAs	Increased extreme precipitation	Future flood volumes may be greater than present.	Increased flood volumes may result in underperformance of the features. Flood waters may damage levees.	Somewhat Likely
Reservoirs & STAs	Increased temperatures	Increased evapotranspiration or drought	Decrease in flows may result in lower reservoir stages, resulting in reduced effectiveness for seepage management, resulting in loss of habitat and vegetation and reducing project benefits.	Somewhat Likely
Water Control Structures	Increased Sea Level	Future sea-level elevation may be greater than present.	Increased sea levels may reduce the discharge capacities of water control structures near the coast	Likely
Water Control Structures	Increased extreme precipitation	Future flood volumes may be greater than present.	Increased flood volumes may exceed the capacity of the existing water control structures, causing flood waters have higher elevations and longer hydroperiods.	Somewhat Likely
Water Control Structures	Increased temperatures	Increased evapotranspiration or drought	Decrease in flows may not supply the structures with necessary volume, reducing project benefits, and exacerbating increased salinity due to SLC	Somewhat Likely
Water Supply / Storage Areas	Increased temperatures	Increased evapotranspiration or drought	Decrease in flows may increase water supply cutbacks from water supply reservoirs / storage features	Somewhat Likely

Feature or Measure	Trigger	Hazard	Harm	Qualitative Likelihood
Water Supply / Storage Areas	Increased Sea Level	Future sea-level elevation may be greater than present.	Increased SLC may cause some groundwater wells to become unusable due to increased salinity, decreasing water supply; increased regional deliveries from Lake Okeechobee may be required to maintain freshwater head, which may reduce water quantity to the natural systems.	Likely

H.4 Summary Findings

These are the summary findings of the climate change assessment:

1) IRL-S is vulnerable to climate change and at risk over the project life cycle (2030-2130) due to the following factors: increasing air temperatures, increases in extreme storm frequency and intensity, increasing streamflow, and rising sea-level elevations.
2) A quantitative climate assessment of SLC was conducted per ER 1110-2-8162 using a USACE statistical tool that projects future SLC.
3) A future with IRL-S provides more resiliency to changes due to SLC than a future without IRL-S. The proposed features will provide operational flexibility to better manage the timing and volume of the releases.
4) The IRL-S project provides substantially higher habitat functionality when compared to the future without in part due to the increased freshwater flows. However, SLC impacts to IRL-S may decrease freshwater habitat in the future due to increased sea levels. Over time, freshwater ecosystem may transition to estuarine caused by increased salinity, and eventually to marine in some extreme SLC scenarios.
5) SLC will be an important factor to monitor in throughout the life of the project to ensure IRL-S benefits can be maintained as long as possible into the future. Since IRL-S is part of a much larger water management system, other parts of the system may begin to feel the impacts of SLC earlier than IRL-S, which could have a cascading effect, potentially impacting the operations of IRL-S features. Additionally, IRL-S features may become impacted sooner than SLC projections predict due to the combination of more frequent tropical cyclone events. This indirect SLC effect may prompt the need for a more detailed regional SLC analysis on the entire C&SF system.
6) A qualitative climate change assessment of inland hydrology was conducted per ECB 2018-14 using USACE statistical tools that evaluate observed and future climate trends.
7) No statistically significant climate change trends were identified that would alter the overall hydrologic evaluations used in support of the validation report.
8) Based on the vulnerability assessment, it is recommended that the project account for risk in climate change by including resiliency and adaptation measures in the project design to account for the risk associated with the impact of climate change for the duration of the project life cycle. This includes the design and operations to handle extreme wet and dry conditions, including floods and droughts. This will ensure that the selected plan is robust enough to accommodate changing climatic conditions. The VA Tool identified the USACE Flood Risk Management business line as the most vulnerable.
9) Currently, climate change has been incorporated into the project design (C-23/24 STA DDR), and project cost contingency through the cost and schedule risk analysis for the IRL-S Validation Report. Because of the complex interaction between the IRL-S project and the C&SF Project structures, adaptations will need to be assessed for the C&SF Project to address questions about the performance and operation of the IRL-S. The project team acknowledges an assessment of the C&SF Project is outside of the IRL-S scope and that resiliency and adaptive management in IRL-S cannot be fully addressed without a comprehensive assessment of the larger C&SF Project.

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