APPENDIX G
LOWRP BENEFIT MODEL

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G LAKE OKECHOBEE WATERSHED RESTORATION PROJECT (LOWRP) BENEFIT MODEL

This appendix describes the documents and methodology used to quantify ecological benefits and support plan evaluation, comparison, and selection for the LOWRP.

G.1 Model documentation

The Department of the Army ER 1105-2-100, "Planning Guidance Notebook," requires that ecosystem restoration planning contribute to national ecosystem restoration (NER), which is measured in terms of increases in the net quantity and/or quality of desired ecosystem resources. The USACE uses NER benefits as the basis to compare alternatives and select plans for ecosystem restoration projects. The LOWRP planning model underwent peer review per EC 1105-2-412, "Assuring Quality of Planning Models," and was recommended for single-use on LOWRP by the National Ecosystem Restoration Planning Center of Expertise (ECO-PCX) on 12 January 2018.

G.2 Overview of LOWRP Planning Model

The LOWRP planning model was specifically developed to evaluate project alternatives within the LOWRP project domain (ecoregion and/or watershed in south Florida). The primary areas to be evaluated include the sub-basins north of Lake Okeechobee (Fisheating Creek, Indian Prairie, Kissimmee River, and Taylor Creek/Nubbin Slough), Lake Okeechobee, and the Northern Estuaries (St. Lucie River and the Caloosahatchee River and Estuary). The LOWRP planning model was developed by USACE-Jacksonville District with support from multiple federal, state, and local agencies including the Fish and Wildlife Service (FWS), Environmental Protection Agency (USEPA), South Florida Water Management District (SFWMD), Florida Fish and Wildlife Commission (FWC), Florida Department of Environmental Protection (FDEP), Natural Resources Conservation Service (NRCS), Lee County, and Martin County. Members of the PDT include subject matter experts on Lake Okeechobee and estuary flora and fauna, with extensive experience working in south Florida and Everglades wetland systems in the fields of ecology, hydrology, engineering, and planning.

Performance measures (PMs) were used to document the linkage between hydrologic output from models and ecosystem functions to evaluate the degree to which alternative plans met restoration objectives. Each of the PMs were updated from the prior Lake Okeechobee Watershed project based on the availability of new tools, changes to the landscape, updated knowledge on the system from peer reviewed literature and technical reports, and RECOVER review comments. RECOVER is the interagency system-wide science team that supports CERP projects. It is made up of Everglades scientists independent of the PDT. Several of the project PMs for the LOWRP planning effort were derived from those PMs approved for use in CERP by RECOVER. Each PM has a predictive target or comparable performance scores and process for how to measure predicted performance of alternatives. Targets were based on peer-reviewed relationships between hydrology and ecological species or communities, and technical synthesis reports of multiple data sources identifying restored conditions in Lake Okeechobee, the sub-basins, and the St. Lucie and Caloosahatchee estuaries. PM scores were displayed as a function of restoration potential or achievement of the target. Habitat unit (HU) scores were produced by indexing the scores 0-1. The indexed scores were then multiplied by their proportion of the total index score for a given ecological zone and then multiplied by the area to get the HUs. HUs are then evaluated for the Existing Conditions Baseline (ECB), FWO condition, and project alternatives, to identify the best performer for each zone and the whole LOWRP area.

G.2.1 Description of Project Performance Measures

Four PMs were developed to measure three restoration objectives (**Table G-1**) for LOWRP within three ecological zones (**Table G-2**):

1. **PM 1 Wetland Restoration** – Measuring potential wetland benefits of managing hydrologic regimes for major plant communities and reconnecting natural areas.
2. **PM 2 Lake Okeechobee** – Hydrologic regimes in Lake Okeechobee specific to three criteria (1-Lake stage envelope; 2-Extreme high and low lake stage; 3-Ecological indicators).
3. **PM 3 Caloosahatchee Estuary Salinity** – Seasonal flows to manage salinity in the Caloosahatchee Estuary to benefit native flora and fauna.
4. **PM 4 St. Lucie Estuary Salinity** – Seasonal flows to manage salinity in the St. Lucie Estuary to benefit native flora and fauna.

The complete RECOVER-approved Performance Measure Documentation Sheets are located in **subsection G.12**.

Table G-1. LOWRP objectives linked to PMs.

LOWRP Objective	PM 1 – Wetland Restoration	PM 2 – Lake Okeechobee Stage	PM 3 – Caloosahatchee Estuary Salinity	PM 4 – St. Lucie Estuary Salinity
1. Improve timing and distribution of flows into Lake Okeechobee to maintain ecologically desired lake stage ranges.	**Yes**	**Yes**	N/A	N/A
2. Reduce flows from Lake Okeechobee to improve the salinity regime and the quality of oyster, SAV, and other estuarine community habitats in the Northern Estuaries.	N/A	N/A	**Yes**	**Yes**
3. Increase spatial extent and functionality of aquatic and wildlife habitat within Lake Okeechobee and surrounding watershed.	**Yes**	N/A	N/A	N/A

Table G-2. Ecosystem zones linked to PMs.

Ecosystem Zones	PM 1	PM 2	PM 3	PM 4
Watershed Wetlands – Freshwater Flora and Fauna	**Yes**	N/A	N/A	N/A
Lake Okeechobee	N/A	**Yes**	N/A	N/A
Estuaries – Oysters	N/A	N/A	**Yes**	**Yes**

G.2.2 Hydrologic Models Used

There are several hydrologic modeling tools that were used to provide the output used in PMs 2, 3 and 4. GIS data was used to analyze PM 1. Each of the PMs has defined metrics and targets. The PMs are hydrologic metrics based on output from regional hydrologic models. These models provided daily, detailed estimates of hydrology across the 41-year period of record (January 1965 – December 2005) and were used to evaluate system responses to project alternatives. The regional model proposed as the primary tool for the LOWRP assessment is the RSM-BN (version 2.3.2). This model was developed by the Hydrologic and Environmental Systems Modeling Section of the SFWMD.

The RSM-BN is a link-node model designed to simulate the transfer of water from a pre-defined set of watersheds, lakes, reservoirs or any waterbody that receives or transmits water to another adjacent waterbody. The model domain covers Lake Okeechobee and four major watersheds related to the northern portion of the project area: Kissimmee, Lake Okeechobee, St. Lucie River, Caloosahatchee River, and the Everglades Agricultural Area (EAA).

Output from the regional models was maintained in a data access, storage, and retrieval system managed by the SFWMD and USACE under the CERP Information and Data Management Program. Output for each PM sub-metric was readily available to project team members and was typically provided in a comma-separated-value (csv) format. Output data was also provided in chart and graphic format to aid in the assessment of restoration benefits.

PM targets were primarily based on output from the Natural System Model version 4.6.2 (NSM), which simulates the hydrologic response of a pre-drained Everglades. The NSM has been used as a planning tool in several Everglades restoration projects.

Additional documentation of the above-mentioned models can be found at https://www.sfwmd.gov/science-data/nsm-model

The hydrologic models referenced above have been validated through the USACE Engineering Model Certification process established under the Engineering and Construction (E&C) Science and Engineering Technology (SET) initiative.

G.2.3 Spatial Extent of Study Area

The study area (~920,000 acres; **Figure G-1** and **Figure G-2**) includes four major drainage basins (Fisheating Creek, Indian Prairie, Taylor Creek/Nubbin Slough, and portions of the Lower Kissimmee (S-65D and S-

65E)) within the Lake Okeechobee Watershed (PM 1; **Figure G-3**), Lake Okeechobee (PM 2), and the Northern Estuaries (Caloosahatchee (**Figure G-4**) and St. Lucie (**Figure G-5**) estuaries;).

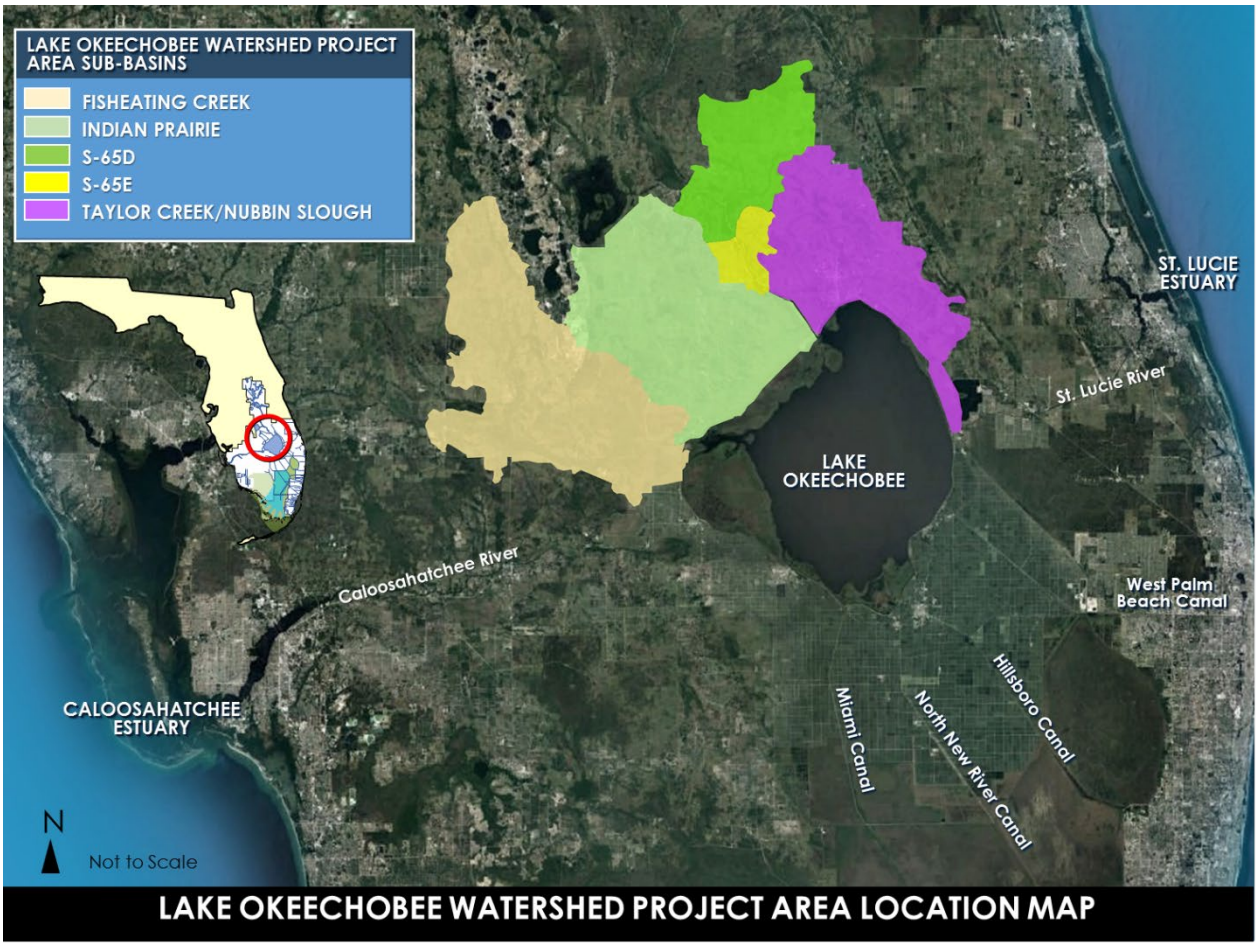

Figure G-1. Lake Okeechobee Watershed Restoration Project Area.

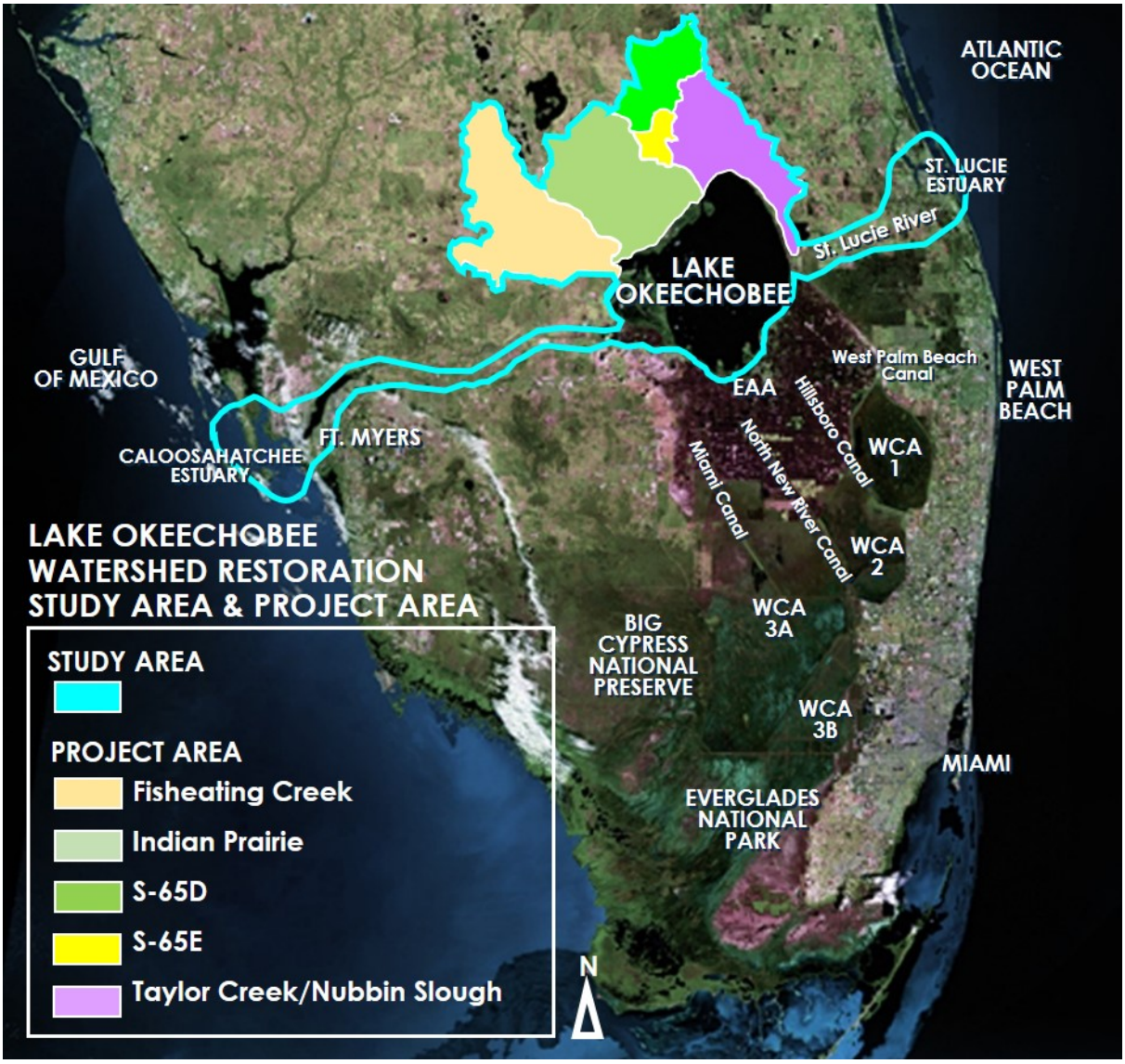

Figure G-2. LOWRP project and study area.

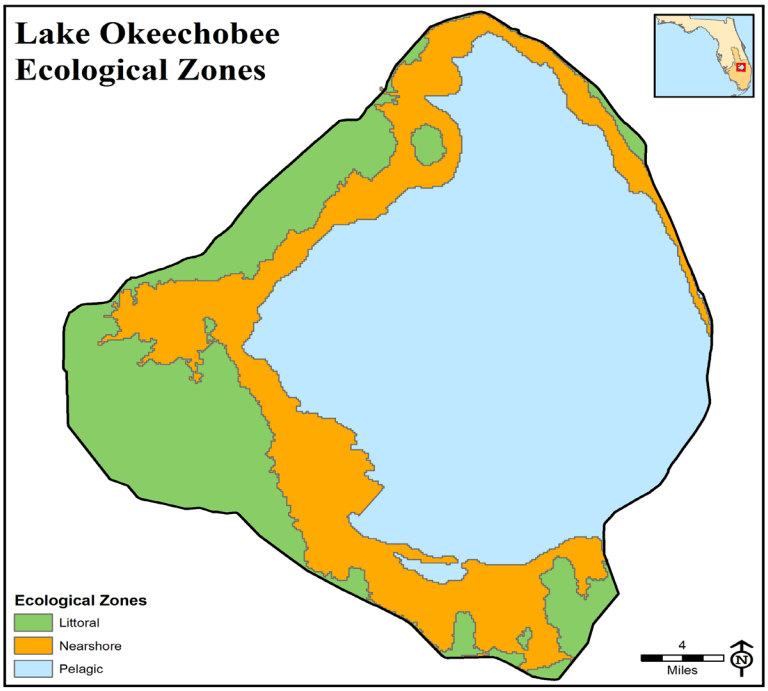

Figure G-3. Littoral, nearshore, and pelagic habitats in Lake Okeechobee (450,000 acres of littoral and nearshore habitat).

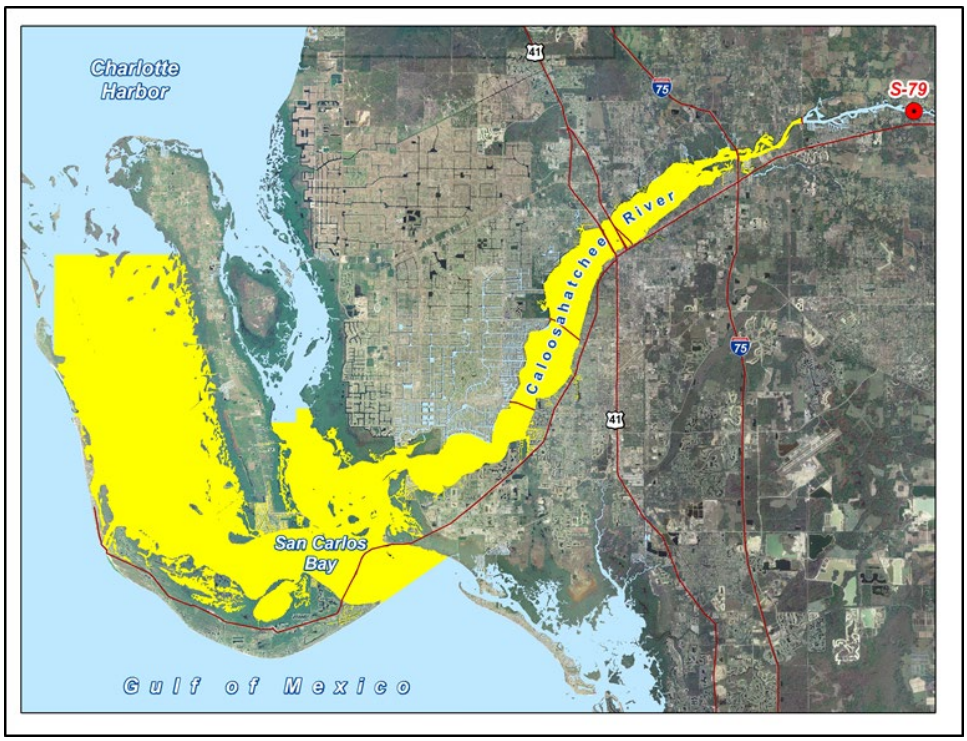

Figure G-4. Estimate of the maximum area of potential ecological benefit for the Caloosahatchee Estuary (70,979 acres).

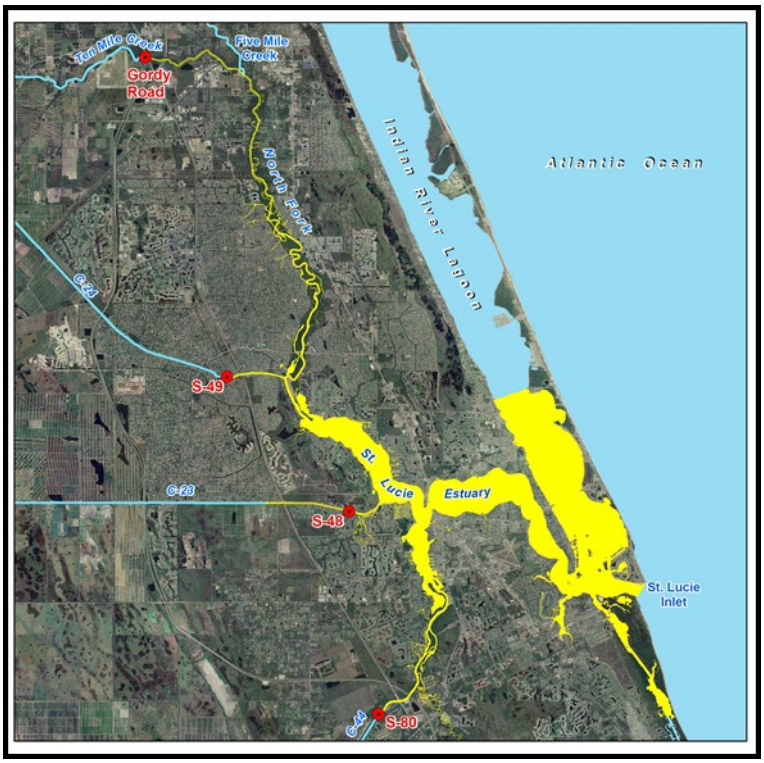

Figure G-5. Estimate of the maximum area of potential ecological benefit for the St. Lucie Estuary (14,994 acres).

G.3 Wetland Restoration Benefit Calculations

Historically, the LOWRP area was about 40 percent wetlands. Historically, these were cypress and bay tree forests, inland swamps, freshwater marsh, wet prairie, and sawgrass marsh (Davis 1943). Land use changes over the last 150 years have resulted in a general conversion to agriculture, primarily pasture (51 percent of the area). After the loss of about 330,000 acres, only about 15 percent of the area is still wetlands. This loss of wetland habitat has resulted in less water storage on the landscape, increased stormwater runoff, and more frequent flashy hydroperiods (periods of high-volume water and dry periods for parts of the year) in Fisheating Creek, Kissimmee River, Taylor Creek and Nubbin Slough. According to the Lake Okeechobee Conceptual Ecological Model (Havens 2003), conversion to agricultural and residential land uses in the watershed, along with water management have resulted in increased nutrient and sediment concentrations and more extreme and frequent high and low stages in Lake Okeechobee. These stressors can negatively affect waterfowl and wading birds, fish and other aquatic fauna, native aquatic vegetation, and water quality.

The Lake Okeechobee Watershed has no CERP Indicator Regions other than the lake itself. The sub-basins (Fisheating Creek, Indian Prairie, Kissimmee River, and Taylor Creek and Nubbin Slough) have varying hydrology and flashiness due to their overall size and varying ecological conditions due to the level of previous land use changes. Fisheating Creek has conservation easements throughout its watershed, resulting in generally better habitat for fish and wildlife. Habitat within the Brighton Reservation is also in a much more native state than the remainder of the Indian Prairie basin. Kissimmee River is a large

watershed and provides most of the surface flow to Lake Okeechobee on an annual basis. As the upper portion, upstream of the LOWRP project area, is restored — completion is expected in a few years —, hydroperiod flashiness should be reduced. Taylor Creek/Nubbin Slough tends to be the flashiest watershed, and at times no surface water flow is visible.

One of the goals of the LOWRP is to restore the hydrology of watershed wetlands. This will serve to increase habitat, water supply, and recreation in the watershed. The overall CERP target for wetland restoration from the Restudy was a minimum of 3,500 acres. The PM used five sub-metrics that establish the wetland targets for screening: wading bird support; percent connectivity; surface water connection; restoration potential; and public access. Based on the screening criteria, 9 potential sites were narrowed down to 4 sites. These 4 sites were carried forward into the final array of alternatives and GIS analysis was used to calculate HUs. The screening process is described in **Appendix E**. The wetland sites that were carried on to the habitat unit analysis are Lake Okeechobee West, IP-10, Paradise Run, and the new Kissimmee River sites.

G.3.1 Wetland Restoration - Existing Condition Baseline Calculations of Habitat Units

Using best professional judgment, supplemented by limited field evaluations, a "quality factor," called ecological value (EV), was assigned for each habitat type within the 4 wetland restoration sites based on land use code (FLUCCS; from the 2015 SFWMD shapefile; **Table G-3**). Wetlands were separated into functional or drained classes; and uplands into native and non-native classes as follows:

a. Functional Wetlands were defined as those represented by FLUCCS 6000 Series (**Table G-3**)
b. Drained or Non-functioning Wetland habitats were defined as areas with historic hydric soils that currently do not exhibit wetland function (although they should have some upland function). These areas are comprised of lands classified by FLUCCS codes in the 2000 (Agriculture), 3000 (Rangeland), 4000 (Upland Forest), or 7000 (Barren Land) Series.
c. Uplands were broadly defined as areas underlain by non-hydric soils that retain some degree of upland ecological functionality (all FLUCCS Level 4 Codes except 5000 [Open Water] and 6000 [Wetlands] Series). Native and Natural Uplands were defined as areas underlain by non-hydric soils that retain a high degree of upland ecological functionality. Specifically, these were unimproved or woodland pasture (FLUCCS 2120 and 2130), rangeland (FLUCCS 3000 Series), rural lands in transition (FLUCCS 7410), and upland forests (FLUCCS 4000 Series) with the exception of those lands infested with exotic plants.
d. Non-native Uplands were FLUCCS Codes 4119, 4220, 4240, 4350, 4400 and 4410. In addition, these included all FLUCCS Codes on non-hydric soils in the 1000, 2000, 7000 (except FLUCCS 7410), and 8000 (except FLUCCS 8160) Series.
e. Open or Deep-Water habitats included FLUCCS Series 5000 (Open Water) and 8160 (Canals). Within our restoration sites these areas included more natural systems like the Kissimmee River oxbows, large ponds, canals, or channelized streams.

Implicit in the above definitions was the need for soil data to separate out uplands from drained wetlands because some non-native upland FLUCCS codes could occur on both hydric and non-hydric soils. The 2010 U.S. Department of Agriculture spatial data were used for this analysis.

Table G-3. Existing condition EV for each land use within the wetland restoration sites.

FLUCCS	Description	Existing Eco-Value
2110	Improved Pastures	0.20
2120	Unimproved Pastures	0.40
6410	Freshwater Marshes	0.50
2156	Field Crops - Sugar Cane	0.01
3100	Herbaceous Rangeland	0.20
6430	Wet Prairies	0.50
4271	Oak - Cabbage Palm Forest	0.40
6440	Emergent Aquatic Vegetation	0.70
6172	Mixed Wetland Hardwoods - Mixed Shrubs	0.50
4340	Hardwood Conifer Mixed	0.40
6300	Wetland Forested Mixed	0.50
7430	Spoil Areas	0.10
4110	Pine Flatwoods	0.40
6170	Mixed Wetland Hardwoods	0.50
6180	Cabbage Palm Savannah	0.40
5120	Channelized waterways, canals	0.50
6110	Bay Swamps	0.50
5110	Streams and Waterways	0.50
5600	Slough Waters	0.70
6411	Freshwater Marshes - Sawgrass	0.50
4200	Upland Hardwood Forest	0.40
4280	Cabbage Palm	0.40
5300	Reservoirs	0.50
6250	Wet Pinelands Hydric Pine	0.50
4220	Brazilian Pepper	0.10
3200	Shrub and Brushland	0.40
4270	Live Oak	0.40
6216	Cypress - Mixed Hardwoods	0.50
8115	Grass Airports	0.10
6240	Cypress - Pine - Cabbage Palm	0.50
3210	Palmetto Prairies	0.40
2430	Ornamentals	0.10
7400	Disturbed Land	0.10
1230	Mixed Units (fixed and mobile home units) 2-5	0.01
3300	Mixed Rangeland	0.40
2510	Horse Farms	0.20

FLUCCS that are more ecologically degraded received lower EVs, but more native or natural habitats received higher EVs (on a scale of 0.0 to 1.0). FLUCCS that indicated wetlands were assigned the highest EVs of 0.5 due to the expectation that restoration (e.g., improved hydrology and removal of exotic vegetation) was still needed. Using ArcGIS, the size of each FLUCCS polygon within each potential restoration site was measured and multiplied by its EV to arrive at a HU for that polygon. All polygons inside the restoration site were then summed to calculate the total HUs. **Table G-4** – **Table G-11** show the ECB for each wetland site and the total ECB HUs. **Figure G-6** – **Figure G-12** show the ECB conditions for all wetland sites.

HUs were calculated in **Table G-4** below as follows:

Existing $\text{Eco-Value}_{FLUCCS2110} \times \text{Acres}_{FLUCCS2110} = HU_1$ *e.g.,* 0.2 x 2515.08 = 503.02 HUs

and then summed as $HU_1 + HU_2 + \ldots HU_9 = HU_{total}$ *e.g.,* 503.02 + 25.22 + … 16.55 = 620.25 HUs

Table G-4. Summation of the ECB HUs for the Lake Okeechobee West wetland site.

FLUCCS Level 4 Code	FLUCCS Code Description	Existing Eco-Value	Area (acres)	ECB HUs
2110	Improved Pastures	0.2	2,515.08	503.02
2120	Unimproved Pastures	0.3	84.06	25.22
3200	Shrub and Brushland	0.3	7.77	2.33
4200	Upland Hardwood Forest	0.4	15.04	6.02
5120	Channelized waterways, canals	0.3	4.20	1.26
5300	Reservoirs	0.3	1.84	0.55
6172	Mixed Wetland Hardwoods - Mixed Shrubs	0.5	3.59	1.79
6410	Freshwater Marshes	0.5	127.02	63.51
6430	Wet Prairies	0.5	33.10	16.55
	TOTAL	**n/a**	**2,791.70**	**620.25**

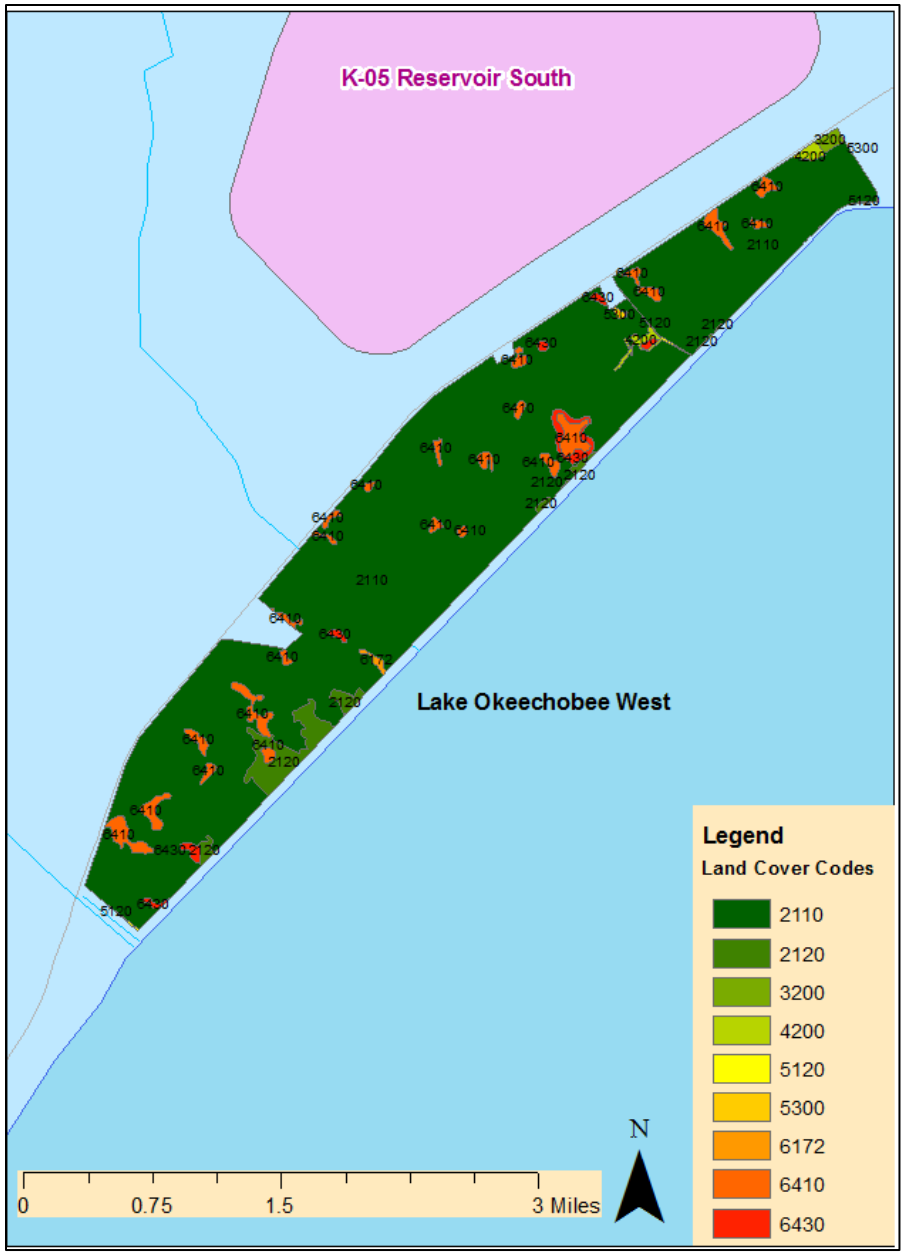

Figure G-6. Land cover (FLUCCS) codes for the ECB Lake Okeechobee West Site.

Table G-5. Summation of the ECB HUs for the IP-10 wetland site.

FLUCCS Level 4 Code	FLUCCS Code Description	Existing Eco-Value	Area (acres)	ECB HUs
1230	Mixed Units (Fixed and mobile home units)	0.01	0.63	0.01
2110	Improved Pastures	0.2	2,513.66	502.73
2120	Unimproved Pastures	0.3	715.11	214.53
2156	Field Crops - Sugar Cane	0.01	0.22	0.00
2210	Citrus Groves	0.1	0.08	0.01
3100	Herbaceous Rangeland	0.3	1.15	0.34
4220	Brazilian Pepper	0.01	10.40	0.10
4271	Oak - Cabbage Palm Forest	0.4	51.61	20.65
4280	Cabbage Palm	0.4	72.43	28.97
4340	Hardwood Conifer Mixed	0.4	1.57	0.63
5300	Reservoirs	0.3	1.02	0.30
6172	Mixed Wetland Hardwoods - Mixed Shrubs	0.5	0.00	0.00
6180	Cabbage Palm Savannah	0.5	0.14	0.07
6410	Freshwater Marshes	0.5	142.42	71.21
6430	Wet Prairies	0.5	14.86	7.43
6440	Emergent Aquatic Vegetation	0.5	6.88	3.44
	TOTALS	n/a	**3,532.18**	**850.42**

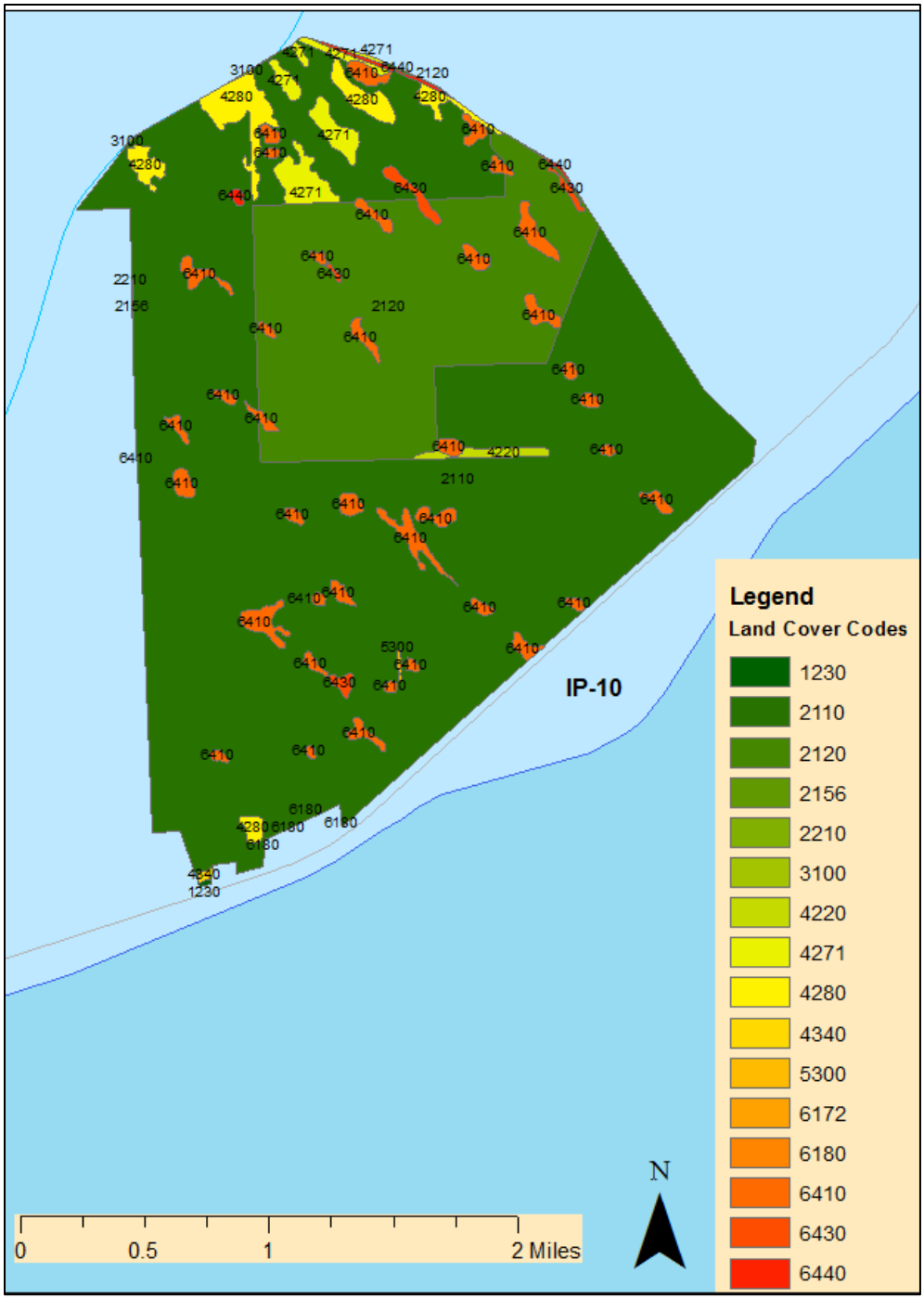

Figure G-7. Land cover (FLUCCS) codes for the ECB IP-10 wetland site.

The Paradise Run wetland site was divided into two separate sites, Paradise Run-North and Paradise Run-South, based on the hydrology and the potential wetland restoration design for the site (**Figure G-8** and **Figure G-9**).

Table G-6. Summation of the ECB HUs for the Paradise Run-North wetland site.

FLUCCS Level 4 Code	FLUCCS Code Description	Existing Eco-Value	Area (acres)	ECB HUs
2110	Improved Pastures	0.2	56.49	11.30
3100	Herbaceous Rangeland	0.3	16.31	4.89
3300	Mixed Rangeland	0.3	40.46	12.14
4200	Upland Hardwood Forest	0.4	35.31	14.12
4280	Cabbage Palm	0.4	3.50	1.40
5110	Streams and Waterways	0.5	76.33	38.17
5600	Slough Waters	0.5	48.14	24.07
6170	Mixed Wetland Hardwoods	0.5	31.64	15.82
6172	Mixed Wetland Hardwoods - Mixed Shrubs	0.5	11.98	5.99
6180	Cabbage Palm Savannah	0.5	1.29	0.65
6410	Freshwater Marshes	0.5	86.60	43.30
6430	Wet Prairies	0.5	243.44	121.72
6440	Emergent Aquatic Vegetation	0.5	885.09	442.55
7430	Spoil Areas	0.1	10.03	1.00
	TOTALS	**n/a**	**1,546.61**	**737.11**

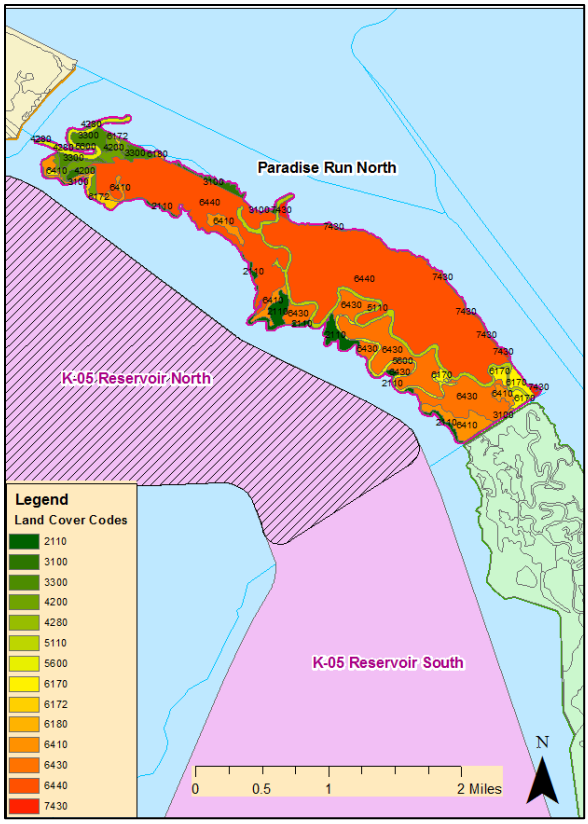

Figure G-8. Land cover (FLUCCS) codes for the ECB Paradise Run-North wetland sites.

Table G-7. Summation of the ECB HUs for the Paradise Run-South wetland site.

FLUCCS Level 4 Code	FLUCCS Code Description	Existing Eco-Value	Area (acres)	ECB HUs
2110	Improved Pastures	0.2	1,229.51	245.90
3100	Herbaceous Rangeland	0.3	2.95	0.88
3200	Shrub and Brushland	0.3	16.55	4.97
5120	Channelized waterways, canals	0.3	1.56	0.47
5600	Slough Waters	0.5	97.40	48.70
6172	Mixed Wetland Hardwoods - Mixed Shrubs	0.5	172.09	86.05
6180	Cabbage Palm Savannah	0.5	14.09	7.05
6410	Freshwater Marshes	0.5	406.23	203.12
6430	Wet Prairies	0.5	596.31	298.16
7430	Spoil Areas	0.1	0.08	0.01
	TOTALS	**n/a**	**2,536.77**	**895.31**

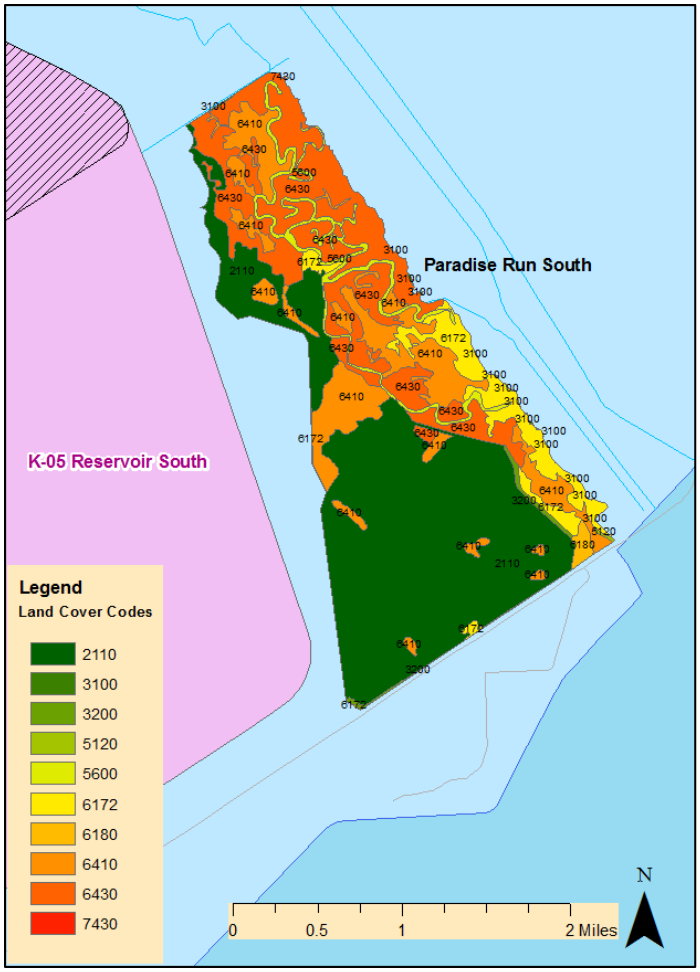

Figure G-9. Land cover (FLUCCS) codes for the ECB Paradise Run-South wetland sites.

The Kissimmee River wetland site was divided into three separate sites, Kissimmee River–North, Kissimmee River–Center and Kissimmee River–South, based on the hydrology and the potential wetland restoration design for the site. There are two options for Kissimmee River–Center: #1 includes the full area and #2 has the southeast portion removed because it contains private property with a homestead and that piece is not critical for the wetland restoration (**Figure G-11**).

Table G-8. Summation of the ECB HUs for the Kissimmee River–North wetland site.

FLUCCS Level 4 Code	FLUCCS Code Description	Existing Eco-Value	Area (acres)	ECB HUs
2110	Improved Pastures	0.2	0.63	0.13
3100	Herbaceous Rangeland	0.3	169.66	50.90
4200	Upland Hardwood Forest	0.4	6.93	2.77
4340	Hardwood Conifer Mixed	0.4	13.60	5.44
5110	Streams and Waterways	0.5	3.83	1.92
5120	Channelized waterways, canals	0.3	0.02	0.01

FLUCCS Level 4 Code	FLUCCS Code Description	Existing Eco-Value	Area (acres)	ECB HUs
5600	Slough Waters	0.5	1.25	0.63
6170	Mixed Wetland Hardwoods	0.5	25.95	12.98
6172	Mixed Wetland Hardwoods - Mixed Shrubs	0.5	177.73	88.86
6180	Cabbage Palm Savannah	0.5	137.57	68.78
	TOTALS	**n/a**	**537.17**	**232.42**

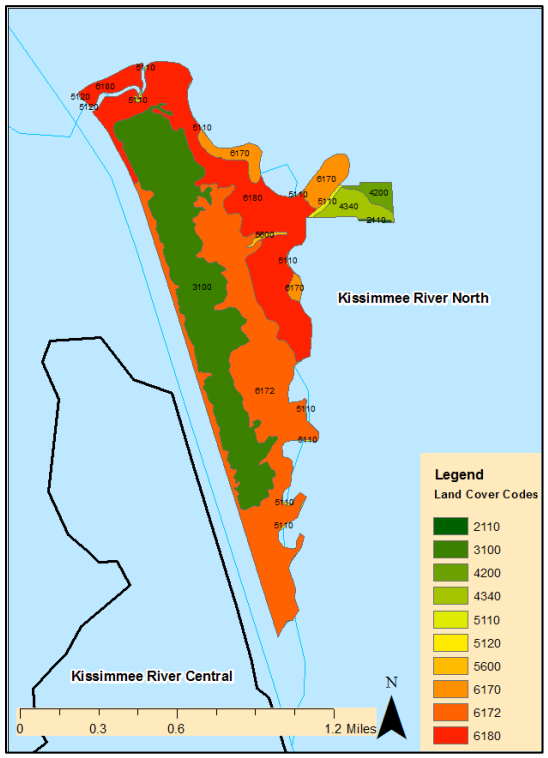

Figure G-10. Land cover (FLUCCS) codes for the ECB Kissimmee River–North wetland site.

Table G-9. Summation of the Existing Conditions Baseline HUs for the Kissimmee River–Center #1 wetland site.

FLUCCS Level 4 Code	FLUCCS Code Description	Existing Eco-Value	Area (acres)	ECB HUs
2110	Improved Pastures	0.2	795.96	159.19
2120	Unimproved Pastures	0.3	70.38	21.11
3100	Herbaceous Rangeland	0.3	122.34	36.70
4200	Upland Hardwood Forest	0.4	3.57	1.43

FLUCCS Level 4 Code	FLUCCS Code Description	Existing Eco-Value	Area (acres)	ECB HUs
4270	Live Oak	0.4	3.05	1.22
4271	Oak - Cabbage Palm Forest	0.4	1.35	0.54
5110	Streams and Waterways	0.5	18.50	9.25
5120	Channelized waterways, canals	0.3	2.71	0.81
5300	Reservoirs	0.3	4.51	1.35
6170	Mixed Wetland Hardwoods	0.5	35.09	17.55
6172	Mixed Wetland Hardwoods - Mixed Shrubs	0.5	213.55	106.77
6180	Cabbage Palm Savannah	0.5	4.00	2.00
6410	Freshwater Marshes	0.5	55.21	27.60
6430	Wet Prairies	0.5	40.88	20.44
6440	Emergent Aquatic Vegetation	0.5	39.61	19.80
7430	Spoil Areas	0.1	58.04	5.80
	TOTALS	n/a	**1,468.75**	**431.56**

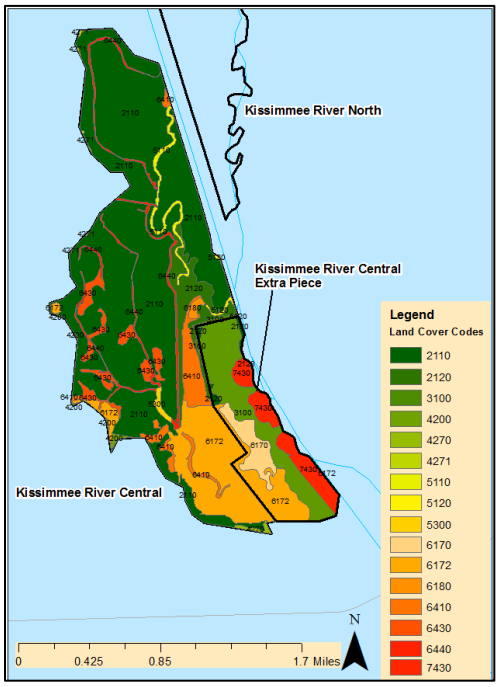

Figure G-11. Land cover (FLUCCS) codes for the ECB Kissimmee River–Center #1 (includes the extra piece) and Kissimmee River-Center #2 (excludes the extra piece) wetland sites.

Table G-10. Summation of the ECB HUs for the Kissimmee River–Center #2 wetland site.

FLUCCS Level 4 Code	FLUCCS Code Description	Existing Eco-Value	Area (acres)	ECB HUs
2110	Improved Pastures	0.2	795.96	159.19
2120	Unimproved Pastures	0.3	63.68	19.10
3100	Herbaceous Rangeland	0.3	3.40	1.02
4200	Upland Hardwood Forest	0.4	3.57	1.43
4270	Live Oak	0.4	3.05	1.22
4271	Oak - Cabbage Palm Forest	0.4	1.35	0.54
5110	Streams and Waterways	0.5	18.50	9.25
5120	Channelized waterways, canals	0.3	2.69	0.81
5300	Reservoirs	0.3	4.51	1.35
6172	Mixed Wetland Hardwoods - Mixed Shrubs	0.5	159.45	79.73
6180	Cabbage Palm Savannah	0.5	4.00	2.00
6410	Freshwater Marshes	0.5	55.21	27.60
6430	Wet Prairies	0.5	40.88	20.44
6440	Emergent Aquatic Vegetation	0.5	39.61	19.80
	TOTALS	**n/a**	**1,195.86**	**343.48**

Table G-11. Summation of the ECB HUs for the Kissimmee River–South wetland site.

FLUCCS Level 4 Code	FLUCCS Code Description	Existing Eco-Value	Area (acres)	ECB HUs
2110	Improved Pastures	0.2	19.14	3.83
3100	Herbaceous Rangeland	0.3	0.28	0.08
5110	Streams and Waterways	0.5	41.94	20.97
6170	Mixed Wetland Hardwoods	0.5	23.60	11.80
6172	Mixed Wetland Hardwoods - Mixed Shrubs	0.5	41.34	20.67
6410	Freshwater Marshes	0.5	418.00	209.00
7430	Spoil Areas	0.1	8.86	0.89
	TOTALS	**n/a**	**553.16**	**267.24**

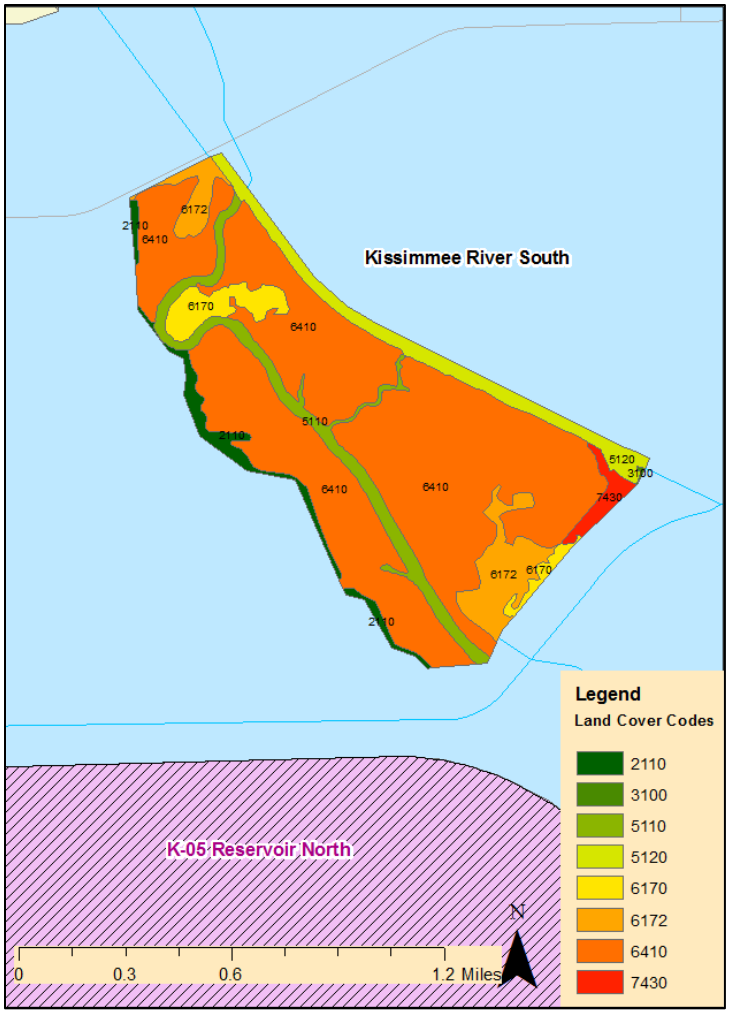

Figure G-12. Land cover (FLUCCS) codes for the ECB Kissimmee River–South wetland site.

G.3.2 Wetland Restoration Future Without Project Calculations of HUs

To estimate HUs under FWO conditions, the team made assumptions about how the wetland and upland land covers would change over time. Because CERP projects are evaluated over a 50-year period, the possible land use change scenarios were estimated as: 1) no change within the site; 2) the site is restored by another entity such as the Wetland Reserve Easement Program; or 3) the ecological value of the site is reduced. The LOWRP area is generally rural; however, given the proximity of Lake Okeechobee as a water resource and the relatively good transportation and utility infrastructure, combined with the recent increase in population immigration into Florida and the possibility that coastal populations of humans will move inland as sea levels rise, it was assumed that it is more likely that these wetland sites would be degraded over time (i.e., converted to more developed conditions). Sites farther from human population centers are probably less likely to undergo habitat degradation, but it is not possible to accurately predict the relative degree.

The LOWRP project authorization is anticipated to occur in 2021; therefore, the project's life span lasts until 2078. For calculation of the FWO condition, we used predictions of land use change outlined in the Florida 2070 report for Central Florida (Carr and Zwick 2016). Specifically, that report predicted a 22.72%

conversion of all land covers to residential/urban by 2070. Therefore, we reduced the EVs of 22.72% of the spatial extent of all FLUCCS codes to 0.01, and then recalculated the HUs. There is some uncertainty with this predicted land use conversion, but it is the best information we have. The following table shows the FWO HUs (**Table G-12**).

Table G-12. Summary of ECB HUs and FWO HUs.

Wetland Site	Acres	ECB HUs	FWO HUs
Lake Okeechobee West	2,792	620	486
IP-10	3,532	850	666
Paradise Run–North	1,547	737	577
Paradise Run–South	2,537	895	701
Kissimmee River–North	537	232	182
Kissimmee River–Central #1	1,469	432	338
Kissimmee River–Center #2	1,196	343	269
Kissimmee River–South	553	267	209

G.3.3 Wetland Restoration with Project Calculations of HUs

For the estimated total restored HUs under with-project conditions, all EVs are assumed to be restored to a quality of 1.0. These would primarily be wetland HUs of varying hydrology but could include some small amount of upland HUs. The total HUs would then equal the total acres of the site (**Table G-13**).

Table G-13. Summary of ECB HUs and FFWO HUs.

Wetland Site	Acres	ECB HUs	FWO HUs	FWP HUs
Lake Okeechobee West	2,792	620	486	2,792
IP-10	3,532	850	666	3,532
Paradise Run	4,083	1,632	1,278	4,083
Kissimmee River–North	537	232	182	537
Kissimmee River–Center #2	1,196	343	269	1,196
Kissimmee River–South	553	267	209	553

G.3.4 Wetland Restoration Alternative Performance

To calculate the benefits for each wetland site, the HUs for the FWO condition are subtracted from the HUs in the future with project (FWP) condition. This results in the habitat unit lift for each wetland site. **Table G-14** shows the HU lift for each wetland site.

Table G-14. HU lift for each wetland site.

Wetland Site	Lake Okeechobee West	IP-10	Paradise Run	Kissimmee River–North	Kissimmee River–Center #2	Kissimmee River–South
ECB HUs	620	850	1,632	232	343	267
FWO HUs	486	666	1,278	182	269	209
FWP HUs	2,792	3,532	4,083	537	1,196	553
HU Lift	**2,306**	**2,866**	**2,806**	**355**	**927**	**344**

The wetland average annual habitat unit (AAHU) lifts were calculated as the difference between the with-project and without project conditions over the period of analysis (through year 2078). For the without project condition, a straight trajectory between existing and FWO HUs was assumed to establish HU totals for each site and year. With project HU trajectory was modeled to reflect the timeline of expected restoration effects. After reaching 70 percent potential 10 years following construction completion, wetland HUs for each site are assumed to maximize and plateau 30 years after construction completion. This is the time required for species such as bald cypress, which are predicted to colonize the restoration sites, to reach maximum height range of 75–100 feet. **Figure G-13** and **Table G-15** display the projection of HU lift for each wetland site over the period of analysis. The resulting AAHU lift is displayed in **Table G-16,** as is average annual project cost of each site calculated for a 50-year project life at the FY 2018 discount rate (2.75%)**.**

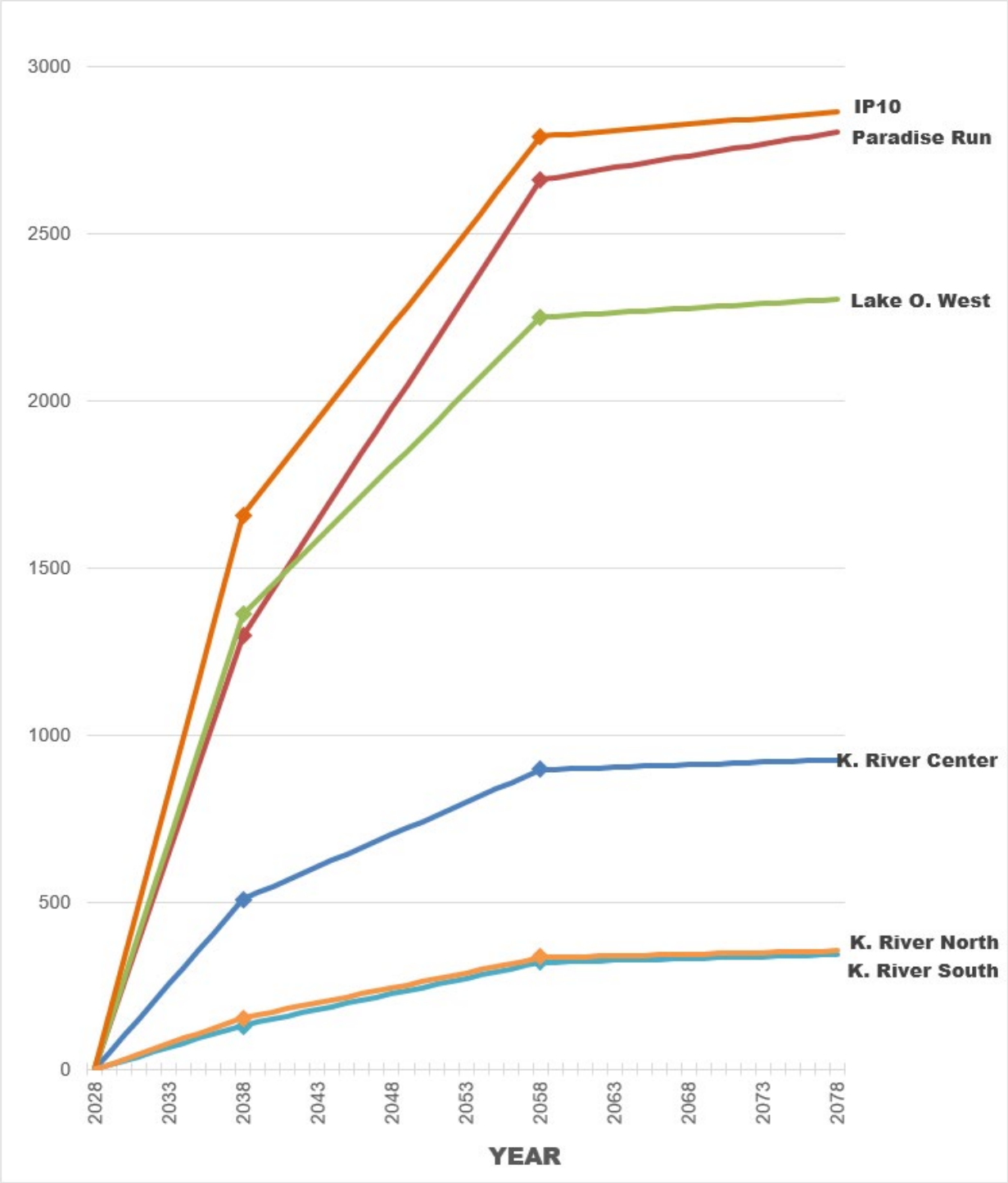

Figure G-13. Wetland HU lift trajectory by site.

Table G-15. Summary wetland habitat unit trajectory by year and site.

Wetland Site	2038			2058			2078		
	FWP	FWOP	Lift	FWP	FWOP	Lift	FWP	FWOP	Lift
Kissimmee River–Center	837	329	509	1,196	299	897	1,196	269	927
Paradise Run	2,858	1,561	1,297	4,083	1,420	2,664	4,083	1,278	2,806
Lake Okeechobee -West	1,954	593	1,361	2,792	539	2,252	2,792	486	2,306
IP10	2,473	813	1,659	3,532	740	2,793	3,532	666	2,866
Kissimmee River–South	387	256	132	553	232	321	553	209	344
Kissimmee River–North	376	222	154	537	202	335	537	182	355

Table G-16. Wetland site AAHU lift and Average Annual Cost (AAC).

Wetland Site	Wetland AAHU Lift	Average Annual Cost*
Kissimmee River–Center	706	$889,000
Paradise Run	2,044	$3,148,000
Lake Okeechobee -West	1,793	$3,260,000
IP10	2,217	$4,889,000
Kissimmee River–South	240	$889,000
Kissimmee River–North	255	$8,297,000

*2.75 % discount rate, 50-year period of analysis

The HU analysis shows that the wetland with the greatest HU lift is IP-10, followed by Paradise Run, then Lake Okeechobee West, then Kissimmee River–Center, then Kissimmee River–North, and lastly Kissimmee River–South (**Table G-16**).

The Institute of Water Resources Planning Suite (IWR-Plan; certified version 2.0) Plan Generator and Cost-effectiveness/Incremental Cost Analysis (CE/ICA) modules were used to combine the 8 wetland sites and identify cost-effective and 'best-buy' combinations. (*The subset of cost-effective plans that offer the greatest increases in output for the least increases in cost (the plans that have the lowest incremental costs per unit of output for successively larger levels of output) are known as "best-buy" plans. These plans are the most efficient in production and are superior financial investments.*) Since project benefits are not measured in dollars, the CE/ICA offers the next-best approach to value. A plan is considered cost-effective if no other plan provides the same level of output for less cost and if no other plan provides more output for the same or less cost. **Table G-17** displays all cost-effective combinations of wetland sites.

Table G-17. Cost-effective wetland site combinations.

Combination of Sites	Acres	AAHU Lift	AAC	AAC per AAHU Lift
Kissimmee River–Center	1,200	706	$889,000	$1,260
Kissimmee River–Center Kissimmee River–South	1,800	946	$1,778,000	$1,880
Paradise Run	4,100	2,044	$3,148,000	$1,540
Kissimmee River–Center Paradise Run	5,300	2,750	$4,038,000	$1,470
Kissimmee River–Center Paradise Run Kissimmee River–South	5,900	2,990	$4,926,000	$1,650
Paradise Run Lake Okeechobee - West	6,900	3,837	$6,408,000	$1,670
Kissimmee River–Center Paradise Run Lake Okeechobee - West	8,100	4,543	$7,297,000	$1,610
Kissimmee River–Center Paradise Run Lake Okeechobee - West Kissimmee River–South	8,700	4,783	$8,186,000	$1,710
Kissimmee River–Center Paradise Run IP10	8,800	4,966	$8,926,000	$1,800
Kissimmee River–Center IP10 Kissimmee River–South Paradise Run	9,400	5,207	$9,815,000	$1,890
Paradise Run Lake Okeechobee - West IP10	10,400	6,054	$11,297,000	$1,870
Kissimmee River–Center Paradise Run Lake Okeechobee - West IP10	11,600	6,760	$12,187,000	$1,800
Kissimmee River–Center Paradise Run Lake Okeechobee - West IP10 Kissimmee River–South	12,200	7,000	$13,075,000	$1,870

Combination of Sites	Acres	AAHU Lift	AAC	AAC per AAHU Lift
Kissimmee River–Center Paradise Run Lake Okeechobee - West IP10 Kissimmee River–North	12,100	7,015	$20,483,000	$2,920
Kissimmee River–Center Kissimmee River Paradise Run Lake Okeechobee - West IP10 Kissimmee River–South Kissimmee River–North	12,700	7,255	$21,373,000	$2,950

Figure G-14 shows all possible combinations of wetland sites. Best-buy combinations are displayed as squares, cost-effective combinations as triangles, and non-cost-effective combinations as circles.

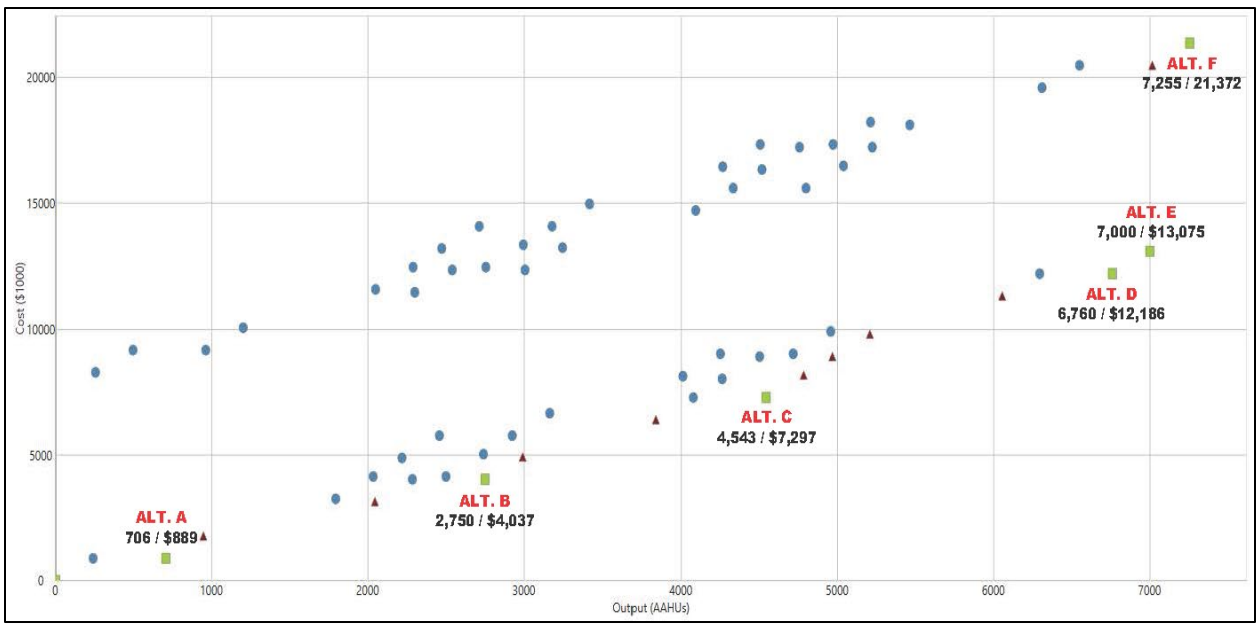

Figure G-14. Wetland combinations – costs and outputs

The first best-buy plan is the most efficient plan, producing the most output at the lowest incremental cost per unit. If a higher level of output is desired than that provided by the first best-buy plan, the second best-buy plan is the most efficient plan for producing additional output, and so on. **Table G-18** and **Figure G-15** display the results of the incremental cost analysis and identify 6 best-buy combinations of wetland sites.

Table G-18. Incremental Cost Comparison for wetland best buy alternatives.

Wetland ALT.	Combination of Sites	Incremental AAHU Lift	Incremental AAC	Incremental AAC per AAHU Lift
A	Kissimmee River–Center	706	$889,000	$1,259
B	Kissimmee River–Center Paradise Run	2,044	$3,148,000	$1,540
C	Kissimmee River–Center Paradise Run Lake Okeechobee - West	1,793	$3,260,000	$1,818
D	Kissimmee River–Center Paradise Run Lake Okeechobee - West IP10	2,217	$4,889,000	$2,206
E	Kissimmee River–Center Paradise Run Lake Okeechobee - West IP10 Kissimmee River–South	240	$889,000	$3,704
F	Kissimmee River–Center Kissimmee River Paradise Run Lake Okeechobee - West IP10 Kissimmee River–South Kissimmee River–North	255	$8,297,000	$32,572

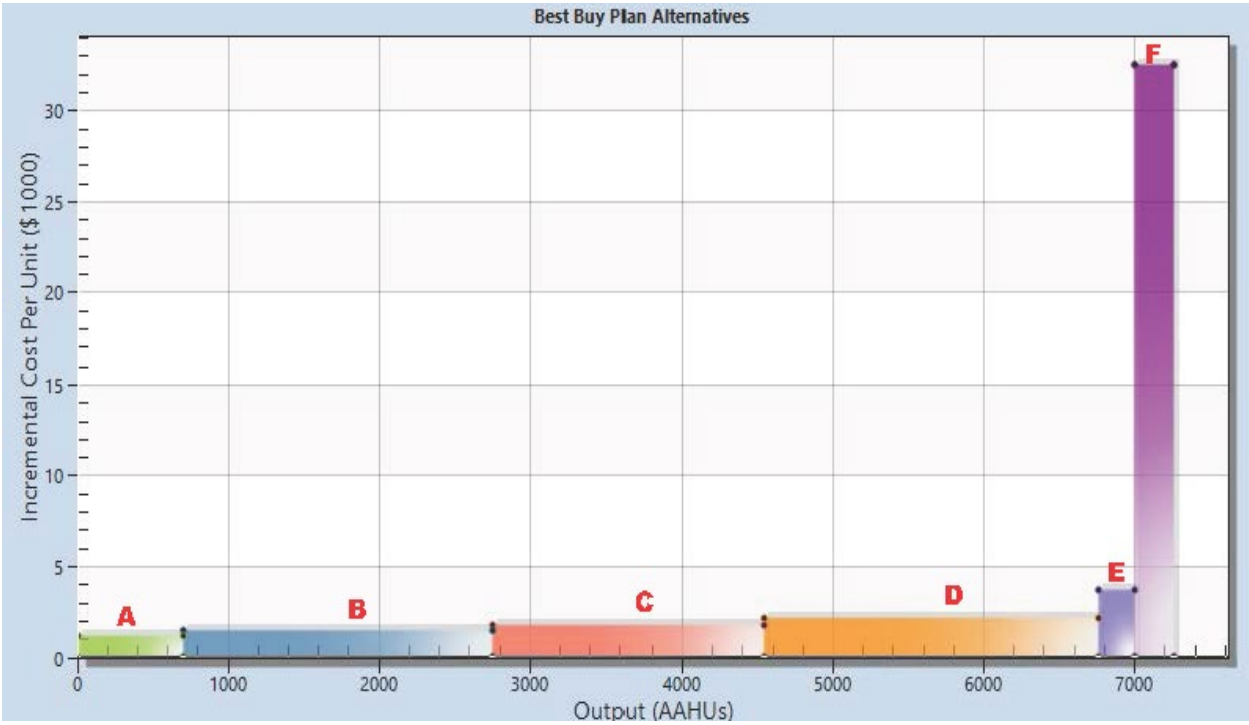

Figure G-15. Wetland combinations incremental cost analysis.

When the wetlands are combined into alternatives for the CE/ICA, Alternative A, which includes only Kissimmee River–Center, is the first best buy; however, at 1,196 acres, Alternative A does not meet the Yellowbook goal of restoring 3,500 acres of wetlands (**Table G-19**). Alterative B, which includes both Kissimmee River Center and Paradise Run, is the second best-buy plan and exceeds the Yellowbook goal, providing 5,279 acres of wetlands (**Table G-19**). Alternative B was selected as the wetland component of the TSP.

Table G-19. Comparison table for wetland best-buy alternatives.

Wetland ALT.	Combination of Sites	Acres	ECB HUs	FWO HUs	FWP HUs	HU Lift	AAHU Lift	AAC per AAHU Lift
A	Kissimmee River–Center	1,196	343	269	1,196	927	706	$1,260
B	Kissimmee River–Center Paradise Run	5,279	1,976	1,547	5,279	3,733	2,750	$1,470
C	Kissimmee River–Center Paradise Run Lake Okeechobee - West	8,071	2,596	2,032	8,071	6,039	4,543	$1,610
D	Kissimmee River–Center Paradise Run Lake Okeechobee - West IP10	11,603	3,447	2,698	11,603	8,905	6,760	$1,800

Wetland ALT.	Combination of Sites	Acres	ECB HUs	FWO HUs	FWP HUs	HU Lift	AAHU Lift	AAC per AAHU Lift
E	Kissimmee River–Center Paradise Run Lake Okeechobee - West IP10 Kissimmee River–South	12,156	3,714	2,907	12,156	9,249	7,000	$1,870
F	Kissimmee River–Center Kissimmee River Paradise Run Lake Okeechobee - West IP10 Kissimmee River–South Kissimmee River–North	12,693	3,946	3,089	12,693	9,604	7,255	$2,950

G.3.5 Wetland Restoration Recommended Plan Performance

Wetland Alternative B was selected as the TSP. As the TSP was refined for the Recommended Plan, the footprint of the Paradise Run wetland site was optimized to remove the space between the WAF and the wetland restoration site as well as accommodate a shift in the WAF footprint. The habitat units were re-calculated for the revised Paradise Run Wetland site. **Figure G-16** shows the updated Paradise Run footprint and land use codes for all components of the Recommended Plan. **Table G-20** shows the existing habitat units for the Recommended Plan wetland restoration sites. To calculate the benefits for each wetland site, the HUs for the FWO condition are subtracted from the HUs in the FWP condition. This results in the habitat unit lift for each wetland site. **Table G-21** shows the HU lift for each wetland site in the Recommended Plan. **Table G-22** shows the AAHU from 2028 through 2078 for each wetland site in the Reccommended Plan.

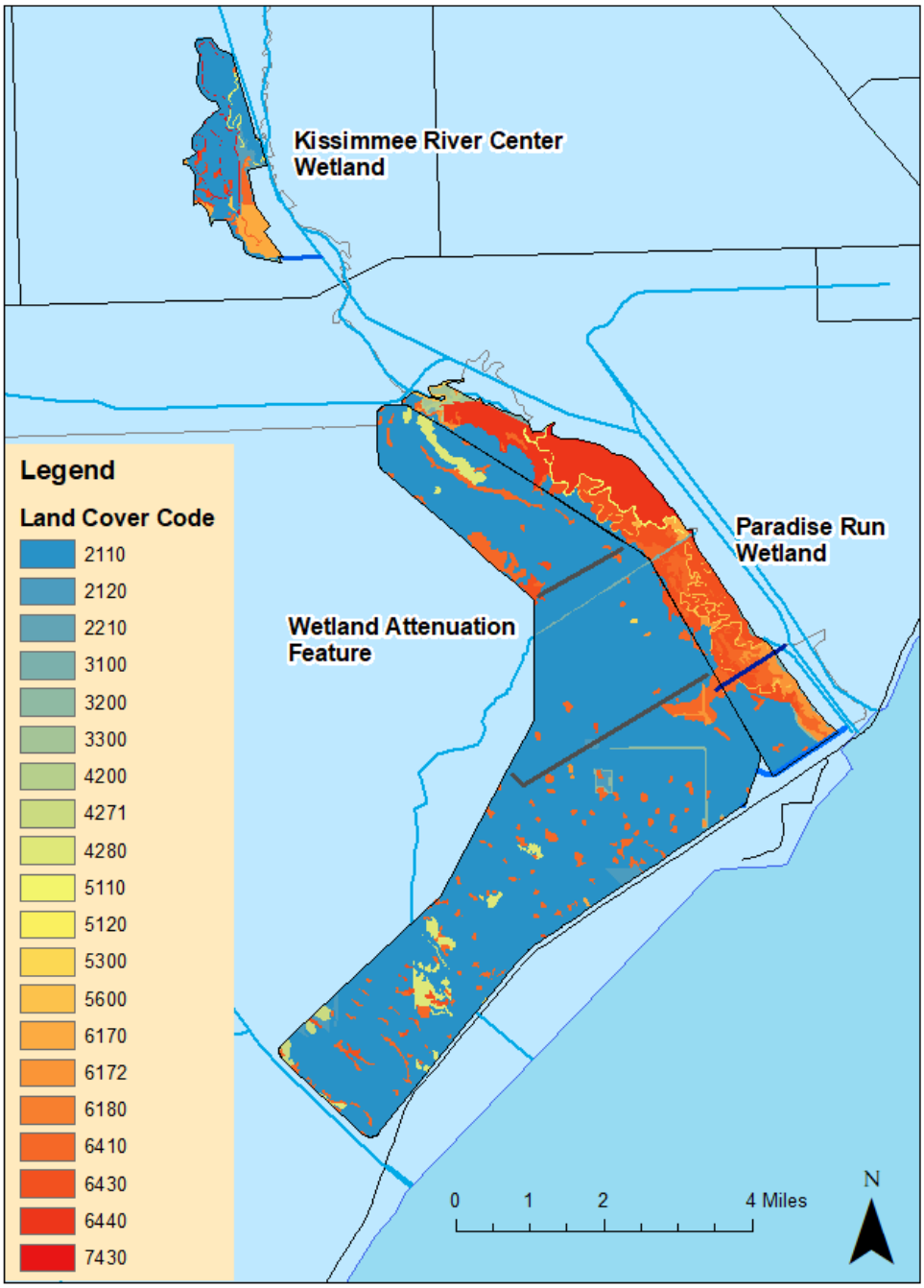

Figure G-16. Land cover (FLUCCS) codes for the ECB for the Recommended Plan including the Kissimmee River Center and Paradise Run wetland restoration sites and the WAF footprint.

Table G-20. Summation of the ECB HUs for the Recommended Plan wetland sites.

FLUCCS Level 4 Code	FLUCCS Code Description	Existing Eco-Value	Kissimmee River Center Area (acres)	Kissimmee River Center ECB HUs	Kissimmee River Center FWO HUs	Kissimmee River Center FWP HUs	Paradise Run Area (acres)	Paradise Run ECB HUs	Paradise Run FWO HUs	Paradise Run FWP HUs
2110	Improved Pastures	0.2	796	159	124	796	836	167	129	836
2120	Unimproved Pastures	0.3	64	19	16	64	0	0	0	0
2130	Pastures	0	5	0	0	0	1	0	0	0
3100	Herbaceous Rangeland	0.3	3	1	1	3	23	16	12	54
3200	Shrub and Brushland	0.3	0	0	0	0	10	3	2	10
3300	Mixed Rangeland	0.3	0	0	0	0	40	12	9	40
4200	Upland Hardwood Forest	0.4	0	1	1	4	35	14	11	35
4270	Live Oak	0.4	3	1	1	3	0	0	0	0
4271	Oak - Cabbage Palm Forest	0.4	0	1	0	1	0	0	0	0
4280	Cabbage Palm	0.4	0	0	0	0	0	2	2	5
5110	Streams and Waterways	0.5	19	9	7	19	76	38	30	76
5120	Channelized waterways, canals	0.3	3	1	1	3	0	0	0	0
5300	Reservoirs	0.3	5	1	1	5	146	0	0	0
5600	Slough Waters	0.5	0	0	0	0	0	73	56	146
6170	Mixed Wetland Hardwoods	0.5	0	0	0	0	32	16	12	32
6172	Mixed Wetland Hardwoods - Mixed Shrubs	0.5	159	80	63	159	182	91	70	182
6180	Cabbage Palm Savannah	0.5	4	2	2	4	7	1	1	3
6410	Freshwater Marshes	0.5	55	28	21	55	402	201	155	402
6430	Wet Prairies	0.5	41	20	16	41	830	415	321	830
6440	Emergent Aquatic Vegetation	0.5	40	20	15	40	909	455	351	909
7430	Spoil Areas	0.1	0	0	0	0	53	2	2	23
	TOTALS	**n/a**	**1,197**	**343**	**269**	**1,197**	**3,582**	**1,506**	**1,163**	**3,583**

Table G-21. HU lift for each wetland site of the Recommended Plan.

Wetland Site	Paradise Run	Kissimmee River-Center	Wetland Recommended Plan
ECB HUs	1,507	343	1,850
FWO HUs	1,165	269	1,434
FWP HUs	3,583	1,196	4,779
HU Lift	**2,418**	**927**	**3,345**

Table G-22. AAHU lift for each wetland site of the Recommended Plan.

Wetland Site	Paradise Run	Kissimmee River-Center	Wetland Recommended Plan
FWO AAHUs	1,363	312	1,675
FWP AAHUs	3,325	1,018	4,344
AAHU Lift	**1,963**	**706**	**2,669**

G.4 Lake Okeechobee Benefit Calculations

This section describes the habitat unit calculations for Lake Okeechobee.

G.4.1 Lake Okeechobee Performance Measures

This subsection provides a brief description of the Lake Okeechobee PMs, including the target(s) for each, and the applicable metrics for the target(s).

G.4.1.1 PM 2.1 – Lake Okeechobee Stage Envelope Performance Measure

A wide body of published research (summarized in Havens 2002) documents the benefits of seasonally variable water levels within the range of 12.5 ft. NGVD29 (June-July low) and 15.5 ft. NGVD29 (November-January high) on the plant and animal communities of Lake Okeechobee. Falling water levels in late winter to spring benefit wading birds by concentrating prey resources in the littoral zone where those birds forage (Smith et al. 1995). Water levels near 12.5 ft. benefit submerged plants and bulrush by providing optimal light levels for photosynthesis in the summer months (Havens et al. 2004). Variation in the prescribed range results in annual flooding and drying of upland areas of the littoral zone, which favors development of a diverse emergent plant community (Richardson et al. 1995, Keddy and Frazer 2000).

1. Lake Stage Envelope: Lake stage remains within the desired envelope of 12.5–15.5 ft. (**Figure G-17**) and should result in an increase in spatial extent of bulrush along the western lakeshore; increased spatial extent of spikerush, beakrush, willow, and other native plants in the littoral zone; increase in spatial extent of vascular submerged plants; a shift in taxonomic structure of zooplankton to better support fishery

resources; increase in diversity, distribution, and abundance of forage fish in the littoral and nearshore zones; and increase in the use of the littoral zone for wading bird foraging and nesting.

Evaluation is based on the 41-year (1 January 1965- 31 December 2005) hydrograph of lake stages that is simulated by the South Florida Water Management Model (SFWMM) model. During each week of the model run, the absolute value of the deviation (in feet) of lake stage from the prescribed envelope is determined. This is done separately for stages above and stages below the envelope. A tally of the number of weeks is kept for each type of deviation.

For the lake stage envelope component, it is necessary to develop separate response curves for stages above and below the envelope. For deviation of lake stage above the envelope, the target is 0 weeks. The response curve is developed from the PM graphic. Consider the stage envelope area with zero values to represent good conditions, the next bands of 0.5 ft. stage above that envelope to represent fair conditions, and the subsequent band of 1.0 ft. to represent poor conditions. For deviation of lake stage below the envelope, the target is 192 weeks. This is the score that would be obtained if all years had hydrographs within the optimal zone, except for once per decade the stage falling to just below 11 ft. for an average of 3 months. These periodic low stage events, which occurred at this approximate frequency and duration in the 1950s to 1970s (prior to implementation of high-stage regulation schedules), are considered to be beneficial to the littoral zone because they allow for periodic exposure of seed banks, oxidation of accumulated organic material, and fires that are important to maintaining species diversity in the littoral zone. For periods where lake stages are above or below the 12.5 – 15.5 ft. stage envelope, the response curves relate the raw scores for each component of the PM to a standardized scale of 0 to 100.

After the standardized scores for amount of time above and below the stage envelope are calculated, they will be adjusted to a 0–1 point score range, weighted (45%), and multiplied by the 100,000 acres in the littoral zone, because the stage envelope most strongly influences this zone of the lake. The determination of how to weight the scores was based on a screening analysis of different scoring weights for the three PMs. The weighted scoring used for all three PMs had the best combination of potential HU lift and highest percentages of the maximum 1-point scores. This PM number of HU acres is then added to the other PM HU acres based on their scores, to calculate the potential amount of HU acres for the ECB, FWO, or any alternative scenarios being examined. The amount of HU acres will then be compared to determine the amount of potential lift based on the model run scenario output.

Stage	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
19	3.5	4.0	4.5	5.0	6.0	6.5	6.5	6.0	5.0	4.0	3.5	3.5
18.5	3.0	3.5	4.0	4.5	5.5	6.0	6.0	5.5	4.5	3.5	3.0	3.0
18	2.5	3.0	3.5	4.0	5.0	5.5	5.5	5.0	4.0	3.0	2.5	2.5
17.5	2.0	2.5	3.0	3.5	4.5	5.0	5.0	4.5	3.5	2.5	2.0	2.0
17	1.5	2.0	2.5	3.0	4.0	4.5	4.5	4.0	3.0	2.0	1.5	1.5
16.5	1.0	1.5	2.0	2.5	3.5	4.0	4.0	3.5	2.5	1.5	1.0	1.0
16	0.5	1.0	1.5	2.0	3.0	3.5	3.5	3.0	2.0	1.0	0.5	0.5
15.5	0.0	0.5	1.0	1.5	2.5	3.0	3.0	2.5	1.5	0.5	0.0	0.0
15	0.0	0.0	0.5	1.0	2.0	2.5	2.5	2.0	1.0	0.0	0.0	0.0
14.5	0.0	0.0	0.0	0.5	1.5	2.0	2.0	1.5	0.5	0.0	0.0	0.0
14	0.5	0.0	0.0	0.0	1.0	1.5	1.5	1.0	0.0	0.0	0.5	0.5
13.5	1.0	0.5	0.0	0.0	0.5	1.0	1.0	0.5	0.0	0.0	1.0	1.0
13	1.5	1.0	0.5	0.0	0.0	0.5	0.5	0.0	0.0	0.5	1.5	1.5
12.5	2.0	1.5	1.0	0.5	0.0	0.0	0.0	0.0	0.0	1.0	2.0	2.0
12	2.5	2.0	1.5	1.0	0.0	0.0	0.0	0.0	0.5	1.5	2.5	2.5
11.5	3.0	2.5	2.0	1.5	0.5	0.5	0.5	0.5	1.0	2.0	3.0	3.0
11	3.5	3.0	2.5	2.0	1.0	1.0	1.0	1.0	1.5	2.5	3.5	3.5
10.5	4.0	3.5	3.0	2.5	1.5	1.5	1.5	1.5	2.0	3.0	4.0	4.0
10	4.5	4.0	3.5	3.0	2.0	2.0	2.0	2.0	2.5	3.5	4.5	4.5
9.5	5.0	4.5	4.0	3.5	2.5	2.5	2.5	2.5	3.0	4.0	5.0	5.0
9	5.5	5.0	4.5	4.0	3.0	3.0	3.0	3.0	3.5	4.5	5.5	5.5
8.5	6.0	5.5	5.0	4.5	3.5	3.5	3.5	3.5	4.0	5.0	6.0	6.0
8	6.5	6.0	5.5	5.0	4.0	4.0	4.0	4.0	4.5	5.5	6.5	6.5
7.5	7.0	6.5	6.0	5.5	4.5	4.5	4.5	4.5	5.0	6.0	7.0	7.0

A

B

Figure G-17. Lake Okeechobee stage envelope targets.

There is also a wide body of published research on the adverse impacts of extreme high and low water levels on the littoral and near-shore areas of Lake Okeechobee (Havens 2002). Extreme high stage (above 17 ft. NGVD29) allows wind-driven waves to directly impact the littoral emergent plant and near-shore submerged plant communities, causing physical uprooting of plants. High stage also permits suspended solids from the mid-lake region (where unconsolidated sediments are thickest) which is transported to the shoreline regions, reducing water clarity and light penetration. This in turn reduces the depth at which SAV growth can occur (James and Havens 2005). High-stage conditions also allow deposition of unconsolidated mud which can cover the natural sand and peat sediment, reducing their ability to sustain healthy and balanced vegetative communities. At extreme high stage, nutrient-rich water from the mid-lake region is transported into the littoral zone where it causes changes in periphyton biomass and taxonomic structure, as well as induces shifts in plant dominance, including expansion of cattail and lily. Overall, high lake stages result in extirpation or reduced growth of emergent and submerged plants, adverse impacts to germination of submerged plants, reductions in fish spawning and fish reproductive success, and undesirable shifts among species that comprise the macroinvertebrate community. Detailed research results regarding high stage impacts on the lake's plant and animal communities can be found in Maceina and Soballe (1990), Havens (1997), Havens et al. (1999), and Havens et al. (2001).

Conversely, extreme low stage (below 10 ft. NGVD29) can result in desiccation of the entire littoral zone, the shoreline fringing bulrush zone, and nearly all of the lake area that would otherwise support

submerged plants. As a consequence, in-lake habitat for reptiles, amphibians, wading birds, snail kites, apple snails, or fish that depend on aquatic plant-dominated regions for successful foraging and recruitment is severely compromised. Extreme low stage also encourages invasive exotic plants, such as torpedograss and melaleuca, to establish in areas of the littoral zone where they did not formerly occur, displacing native vegetation and increasing fire risk. Recovery from the impacts of prolonged low stage events (below 10 ft. MSL) is slow, requiring multiple years of appropriate stage regime to recover, as documented for submerged plants by Havens et al. (2004) and for sport fish such as largemouth bass by Havens et al. (2005).

2. Extreme High and Low Lake Stage: Lake stage remains below extreme high stage (above 17 ft. NGVD29) and above extreme low stage (below 10 ft. NGVD29). For extremes in high (>17 ft. NGVD29) and low (<10 ft. NGVD29) lake stages, the response curves relate the raw scores for each component of the PM to a standardized scale of 0 to 100. After the standardized scores for the amount of time above and below the extreme high and low stages are calculated, their scores are adjusted to a 0 to 1 score range, weighted at 7.5% for >17 ft. NGVD29, and 2.5% for <10 ft. NGVD29, for an overall 10% weight, and multiplied by the 450,000 acres that comprise all three lake zones, because these extreme lake stages impact the entire lake. The determination of how to weigh the scores was based on a screening analysis of different scoring weights for the three PMs. The weighted scoring used for all three PMs had the best combination of potential habitat unit lift and highest percentages of the maximum 1-point scores. This PM number of HU acres is then added to the other PM HU acres based on their scores, to calculate the potential amount of HU acres for the ECB, FWO, or any alternative scenarios being examined. The amount of HU acres will then be compared to determine the amount of potential lift based on the model run scenario output.

G.4.1.2 PM 2.2 – Lake Okeechobee Ecological Indicator Score Performance Measure

The nearshore and pelagic regions of Lake Okeechobee are occupied by a number of key ecological communities which can be used to evaluate the environmental health of the lake as a function of their responses to changing hydrologic conditions. For example, nearshore vascular SAV and Chara provide important habitat for fish, wading birds, macroinvertebrates, other taxa and epiphytic algae (Havens et al. 2002). Similarly, the epipelic and epiphytic communities are important components of the lake's food web and compete with algal species for available nutrients (Zimba 1995; Carrick & Steinman 2001; Rodusky et al. 2001; 2010), while cyanobacteria can cause major health and safety issues if they are present in high abundance (US EPA 2016). Fish (panfish), because they are higher on the food web, in turn integrate many other aspects of the ecological status of the lake. Because these components of the Lake Okeechobee ecosystem are so important, they have been the subject of regular monitoring and thus the long-term monitoring data sets are available to elucidate their relationship to lake hydrology.

The ecological indicator scores used in this combined PM are based on the strongest statistical significant correlations between the ecological indicator data and average monthly lake stages during the data collection periods, or average monthly lake stages during the previous 1, 2, 3, or 6 months, or the previous year. The summer cyanobacteria abundance data were collected during July (1994, 2000–2011) and June (1995). The panfish creel data were collected during January and February 1997-2005. The epipelon abundance data were collected near the end of August 2002, and March/April and September/October of 2003–2005 and 2008–2010. The epiphyte abundance data were collected during the same timeframe as the epipelon data during 2002-2005; the spring collection did not resume until 2009 due to lack of host vegetation and continued in 2010, fall 2011, and spring and fall 2012. The annual summer Chara and SAV coverage data were collected 2000–2012 (SAV) and 2000–2013 (Chara). For all of the indicators, the lake

stages in the correlation data sets were between approximately 3m and 5m, which defines the approximate range of lake stages over which this PM can be used.

This combined ecological indicator PM is an evaluation of Lake Okeechobee hydrology as measured using 6 nearshore ecological scoring metrics which can be used combined or individually to evaluate the effects of Lake hydrology on each indicator (RECOVER, 2016). PM output is in the form of an annual numeric score for each individual metric (0 – 2 pt) or as a combined annual or POR score for all metrics. The individual scores can also be related to areal submerged plant coverage for 2 of the 6 individual PMs and to abundances for the other 4 PMs; based on experiential data obtained from multiple years of baseline monitoring. Scores can be used to compare regulation schedules, varying climate conditions, or the effects of projects on lake ecology by the differences in lake stages.

The desired restoration condition is a combination of lake stage envelope (12.5–15.5 ft. NGVD29) and annual fluctuation in stage from maximum elevation at the end of the wet season (generally October) to minimum elevation at the end of the dry season (generally May) which results in a high annual point score for high epiphyton, panfish abundance, and vascular SAV. Conversely, the annual point score for low cyanobacterial abundance and epipelon and Chara coverage are high when the lake stage is below the stage envelope. Cumulative point scores over a 41-year POR range 0–447. The target is a cumulative point score of 427 points, which would have resulted had the highest annual cumulative score that the 2008 LORS regulation schedule generated occurred every year over the 1965-2005 41-year period of record. The interim goal is a cumulative point score of 324 points, which is the cumulative score over the 41-year POR generated by the 2008 LORS schedule. After the combined score for the POR is calculated, the score is adjusted to a 0–1 score range, weighted (45%) and multiplied by the 350,000 acres that comprise the open water nearshore and pelagic zones. The 6 ecological indicators have been monitored where they exist in either one or both of these lake zones.

Chara abundance: When the average July lake stage is below 12 ft. NGVD29 (2 pts), between 12 ft. and 15.5 ft. NGVD29 (1 pt), and above 15.5 ft. NGVD29 (0 pts), the probability of peak summer (July and August) coverage conditions are optimal, sub-optimal, and poor, respectively. The July lake stage and peak summer Chara coverage correlation: (ρ= -0.74505; p=0.002).

Cyanobacteria abundance: When the average May lake stage is below 12 ft. NGVD29 (2 pts), between 12 ft. and 14 ft. NGVD29 (1 pt), and above 14 ft. NGVD29 (0 pts), the probability of elevated summer (July) cyanobacteria abundance is low, intermediate, and high, respectively. The May lake stage and July cyanobacteria abundance correlation: (ρ=0.28001; p=0.015).

Epipelon abundance: When the average monthly lake stages the previous year that correspond to the spring (usually March or April) and fall (usually September or October) sampling periods are below 12 ft. NGVD29 (2 pts), between 12 ft. and 15 ft. NGVD29 (1 pt), or above 15 ft. NGVD29 (0 pts), spring and fall growth conditions are optimal, intermediate, and poor, respectively. The previous year spring and fall month lake stage and spring and fall abundance correlation: (ρ= -0.71868; p=0.0038).

Epiphyte abundance: When the average monthly lake stages the previous month that correspond to the spring (usually March or April) and fall (usually September or October) sampling periods are below 14 ft. NGVD29 (2 pts), between 14 ft. and 15 ft. NGVD29 (1 pt), or above 15 ft. NGVD29 (0 pts), and submerged and emergent aquatic plant host communities are present, spring and fall growth conditions are optimal, intermediate, and poor, respectively. The spring and fall previous month lake stage and spring and fall abundance correlation: (ρ= -0.79643; p=0.0004).

Panfish (Bluegill and Redear Sunfish) creel survey abundance: When the average November and December lake stages are between 12 ft. NGVD29 and 15 ft. NGVD29 (2 pts), below 12 ft. NGVD29, between 15 ft. NGVD29 and 16 ft. NGVD29 (1 pt), or above 16 ft. NGVD29 (0 pts), winter creel survey abundance conditions are optimal, sub-optimal, and poor, respectively. The previous two months lake stages and January and February abundance correlation: (ρ= -0.8833; p=0.0016).

Submerged vascular aquatic plant (SAV) communities: When the average July lake stage is between 12 ft. NGVD29 and 15.5 ft. NGVD29 (2 pts), 10 ft. and <12 ft. or above 15.5 ft. NGVD29 (1 pt), and <10 ft. or $\geq$18 ft. NGVD29 (0 pts), the probability of summer peak (July and August) coverage conditions are optimal, sub-optimal, or poor, respectively. The July lake stage and peak summer vascular SAV coverage correlation: (ρ=0.62088; p=0.0235).

The overall POR score is the sum of the ecological indicator annual combined scores. Because the epipelon and panfish ecological indicator scores are based on the previous year's lake stages, the overall POR score does not include a first year score for these two indicators. After the ecological indicator scores are combined, the scores are adjusted to a 0–1 score range, weighted (45%), and multiplied by the 350,000 acres which comprise the nearshore and pelagic regions of the lake.

G.4.2 Lake Okeechobee Habitat Unit Calculation

The calculation of ecosystem benefits (quantitative scoring) consisted of the following steps: 1) Normalize Scores—normalizing PMs output to a common scale (0–1); 2) Combine Scores and Calculate HUs—combine PMs into aggregates scores for each habitat zone in the project area (e.g., Lake Okeechobee watershed, Lake Okeechobee and the Northern Estuaries) and multiply by acreages to get HUs; and 3) Compare HUs—Aggregate watershed HUs and compare alternatives by habitat zones.

In Step 1, PM scores were calculated for restoration alternatives and then scaled to 0–1 scale using the processes described in this subsection for each PM. In Step 2, PM output scores are multiplied by the areas of the zones they represent to generate HUs. The process is described in more detail below.

G.4.2.1 Lake Okeechobee – Normalization, Combining Score and Calculating HUs

The evaluation for the lake stage ecologically beneficial envelope and the extreme high and low PMs was based on the 41-year POR (1965-2005) lake stage hydrograph that was simulated by the RSM-BN model. During each week of the model run, the absolute value of the deviation (in feet) of lake stage from the ecologically beneficial envelope was determined. This was done separately for stages above and below the envelope. A sum of the number of weeks was kept for each type of deviation. For the extreme high and low lake stage periods, the total number of weeks that the stage was above 17 ft. or below 10 ft. NGVD29 was summed. Integrated post-processing then converted these rough scores into standard percent scores wherein a higher score represents improved conditions. **Figure G-18** shows the stage hydrographs for the final array of alternatives.

The evaluation for the ecological indicator score PM was based on end-of-month Lake Okeechobee stages for the 41-year POR which are obtained from either Reservoir Sizing and Operations Screening (RESOPS) model, SFWMM, or another suitable model. Each of the six ecological indicators is scored for by year in the POR and then summed. The resulting six individual indicator scores are then combined to give a single value for each model run. These scores are likewise directly comparable amongst output for different

model runs. **Figure G-19** shows the combined ecological score for each alternative. The ECB ecological score was 309.5 from the first round of modeling and did not change in this final round of modeling.

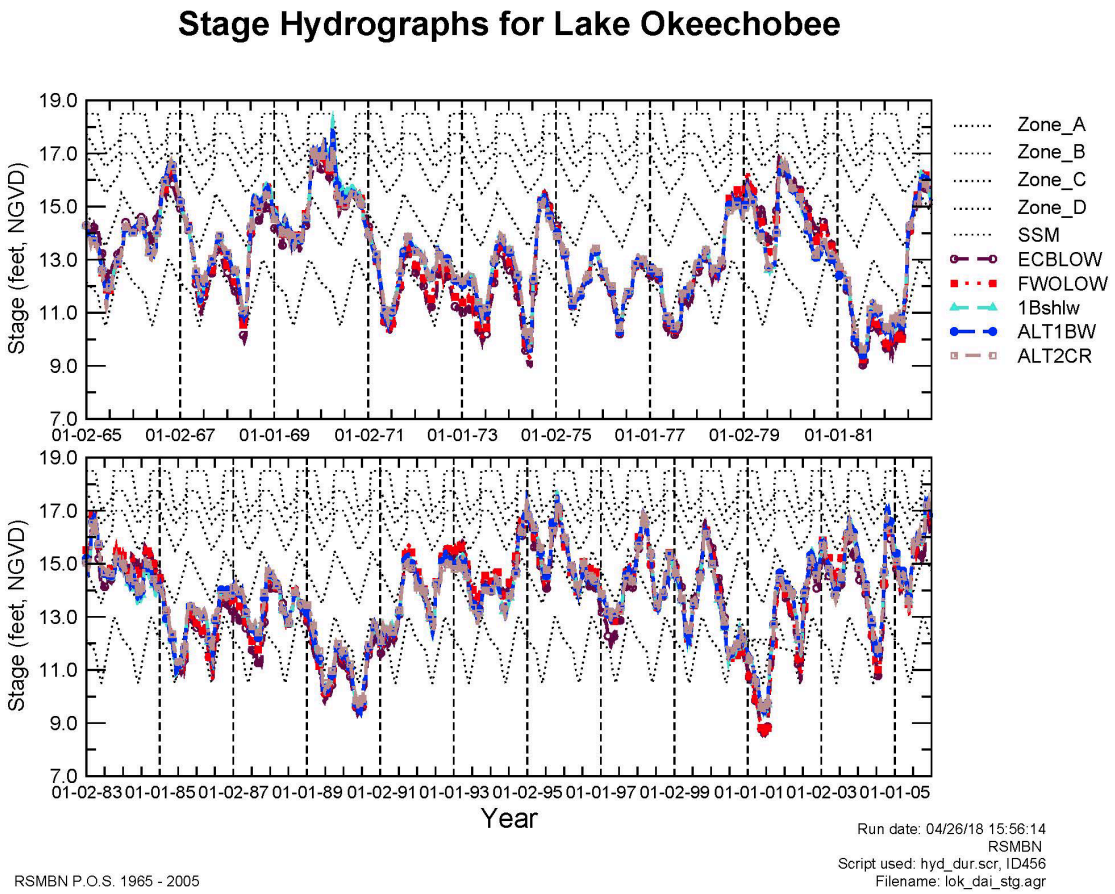

Figure G-18. Lake Okeechobee Stage hydrographs for the final array of alternatives.

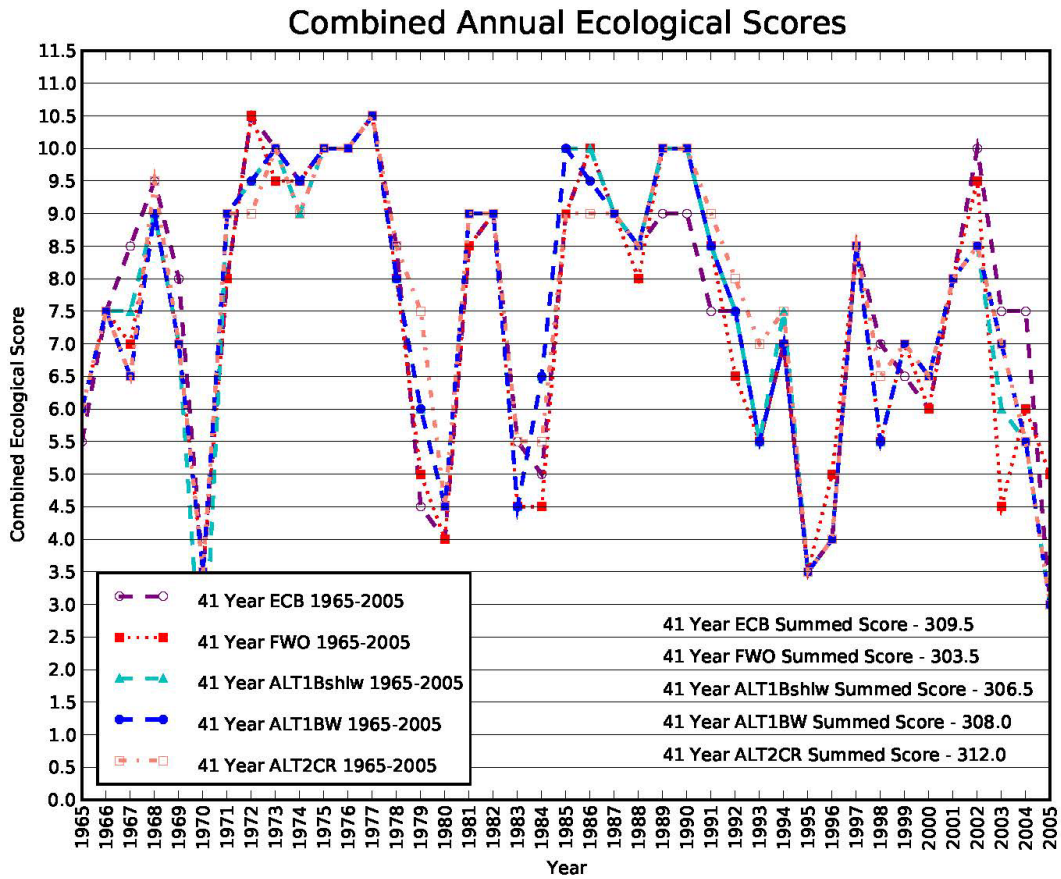

Figure G-19. The annual ecological indicator scores for the final array of alternatives over a 41-year period of record (1965-2005).

Habitat Unit Scoring: The hydrologic and ecological PM scoring which was used to calculate littoral and nearshore zone HUs (acres) needs to be combined and adjusted to score 0–1 points to calculate the potential HUs for Lake Okeechobee. Decimal equivalent percentages of the raw scores for each PM, where a zero score equals 0% and the best score equals 100% (1 pt) are combined at a ratio allotting 45% of the total score each to the lake stage envelope and the combined ecological PM score. The remaining 10% of the combined score is allotted to the > 17 ft. (7.5%) and the <10 ft. (2.5%) PMs. The lake stage envelope score is multiplied by 100,000, the estimated acreage of the littoral zone which is most strongly influenced by the stage envelope. The combined ecological PM score is multiplied by 350,000 acres, the estimated acreage for the nearshore and pelagic zones which are the locations for the six ecological parameters in this component of the PM. The >17 ft. and < 10 ft. PM scores are multiplied by 450,000 acres, because excessive high and excessive low lake stage conditions are considered to impact the entire lake. The total acres of lift for any alternative scored in this fashion is equivalent to the difference between the FWO score and the alternative score.

G.4.2.2 Lake Okeechobee Ecological Indicator HUs

The Ecological Indicator PM output is shown in **Figure G-19** for the final array of alternatives. The combined ecological scores are normalized to a 0-1 scale by dividing each score by the maximum score of 447. This score is multiplied by 350,000 acres (the nearshore and pelagic regions of the lake) to get the HUs. The HUs are then multiplied by 0.45 to get the weighted HUs for the Lake Okeechobee PM. **Table**

G-23. shows the individual ecological indicator score for the six indicators. **Table G-24** shows the PM output, the normalization, the HUs, and the weighted HUs for the combined annual ecological indicator PM. Alternative 2Cr scored the highest while Alt1Bshlw scored the lowest for the alternatives, although they all scored higher than the FWO scenario (**Table G-23.**). The individual ecological PM POR scores indicate that three of the ecological PMs will improve in abundance (epipelon and epiphyte periphyton and PanFish) and Alts 1BW and 2Cr scored higher for the vascular SAV PM (**Table G-23.**). Slight abundance improvements in effects to vegetation within Lake Okeechobee's extensive littoral and the other nearshore zone species are anticipated.

Table G-23. Lake Okeechobee Individual Ecological Indicator PM POR measure scores for the final array of alternatives.

	Summer Chara	Summer Cyan-obacteria	Spring + Fall Epipelon	Spring + Fall Epiphytes	January + February Panfish	Summer Vascular SAV	Combined Ecological Score
ECB	63	54	49	53	37.5	53	**309.5**
FWO	55	49	35	50	43.5	66	**303.5**
Alt 1Bshlw	51	49	36	53.5	49.5	66	**306.5**
Alt 1BW	52	48	36.5	52.5	52	67	**308**
Alt 2Cr	52	45	36	56	54	67	**312**

Table G-24. Lake Okeechobee Ecological Indicator Score PM output, normalization, and HUs for the final array of alternatives.

	Combined Annual Ecological Indicator Scores	0-1 Score	HU (350,000 acres max)	Weighted HU for LO (45%)
ECB	309.5	0.692	242,338	109,052
FWO	303.5	0.679	237,640	106,938
Alt 1Bshlw	306.5	0.686	239,989	107,995
Alt 1BW	308	0.689	241,163	108,523
Alt 2Cr	312	0.698	244,295	109,933
Max Score	447	1	350,000.00	157,500

G.4.2.3 Lake Okeechobee Stage Envelope HUs

The Lake Okeechobee Stage PM output is shown in **Figure G-20** and **Figure G-21** for the final array of alternatives. The scores for above and below the envelope are combined and normalized to a 0-1 scale by dividing each score by the maximum score of 100. This score is multiplied by 100,000 acres (the littoral region of the lake) to get the HUs. The HUs are then multiplied by 0.45 to get the weighted HUs for the

Lake Okeechobee PM. **Table G-25** shows the PM output, the normalization, the HUs and the weighted HUs for the Lake Okeechobee Stage PM.

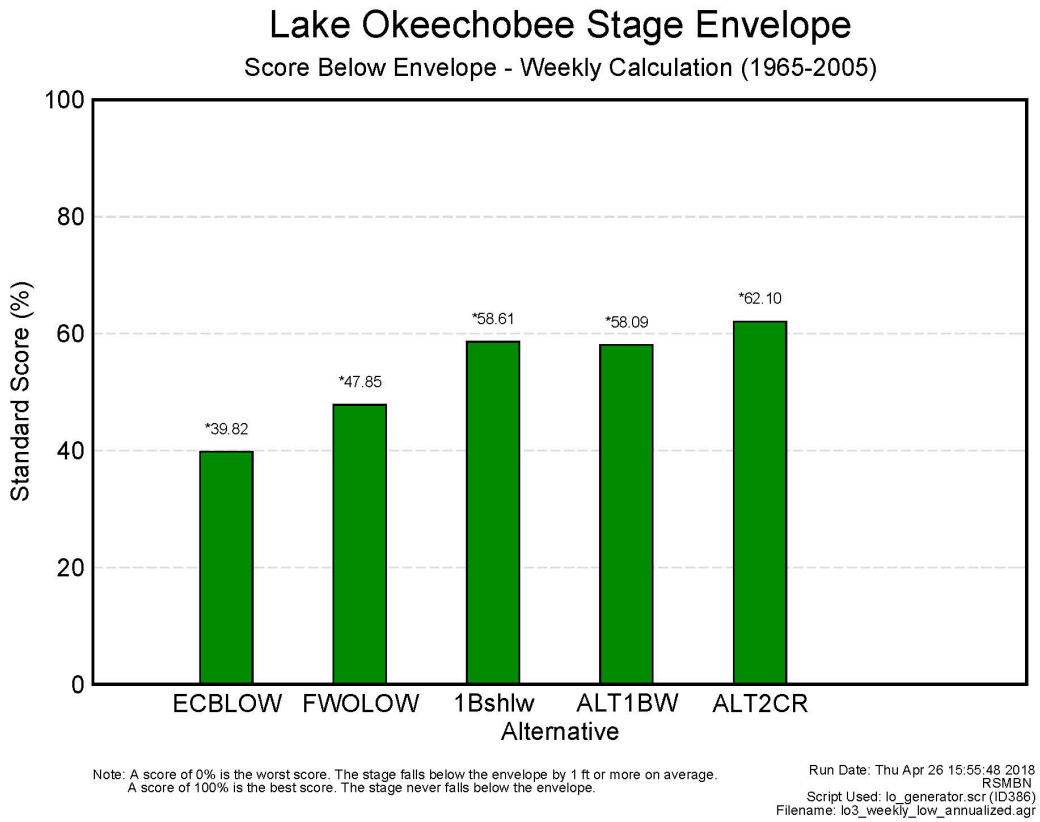

Figure G-20. Lake Okeechobee Low Stage Envelope PM output for the final array of alternatives.

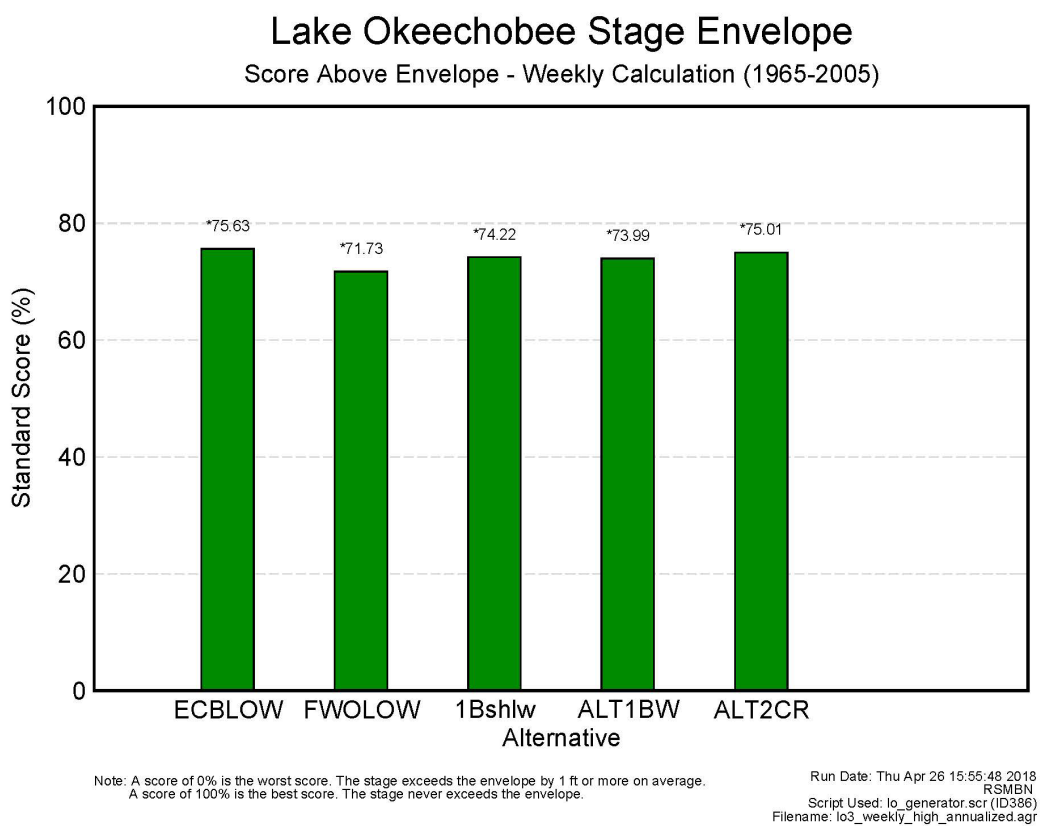

Figure G-21. Lake Okeechobee High Stage Envelope PM output for the final array of alternatives.

Table G-25. Lake Okeechobee Stage Envelope PM output, normalization and HUs for the final array of alternatives.

	Score Below	Score Above	0-1 Score	HU (100,000 max)	Weighted HU for LO (45%)
ECB	39.82	75.63	0.577	57,725	25,976
FWO	47.85	71.73	0.598	59,790	26,906
Alt 1Bshlw	58.61	74.22	0.664	66,415	30,472
Alt 1BW	58.1	73.99	0.660	66,045	29,720
Alt 2Cr	62.1	75.01	0.686	68,555	30,850
Max Score	100	100	1	100,000	45,000

G.4.2.4 Lake Okeechobee Extreme Lake Stage HUs

The Lake Okeechobee Extreme Lake Stage PM output is shown in **Figure G-22** and **Figure G-23** for the final array of alternatives. The scores for extreme low and high lake stages are normalized to a 0-1 scale by dividing each score by the maximum score of 100. This score is multiplied by 450,000 acres (all three lake zones) to get the HUs. The HUs for the extreme low lake stage are then multiplied by 0.025 to get the

weighted HUs for the Lake Okeechobee PM and the HUs for the extreme high lake stage are multiplied by 0.075 to get the weighted HUs for the Lake Okeechobee PM. **Table G-26** shows the PM output, the normalization, the HUs and the weighted HUs for the Extreme Low Lake Stage PM. **Table G-27** shows the PM output, the normalization, the HUs, and the weighted HUs for the Extreme High Lake Stage PM. **Table G-28** show the HUs for the combined Extreme Lake Stage PM.

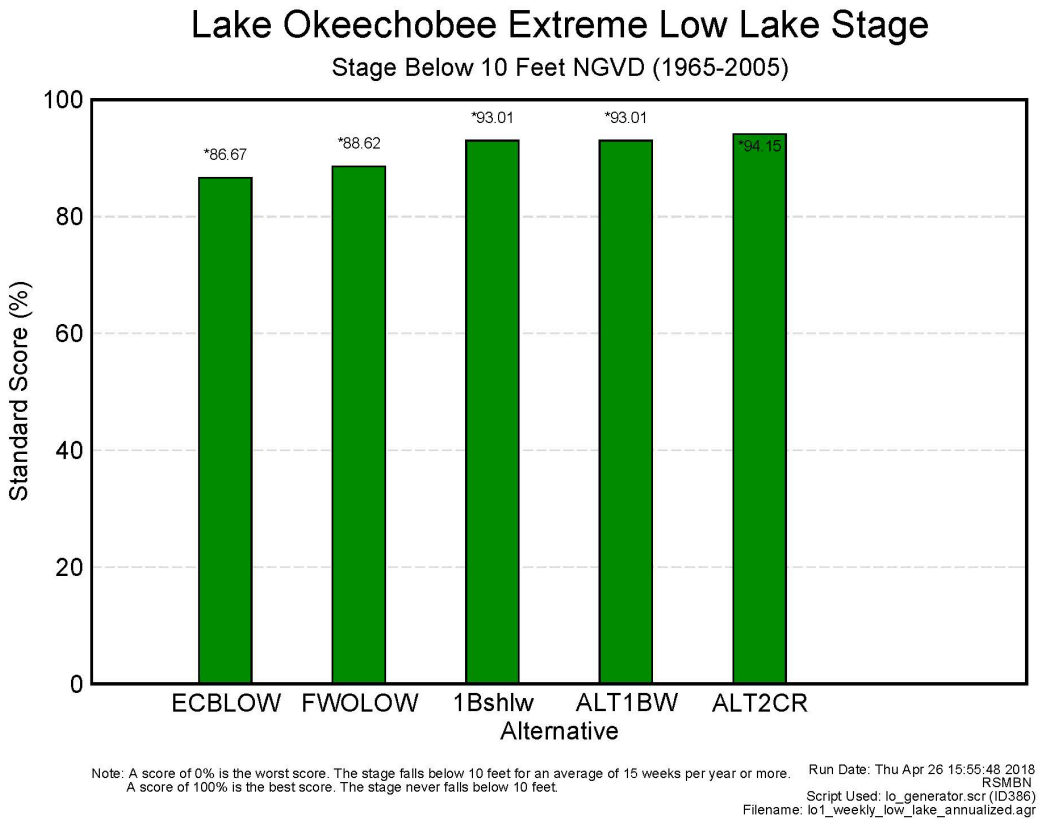

Figure G-22. Lake Okeechobee Extreme Low Stage PM output for the final array of alternatives.

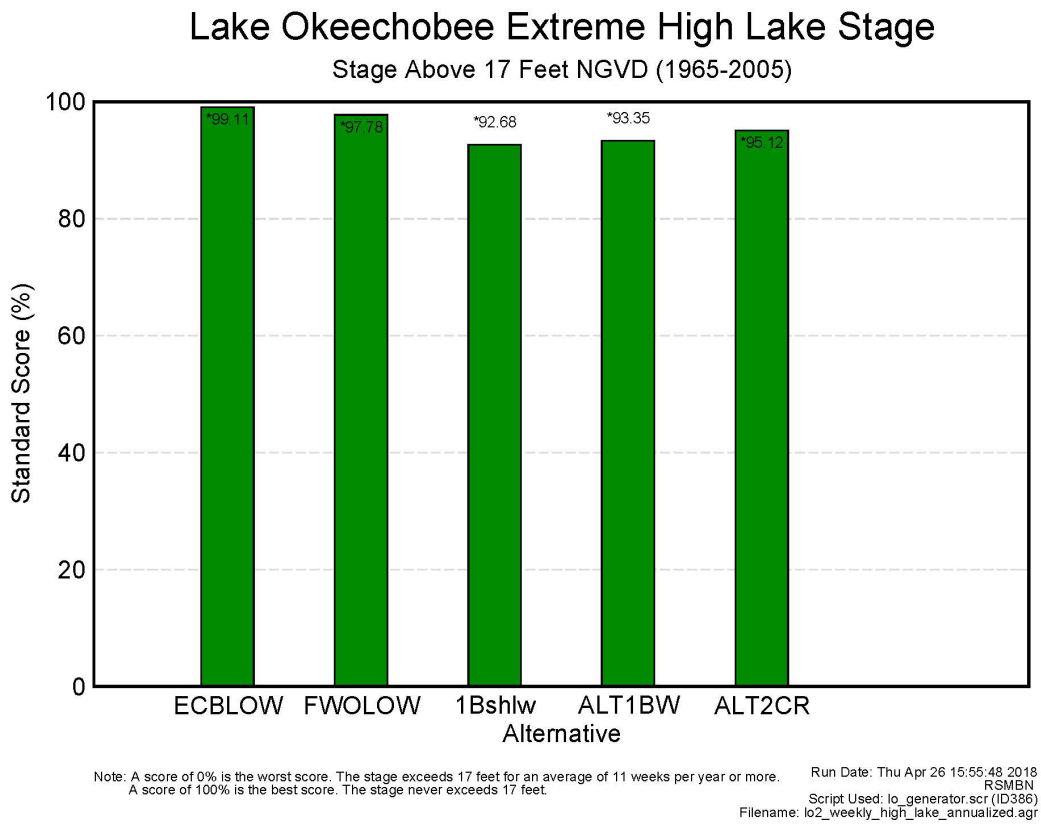

Figure G-23. Lake Okeechobee Extreme High Stage PM output for the final array of alternatives.

Table G-26. Lake Okeechobee Extreme Low Lake Stage PM output, normalization, and HUs for the final array of alternatives.

	Extreme Low Score	0-1 Score	HU (450,000 max)	Weighted HU for LO (2.5%)
ECB	86.67	0.867	390,015	9,750
FWO	88.62	0.886	398,790	9,970
Alt 1Bshlw	93.01	0.930	418,545	10,464
Alt 1BW	93.01	0.930	418,537	10,463
Alt 2Cr	94.15	0.942	423,675	10,592
Max	100	1	450,000	11,250

Table G-27. Lake Okeechobee Extreme High Lake Stage PM output, normalization, and HUs for the final array of alternatives.

	Extreme High Score	0-1 Score	HU (450,000 max)	Weighted HU for LO (7.5%)
ECB	99.11	0.991	445,995	33,450
FWO	97.78	0.978	440,010	33,001
Alt 1Bshlw	92.68	0.927	417,060	31,280
Alt 1BW	93.35	0.934	420,075	31,506
Alt 2Cr	95.12	0.951	428,040	32,103
Max	100	1	450,000	33,750

Table G-28. Lake Okeechobee Extreme Lake Stage PM HUs for the final array of alternatives.

	Extreme Low HUs	Extreme High HUs	Extreme High and Low HUs
ECB	9,750	33,450	43,200
FWO	9,970	33,001	42,971
Alt 1Bshwl	10,464	31,280	41,743
Alt 1BW	10,463	31,506	41,969
Alt 2Cr	10,592	32,103	42,695

G.4.3 Lake Okeechobee Alternative Performance

Table G-29 shows the Lake Okeechobee HUs. The three PMs are combined with the Ecological Indicator HUs contributing 45%, the Stage Envelope HUs contributing 45% and the Extreme Stage HUs contributing 10% (2.5% for extreme low and 7.5% for extreme high). Alternative 2Cr provides the greatest habitat unit lift of 6,664 acres, followed by Alt 1BW with 3,399 acres, and then Alt 1Bshlw with 2,811 acres.

Table G-29. Combined Lake Okeechobee HUs for the final array of alternatives.

	ECB	FWO	Alt 1Bshlw	Alt 1BW	Alt 2Cr
Ecological Indicator HUs	109,052	106,938	107,995	108,523	109,933
Stage Envelope HUs	25,976	26,906	29,887	29,720	30,850
Extreme Stage HUs	43,200	42,971	41,743	41,969	42,695
Overall Lake O HUs	**178,228**	**176,814**	**179,625**	**180,213**	**183,478**
Potential Lift (acres)	**1,414**	**0**	**2,811**	**3,399**	**6,664**

The Lake Okeechobee average AAHU lifts were calculated as the difference between the with-project and without project conditions over the period of analysis (through year 2071). For the without project

condition, a straight trajectory between existing and future without project HUs was assumed to establish HU totals for each site and year.

With project HU trajectory was modeled to reflect the timeline of expected restoration effects. Lake Okeechobee HUs for each alternative are assumed to reach 25 percent potential 2 years following construction completion, 50 percent potential 5 years following construction completion, 60 percent potential 10 years following construction completion, and 100 percent potential 25 years following construction completion. At that point, the full potential of HUs will be realized for the remainder of the period of analysis. **Figure G-24** show the trajectory of Lake Okeechobee HUs for each alternative over the period of analysis starting at an existing condition of 178,228 in 2028. The resulting average annual habitat unit lift is also displayed in **Table G-30**.

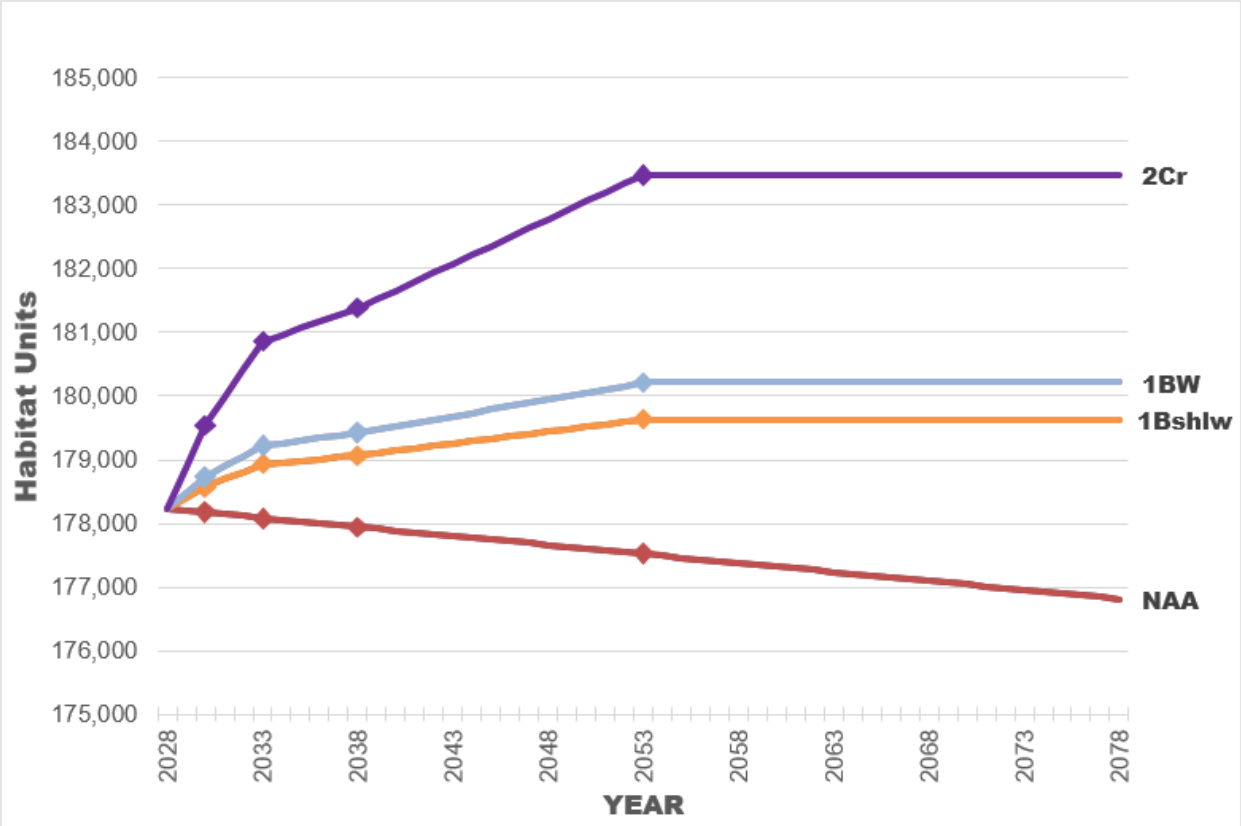

Figure G-24. Lake Okeechobee habitat unit trajectory.

Table G-30. Summary Lake Okeechobee habitat unit trajectory by alternative.

Alternative	ECB* Lake O HUs (2028)	FWP* Lake O HUs (2030)	FWP Lake O HUs (2033)	FWP Lake O HUs (2038)	FWP Lake O HUs (2053)	FWP Lake O HUs (2078)	Average Annual Lake O HU Lift
NAA	178,228	178,172	178,087	177,945	177,521	176,814	-
1Bshlw	178,228	178,577	178,927	179,066	179,625	179,625	1,884
1BW	178,228	178,724	179,221	179,419	180,213	180,213	2,374
2Cr	178,228	179,541	180,853	181,378	183,478	183,478	5,091

The AAHUs for Lake Okeechobee will be combined with the Northern Estuaries HUs for the storage CE/ICA. The CE/ICA is evaluated in **Section G.5.4**.

G.4.4 Lake Okeechobee Recommended Plan Performance

The TSP was refined to optimize the WAF shape for the Recommended Plan (Alternative 1BWR). The revised WAF footprint leads to additional modeling of the Recommended Plan. This section outlines the HU analysis for the Recommended Plan (Alt 1BWR).

G.4.4.1 Lake Okeechobee Ecological Indicator Recommended Plan HUs

The Ecological Indicator PM output is shown in **Figure G-25** for the Recommended Plan. The combined ecological scores are normalized to a 0-1 scale by dividing each score by the maximum score of 447. This score is multiplied by 350,000 acres (the nearshore and pelagic regions of the lake) to get the HUs. The HUs are then multiplied by 0.45 to get the weighted HUs for the Lake Okeechobee PM. **Table G-31** shows the individual ecological indicator score for the six indicators. **Table G-32** shows the PM output, the normalization, the HUs, and the weighted HUs for the combined annual ecological indicator PM. The individual ecological PM POR scores indicate that four of the ecological PMs will improve in abundance; epipelon and epiphyte periphyton, vascular SAV, and PanFish (**Table G-32**). Slight abundance improvements in effects to vegetation within Lake Okeechobee's extensive littoral and the other nearshore zone species are anticipated.

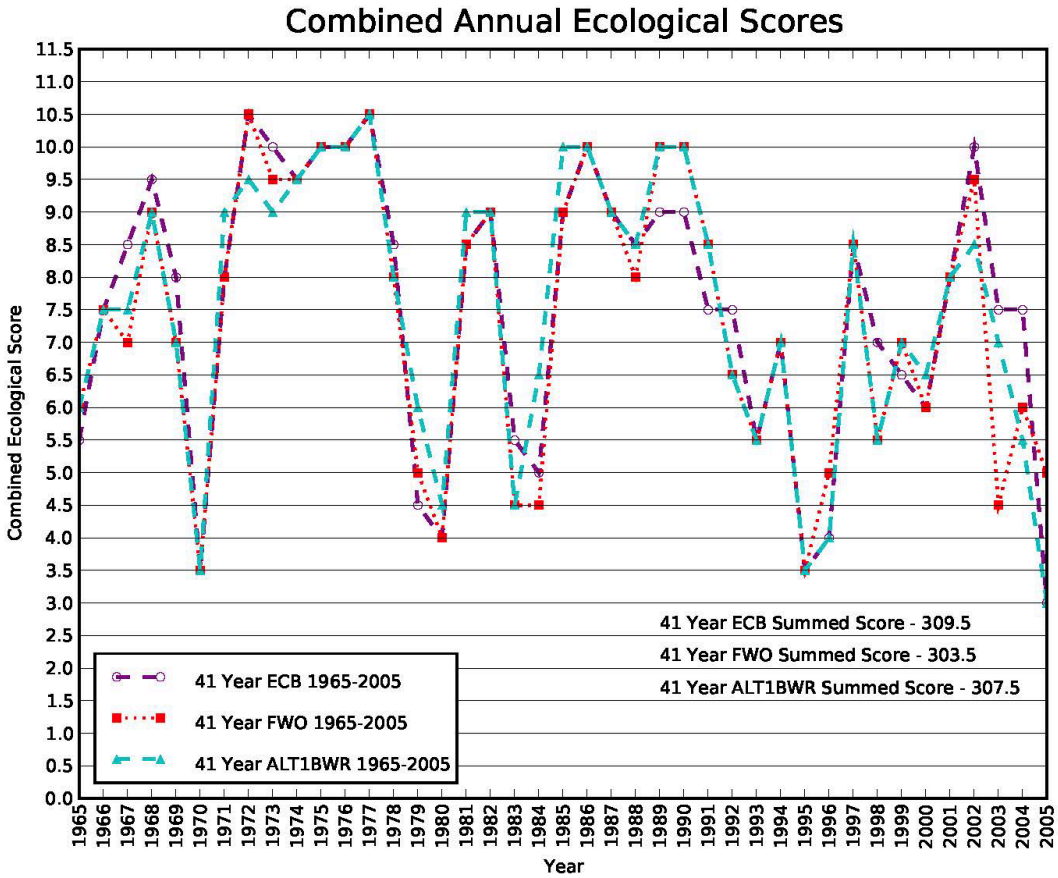

Figure G-25. Lake Okeechobee Ecological Indicator Combined Period of Record Performance Measure Scores for the Recommended Plan.

Table G-31. Lake Okeechobee Individual Ecological Indicator PM POR measure scores for the Recommended Plan.

	Summer Chara	Summer Cyano-bacteria	Spring + Fall Epipelon	Spring + Fall Epiphytes	January + February Panfish	Summer Vascular SAV	Combined Ecological Score
ECB	63	54	49	53	37.5	53	**309.5**
FWO	55	49	35	50	43.5	66	**303.5**
Alt 1BWR	52	49	36.5	53	50	67	**307.5**

Table G-32. Lake Okeechobee Ecological Indicator Score PM output, normalization, and HUs for the Recommended Plan.

	Combined Annual Ecological Indicator Scores	0-1 Score	HU (350,000 acres max)	Weighted HU for LO (45%)
ECB	309.5	0.692	242,338	109,052
FWO	303.5	0.679	237,640	106,938
Alt 1BWR	307.5	0.688	240,772	108,347
Max Score	447	1	350,000.00	157,500

G.4.4.2 Lake Okeechobee Stage Envelope Recommended Plan HUs

The Lake Okeechobee Stage PM output is shown in **Figure G-26** and **Figure G-27** for the Recommended Plan. The scores for above and below the envelope are combined and normalized to a 0-1 scale by dividing each score by the maximum score of 100. This score is multiplied by 100,000 acres (the littoral region of the lake) to get the HUs. The HUs are then multiplied by 0.45 to get the weighted HUs for the Lake Okeechobee PM. **Table G-33** shows the PM output, the normalization, the HUs and the weighted HUs for the Lake Okeechobee Stage PM.

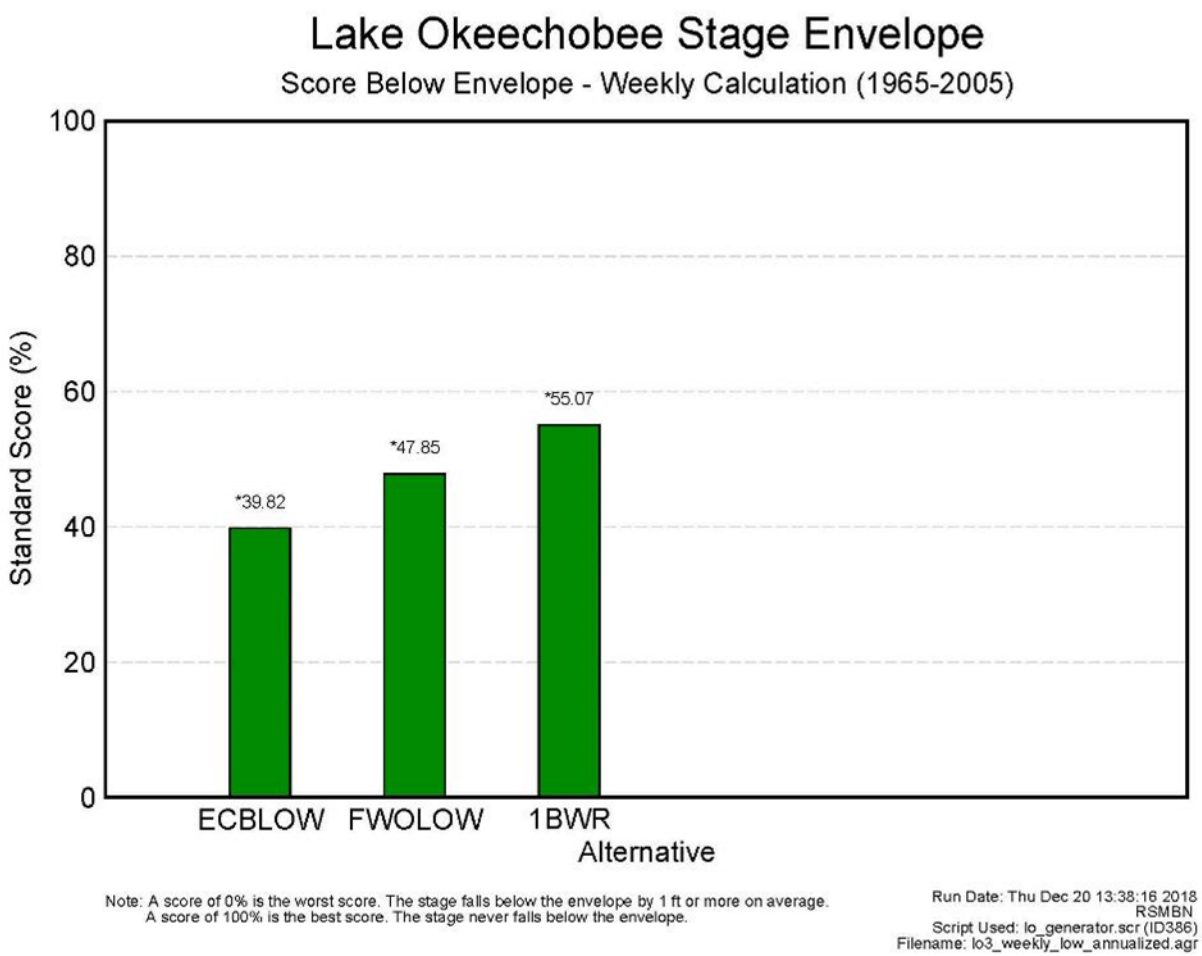

Figure G-26. Lake Okeechobee Low Stage Envelope PM output for the Recommended Plan.

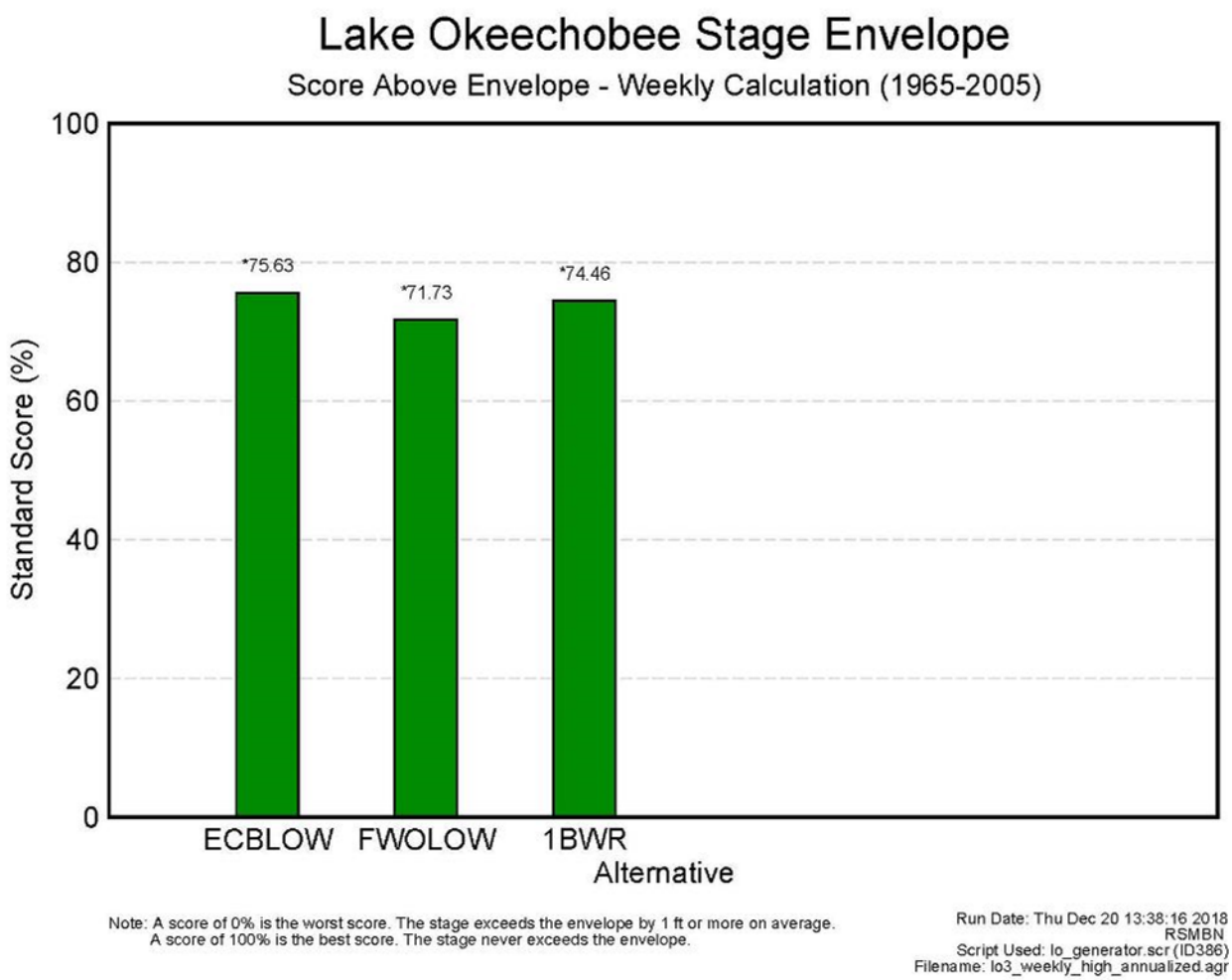

Figure G-27. Lake Okeechobee High Stage Envelope PM output for the Recommended Plan.

Table G-33. Lake Okeechobee Stage Envelope PM output, normalization and HUs for the Recommended Plan.

	Score Below	Score Above	0-1 Score	HU (100,000 max)	Weighted HU for LO (45%)
ECB	39.82	75.63	0.577	57,725	25,977
FWO	47.85	71.73	0.598	59,790	26,906
Alt 1BWR	55.07	73.99	0.645	64,532	29,039
Max Score	100	100	1	100,000	45,000

G.4.4.3 Lake Okeechobee Extreme Lake Stage Recommended Plan HUs

The Lake Okeechobee Extreme Lake Stage PM output is shown in **Figure G-28** and **Figure G-29** for the final array of alternatives. The scores for extreme low and high lake stages are normalized to a 0-1 scale by dividing each score by the maximum score of 100. This score is multiplied by 450,000 acres (all three lake zones) to get the HUs. The HUs for the extreme low lake stage are then multiplied by 0.025 to get the weighted HUs for the Lake Okeechobee PM and the HUs for the extreme high lake stage are multiplied by 0.075 to get the weighted HUs for the Lake Okeechobee PM. **Table G-34** shows the PM output, the normalization, the HUs and the weighted HUs for the Extreme Low Lake Stage PM. **Table G-35** shows the PM output, the normalization, the HUs, and the weighted HUs for the Extreme High Lake Stage PM. **Table G-36** shows the HUs for the combined Extreme Lake Stage PM.

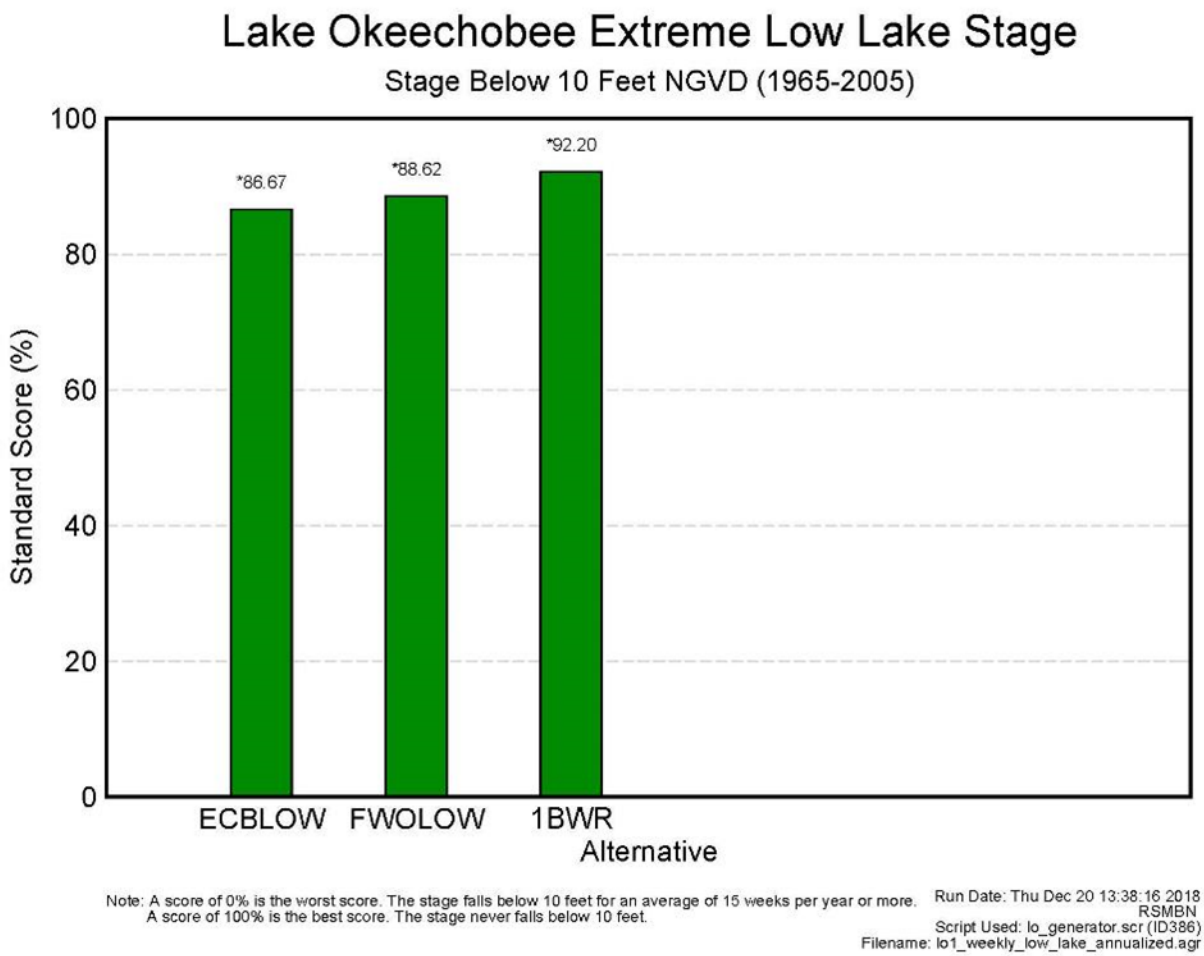

Figure G-28. Lake Okeechobee Extreme Low Stage PM output for the Recommended Plan.

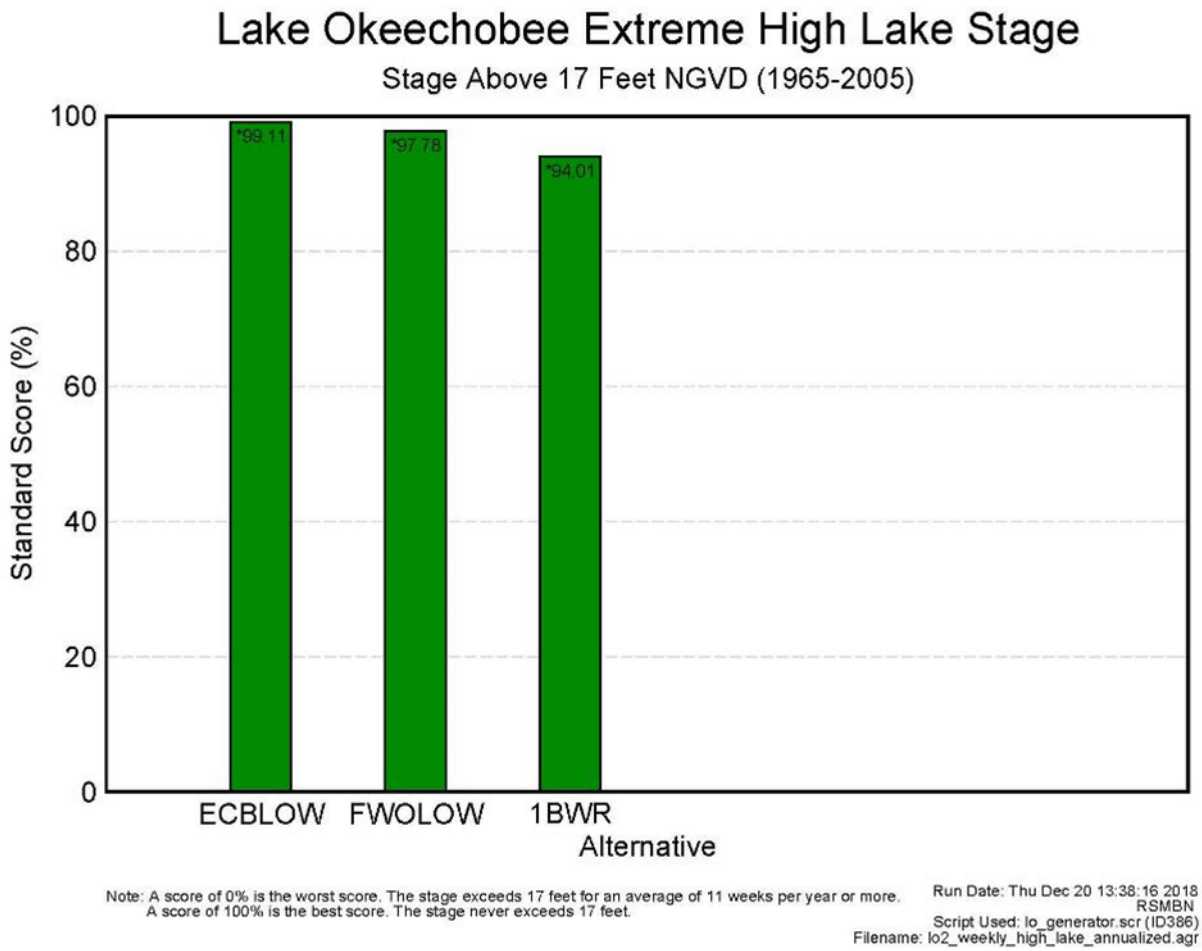

Figure G-29. Lake Okeechobee Extreme High Stage PM output for the Recommended Plan.

Table G-34. Lake Okeechobee Extreme Low Lake Stage PM output, normalization, and HUs for the Recommended Plan.

	Extreme Low Score	0-1 Score	HU (450,000 max)	Weighted HU for LO (2.5%)
ECB	86.67	0.867	390,015	9,750
FWO	88.62	0.886	398,790	9,970
Alt 1BWR	92.20	0.922	414,878	10,372
Max	100	1	450,000	11,250

Table G-35. Lake Okeechobee Extreme High Lake Stage PM output, normalization, and HUs for the Recommended Plan.

	Extreme High Score	0-1 Score	HU (450,000 max)	Weighted HU for LO (7.5%)
ECB	99.11	0.991	445,995	33,450
FWO	97.78	0.978	440,010	33,001
Alt 1BWR	94.01	0.940	423,060	31,729
Max	100	1	450,000	33,750

Table G-36. Lake Okeechobee Extreme Lake Stage PM HUs for the Recommended Plan.

	Extreme Low HUs	Extreme High HUs	Extreme High and Low HUs
ECB	9,750	33,450	43,201
FWO	9,970	33,001	42,971
Alt 1BWR	10,372	31,729	42,101

G.4.4.4 Lake Okeechobee Recommended Plan Performance

Table G-37 shows the Lake Okeechobee HUs. The three PMs are combined with the Ecological Indicator HUs contributing 45%, the Stage Envelope HUs contributing 45% and the Extreme Stage HUs contributing 10% (2.5% for extreme low and 7.5% for extreme high). The Recommended Plan (Alt 1BWR) provides a habitat unit lift of 2,673 acres. **Table G-38** shows the trajectory of Lake Okeechobee HUs for the reccomended plan from 2028 through 2078, as well as the average annual Lake Okeechobee HU lift. **Figure G-30** shows this information graphically. The average annual Lake Okeechobee HU lift for the Recommended Plan is 1,770.

Table G-37. Combined Lake Okeechobee HUs for the Recommended Plan.

	ECB	FWO	Alt 1BWR
Ecological Indicator HUs	109,052	106,938	108,347
Stage Envelope HUs	25,977	26,906	29,039
Extreme Stage HUs	43,201	42,971	42,101
Overall Lake O HUs	**178,230**	**176,814**	**179,488**
Potential Lift (acres)	**1,416**	**0**	**2,673**

Table G-38. Summary Lake Okeechobee Recommended Plan habitat unit trajectory.

Alternative	ECB* Lake O HUs (2028)	FWP* Lake O HUs (2030)	FWP Lake O HUs (2033)	FWP Lake O HUs (2038)	FWP Lake O HUs (2053)	FWP Lake O HUs (2078)	Average Annual Lake O HU Lift
NAA	178,228	178,172	178,087	177,945	177,521	176,814	-
1BWR	178,228	178,543	178,858	178,984	179,488	179,488	1,770

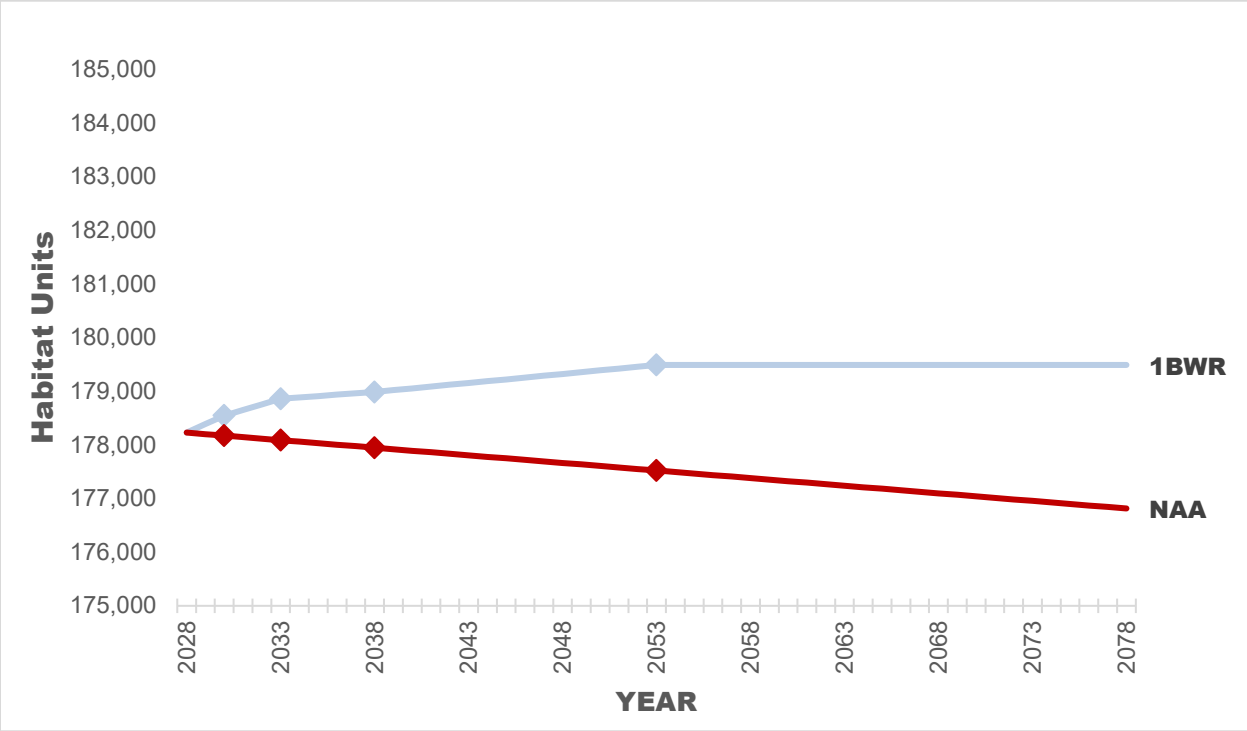

Figure G-30. Lake Okeechobee Recommended Plan habitat unit trajectory.

G.5 Northern Estuaries Benefit Calculation

The primary areas evaluated in the Northern Estuaries are Caloosahatchee Estuary (**Figure G-4**) and St. Lucie Estuary (**Figure G-5**). These two estuaries connect directly to Lake Okeechobee.

G.5.1 Northern Estuaries Performance Measures

PMs within the Northern Estuaries were used to evaluate habitat suitability for oyster and SAV based on target flows over water control structures. Within the Caloosahatchee Estuary, targets were based on freshwater flows at the S-79 structure (**Figure G-4** and **Figure G-31**). Within the St. Lucie Estuary, targets were based on freshwater flows at the S-80, S-48, S-49, and Gordy road structures (**Figure G-5** and **Figure G-31**). The LOWRP is expected to improve conditions for estuarine and marine resources throughout the Northern Estuaries by restoring more natural timing, volume, and duration of freshwater flows to the

Northern Estuaries. It has the potential to provide a more appropriate range of salinity conditions by reducing extreme salinity fluctuations and maintaining flows during dry periods. The salinity envelope target for the Caloosahatchee Estuary is a salinity range of 16–28 practical salinity unit (psu). The salinity envelope target for the St. Lucie Estuary is a salinity range of 12–20 psu. Extensive monitoring of the Caloosahatchee and St. Lucie Estuaries, as well as flows from the associated basins and Lake Okeechobee, has been performed to determine representative median salinities associated with flow events at these structures. Salinity levels at stations throughout each of the estuaries have been recorded. Calculation of habitat benefits achieved by each of the project alternatives were restricted to portions of the estuary where changes in salinity in relation to freshwater flows across water control structures (e.g., S-79, S-80, S-48, S-49, and Gordy road structures) could be reasonably predicted. For analytical purposes, the area to be potentially affected by the project was assumed to encompass 85,973 acres (70,979 acres for the Caloosahatchee Estuary (**Figure G-4**) and 14,994 acres for the St. Lucie Estuary (**Figure G-5**)). PM scores within the Northern Estuaries were generated from the RSM-BN model runs. The subsections below provide a brief description of the Northern Estuaries PMs, including the target(s) for each and the applicable metrics for the target(s).

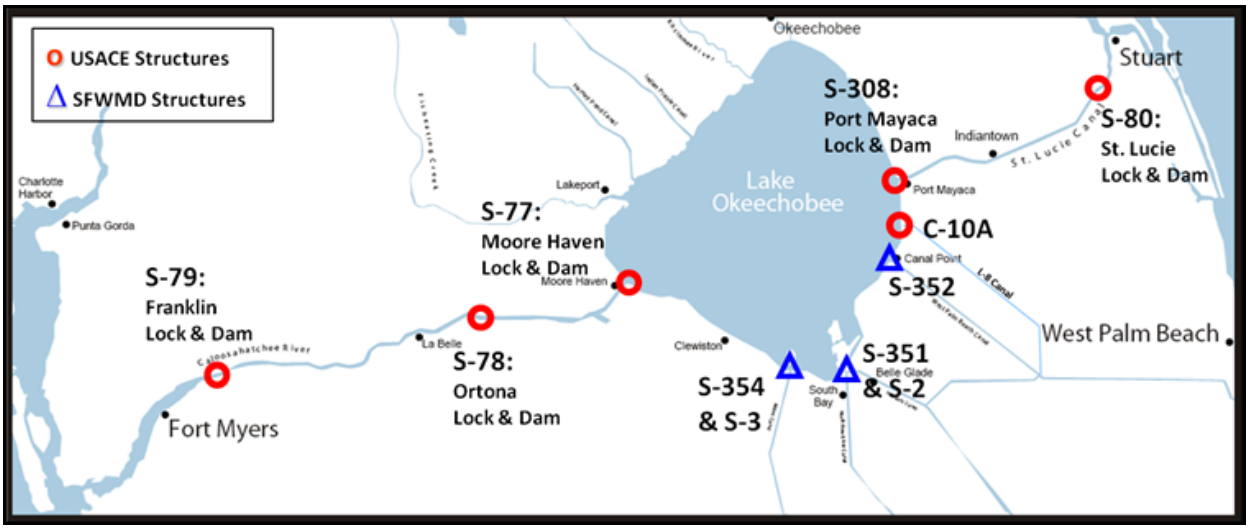

Figure G-31. Key structures of Lake Okeechobee and the Northern Estuaries.

G.5.1.1 PM 3 - Caloosahatchee River Estuary Salinity Envelope Performance Measure

Overall restoration goals for PM 3 include re-establishment of a salinity range favorable to juvenile marine fish, shellfish, oysters, and SAV; re-establishment of seasonally appropriate freshwater flows of favorable quality that maintain low salinities in the upper estuary; and re-establishment of more stable salinities and ranges in the lower estuary.

Targets are based on freshwater flows from the C-43 canal at the S-79 structure where the mean monthly inflow should be maintained between 450 and 2,800 cfs. The low-flow target is no months during October to July when the mean monthly inflow from the Caloosahatchee watershed falls below a low-flow limit of 450 cfs (C-43 basin runoff and Lake Okeechobee regulatory flows). The high-flow target is no months with mean monthly flows greater than 2,800 cfs from Lake Okeechobee regulatory flows in combination with flows from the Caloosahatchee River (C-43) basin.

G.5.1.2 PM 4 - St. Lucie Estuary Salinity Envelope Performance Measure

Overall restoration goals include maintaining a salinity range favorable to fish, benthic invertebrates, oysters, and SAV. This requires addressing high-volume, long duration flow events from Lake Okeechobee, C-44, C-23, and C-24 watersheds. The flow targets are designed to result in a favorable salinity envelope of 12–20 psu salinity in the mid estuary.

For the LOWRP the flow targets for the St. Lucie Estuary focus on flows from Lake Okeechobee only. This is due to the fact that the watershed flow targets are being addressed in the Indian River Lagoon South Project which is included in the 2050 base conditions. From the *RECOVER Northern Estuaries Salinity Performance Measure* (RECOVER 2007), full restoration targets are estimated to be:

- Thirty-one months where mean flow is less than 350 cubic feet per second (cfs)
- 0 Lake Okeechobee regulatory flow events (14 day moving averages > 2000 cfs)

For each of the estuaries, scores are reported for project alternatives indicating the numbers of times flow targets and/or corresponding salinity envelope criteria are not met. Alternatives are scored based on achievement of targets.

G.5.2 Northern Estuaries Habitat Unit Calculation

The calculation of ecosystem benefits (quantitative scoring) consisted of the following steps: 1) Normalize Scores—normalizing PMs output to a common scale (0-1); 2) Combine Scores and Calculate HUs—combine PMs into aggregates scores for each habitat zone in the project area (e.g., Lake Okeechobee watershed, Lake Okeechobee, and the Northern Estuaries) and multiply by acreages to get HUs; and 3) Compare HUs—Aggregate watershed HUs and compare alternatives by habitat zones.

The score calculation process is described in detail below.

G.5.2.1 Northern Estuaries – Normalization, Combining Score and Calculating HUs

Survey information from the *2007 System Status Report* (RECOVER 2007b) was used to determine the zero score on the 0–100 scale for current conditions ECB. Oyster surveys performed in 2003 and 2004 indicate that, as of those dates, there were 18 acres of live oyster bars in the Caloosahatchee Estuary and 117 acres in the St. Lucie Estuary. Target acreages for these locations are 500 acres and 834 acres, respectively. These targets were determined to be the maximum acres achievable after all CERP components affecting these areas are built and operational (RECOVER 2005). This target assumes all reservoir, STA, and wetland rehydration features necessary to obtain favorable salinities are in place. In order to reach these targets, substrate improvements—which includes muck removal and the addition of suitable substrate such as oyster cultch—will also be needed. To calculate the score on the 0–100 scale for current conditions, a percentage of the target was used (e.g., 14% for the St. Lucie Estuary and 4% for the Caloosahatchee Estuary) based on the acres of oysters from the 2003 and 2004 surveys. Original scores for each PM for the ECB were then rescaled to these values. The minimum value for each PM for the original scale was then extrapolated using the known score determined for the ECB (14 for the St. Lucie Estuary and 4 for the Caloosahatchee Estuary) and the target score of 100 (**Table G-39**). The same methodology that was used in the CEPP was used in the LOWRP to normalize and calculate estuary HUs.

Table G-39. Rescaling of ECB.

Estuary	Existing Oyster Acres (year recorded)	Restoration Target (acres)	% of Target
Caloosahatchee	18 (2004)	500	4%
St. Lucie	117 (2003)	834	14%

Acreages of oysters were determined to be a suitable measure for purposes of determining the 0 to 100 score for current conditions. Oysters, which naturally dwell in the middle (mesohaline) portion of the estuaries, are affected by both high-flow and low-flow violations of the salinity PM. Oysters provide many benefits to the estuaries because they improve water quality by filtering particles from the water and serving as prey and habitat for numerous other organisms, and play an important role in the estuarine food chain. Oysters serve as excellent indicator species because salinity conditions suitable for oysters also produce favorable conditions for a suite of other desirable estuarine organisms that dwell both directly on the reef and in other areas of the estuary. As a keystone species and valued ecosystem component, oysters are indicative of the ecosystem's health.

G.5.2.2 Caloosahatchee Estuary Final Array HUs

Table G-40 shows rescaled PM scores on a 0–100 scale for the Caloosahatchee Estuary based on the RSM-BN model output for the final array of alternatives (**Figure G-32**). The scores were then normalized based on their habitat suitability index (HSI score of a 0–1 scale to calculate HUs. The low-flow and high-flow habitat suitability indices were combined to give one HSI for the Caloosahatchee Estuary. This HSI was multiplied by the acreage (70,979 acres) to get the HUs (**Table G-41**).

Table G-40. Rescaled PM scores normalized on a 0–100 scale for Caloosahatchee Estuary for the final array of alternatives.

Metric #	PM Metric	ECB	FWO	Alt 1Bshlw	Alt 1BW	Alt 2Cr
3.1	Low Flow (< 450 cfs)	4	81	80	81	81
3.2	High Flow (>2800 cfs)	4	29	36	39	35

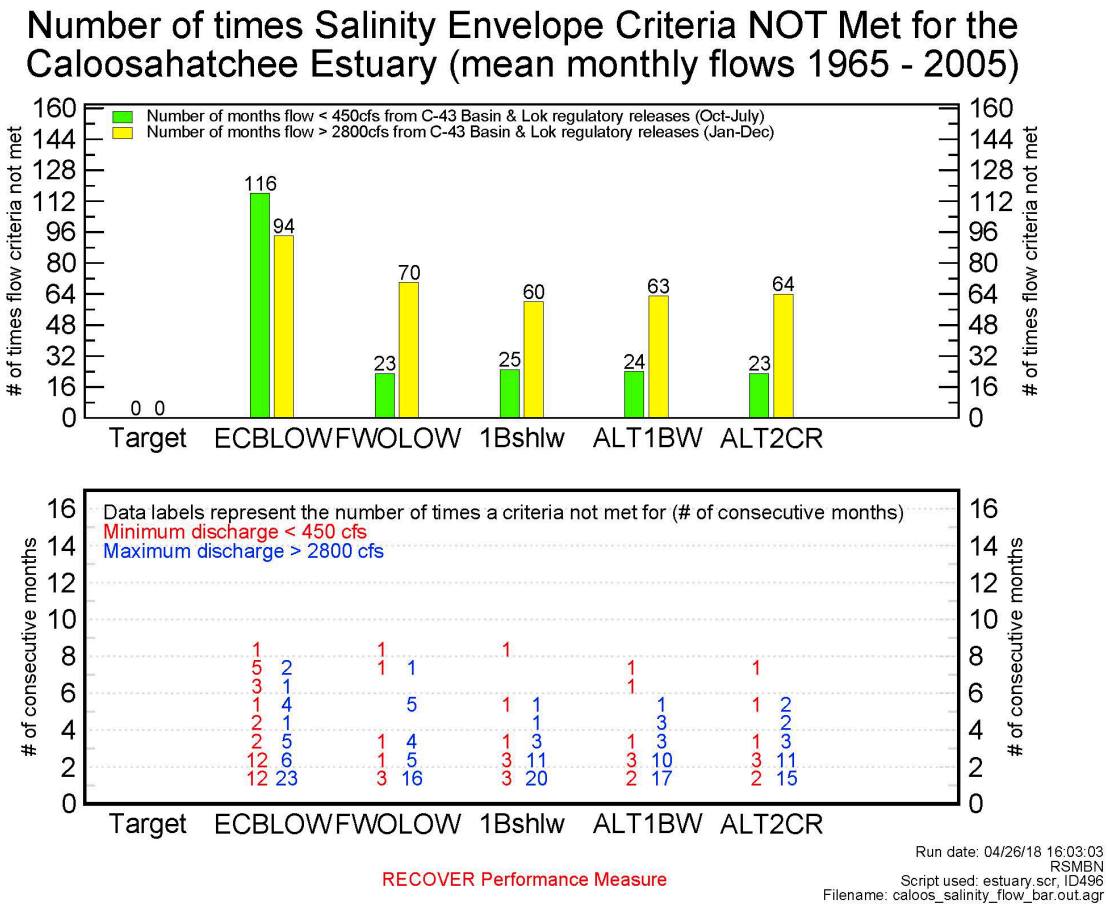

Figure G-32. Number of times salinity criteria not met for the Caloosahatchee Estuary for the final array of alternatives.

Table G-41. HSI and HUs for the Caloosahatchee Estuary.

Metric #	PM Metric	ECB	FWO	Alt 1Bshlw	Alt 1BW	Alt 2Cr
3.1	Low Flow (< 450 cfs) Habitat Suitability Index	0.02	0.405	0.395	0.400	0.405
3.2	High Flow (>2800 cfs) Habitat Suitability Index	0.02	0.145	0.195	0.180	0.175
	Total Caloosahatchee HSI	**0.04**	**0.55**	**0.59**	**0.58**	**0.58**
	Caloosahatchee Estuary HUs	**2,839**	**39,038**	**41,878**	**41,168**	**41,168**

G.5.2.3 St. Lucie Estuary Final Array HUs

Table G-42 shows rescaled PM scores on a 0–100 scale for the St. Lucie Estuary based on the RSM-BN model output for the final array of alternatives (**Figure G-33**). The scores were then normalized using HSI to a 0–1 scale to calculate HUs. The low-flow and high-flow HSIs were combined to give one HSI for the St. Lucie Estuary. This HSI was multiplied by the acreage (14,994 acres) to get the HUs (**Table G-43**).

Table G-42. Rescaled PM scores normalized on a 0–100 scale for St. Lucie Estuary for the final array of alternatives.

Metric #	PM Metric	ECB	FWO	Alt 1Bshlw	Alt 1BW	Alt 2Cr
4.1	Low Flow (< 350 cfs)	14	31	31	31	31
4.2	High Flow (>2000 cfs)	14	55	76	73	71

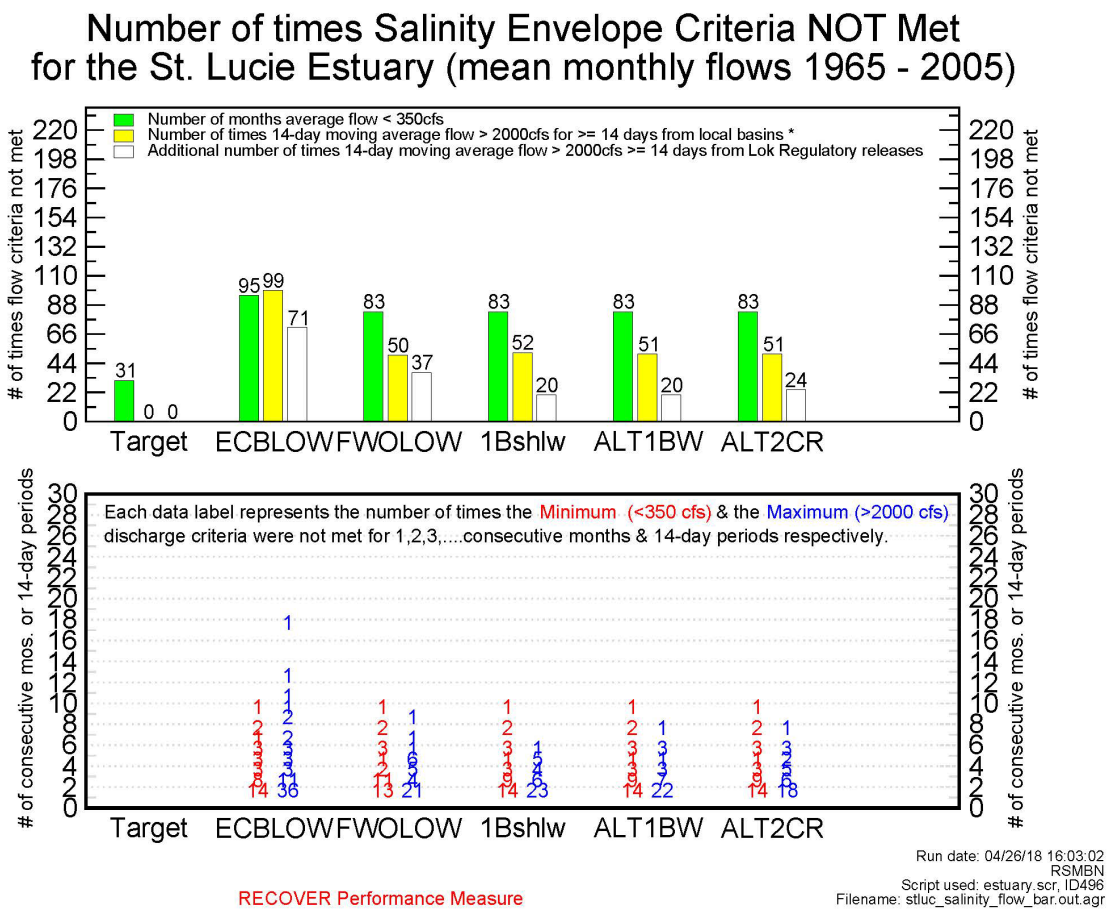

Figure G-33. Number of times salinity criteria not met for the St. Lucie Estuary for the final array of alternatives.

Table G-43. Habitat Suitability Index and HUs for the St. Lucie Estuary.

Metric #	PM Metric	ECB	FWO	Alt 1Bshlw	Alt 1BW	Alt 2Cr
4.1	Low Flow (< 350 cfs) Habitat Suitability Index	0.07	0.155	0.155	0.16	0.155
4.2	High Flow (>2000 cfs) Habitat Suitability Index	0.07	0.275	0.38	0.38	0.355
	Total St. Lucie HSI	**0.14**	**0.43**	**0.535**	**0.54**	**0.51**
	St. Lucie Estuary HUs	**2,099**	**6,447**	**8,022**	**8,097**	**7,647**

G.5.3 Northern Estuaries Alternative Performance

Table G-44 shows the Northern Estuaries HUs. The PMs for each estuary are combined with equal weighting. Alternative 1Bshlw has the greatest habitat unit lift of 4,414 acres, followed by Alt 1BW with 3,779 acres, and then Alt 2Cr with 3,330 acres. The HUs for the Northern Estuaries will be combined with the Lake Okeechobee HUs for the CE/ICA analysis. The CE/ICA is evaluated in **Section G.5.4**.

Table G-44. Combined Northern Estuaries HUs for the final array of alternatives.

	ECB	FWO	Alt 1Bshlw	Alt 1BW	Alt 2Cr
Caloosahatchee HUs	2,839	39,038	41,878	41,168	41,168
St. Lucie HUs	2,099	6,447	8,022	8,097	7,647
Overall Northern Estuaries HUs	**4,938**	**45,485**	**49,899**	**49,265**	**48,815**
Potential Lift	**-40,547**	**0**	**4,414**	**3,779**	**3,330**

The Northern Estuaries average AAHU lifts were calculated as the difference between the with-project and FWO conditions over the period of analysis (through year 2071). For the without project condition, a straight trajectory between existing and future without project HUs was assumed to establish HU totals for each site and year.

With project HU trajectory was modeled to reflect the timeline of expected restoration effects. An ecological response time for the Northern Estuaries was estimated based on the expected response time of oysters and submerged aquatic vegetation to improved salinities. The ecological response time was estimated at approximately 6 years following construction completion until full impact would be realized. **Table G-45** and **Figure G-34** show the trajectory of northern estuary HUs for each alternative over the period of analysis, as well as the resulting average AAHU lift**.**

Table G-45. Combined Northern Estuaries HU trajectory and average annual lift.

Alternative	ECB Estuary HUs (2028)	FWP Estuary HUs (2034)	FWP Estuary HUs (2078)	Average Annual Estuary HU Lift
NAA	4,938	45,486	45,485	-
1BW	4,938	49,265	49,265	3,591
1Bshlw	4,938	49,899	49,899	4,194
2Cr	4,938	48,815	48,815	3,163

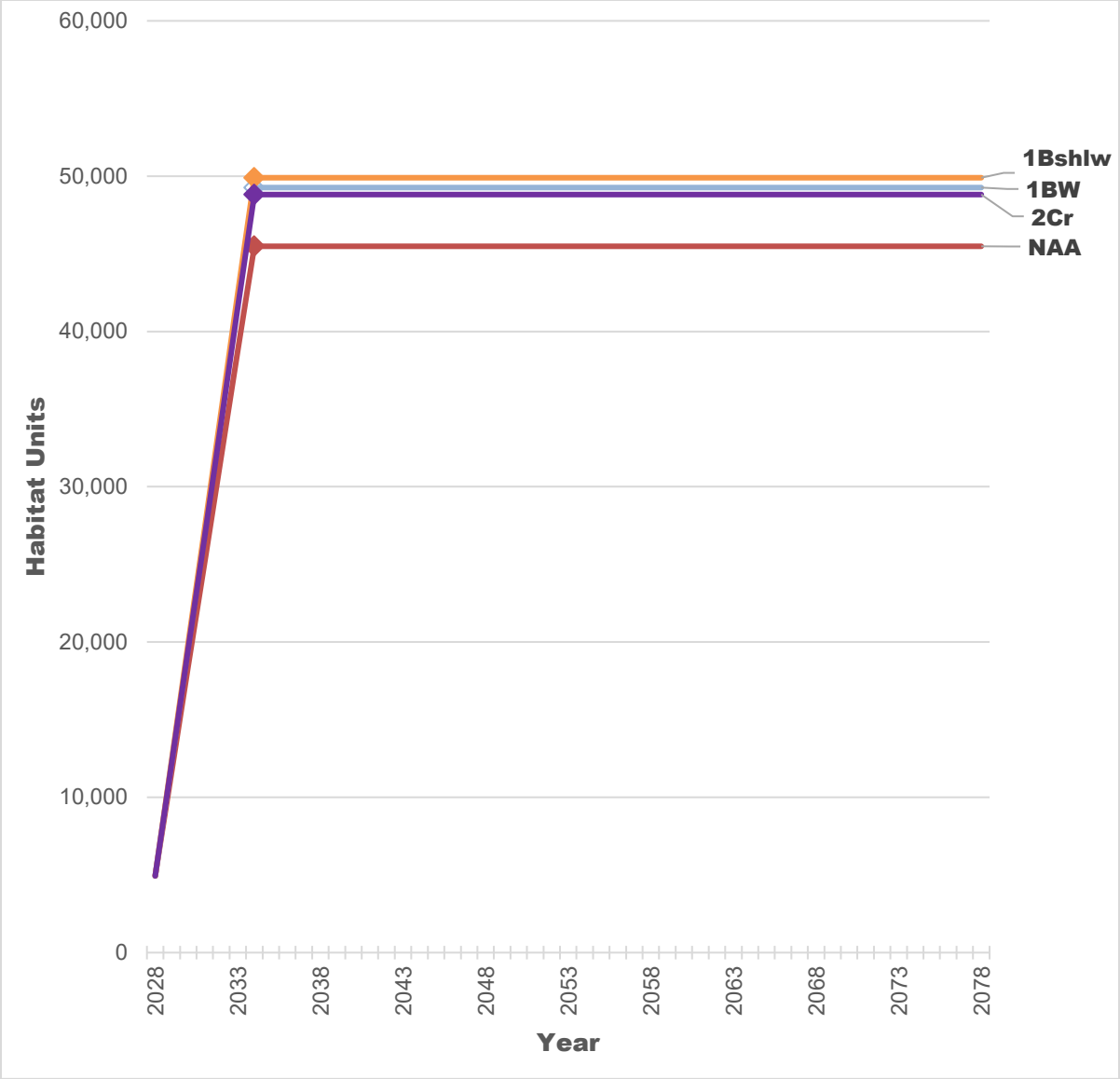

Figure G-34. Northern Estuaries HU trajectory.

G.5.4 Northern Estuaries Recommended Plan Performance

The TSP was refined to optimize the WAF shape for the Recommended Plan (Alternative 1BWR). The revised WAF footprint lead to additional modeling of the Recommended Plan. This section outlines the HU analysis for the Recommended Plan (Alt 1BWR).

G.5.4.1 Caloosahatchee Estuary Recommended Plan HUs

Table G-40 shows rescaled PM scores on a 0–100 scale for the Caloosahatchee Estuary based on the RSM-BN model output for the Recommended Plan (**Figure G-32**). The scores were then normalized using HSI to a 0–1 scale to calculate HUs. The low-flow and high-flow HSIs were combined to give one HSI for the Caloosahatchee Estuary. This HSI was multiplied by the acreage (70,979 acres) to get the Recommended Plan HUs (**Table G-41)**.

Table G-46. Rescaled PM scores normalized on a 0–100 scale for Caloosahatchee Estuary for the Recommended Plan.

Metric #	PM Metric	ECB	FWO	Alt 1BWR
3.1	Low Flow (< 450 cfs)	4	81	80
3.2	High Flow (>2800 cfs)	4	29	39

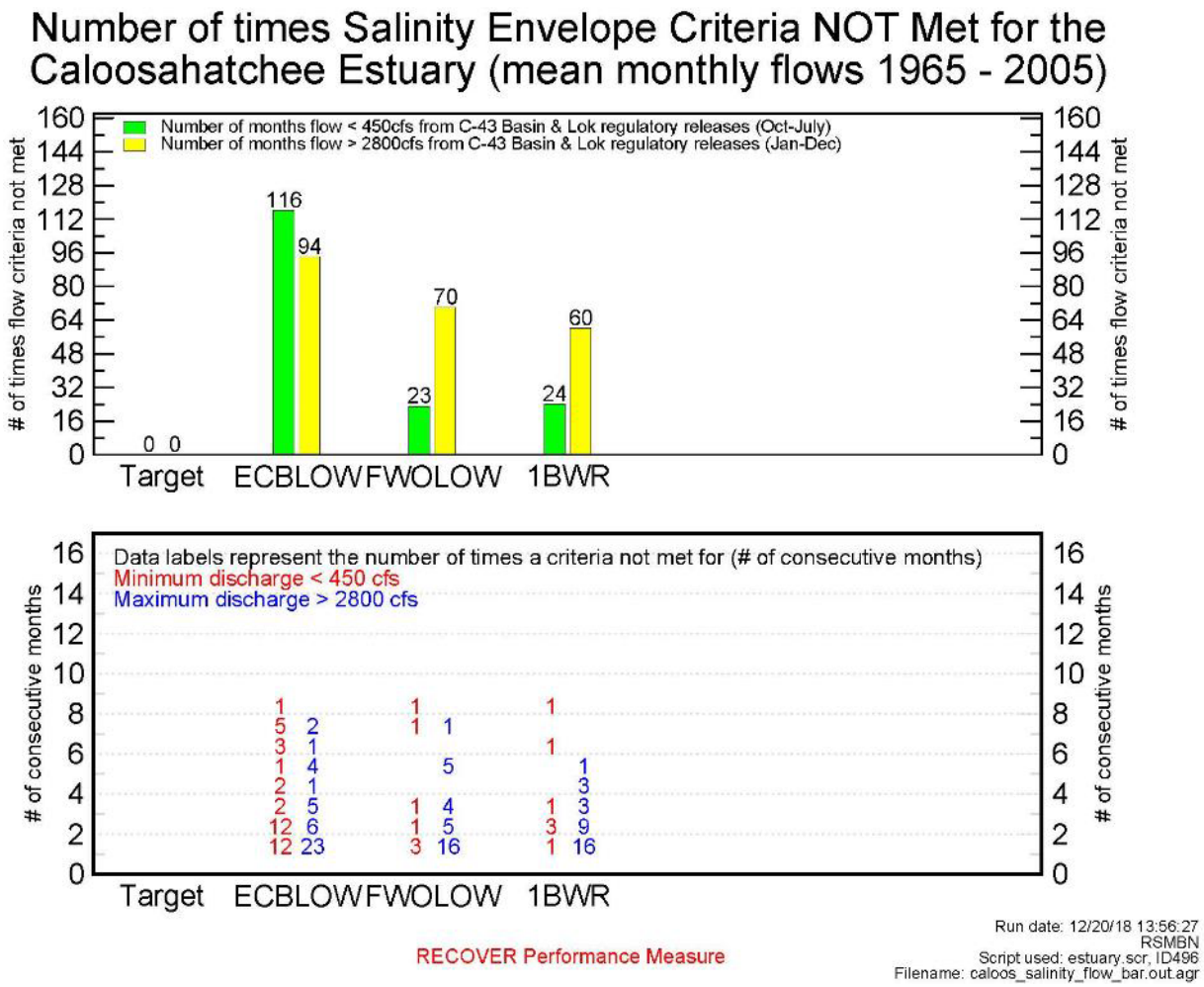

Figure G-35. Number of times salinity criteria not met for the Caloosahatchee Estuary for the Recommended Plan.

Table G-47. HSI and HUs for the Caloosahatchee Estuary Recommended Plan.

Metric #	PM Metric	ECB	FWO	Alt 1BWR
3.1	Low Flow (< 450 cfs) Habitat Suitability Index	0.02	0.405	0.400
3.2	High Flow (>2800 cfs) Habitat Suitability Index	0.02	0.145	0.195
	Total Caloosahatchee HSI	0.04	0.55	0.60
	Caloosahatchee Estuary HUs	2,839	39,038	42,233

G.5.4.2 St. Lucie Estuary Recommended Plan HUs

Table G-48 shows rescaled PM scores on a 0–100 scale for the St. Lucie Estuary based on the RSM-BN model output for the Recommended Plan (**Figure G-36**). The scores were then normalized using HSI to a 0–1 scale to calculate HUs. The low-flow and high-flow HSIs were combined to give one HSI for the St. Lucie Estuary. This HSI was multiplied by the acreage (14,994 acres) to get the Recommended Plan HUs (**Table G-49**).

Table G-48. Rescaled PM scores normalized on a 0–100 scale for St. Lucie Estuary for the Recommended Plan.

Metric #	PM Metric	ECB	FWO	Alt 1BWR
4.1	Low Flow (< 350 cfs)	14	31	31
4.2	High Flow (>2000 cfs)	14	55	77

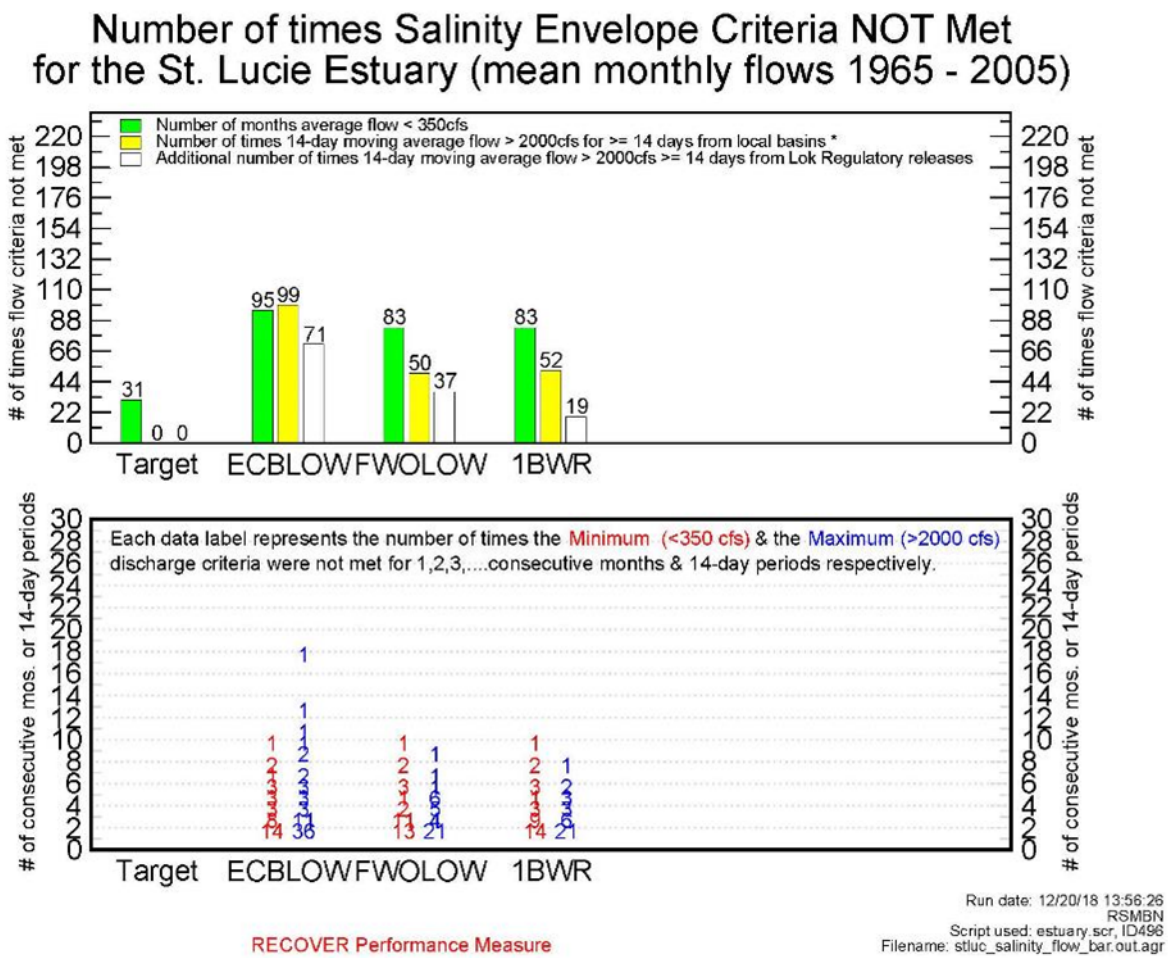

Figure G-36. Number of times salinity criteria not met for the St. Lucie Estuary for the Recommended Plan.

Table G-49. Habitat Suitability Index and HUs for the St. Lucie Estuary Recommended Plan.

Metric #	PM Metric	ECB	FWO	Alt 1BWR
4.1	Low Flow (< 350 cfs) Habitat Suitability Index	0.07	0.155	0.155
4.2	High Flow (>2000 cfs) Habitat Suitability Index	0.07	0.275	0.385
	Total St. Lucie HSI	**0.14**	**0.43**	**0.54**
	St. Lucie Estuary HUs	**2,099**	**6,447**	**8,097**

G.5.4.3 Northern Estuaries Final Array Performance

Table G-44 shows the Northern Estuaries Recommended Plan HUs. The PMs for each estuary are combined with equal weighting. The Recommended Plan (Alt 1BWR) provides a habitat unit lift of 4,843 acres. **Table G-50** shows the trajectory of northern estuary HUs for the reccomended plan from 2028 through 2078, as well as the average annual nothern estuary HU lift. **Figure G-37** shows this information graphically. The average annual Northern Estuaries HU lift for the Recommended Plan is 4,601 (**Table G-51**).

Table G-50. Combined Northern Estuaries HUs for the Recommended Plan.

	ECB	FWO	Alt 1BWR
Caloosahatchee HUs	2,839	39,038	42,233
St. Lucie HUs	2,099	6,447	8,097
Overall Northern Estuaries HUs	**4,938**	**45,485**	**50,329**
Potential Lift	**-40,547**	**0**	**4,843**

Table G-51. Combined Northern Estuaries HU trajectory and average annual lift for Recommended Plan.

Alternative	ECB Estuary HUs (2028)	FWP Estuary HUs (2034)	FWP Estuary HUs (2078)	Average Annual Estuary HU Lift
NAA	4,938	45,486	45,486	-
1BWR	4,938	50,329	50,329	4,601

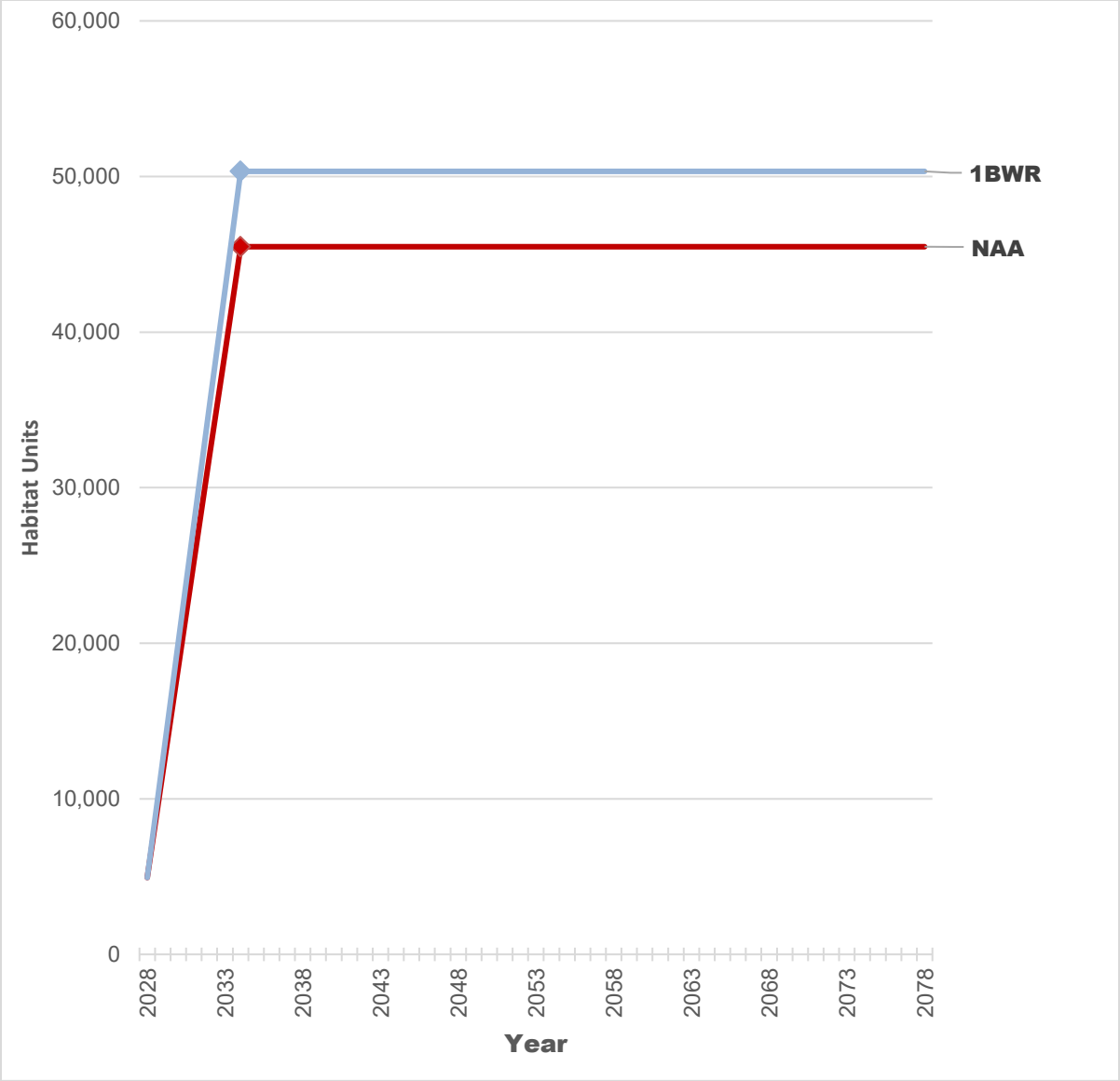

Figure G-37. Northern Estuaries HU trajectory for Recommended Plan.

G.6 Summary of Storage Alternative Performance

HUs are used to compare project alternatives compared to the FWO for each habitat zone and for the total project area (**Table G-52**). **Figure G-38** displays storage AAHU by alternative, and **Figure G-39** presents the percent composition of the total storage AAHU for each alternative.

Table G-52. Total Storage HUs for each storage alternative.

Project Region	ECB	FWO	Alt 1Bshlw	Alt 1BW	Alt 2Cr
Lake O Ecological Indicator	109,052	106,938	107,995	108,523	109,933
Lake O Stage Envelope	25,976	26,906	29,887	29,720	30,850
Lake O Extreme Stage	43,200	42,971	41,743	41,969	42,695
Total Lake Okeechobee	**178,228**	**176,814**	**179,625**	**180,213**	**183,478**
Caloosahatchee Estuary	2,839	39,038	41,878	41,168	41,168
St. Lucie Estuary	2,099	6,447	8,022	8,097	7,647
Total Northern Estuaries	**4,938**	**45,485**	**49,899**	**49,265**	**48,815**
Total HUs	**183,166**	**222,299**	**229,524**	**229,487**	**232,293**

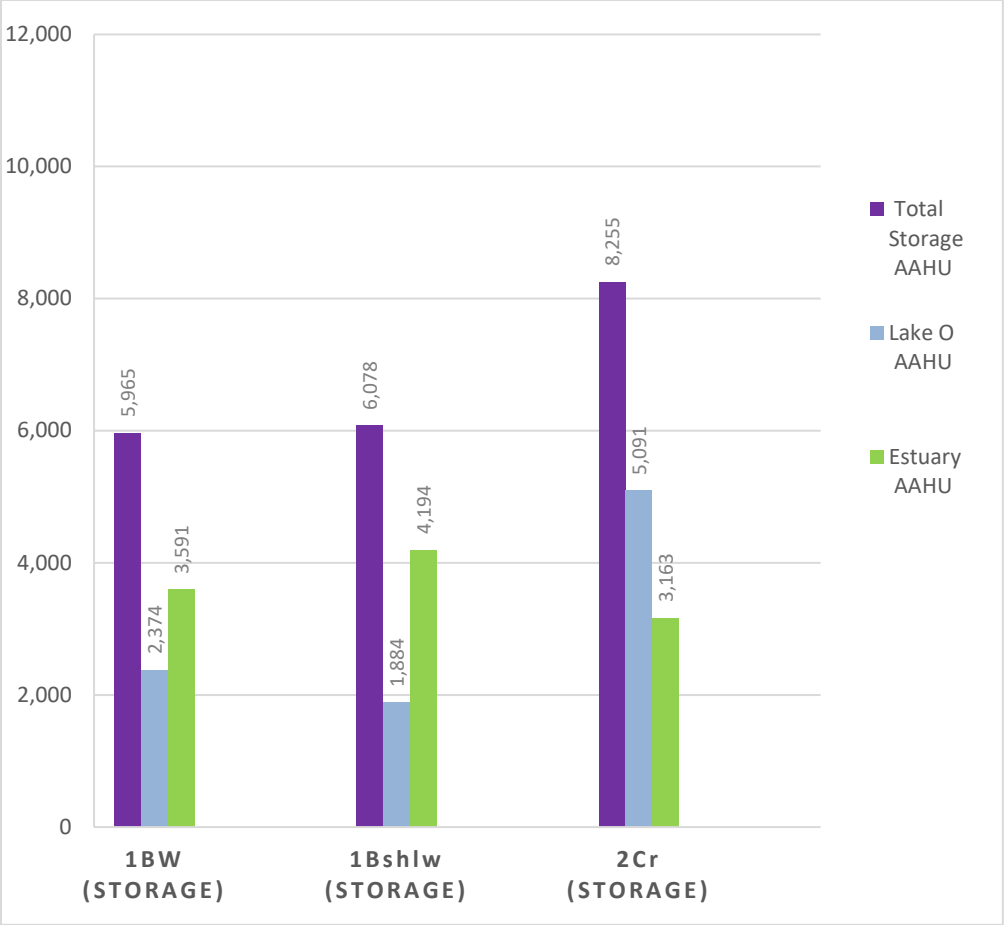

Figure G-38. Average annual HUs for storage alternatives.

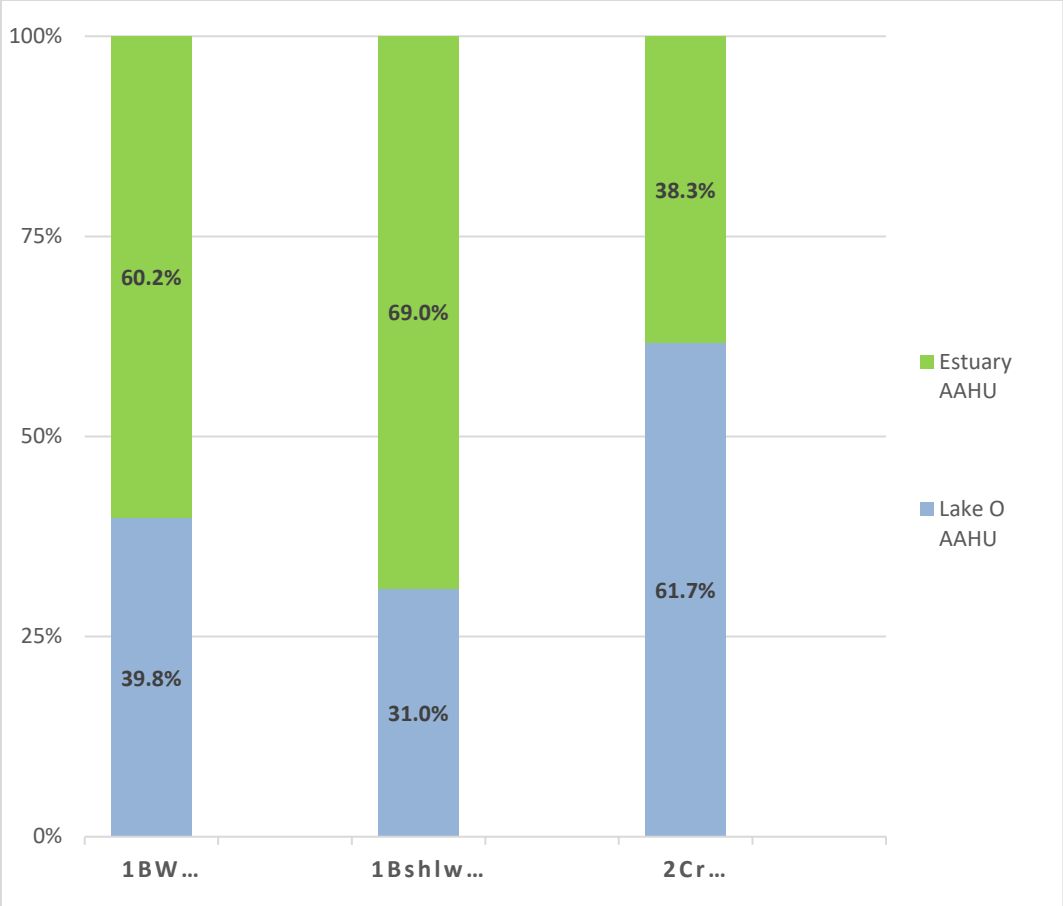

Figure G-39. Storage alternatives AAHU percent composition.

The storage cost-effectiveness and incremental cost analysis (CE/ICA) identifies the most cost-effective alternative for achieving optimum estuary and Lake Okeechobee AAHU. The results are displayed in **Table G-53**.

Because each storage alternative produces a unique level of total storage AAHU and no alternative provides more output at a lower cost, each is cost-effective. Alternative 1BW produces the least amount of storage AAHU at 5,965, which is split between Lake Okeechobee AAHU and estuary AAHU at 39.8% and 60.2%, respectively. Although Alternative 1Bshlw produces 490 fewer Lake Okeechobee AHHU than does 1BW, it generates 603 more estuary AAHU than 1BW for a net increase of 113 AAHU. Alternative 1Bshlw has a comparable split between storage AAHU types (31% Lake Okeechobee and 69% estuary) to 1BW, but is less efficient at an AAC per AAHU of $10,787. Alternative 2Cr is the most efficient plan at $9,470 AAC per AAHU. Unlike 1BW and 1Bshlw, the majority (61.7%) of this alternative's benefits are achieved at Lake Okeechobee. As both the most efficient plan and the plan with the greatest output, Alternative 2Cr is the first and only storage best buy.

G.7 Summary of Alternative Performance

For the final CE/ICA, costs and benefits for the selected wetland component of the TSP, which includes the Kissimmee River–Center and Paradise Run sites (**Section G.3.4**), are incorporated into the final array

of storage alternatives. **Figure G-40** displays total AAHU by alternative, and **Figure G-41** presents the percent composition of the total AAHU for each alternative.

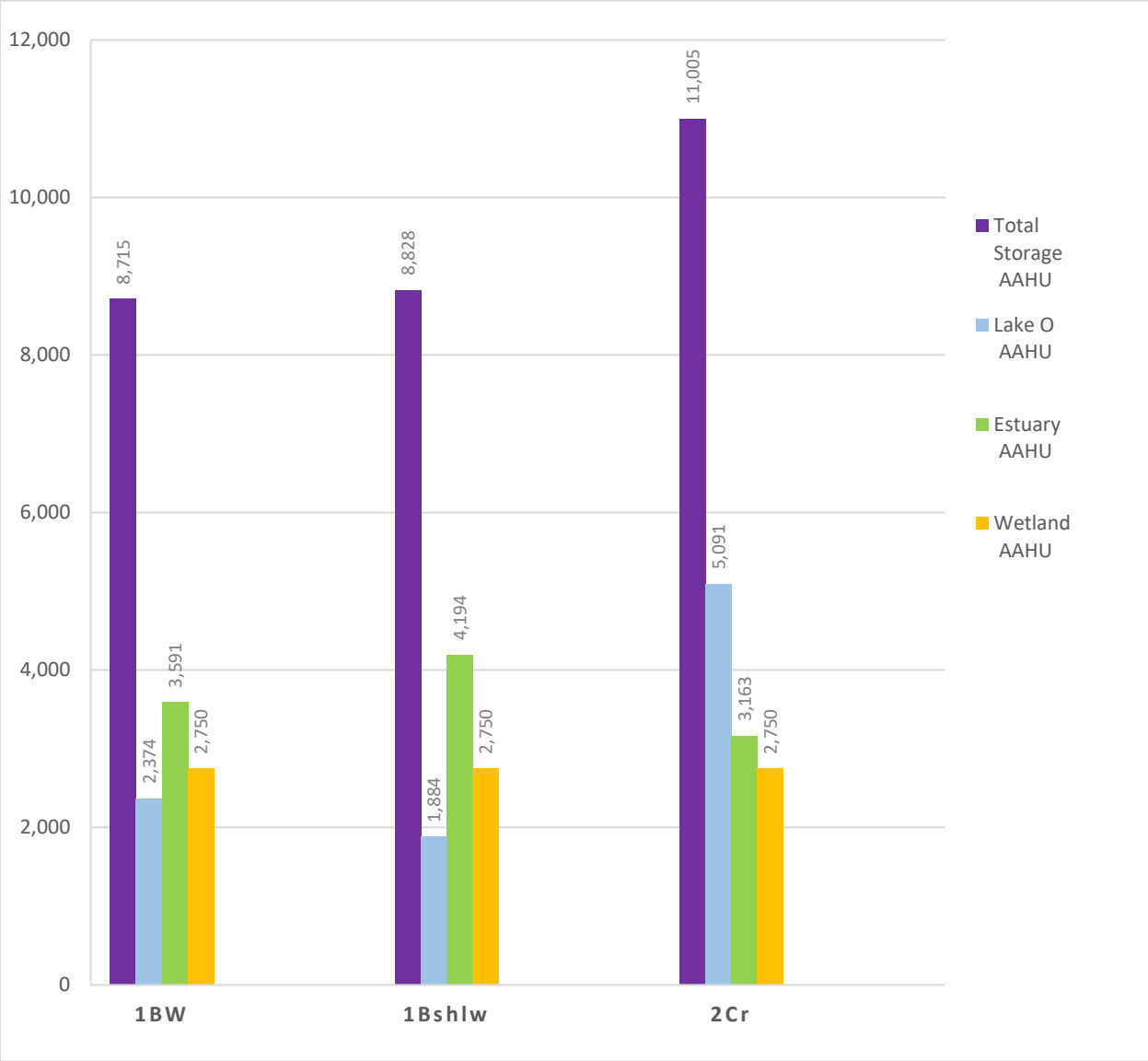

Figure G-40. Average annual HUs by alternative.

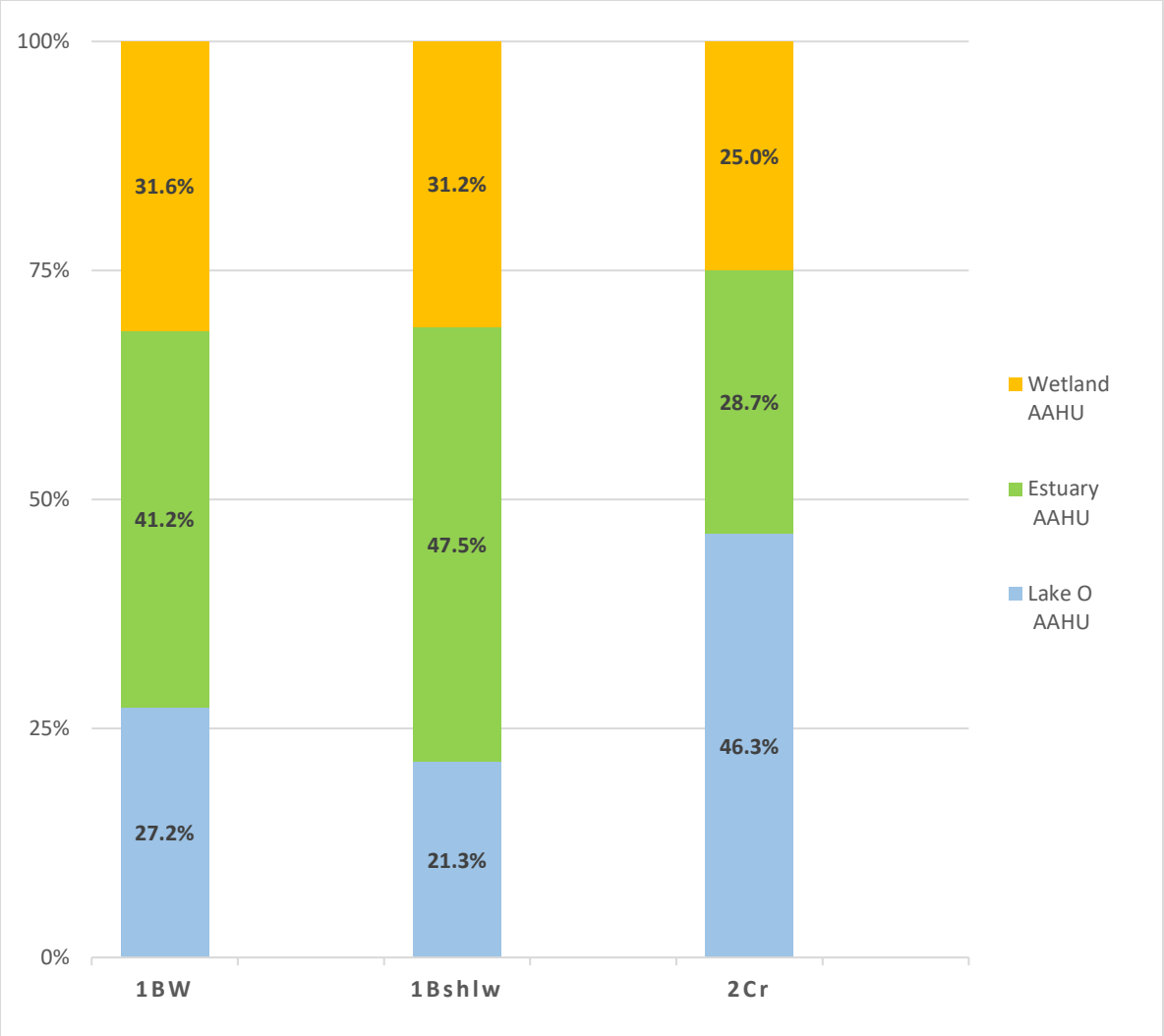

Figure G-41. Alternative AAHU percent composition.

The final cost-effectiveness and CE/ICA identifies the most cost-effective alternative. The results are displayed in **Table G-53**.

Table G-53. Complete Alternatives (storage and wetland) CE/ICA summary.

	1BW	1BShlw	2Cr
Total Implementation Costs	$1,420,000,000	$1,490,000,000	$1,884,000,000
Interest During Construction	$41,000,000	$43,000,000	$55,000,000
Annual O&M	$14,400,000	$14,400,000	$12,400,000
Average Annual Cost*	**$68,500,000**	**$71,200,000**	**$84,200,000**
Wetland AAHU	2,750	2,750	2,750
Lake O AAHU	2,374	1,884	5,091
Estuary AAHU	3,591	4,194	3,163
Total AAHU	**8,715**	**8,828**	**11,005**
Cost Effective	**YES**	**YES**	**YES**
AAC per AAHU	$7,861	$8,064	$7,653
1st Best Buy	**NO**	**NO**	**YES**

*Discounted over a 50-year period of analysis at 2.75% discount rate

Because each alternative produces a unique level of total AAHU and no alternative provides more output at a lower cost, each is cost-effective. Alternative 1BW produces the least amount of AAHU at 8,715, which is split between estuary AAHU, wetland AAHU, and Lake Okeechobee AAHU at 41.2%, 31.6%, and 27.2%, respectively. Although Alternative 1Bshlw produces 490 fewer Lake Okeechobee AHHU than does 1BW, it generates 603 more estuary AAHU than 1BW for a net increase of 113 AAHU. Alternative 1Bshlw has a comparable split between AAHU types (47.5% estuary, 31.2% wetland, and 21.3% Lake Okeechobee) to 1BW, but is less efficient at an AAC per AAHU of $7,884. Alternative 2Cr is the most efficient plan at $9,470 AAC per AAHU. Unlike 1BW and 1Bshlw, a plurality (46.3%) of this alternative's benefits is achieved at Lake Okeechobee. As both the most efficient plan and the plan with the greatest output, Alternative 2Cr is the first and only best buy.

G.7.1 Conclusions

All alternatives are cost-effective and Alt 2Cr is the best buy in the final array (**Table G-53**). However, due to total cost of Alt2Cr, the small differences between the HUs, and the acceptability of the alternatives, Alternative 1BW was selected as the TSP. **Figure G-42** displays the trajectory of benefit accumulation by AAHU type over the period of analysis for alternative 1BW.

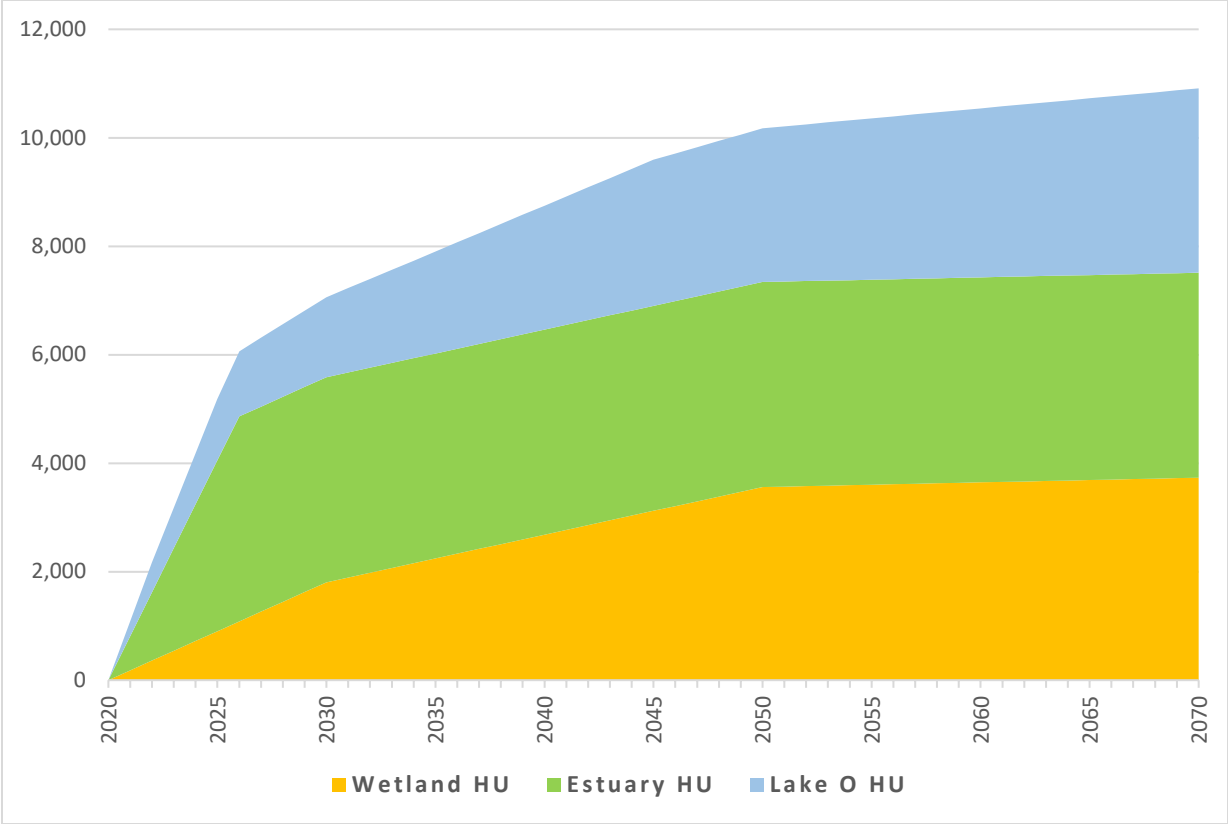

Figure G-42. Benefit Trajectory for Alternative 1BW.

G.8 Summary of Storage Recommended Plan Performance

The TSP was subsequently updated from the TSP presented in the July 2018 Draft PIR/EIS to become the Recommended Plan referred to as Alternative 1BWR. The footprint was revised based on feedback from stakeholders, along with more detailed design optimizations to increase the cost-effectiveness of the LOWRP. Specifically, the eastern boundary of the WAF was moved to the east to eliminate a gap between the WAF and Paradise Run that is now incorporated into the project footprint. This resulted in an increase in the WAF area and a decrease in the Paradise Run area. The WAF boundary and the Paradise Run boundary are now contiguous on the entire east side of the WAF. The WAF boundary area changed from 12,500 acres to 13,600 acres and was further modified to avoid a communication tower in the south east corner. The Paradise Run area changed from 4,100 acres to 3,600 acres and was modified to include an approximate 1,000 foot buffer from State Road 78. All of the WAF infrastructure was developed from the conceptual level. This included the addition of internal embankments, tree islands, ungated auxiliary spillways, gated spillways, and culverts. The location of the outlet to HHD was moved to the north. In addition, the intake for the Kissimmee River- Center wetland was changed from a submerged weir to a pump station.

HUs are used to compare the Recommended Plan to the FWO for each habitat zone and for the total project area (**Table G-54**). **Figure G-43** displays storage AAHU by alternative, and **Figure G-44** presents the percent composition of the total storage AAHU for each alternative. The Recommended Plan has total storage AAHU of 6,371, which is composed of 72.2 percent estuary AAHU and 27.8 percent Lake O AAHU.

Table G-54. Total Storage HUs for the Recommended Plan.

Project Region	ECB	FWO	Alt 1BWR
Lake O Ecological Indicator	109,052	106,938	108,347
Lake O Stage Envelope	25,977	26,906	29,039
Lake O Extreme Stage	43,201	42,971	42,101
Total Lake Okeechobee	**178,230**	**176,814**	**179,488**
Caloosahatchee Estuary	2,839	39,038	42,233
St. Lucie Estuary	2,099	6,447	8,097
Total Northern Estuaries	**4,938**	**45,485**	**50,329**
Total HUs	**183,168**	**222,299**	**229,817**

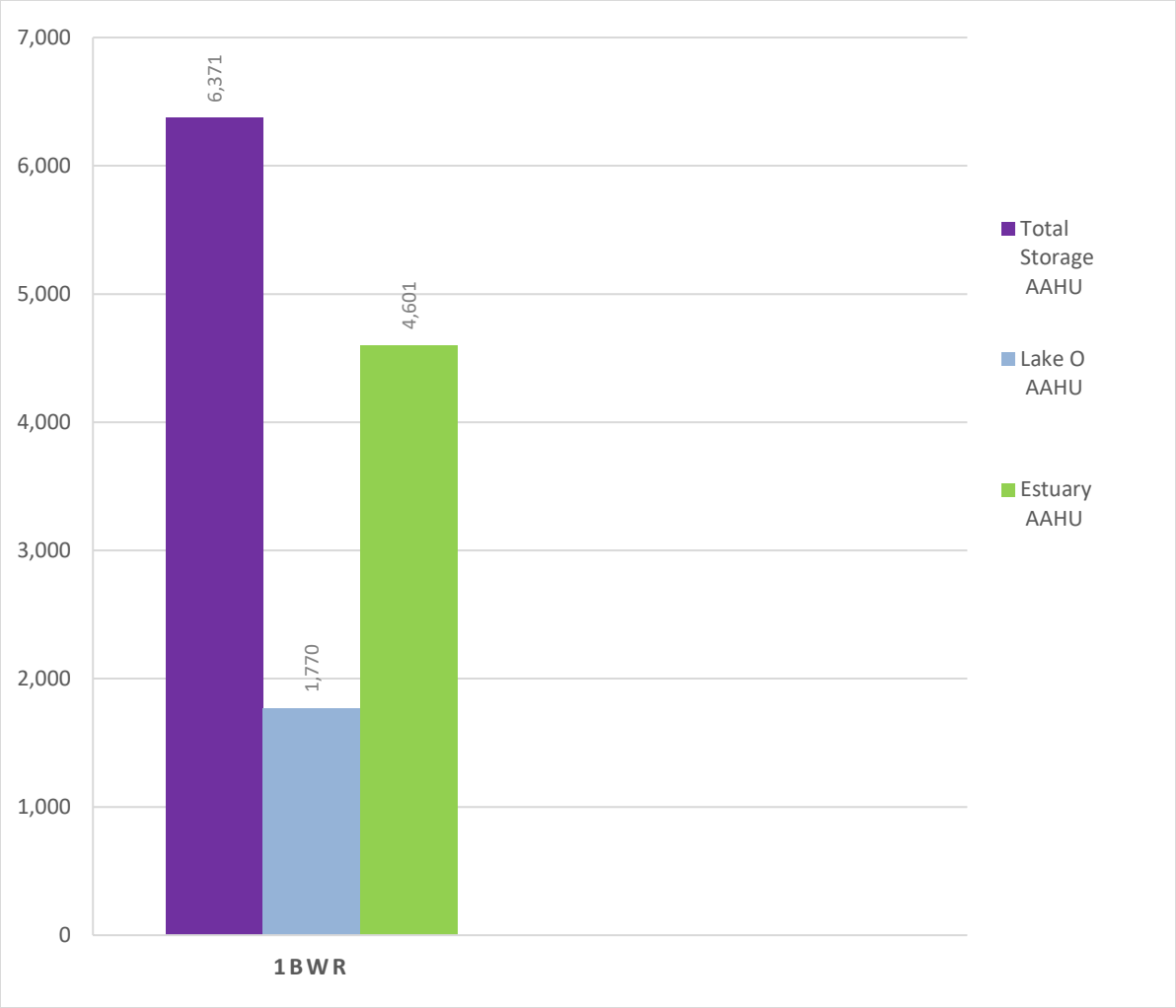

Figure G-43. Average annual HUs for storage for the Recommended Plan.

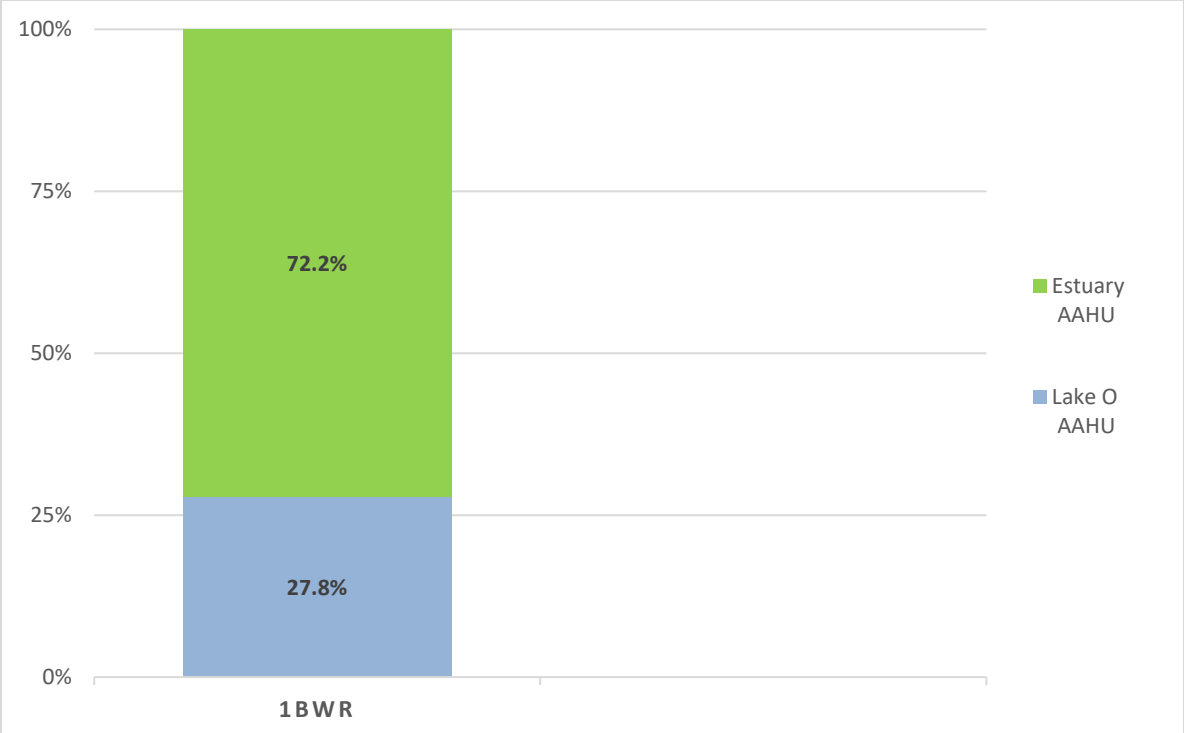

Figure G-44. Storage Recommended Plan AAHU percent composition.

G.9 Summary of Recommended Plan Performance

Figure G-45 displays total AAHUs for the Recommended Plan, and **Figure G-46** presents the percent composition of the total AAHU for the Recommended Plan. The Recommended Plan produces 9,040 AAHUs from 2028 through 2078. Of these, 29.5 percent are wetland AAHUs, 50.9 percent are estuary AAHUs, and 19.6 percent are Lake Okeechobee AAHUs. **Figure G-47** displays the trajectory of benefit accumulation by AAHU type over the period of analysis for the selected alternative.

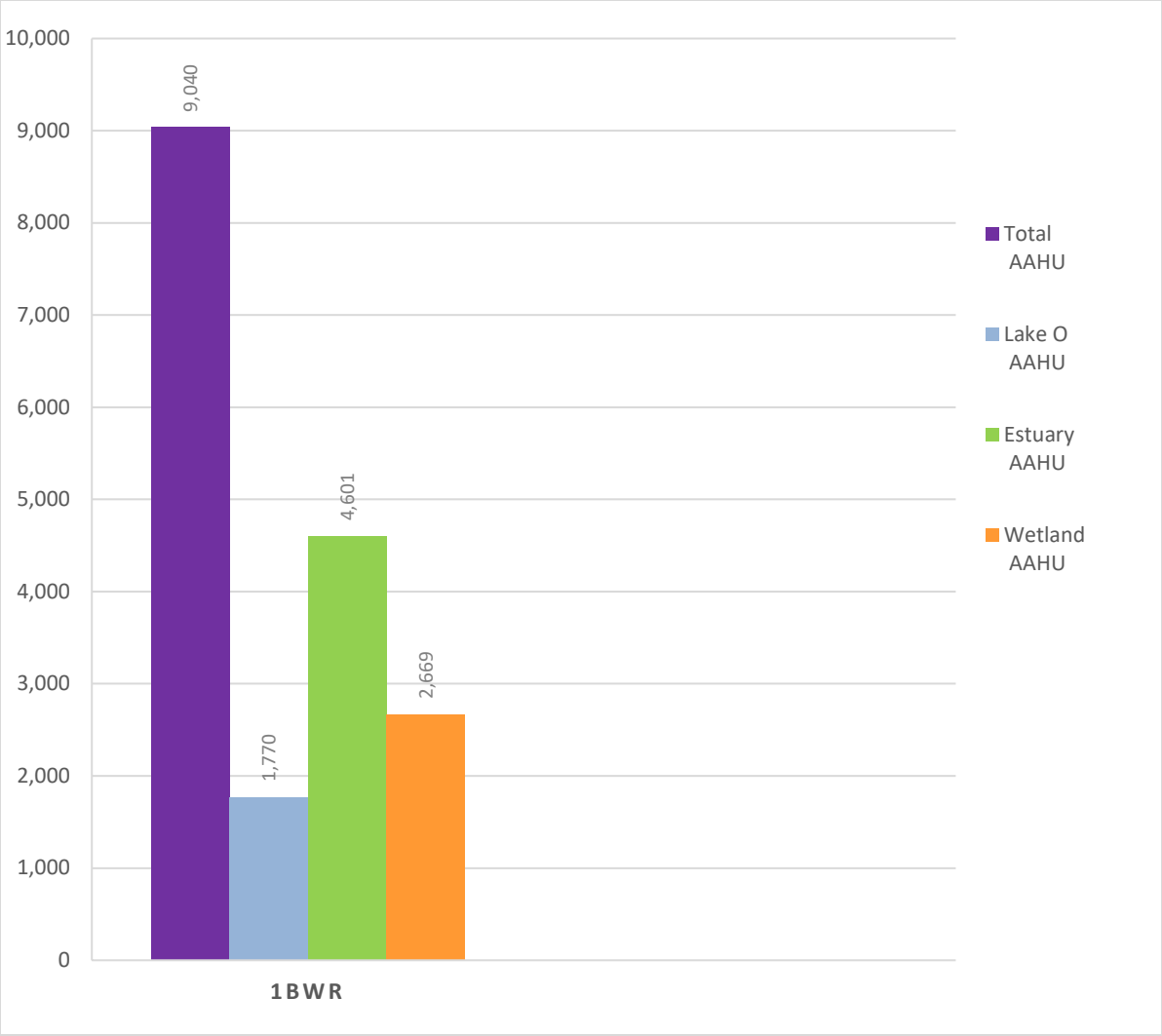

Figure G-45. Average annual HUs for Recommended Plan.

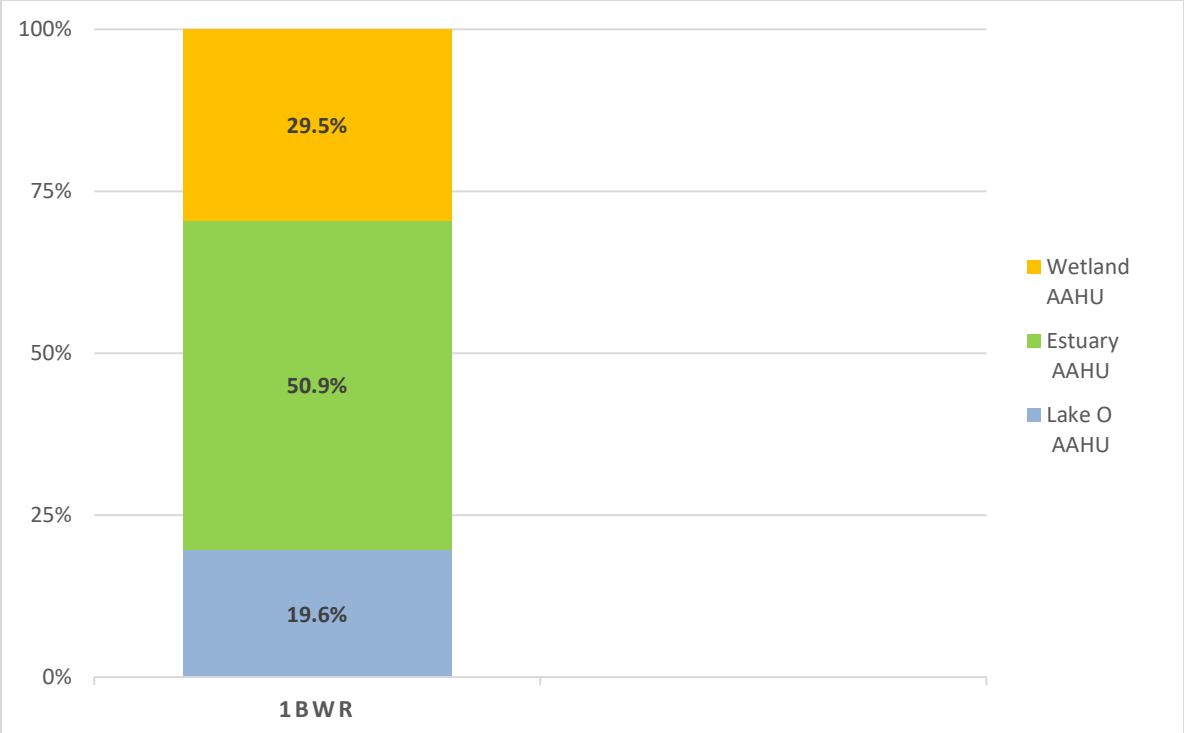

Figure G-46. Storage Recommended Plan AAHU percent composition.

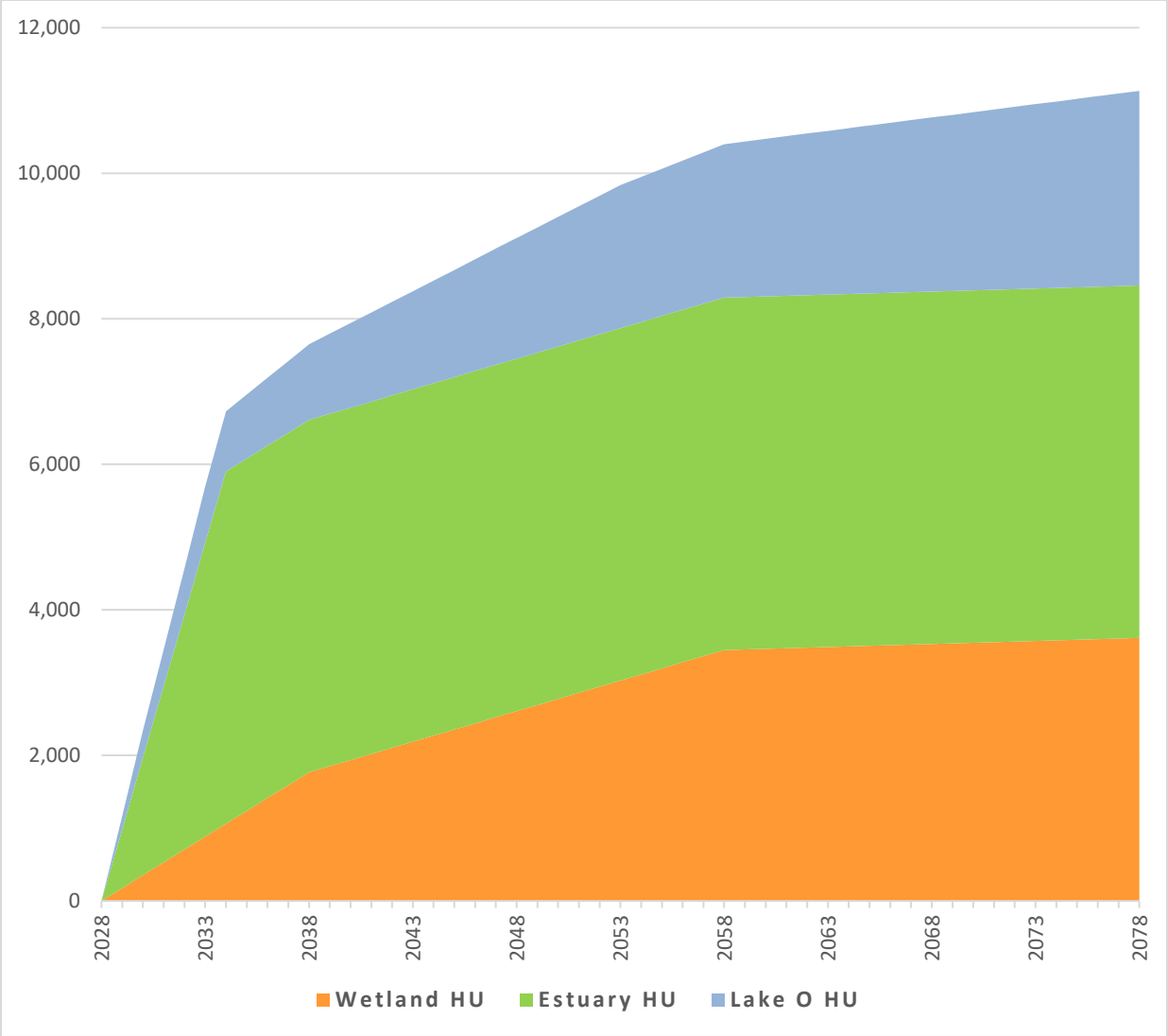

Figure G-47. Benefit Trajectory for Recommended Plan.

G.10 Technical Quality of the LOWRP Planning Model

The LOWRP is highly dependent on the results of dynamic regional hydrologic and ecologic simulation models. The LOWRP planning model's calculation of environmental benefits is based on inputs derived from the RSM-BN and the working hypotheses set forth in the *Lake Okeechobee and Northern Estuaries Conceptual Ecological Models* (Barnes 2005, Sime 2005). These models are considered to be appropriate tools for planning for the CERP. The RSM-BN has been validated through the USACE Engineering Model Certification process established under the E&C SET initiative. Each of the project PMs for the storage component of the LOWRP planning effort described above were derived from those PMs approved for use by RECOVER. The scientists of RECOVER have extensive experience working in south Florida and Everglades wetlands ecosystems. These members are considered by their peers to be the experts in their fields. In addition, the CEMs from which the LOWRP PMs were developed have been extensively peer reviewed and provide the framework for the planning and assessment of the CERP.

The basins version of the RSM model is a long-term water balance model that considers basins as large waterbodies with homogeneous properties and negligible variability of hydrologic properties of interest within the basins. Traditionally, these models have been used for reservoir capacity design problems where the capacities are large, and long-term basin outflow time series are known at large time steps. Spatial variability of parameters and state variables within basins are not available or not critical for these problems where the focus is the storage behavior in the recipient water body. Long-term water balance models are not capable of providing spatially varying hydraulic state variables such as water levels or flow distributions within the basins. They cannot provide short-term variability of outflow releases since small scale hydraulic behaviors are not simulated in these models. Total error consists of input data errors, model structure errors (algorithm), and parameter errors. With water balance models, you have a potential to have large structure errors when focusing on small-scale features or short-term fluctuations because some of the mechanics (algorithms) are not there. But by design, the objective is to focus on long-term variations and large spatial extents. For such spatial and temporal solutions of interest, the error is small.

The RSM-BN assumes that water in each waterbody is held in level pools. The model domain covers five major watersheds: Kissimmee, Lake Okeechobee, St. Lucie River, Caloosahatchee River, and the Everglades Agricultural Area, the latter being the latest addition. The watersheds are further divided into sub-watersheds until fundamental waterbodies can be considered as separate model nodes. Individual operating rules were encapsulated into the model that define how water is moved between two nodes. Taken together, the set of management rules defines the linkage of all nodes within the model domain. It is important to note that RSM-BN has successfully been used in project planning support for both State of Florida and CERP initiatives previously. RSM-BN has also undergone many independent scientific reviews and has received formal engineering model certification by USACE and is approved for use in LOWRP. More importantly, the computational methodology of RSM-BN uses a “water budget” approach that significantly reduces model error typically found in mesh-based models.

Output from RSM-BN are typically post-processed into project PMs and used in a comparative manner to evaluate the differences between current, no action and a range of potential future project actions being contemplated. The primary emphasis of the LOWRP evaluation involves PMs associated with Lake Okeechobee stage and flows to the Northern Estuaries. Given the intended use of RSM-BN in the LOWRP, an effort was undertaken to evaluate how sources of model error and uncertainty may affect model outputs and project decision-making.

The RSM-BN is an excellent tool for assessing the water budget interaction in a complex hydrologic system and an effective tool in comparing the relative performance of proposed alternatives. In addition, it is generally assumed that relative performance of proposed alternatives is of equal credibility and reliability. The LOWRP planning process assumed that each performance measure used within the project area could be extrapolated from point locations simulated by alternative plans to larger areas they represent. It also assumed that results from hydrologic models were similar across spatial scales within these geographic regions. Due to differences in model accuracy and precision (within and among regions of each model domain), differences in sensitivities of each performance measure to changes in hydrologic conditions, and an assumption that all performance measure results are of equal credibility could be viewed with skepticism. To address this concern, the LOWRP modeling team developed and applied a methodology to validate the robustness of RSM-BN as decision-making. The analysis verified that observed differences between alternatives were not the result of differential exploitation of hydrologic model error/bias.

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G.12 RECOVER Approved Performance Measures

Lake Okeechobee Performance Measure
Lake Stage

Last Date Revised: March 7, 2007

Acceptance Status: Accepted

1.0 Desired Restoration Condition

In most years, lake stage will vary within an "envelope" based on the annual hydrograph described above and shown in the response curve below. There will not be frequent or prolonged departures of lake stage outside of this prescribed envelope and the occurrence of extreme high and low lake stage events will be rare.

1.1 Predictive Metric and Target

Lake stage remains within the desired envelope – targets differ for deviations above vs. below the envelope, as described below. Also, extreme lake stages above 17 ft and below 10 ft NGVD (target = zero weeks for extremes).

1.2 Assessment Parameter and Target

Same as described in 1.1.

2.0 Justification

A wide body of published research (summarized in Havens 2002) documents the benefits of seasonally variable water levels within the range of 12.5 ft (National Geodetic Vertical Datum-NGVD, June-July low) and 15.5 ft (November-January high) on the plant and animal communities of Lake Okeechobee. Falling water levels in late winter to spring benefit wading birds by concentrating prey resources in the littoral zone where those birds forage (Smith et al. 1995), water levels near 12.5 ft benefit submerged plants and bulrush by providing optimal light levels for photosynthesis in the summer months (Havens et al. 2004), and variation in the prescribed range results in annual flooding and drying of upland areas of the littoral zone, which favors development of a diverse emergent plant community (Richardson et al. 1995, Keddy and Frazer 2000).

Conversely, there is also a wide body of published research on the adverse impacts of extreme high and low water levels on the littoral and near-shore areas of Lake Okeechobee (Havens 2002). Extreme high stage (above 17 ft NGVD) allows wind-driven waves to directly impact the littoral emergent plant and near-shore submerged plant communities, causing physical uprooting of plants. In addition, high stage permits suspended solids from the mid-lake region (where unconsolidated sediments are thickest) are transported to the shoreline regions, reducing water clarity and light penetration which in turn reduces the depth at which SAV growth can occur (James and Havens 2005). High stage conditions also allow deposition of unconsolidated mud which can cover the natural sand and peat sediment, reducing their suitability to sustain healthy and balanced vegetative communities. At extreme high stage, nutrient-rich water from the mid-lake region is transported into the littoral zone where it causes changes in periphyton biomass and taxonomic structure, as well as induce shifts in plant dominance including expansion of cattail. Overall, high lake stages result in

extirpation or reduced growth of submerged plants, adverse impacts to germination of submerged plants, reductions in fish spawning and fish reproductive success, and undesirable shifts among species that comprise the macroinvertebrate community. Detailed research results regarding high stage impacts on the lake's plant and animal communities can be found in Maceina and Soballe (1990), Havens (1997), Havens et al. (1999), and Havens et al. (2001).

Conversely, extreme low stage (below 10 ft NGVD) can result in desiccation of the entire littoral zone, the shoreline fringing bulrush zone, and nearly all of the lake area that would otherwise support submerged plants. As a consequence, in-lake habitat for reptiles, amphibians, wading birds, apple snails, or fish that depend on aquatic plant-dominated regions for successful foraging and recruitment is severely compromised. Extreme low stage also encourages invasive exotic plants such as torpedograss and *Melaleuca* to establish in areas of the littoral zone where they did not formerly occur, displacing native vegetation. Recovery from the impacts of prolonged low stage events (below 10 ft MSL) is slow, requiring multiple years of appropriate stage regime to recover, as documented for submerged plants by Havens et al. (2004) and for sport fish such as largemouth bass by Havens et al. (2005).

3.0 Scientific Basis

3.1 Relationship to Conceptual Ecological Models

The indicator for this performance measure is stressor in the following conceptual ecological models:

Regional Models

Lake Okeechobee

Ecological Model for Hypothesis Clusters

Ecological Communities and Effects of Water Stages Conceptual Ecological Model

3.2 Relationship to Adaptive Assessment Hypothesis Clusters

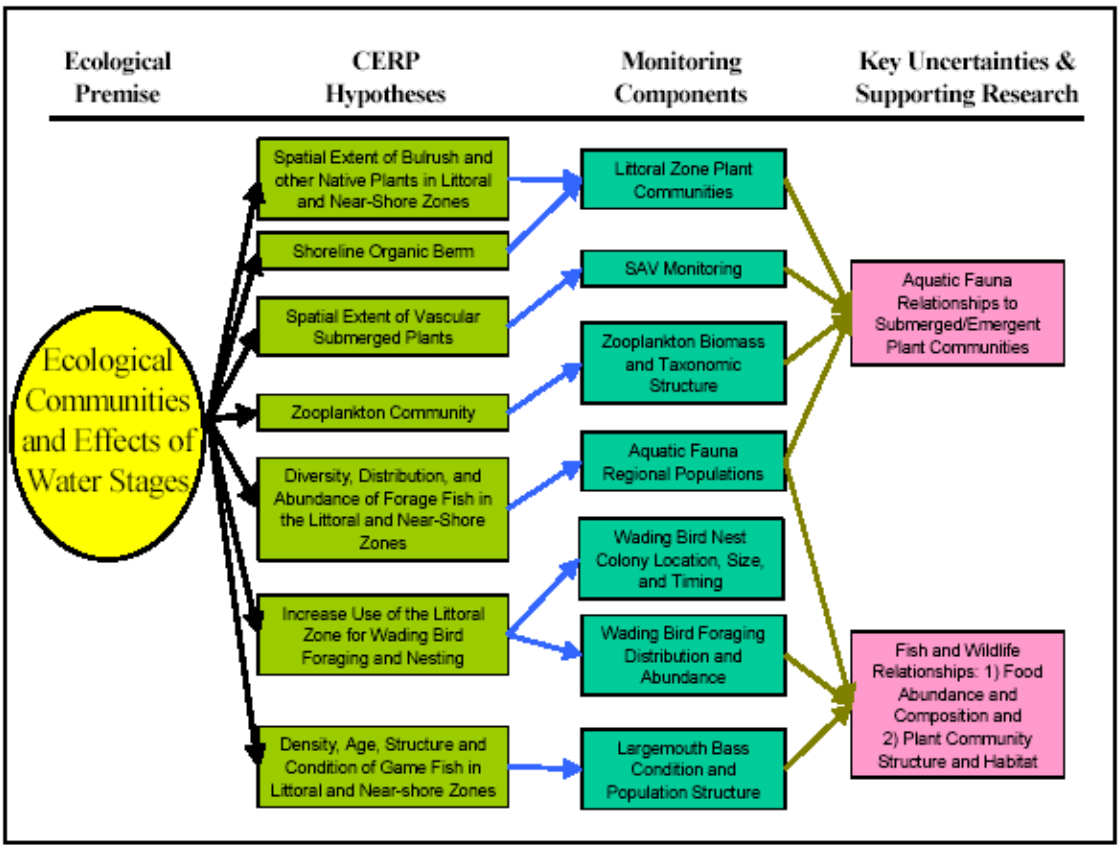
***Ecological Premise*:** Sustained lake levels and a reduction of spring recession conditions have resulted in the loss and degradation of predrainage floral and faunal communities in Lake Okeechobee.

***CERP Hypotheses*:** Providing a reduction in the frequency of extreme high water levels (stage >17 feet and stage >15 feet for more than 12 consecutive months) and low water levels (stage <11 feet and stage <12 feet for more than 12 consecutive months) and an increase in the frequency of spring recessions (yearly stage decline from near 15.5 feet in January to near 12.5 feet in June, with no reversal >0.5 feet) will result in the following changes (see Havens 2002).

- Increase in spatial extent of bulrush along the western lakeshore; increased spatial extent of spikerush, beakrush, willow, and other native plants in the littoral zone; and a reduction in the rate of expansion of exotic and nuisance plants

- Increase in spatial extent of vascular submerged plants, in particular eelgrass, peppergrass, and southern naiad

- Shift in taxonomic structure of zooplankton to better support fishery resources
- Increase in diversity, distribution, and abundance of forage fish in the littoral and near-shore zones.
- Increase in the use of the littoral zone for wading bird foraging and nesting
- Improvement in the density, age structure, and condition of black crappie, largemouth bass, and bream in the littoral and near-shore zones
- Reduction in the occurrence of harmful shoreline organic berms



4.0 Evaluation Application

4.1 Evaluation Protocol

Evaluation is based on the 36-year (January 1, 1965 through December 31, 2000) hydrograph of Lake stages that is simulated by the SFWMM model. During each week of the model run, the absolute value of the deviation (in feet) of lake stage from the prescribed envelope is determined. This is done separately for stages above and stages below the envelope. A tally of the number of weeks is kept for each type of deviation. For extreme high and low lake stage events, a tally is made of the total number of weeks that the stage is above 17 ft or below 10 ft NGVD.

This graphic illustrates how the evaluation is performed for the lake stage envelope, where the vertical axis is stage in feet NGVD and the horizontal axis is in months of the year. The shaded central area is the desired stage envelope. In this example, hydrograph A has a score of 25.5 feet-months for stages above the envelope, and a score of 0 for stages below the envelope. Hydrograph B has a score of 0 feet-months for stages above the envelope and a score of 24.0 for stages below the envelope. The actual scoring based on a 36-year hydrographs will be performed with a smoothed upper and lower envelope boundary, in weekly time steps rather than months, and calculation of absolute deviations (ft) above or below the envelope rather than in discrete 0.5 ft units.

Stage	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
19	3.5	4.0	4.5	5.0	6.0	6.5	6.5	6.0	5.0	4.0	3.5	3.5
18.5	3.0	3.5	4.0	4.5	5.5	6.0	6.0	5.5	4.5	3.5	3.0	3.0
18	2.5	3.0	3.5	4.0	5.0	5.5	5.5	5.0	4.0	3.0	2.5	2.5
17.5	2.0	2.5	3.0	3.5	4.5	5.0	5.0	4.5	3.5	2.5	2.0	2.0
17	1.5	2.0	2.5	3.0	4.0	4.5	4.5	4.0	3.0	2.0	1.5	1.5
16.5	1.0	1.5	2.0	2.5	3.5	4.0	4.0	3.5	2.5	1.5	1.0	1.0
16	0.5	1.0	1.5	2.0	3.0	3.5	3.5	3.0	2.0	1.0	0.5	0.5
15.5	0.0	0.5	1.0	1.5	2.5	3.0	3.0	2.5	1.5	0.5	0.0	0.0
15	0.0	0.0	0.5	1.0	2.0	2.5	2.5	2.0	1.0	0.0	0.0	0.0
14.5	0.0	0.0	0.0	0.5	1.5	2.0	2.0	1.5	0.5	0.0	0.0	0.0
14	0.5	0.0	0.0	0.0	1.0	1.5	1.5	1.0	0.0	0.0	0.5	0.5
13.5	1.0	0.5	0.0	0.0	0.5	1.0	1.0	0.5	0.0	0.0	1.0	1.0
13	1.5	1.0	0.5	0.0	0.0	0.5	0.5	0.0	0.0	0.5	1.5	1.5
12.5	2.0	1.5	1.0	0.5	0.0	0.0	0.0	0.0	0.0	1.0	2.0	2.0
12	2.5	2.0	1.5	1.0	0.0	0.0	0.0	0.0	0.5	1.5	2.5	2.5
11.5	3.0	2.5	2.0	1.5	0.5	0.5	0.5	0.5	1.0	2.0	3.0	3.0
11	3.5	3.0	2.5	2.0	1.0	1.0	1.0	1.0	1.5	2.5	3.5	3.5
10.5	4.0	3.5	3.0	2.5	1.5	1.5	1.5	1.5	2.0	3.0	4.0	4.0
10	4.5	4.0	3.5	3.0	2.0	2.0	2.0	2.0	2.5	3.5	4.5	4.5
9.5	5.0	4.5	4.0	3.5	2.5	2.5	2.5	2.5	3.0	4.0	5.0	5.0
9	5.5	5.0	4.5	4.0	3.0	3.0	3.0	3.0	3.5	4.5	5.5	5.5
8.5	6.0	5.5	5.0	4.5	3.5	3.5	3.5	3.5	4.0	5.0	6.0	6.0
8	6.5	6.0	5.5	5.0	4.0	4.0	4.0	4.0	4.5	5.5	6.5	6.5
7.5	7.0	6.5	6.0	5.5	4.5	4.5	4.5	4.5	5.0	6.0	7.0	7.0

A

B

4.2 Normalized Performance Output

LAKE STAGE ENVELOPE

For the lake stage envelope component, it is necessary to develop separate response curves for the stage above and below the envelope. For deviation of lake stage above the envelope, the target is 0 weeks. The response curve is developed from the performance measure graphic. Consider the stage envelope area with zero values to represent good conditions, the next bands of 0.5 ft stage above that envelope to represent fair conditions, and the subsequent (1.0 ft) band to represent poor conditions. The worst case scenario is considered to be one where the lake stage hydrograph always is in the poor zone. This equates to a total score of 1.0 ft x 52 weeks / year *

36 years 1,872 ft weeks. The response curve is a line between 0 (target) and 1,872 (worst case). Raw scores can be calculated from the following equation:

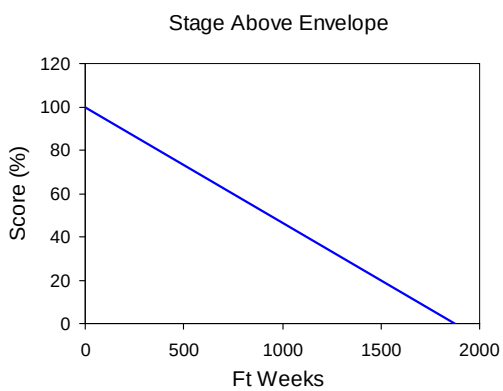
*Standardized score (%) = raw score * -0.0534 + 100*

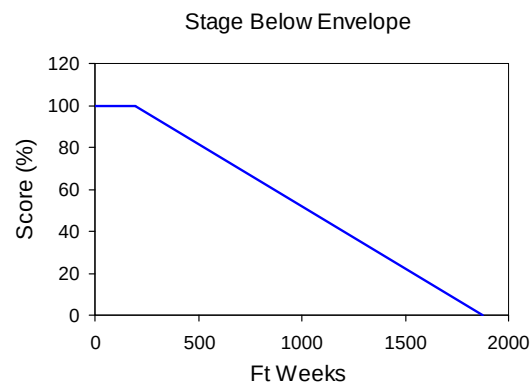
For deviation of lake stage below the envelope, the target is 192 ft weeks. This is the score that would be obtained if all years had hydrographs within the optimal zone, except for once per decade the stage falling to just below 11 ft for an average of 3 months. These periodic low stage events, which occurred at this approximate frequency and duration in the 1950s to 1970s (prior to implementation of high stage regulation schedules), are considered to be beneficial to the littoral zone because they allow for periodic exposure of seed banks, oxidation of accumulated organic material, and fires that are important to maintaining species diversity in the littoral zone.

In this case the response curve is a line between 192 (target) and 1,872 (worst case):

Standardized score (%) = raw score * -0.0595 +111.429

Except where the score is below 192, where the score remains at 100%. The following graphs show the response curves.





HIGH AND LOW LAKE STAGE

For extremes in high (>17 ft NGVD) and low (<10 ft NGVD) lake stages, the response curves (shown below) relate the raw scores for each component of the performance measure to a standardized scale of 0 to 100. Once a standardized score is calculated, it can be converted to other units of measure, such as habitat units, and/or combined with other scores to get a weighted or non-weighted average score for the alternative under consideration.

In the case of extreme high lake stage, the maximal value for the raw score is 52 weeks / year x 36 years = 1,872 weeks. However, based on our understanding of the impacts of high stage, it is quite certain that maximal impacts would occur at a lower frequency of these extreme events. For example, in 1998 and 1999, nearly 100% of the lake's submerged plant community was physically uprooted and piled up on the western shoreline and over 100 m of littoral emergent vegetation was also uprooted – when stage was over 17 ft for just 16 and 7 weeks, respectively. This was the most severe case of high water damage documented on the lake during the last 30 years. Thus, we take this duration for >17 ft stage (average 11 weeks / year = 396 weeks in a 36 year model run) and set it as

the point equivalent to a score of 0 on the standardized scale. To convert from a raw score to a standardized score, the following simple regression equation is applied:

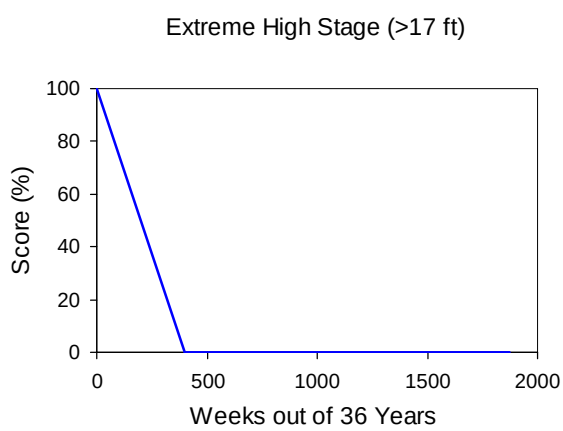
*Standardized score = raw score * -0.253 + 100*

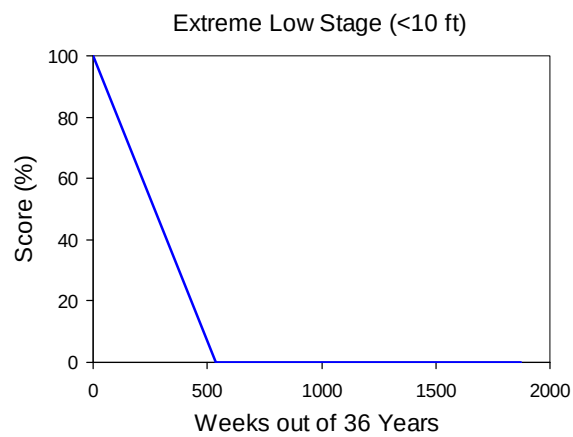
This assumes a linear increase in risk of ecological damage between the optimal conditions (zero weeks) and the most severe condition (396 weeks), which is the most conservative approach to take until there are data to support a more complex relationship. The equation will need to be re-calculated if in the future the model period is extended beyond 36 years.

In the case of extreme low lake stage, the maximal value for the raw score is 52 weeks / year x 36 years = 1,872 weeks. However, based on our observations of the impacts of just 15 weeks of lake stage below 10 ft during the 2001 drought, we can assign this value as the worst case situation, knowing that it produced impacts that took multiple years to recover (e.g., lost apple snail populations, extensive woody vegetation in shoreline areas). We take this duration for <10 ft stage (15 weeks / year = 540 weeks in a 36 year model run) and set it as the point equivalent to a score of 0 on the standardized scale. To convert from a raw score to a standardized score, the following simple regression equation is applied:

*Standardized score = raw score * -0.185 + 100*

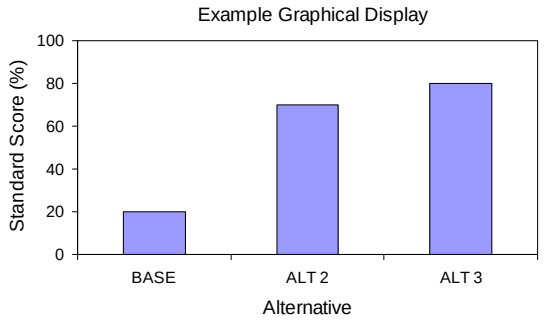
This assumes a linear increase in risk of ecological damage between the optimal conditions (zero weeks) and the most severe condition (540 weeks), which is the most conservative approach to take until there are data to support a more complex relationship. The equation will need to be re-calculated if in the future the model period is extended beyond 36 years.





4.3 Model Output

For each component of this performance measure, results for different planning alternatives can be displayed as simple bar graphs, where height of bars corresponds to standardized scores for this performance measure. The following is a generic example.



4.4 Uncertainty

There has not been a formal uncertainty analysis for this performance measure. There is a known amount of uncertainty associated with lake stages predicted by the SFWMM, and an unknown amount of uncertainty associated with how seasonal variation in lake stage affects various components of the lake's plant / animal community.

5.0 Monitoring and Assessment Approach

5.1 MAP Module and Section

Hydrology Monitoring Network Module section 3.5.3.1 (RECOVER 2004a). Daily lake stages are recorded by the USACE at an array of stations in the lake. Assessment is performed by tracking changes in lake stage relative to the envelope described above. Additional assessment is performed by identifying the frequency of occurrence and duration of events where stage rises above 17 ft or falls below 10 ft NGVD. See *The RECOVER Teams' Recommendations for Interim Goals and Interim Targets for the Comprehensive Everglades Restoration Plan* – Indicator 2.2 Water Levels in Lake Okeechobee (RECOVER 2005)

5.2 Assessment Approach

6.0 Future Tool Development Needed to Support Performance Measure

6.1 Evaluation Tools Needed

Lake Okeechobee Revised Stage Schedule model (LORSS).

6.2 Assessment Tools Needed

Daily lake stage information.

7.0 Notes

This Performance Measure supersedes and addresses LO-1 Lake Okeechobee Extreme Low Lake Stage (Last Date Revised: Nov 18, 2004), LO-2 Lake Okeechobee Extreme High Lake Stage (Last Date Revised: Nov 18, 2004), and LO-3 Lake Okeechobee Stage Envelope (Last Date Revised: Nov 18, 2004).

8.0 Working Group Members

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Lake Okeechobee Performance Measure
Ecological Indicator Score
(Vascular SAV, Chara, panfish, Cyanobacteria, Epiphyton and Epipelon)

Last Date Revised: October 20, 2016

Acceptance Status: Accepted

1.0 Desired Restoration Condition

This Performance Measure is an evaluation of Lake Okeechobee hydrology as measured using six nearshore ecological scoring metrics which can be used combined or individually to evaluate the effects of Lake hydrology on each indicator. Performance measure output is in the form of a numeric score for each individual metric or as a combined score for all metrics. The individual scores can also be related to areal submerged plant coverage for two of the six individual performance measures and to abundances for the other 4 performance measures; based on experiential data obtained from multiple years of baseline monitoring. Scores can be used to compare regulation schedules, varying climate conditions, or the effects of projects on lake ecology.

The desired restoration condition is a combination of lake stage envelope (12.5 ft NGVD-15.5 ft NGVD) and annual fluctuation in stage from maximum elevation at the end of the wet season (generally October) to minimum elevation at the end of the dry season (generally May) which results in a high annual point score for low cyanobacterial abundance and high epipelon, epiphyton, panfish abundance, and vascular SAV and Chara coverage. Cumulative point scores over a 41 year period of record (POR) range from 0 to 447. The target is a cumulative point score of 427 points, which would have resulted had the highest annual cumulative score that the LORS2008 regulation schedule generated occurred every year over the 1965-2005 41 year period of record. The Interim Goal is a cumulative point score of 324 points, which is the cumulative score over the 41 year POR generated by the LORS2008 schedule.

1.1 **Predictive Metric and Target –**The predictive metric is based on scores obtained from the following empirically derived statistical relationships between lake stage and associated measured ecological responses; which also are graphically displayed in Appendix A:

<u>Chara abundance –</u> When the average July lake stage is below 12 ft NGVD (2 pts), between 12 ft and 15.5 ft NGVD (1 pt) and above 15.5 ft NGVD (0 pts), the probability of peak summer (July and August) coverage conditions are optimal, sub-optimal and poor, respectively. The equation used for the Chara score in Excel to generate the annual score is: =IF(July lake stage cell value is<12,2, IF(July lake stage cell value is <15.5,1,0). For this formula <12 and <15.5 means lake stages <12 ft or <15.5 ft, followed by the point value to generate in the cell with this formula.

<u>Cyanobacteria abundance</u> – When the average May lake stage is below 12 ft NGVD (2 pts), between 12 ft and 14 ft NGVD (1 pt) and above 14 ft NGVD (0 pts), the probability of elevated summer (July) cyanobacteria abundance is low, intermediate and high, respectively. The equation used for the cyanobacteria score in Excel to generate the annual score is:=IF(May lake stage cell value is<12,2,IF(May lake stage cell value is<14,1,0)). For this formula <12 and <14 means lake stages <12 ft or <14 ft, followed by the point value to generate in the cell with this formula.

Epipelon abundance – When the average monthly lake stages the previous year that correspond to the spring (usually March or April) and fall (usually September or October) are below 12 ft NGVD (2 pts), between 12 ft NGVD and 15 ft NGVD (1 pt) or above 15 ft NGVD (0 pts), spring and fall growth conditions are optimal, intermediate and poor, respectively. Fall and spring conditions points are averaged to obtain a maximum 2 point score for epipelon. The epipelon scores are averaged so all of the annual scores are equally weighted for each indicator. The equation used for the epipelon score in Excel to generate the annual score is: =IF(prior year April lake stage cell value is<12,2,IF(prior year April lake stage cell value is<15,1,0)/2) + IF(prior year October lake stage cell value is <12, 2, IF(prior year October lake stage cell value is<15, 1, 0)/2). For this formula <12 and <15 means lake stages <12 ft or <15 ft, followed by the spring and fall point values, added together to generate the annual point value in the cell with this formula.

Epiphyte abundance – When the average monthly lake stages the previous month that correspond to the spring (usually March or April) and fall (usually September or October) are below 14 ft NGVD (2 pts), between 14 ft NGVD and 15 ft NGVD (1 pt) or above 15 ft NGVD (0 pts), and submerged and emergent aquatic plant host communities are present, spring and fall growth conditions are optimal, intermediate and poor, respectively. Fall and spring conditions points are averaged to obtain a maximum 2 point score for epiphyton. The epiphytic scores are averaged so all of the annual scores are equally weighted for each indicator. The equation used for the epiphyte score in Excel to generate the annual score is: =IF(March lake stage cell value is<14,2,IF(March lake stage cell value is<15,1,0)/2) + IF(September lake stage cell value is <14, 2, IF(September lake stage cell value is<15, 1, 0)/2). For this formula <14 and <15 means lake stages <14 ft or <15 ft, followed by the spring and fall point values, added together to generate the annual point value in the cell with this formula.

Panfish (Bluegill and Redear Sunfish) creel survey abundance – When the average November and December lake stages are between 12 ft and 15 ft NGVD (2 pts), below 12 ft NGVD or between 15 ft NGVD and 16 ft NGVD (1 pt) and above 16 ft NGVD (0 pts), winter creel survey abundance conditions are optimal, sub-optimal and poor, respectively. The equation used for the panfish score in Excel to generate the annual score is: =(IF(AND(prior November lake stage cell value is<15 or >12,2,1) x IF(prior November lake stage cell value is >16,0,1) x (IF(AND(prior December lake stage cell value is<15 or >12,2,1) x IF(prior December lake stage cell value is >16, 0, 1))/2. For this formula <15 and >12 and >16 means lake stages <15 ft or >12 ft or >16 ft, followed by the point values, with the November and December point values multiplied then divided by 2 to generate the annual point value in the cell with this formula.

Submerged vascular aquatic plant (SAV) communities – When the average July lake stage is between 12 ft and 15.5 ft NGVD (2 pts), 10 ft and 12 ft or above 15.5 ft NGVD (1 pt) and below 10 ft or above 18 ft NGVD (0 pts), the probability of summer peak (July and August) coverage conditions are optimal, sub-optimal or poor, respectively. The equation used for the vascular SAV score in Excel to generate the annual score is: =IF(July lake stage cell value is<10,0, IF(July lake stage cell value is<12,1, IF(July lake stage cell value is <15.5,2), IF(July lake stage cell value is>15.5,1), IF(July lake stage cell value is>18,0))))). For this formula <10, <12, >12 and <15.5 and >15.5, >18, means lake stages <10 ft, <12 ft, <15.5 ft, >15.5 or >18 ft followed by the point value to generate in the cell with this formula.

The overall period of record (POR) score is the sum of all the annual POR scores for each of the ecological indicators. However, since 2 of the ecological indicators are calculated based on previous year's Lake stages, only 40 years of the 41 year period of record are used in calculating scores for all the ecological indicators; resulting in a maximum scoring range of 0 to 440 points.

2.0 Justification

The nearshore and pelagic regions of Lake Okeechobee are occupied by a number of key ecological communities which can be used to evaluate the environmental health of the lake as a function of their responses to changing hydrologic conditions. For example, nearshore vascular SAV and Chara provide important habitat for fish, wading birds, macroinvertebrates, other taxa and epiphytic algae (Havens et al. 2002). Similarly, the epipelic and epiphytic communities are important components of the lake's food web and compete with algal species for available nutrients (Zimba 1995; Carrick & Steinman 2001; Rodusky et al. 2001; 2010) while cyanobacteria can cause major health and safety issues if they are present in high abundance (US EPA 2016). Fish (panfish) because they are higher on the food web in turn integrate many other aspects of the ecological status of the lake. Since these components of the Lake Okeechobee ecosystem are so important, they have been the subject of regular monitoring and thus the long term monitoring data sets needed to elucidate their relationship to lake hydrology are available.

The ecological indicator scores used in this combined performance measure are based on the strongest statistically significant correlations between the ecological indicator data and average monthly lake stages during the data collection periods, or average monthly lake stages during the previous month, two, three, six months, or previous year. The summer cyanobacteria abundance data were collected during July, (1994, 2000-2011) and June (1995). The panfish creel data were collected during January and February, 1997-2005. The epipelon abundance data were collected near the end of August 2002, March/April and September/October of 2003-2005 and 2008-2010. The epiphyte abundance data were collected during the same timeframe as the epipelon data during 2002-2005; the spring collection did not resume until 2009 due to lack of host vegetation and continued in 2010, fall 2011 and spring and fall 2012. The annual summer Chara and SAV coverage data were collected between 2000 and 2012 (SAV) and 2000 and 2013 (Chara). For all of the indicators, the lake stages in the correlation data sets was between approximately 3m and 5m, which defines the approximate range of lake stages over which this performance measure can be used.

3.0 Scientific Basis

3.1 Relationship to Conceptual Ecological Models

All the ecological indicators included in this performance measure are represented in the Lake Okeechobee Conceptual Ecological Model, the development of which was based on similar long term baseline monitoring sets**.** Although the Conceptual Model includes linkages that are not reflected in this performance measure, none of the relationships used in the performance measure run counter to the linkages presented in the model. However, a number of the performance measure components have additional linkages in the model unrelated to hydrology.

The conceptual model has no quantitation or ability to be used to score ecological or hydrologic conditions, and the only evaluation tools that currently exist are purely hydrologic, scoring percent of time the lake remains in the ecologically preferred stage envelope and various metrics related to time spent under excessive high or low lake stage conditions.

Regional Models

This performance measure can be used either with the RESOPS screening model or with the SWMM model. If used with the SWMM, end of month lake stages for the POR need to be extracted. The RESOPS model uses the SWMM generated hydrology and rainfall and runoff input data. Both of these models have been peer reviewed and used in the CEPP portion of CERP modeling and in the SFWMD River of Grass modeling However, generally speaking this performance measure could be used with, any model that produces Lake Okeechobee stage data as an output. Performance measure indicator scores are generated from equations in a EXCEL spreadsheet that uses end of month or average monthly lake stage as its sole input, as illustrated in Appendix B.

3.2 Relationship to Adaptive Assessment Hypothesis Clusters

Ecological Premise: When lake elevations are within the ecologically beneficial stage envelope of 12.5-15.5 ft NGVD, with an annual fluctuation between the May end of the dry season low (12.5 ft NGVD) and the October end of the wet season high (15.5 ft NGVD), ecological conditions should be suitable for vascular SAV, epipelon, epiphyton, panfish, and unsuitable for cyanobacterial blooms.

CERP Hypotheses: Keeping lake stages in the ecologically beneficial stage envelope, maintaining the correct temporal pattern of increasing and decreasing water levels, and minimizing the occurrence of water levels above and below the ecologically beneficial stage envelope, especially during the spring and summer months will increase the potential for nearshore SAV to colonize the largest amount of potentially colonize-able nearshore area during the peak summer growing season and should increase associated epiphytic abundance, panfish abundance, result in robust epipelon abundance and limit cyanobacteria abundance.

4.0 Evaluation Application

To test the functioning of the performance measure, The SWMM model using the LORS2008 and WSE regulation schedules end of month lake stages were compared over a 35 year POR (1965-1999). Both the individual and combined performance measure scores were examined. The individual performance measure scores for the LORS2008 stages output were higher for all of the ecological indicators except vascular SAV. The overall score for the combined performance measure was also higher for the LORS2008 stages output. Similarly, the individual and combined scores were both higher for the LORS2008 time frame of the actual hydrograph (2008-2015) compared to the WSE time frame of the actual hydrograph (2000-2007). The scores for both the individual and combined ecological performance measure are realistic and reliable since the LORS2008 regulation schedule is designed to keep the lake stage approximately 0.30 meters lower than the WSE schedule which also results in the lake being in the preferred stage envelope more frequently. Further, the performance measure scores reflect trends noted in the monitoring data collected over the years when Lake Okeechobee was operated using these two schedules. Therefore both the individual and combined ecological performance measure scores appear to be informative since both can differentiate among lake stage regulation schedules. An example of a comparison of two regulation schedule 35 year POR individual ecological indicator scores and combined ecological indicator scores are presented in Appendix C.

4.1 Evaluation Protocol

1. End of month Lake Okeechobee stages for the POR are obtained from either RESOPS, the SWMM, or another suitable model.
2. Each ecological indicator is scored for each year in the POR. Each individual annual score is then summed over the POR so each indicator score can be compared amongst various model runs.
3. The resulting 6 individual indicator summed scores are then combined to give a single value for each model run. These scores are likewise directly comparable amongst different model runs.

4.2 Uncertainties:

There are two major areas of uncertainty in the use of this performance measure:

1. If model input generates lake stages that are outside the range of lake stages encountered in developing the scoring based on empirical statistical relationships then the relationships on which the scoring was based may not apply. It is probable that the degree of uncertainty increases as the degree of deviation from empirical lake stages increases.
2. If there were to be major and or long lasting stochastic events such as hurricanes or droughts which permanently shifted the ecological functioning of the lake. For example, if as almost happened in 2004 and 2005 storm events destroyed almost the entire emergent and submerged vegetation community in the lake precipitating what might have been a permanent shift in stable steady state to a phytoplankton dominated ecosystem.

4.3 Performance Measure Sensitivities

The above methodology results in a score which varies between model runs based on the modeled schedule's operating conditions and the resulting POR hydrograph. If climate change variables such as an increase in evapotranspiration rates or an change in rainfall amounts or other operating conditions such as adding additional storage in the watershed (Sharfstein et al., in review) are added or modified in the model runs, the modified lake stage output can be scored by the same method used for any other operating conditions, provided that the resulting lake stages do not exceed the range, or duration of lake stages encountered in the monitoring data sets from which the performance measure values were derived.

4.3 Model Output Needed

End of month Lake Okeechobee stage levels for duration of the POR to be evaluated.

5.0 Monitoring and Assessment Approach

5.1 MAP Module and Section

Additional background Lake Okeechobee SAV information can be found in the *CERP Monitoring and Assessment Plan: Part 1 Monitoring and Supporting Research* - Lake Okeechobee Module section 3.4.3.2 (RECOVER 2004a). The long-term annual summer nearshore mapping project results in the development of a map that shows the spatial extent of nearshore SAV coverage. Additional background

fish, cyanobacteria and periphyton information can be found in the same *CERP Monitoring and Assessment Plan* Lake Okeechobee Module sections 3.4.4.1, 3.4.4.4 and 3.4.3.1, respectively.

5.2 Assessment Approach

6.0 Future Tool Development Needed to Support Performance Measure

6.1 Evaluation Tools Needed – Calculation of this performance measure should be incorporated as automatically generated post processing output in the RESOPS and SWMM models. This should include the ability to generate a line graphic representing the annual combined scores for each POR modeled (Figure 1). Continuation of the ecological indicator monitoring also will provide validation data for each of the ecological indicators.

6.2 Assessment Tools Needed –

7.0 Notes

This Performance Measure is an overall evaluation obtained by combining several nearshore ecological indicator scoring metrics which also can be used to individually evaluate each indicator. Since this performance measure is based on correlations between ecological indicators and Lake Okeechobee lake stages, it may not be applicable for other lakes, since relationships between ecological indicators and lake stages may be different or nonexistent, given different lake stages in other lakes. Also, this performance measure may not be applicable to extremely low (e.g. <8 ft NGVD) or extreme high (e.g. >18 ft NGVD) lake stages in Lake Okeechobee since these stages are outside the range that the lake has experienced during the years that the monitoring data used herein was collected.

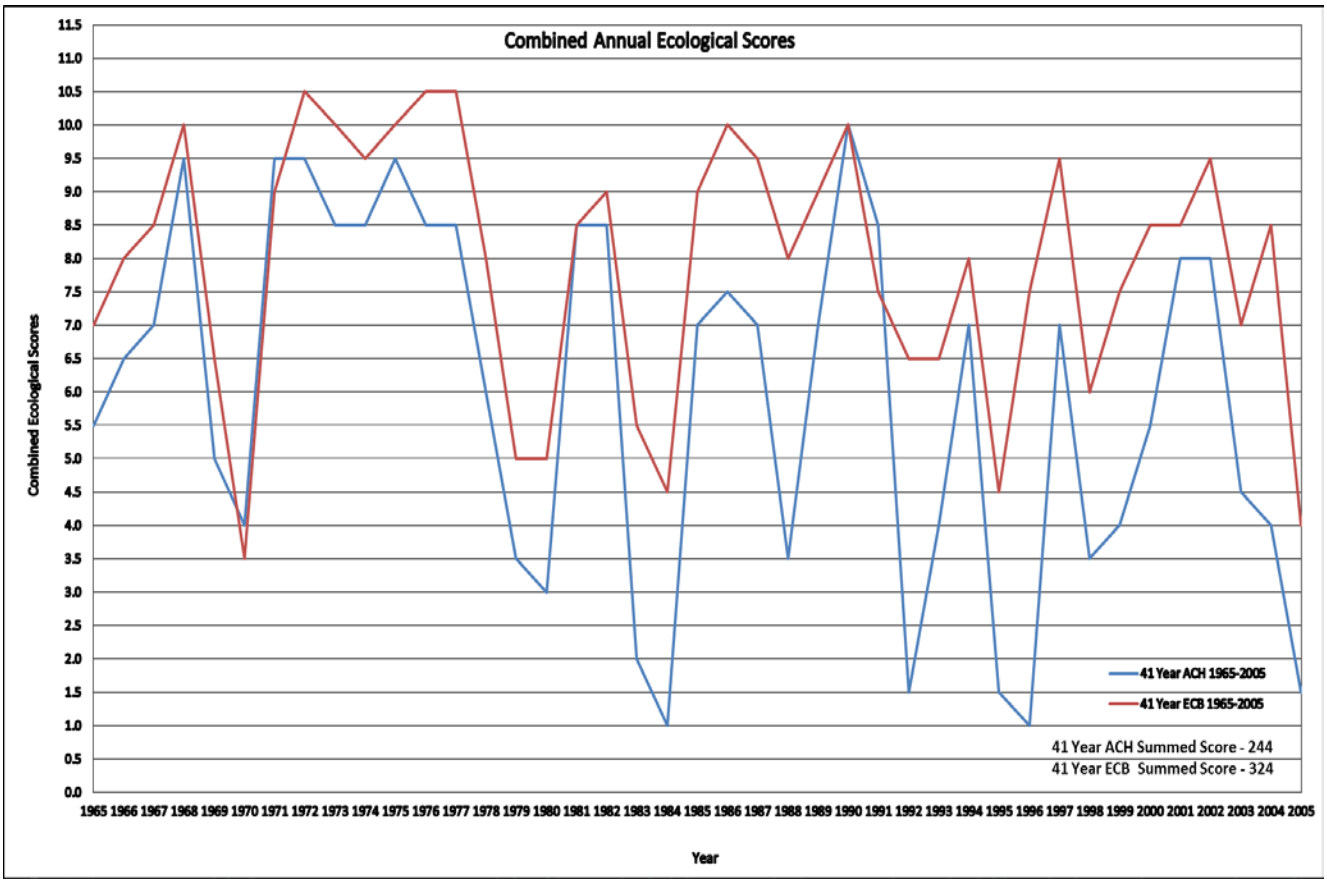

Figure 1. The annual ecological indicator scores for a 41 year Lake Okeechobee actual historical hydrograph (ACH) and a 41 period of record (1965-2005) for the hydrograph if the LORS 2008 and adaptive protocols current regulation schedule (ECB, existing condition baseline) would have been in place during that time frame. The summed ACH and ECB scores are listed in the bottom right hand corner.

8.0 Working Group Members

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Steve Schubert (USFWS)

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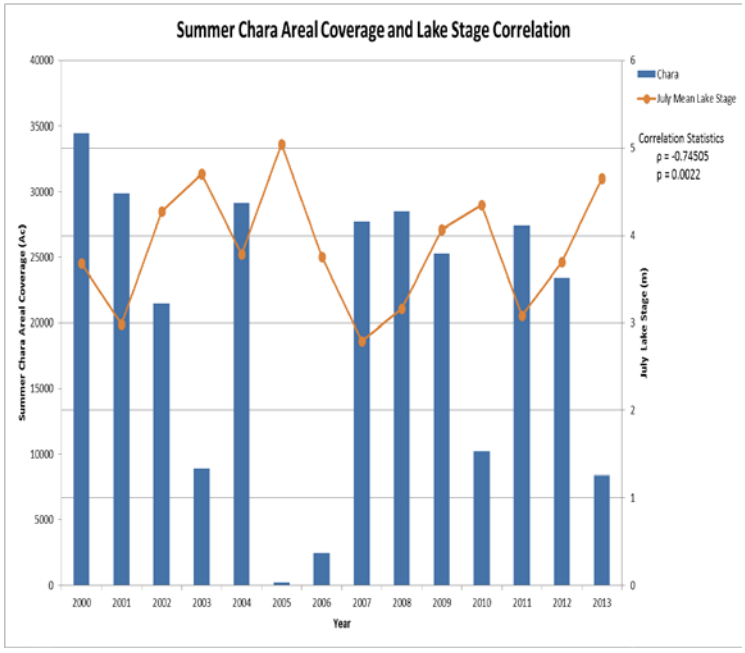
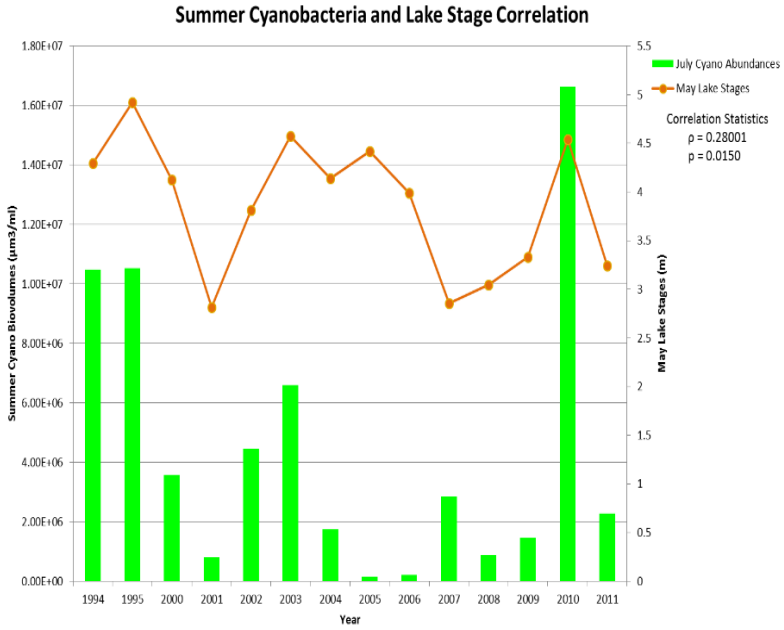
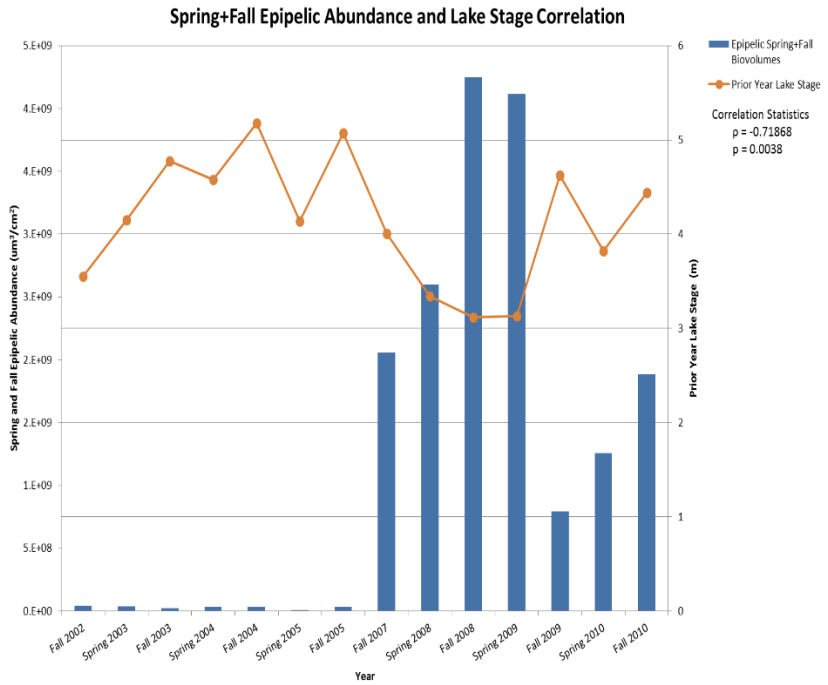
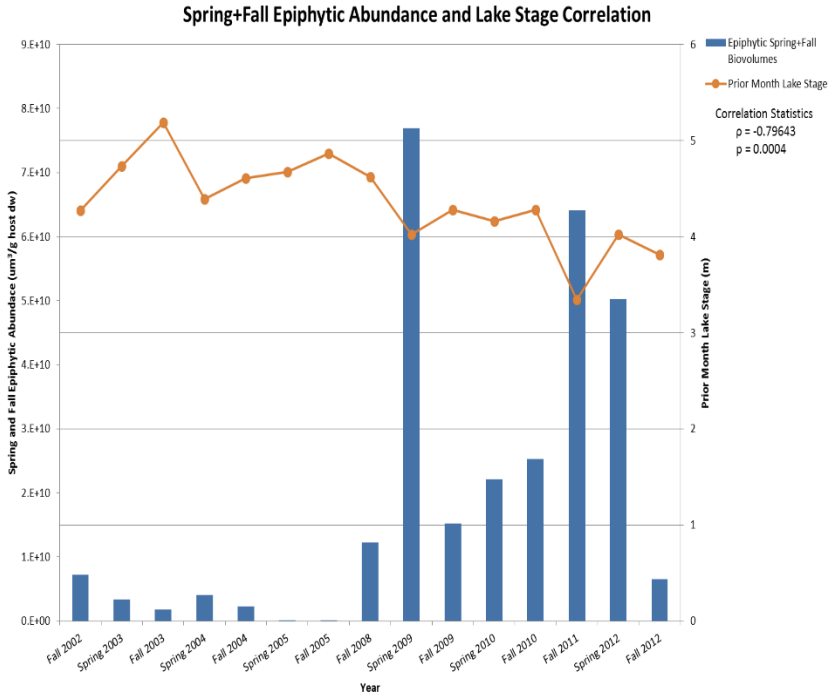
Appendix A

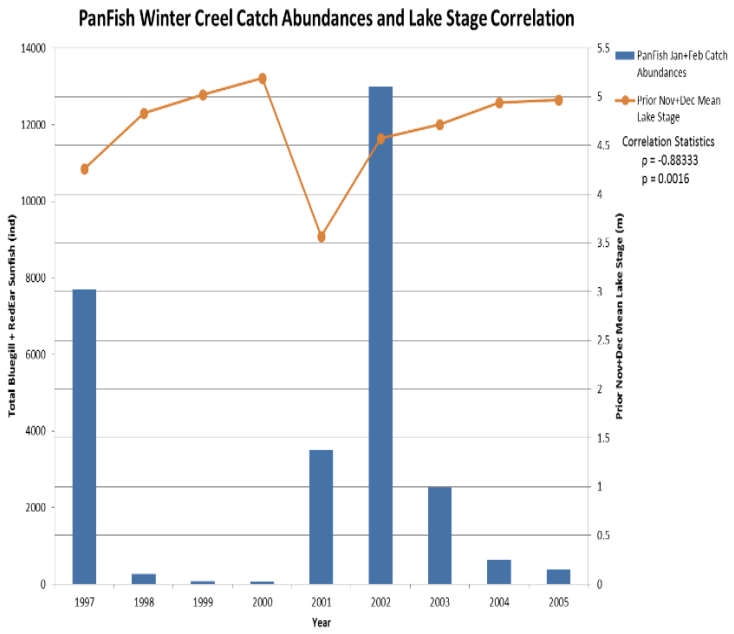
Graphical representation of the strongest statistical relationship between each ecological indicator and lake stages. These relationships consist of Spearman correlations using ecological data and monthly average lake stages from either the month the ecological data were collected (Chara, Vascular SAV), the prior month (Epiphyte), two months prior (Cyanobacteria, PanFish) and the previous year (Epipelon).

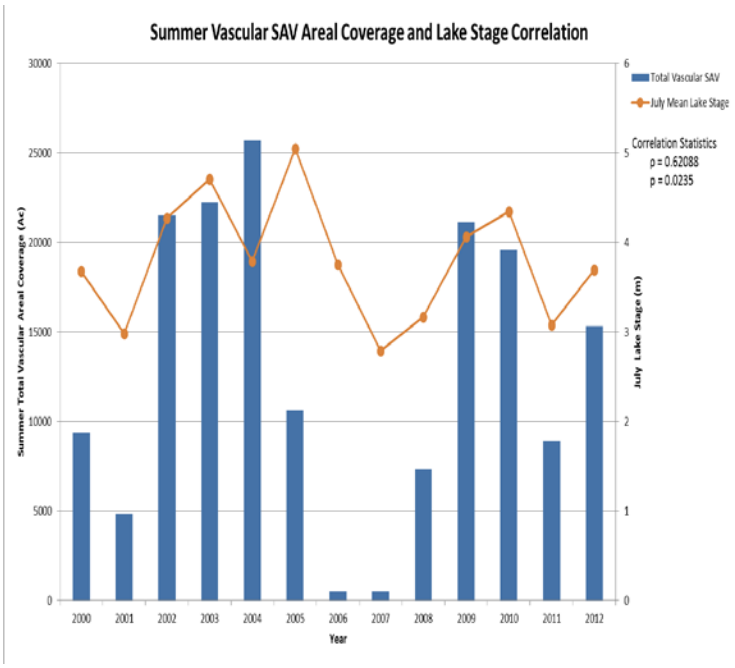





Spring+Fall Epipelic Abundance and Lake Stage Correlation
Epipelic Spring+Fall Biovolumes
Prior Year Lake Stage
Correlation Statistics
ρ = -0.71868
p = 0.0038
Spring and Fall Epipelic Abundance (um³/cm²)
Prior Year Lake Stage (m)
Year
5.E+09
4.E+09
4.E+09
3.E+09
3.E+09
2.E+09
2.E+09
1.E+09
5.E+08
0.E+00
6
5
4
3
2
1
0
Fall 2002
Spring 2003
Fall 2003
Spring 2004
Fall 2004
Spring 2005
Fall 2005
Fall 2007
Spring 2008
Fall 2008
Spring 2009
Fall 2009
Spring 2010
Fall 2010

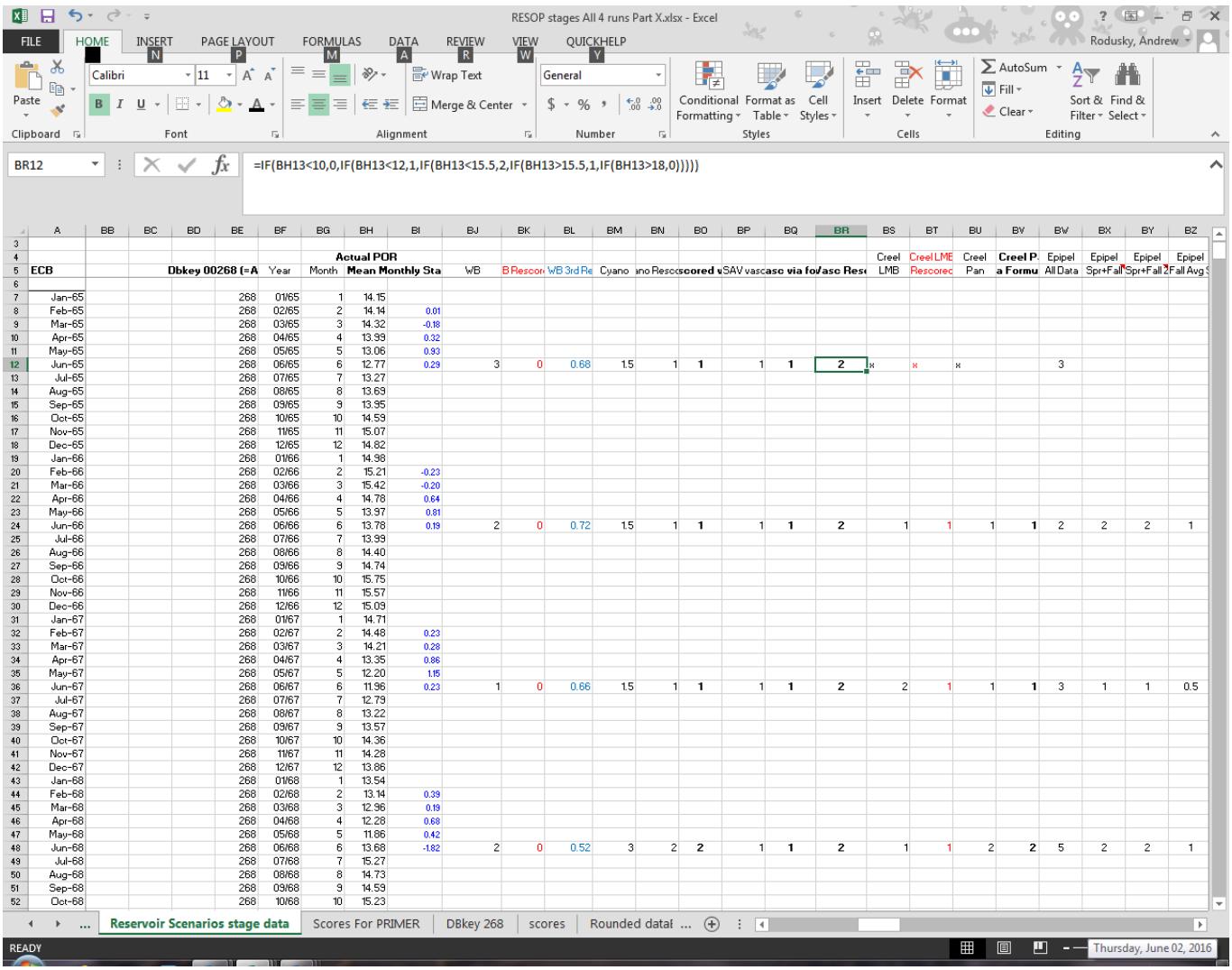

Spring+Fall Epiphytic Abundance and Lake Stage Correlation
Epiphytic Spring+Fall Biovolumes
Prior Month Lake Stage
Correlation Statistics
ρ = -0.79643
p = 0.0004
Spring and Fall Epiphytic Abundace (um³/g host dw)
Prior Month Lake Stage (m)
Year
9.E+10
8.E+10
7.E+10
6.E+10
5.E+10
4.E+10
3.E+10
2.E+10
1.E+10
0.E+00
6
5
4
3
2
1
0
Fall 2002
Spring 2003
Fall 2003
Spring 2004
Fall 2004
Spring 2005
Fall 2005
Fall 2008
Spring 2009
Fall 2009
Spring 2010
Fall 2010
Fall 2011
Spring 2012
Fall 2012


PanFish Winter Creel Catch Abundances and Lake Stage Correlation
Total Bluegill + RedEar Sunfish (ind)
Prior Nov+Dec Mean Lake Stage (m)
Year
PanFish Jan+Feb Catch Abundances
Prior Nov+Dec Mean Lake Stage
Correlation Statistics
ρ = -0.88333
p = 0.0016
1997
1998
1999
2000
2001
2002
2003
2004
2005


Summer Vascular SAV Areal Coverage and Lake Stage Correlation
Summer Total Vascular Areal Coverage (Ac)
July Lake Stage (m)
Year
Total Vascular SAV
July Mean Lake Stage
Correlation Statistics
ρ = 0.62088
p = 0.0235
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012

Appendix B

A copy of an Excel spreadsheet containing lake stage output on a mean monthly (Mean Stages). The annual scores for each ecological indicator PM for 1965 – 1968 are shown as part of the 41 year POR (1965-2005) data, with the Vascular SAV point score for 1965 highlighted to illustrate the formula used to determine the point score based on the July mean lake stage. This type of formula is used for all of the indicators and the scores for each indicator are summed to calculate the POR Combined Ecological Score. There are no data for the PanFish and Epipelon indicators for 1965 because monthly lake stages for 1964, which are prior to this POR, would be needed to be able to score these indicators for 1965.



Appendix C

The individual and combined ecological performance measure scores for the 35 year period of record for both the WSE and LORS2008 regulation schedule model runs. The individual and combined ecological performance measure scores for the actual hydrograph time frame that coincides with both of the regulation schedules are in the second table. The maximum scores for each performance measure and the combined average scores are also listed.

Regulation Schedules	Cyano	Vascular SAV	PanFish	Epipelon	Epiphyte	Chara	Combined Scores
WSE35 EOM Score	37	61	38	28	37	40	241
LORS2008 35 EOM Score	49	55	46	36	47	46	279
Max Score	70	70	68	68	70	70	416

Actual POR Hydrograph	Cyano	Vascular SAV	PanFish	Epipelon	Epiphyte	Chara	Combined Scores
2000-2007	7	9	6	5	7	10	44
2008-2015	11	14	13	9.5	11	10	69
Max Score	16	16	16	16	16	16	96

Northern Estuaries Performance Measure
Salinity Envelopes

Last Date Revised: April 5, 2007

Acceptance Status: Accepted

1.0 Desired Restoration Condition

The restoration goal is to re-establish salinity regimes suitable for the maintenance of healthy, naturally-diverse and well-balanced estuarine ecosystems. Accomplishing restoration will require ameliorating inordinate canal discharges (including regulatory releases from Lake Okeechobee) and insuring sufficient dry-season flows necessary to avoid ecologically damaging high and low salinity extremes. Success in meeting restoration expectations will be measured by the degree in which constructed features and operational considerations sufficiently enhance estuarine flora and fauna as appropriate for each of the four estuaries being restored.

Caloosahatchee Estuary: Specific Restoration Goals

Re-establish a salinity range favorable to juvenile marine fish, shellfish, oysters and submerged aquatic vegetation (SAV). Re-establish consistent, clear, clean, freshwater flows that maintain low salinities in the upper estuary. Re-establish more stable salinities and ranges in the lower estuary that the seagrasses can tolerate.

Lake Worth Lagoon: Specific Restoration Goals

Manage flows through the C-51 canal where ecological benefits realized in the area most sensitive to freshwater discharge (e.g., potential oyster habitat) may translate into benefits in the northern and southern portions of the lagoon, thus increasing the spatial extent of flora and fauna throughout.

Loxahatchee River Estuary: Specific Restoration Goals

Improved freshwater deliveries to the Northwest Fork of the Loxahatchee River will reverse saltwater intrusion in the upstream reaches of the Northwest Fork. Reducing the frequency and duration of peak freshwater discharges through S-46 will decrease excessive salinity variability (i.e., re-establish more natural salinity regimes), which will benefit estuarine flora and fauna (e.g., seagrasses and oysters).

St. Lucie Estuary: Specific Restoration Goals

Maintain a salinity range favorable to fish, oysters and submerged aquatic vegetation (SAV), which necessarily requires addressing high volume, long duration discharge events from Lake Okeechobee, the C-23 and C-24 watersheds.

1.1 Predictive Metric and Target

Caloosahatchee Estuary: Specific Predictive Metrics and Targets

The target is based on optimization model outputs, natural variation that would occur during the

period 1965-2000, and desirable salinity conditions for existing and potential aquatic resources within the CE. Targets are based on freshwater discharges from the C-43 canal at the S79 structure where the mean monthly inflow should be maintained between 450 and 2,800 cfs. Targets were developed to reduce minimum discharge and high flow events to the estuary to improve estuarine water quality and protect and enhance estuarine habitat and biota.

Low Flow

• Ultimately, the low flow target is no months during October to July when the mean monthly inflow from the Caloosahatchee watershed, as measured at S79, falls below a low-flow limit of 450 cfs (C-43 basin runoff and Lake Okeechobee regulatory releases).

High Flow

• Ultimately, the high flow target is no months with mean monthly flows greater than 2,800 cfs, as measured at the S79, from Lake Okeechobee regulatory releases in combination with flows from the Caloosahatchee River (C-43) basin.

Frequency of Flows

• The frequency distribution of monthly average freshwater inflows through S-79 for the entire period of record has been found to be important for protecting and restoring estuarine resources, while further promoting biotic diversity. Approximately 75% of the flows from S-79 should be in the 450-800 cfs range and most of the remaining inflow should be in the 800 to 2800 cfs range.

Lake Okeechobee Regulatory Releases

• The alternative with the least daily discharge volume, the fewest number of total days of discharge, and the fewest number of consecutive days is preferred. Special consideration is provided for pulse releases that may benefit the estuary.

Tape grass and Seagrass Goals

Seagrasses at the river mouth need high salinities (over 20 psu (Doering and Chamberlain 2000)) and clear water (Dennison et al., 1993) (low blue light attenuation) and no time periods of greater than 1 week at salinities below 10 PSU (e.g., Moffler and Durako, 1987) or blue light levels below 5 % of surface irradiance. Tape grass needs low salinities < 10 psu and clear water (Kemp et al., 2004), and no continuous time periods of salinities > 20 psu. Restoration goal of 100% tape grass, turtle grass or manatee grass coverage to 3 m mlw.

Lake Worth Lagoon: Specific Predictive Metrics and Targets

The Lake Worth Lagoon can be subdivided into three zones: northern, central, and southern. The northern and southern zones of the lagoon will be evaluated for salinities appropriate for seagrasses, while the central portion of the lagoon will be evaluated for salinities suitable for oyster recruitment and sustainability. Management of freshwater discharges into the lagoon as demonstrated below will maximize the potential growth of these VECs.

Central Zone:

A minimum salinity target of 15 parts per thousand (ppt) for the Lake Worth Lagoon was selected based on the habitat requirements of oysters (*Crassostrea viriginica*) for the central portion. A target of 15 ppt was selected for the American oyster because this is a mid-range salinity that meets the requirements for all life stages (see table below).

OYSTER STAGE	**SALINITY**	**REFERENCE**
Adult tolerance	5 – 30 ppt (optimum 10 – 28 ppt)	Loosanoff, 1965 in Rudolph, 1998
Adult	Large mortality occurs during prolonged periods of freshwater releases where salinities reach 2 ppt	Sellers and Stanley, 1984
Adult	Mean size greatest where surface salinities 8 – 22 ppt	Mote Marine Laboratory in Rudolph, 1998
Spat	Optimum growth at 15 – 22 ppt	Sellers and Stanley, 1984
Larvae	Maximum survival and growth >12.5 ppt	Sellers and Stanley, 1984
Spawning	Inhibited < 7.5 ppt	Sellers and Stanley, 1984
Gonadal maturation	Inhibited by low salinity < 5 ppt	Sellers and Stanley, 1984

Northern and Southern Zones:

Based on the requirements of three species of seagrass found within LWL, a minimum salinity of 20 ppt is considered an appropriate target (see table below). Kenworthy (1991) found no mortality at salinity concentrations as low as 15 ppt, but quick death at 5 ppt, with the threshold apparently somewhere between 5 and 15 ppt. While 15 ppt appears low in regard to the requirements of Halodule wrightii at different life-stages, extensive mortality was found only after prolonged exposure to conditions below 9 ppt. Optimal growth of seagrass beds is expected to occur within the northern and southern portions of the lagoon.

SEAGRASS SPECIES	**SALINITY**	**REFERENCE**
Halophila johnsonii	No stressful physiological response, as measured by photosynthesis and respiration, at salinities of 15, 25, and 35 ppt	Kenworthy and Dipiero, 1991
Halophila johnsonii and H.	Death within 3 days at 5 ppt	Kenworthy and Dipiero, 1991

decipiens		
Holodule wrightii	Normal tolerance range 5 – 55 ppt	Woodward-Clyde 1998
Halodule wrightii	Vigorous growth at 23 – 37 ppt	McMahan, 1968 in Rudolph 1998
Halodule wrightii	Flowers at 26 – 36 ppt	McMahan, 1968 in Rudolph 1998
Halodule wrightii	Adverse effects 2+ weeks <9 ppt	Moffler and Durako, 1987 in Rudolph, 1998

Target:

In an attempt to accomplish these targets, two upper limitations are recommended: (1) elimination of the devastating high flow events of 1,000 cfs or greater and (2) elimination of flows greater than 500 cubic feet per second (cfs) for extended periods of time (7-days or greater). To attain this salinity threshold, the targets are as follows:

- Inflows should be maintained between 0 and 500 cfs based on a 7-day moving average.
- High flow events of 1,000 cfs or greater, based upon a 2-day moving average, should not occur.
- Flows greater than 500 cfs based on a 7-day moving average should be eliminated. (Rudolph 1998).

Loxahatchee River Estuary: Specific Predictive Metrics and Targets

The Loxahatchee River can be subdivided into two major zones: (1) Northwest Fork, and (2) Estuary. The Northwest Fork will be evaluated for base flows and salinities appropriate for freshwater swamp communities, i.e., saltwater wedge near river mile 7.5. The Estuary will be evaluated for salinities appropriate for seagrasses.

Restorative flow targets for the Northwest Fork of the Loxahatchee River are defined as "variable dry season flow between 50 cfs and 110 cfs, with a mean monthly flow of 69 cfs over Lainhart Dam, while providing an additional 30 cfs of flow from the downstream tributaries" (SFWMD 2006). Such flows will effectively reverse saltwater intrusion in the upstream reaches of the Northwest Fork, and shift the typical distribution of the saltwater wedge downstream of river mile 7.5.

Freshwater discharge targets for the estuary are based on mean daily salinity conditions in the estuary (i.e., at river mile 1.74) and based on ecological requirements of manatee grass (*Syringodium filiforme*). Flood control discharges that result in the mean daily salinity equaling or falling below 15 ppt for a period of 6 days should not occur (Ridler et al 2006).

St. Lucie Estuary: Specific Predictive Metrics and Targets

SFWMD has performed extensive monitoring of the SLE as well as flows and loads from the associated basins and Lake Okeechobee (RECOVER 2006a). Flows were classed into sized flow events and flow events were subsequently correlated to representative median salinities. A discharge/salinity relationship was established for very low salinities using these classifications. Flow ranges of 725-3280 cfs produced salinities that ranged from 1-5 ppt. Flows of 2000 cfs, the mid-range of this flow class, would result in a salinity of 3 ppt, a salinity implicated in the oyster mortality of 1998 and 1999. Kenworthy and Dipiero (1991) found that such low salinities would result in *Halodule wrightii* mortality. Therefore, 3 ppt and 2000 cfs are threshold values for survival.

Evaluation targets were developed from natural systems modeling of the Indian River lagoon (NSM-IRL) from the Hydrologic Simulation Program Fortran (HSPF) and historic flow data using the 1965 - 2000 36-year rainfall period of record. The target salinity gradients in St. Lucie Estuary were determined by a hydrodynamic salinity model (Morris 1987) combined with estimates of salinity requirements for two indicator species in the estuary: shoal grass (*Halodule wrightii*) and American oyster (*Crassostrea virginica*). The salinity envelop target at the Roosevelt Bridge (mid-estuary) is a salinity range of 12-20 ppt).

The interim target flow numbers as of June 1, 2006 are as follows:

- 63 months where mean flow is less than 350 cubic feet per second (cfs).
- 24 Lake Okeechobee regulatory discharge events (14 day moving averages > 2000 cfs)
- 36 Local basin flow > 2000 CFS (based upon 14 day moving averages > 2000 cfs)

This target is the minimum condition for defining restoration per RECOVER 2006 and will the basis for a .5 normalized score.

Full restoration targets are estimated to be:

- 31 months where mean flow is less than 350 cubic feet per second (cfs).
- 0 Lake Okeechobee regulatory discharge events (14 day moving averages > 2000 cfs)
- 28 Local basin flow > 2000 cfs (based upon 14 day moving averages > 2000 cfs)

No more than 12 months of mean monthly greater than 2000 CFS, based upon the assumption that flows in excess of 2000 cfs produce salinities below 3 ppt at Roosevelt Bridge.

1.2 Assessment Parameter and Target

Caloosahatchee Estuary: Specific Assessment Parameter and Target

Vallisneria americana (tape grass)

A mean monthly inflow of at least 300 ft^3/sec (cfs) is needed from S-79 to ensure that the average monthly salinity at Ft. Myers (Yacht Basin) is $\leq$ 10 ppt (target maximum salinity for tape grass) and daily average salinity does not exceed 20 ppt more than once in two consecutive years. This estimated

minimum flow level (MFL) depends on about 200 cfs of additional flow from the downstream tidal basin between S-79 and Ft. Myers. However, violations of the salinity criteria commonly occurs during dryer than normal periods in the dry season when the combined tidal tributary flows are < 200 cfs. Therefore, a minimum flow of 300 from S-79 is not enough. Greater frequency of flows that approach 500 cfs is needed from S-79 in order to achieve the intended salinity goals.

At the other extreme, mean monthly flows that exceed 2,800 cfs should be minimized, because greater flows cause more than half the estuary upstream of Shell Point to become freshwater and salinity near Shell Point drops to levels that threaten many of the species in this region. Mean monthly inflows greater than 4,500 cfs from S-79 causes: salinity and other water quality parameters in San Carlos Bay to decline below desired levels; and the entire estuary upstream of Shell Point to approach freshwater conditions.

Crassostrea virginica (American oyster)

Volety et al. (2003) recommended freshwater inflows for the protection and enhancement of oyster recruitment and survival around Shell Point and San Carlos Bay, which are consistent with the flows outlined above for SAV. "Flows between 500 and 2000 cfs would result in salinities of 16-28 ppt at all stations, conditions that are favorable to sustain and enhance oyster populations in the Caloosahatchee Estuary." Under current water management practices, oysters in the Caloosahatchee are not stressed by low flows of < 300 cfs from S-79. However, complete cessation of discharges during the winter will increase salinities in areas normally associated with lower salinity, and result in the migration of marine predators and pests. They further speculate that oyster spat that recruit to downstream areas also will be exposed to higher salinity and heavy predation pressure resulting in very little survival. However, the greatest threat to oysters under current water management practices is due to high flows that exceed 3,000 cfs for extended periods (2-4 weeks). This is especially true for summer months during peak spawning, juvenile recruitment, and oyster growth. Volety et al. (2003) recommends that when freshwater releases are necessary, repeated pulses of < 1 week duration during winter months be made instead of sustained releases of freshwater during summer or winter months. Interpretation of these results also indicates that such pulses would be least damaging during December through February, before increased spawning and recruitment begins at upstream locations.

Salinity preferred by oysters will be maintained if the target flow frequency distribution is achieved, especially if 75% of the flows are between 450 and 800 cfs.

Lake Worth Lagoon: Specific Assessment Parameter and Target

The minimum desirable salinity is 15 parts per thousand (ppt).

Loxahatchee River Estuary: Specific Assessment Parameter and Target

In the Northwest Fork the specific assessment parameter and target are the accomplishment of the restorative flows outlined in the *Restoration Plan for the Northwest Fork of the Loxahatchee River*, which will result in a downstream shift in the typical location of the saltwater wedge (to approximately river mile 7.5). In particular, dry season freshwater discharges into the Northwest Fork and flowing over Lainhart Dam should be between 50 cfs and 110 cfs, with a mean monthly flow of 69 cfs, and an additional 30 cfs of flow should be achieved through the downstream tributaries (SFWMD 2006).

Manatee grass (*Syringodium filiforme*) is a highly productive seagrass species occurring in the Loxahatchee River estuary, and past studies have shown manatee grass to be susceptible to altered freshwater discharges and excessive salinity fluctuations (SFWMD and FDEP 2006, Ridler et al. 2006). Therefore, the following salinity threshold target with duration is established for manatee grass at river mile 1.74: ≤15 ppt for 6 days, because mean daily salinity ≤15 ppt for 6 days (over a 30 day period) resulted in significant mortality of *Syringodium filiforme* in the Loxahatchee River estuary.

Saint Lucie Estuary: Specific Assessment Parameter and Target

Reestablish a salinity range most favorable to juvenile marine fish, shellfish, oysters and submerged aquatic vegetation. This is estimated at 12 to 20 parts per thousand (ppt) as measured at the US-1 Highway Roosevelt Bridge over the estuary, and has been chosen as a Valued Ecosystem Component (for more information on oysters see NE-5).

2.0 Justification

The Northern Estuary Module encompasses five estuarine systems, namely the Caloosahatchee, Loxahatchee, and Saint Lucie estuaries, and the Indian River and Lake Worth Lagoons. The Indian River Lagoon is not addressed by this Performance Measure, since "salinity envelope" in the lagoon is not an issue. Under natural conditions estuarine environments may experience substantial variation in salinity due to storm events, changes in season, and decadal cycles in regional weather patterns. On geologic time scales, plants and animals have adapted to estuarine variability to the extent that many species rely upon estuaries for habitat, complex reproductive cycling, sanctuary from predation, and sustenance of key elements of an expanded food web including birds, marine fish and mammals, etc. The manner in which freshwater inputs are balanced via tidal exchange with the open ocean defines the salinity envelope, which may be differ among estuaries as a consequence of unique morphology, degree of connection with the sea, tidal height, and so forth. Salinity patterns directly influence productivity, population distribution, community composition, predator-prey relationships and food web structure in the inshore marine habitat (Myers and Ewel 1990, Kennish 1990).

The volume, distribution, circulation, and temporal patterns of freshwater discharges to all four of the estuaries within the Northern Estuaries Module were altered due to construction and operation of the Central and Southern Flood Control District (C&SF) canals, and the resultant urban and agricultural development afforded by enhanced drainage and flood protection. These alterations have placed severe stress upon these ecosystems. Large volume freshwater discharges cause sudden drops in salinity and exacerbate transport of organic and inorganic sediments. Drainage systems designed to rapidly remove water from the land often do not afford time necessary for natural processes to absorb contaminants and nutrients, to the extent that large volume freshwater discharges may also transport large loads of nutrients and other contaminants into the estuarine environment. When stress repeatedly exceeds the resiliency of an estuarine system to absorb and ameliorate adverse conditions, negative effects will be compounded and estuarine ecosystem quality will decline. Examples include: decreased spatial extent of submerged aquatic vegetation (SAV), increased harmful algae blooms, declines in desirable fish species, and changes in the macroinvertebrates community such as loss of oysters (Haunert 1988).

2.1 Caloosahatchee Estuary

The Caloosahatchee River is the major source of freshwater for the Caloosahatchee Estuary (CE) and southern Charlotte Harbor aquatic environment. The river bisects its watershed and now functions as a primary canal (C-43) that conveys both runoff from the Caloosahatchee watershed and regulatory releases from Lake Okeechobee. The canal has undergone a number of alterations to facilitate this increased freshwater discharge and flood protection. These alterations include: channel enlargement; bank stabilization; the development of an intricate network of canals within the watershed; and the addition of three lock and dams. The final downstream structure, Franklin Lock and Dam (S-79), demarcates the beginning of the estuary, and acts as a barrier to salinity and tidal action, which historically extended to nearly the LaBelle area.

Because of water management practices, the watershed of the Okeechobee is now larger than it was historically, and the water coming into the lake is higher in nutrients. This high nutrient water can not flow south as it would originally because of the Hoover Dike and Everglades restoration P loading limits. Much of the high nutrient high turbidity water is directed west to the Caloosahatchee. The watershed of the Caloosahatchee is also larger because of water management practices, and runoff amounts are higher. This results in fast swings in local watershed inputs of freshwater as opposed to slower sheet-flow or groundwater discharge. The groundwater and sheet-flow inputs are preferred since the water gets filtered, and the flow rate changes gradually and is sustained longer than it is the existing fast runoff system.

Alterations to the Caloosahatchee River and watershed have resulted in a drastic change in freshwater inflow to the downstream ecosystem. The resulting large fluctuation of salinity and water quality can adversely impact estuarine biota (Chamberlain and Doering 1998a; Sklar and Browder 1998).

An important upper estuarine feature is the freshwater-brackish submerged grass, *Vallisneria americana* (tape grass), which when present is located near the shoreline in the upper estuary to a depth of about 1.0 m. Its greatest coverage occurs from Beautiful Island to just past the Ft. Myers bridges (Hoffacker et al. 1994, Chamberlain and Doering 1998b). During times of extended low inflow conditions, when salinity is too high, this grass becomes very sparse and can disappear completely (Chamberlain et al. 1995, Doering et al. 2002, SFWMD 2000).

Downstream, sparse beds of the seagrass *Halodule wrightii* (shoal grass) extend up from San Carlos Bay to nearly the Cape Coral Bridge (Hoffacker et al. 1994, Chamberlain and Doering 1998b). Like tape grass, it is restricted to the shoreline margins and historically represented a valued ecosystem component of the estuary. Oysters also exist near the mouth at Shell Point and historical accounts of the river indicate that oysters were once a more prominent feature in the area upstream (Sackett 1888). Both shoal grass and oysters in this area of the estuary are sensitive to high freshwater inflows from S-79 (Chamberlain and Doering 1998b, Doering et al. 2002, Volety et al. 2003).

The dominant biological features in the San Carlos Bay area are its numerous mangrove islands and many kilometers of mangrove shoreline, which are often closely associated with oysters and large meadows of seagrass. Because of its biotic richness and aesthetic appeal, San Carlos Bay supports a wide variety of recreational and fishery activities with significant economic value. The natural resources of this area are also negatively affected by large freshwater releases and are threatened by long-term shifts in water quantity and quality (Chamberlain and Doering 1998b, Doering et al. 2002, Volety et al. 2003). Recent environmental investigations in the CE have resulted in an estimate of the optimum quantity of water needed by the CE to protect key biota. These species, or Valued

Ecosystem Components (VECs), help sustain the ecological structure and function of the estuary by providing food, living space, and foraging sites for other naturally occurring estuarine species. Oysters and submerged aquatic vegetation (SAV) represent VECs in the CE. Limits on water quantity and related water quality, such as salinity, will protect these species and should lead to a healthy and diverse estuarine ecosystem.

Research results (Chamberlain et al. 1995, Doering et al. 1999 and 2001, Doering and Chamberlain 2000, and Kraemer et al. 1999) were used to determine optimum salinity envelope for SAV in the Caloosahatchee Estuary. A steady-state salinity model (Scarlatos 1988, Bierman 1993) and a statistical model of salinity (SFWMD 2000) were used to estimate mean monthly flows from S-79 that will establish a desirable salinity range in the geographic locations of SAV, without adverse effects on benthic invertebrates, ichthyoplankton, and zooplankton (Chamberlain et al. 1995, 1999, 2001; Chamberlain and Doering 1998b, Doering et al. 2002 SFWMD 2000 and 2002a). An upgraded, fully hydrodynamic model has been developed and is under refinement. An early version of this model has been used to verify and improve estimates of inflow requirements based on model prediction of salinity distribution in the estuary.

Research results reported by Volety et al. (2003) further demonstrated the importance of *Crassostrea virginica* (American oyster = oyster) as a VEC. They found that a greater abundance of decapods and fishes were associated with clusters of live oyster compared to dead-articulated clusters, while the structure provided by both living and dead oysters shells supported a greater abundance than no shells. Species richness and dominance were higher for samples with oyster clusters (dead or live) compared to controls with no oyster shell. This study points out that, "perhaps the real significance of living oysters to habitat value lies not only in creating a three-dimensional structure, but also in maintaining this structure of clusters through time." Individual oysters may die, leaving empty compartments for reef residents, but "mass mortality within a cluster results in the disarticulation of the oysters shell."

Volety et al. (2003) in their field and lab research evaluated the survival of oyster adults and juveniles, as well as oyster health, the prevalence and intensity of disease, and oyster recruitment success. The results were compared to environmental factors, including salinity and freshwater flow from S-79. Oysters grow best at a salinity of 14 to 28 parts per thousand (ppt). Infection by the oyster pathogen, *Perkinsus marinus*, increases during higher salinity and temperature. Field studies during this research determined that the prevalence of infection was high, but disease intensity was low, because temperature and salinity act antagonistically (i.e., high summer temperature occurs during the wet season and lower salinity). Therefore, freshwater releases to diminish *Perkinsus marinus* are generally not advised during warm summer months because of the potential threat to oyster populations from further lowering salinity.

The greatest oyster growth and recruitment occurs during the wet season, but slower growth, poor spat production, and excessive valve closure occurs at salinities below 14 ppt. During their study, salinity conditions were best suited for oyster growth just upstream of Shell Point. However, this upstream area is also the most vulnerable to high mortality when large releases cause salinity to fall below threshold tolerance, sometimes for prolonged periods. The Volety et al (2003) report suggests, "that while adult oysters are tolerant, salinities of 5 ppt or lower will result in > 95% mortality of juvenile oysters." High juvenile mortality can occur when exposed to this salinity for just a week. Experimental results indicate that adults are able to tolerate salinities as low as 5 ppt up to 8 weeks, but can not tolerate salinities lower than 3 ppt, which can occur upstream of Shell Point when S-79

discharges exceed 4,000 cfs. Therefore, high discharges can limit population survival and abundance in this region where they were historically present. As a restoration note, Volety et al. (2003) indicated that because of high spat recruitment at intermediate salinities, along with good growth rates and low disease, it is very feasible to develop oyster reefs upstream of Shell Point by strategically placing oyster clutch in suitable areas, if provided the ability to control current [high] freshwater inflows.

Oysters in southwest Florida spawn continuously, with peak recruitment (spat settlement) occurring during May to November. Recruitment near Shell Point and possibly upstream begins to peak in March, a full 3 months earlier than in San Carlos Bay, thus making these newly settled juveniles vulnerable to large releases from S-79, which have often occurred during this period to regulate Lake Okeechobee water level for flood protection. Large freshwater flows at this time and during the summer also expose oyster larvae to lethal low salinities, or flush the larvae to more downstream locations where there may not be suitable substrate for settlement.

2.2 Lake Worth Lagoon

Historically a freshwater system, Lake Worth Lagoon was converted in the late 1800s and early 1900s into an estuarine system with the construction of two permanent inlets, North Lake Worth Inlet (Palm Beach Inlet) and South Lake Worth Inlet (Boynton Beach Inlet), and the Intracoastal Waterway. As an estuary, the lagoon has developed to serve as spawning, nursery, and feeding grounds for many fish and invertebrate species that sustain and mature into important inshore and offshore recreational and commercial species.

Salinity is a key ecological variable that controls important aspects of community structure and food web organization (Myers and Ewel 1990). Altered estuarine salinity has resulted in large decreases in the spatial extent of submerged aquatic vegetation (SAV) in the Lake Worth Lagoon. The lagoon could experience an increase in diversity of estuarine fauna if the large fluctuations in salinity were controlled. Management of freshwater discharges into LWL will maximize the potential growth of such valued ecosystem components (VECs) as oysters (*Crassostrea viriginica*) and seagrasses (represented by *Halophila decipiens, H. johnsonii*, and *Halodule wrightii*). The species listed were selected because they represent key estuarine components that are currently present in the Lagoon, but are impacted by anthropogenic alteration of lagoon habitats. Oysters are particularly susceptible to high flows which drastically lower salinity levels in LWL during the spawning season. One key component of spawning success is the requirement of salinities of approximately 10 ppt or greater" (Lorio and Malone 1994).

2.3 Loxahatchee River Estuary

The hydrologic conditions of the Loxahatchee Basin have been extensively altered by the construction of canals, channelization of natural waterways, drainage and/or impoundment of wetlands, increases in ground water withdrawals for water supply and stabilization of Jupiter Inlet to the Atlantic Ocean. Construction of the C-18 canal resulted in severance of the Northwest Fork of the Loxahatchee River from its headwaters, the Loxahatchee Slough, while construction of the S-46 flood control structure (connecting the C-18 with the Southwest Fork) resulted in an artificial connection between its headwaters and the downstream estuary. These modifications to the system resulted in insufficient base flows to the Northwest Fork and excessive flows into the Southwest Fork during storm events. Consequently, the Northwest Fork has been degraded by receiving too little freshwater during dry

periods and the estuary has been degraded by receiving too much freshwater during storm events.

Insufficient baseflows to the Northwest Fork of the Loxahatchee River resulted in extensive change to the riparian vegetation between river mile 6 and 10 (SFWMD 2006). Within the span of a decade or two following World War II, the giant cypress trees living along much of the Northwest Fork of the Loxahatchee River died because of saltwater intrusion. As the riparian habitat changed, the native fauna, including otter, alligator and largemouth bass, all retreated upstream within Jonathan Dickinson State Park, especially along the floodplain of Kitching Creek (Dent and Ridler 1997).

Excessive freshwater discharges to the estuary through S-46 have resulted in the degradation of oysters and seagrass habitats (SFWMD 2006). In particular, flood control discharges through S-46 reduce minimum daily salinity and increase salinity variability throughout much of the estuary. Lowered salinity and highly variable salinity conditions are known to stress estuarine organisms, in particular seagrasses (Ridler et al. 2006). Therefore, there is a need to reduce the frequency and duration of peak discharges (excessively large freshwater discharges) through S-46 to the Southwest Fork of the Loxahatchee River.

From 1970 through 1980, a great deal of attention was given to the problem of saltwater intrusion into the river. A summary of the major efforts includes the work in the early 1970s by the U.S. Geological Survey (USGS) under Harry Rodis and later by Ben McPhearson and others. Dewey Worth and the South Florida Water Management District (SFWMD) analyzed the saline environment in the estuary and northwest fork of the river in 1980. The Jupiter Inlet District (JID) commissioned a series of studies over a fifteen-year span beginning in 1975 (Dent and Ridler 1997).

These reports described the process of saline intrusion and defined the conditions present, set goals for holding the encroaching salt water below Kitching Creek and recommended actions needed to achieve the goal. The first and most significant technical recommendation was made by Rodis in 1971 who called for a minimum 50 cubic feet per second (cfs) flow in the vicinity of the State Road 706 bridge and the Lainhart dam (Dent and Ridler 1997). This recommendation resulted in the installation of a culvert in the C-18 canal. This structure, G-92, allowed water from the Loxahatchee Slough and the C-18 canal to be directed to a conveyance canal, C-14, and into the uppermost reach of the northwest fork of the Loxahatchee River. A three way operational accord was developed with the SFWMD installing the structure, the South Indian River Water Control District (SIRCD) allowing the use of the C-14 canal and the Loxahatchee River Environmental Control District (LRECD) providing the personnel to operate the structure. In the mid-1980s, the SFWMD took three important steps to enhance the ability to provide the requested minimum flow. Operating protocols were improved which caused greater amounts of water to be held in the C-18 basin, two dams were rebuilt in the freshwater reach of the northwest fork, and the G-92 structure was replaced with a larger culvert, and provided automatic operational controls (Dent and Ridler 1997).

The early technical research on the Northwest Fork of the Loxahatchee River lead to the federal 'Wild and Scenic River' designation of the Northwest fork of the Loxahatchee in 1985. Along with the recognition came the establishment of the Loxahatchee River Management Coordinating Council (LRMCC) and the formulation of a management plan. The original management plan endorsed the 50 cfs minimum flow requirement at the Lainhart dam and encouraged further investigation to more accurately project future needs (Dent and Ridler 1997).

Three additional initiatives were enacted in the 1990s as measures to retard the further migration of saline waters and begin 'turning the tide' to reclaim a portion of the lost habitat.

1. The JID constructed earthen and rock dams to seal off certain channels through the mangroves that had been created within the past twenty-five years and were acting to short cut the historic meandering flow pattern of the northwest fork and re-establish the longer flow routes for the river. Salinity studies conducted by the LRECD demonstrated that the construction was successful in lowering the concentration of salt water above the closures.

2. The LRECD in 1994, after new salinity and flow relationships were recorded and analyzed, presented the new data, compared it to USGS data generated 10-20 years earlier and suggested that the 50 cfs minimum flow at the Lainhart dam requirement for the river should be modified. The new recommended flow requirements incorporate a seasonal element and set new minimum needs in a range between 70 to 110 cfs.

3. Remnant portions of the historic Loxahatchee slough were purchased in recent years and planning for its beneficial management began (Dent and Ridler 1997).

In 2006 the *Restoration Plan for the Northwest Fork of the Loxahatchee River* was approved by the SFWMD Governing Board and the Secretary of FDEP. The plan calls for a daily variable flow that is based on a seasonal hydrograph to the Northwest Fork. Scientific and modeling analysis resulted in the identification of a Preferred Restoration Flow Scenario. This scenario, LV90 – TV60, will result in variable dry season flow over Lainhart Dam between 50 cfs and 110 cfs, with a mean monthly flow of 69 cfs, while providing an additional 30 cfs of flow from the downstream tributaries. These restorative flows will provide adequate freshwater flows to protect and enhance the riverine floodplain, maintains conditions for the propagation of cypress trees in the tidal floodplain, and promotes a healthy estuarine system in the Northwest Fork of the Loxahatchee River. This scenario includes seasonal variation, including rainfall driven monthly and daily flow variability necessary for restoration.

By implementing the Preferred Restoration Flow Scenario it is expected that saltwater intrusion will be reversed and portions of the tidal floodplain will be restored to a freshwater swamp system where during the dry season the proposed restoration flows will push the salinity wedge from its current location, near RM 9, downstream to a location near RM 7.5. This scenario is also designed to minimize impacts on the estuarine ecosystems. The low salinity zone, located between RM 9.5 and RM 5.5 requires a salinity range of 2 ppt - 8 ppt during the dry season to function as a nursery for many saltwater fishes. Although restorative flows will move the appropriate salinity range downstream, the low salinity will remain within an area that will provide suitable habitat for juvenile fish development. The optimal salinity range for oysters is from 10 ppt to 20 ppt, which is currently located between RM 6 and RM 4. With increased flows during the dry season through the Northwest Fork these salinity levels will be moved downstream and the upstream oyster beds at RM 6 will be lost. However, the majority of the oysters are located downstream of RM 5 and will not experience harmful drops in salinity levels. The addition of oyster substrate near RM 4 will mitigate the loss of oysters at RM 6. The Preferred Restoration Flow Scenario will have minimal impact on seagrasses in the Central Embayment area.

In addition, the SFWMD has teamed up with other agencies to model the Loxahatchee Slough, to

provide optimal water elevation ranges for protection of this valuable ecosystem. Increased water storage in the Loxahatchee Slough and C-18 Canal should facilitate increased freshwater deliveries to the Northwest Fork. The majority of the supplemental flows are planned to come from the L-8 Reservoir and delivered by a conveyance system that is included in the North Palm Beach County CERP Project, Part 1.

2.4 Saint Lucie Estuary

The St. Lucie Estuary (SLE), located on the southeast coast of Florida, flows into the Indian River Lagoon and the Atlantic Ocean. Historically, this estuary was a fresh water system influenced by ephemeral ocean inlets. When the St Lucie Inlet was permanently established in 1898, the system became an estuary, characterized by abundant mangroves, submerged oyster bars and submerged aquatic vegetation (SAV). Agricultural and urban drainage projects beginning in the 1910s expanded the area that now drains into the estuary to its present size of almost 775 square miles. Major drainage canals constructed in the watershed include the C-23 and C-24 canals. The SLE is connected to Lake Okeechobee by the C-44 canal, which is used for navigation and regulatory releases from Lake Okeechobee. As a result, freshwater flow into the estuary tends to be excessive in the wet season and occasionally insufficient in the dry season. The estuary has also been degraded by thick deposits of mucky silt that cover large portions of the bottom and make it unsuitable for SAV and oysters. These sediments also become re-suspended by wind, current and boat traffic resulting in diminished light penetration through the water column.

There has been a continued decline in the spatial coverage of beds of SAV in the St. Lucie Estuary. Studies have shown that the only areas in the St. Lucie Estuary that currently support SAV are in the lower estuary near Hell Gate Point (Woodward-Clyde 1999). The SAV identified in these recent studies were primarily shoots and not actual beds. Shoal grass (*Halodule wrightii*) was the dominant species throughout most of this area, with Johnson's seagrass (*Halophila johnsonii*) as the secondary species. The only other documented occurrences of SAV during that study was a very small amount of Widgeon grass (*Ruppia maritima*), wild celery or tape grass (*Vallisneria americana*) and common water nymph (*Najas guadalupensis*) in the South Fork of the estuary as well as a small area of Widgeon grass (Ruppia maritima) in the North Fork. *Halodule wrightii* and *H. johnsonii* exist near the mouth of the St. Lucie Estuary, but are sometimes extirpated during periods of high flow. A very small population of *V. americana* reoccurs by seed periodically in the upper estuary during periods of exceptional water quality conditions.

The average maximum depth that "healthy" seagrasses will grow in the St. Lucie Estuary is 1.7 meters (Virnstein and Morris 1996). The St. Lucie Estuary has approximately 922 acres of suitable habitat. This acreage is based on South Florida Water Management District 1999 aerial photography.

In the St. Lucie Estuary, oysters have been identified as VECs. Oysters are natural components of southern estuaries and were documented to be abundant in the system. The American oyster is the dominant species in these oyster reef communities. Oyster bars provide important habitat and food for numerous estuarine species including gastropod mollusks, polychaete worms, decapods crustaceans, various boring sponges, fish and birds. Over 300 macrofauna species can live in oyster beds and over 40 species may live in a single oyster bed (Wells 1961). Oysters are also an important commercial and recreational resource. Salinity is important in determining the distribution of coastal and estuarine bivalves. Adult oysters normally occur at salinities between 10 and 30 parts per thousand (ppt) but

they tolerate a salinity range of 2 to 40 ppt (Gunter and Geyer 1955). Short pulses of freshwater inflow can greatly benefit oyster populations by killing predators, such as the southern oyster drill and the whelk, that cannot tolerate low salinity water (Owen 1953), while excessive freshwater inflows may kill entire populations of oysters (Gunter 1953, Schlesselman 1955, MacKenzie 1977).

The American oyster, *Crassostrea virginica*, are highly valued as food, but their ecological significance remains under-appreciated and under-studied (Coen et al. 1999a). Individual oysters filter 4-34 liters of water per hour, removing phytoplankton, particulate organic carbon, sediments, pollutants, and microorganisms from the water column. This process results in greater light penetration immediately downstream, thus promoting the growth of submerged aquatic vegetation. Although oysters assimilate the bulk of the organic matter that they filter, the remainder is deposited on the bottom where it provides food for benthic organisms. Furthermore, the oyster's ability to form large biogenic reefs (Coen et al. 1999b) qualifies it as a keystone species. Oysters and the complex, three-dimensional, reef structure they form, attract numerous species of invertebrates and fishes.

Historic oyster acreage was calculated from a 1940-1960 GIS coverage developed by Woodward-Clyde under contract to the South Florida Water Management District (Woodward-Clyde Inc. 1998a). The estimate of approximately 1,400 acres represents an interpretation of anecdotal information and general oyster location accounts found through a literature review (Woodward-Clyde Inc. 1998b), and is based on the only known source of information. In 1997, 207 acres of oyster habitat were identified in the St. Lucie Estuary (Woodward-Clyde 1998a), which equates with an 85% loss in oyster cover. Shell mining, dredge and fill activities, altered freshwater inflow, changes in hydrodynamics, and increased “mucky” sediments from canal discharges (which greatly decreased availability of suitable hard bottom substrate needed for recruitment) – contributed to these losses. Large freshwater discharges from Lake Okeechobee and the St. Lucie Estuary watershed occurred in Spring 1998 and Summer 1999, killing more than 90% of the remaining oysters. These flows were above 2000 cfs and produced salinities below 1 part per thousand (ppt) DBHydro dataset (2006). Subsequent to this event, some recruitment has been documented by the comprehensive study part of RECOVER’s Monitoring and Assessment Plan which began in January 2005. This study will provide baseline monitoring to provide an accurate accounting of changes in coverage and health of oysters in the St. Lucie Estuary.

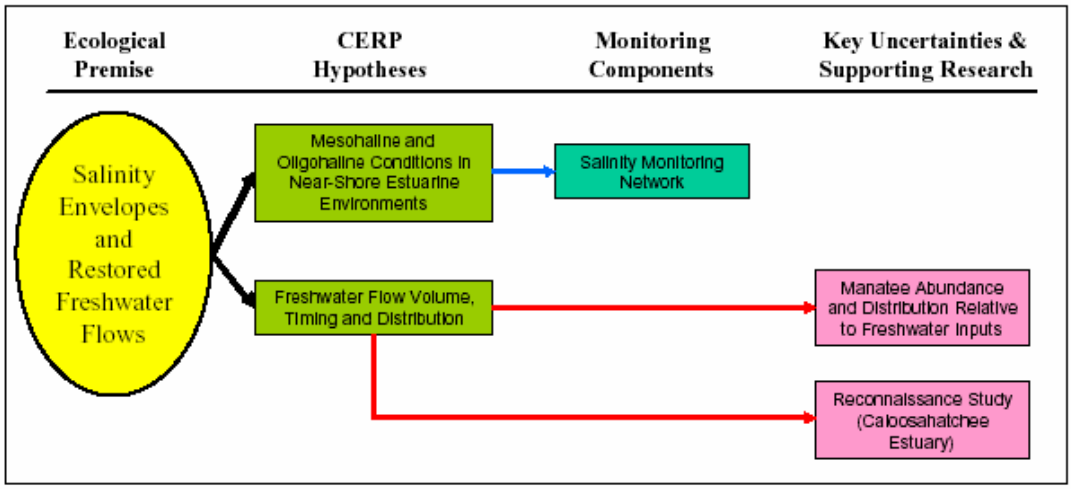
3.0 Scientific Basis

3.1 Relationship to Conceptual Ecological Models

The indicator for this performance measure is a stressor in the following conceptual ecological models:

<u>Regional Models (RECOVER 2004b), see following diagram</u>

St. Lucie Estuary and Indian River Lagoon
Loxahatchee
Lake Worth Lagoon
Caloosahatchee Estuary



3.2 Relationship to Adaptive Assessment Hypothesis Clusters

Ecological Premise: Prior to water management, natural patterns of freshwater inflow to the Caloosahatchee Estuary, sustained an ecologically appropriate range of salinity conditions in the river and estuary with fewer high and low salinity extremes.

CERP Hypothesis: The construction and operation of water storage and treatment facilities in the C-43 basin as well as water storage projects around and in the headwaters of Lake Okeechobee will help regulate flows which will in-turn provide a salinity envelope that avoids ecologically damaging high and low salinity extremes.

3.2 Lake Worth Lagoon

Ecological Premise: Prior to water management, and post inlet construction natural patterns of freshwater inflow to Lake Worth Lagoon sustained an ecologically appropriate range of salinity conditions in the lagoon with fewer high and low salinity extremes.

CERP Hypothesis: The construction and operation of water storage, water diversion and treatment facilities in the Northern Estuaries regions will provide salinity envelopes that avoid ecologically damaging high and low salinity extremes.

3.3 Loxahatchee River Estuary

Ecological Premise: Prior to water management (post inlet maintenance), natural patterns of freshwater inflow into the Loxahatchee River and Estuary, achieved an ecologically appropriate range of freshwater, oligohaline and estuarine salinity conditions with fewer high and low salinity extremes.

CERP Hypothesis: The construction and operation of water storage and treatment facilities in the Loxahatchee River watershed will provide appropriate freshwater inflows through the Northwest and Southwest Forks, Kitching, Cypress and other freshwater tributaries as well as elevated levels of groundwater flow through the rehydration of watershed wetland systems. Increased base flows and decreased frequency and duration of flood control discharges through S-46 will provide for more stable and appropriate salinity envelopes that avoid ecologically damaging high and low salinity extremes.

3.4 Saint Lucie Estuary

Ecological Premise: Prior to water management, (post inlet construction) natural patterns of freshwater inflow to the St. Lucie Estuary and Indian River Lagoon sustained an ecologically appropriate range of salinity conditions in the estuary with fewer high and low salinity extremes.

CERP Hypothesis: The construction and operation of water storage and treatment facilities in the Northern Estuaries regions will improve the quantity, timing and distribution of flows into the estuary which will in turn provide a salinity envelope that avoid ecologically damaging high and low salinity extremes.

4.0 Evaluation Application

4.1 Evaluation Protocol

Caloosahatchee Estuary

The South Florida Water Management Model (SFWMM) version 5.0 and a 36-year rainfall period of record will be used. The output is a bar chart displaying the number of months mean monthly flows are greater than the target flows.

Hydrologic Performance Targets (HT) to achieve the ecological targets:

HT 1a. For each alternative, compare the number of times that the mean monthly inflows from the Caloosahatchee watershed fall below a low-flow limit of 450 cfs at S-79 during October to July. The alternative with the fewest number of times that flows fall below 450 cfs will be considered better for protecting aquatic vegetation, oysters, and fish communities.

HT 1b. For each alternative, compare the frequency that the mean monthly low-flow limit of 450 cfs through S-79 was not met for just one month (not followed by another month below 450 cfs), as well as the frequency for 2, 3, 4…etc. consecutive months. The water management alternative with the fewest number of consecutive months with average flows below 450 cfs will be considered better for protecting estuarine aquatic resources.

HT 1c. For each alternative, compare the frequency that the mean monthly low-flow limit of 450 cfs through S-79 from the watershed was not met for just one year (not followed by another year with months below 450 cfs), as well as the frequency for 2, 3, 4…etc. consecutive years. The water management alternative with the fewest number years and consecutive years with average monthly flow occurrences below 450 cfs will be considered better for protecting estuarine aquatic resources.

HT 2a. For each management alternative, compare the number of times that mean monthly inflow from the watershed exceeds 2,800 cfs at S-79. The alternative with the fewest number of times that this criterion is exceeded at any time of year will be considered better for protecting both SAV and juvenile oysters at Shell Point and upstream. Additionally, a better ranking will be given to the alternative with the least number of discharges above these limits during March through October, in order to limit critically low salinity conditions from occurring both upstream and downstream of Shell Point, which threatens estuarine resources, including SAV and juvenile oyster recruitment and survival.

HT 2b. For each alternative, compare the frequency that the mean monthly inflow from the watershed, measured at S-79, exceeds 2,800 cfs for just one month (not followed by another month above this limit), as well as the frequency for 2, 3, 4… etc. consecutive months. The alternative with the fewest consecutive months that violate this criterion throughout the year will be considered better for protecting estuarine resources, including juvenile oyster recruitment and survival. Additionally, a better ranking will be given to the alternative with the least number of discharges above these limits during March through October, in order to limit critically low salinity conditions from occurring both upstream and downstream of Shell Point, which threatens estuarine resources, including SAV and juvenile oyster recruitment and survival.

HT 3a. For each alternative, compare the number of times that mean monthly and mean weekly inflows from the watershed exceed 4,500 cfs at S-79 (weekly is important for protecting oyster recruitment and survival). The alternative with the least number of times flows exceed these limits will be considered better for protecting the estuarine resources, including those downstream in the San Carlos Bay region. Additionally, a better ranking will be given to the alternative with the least number of discharges above these limits during March through October, in order to limit critically low salinity conditions from occurring both upstream and downstream of Shell Point, which threatens estuarine resources, including SAV and juvenile oyster recruitment and survival.

HT 3b. For each alternative, compare the frequency that mean monthly and mean weekly inflows from the watershed, measured at S-79, exceeds 4,500 cfs for just one month and 1 week (not followed by another month or week above this limit), as well as the frequency for 2, 3, 4…etc. consecutive months and weeks. The alternative with the fewest number of consecutive months and weeks that violate this criterion will be considered better for protecting aquatic resources, including juvenile oysters. Additionally, a better ranking will be given to the alternative with the least number of consecutive discharge periods above these limits during March through October, in order to limit critically low salinity conditions from occurring both upstream and downstream of Shell Point, which threatens estuarine resources, including SAV and juvenile oyster recruitment and survival.

HT 4. For each alternative, compare the number of days that regulatory discharges from Lake Okeechobee are made to the Caloosahatchee River. The alternative with the least daily discharge volume, the fewest number of total days of discharge, and the fewest number of consecutive days will be preferred. Special consideration will be provided for pulse releases that may benefit the estuary.

HT5. For each alternative, compare the frequency distribution of monthly average freshwater inflows through S-79 for the entire period of record being evaluated. The alternative that maximizes, up to 75% of the flows from S-79 in the 450-800 cfs range and almost all the remaining inflow in the 800 to 2800 cfs range will be considered the most desirable for protecting and restoring estuarine resources, while further promoting biotic diversity.

Lake Worth Lagoon

The South Florida Water Management Model (SFWMM) is used to predict flows at selected structures including the S155. The graphic output will depict the percentage of the period of record (POR) that the salinity criteria were not met for the Lake Worth Lagoon. The graphic output will include the percent of days, based upon the modeled POR, that:

1. The 2-day moving average is 1,000 cfs or greater and

2. The 7-day moving average is 500 cfs or greater.

3. The target is zero percent for events 1,000 cfs or greater, and events above 500 cfs.

Loxahatchee River Estuary

The Lower East Coast Sub-Regional (LECsR) MODFLOW Model will be used to simulate long-term freshwater inflows from tributaries into the Loxahatchee River and Estuary for various alternatives. This information will provide the input needed for the Hydrodynamic/Salinity Model (RMA) and Long-Term Salinity Management Model (LSMM). The long-term salinity management model (LSMM) was developed from RMA results to predict tidally averaged salinity in response to various alternatives. These salinity models will be used to help assess the effect of various flows from S-46 and the other tributaries on salinity conditions throughout the system. Evaluation of alternative model runs will follow the same approach explained in the Chapter 7 of the Restoration Plan (SFWMD 2006). For the estuary, results of alternative model runs will be compared by determining the total number of days within the period of record that did not meet target salinity thresholds for various portions of the system (e.g., river mile 7.5, river mile 1.74). Models runs with more days of non-compliance will be considered less desirable and potentially detrimental to the system.

Saint Lucie Estuary

The SFWMM version 5.0 will be used to predict flows from the C-44 canal, including Lake Okeechobee regulatory releases. The watershed hydrology model (WASH) will be used to predict flows from the C-23, C-24 and C-25 canals.

4.2 Normalized Performance Output

1.2.2 Caloosahatchee Estuary

An index comparing the alternatives on the scale of 0-1 will be developed.

1.2.2 Lake Worth Lagoon

Not available at current time.

1.2.2 Loxahatchee River Estuary

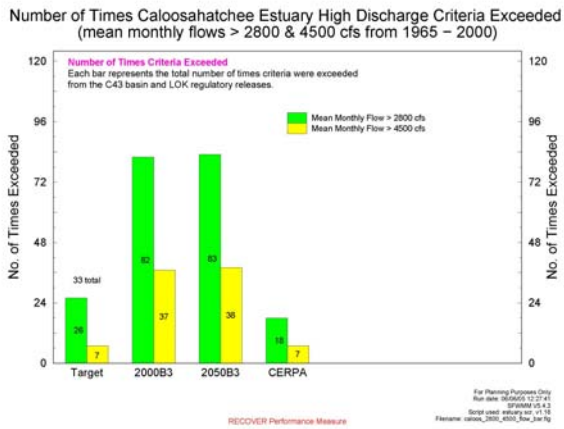
Not available at current time.

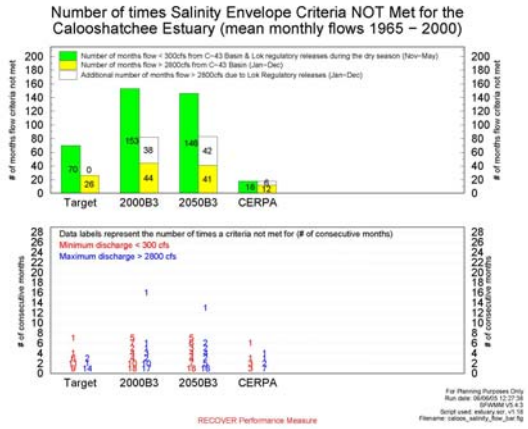
1.2.2 Saint Lucie Estuary

Parameter	2000B3 Conditions	CERP A Outer Bounds	Full Restoration
Number of months flow is less than 350 CFS	130	63	31
Number 14 day moving average LO Regulatory Releases	57	24	0
Number of 14 day moving average > 2000-CFS from local basins	72	36	21
Normalized score	0	.5	1.0

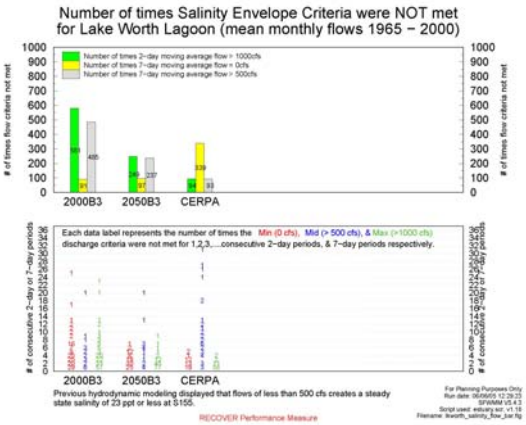
4.3 Model Output

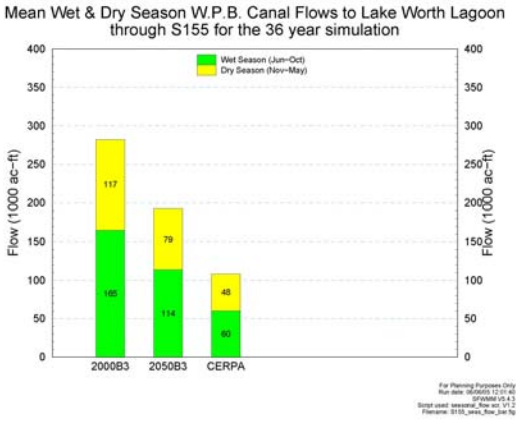
1.2.2 Caloosahatchee Estuary





1.2.2 Lake Worth Lagoon

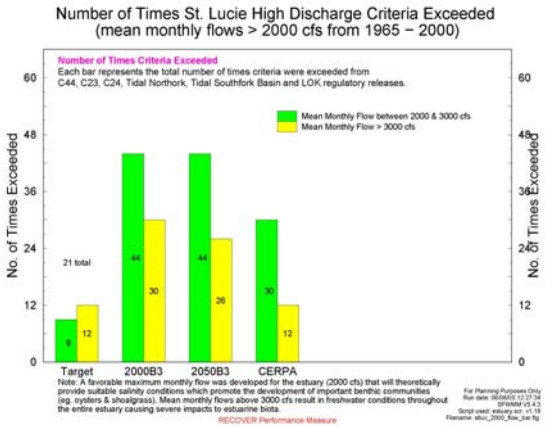


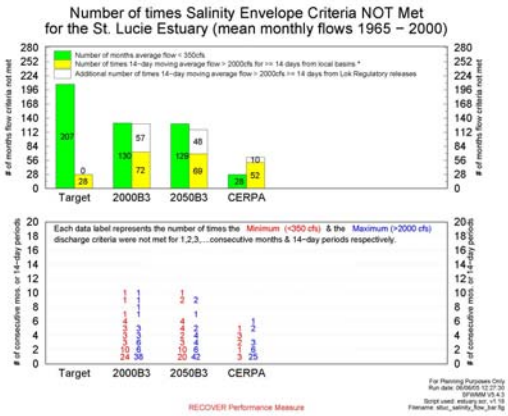


1.2.2 Loxahatchee River Estuary

No example currently available

1.2.2 Saint Lucie Estuary





4.4 Uncertainty

Uncertainty associated with salinity-based estuarine performance measures, targets and evaluation protocols is low. Future modeling within the context of refined end-state targets will better define salinity envelope targets in terms of duration, seasonality, and appropriate salinity levels

5.0 Monitoring and Assessment Approach

5.1 MAP Module and Section

See *CERP Monitoring and Assessment Plan: Part 1 Monitoring and Supporting Research* - Northern Estuaries Module section 3.3.3.1 and South Florida Hydrology Monitoring Network Module section 3.5.3.3 (RECOVER 2004a).

5.2 Assessment Approach

NA

6.0 Future Tool Development Needed to Support Performance Measure

6.1 Evaluation Tools Needed

1.2.2 7.1.1 Caloosahatchee Estuary

SFWMM, CH3D, as well as local and region models like the Mike-She model to quantify the flows reaching S-79 and the downstream tributaries.

1.2.2 7.1.2 Lake Worth Lagoon

None identified at this time.

1.2.2 7.1.3 Loxahatchee River Estuary

None identified at this time.

1.2.2 7.1.4 Saint Lucie Estuary

SFWMM and HSPF models were used, future models would include WASH and RMA 2 and 4.

6.2 Assessment Tools Needed

1.2.2 Caloosahatchee Estuary

Assessment tools include the graphical displays of data, as well as, the results of the Habitat Suitability Index (HSI) models that will determine habitat unit changes for the base conditions and the final selected alternative. HSI model development is being planned for SAV (tape grass and seagrasses), oysters, blue crabs, sea trout, and an assortment of commercially and ecologically important zooplankton groups.

Additional Information Needs and Recommended Assessment Studies:

1. Define and assess appropriate attributes (specific species and/or community values) to ascertain if this project's ecological goals are attained and there is a discernable positive effect on the estuary, specifically including SAV, oyster, and fish as follows:
    a. Routinely (at seasonally important intervals) monitor SAV coverage, density, and canopy height to at least 1.5-2.0 m depth at key species locations.
    b. Routinely monitor (at seasonally important intervals) oyster survival and recruitment at key locations.
    c. Routinely monitor (seasonally) water quality, including temperature, D.O., salinity, nutrients, chlorophyll, suspended solids, blue light at depth, and water clarity along the longitudinal axis of the estuary (S-79 – Sanibel Causeway and into lower Pine Island Sound and Matlacha Pass).
    d. Monitor routinely (at appropriate seasonal intervals) species and biotic groups of concern as separately defined in performance measure documents and the CE conceptual model. At a minimum, insure the Monitoring Assessment Plan (MAP) effort within RECOVER is being fulfilled.
2. Scientifically assess and publicly agree what constitutes desirable natural variability (predevelopment conditions) related to salinity and causal freshwater inflow from S-79 and the tidal basin.
3. Install and monitor flow gages in downstream tidal tributaries to begin assembling a long term data set to: verify model predictions of flows; determine actual amount and timing of tidal tributary flows related to MFL requirements for achieving the salinity criteria; and to help assess flow effects on biota being monitored for CERP (RECOVER).
4. Monitor S-79 discharge adherence to the selected alternative flow distribution.
5. Continue to maintain and monitor existing seven salinity recorders and other permanent sensors in the Caloosahatchee Estuary. Install new sensors to monitor salinity and other water quality parameters of concern at key locations for VEC. Suggest additional sensors be located in western San Carlos Bay, lower Pine Island Sound, and Matlacha Pass.
6. Assess limits of SAV morphology for providing suitable habitat as a VEC and its relationship to flow, salinity, and water quality conditions.

Finish development of the tape grass model; Caloosahatchee Hydrodynamic/Salinity Model; a water quality model component; habitat suitability models; and a seagrass model for the lower estuary.

1.2.2 Lake Worth Lagoon

None as yet identified.

1.2.2 Loxahatchee River Estuary

None as yet identified.

1.2.2 Saint Lucie Estuary

Salinity monitoring needs to continue, RMA 2 and 4 need to be run and the oyster model described in NE-5 needs to be developed and used to fine-tune the salinity envelope.

7.0 Notes

This Performance Measure supersedes and addresses NE-1 St. Lucie Estuary Salinity Envelope (Last Date Revised: September 9, 2005), NE-2 Lake Worth Lagoon Salinity Envelope (Last Date Revised: September 9, 2005), NE-3 Caloosahatchee Estuary Salinity Envelope (Last Date Revised: September 9, 2005), and Loxahatchee River Estuary Salinity Envelope (Last Date Revised: September 21, 2005).

8.0 Working Group Members

Caloosahatchee Estuary	Robert Chamberlain (SFWMD), Peter Doering (SFWMD), Tomma Barnes (SFWMD), Patti Sime (SFWMD), Gretchen Ehlinger (EPJV)
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Loxahatchee River Estuary	Eric Hughes (USEPA), Rick Dent (LRD), Albrey Arrington (LRD), Pat Walker (SFWMD), Gretchen Ehlinger (EPJV)
Saint Lucie Estuary	Ken Konyha (SFWMD), Patti Sime (SFWMD), Dan Haunert (SFWMD), Gretchen Ehlinger (EPJV)

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