Lake Okeechobee Performance Measure
Lake Stage

Last Date Revised: November 08, 2019

Acceptance Status:

1.0 Desired Restoration Condition

In most years, lake stage will vary within an "envelope" based on the annual hydrograph described below. Stages will mimic historic conditions by receding from wet season highs (approx. Nov-Jan) to dry season lows (approx. May-Jun), with recession rates generally increasing along with evapotranspiration rates through the dry season. These rates would typically vary from 0 – 0.07 ft/wk (0.02 m/wk) early in the season up to 0.16 ft/wk (0.05 m/wk) later in the dry season. Stages will ascend at moderate rates (<0.25 ft/wk) (0.08 m/wk) back to seasonal highs. The ecological envelope generally encompasses stages from 11.5 – 15.5 feet (3.51 – 4.72 m) (National Geodetic Vertical Datum 29 throughout) and allows for seasonal fluctuation around a 12 – 15 feet (3.66 – 4.57 m) stage target. The ecological envelope varies between Normal or Recovery conditions (see **Figures 5A** and **5B**), depending on whether impacts from high-water or tropical storm events necessitate lower stages for vegetation recovery. When lake stages do occur outside of the stage envelope, they would not go above or below extreme stage thresholds, defined as 17 ft (5.18 m) and 10 ft (3.05 m), respectively. In the desired restoration condition, there will not be frequent (semi-annual) or prolonged (several months) departures of lake stage outside of the defined envelopes and the occurrence of extreme high or low lake stage events will be rare (once per decade or less).

1.1 Predictive Metric and Target

The target for the lake is to remain within the desired envelope and avoid extreme stages, scoring zero points. Point penalties are prescribed as stages deviate from the desired envelope, as well as when extreme highs (>17 ft [5.18 m]) or lows (<10 ft [3.05 m]) are exceeded. Extreme stage exceedances are calculated separately from lake envelope scores as additional metrics.

1.2 Assessment Parameter and Target Daily lake stages will be assessed relative to the seasonally fluctuating lake stage envelope, which is described below. The target is the 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 12.0 ft (3.66 m) as a June-July low and 15.0 ft (4.57 m) as a November-January high, on the plant and animal communities of Lake Okeechobee. For example;

- Falling water levels from late winter to spring concentrates prey resources in the littoral zone for improved wading bird foraging and nesting (Smith et al. 1995)
- Water levels near 12.0 ft benefit submerged plants and bulrush (*Schoenoplectus californicus*) at the outer edges of the marsh by reducing light attenuation in the summer months and promoting growth of underground biomass for survival during turbid, high water events (Havens et al. 2004)

US Army Corps of Engineers®

- A natural rocky reef in the southern portion of the lake isolates turbid, pelagic water from large areas of nearshore zone at a lake stage of around 14 ft (4.27 m). This helps improve water clarity, promotes submerged plant coverage, and reduces phosphorus levels (Havens and Walker 2002)
- Seasonal variation within the envelope results in annual flooding and drying of the majority of the marsh, which favors development of a diverse emergent plant community (Richardson et al. 1995, Keddy and Frazer 2000) and reduces muck accumulation. There is also a wide body of published research on the adverse impacts of extreme high (>17 ft) and low (<10 ft) water levels on the littoral and nearshore areas of Lake Okeechobee (Havens 2002). Extreme high stage allows wind-driven waves to directly impact the littoral emergent plant and nearshore 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) to be transported to the shoreline regions; reducing water clarity and light penetration, increasing nutrients, and in turn reducing the depth at which submerged aquatic vegetation (SAV) growth can occur (James and Havens 2005). High stages also allow deposition of unconsolidated mud into nearshore regions, covering sand and peat sediments and reducing their suitability for SAV. High stages transport nutrient-rich water from the mid-lake region into the littoral marsh where changes in periphyton biomass and taxonomic structure can occur, as well as expansion of invasive vegetation like cattail (*Typha* spp.). 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, undesirable shifts in marsh vegetation composition, and shifts in the macroinvertebrate community to those representative of disturbed ecosystems.

Extreme low stages (<10 ft) also have multiple negative impacts to lake health. Most of the littoral marsh is dried when lake stages are <12 ft (3.66 m), and at <10 ft nearly the entire shoreline fringing bulrush zone and much of the lake area that would otherwise support submerged plants also dries out. These low stages encourage invasion or expansion of exotic or nuisance species at both high (e.g. torpedograss [*Panicum repens*], Brazilian pepper [*Schinus terebinthifolia*], punk tree [*Melaleuca quinquenervia*]) and low elevations (e.g. cattail, common reed [*Phragmites australis*], tropical American water grass [*Luziola subintegra*]); and displace desirable habitats like spikerush (*Eleocharis* spp), sawgrass (*Cladium jamicense*), and water lilies (*Nymphaea* spp.) (Sharfstein and Zhang 2017). Prolonged extreme low stages, like those experienced in 2007 – 2008, convert areas of former open-water or SAV to dense stands of cattail, resulting in long-term losses (>10 yrs) of fish habitat, increased muck accumulation, and large-scale uses of herbicide and fire management for restoration (Zhang and Welch 2018).

Low lake stages also result in direct losses of habitat that can severely limit or even eliminate entire breeding seasons for many species of fish and wildlife. These impacts are severe and long-term for short lived species like the native Florida apple snail (Darby et al. 2004), which was nearly extirpated from the lake after record-low lake levels in 2007 – 2008. Exposing peat substrates in southern portions of the lake can also degrade habitat for the endangered Okeechobee gourd and increase risk of peat fires, leading to a permanent loss of marsh elevation.

Ecological recovery from extreme lake stages can be slow, requiring multiple years of appropriate stage regime to recover. Recovery from low lake stages can be expedited primarily through habitat management activities, restoring marshes with the selective use of herbicides and prescribed fires. Large-scale management of cattail in Moonshine Bay, for example, led to dramatic increases in

wading bird and snail kite activity in subsequent years (Sharfstein and Zhang 2017, Fletcher et al. 2017), after low lake stages promoted cattail expansion into former water lily-dominated habitats. Similarly, burning and spraying torpedograss at high marsh elevations has restored thousands of acres of spikerush and beakrush (*Rhynchospora* spp.) habitat over the past decade (Sharfstein et al. 2015).

Recovery from extreme high lake stage events can be expedited by low lake stages, as documented for submerged plants by Havens et al. (2004) and for sport fish by Havens et al. (2005). Lower lake stages, while posing their own risks, promote recovery of habitat (and subsequently, fish and wildlife) in several ways;

- Increased light penetration in nearshore zones, prompting germination and expansions of submerged plant habitats and increased densities of desirable native plants like bulrush and deep-water grasses (*Paspalidium geminatum*, *Panicum hemitomon*).
- Higher stem densities and associated periphyton further improve water clarity and reduce phytoplankton, creating positive feedbacks for recovery of vegetation at even lower elevations.
- Natural shoreline bathymetry isolates nearshore zones from turbid water in the central mud regions of the lake, further improving light penetration (Maceina 1993, James and Havens 2005, Havens 1997).

Light penetration improves non-linearly as lake stages decline due to the combination of reduced depth, shoreline bathymetry, reduced turbidity, reduced phytoplankton growth, and positive feedbacks to water clarity as SAV coverage expands. Therefore, impacts from high-water events are reduced both in duration and extent when followed by low lake stages and expedited recovery.

Musk grass (*Chara* spp.) is an excellent indicator of growing conditions for SAV along nearshore regions and is often the first to benefit from higher light penetration associated with lower lake stages (Havens et al. 2001). **Figure 1** shows the estimated coverage of macroalgae (*Chara* spp.) from (calendar year) 2001 – 2018, which is highly correlated with summer lake stage (**Figures 2** and **3).** Summer, particularly the months of June and July, tends to have less wind (lower turbidity), lower lake stage, and a long photoperiod. Annual coverage of *Chara* (2001-2018) appears to be best explained by minimum summer lake stages, rather than maximum winter lake stage. Using a recursive partition tree (JMP 14), the 30-day minimum lake stage during June and July (lowest elevation exposed for at least 30 days) was a better predictor of *Chara* coverage than absolute minimum stage, or the 60 and 90 day minimum stages. In fact, a single stage threshold of 13 ft (30d Jun/Jul min) explained 71% of the variation in *Chara* coverage.

Similarly, a simple regression of *Chara* and the Jun/Jul 30d min shows a strong negative correlation (R2 = 0.76) **(Figure 2),** especially when excluding years where coverage was affected by high turbidity following hurricanes (2005, 2006, 2018). **Figure 3** shows daily lake stages for years with the highest and lowest *Chara* coverages in Figures 1 and 2. These analyses demonstrate how poor growing conditions are for SAV communities when summer lake stages are high (30 day mins >13 feet), and how important low lake stages are for their recovery (see also Havens et al. 2004). For these reasons, we recommend lower target stages for the envelope following years with high water, particularly during the summer growing season. 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), and Havens et al. (1999, 2001).

The resultant ecological envelope encompasses several important features, which are described below. While the envelope appears very specific in terms of stage requirements throughout the year, the general shape reflects a broad literature review and the best professional judgement of panel members using monthly time-steps. Variations in the width of the envelope generally encompass the degree of desired flexibility or interannual variability, while variations in slope are related to desired recession/ascension rates or a function of linear extrapolations between average monthly stage targets. Additionally, non-linear penalty calculations around the envelope further define the importance of various stages throughout the year. Overall, these envelopes represent the importance of:

- High lake stages (14.5 – 15.5 ft [4.42 – 4.72 m]) at the end of the wet season or into winter (November – January) provide inundation of high elevation marshes, maximizing wetland extent and aquatic habitat prior to the dry season and breeding season for many species of fish and wildlife.
- Moderate stage recessions (<0.2 ft/wk) throughout the majority of spring to avoid stranding breeding fish and wildlife, reaching target lows at the end of the dry season.
- A wider envelope in the March – June time frame reflects importance of inter-annual variability, maximizing habitat inundation with higher stages in some years and improving light penetration in lower elevation marshes in others.
- Seasonal lows (11.5 – 12.5 ft [3.51 – 3.81 m]) at the peak of the growing season and when turbidity is minimized (low wind activity) provides critical growth and root storage for SAV and low elevation marsh communities, as well as oxidation of organic soils and seed germination at high elevations.
- Moderate ascension rates (<0.25 ft/wk) throughout the majority of the wet season reduce flooding of alligator nests, snail kite nests, and apple snail eggs, while allowing SAV growth to keep up with reducing light penetration.
- Greater flexibility in the September – November season reflects the variability in wet season rainfall and the importance of inter-annual variability.
- Following impacts from high lake stages, lower stage targets (as defined by the Recovery Envelope) expedite recovery of littoral habitat and fish and wildlife communities.

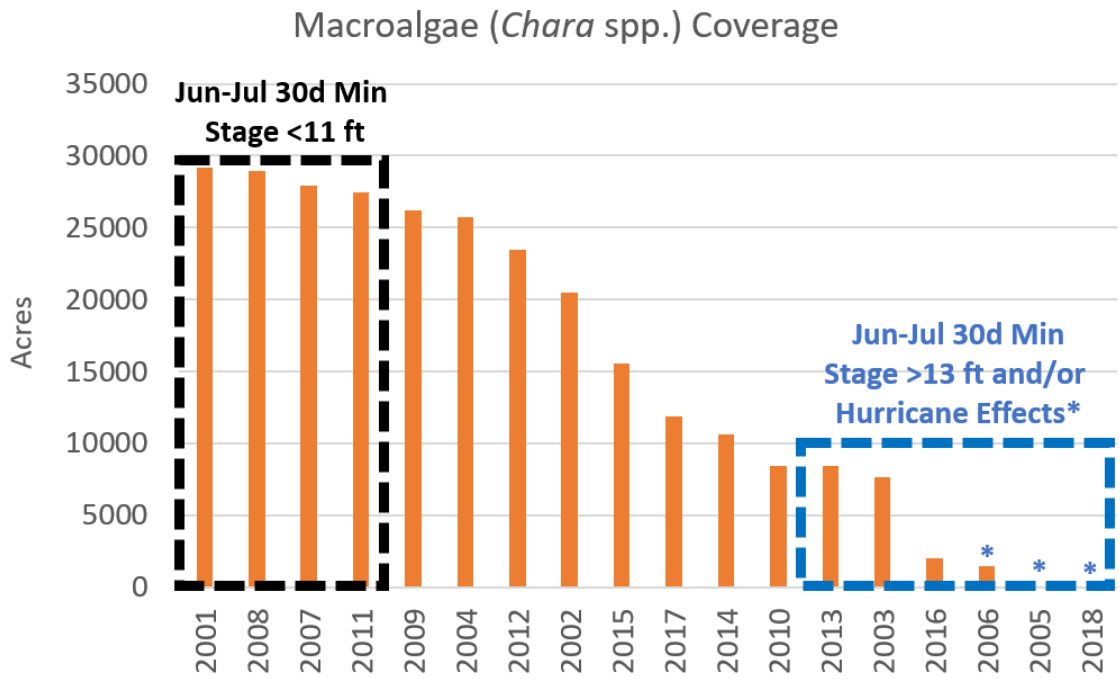

Figure 1. Estimated maximum annual coverage (2001-2018) of *Chara* in descending order. Black dashed box represents low stage years in Figures 2 and 3 and blue dashed box represents high stage years in Figures 2 and 3. Note that 2006 and 2018 did not have high summer stages but had extremely turbid water due to hurricanes the year prior.

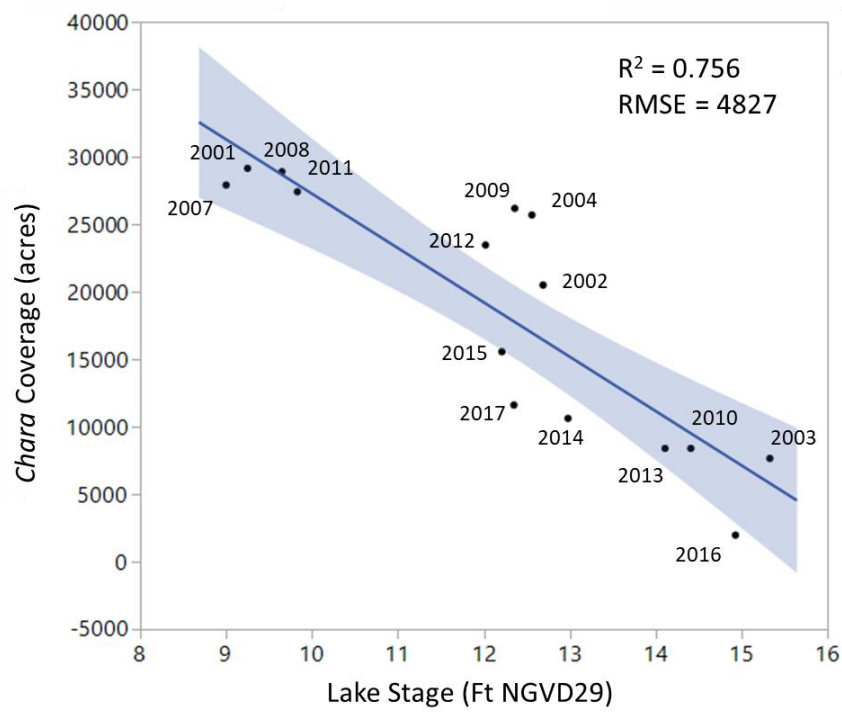

Figure 2. Linear regression of estimated *Chara* coverage relative to the 30-day minimum stage from June through July. Years 2005, 2006 and 2018 were excluded due to hurricane effects on turbidity.

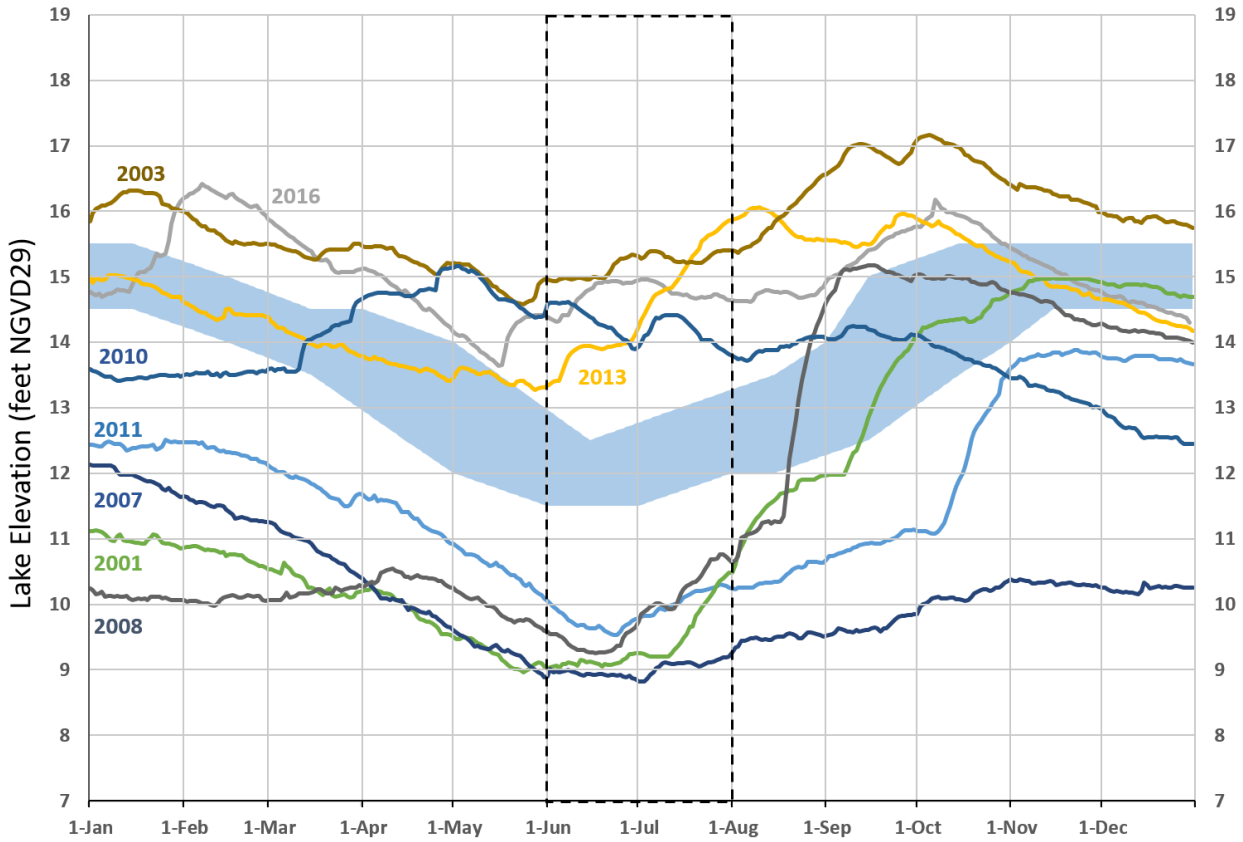

Figure 3. Years with high and low lake stages in the summer that correspond to extremes in *Chara* coverage estimates in Figure 1. The dashed box highlights the June-July period analyzed in Figure 2 while the blue shaded area represents the proposed Ecological Envelope under normal conditions.

3.0 Scientific Basis

3.1 Relationship to Conceptual Ecological Models

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

<u>Regional Models</u>

Lake Okeechobee

<u>Ecological Model for Hypothesis Clusters</u>

Ecological Communities and Effects of Water Stages Conceptual Ecological Model

3.2 Relationship to Adaptive Assessment Hypothesis Clusters

***Ecological Premise*:** Sustained high lake levels and a reduction of spring recession conditions have resulted in the loss and degradation of historical (early 1970s) floral and faunal communities in Lake Okeechobee.

***CERP Hypotheses*:** Providing a reduction in the frequency of extreme high water levels (stage >17 ft) and extreme low water levels (stage <10 ft) and an increase in the frequency of spring recessions (yearly stage decline from near 15.0 ft in January to near 12.0 ft in June, with no reversal >0.5 feet), *and* providing recovery years after high-water events of stages between 14.5 ft (4.42 m) in the winter to near 11.5 ft in summer, will result in the following changes (see Havens 2002):

- Increase in spatial extent of submerged plants, in particular eel/tapegrass (*Vallisneria americana*), peppergrass/pondweed (*Potamogeton* spp.), and shrimp/musk grass (*Chara* spp.), particularly in the south and southwest portions of the lake.

- Increase in spatial extent and density of bulrush along the outer littoral zone; increased spatial extent of spikerush, beakrush, willow, and other native plants in the littoral zone; long-term maintenance of sawgrass communities in mid-marsh elevations; and a reduction in the rate of expansion of exotic and nuisance plants.

- 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.

- 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.

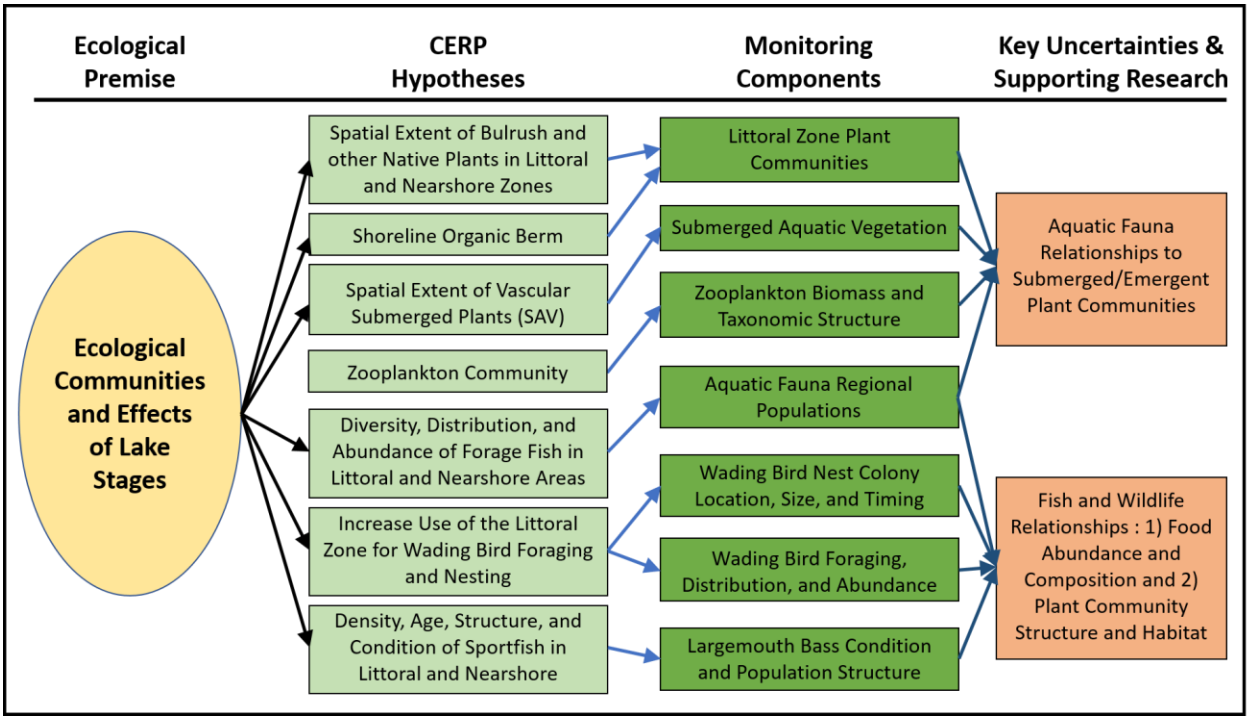

Figure 4. Conceptual framework showing relationships between ecological communities on the lake and water levels, or lake stage.

4.0 Evaluation Application

4.1 Evaluation Protocol

Evaluation is based on the 52-year (January 1, 1965 through December 31, 2016) hydrograph of Lake stages that is simulated by the RSM-BN model. During each day of the model run, the absolute value of the deviation (in hundredths of a foot) of lake stage from the prescribed envelope is determined and a penalty factor is applied that varies by season and distance from envelope. There are two target envelopes, one for normal years and one for recovery years following high-water events. The thresholds for switching between envelopes are:

- Shift from Normal to Recovery envelope (starting Jan 1) when
  - Stages are >17 ft (5.18 m) at any time of the year (e.g. 2003, 2004, 2005, 2017)
  - The 30-day minimum lake stage (elevations exposed for at least 30d) in the June 1 – July 31 window is >13 ft (3.96 m), which represents the years (excluding hurricanes) with the lowest coverage of *Chara* on record (2003, 2010, 2013, 2016)

- Shift from Recovery to Normal envelope (starting Jan 1) when
  - Lake stages are below 12 ft (3.66 m) for 90 days between Apr 15 and Sep 15 OR
  - Stages are below 11.5 ft (3.51 m) for 60 days between May 1 and Aug 1
  - One of above criteria AND Lake stages do not exceed 16 ft (4.88 m) before Jan 1

Scoring tallies will be done separately for stages above and below the envelope. A tally of the number of days is kept for each type of deviation, as well as the total penalty score. For extreme high and low lake stage events, a tally is made of the total number of days that the stage is above 17 ft or below 10 ft NGVD. Deviations above and below the envelope are generally scored, tallied, and compared the same.

Figures 5A and **5B** below illustrate how the evaluation is performed for the lake stage envelopes, where the vertical axis is stage in feet and the horizontal axis is in days of the year. The white central area (0.0 pts) is the stage envelope for Normal (A) and Recovery (B) years. The point ranges identified in each band represent the range of points from the bottom to the top of the band (for stages above the envelope, and vice versa for below). For example, a stage of 12.5 on June 15 would have a score of 0.5, while a stage of 13 would have a score 1.0 and 13.5 would be 2.0. Note that penalty scores are not simply linear in all cases; going from 0.5 to 2.0 points over a 0.5 foot stage difference in December, for example, but from 0.5 to 2.0 over a 1 foot stage difference in June. Similarly, the width of the beneficial envelope varies as well, with a minimum of 1 foot in winter and summer and a maximum of 2.5 feet in mid-September. The Recovery envelope is similar to the Normal envelope, except that all bands are shifted down 0.5 feet most of the year; except between January to mid-May when the target envelope is shifted down 1.0 foot while the penalty bands are only shifted 0.5 feet. Most penalties are 2x the absolute deviation in feet from the envelope once a penalty of 2.0 is reached, except for the spring months below the envelope, where penalties are linear until 3.0.

As an example, the hydrographs for years 2016 and 2017 are overlaid onto the envelopes. 2016 would have a score of 541 for stages above the envelope and a score of 7 for stages below the envelope (548 total), and was inside the envelope 77 days. The maximum penalty was 4.65 points, which occurred on June 17 with a lake stage of 14.89 feet. Note that the high stages in June and July of 2016 (30 day minimum >14 feet) also triggered the Recovery envelope for 2017, shifting targets and penalties downward. 2017 would have a score of 471 for stages above the Recovery envelope and only 2 for stages below the Recovery envelope (474 total), and was inside the envelope for 173 days. The maximum penalty was 5.60 points, which occurred on October 9 with a lake stage of 17.20 feet due to Hurricane Irma. In this case, stages were not low enough for long enough (<12 ft for 63 days vs 90 day target, or <11.5 ft for 26 days vs 60 day target) to return to Normal envelope targets the following year. Regardless, high lake stages in the fall of 2017 (>16 ft) would have negated whether stages were low enough in the summer, and the October stages that exceeded 17 ft would have triggered a Recovery envelope even if one was not in place for 2017. The actual scoring based on the 52-year model outputs will be performed as described above, switching between envelopes based on the above triggers.

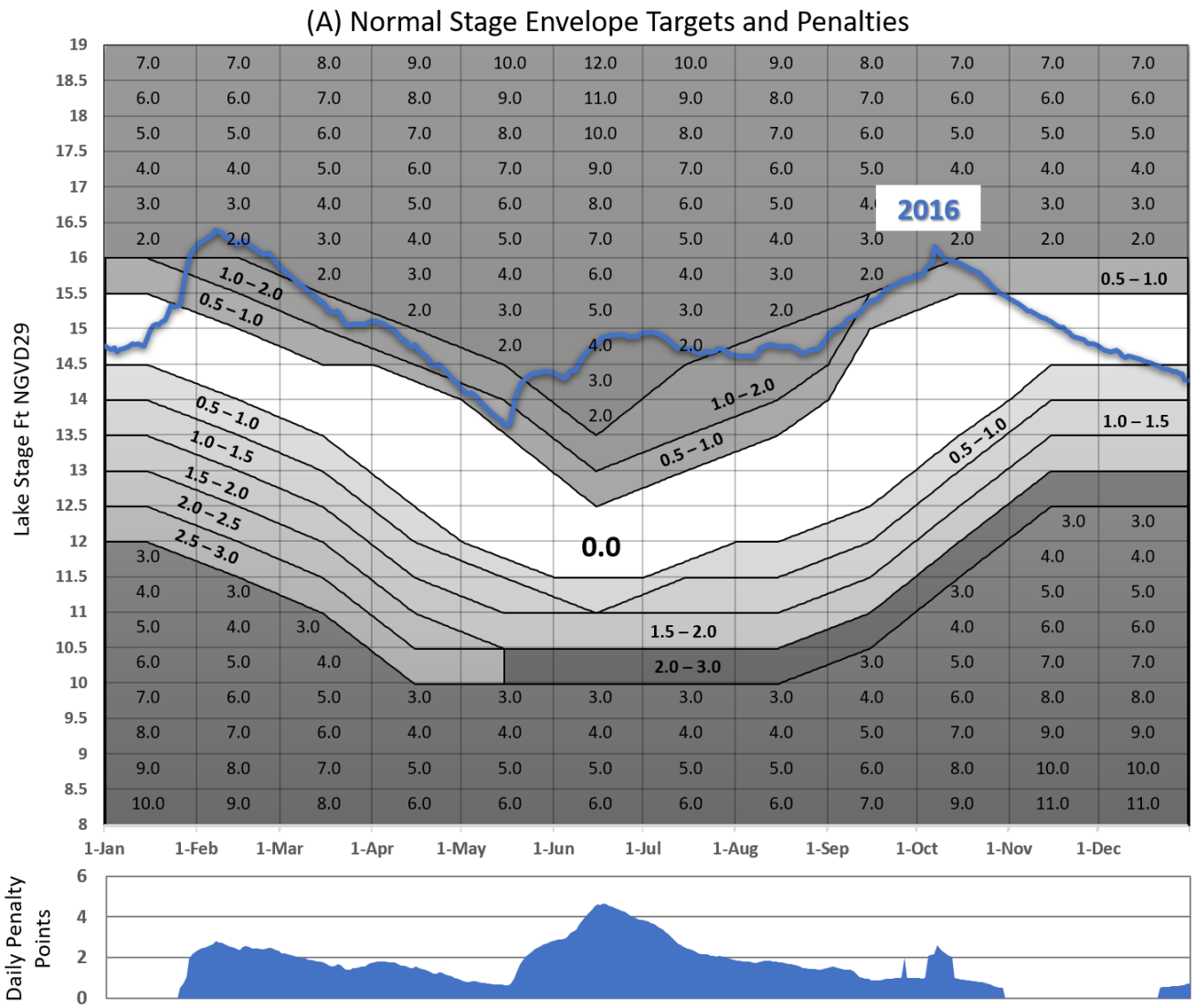

Figure 5A. The Normal lake stage envelope and approximate corresponding penalties that apply for lake stages outside the desired range. Penalties are actually applied by the hundredths of a foot on a daily basis and may not correspond exactly to the boxes shown. For reference and as an example, 2016 stages are overlaid onto the envelope and penalties are shown in the lower panel.

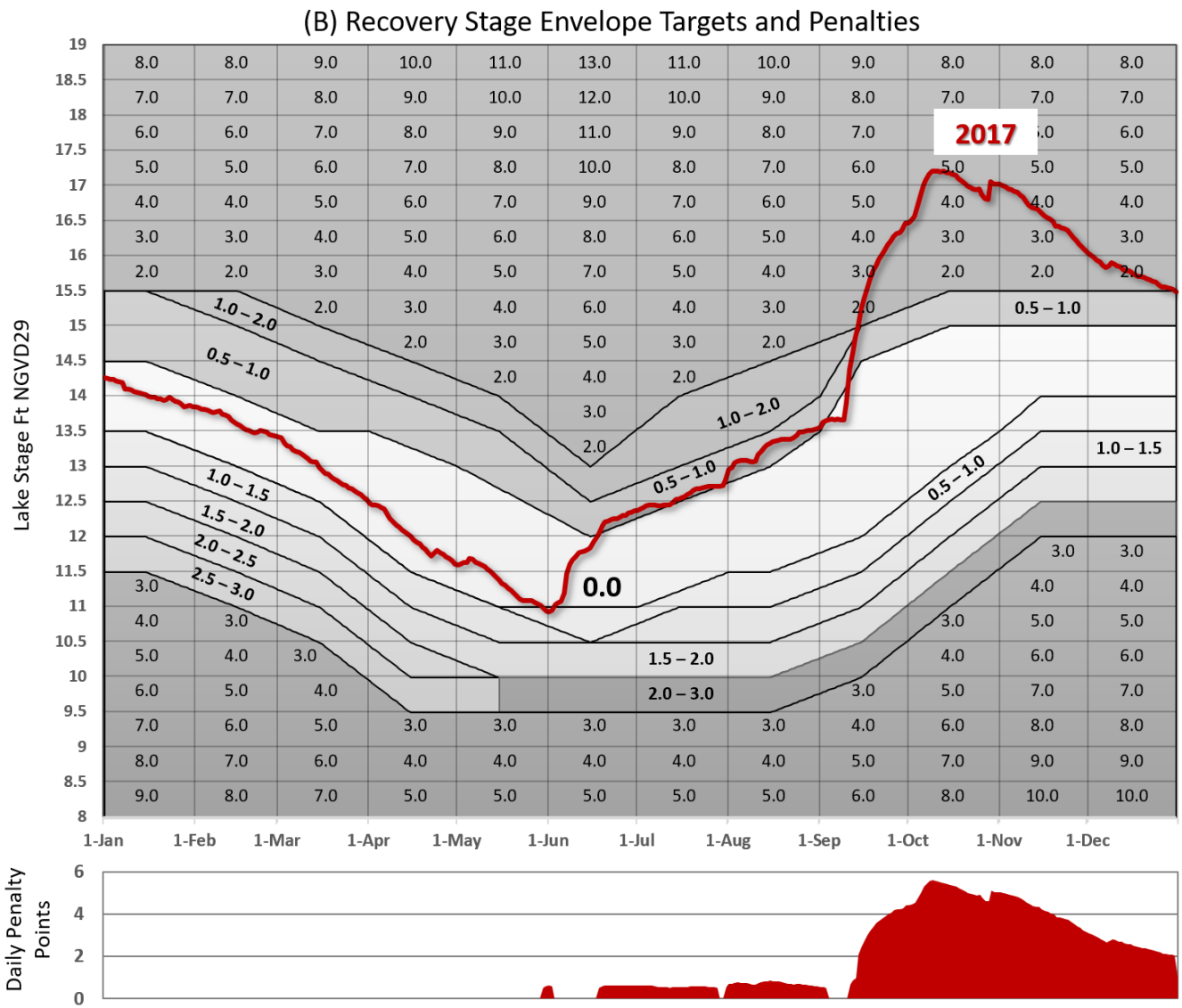

Figure 5B. The Recovery lake stage envelope and approximate corresponding penalties that apply for lake stages outside the desired range. Penalties are actually applied by the hundredths of a foot on a daily basis and may not correspond exactly to the boxes shown. For reference and as an example, 2017 stages are overlaid onto the envelope and penalties are shown in the lower panel.

4.2 Model Output

For the ecological envelope component of this performance measure, total penalty scores should be tallied for each alternative, as well as the separate penalty scores for above and below the envelope. The percent of time within, above, and below the envelopes should also be reported. For extreme lake stages, a histogram of the durations of events above 17 ft and below 10 ft should be displayed, as well as the total number of days for all exceedances.

4.3 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 RSM-BN model, and an unknown amount of uncertainty associated with how seasonal variation in lake stage affects various components of the lake's plant / animal community. For example, while the envelope appears very specific in terms of stage requirements throughout the year, the shape reflects a broad literature review and the best professional judgement of panel members on a monthly time-step. Average monthly values were converted to daily stages using linear interpolations, and the uncertainty around specific stages is captured in the scoring methodology; penalties increase as you move farther from general targets, or at times of year where specific targets were deemed important. The varying width of the envelope and the varying penalty scores together account for uncertainty in the recommendations.

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 envelopes 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. Further, results from long-term monitoring of a variety of environmental parameters (see below) is used to assess and validate lake health, and to inform this performance measure. 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

Long-term monitoring of the status of Lake Okeechobee health is generally related to (1) phosphorus levels, (2) nutrient and phytoplankton dynamics, (3) submerged aquatic vegetation, (4) emergent plants, and (5) wildlife. Conceptual ecological models were developed to address how hydrologic and nutrient issues affect these attributes, and those efforts were used to select indicators of the overall ecological condition of the lake. These indicators are representative of the three sub-regions in the lake (marsh, nearshore, and pelagic) and are affected by changes related to lake stage, i.e. the relationship between stage and horizontal mixing of nutrient laden sediments. They include a variety of water quality indicators, including; total phosphorus concentration and load, chlorophyll *a*, phytoplankton (diatom and cyanobacteria ratios), and water clarity; and also, submerged and emergent vegetation communities; important recreational sportfish species black

crappie (*Pomoxis nigromaculatus*) and largemouth bass (*Micropterus salmoides*); and wading birds and snail kites (*Rostrhamus sociabilis*).

Monitoring programs through the South Florida Water Management District, Florida Fish and Wildlife Conservation Commission, US Army Corps of Engineers, US Geological Survey and others provide assessments of indicator health, as well as verification of their relationships to lake stage. Together these programs have provided decades of assessment data and will continue to inform the efficacy of performance measures like the one described in this document. Data from these programs form the basis of this current update and will be used to evaluate and validate this performance measure in the future.

6.0 Future Tool Development Needed to Support Performance Measure

6.1 Evaluation Tools Needed

RSM-BN and daily penalty factors for the lake stage envelope.

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: Mar 7, 2007). The extreme lake stage performance measure targets are unchanged but there are slight modifications to their scoring methodology. Earlier versions suggested relativized scoring methods, which were dropped in favor or simple tallying of events and durations beyond specific thresholds.

The earlier Lake Okeechobee Stage Envelope performance measure was modified in several ways;

- Adjusted approximately 0.5 ft lower to align with originally cited research that specified 12.0 ft and 15 ft as low and high targets, rather than 12.5 ft and 15.5 ft.
- Adjusted width of envelope to allow greater flexibility in spring and fall due to importance of inter-annual variability, and reduced flexibility for low-stage target to reflect critical nature of low stage for SAV and other communities
- Modified scoring methodology to reflect a softer buffer around stage targets at certain times of year and harder buffers where stage targets were deemed critical. Also increased penalties farther outside of the envelope to attain more variation when scoring alternative model outputs.
- Also eliminated the relativized scoring method, similar to extreme stage performance measures.

8.0 Working Group Members

Mike Baranski (SFWMD)
Tyler Beck (FWC)
Rich Botta (SFWMD)
Andrea Dominguez (FWC)
Therese East (SFWMD)
Andrew Eastwick (FWS)
Steven Gornak (FWC)
Paul Gray (Audubon of Florida)
Chuck Hanlon (SFWMD)
Alyssa Jordan (FWC)
Andy Rodusky (SFWMD)
Steve Schubert (FWS)
Zach Welch (SFWMD)

9.0 References

Darby, P., P. Valentine-Darby, F. Percival, and W. Kitchens. 2004. Florida apple snail (*Pomacea paludosa* SAY) responses to lake habitat restoration activity. Archiv fur Hydrobiologie 161(4):561-575.

Fletcher, R., C. Poli, E. Robertson, B. Jeffery, S. Dudek, and B. Reichert. 2017. Snail Kite Demography 2016 Annual Report. University of Florida, Gainesville, FL

Havens, K.E. 1997. Water levels and total phosphorus in Lake Okeechobee. *Lake and Reservoir Management* 13:16-25.

Havens, K.E. 2002. Development and application of hydrologic restoration goals for a large subtropical lake. Lake and Reservoir Management 18: 285-292.

Havens, K.E. and W.W. Walker. 2002. Development of a total phosphorus concentration goal in the TMDL process for Lake Okeechobee, Florida (USA). Lake and Reservoir Management 18(3): 227-238.

Havens, K.E., D. Fox, S. Gornak, C. Hanlon. 2005. Aquatic vegetation and largemouth bass population responses to water level variations in Lake Okeechobee, Florida (USA). Hydrobiologia 539(1): 225-237.

Havens, K.E., T.L. East, A.J. Rodusky and B. Sharfstein. 1999. Littoral periphyton responses to nitrogen and phosphorus: an experimental study in a subtropical lake. Aquatic Botany 63: 267-290.

Havens, K.E., K.R. Jin, A.J. Rodusky, B. Sharfstein, M.A. Brady, T.L. East, N. Iricanin, R.T. James, M.C. Harwell, and A.D. Steinman. 2001. Hurricane effects on a shallow lake ecosystem and its response to a controlled manipulation of water level. The Scientific World Journal 1: 44-70.

Havens, K.E., B. Sharfstein, M.A. Brady, T.L. East, M.C. Harwell, R.P. Maki, A.J. Rodusky. 2004. Recovery of submerged plants from high water stress in a large subtropical lake in Florida, USA. Aquatic Botany 78: 67-82.

James, R. T., and K. E. Havens. 2005. Outcomes of Extreme Water Levels on Water Quality of Offshore and Nearshore Regions in a Large Shallow Subtropical Lake. Archiv für Hydrobiologie 163: 225-239.

Keddy, P., and H. L. Fraser. 2000. Four general principles for the management and conservation of wetlands in large lakes: The role of water levels, nutrients, competitive hierarchies and centrifugal organization. Lakes & Reservoirs: Research and Management 5: 177-185.

Maceina, M.J. and D.M. Soballe. 1990. Wind-related limnological variation in Lake Okeechobee, Florida. Lake and Reservoir Management 6: 93-100.

RECOVER. 2004a. CERP Monitoring and Assessment Plan: Part 1 Monitoring and Supporting Research. Restoration Coordination and Verification Program, c/o United States Army Corps of Engineers, Jacksonville District, Jacksonville, Florida, and South Florida Water Management District, West Palm Beach, Florida.

RECOVER. 2004b. Draft Conceptual Ecological Models. In: RECOVER. CERP Monitoring and Assessment Plan: Part 1 Monitoring and Supporting Research, Restoration Coordination and Verification Program, c/o United States Army Corps of Engineers, Jacksonville District, Jacksonville, Florida, and South Florida Water Management District, West Palm Beach, Florida, Appendix A.

RECOVER. 2005. The RECOVER Team's Recommendations for Interim Goals and Interim Targets for the Comprehensive Everglades Restoration Plan, c/o United States Army Corps of Engineers, Jacksonville District, Jacksonville, Florida, and South Florida Water Management District, West Palm Beach, Florida.

Richardson, J.R., T.T. Harris, and K.A. Williges. 1995. Vegetation correlations with various environmental parameters in the Lake Okeechobee marsh ecosystem. *Archiv für Hydrobiologie, Advances in Limnology* 45: 41-61.

Sharfstein, B. and J. Zhang. 2017. Chapter 8B: Lake Okeechobee Watershed Research and Water Quality Monitoring Results and Activities. In: 2017 South Florida Environmental Report – Volume I, South Florida Water Management District, West Palm Beach, FL.

Sharfstein, B. J. Zhang and L. Bertolotti. 2015. Chapter 8B: Lake Okeechobee Watershed Protection Program Annual Update. In: 2015 South Florida Environmental Report – Volume I, South Florida Water Management District, West Palm Beach, FL.

Smith, J.P., J.R. Richardson, and M.W. Callopy. 1995. Foraging habitat selection among wading birds (Ciconiiformes) at Lake Okeechobee, Florida, in relation to hydrology and vegetative cover. *Archiv für Hydrobiologie, Advances in Limnology* 45: 247-285.

Zhang. J. and Z. Welch. 2018. Chapter 8B: Lake Okeechobee Watershed Research and Water Quality Monitoring Results and Activities. In: 2018 South Florida Environmental Report – Volume I, South Florida Water Management District, West Palm Beach, FL.