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

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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:

Chara abundance – 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.

Cyanobacteria abundance – 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.

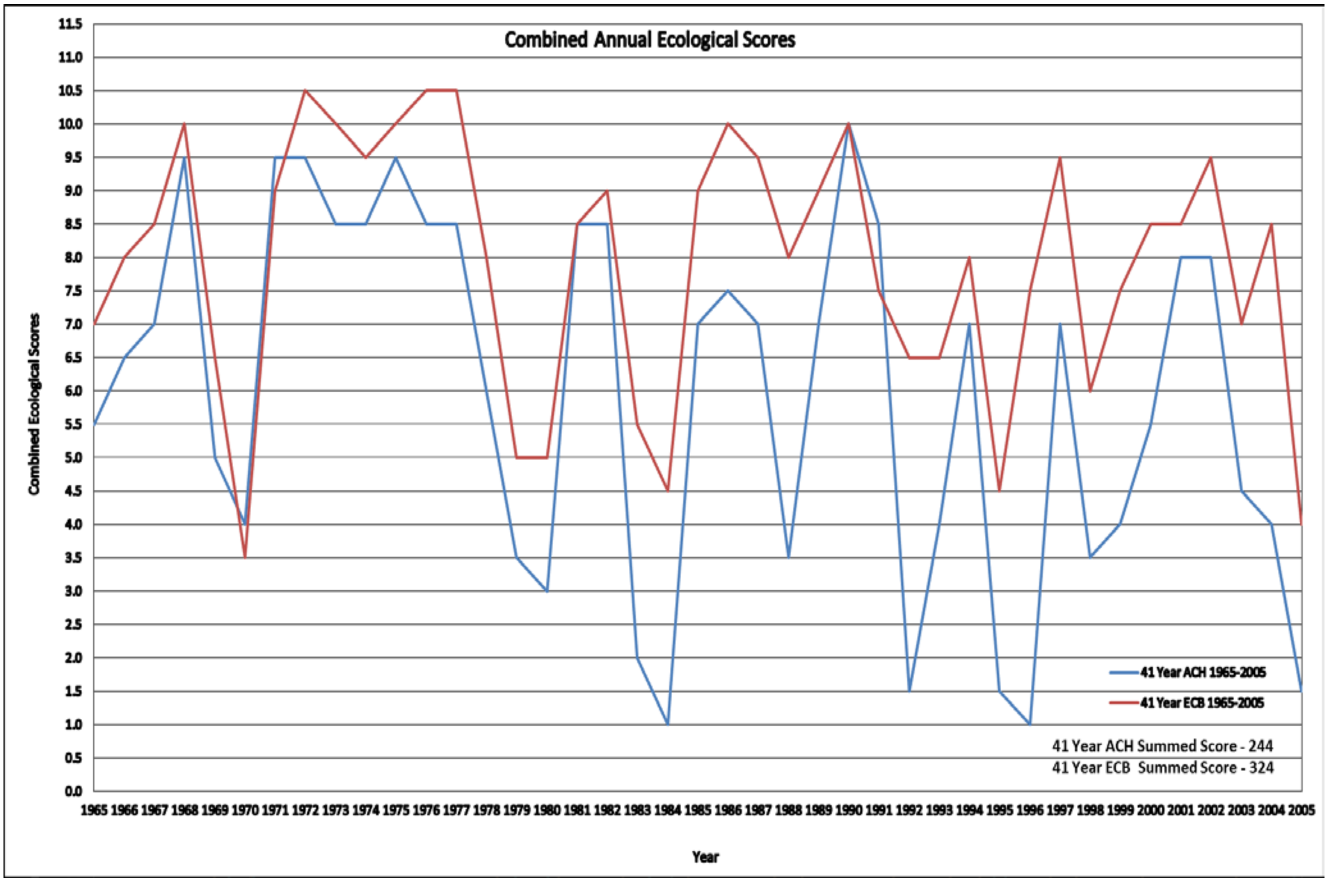

Figure 1. The annual ecological indicator scores for a 41 year Lake Okeechobee actual historical hydrograph (ACH) and a 41 period of record (1965-2005) for the hydrograph if the LORS 2008 and adaptive protocols current regulation schedule (ECB, existing condition baseline) would have been in place during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

9.0 References

Carrick, H.J., and A.D. Steinman. 2001. Variation in periphyton biomass and species composition in Lake Okeechobee, USA: distribution of algal guilds along environmental gradients. Arch Hydrobiol 152:411-438.

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Rodusky, A.J. 2010. The influence of large water level fluctuations and hurricanes on periphyton and associated nutrient storage in subtropical Lake Okeechobee, USA. Aquatic Ecology. 44:797-815.

Sharfstein, B., Rodusky, A.J., Neidrauer, C.J. 2015. The effects of various external storage volumes on the hydrology and ecology of Lake Okeechobee, USA, a large, shallow subtropical lake. In Review.

US EPA. 2016. Harmful algal blooms:www.epa.gov/nutrientpollution/harmful-algal-blooms.

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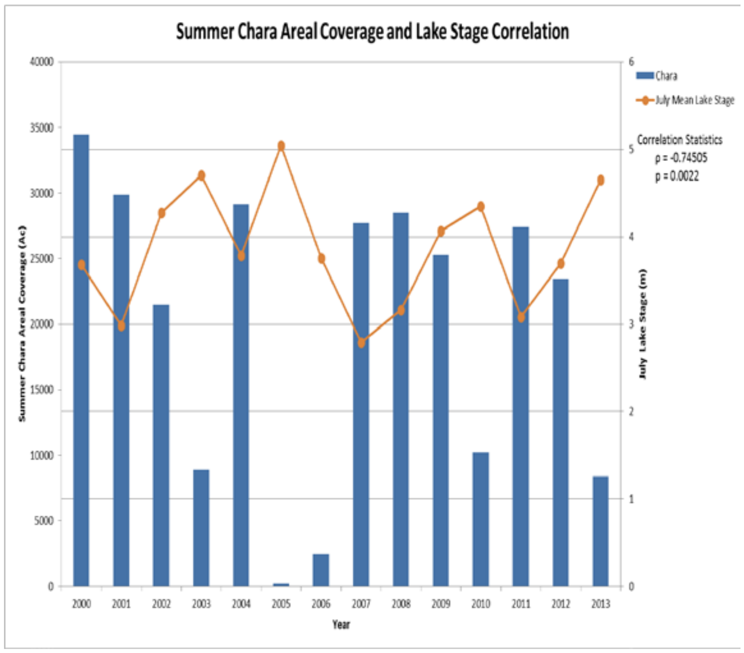
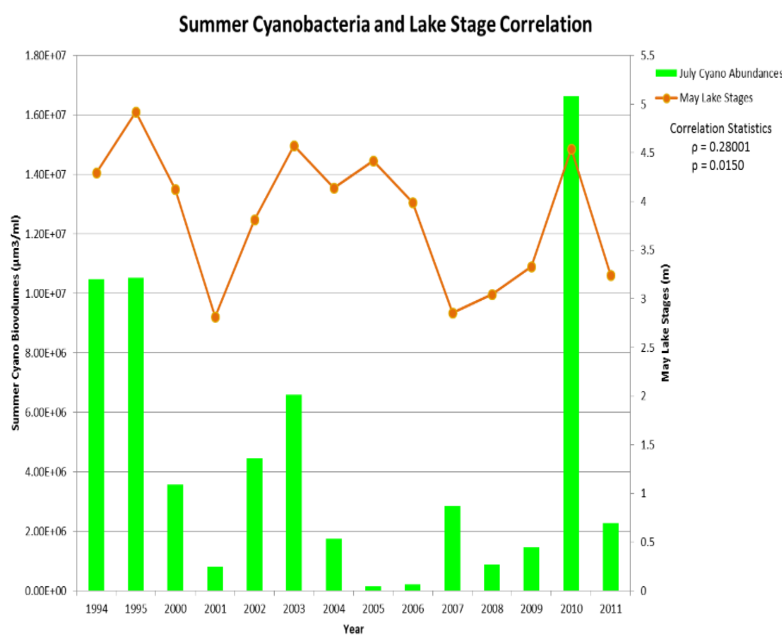
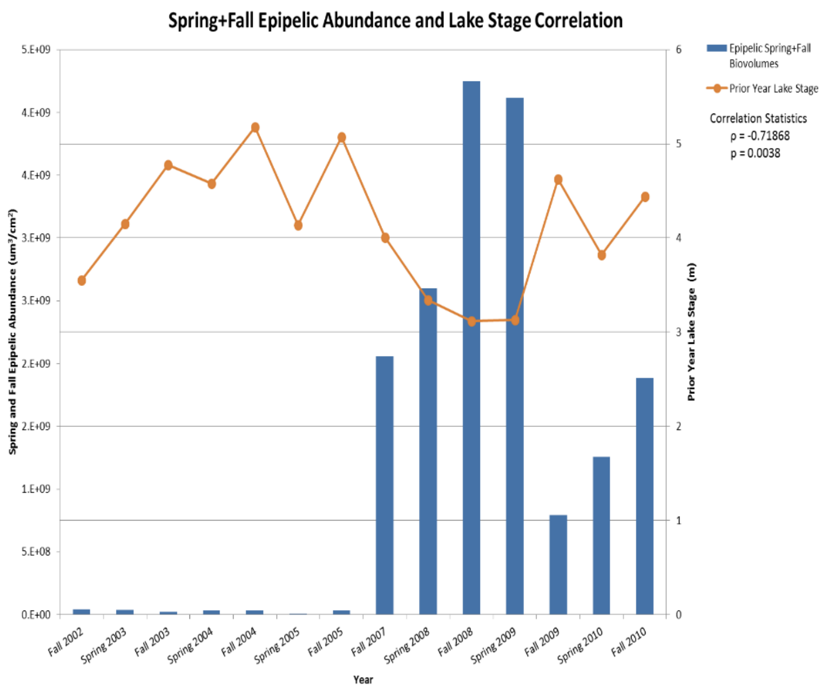
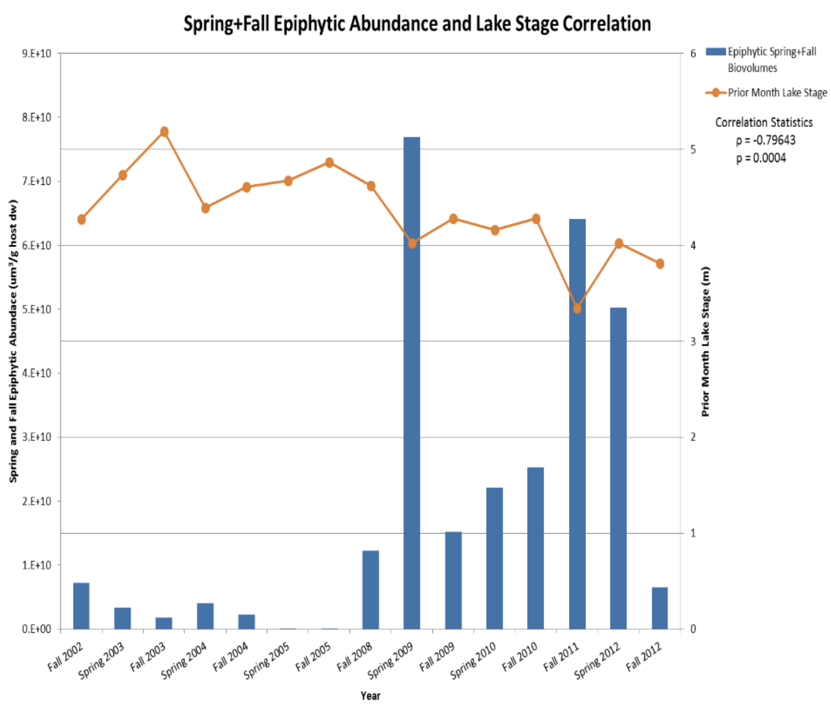
Appendix A

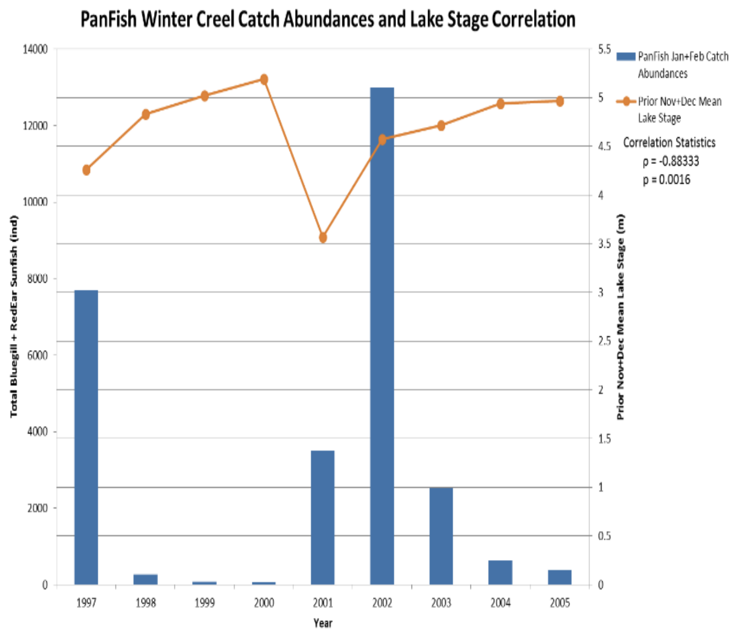
Graphical representation of the strongest statistical relationship between each ecological indicator and lake stages. These relationships consist of Spearman correlations using ecological data and monthly average lake stages from either the month the ecological data were collected (Chara, Vascular SAV),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

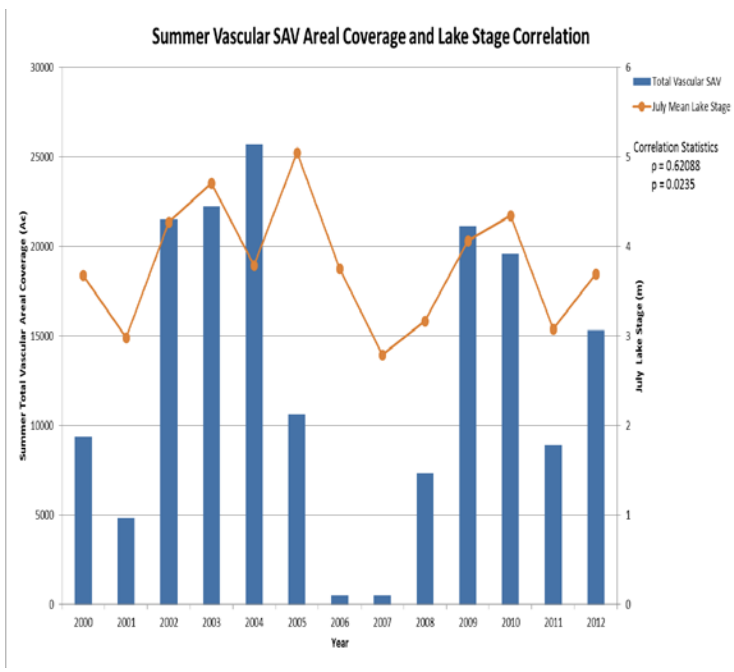





Spring+Fall Epipelic Abundance and Lake Stage Correlation
Epipelic Spring+Fall Biovolumes
Prior Year Lake Stage
Correlation Statistics
ρ = -0.71868
p = 0.0038
Spring and Fall Epipelic Abundance (um³/cm²)
Prior Year Lake Stage (m)
Year
Fall 2002
Spring 2003
Fall 2003
Spring 2004
Fall 2004
Spring 2005
Fall 2005
Fall 2007
Spring 2008
Fall 2008
Spring 2009
Fall 2009
Spring 2010
Fall 2010

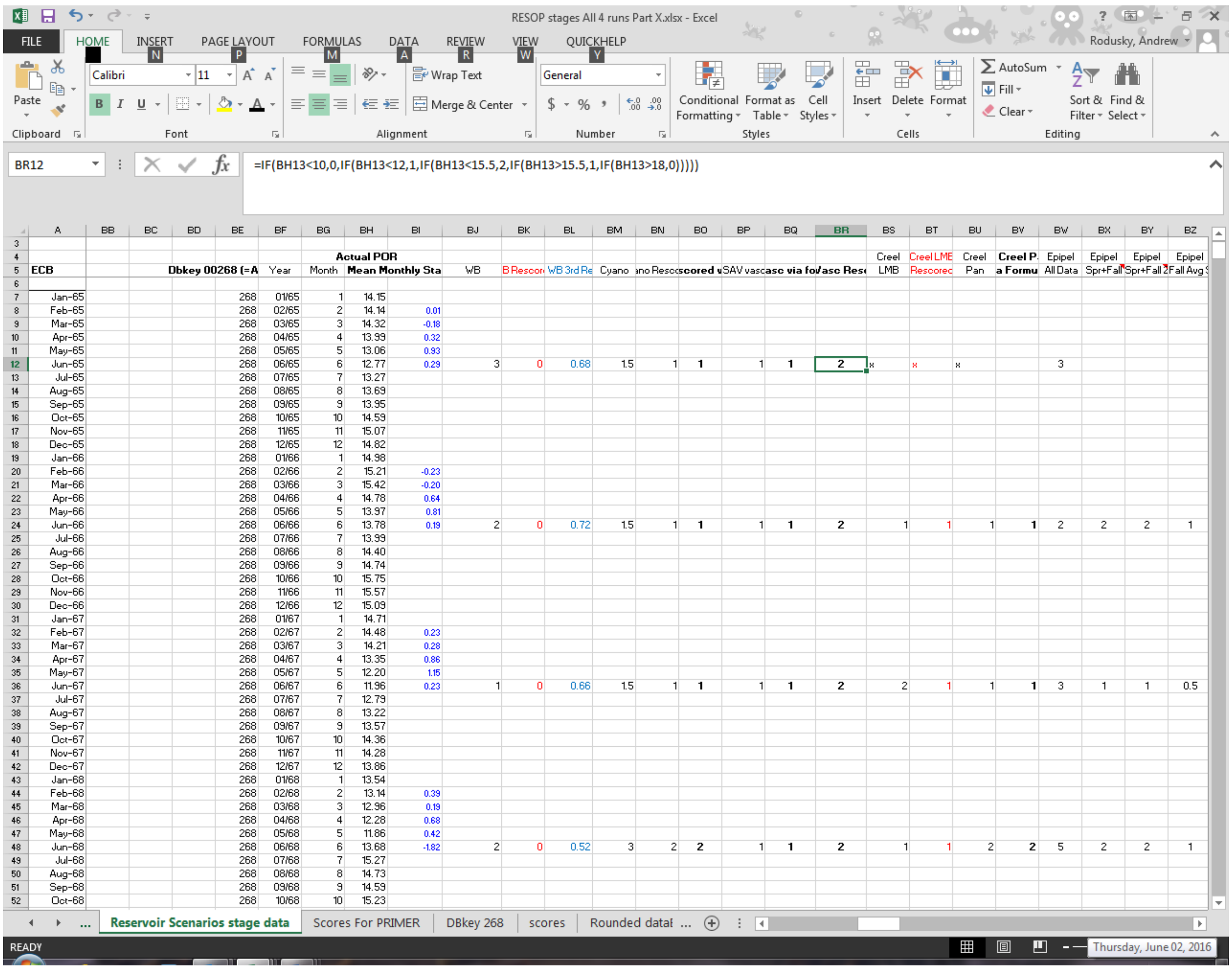

Spring+Fall Epiphytic Abundance and Lake Stage Correlation
Epiphytic Spring+Fall Biovolumes
Prior Month Lake Stage
Correlation Statistics
ρ = -0.79643
p = 0.0004
Spring and Fall Epiphytic Abundace (um³/g host dw)
Prior Month Lake Stage (m)
Year
Fall 2002
Spring 2003
Fall 2003
Spring 2004
Fall 2004
Spring 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


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

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.



	A	BB	BC	BD	BE	BF	BG	BH	BI	BJ	BK	BL	BM	BN	BO	BP	BQ	BR	BS	BT	BU	BV	BW	BX	BY	BZ
3																										
4								Actual POR											Creel	Creel LME	Creel	Creel P.	Epipel	Epipel	Epipel	Epipel
5	ECB			Dbkey 00268 (=A		Year	Month	Mean Monthly Sta		WB	B Rescor	WB 3rd Re	Cyano	ano Rescc	scored v	SAV vasc	asc via fo	/asc Res	LMB	Rescorec	Pan	a Formu	All Data	Spr+Fall	Spr+Fall 2	Fall Avg S
6																										
7	Jan-65				268	01/65	1	14.15																		
8	Feb-65				268	02/65	2	14.14	0.01																	
9	Mar-65				268	03/65	3	14.32	-0.18																	
10	Apr-65				268	04/65	4	13.99	0.32																	
11	May-65				268	05/65	5	13.06	0.93																	
12	Jun-65				268	06/65	6	12.77	0.29	3	0	0.68	1.5	1	1	1	1	2	x	x	x		3			
13	Jul-65				268	07/65	7	13.27																		
14	Aug-65				268	08/65	8	13.69																		
15	Sep-65				268	09/65	9	13.95																		
16	Oct-65				268	10/65	10	14.59																		
17	Nov-65				268	11/65	11	15.07																		
18	Dec-65				268	12/65	12	14.82																		
19	Jan-66				268	01/66	1	14.98																		
20	Feb-66				268	02/66	2	15.21	-0.23																	
21	Mar-66				268	03/66	3	15.42	-0.20																	
22	Apr-66				268	04/66	4	14.78	0.64																	
23	May-66				268	05/66	5	13.97	0.81																	
24	Jun-66				268	06/66	6	13.78	0.19	2	0	0.72	1.5	1	1	1	1	2	1	1	1	1	2	2	2	1
25	Jul-66				268	07/66	7	13.99																		
26	Aug-66				268	08/66	8	14.40																		
27	Sep-66				268	09/66	9	14.74																		
28	Oct-66				268	10/66	10	15.75																		
29	Nov-66				268	11/66	11	15.57																		
30	Dec-66				268	12/66	12	15.09																		
31	Jan-67				268	01/67	1	14.71																		
32	Feb-67				268	02/67	2	14.48	0.23																	
33	Mar-67				268	03/67	3	14.21	0.28																	
34	Apr-67				268	04/67	4	13.35	0.86																	
35	May-67				268	05/67	5	12.20	1.15																	
36	Jun-67				268	06/67	6	11.96	0.23	1	0	0.66	1.5	1	1	1	1	2	2	1	1	1	3	1	1	0.5
37	Jul-67				268	07/67	7	12.79																		
38	Aug-67				268	08/67	8	13.22																		
39	Sep-67				268	09/67	9	13.57																		
40	Oct-67				268	10/67	10	14.36																		
41	Nov-67				268	11/67	11	14.28																		
42	Dec-67				268	12/67	12	13.86																		
43	Jan-68				268	01/68	1	13.54																		
44	Feb-68				268	02/68	2	13.14	0.39																	
45	Mar-68				268	03/68	3	12.96	0.19																	
46	Apr-68				268	04/68	4	12.28	0.68																	
47	May-68				268	05/68	5	11.86	0.42																	
48	Jun-68				268	06/68	6	13.68	-1.82	2	0	0.52	3	2	2	1	1	2	1	1	2	2	5	2	2	1
49	Jul-68				268	07/68	7	15.27																		
50	Aug-68				268	08/68	8	14.73																		
51	Sep-68				268	09/68	9	14.59																		
52	Oct-68				268	10/68	10	15.23																		

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