APPENDIX B:
A Conceptual Habitat Area-Based Approach for Flow Envelope Alternatives

1 INTRODUCTION

Using the updated Salinity Envelopes (Table 1 in the main Northern Estuaries Salinity Envelope Documentation Sheet ["Documentation Sheet"]), the following describes how the corresponding Flow Envelopes were derived for the St. Lucie Estuary (SLE) and the Caloosahatchee River Estuary (CRE). Mathematically, this was an inverse approach to answer the question as to what freshwater flows are required to achieve the desirable salinity conditions in an estuary, vs. the question of what the salinities would be given known flow conditions. The former can now be reliably answered by a hydrodynamic-salinity model, while the latter has no empirical answer due to the strong nonlinear relationship of flow and salinity in the estuaries: it's not a one-to-one relationship, despite general trends such as higher freshwater inflow resulting in lower salinity. For example, to reduce the salinity to a specific condition at a given location in the estuary, higher flows are generally required in the dry season than in the wet season. In addition, there are other contributing factors such as tides at the offshore boundary and physical wind forces at the water surface which increases complexity of this relationship.

In the development of the 2007 Performance Measures for the SLE and CRE (RECOVER 2007), hydrological modeling of natural system flows and steady state hydrodynamic modeling of salinities were used to help determine appropriate flow envelopes for the chosen indicators (SFWMD 2004; Chamberlin and Doering 2001). There are some limitations to these approaches: hydrological conditions have significantly (and irreversibly) changed from natural system flow conditions and estuaries are very dynamic. A steady state hydrodynamic/salinity model is unable to capture the significant variation of salinity conditions in the estuary. The modeling approach employed for this Performance Measure update is described in the main Documentation Sheet (Evaluation Application, Section 3) and below.

2 METHODOLOGY

To narrow the scope of possible Optimum Flow Envelopes evaluated, a habitat area-based approach was applied, by which flow ranges that can maximize the potential habitat area (PHA) – the area where salinities meet the Optimum Salinity Envelope in the estuary for a given organism – was identified. First, a well-calibrated and verified three-dimensional hydrodynamic-salinity model, CH3D (Curvilinear Hydrodynamic 3-Dimensional; Sheng 1986; 1987) was applied to simulate long-term (1965–2015) salinity using historical daily flow data from upstream gauge locations, tides at the offshore boundaries, and meteorological influences (wind, rainfall, evaporation) at the water surface. A brief description of the CH3D models for the SLE and CRE is given in Appendix A.

Second, a potential habitat area (PHA) was computed based on the updated Optimum Salinity Envelopes for the ecological indicators selected (Table 1, Documentation Sheet). Specifically, for each grid cell k in the model, if the salinity in the cell averaged over a 14-day period is within the Optimum Salinity Envelope, the area for the cell would be counted as potential habitat area (PHA) and the total area over the two-week period would be:

$$PHA(i) = \sum_k A_{k,i}$$

When S(k,i) is within an optimum range for an indicator, S is salinity averaged over a 14-day period, and i is the number of 14-day periods counted from January 1, 1965.

The third step, an average PHA for a given flow range (Q_{low} to Q_{high}) was computed:

$$APHA(Q_{low}, Q_{high}) = \frac{\sum_i PHA(i)}{T}$$

where Q_i is within the given flow range and Q_i is the flow averaged over the ith 14-day period, and T is the total number of 14-day periods in 51 years when the flow Q meets the given range.

For example, the 2007 PM flow target for the SLE is 350–2000 cfs (RECOVER 2007), thus T would be the total number of the two-week periods when the total inflow into the SLE was within the flow target, PHA(i) would be potential area where salinity falls within the Optimum Salinity Envelope for the selected indicator at the ith period when flow Q_i is within the 350–2000 cfs range, and the APHA would be the average potential habitat area for the selected indicator for the time whenever flow Q is within 350–2000 cfs. Note that the flow Q used for the SLE is the total flow into the estuary while for CRE, Q is the flow at S-79 to be consistent with the 2007 Salinity Envelope Performance Measure.

The lower and upper flow bounds were then incrementally adjusted and APHA for each adjustment was computed, resulting in a series of sensitivity curves (Figure 1–Figure 5). Note that in Figure 1–Figure 5, APHA was normalized to the APHA for the 2007 Salinity PM flow range for each estuary, therefore the result is a relative area with respect to the 2007 PM flow target performance. Further details are provided in descriptions for each estuary.

3 SENSITIVITY ANALYSES AND SELECTION OF OPTIMUM FLOW ENVELOPES

3.1 St. Lucie Estuary

Figure 1 and Figure 2 are the computed relative APHA for shoal grass and oysters, respectively, where the x-axis is the high flow bound ranging 1000–2400 cfs in 200 cfs increments, and the y-axis represents the computed habitat area for each indicator relative to the 2007 PM for the SLE. Each curve represents one lower flow bound from 150–450 cfs in 100 cfs increments. The red dot is the APHA performance for the 2007 PM target (lower bound flow 350 cfs and upper bound flow 2000 cfs), and has a score of 1.0 on the y-axis. Within the plots, values greater than 1.0 would suggest better performance, i.e., a greater area within the Optimum Salinity Envelope for that indicator, relative to the 2007 PM. This implies a fundamental assumption: the computed PHA was used as a surrogate based solely on salinity as potential habitat for each indicator in this estimation of predicting indicator performance. Ideally, the next step for calculating and predicting indicator performance (e.g., biomass and productivity) is to develop ecological models (Appendix C).

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The sensitivity curves (Figure 1 and Figure 2) offered a number of Optimum Flow Envelope alternatives that took into account each ecological indicator's sensitivity (i.e., flows from the part of the curve >1.0 on the y-axis), from which a final selection was made to best balance benefits across all indicator species.

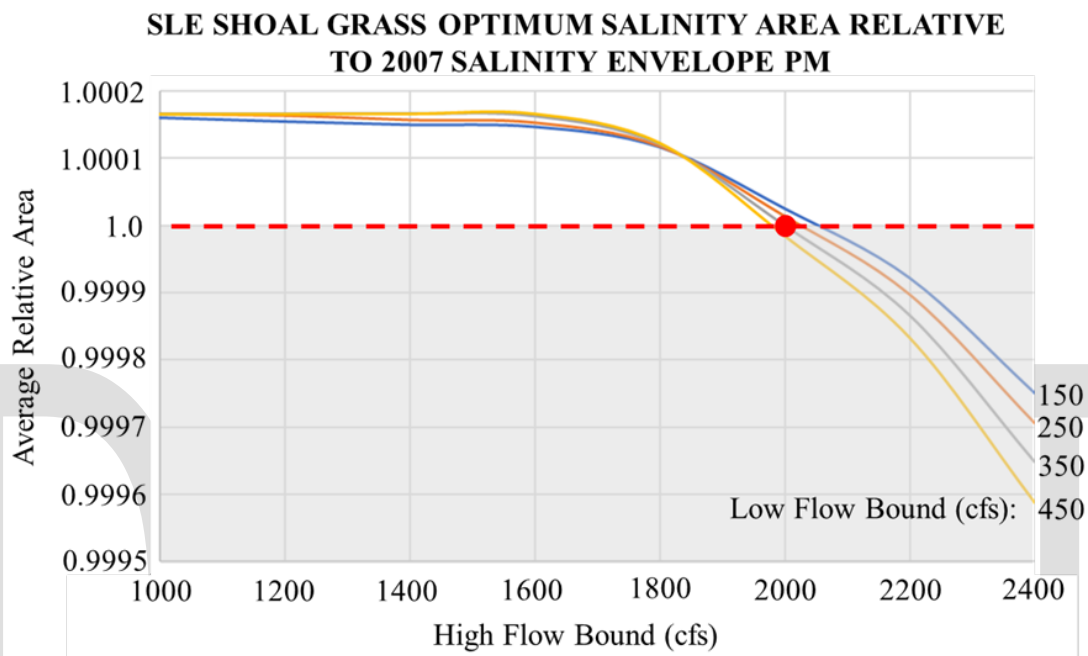

***Figure 1**. St. Lucie Estuary (SLE) shoal grass Optimum Salinity (salinities 15–45) area, i.e., Potential Habitat Area (PHA) based on 14-day average salinity, relative to the SLE 2007 Salinity PM Flow Envelope (red dot: 350–2000 cfs, a score of 1.0 on the y-axis). High flow bounds on the x-axis, low flow bounds represented by colored lines, labeled on the right of the plot.*

Selecting Optimum Flow Envelope alternatives for the SLE was straightforward in that shoal grass was not a sensitive indicator for the flow envelopes tested (**Figure 1**).There was little difference between the low flow bounds (150, 250, 350, and 450 cfs) until the high flow bound exceeded 1800 cfs, at which point the average relative area began to decrease, though only by hundredths of a percent. The spatial area bound for shoal grass was in the lower SLE and part of the southern Indian River Lagoon (IRL) in proximity to the St. Lucie Inlet, north to the A1A bridge in the southern IRL and therefore the lack of sensitivity is likely the factor of tidal influence on salinity.

For oysters, sensitivity was evident at combinations of higher low flow bounds, and higher high flow bounds (Figure 2). The greatest improvement in average relative PHA (21–23% improvement) included lower low flow bounds and lower high flow bounds. High flow bounds starting at 1200 cfs and incrementally increasing by 200 cfs to 1600 cfs was selected for further evaluation, wherein it estimated that average relative PHA would increase by 5% from 1600 cfs to 1400 cfs, and another 5% from 1400 cfs to 1200 cfs.

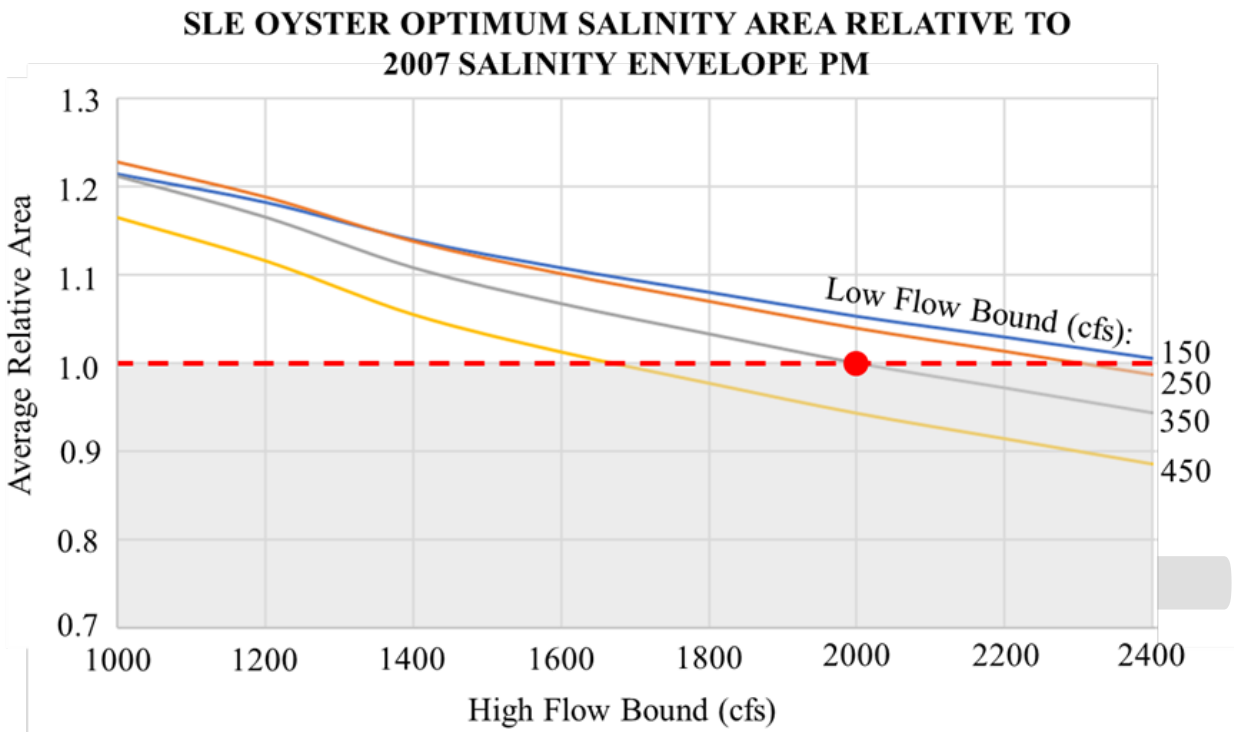

Figure 2. *St. Lucie Estuary (SLE) Eastern oyster Optimum Salinity (salinities 10–25) area, i.e., Potential Habitat Area (PHA) based on 14-day average salinity, relative to the SLE 2007 Salinity Envelope PM flow envelope (red dot: 350–2000 cfs, a score of 1.0 on the y-axis). High flows are on the x-axis, low flows represented by the colored lines, labeled to the right of the plot. Flow Envelopes above the red dashed line/grayed area indicative of an improvement in PHA (based on Optimum Salinity) by 10, 20, and 30%.*

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3.2 Caloosahatchee River Estuary

Like the SLE, Figure 3–Figure 5 are the relative PHA for three indicators in the CRE: Eastern oyster, shoal grass, and tape grass respectively. The high flow bound range (x-axis) was from 1800–3000 cfs in 200 cfs increments, and there were four curves applied for the lower flow bounds 450–750 cfs in 100 cfs increments. The red dot is the value for the 2007 PM target (lower bound flow 450 cfs and upper bound flow 2800 cfs) and has a score of 1.0 on the y-axis. Within the plots, values greater than 1.0 would suggest better performance, i.e., a greater area within the Optimum Salinity Envelope for that indicator, relative to the 2007 PM. The same fundamental assumption is true: the computed PHA was used as a surrogate based solely on salinity as potential habitat for each indicator in this estimation of predicting indicator performance.

Selecting Optimum Flow Envelope alternatives for the CRE had an additional challenge that required balancing the salinity optima of a freshwater/oligohaline SAV species (i.e., tape grass) in the upstream estuary, and mesohaline/marine SAV (i.e., shoal grass) and the Eastern oyster

downstream. By comparing plots, estimations were made as to which alternatives could provide an estuarine salinity gradient suitable for all ecological indicator species.

Oysters were less sensitive than shoal grass at increased high flow bound volumes in excess of 2300 cfs, depending on the low flow bound. This is expected, as the low end of the optimum salinity range for oysters is salinity of 10, whereas shoal grass is salinity of 15. Average relative PHA for oysters improved by 3–14% across all flow envelopes tested with a minimum low flow bound of 550 cfs (Figure 3). Both oysters and shoal grass performed best at a high flow bound of approximately 2000 cfs: average PHA for oysters decreased slightly at 1800 cfs, which indicates that continued decreases in the high flow bound <1800 cfs would cause a commensurate decrease in PHA due to increased salinity; meanwhile, shoal grass showed a continued increase relative PHA area < 2000 cfs, as expected due to its preference for higher salinities (Figure 4).

Tape grass sensitivity had the opposite trend, with higher relative average PHA with both higher low flow bounds and higher high flow bounds (Figure 5); this is expected considering it is a freshwater/ oligohaline SAV species. The flow envelopes indicative of increased relative PHA for tape grass are conversely less beneficial (or detrimental) to mesohaline and marine species downstream at high flow bounds greater than 2300 cfs (Figure 3 and Figure 4).

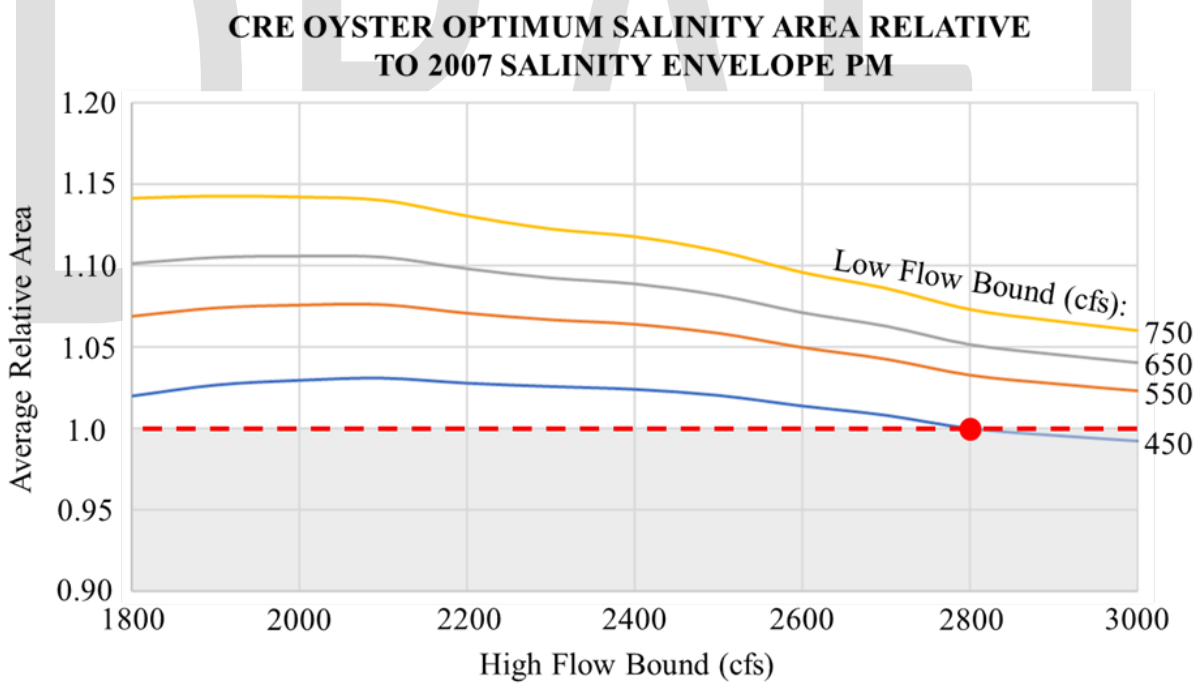

Figure *3*. *Caloosahatchee Estuary (CRE) Eastern oyster Optimum Salinity (salinities 10–25) area, i.e., Potential Habitat Area (PHA) based on 14-day average salinity, relative to the CRE 2007 Salinity PM flow envelope (red dot: 450–2800 cfs, a score of 1.0 on the y-axis). High flow bounds represented on the x-axis; low flow bounds represented by colored lines labeled to the right of the plot. Flow Envelopes above the red dashed line/grayed area indicative of an improvement in PHA by 5, 10, 15, and 20%.*

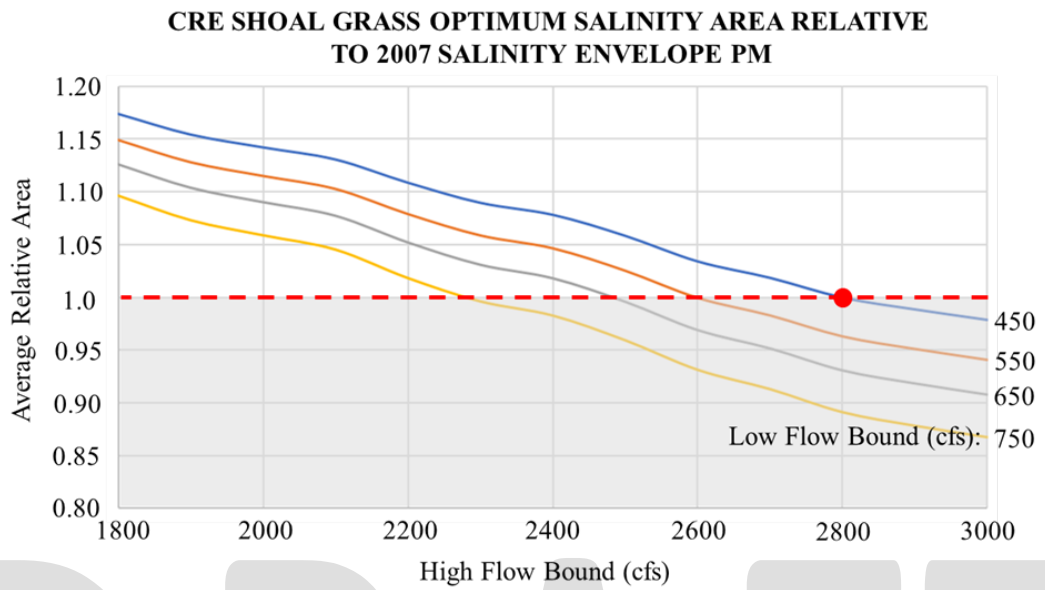

Figure 4. *Caloosahatchee Estuary (CRE) shoal grass Optimum Salinity (salinities 15–45) area, i.e., Potential Habitat Area (PHA) based on 14-day average salinity, for the shoal grass, relative to the CRE 2007 Salinity PM flow envelope (red dot: 450–2800 cfs, a score of 1.0 on the y-axis). High flow bounds represented on the x-axis; low flow bounds represented by colored lines labeled to the right of the plot. Flow Envelopes above the red dashed line/grayed area indicative of an improvement PHA by 5, 10, 15, and 20%.*

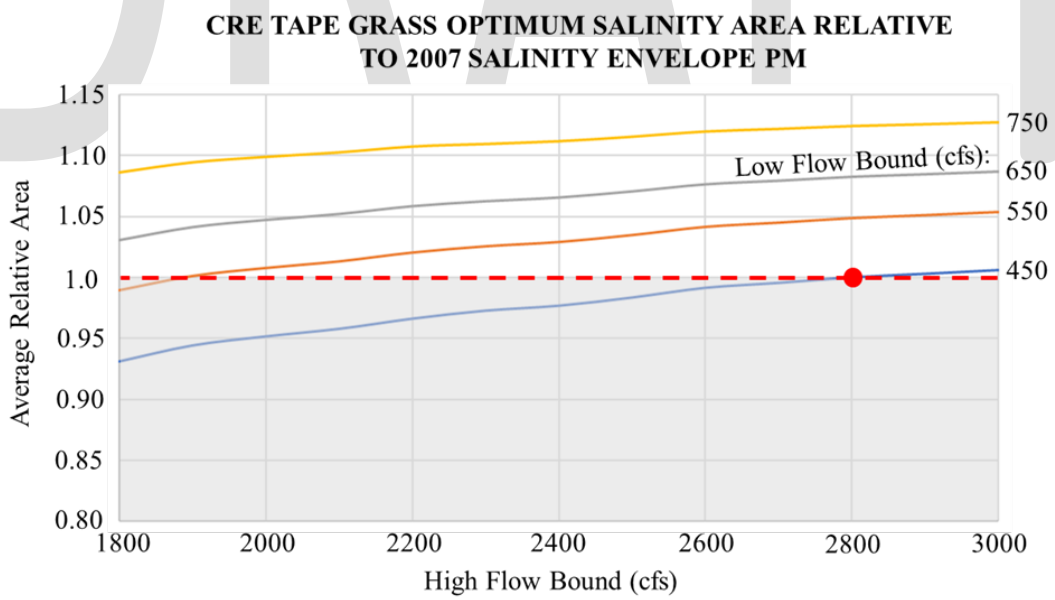

Figure 5. *Caloosahatchee Estuary (CRE) tape grass Optimum salinities (<10) area for the tape grass, i.e., Potential Habitat Area (PHA) based on 14-day average salinity, relative to the CRE 2007 Salinity PM flow envelope (red dot: 450–2800 cfs, a score of 1.0 on the y-axis). High flow bounds represented on the x-axis; low flow bounds represented by colored lines labeled to the right of the plot. Flow Envelopes above the red dashed line/grayed area indicative of an improvement in PHA by 5, 10, and 15%.*

The plots for each of the three indicators (Figure 3–Figure 5) were compared to find a "best-case" Flow Envelope most beneficial to all three ecological indicator species. To mitigate the negative impacts to mesohaline and marine species downstream at higher high flow bounds, average PHA for tape grass will still see improvement if the low flow bound is higher, more than 550 cfs (Figure 5). Therefore, flow envelope alternatives used for further evaluation for the CRE included low flow bounds no less than 650 cfs, no high flow bound lower than 2000 cfs, and no higher than 2400 cfs.

3.3 PM Tool Sensitivity

The final set of Optimum Flow Envelope alternatives for both the SLE and CRE tested were narrowed down by running each through PM post-processing tools used in CERP project alternative evaluation. Each Optimum Flow Envelope was run through these PM tools and the number of 14-day moving average excursions outside the given envelope were counted against observed flows from 1965–2005. This ensured that the target Optimum Flow Envelopes are sensitive enough to detect changes in hydrology per the implementation of new infrastructure and operations, including pre- and post-Lake Okeechobee Regulatory Schedule 2008, and several future scenarios that include the implementation of CERP projects (e.g., IRL-South; C-43).

The remaining Optimum Flow Envelope alternatives were further evaluated using CH3D model result to produce maps of the mean salinity for each alternative over the 50 year period to determine which provide a best-case for all the ecological indicators in either estuary. Maps of percent time when 14-day average salinities fall within the optimum envelope for each indicator and for each alternative were also produced to assist the evaluation and final selection of the Optimum Flow Envelopes for each estuary (Figure 10–Figure 18, Documentation Sheet).

4 LITERATURE CITED

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