Indicator 4.4 - American Crocodile

What is the desired restoration condition?

The desired restoration condition for American crocodiles is to restore freshwater flow volume and duration and thus the frequency of low salinities in Florida Bay throughout the hatchling period for optimal growth and survival of juvenile crocodiles.

Why is this indicator important and why is it a good indicator of CERP restoration?

American crocodiles rely on estuarine environments characterized by appropriate salinity regimes and freshwater inflows (Mazzotti 1999); therefore, crocodiles can be used as an indicator of the ecological condition of mangrove estuaries to evaluate restoration success in areas affected by the Comprehensive Everglades Restoration Plan (CERP). Though adults are tolerant of a wide salinity range because of their ability to osmoregulate, juvenile crocodiles lack this ability (Mazzotti 1989). Several laboratory and field studies have investigated the relationship of salinity to growth and survival in juvenile American crocodiles (Ellis 1981, Mazzotti et al. 1986, Dunson and Mazzotti 1989, Mazzotti and Brandt 1995, Richards 2003). Most of these studies have reported a negative relationship between salinity and growth rate, particularly in hatchling and juvenile crocodiles. While predation is the primary documented cause of mortality in hatchling and juvenile crocodiles in Florida (Kushlan and Mazzotti 1989), increased growth rates are hypothesized to result in increased survival rates of hatchling crocodiles by reducing their vulnerability to some predators (Thorbjarnarson 1989), though this relationship has not been empirically tested. Crocodiles are known to nest in the southern portions of Everglades National Park and Florida Bay (Figure 4.4.1). Because the CERP will affect salinity in habitats occupied by crocodiles, reduced salinity is expected to increase the productivity of prey and allow for increased juvenile crocodile growth through greater prey availability and reduced physiological stress resulting from osmotic regulation in a saline environment.

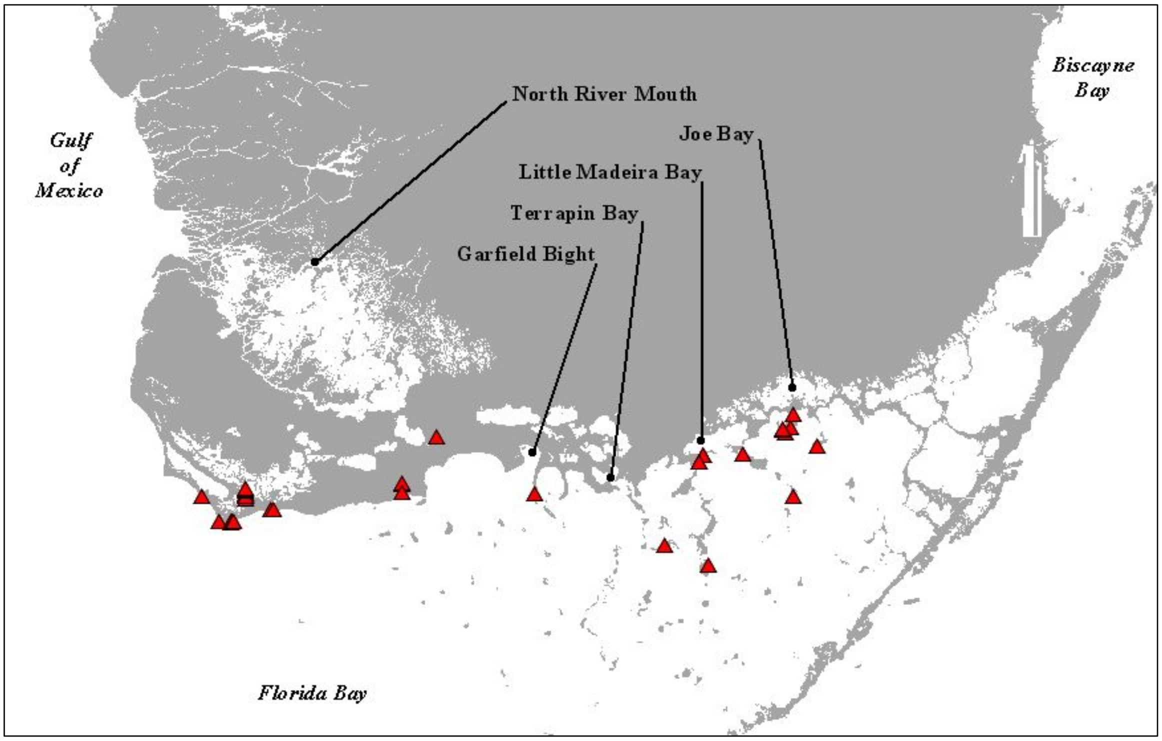

Figure 4.4.1. Known nesting sites of the American crocodile in Florida Bay

How is the interim goal for this indicator predicted?

The prediction of reduced salinity within crocodile habitat, especially nursery habitats where hatchling and juvenile crocodiles are most likely to occur, will be based on simulations of the South Florida Water Management Model (SFWMM). Salinity data for coastal basins were estimated based on relationships of salinity to water level upstream in the Everglades. The salinity data were predicted using multivariate linear regression (MLR) models developed by Frank Marshall (Marshall et al. 2003) that relate salinities in coastal embayments to upstream stages.

Detailed analyses were conducted to select the parameters for the models for each location in Figure 4.4.1. The set of parameters used in each model is the smallest possible to obtain reasonable predictive accuracy at modes and extremes of the ecosystem (i.e., the most common salinities and extreme high and low salinities). Only parameters that were significant at 0.999 were included.

Each parameter set is distinct, although some gages or other parameters are common to more than one model. Gages most directly upstream from each embayment were selected preferentially over those further away, providing they were significant in the model. This is important because the CERP will change the proportion of water released to Taylor Slough relative to the C-111 Canal, effecting Joe Bay differently than the bays to the west.

Gage stage thresholds corresponding to salinity thresholds in each embayment will be determined for each embayment. Where threshold stages at the same gage differ among embayments, the low and high stage thresholds for the embayment with the highest required stages (greatest freshwater deficit) was most heavily weighted.

The final MLR models selected are based on actual salinities and stages modeled by the SFWMM version 5.0 for the 1995 base case. The MLR models salinity models are as follows:

Terrapin Bay = 30.3 - 10.0 CP(lag1) - 2.7 E146 - 0.13 U_KW - 0.24 U_KW(lag1) - 0.1 V_KW - 0.21 V_KW(lag2) + 4.4 KWSL(lag2)

North River Mouth = 38.1 - 2.9 CP - 4.2 NP206(lag3) - 3.7 NP46(lag2) + 3.1KWSL(lag2)

Little Madeira = 43.6 - 2.9 (EVER4-EVER6) - 1.5 CP - 4.0 CP(lag21) - 1.9 R127(lag8) - 2.4 P33 - 0.15 V_MIA(lag1) + 4.2 KWSL

Joe Bay = 72.1 - 6.9 (P33-P35) - 6.2 E146 - 7.1 EVER6 - 5.8 P35(lag7) - 0.1 U_KW - 0.1 U_MIA(lag1) - 0.15 V_MIA(lag1) + 7.4 KWSL(lag2)

Garfield Bight = 39.4 - 5.0 CP - 6.5 NP46(lag1) - 0.25 U_KW - 0.12 U_KW(lag2) + KWSL(lag1)

Where KWSL is the water level measured at Key West; U_MIA and V_MIA are the U and V vectors of wind as measured at the Miami weather station; and U_KW and V_KW are the U and V vectors of wind measured at Key West. These components are computed as follows: U = (Resultant wind speed) * Cosine (Resultant direction); V = (Resultant wind speed) * Sine (Resultant direction). Resultant wind speed and direction are the daily average values as reported in the National Weather Service data archives. The other variables in the models are daily average stage at indicated Everglades National Park stage gages, lagged by number of days indicated. The R2 values for these models were as follows: Joe Bay (0.86), Little Madeira Bay (0.79), Terrapin Bay (0.78), Garfield Bight (0.69), and North River (0.87).

During the prediction process, cells in the SFWMM that correspond to the locations of the gages used in the equations were identified. Then the stage output for those cells was acquired from the 31-year model simulations for each alternative. The appropriate stage output from the SFWMM was used in each MLR model to predict a daily salinity time series for each embayment.

For all CERP model runs, the frequency of months from July 1 - November 31 during which the salinity was less than 20 parts per thousand (ppt), 20-40 ppt, and greater than 40 ppt was calculated for Joe Bay, Little Madeira Bay, Terrapin Bay, Garfield Bight, and North River Mouth. The July through November period was used because it is the primary growth period for hatchling American crocodiles (Mazzotti 1989, Moler 1991). Salinity greater than 20 ppt has been correlated with a decrease in juvenile growth rates and survival (Dunson and Mazzotti 1989), and salinity below 20 ppt likely result in improved growth rates and survival. Therefore, the lower salinity range represents the potential for rapid growth of crocodile hatchlings, while the intermediate and high salinity categories represent conditions that could promote moderate and low hatchling growth, respectively (Mazzotti and Brandt 1995, Mazzotti et al. 2002).

What are the predictions for five-year increments?

The predictions for each known nesting site are as follows:

- **Terrapin Bay** - The frequency of optimal salinities between the 1995 (baseline), and 2010, 2015, and D13R (full CERP implementation) runs increases and should provide improved conditions for growth and survival of juvenile crocodiles (Figure 4.4.2). Overall, the interim and full CERP simulations may only provide very small benefits versus the 2050 (future without the CERP).

- **North River Mouth** - The model simulations do not show any differences in the frequency of optimal salinities at the North River Mouth (Figure 4.4.3.

- **Little Madeira Bay** - Small improvement in the frequency of optimal salinities were predicted for Little Madeira Bay (Figure 4.4.4).

- **Joe Bay** - The model simulations do not show any improvements in the frequency of optimal salinities at Joe Bay (Figure 4.4.5).

- **Garfield Bight** - The model simulations do not show any improvements in the frequency of optimal salinities at Garfield Bight (Figure 4.4.6).

Overall, some reductions in the frequency of months with high salinities were observed in the 2010, 2015, and D13R model predictions. Though any improvement may be expected to result in small, incremental improvements in habitat suitability, it is unlikely that such small increases will result in measurable increases in juvenile growth and survival. Further reductions in the frequency of months with mean salinities above 20 ppt would be more likely to benefit hatchling crocodiles.

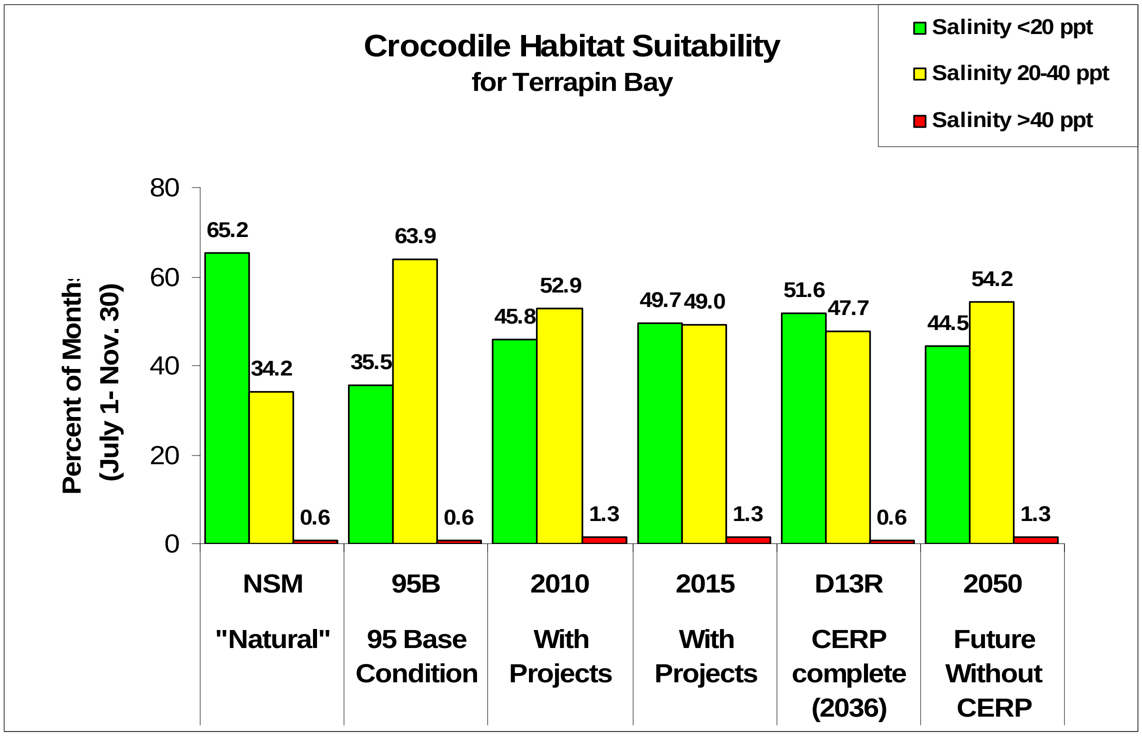

Figure 4.4.2. Predicted American crocodile habitat suitability in Terrapin Bay based on mean monthly salinity from July through November

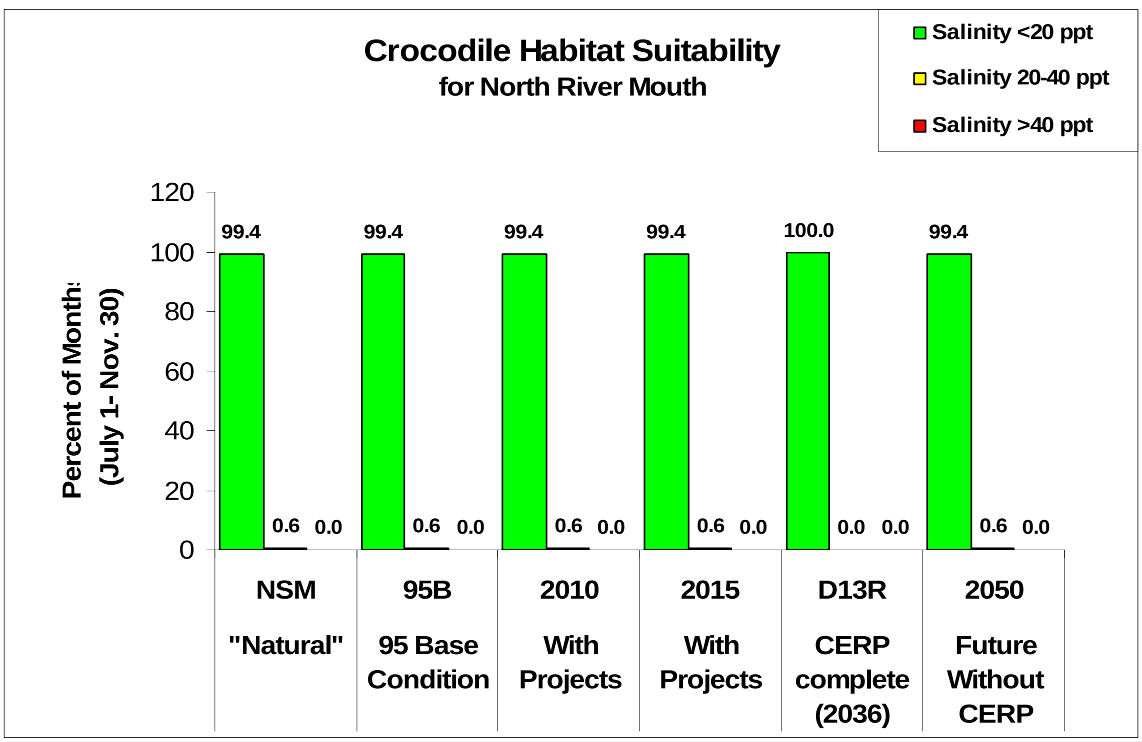

Figure 4.4.3. Predicted American crocodile habitat suitability in North River Mouth based on mean monthly salinity from July through November

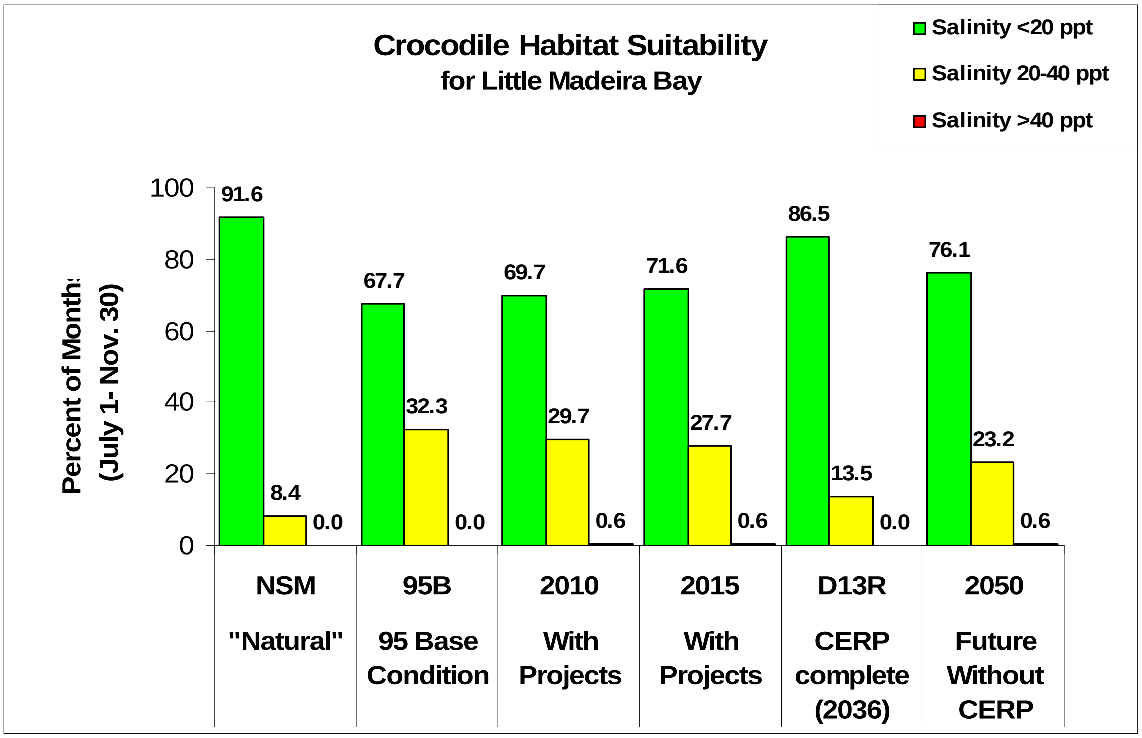

Figure 4.4.4. Predicted American crocodile habitat suitability in Little Madeira Bay based on mean monthly salinity from July through November

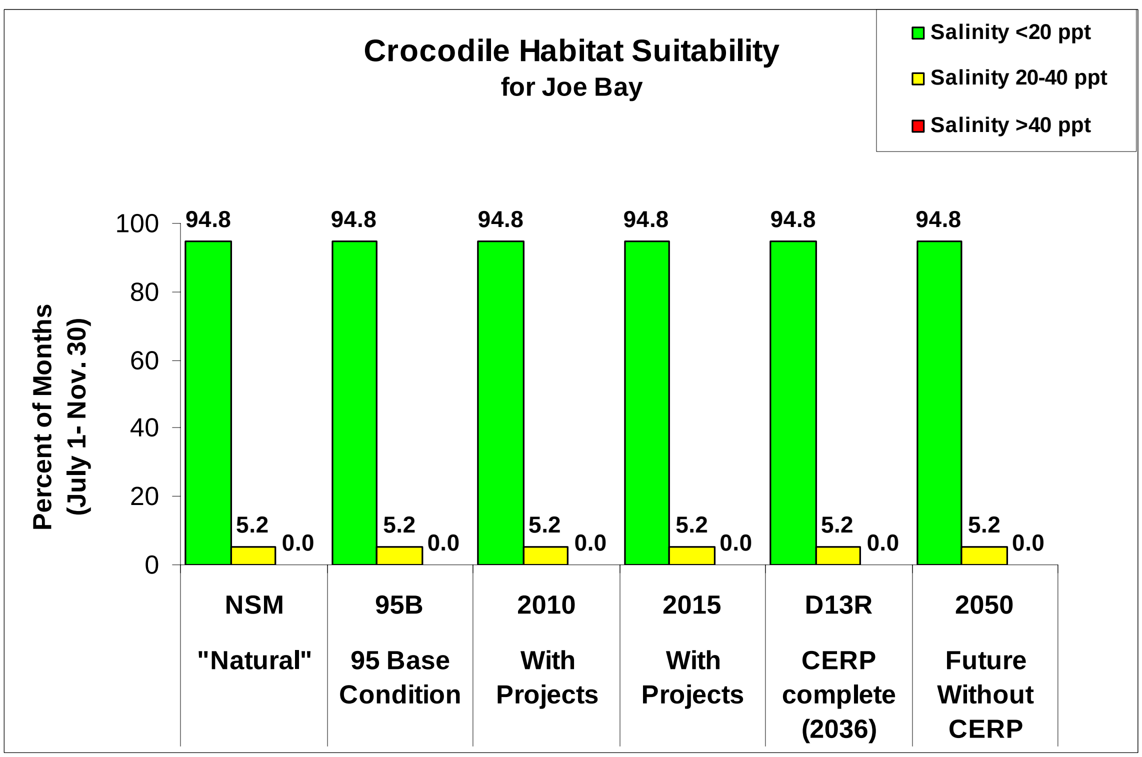

Figure 4.4.5. Predicted American crocodile habitat suitability in Joe Bay based on mean monthly salinity from July through October.

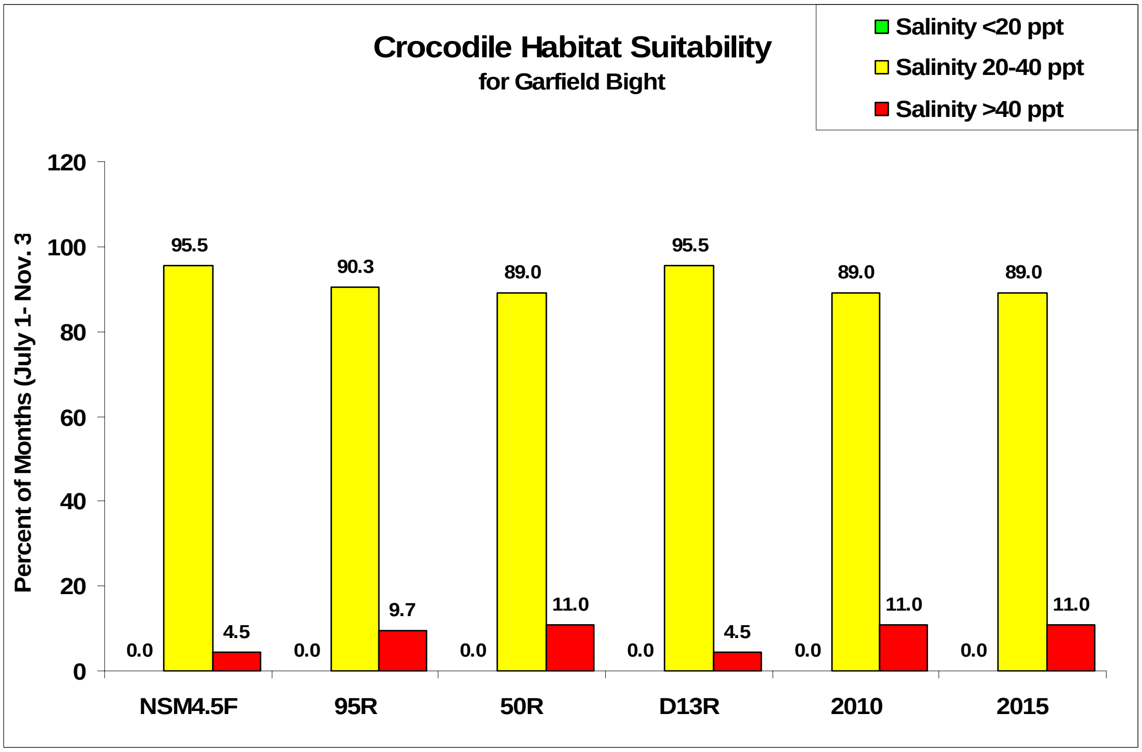

Figure 4.4.6. Predicted American crocodile habitat suitability in Garfield Bight based on mean monthly salinity from July through November

How will we track whether the interim goals established for this indicator have been achieved?

The *CERP Monitoring and Assessment Plan: Part 1, Monitoring and Supporting Research* includes monitoring of American crocodile juvenile growth and survival (RECOVER 2004). Surveys will be conducted using methods described in Mazzotti and Cherkiss (2002). Surveys for crocodile nests will be conducted April through August in Biscayne Bay and Florida Bay from Crandon Park to Shark River. Nests will be monitored through incubation, and hatchlings will be captured, measured, and marked upon emergence. Surveys and captures of juvenile crocodiles will be conducted four times per year in the same areas (early nesting, late nesting, and twice in the winter dry season). All animals will be weighed, measured, sexed, and given an individual mark. At each capture, location using a global positioning system [GPS], salinity, and temperature will be recorded.

What additional work is needed to improve this interim goal?

The MLR models will be improved over time. Other models may later be used to relate salinity to modeled upstream water conditions. The basin models under development by Nuttle, or the Southern Inland and Coastal Systems or Tides and Inflows in the Mangrove Ecotone Model by the United States Geological Survey may be used alongside the MLR models or replace them if they prove more capable of approximating the distinct changes in salinity patterns in the individual. The current version of the Southern Inland and Coastal Systems Model represents a five-year period from January 1995 to December 1999 and comparisons between observed and simulated values of flow, stage, and salinity suggest that this model provides a good representation of the physical system, although additional effort is needed to be able to use the model to evaluate the effects of the CERP in coastal wetlands and South Florida estuaries (Langevin et al. 2003). Because the calibrated Southern Inland and Coastal Systems model only represents a five-year period of record, conditions will be modeled separately for each five-year evaluation period. The model assumes completion of CERP project features as scheduled. Boundary conditions for expected future conditions will include canal flows and stages at South Florida gages that are generated from SFWMM. Weather patterns (wind and temperature) will be modeled for all simulations as the 1995-1999 period of record for the model domain. The Southern Inland and Coastal Systems Model should continue to be calibrated, and should be adopted in the future for evaluating expected salinity and crocodile growth and survival.

The research relating salinity to growth and survival is sparse and should be refined to improve our understanding and justification for these predictions of crocodile hatchling survival relative to hydrology and salinity. Specifically, it will be important to obtain population- and location-specific information on crocodile suitability relative to local salinity variability and on nearby sources of fresh water. Finally, a crocodile hatchling survival model should be developed and coupled with a fine-scale salinity model to allow for more accurate predictions of the effect of the CERP.

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