U.S. Army Corps of Engineers

Galveston District
Southwestern Division

Houston Ship Channel Expansion Channel Improvement Project, Harris and Chambers Counties, Texas

Final Integrated Feasibility Report–Environmental Impact Statement

APPENDIX O

HABITAT MODELING REPORT AND COST EFFECTIVENESS/INCREMENTAL COST ANALYSIS

November 2019

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1.0 INTRODUCTION

The USACE planning regulation applicable to feasibility studies, Engineering Regulation (ER) 1105-2-100, Planning Guidance Notebook (PGN) requires project-caused adverse impacts to significant ecological resources be avoided or minimized to the extent practicable, and that remaining, unavoidable impacts be compensated to the extent justified through mitigation (USACE 2000). The National Economic Development plan (NED) and the Local Preferred Plan (LPP) for the Houston Ship Channel (HSC) Expansion Channel Improvement Project (HSC-ECIP) would have unavoidable impacts to oyster reef lining the HSC and Bayport Ship Channel (BSC) from the various measures comprising the NED and LPP such as channel widening, bend easings, and turning basins. The LPP includes all of the NED features plus additional features that for this analysis would be called Increment LPP. The oyster reef habitat mitigation plan is provided in **Appendix P**. The PGN and other mitigation planning regulations require impacts and mitigation for those impacts to be quantified. Habitat units calculated using habitat evaluation procedures or similar methodology are one acceptable way to measure impacts and mitigation planning outputs. These are calculated using habitat models that quantify the functions provided by the impacted habitat.

USACE planning regulations also require that project impacts to significant resources be forecasted, and compared and contrasted with the condition of these resources without the project over the project period of analysis. The period of analysis is the time required for implementation of a project plus 50 years for this type of project (deep draft navigation). This report describes the habitat modeling procedures used to calculate the with-project impacts to oyster reef and compare them to the without project condition of the impacted reef. The report also provides the Cost Effectiveness Incremental Cost Analysis (CE-ICA) for the NED and LPP at this stage of planning. The report would be updated once the NED and LPP are refined in the next planning phase following the release of the Draft Integrated Feasibility Report and Environmental Impact Statement (DIFR-EIS).

2.0 MODEL SELECTION

USACE Civil Works policy in the CECW-CP policy memorandum *Policy Guidance on Certification on Ecosystem Output Models*, dated August 13, 2008, requires that only standard habitat models already certified by the USACE Ecosystem Planning Center of Excellence (PCX) be used to determine mitigation, or that models proposed for use undergo the model certification process outlined by the USACE. The Oyster Habitat Suitability Index Model (OHSIM) developed by Swannack *et al.* (Swannack *et al.* 2014) was certified under the process mandated by this memo and was selected for use in this mitigation plan. This model is a modification of a 2012 suitability index model that follows the methodology in the USFWS habitat suitability indices (HSI) model for the Gulf of Mexico American Oyster (Cake 1983). Reefs in Galveston Bay are predominantly American oyster. An associated spreadsheet was also certified that uses this model was selected to be used to assess the reef function and quality (Young. 2018).

3.0 RESOURCE AGENCY COORDINATION AND INPUT

The agency coordination during the initial Scoping phase and subsequent NED and LPP phase of this feasibility study include several agency stakeholder meetings, which resulted in the formation of an Oyster Subcommittee to focus on the issue of oyster reef impact quantification, mitigation, and habitat modeling. The National Marine Fisheries Service (NMFS), Texas Parks and Wildlife Department (TPWD), Texas General Land Office (TGLO), and U.S. Fish and Wildlife Service (USFWS) elected to participate in the Oyster Subcommittee. The OHSIM model was first introduced during the September 29, 2016 resource agency meeting update conducted during the Port of Houston's Beneficial Uses Group (BUG) meeting, which coordinates with these resource agencies for all Port projects involving the construction and maintenance of the Federal navigation channels and beneficial use of that dredged material.

The OHSIM model was presented in more detail and discussed during the first Oyster Subcommittee teleconference on January 19, 2017. The reason it was selected (USACE-certified), its origins (abridged version of the Gulf of Mexico American oyster USFWS HSI), and an overview of model variables were discussed. Basic period of analysis assumptions for growth, regrowth and progression of impacted and mitigated reef, were also discussed to gain resource agency input. This input was incorporated into the assumptions used for modeling.

4.0 POTENTIAL MITIGATION SITES

The potential mitigation sites were identified in coordination with the resource agencies. These sites are shown in **Figure 1** and most represent reefs that were impacted by sedimentation during Hurricane Ike in 2008 and targeted for restoration efforts by TPWD. The selection basis is discussed in detail in the Mitigation Plan provided in **Appendix P**. Currently, the HSC-ECIP has completed the Feasibility-Level Analysis milestone phase of the U.S. Army Corps of Engineers (USACE) Specific, Measurable, Attainable, Risk Informed, Timely (SMART) Civil Works planning process. Changes may still occur in the Preconstruction Engineering Design (PED) phase as to the final size and list of measures that make up the NED and/or LPP. The proposed method for mitigation, discussed later in this report, would involve beneficial use of dredged material to build the relief off the bay floor for capping with suitable cultch. Many factors that may affect the decision to select a particular site with respect to both dredging and the proposed method, such as final dredge material quantities, and construction sequence, would be analyzed in the next planning phase. More detailed design considerations for site selection such as foundation conditions and constraints may influence specific site(s) selected. Also, further coordination and input from the resource agencies on the desired part of the Bay to restore is planned, which would influence selection. These sites represent a range of average salinities that influence the quality of the habitat with respect to the OHSIM model as discussed later in the report. Therefore, the modeling at this study phase focused on the most optimal sites (Dollar and San Leon) in terms of the quality indicated by the OHSIM model (shown as the HSI scores in **Figure 1**) and salinity associated with these sites.

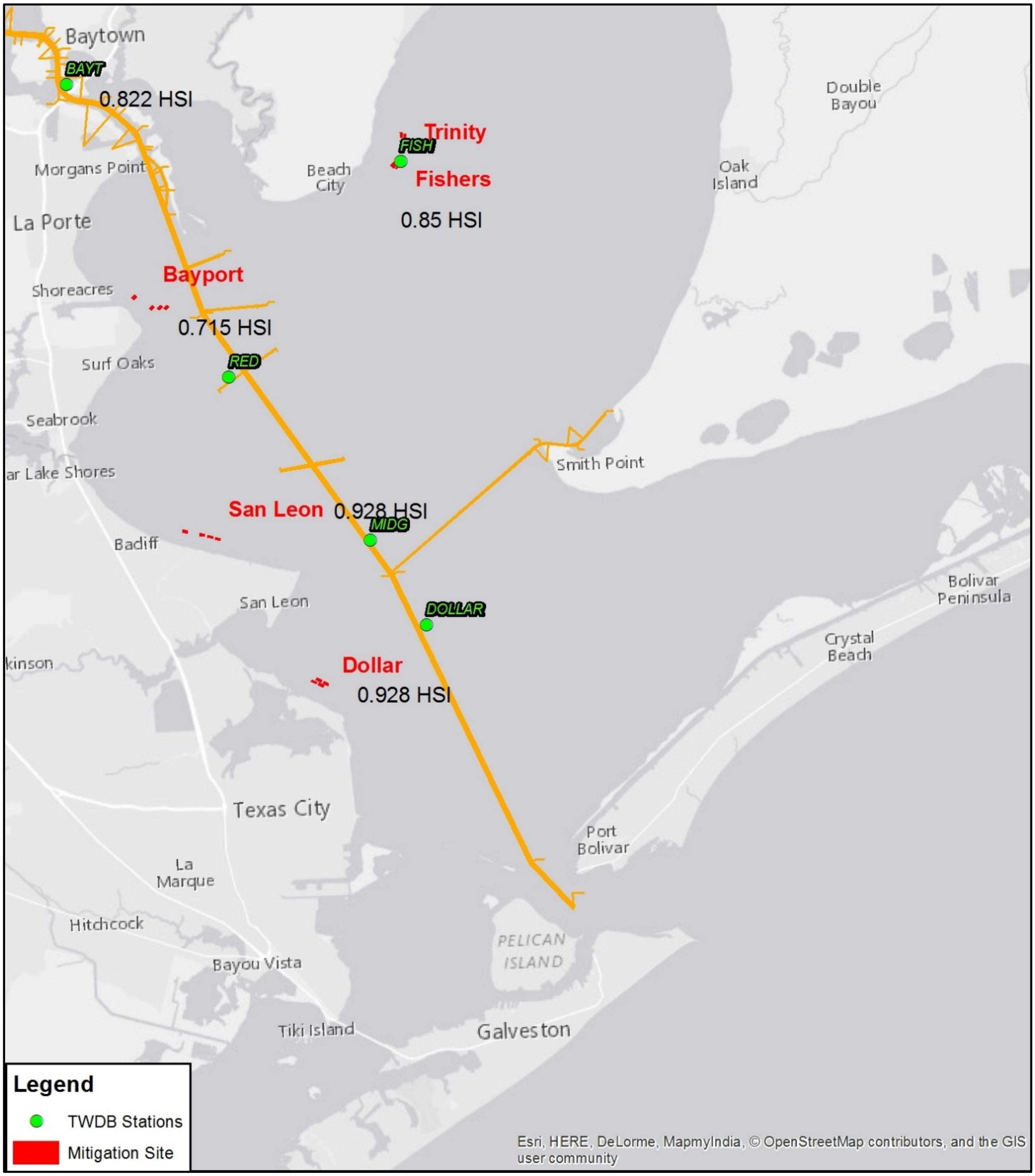

Figure 1 – Potential Mitigation Sites

5.0 FUNCTIONAL MODEL PROCEDURE

The determination of significant net losses over the period of analysis requires forecasting future habitat conditions, and the associated functional or habitat units (HU) over the period of analysis and calculating average annual habitat units (AAHUs) that express the average habitat quality over time, in a time-weighted fashion. The HUs available in the reef habitat are calculated simply by multiplying the HSI of the given reef by the area of the reef. Next, the condition of the habitat into the future is projected, over the period of analysis to determine what the value of the habitat would be at certain points in time (target years [TY]), when a change in habitat conditions is likely to occur. The HSI changes accordingly. Finally, AAHUs are calculated in accordance with the HEP methodology in USFWS Ecological Service Manual (ESM) 102, (USFWS 1980). This calculation requires annualizing HUs by summing cumulative HUs for all time intervals in the period of analysis and dividing the total by the number of years in the period of analysis, resulting in AAHUs. The cumulative HU term provides simplified integration of HSI scores over time, to provide time-weighting of habitat value. The certified spreadsheet calculated these values automatically.

This section explains how the model was used to calculate HUs and AAHUs. The OHSIM model was used to assess the quality of impacted reef and proposed mitigation to calculate HSI scores. The following subsections detail the process.

5.1 OHSIM Model Background

The OHSIM model is a modification of an Eastern oyster habitat suitability index model by Soniat (2012) which followed the methodology established by Cake (1983) and Soniat and Brody (1988) [Swannack *et al.* 2014]. The model uses four variables: three are related to salinity, and one related to substrate. Each variable is used to calculate a dimensionless oyster suitability index (OSI) value representing the relationship between an environmental variable and a stage of the oyster's life history. Each OSI is represented by a linear suitability curve, with a minimum value of 0 for unsuitable to 1.0 for optimal habitats. A restoration suitability index (RSI) is calculated as the geometric mean of the four OSI values to represent the overall suitability of a particular location. The details and suitability curves of the model are discussed in the paper, *A Robust, Spatially Explicit Model for Identifying Oyster Restoration Sites: Case Studies on the Atlantic and Gulf Coasts* (Swannack *et al.* 2014).

5.2 Model Variable Inputs

The following bullets summarizes the four variables used in the OHSIM model:

- % Clutch – Percentage of the bottom covered with hard substrate (e.g., oyster shell or other suitable bottom) or other hard surfaces (e.g., limestone, concrete, granite, etc.).
- MSSS – Mean salinity during the spawning season calculated by averaging daily values of salinity from May 1 through September 30th.
- MAS – Minimum annual salinity is the minimum value of the 12 monthly mean salinities.
- AS – Annual mean salinity is calculated by averaging mean monthly salinity values

The four OSI are used in the following formula to obtain the Restoration Suitability Index (RSI) which is synonymous with the HSI:

$$RSI = (OSI_{AS} \times OSI_{MAS} \times OSI_{MSSS} \times OSI_{Cultch})^{\frac{1}{4}}$$

The following subsections explain how data or assumptions were used to provide values for these variables.

5.2.1 Cultch

Natural reef in Galveston Bay is comprised of varying densities of sea floor coverage at a local scale, where 100 percent of the bay surface area may not be covered by shell or hard substrate. Mapping from side scan sonar results in generalized extents around these areas and does not reflect local scale coverage of the sea floor. Absent of quadrat dive surveys of the mapped extent, percent coverage data at a local scale is not available.

The TPWD 2012 side-scan sonar data does not provide for percent coverage by cultch by area. From limited diving surveys around the confluence of the BSC and HSC for the BSC Improvements Project by the Port of Houston Authority (PHA), indications were that reef lining the HSC were mixtures of denser substrate ranging from 50 percent to 75 percent coverage to fully consolidated reef (100 percent coverage). To be conservative, all areas indicated by TPWD were determined to be 100 percent culch for this modelling. This mapping is explained in more detail in **Section 5.1** of the Mitigation Plan in **Appendix P** and its **Attachment 2018 Oyster Groundtruthing Report** (2018 Report).

For the areas mapped for the 2018 Report, the potential oyster reefs identified by the side-scan sonar were field reviewed and placed into four groups: consolidated reef, hard-bottom; reef building or higher recruitment; scatter shell, little recruitment; and scattered shell, no recruitment. For the model, the identified consolidated reef, hard –bottom was classified as 100 percent cultch; reef building or higher recruitment and scatter shell, little recruitment groups were classified as 50 percent coverage and scattered shell; and no recruitment was classified as 0 percent cultch. The 2018 Report is an attachment to **Appendix P**. The areas mapped by TPWD and by the 2018 Report supersedes earlier mapping by 1991 Powell historical reef mapping conducted for the Galveston Bay National Estuary Program (GBNEP) and was not used for this modelling study (Powell et al. 1997)

The values for percent cultch of the existing reef under with-project conditions, and for mitigation, are based on assumptions explained in **Section 5.4**, **Assumptions**.

5.2.2 Salinity

The three salinity variables are averages over different periods within a year, ranging from averaging of daily values to averaging of monthly averages. Salinity varies widely seasonally with changes in freshwater inflow from storm events (i.e. freshets) or drought, and can change significantly daily during storm events. Values can vary within a day due to the tides with inflows and outflows of sea water. Average values within an estuary also vary by location with more saline values seaward, and fresher values further upstream. The best data would capture these variations over the course of several years of seasonal events. The best available data with a long period of record over the several regions of Galveston Bay is the continuous data collected for the Estuary Monitoring Program under a partnership between the Texas Water Development Board (TWDB) and TPWD which started collection in 1986 in State estuaries including Galveston Bay. Data is collected via continuously monitoring buoyed instruments (datasonde) that measure salinity at least hourly. The datasondes have been deployed throughout Galveston Bay through different time periods from 1986 to present.

Data was obtained from the TWDB's web portal for distributing this data (https://waterdatafortexas.org/coastal). Of 10 datasonde stations located throughout the Bay, five were initially chosen because they best represented geographically the area of reef impact by the NED and the geographic spread of the candidate mitigation sites. The hourly data was averaged by the appropriate time periods (monthly, daily, spawning months etc.) associated with the variable definitions given in Section 5.2, using Microsoft Access. OSI's for these salinity variables were calculated to further screen the sites to see how they affected the RSI scores for possible station reduction, and to frame the least and most optimal sites in terms of mitigation sites. Two stations (Mid-Galveston Bay and Dollar Point) were found to yield the same quality scores and were the most optimal sites. One station (Red Bluff) was found to be the least optimal. Therefore, the sites that captured the geographic extent of the NED reef impact and the least and most optimal potential mitigation sites were the following three, with the indicated period of record, in upstream to downstream order:

- Baytown (4/17/2001 through 1/11/2016)
- Red Bluff (5/14/1990 through 5/04/1999)
- Mid-Galveston (2/07/2001 through 1/11/2016)
- Dollar (1/30/1987 through 9/13/2000)

These four stations represent the salinity regimes characterizing the average salinities that the impacted reef and restored reef sites would experience. Though not all stations overlap through a common time period, the period of record at each was long enough to capture high outflow and drought cycles within their periods of record and would reflect long term averaging of the wide variability and position in the Bay. These data were compiled and averaged to determine the three salinity variables for each salinity regime. For the extent of the mapped reef, the HSC was divided into three segments that correspond to the three salinity regimes, and the acreage of mapped reef was calculated for segment.

Accordingly, the potential mitigation sites shown in **Figure 1** closest to the least and most optimal salinity regime were selected and assigned those stations' salinity values. These were the least optimal mitigation site of Bayport, assigned to the Red Bluff salinity regime, and the San Leon Reef or Dollar Reef mitigation sites, assigned to the Mid-Galveston salinity regime. As shown in **Figure 1**, the resultant HSI score using the salinity is the same for either San Leon Reef or Dollar Reef; therefore mitigating at either site would yield the same required mitigation acreage.

5.3 Certified Spreadsheet Procedure

The certified spreadsheet was used to implement the OHSIM model calculations. The certified spreadsheet provides an easy way to quantify benefits and impacts of changing habitat communities, and ecosystem functions. The certified spreadsheet allows entry of basic before and after values, and calculates AAHUs under various with and without project scenarios and timelines. The certified spreadsheet employs the concept of habitat cover types to represent the various types of habitat impacted or restored, their condition or quality, and the acreages of each through time. The following were conditions associated with existing reef that would be impacted, and mitigation site that would be restored. The values entered depended on assumptions described in the next section.

% Cultch At impacted reef

- 100 percent for TPWD mapped reef areas
- 100 percent for areas in 2018 Report mapped as consolidated reef and
- 50 percent for areas reef building or higher recruitment and scatter shell, little recruitment groups to simplify the calculations the total acreage of this group was divided by 2 and added to the total of the above acres

Salinity values for MSSS, MAS. and AS at impacted reef

- existing reef in the Baytown salinity regime
  a. MSSS = 12.23
  b. MAS = 8.68
  c. AS = 12.78
- existing reef in the Red Bluff salinity regime
  a. MSSS = 11.66
  b. MAS = 6.51
  c. AS = 11.65
- existing reef in the Mid-Galveston salinity regime
  a. MSSS = 17.88
  b. MAS = 13.68
  c. AS = 18.08

  d. Existing reef in Dollar salinity regime
  e. MSSS = 17.66
  f. MAS = 14.19
  g. AS = 17.84

% Cultch At mitigated reef – 100%

Salinity values for MSSS, MAS. and AS at mitigated reef are same as existing reef in Mid-Galveston salinity regime

a. MSSS = 17.88
b. MAS = 13.68
c. AS = 18.08

Assumptions

To project conditions of the reef, the following was considered: the nature of the extent of reef, its accretion along the channel, previous assumptions and knowledge of growth in the Houston-Galveston Navigation Channel (HGNC) feasibility study, and feedback/coordination with resource agencies. Also the way mitigation would be conducted enables assumptions of the conditions of restored reef. The following subsections discuss these assumptions.

5.3.1 Cultch Without and With Project Assumptions

Without Project

Natural reef waxes and wanes in extent due to various events and changes in the environment such as periodic prolonged salinities that are too high (drought) or low (freshets), diseases like *Perkinsus marinus*, hurricanes that may smother reef, and commercial harvesting (which has been suggested to expand horizontal extent, though suppressing vertical relief). From the Powell historical mapping and more modern TPWD mapping and 2018 Report, the reef extent is constant and continuous along the HSC. The report for the Powell survey found that in comparing the 1991 reef survey to mapping available earlier in the century that the largest gain in the upper Bay had been along the HSC, presumably due to more favorable local salinity and current conditions that changed when the HSC was dredged. The extent appears more solid and continuous in areas comparing the Powell mapping to the more recent TPWD mapping and 2019 Report for areas covered in common, especially at the margins of the current HSC where most of the impact would occur. The zone between the 20-foot depth contour and old spoil bank along the HSC was also called prime reef growth area in the Fish and Wildlife Coordination Act Report (FWCAR) for the 1995 Houston and Galveston Navigation Channels (HGNC) Limited Reevaluation Report [LRR] (Appendix E, USACE 1995). Therefore, given these trends and information, and time periods involved, it can be assumed the reef would continue to be there through the period of analysis without a project. It was assumed that percent cultch would remain at the optimal value through the period of analysis as the area would not be removed by dredging. In the spreadsheet, this was represented by a 100 percent cultch value being present through the 50 year period of analysis.

At the mitigation site, restoration would occur where no hard substrate is available and avoid restoration over extant reef. Burial by Hurricane Ike was part of the reason these candidate sites were proposed by restoration. Confirmation of the absence of extant reef would be achieved through pre-restoration site surveys or use of existing post-Ike side scan imagery to target areas where only soft bottom conditions exist. Therefore the assumption was made that percent cultch at the mitigation site before restoration (i.e. without project condition) is zero (0). In the certified spreadsheet this condition is zero (0) percent cultch being present throughout the 50-year period of analysis.

With Project

In the with-project condition for the existing reef, the NED or LPP channel modifications would be dredged, and the existing reef would be removed. The channel would be excavated to depths greater than the typical vertical relief (<18 inches) and all reef would be removed in the dredge footprint. Reef regrowth has occurred in the existing HSC margins from the 20-foot depth outward, consistent with what was assumed would happen in the HGNC LRR. It also regrew in the dredged barge lanes adjacent to the main channel. This is discussed in more detail in the **Section 7.2.2.3** of the DIFR-EIS, and **Section 5.3** of the Mitigation Plan in **Appendix P**. This regrowth phenomena was discussed with resource agencies during the Oyster Subcommittee Meetings on January 19, 2017, and revisited during the May 17, 2018 BU meeting. Many factors that haven't yet been robustly studied could be responsible, such as exposure of old geologic shell, sidecasting of the stiff clays making up the Beaumont formation geology of the bay bottom, among other possibilities. Without a time-series of sonar scans following dredging, the rate and timing of regrowth would be speculative. Based on these discussions, the responsible factors are complex and not yet well-investigated, and the specific amount of regrowth expected is not yet predictable with any confidence. Some of the factors thought to be responsible that would be required to establish confidence of regrowth, such as geologic shell presence, would require geotechnical data not yet available in the feasibility phase. Therefore, in the with-project condition, the existing reef percent cultch was assumed to be zero (0), and recovery of the extent through regrowth through the period of analysis was not assumed. In the certified spreadsheet, this was represented as zero (0) percent cultch value being present at Year 1, when construction impacts the reef and through the 50 year period of analysis.

In the with-project condition for the mitigation reef, the reef would be constructed to provide a continuous surface area of hard substrate by placement of suitable cultch material like cleaned, crushed limestone or crushed concrete that has been demonstrated to recruit oyster spat successfully in this bay and others in the U.S. The continuous surface area would effectively provide a 100 percent cultch coverage once placed. However, the OHSIM model does not have a live oyster variable (e.g. live oysters per square meter [m^2]) to account for the successful recruitment and progression of growth to a living reef. During the initial January 19, 2017 subcommittee meeting, resource agencies expressed a desire to have this aspect of a successfully restored reef reflected in the modeling. The key expectation and assumption incorporated into the modeling was that a functional reef would not be present until Year 3, until initial oyster recruits could reach full adult stage and harvestable sizes, renewing an assumption used in the HGNC oyster mitigation determination. The basis for the HGNC assumption is described in the FWCAR of the 1995 HGNC LRR, which documents the expectation of functional recovery in 3 years, and supporting observations from oyster ecology experts from experimental reefs and oil exploration shell drilling pads. This is consistent with modern observations and literature for the American oyster growth in the Gulf of Mexico (TPWD 2010, NOAA undated). Because the OHSIM does not have a live oyster density-based variable, the assumption was implemented by making the restored reef cover type % Clutch appear in Year 3, to reflect the attainment of functional reef and the maximum score of 100 percent for percent cultch. To summarize, in the with-project condition (mitigation constructed) at the mitigation site, the site would reflect a zero % Clutch cover for Year 1 (even though cultch is placed) and become restored reef with the optimal score of 100% at Year 3 to mimic the live growth progression, continuing at 100% through the rest of the 50 year period of analysis.

5.3.2 Salinity

Without Project

The salinity of the Bay fluctuates year to year in response to events such as drought and freshets and other periodic natural phenomena as previously discussed. Other man-made changes on land that can influence salinity are changes such as those to normal freshwater inflows from water being diverted or returned to streams for supply or sewerage. Diversions from streams for water supply decreases inflow from the stream where water is diverted from, while increased development and sewage and drainage return result in increases in freshwater inflow. These types of changes have been the subject of studies attempting to forecast how this could affect estuaries. Most notably, studies by TWDB to determine freshwater inflows for water availability and environmental flow planning purposes have examined this through modeling studies, including for Galveston Bay.

A more recent study modeled various inflow scenarios of 1) maximum water rights usage with no return, 2) anticipated demands and strategies exercised, 3) a TPWD-desirable ecological productivity inflow, and 4) minimum inflow necessary to meet identified salinity and ecological constraints (Guthrie *et al.* 2012). Scenarios 1 and 2 represent demands and conditions for the Year 2060. For Scenario 1 where anticipated demands and strategies are implemented (the most expected scenario), the change in median daily salinity was an increase of 1 part per thousand (ppt), and was very consistent with existing conditions in terms of frequency of occurrence of the desirable 10-20 ppt salinity range events. Scenario 2, which is a more extreme case of full demand and not return, had a median daily salinity increase of 4 ppt. There was little effect on frequency of occurrence of the desirable 10-20 ppt salinity range events in the upper Bay, but the number low salinity events (<10 ppt) decreases. In the lower Bay, Scenario 2 decreases desirable 10-20 ppt salinity range events and increases high salinity events (>25 ppt). Given that Scenario 1 would be more likely as there would be returns expected and water planning and conservation strategies would be implemented. Given this information, salinity in the Bay in the future would not change significantly if these strategies are implemented.

To see how salinity might have been changing using monitored data, annual average salinities from the various TWDB stations were calculated and plotted with simple linear trend lines, and polynomial lines that are often used for data that fluctuates greatly, such as the salinity values shown. These are shown in **Figures 2** through **4** for the TWDB stations used. The annual averages. For all but the Baytown station, the linear trend showed almost no increase or only very slight increase of 1 to 2 ppt, while the polynomial trend showed a rise and fall almost to the same starting values over the period. The Baytown station shows a linear trend upward of around 4 to 5 ppt while the polynomial shows a rise and fall ending up about 4 to 5 ppt higher. This station is in a narrower river mouth part of the estuary with several streams converging, including Buffalo Bayou and San Jacinto, two of the major drainages into the Bay. Therefore, it may be prone to greater fluctuations to drought condition inflows as well as freshets than the other stations.

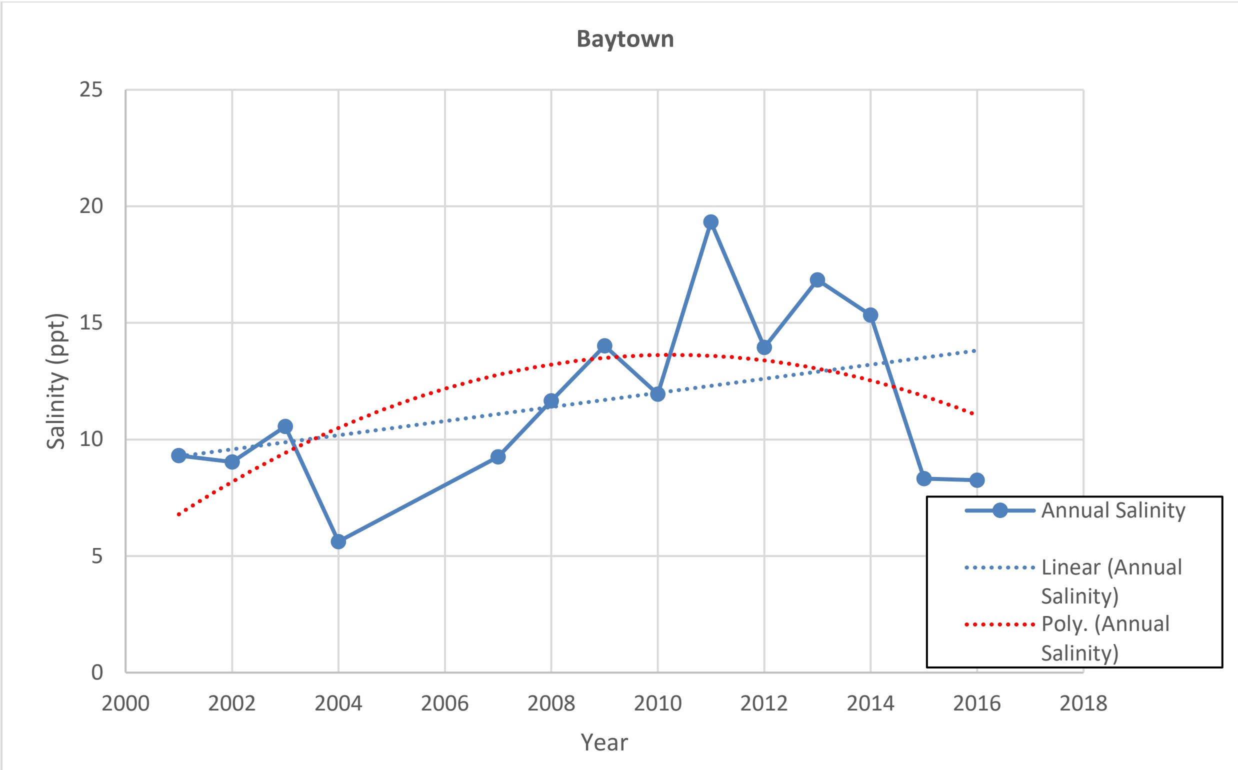

Figure 2 – Average Annual Salinity at Baytown Station

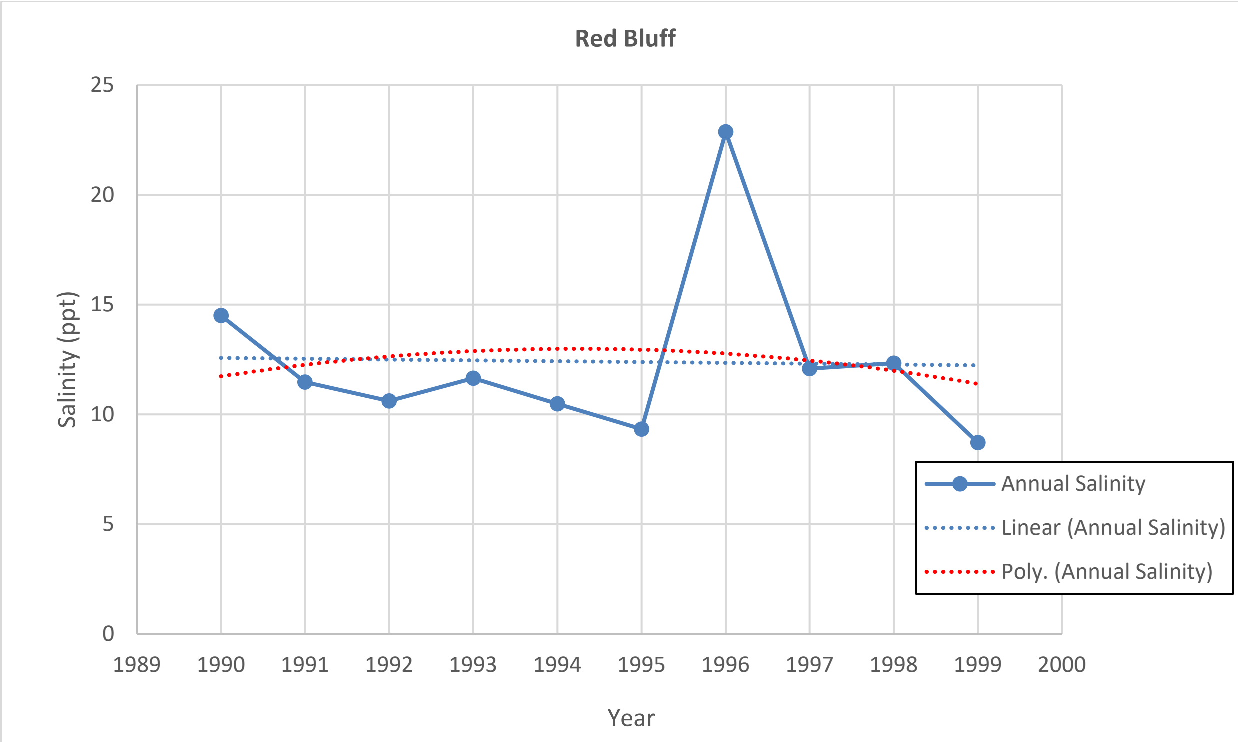

Figure 3 – Average Annual Salinity at Red Bluff Station

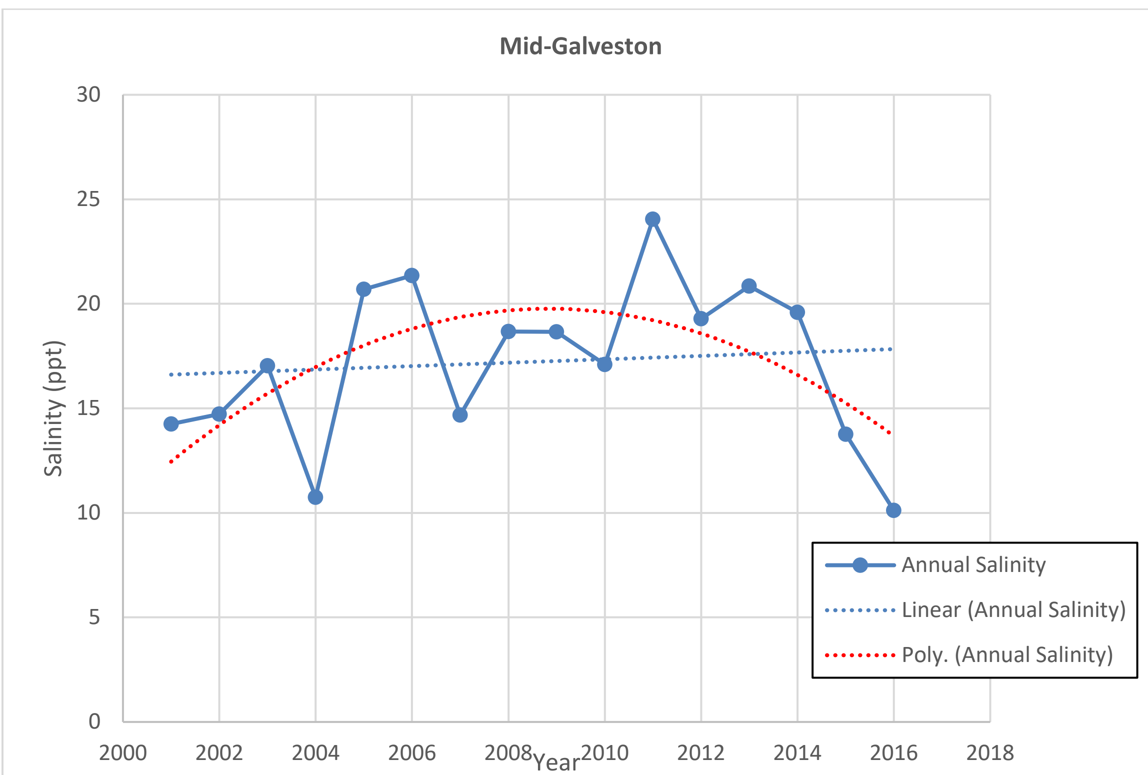

Figure 4 – Average Annual Salinity at Mid-Galveston Station

Given the information in the inflows study for the more likely scenario and the majority of the station annual trends showing a small negligible change in trends so far, it was decided to not change the salinity variables over the period of analysis due to the high variability, and no clear common trend. Therefore, the salinity variable values were not changed over the period of analysis.

With Project

In the with-project conditions, neither the impact of NED or LPP construction or mitigation site construction would be expected to alter ambient salinity significantly. Thought the NED and LPP would widen the channel in the Bay, there would be no deepening in the Bay, which is what typically causes slight salinity increases in hydrodynamic modeling of channel modifications. Deepening in the NED and LPP is limited only to the far upper reach of the study above Boggy Bayou, many miles upstream of the Bay and the reef impacts being modeled. Although hydrodynamic modeling was be performed for the LPP, no significant changes are anticipated. Therefore, the salinity variable values were not changed over the period of analysis.

6.0 PROPOSED MITIGATION STRATEGIES

This step requires identifying suitable management features responsive to mitigation objectives, and potential project lands, other public lands, and separable private lands determined suitable for applying each candidate management feature. The identification of potential mitigation sites should not be constrained for analysis purposes, and should focus on determining the management potential of each candidate site relative to its ability to meet mitigation objectives. For the purpose of analysis, the PGN states that preference shall not be given to the management of project and other public lands over the use of suitable private lands.

Regarding project, public, and private lands for implementing management features responsive to mitigation, oyster reef restoration by necessity requires estuarine waters with the conditions conducive to oyster recruitment and/or growth. The entire bay bottom of Galveston Bay is public lands owned by State-chartered entities consisting of either the Texas General Land Office (TxGLO) or navigation districts such as Chambers-Liberty Counties Navigation District. There are no private lands that would provide the required area or environment for oyster reef restoration. There are no extra project lands within the Bay waters on which to site reef restoration: the entire recommended project footprint consists of channel modifications that would be dredged. By necessity, restoration would take place in the public waters of Galveston Bay. Therefore, the identification of potential strategies would focus on the various possible management features to restore oyster reef in the Bay.

6.1 Types of Strategies

Several potential mitigation strategies were identified and assessed, considering the range of practices in oyster reef restoration and the types of mitigation strategies considered elsewhere in other mitigation planning (e.g. wetlands). Mitigation banks would involve the purchase of credits at banks developed and established to mitigate oyster reef habitat specifically. Locally, there are no banks established for oyster reef habitat. Therefore, this strategy was eliminated. For participation in local restoration projects, these projects tend to be much smaller in scale than needed, consisting of diffuse projects involving local citizens and pier owners using recycled shell from restaurant collection efforts placed in mesh bags and hung from shore side structures, or distributed along the shoreline. Therefore, this strategy was eliminated. Bagless dredging involves pulling oyster dredges without the bags that capture dredged shell, to deposit buried shell back on the surface of the bay bottom, thereby re-exposing old shell to provide the cultch surface for reef development. The efficacy of bagless dredging is modest according to efforts done by TPWD for post-Hurricane Ike restoration. Also, the predictability, certainty, and controllability of the area restored are low, leaving the possibility that several passes may be required to achieve the target area. Also finding sufficient buried shell for the scale of mitigation needed is not practical. Considering all of these factors, bagless dredging was eliminated.

Reef restoration through artificial cultch placement involves placement of artificial cultch on the bay bottom to provide a hard substrate for oyster spat to attach to and mature into adults, developing reef in the process. This is the most common method employed, especially for large scale restoration efforts, it is the main technique used in Galveston Bay, and has been employed successfully many times including local restoration projects in the Bay including for the previous HSC impacts during the HGNC project. Therefore, this method was selected.

6.2 Artificial Cultch Restoration Methods

Once artificial cultch is placed, colonization of the cultch occurs through one of two basic methods; using natural recruitment, or using spat seeding. Natural recruitment relies on the natural fecundity and distribution of oyster larvae that occurs throughout the Bay as part of the oyster life cycle for cultch to be colonized. Oyster larvae (known as veligers) drift with Bay currents during spawning seasons, then settle on the cultch as they seek firm surfaces to begin the maturation stage of their life cycle, a process known as spat set. This has been the primary manner that oyster restoration in the Bay has relied on for colonization and reef development. It has a high and consistent rate of success due to the presence of reef throughout the Bay, the fecundity of the American oyster in the conditions in this Bay, and the broad tidal movement and Bay currents available for distribution. Inspections of the previous oyster restoration for the HGNC project barge lanes in 2004 showed substantial oyster growth within three months of reef pad completion.

Using spat seeding would rely on use of harvested or farmed oyster spat to directly release to and seed cultch to achieve colonization. Spat seeding would require the costs of seed purchase, and transportation. Cultch contractors, who typically are in the construction aggregates industry, would typically not have the experience to distribute spat to minimize larval damage. Therefore, it would be anticipated that oyster farmers would be required to provide the service, adding costs to this option. The only reason this option would be employed in the context of Civil Works mitigation planning, is if it produced a cost effectiveness advantage in terms of habitat units produced per dollar spent. For spat seeding to be justified, it would have to provide a sufficiently quicker jumpstart to the HSI score and resultant AAHUs than natural recruitment would. However, the model chosen does not account for live oyster density. Also, the jumpstart would not be substantial, because natural oyster recruitment happens within a few months to a year, and the advantage and increase in resulting AAHUs would be too small to make it worth it.

Because of the consistent success, including on previous HGNC reef pad restoration, and lesser cost than spat seeding, relying on natural recruitment was selected.

There are various ways to provide the artificial hard substrate for recruitment. Mass placement of suitable cultch material like clean crushed limestone or concrete, or river rock is mostly employed for large scale reef restoration. Other techniques relying on precast structures like reef castles and reef balls are available. However, these are used more to mimic higher vertical three dimensional reef, are used more for intertidal restoration in the Gulf and cost more per acre than mass cultch placement. The reef being impacted is subtidal lower relief reef. Regardless of the technique, how it would be reflected in the model would be the same; the surface area provided would effectively be a 100 percent cultch coverage. For the purposes of the modeling, artificial cultch placement using mass suitable cultch material like limestone, concrete or river rock, was assumed.

7.0 MODELING AND RESULTS

The NED and LPP are currently proposed with a 700-foot wide channel within the Bay, which drives the range of impacts and required mitigation. Modeling for the NED and LPP for the 700-wide channel was done with the resulting spreadsheet calculations for each of the features in the various salinity regimes are in **Appendix 1**. The following describes the modeling and results for both the without project and with project scenarios.

7.1 Without-Project

Salinity values and acreage associated with each salinity regime cover type for the existing reef were entered. No changes in the values of cultch or salinity at the existing reefs were projected. **Table 1** shows the acreages and resultant AAHUS calculated for the existing reef that would be impacted by each option. The net acres, after subtracting out previously mitigated barge reef in the footprint, are shown. This is explained more in **Section 5.3** of the Mitigation Plan in **Appendix P**.

Table 1 – Without Project Acreages and AAHUs of Existing Reef in NED and Increment LPP Footprint

	Oyster Impacts (Net)	
Version	Acres	AAHUS
NED	88.2	73.2
Increment LPP	321.3	259.6

These AAHUs represent the target for restored mitigation reef to achieve.

7.2 With-Project

For the with project run for impacted reef, at Year 1, all reef reflects zero percent cultch coverage, which forces the HSI to zero, and as a result, the AAHUs to zero through the period of analysis. This reflects all reef function lost. The net change for impacted reef is simply a negative decrease in AAHUs of the magnitude shown in **Table 1**.

For the with project mitigation, separate model runs for the least and most optimal sites were set up, and salinity values associated with those sites entered. In this exercise, the acreage required to offset the AAHUs is unknown at the beginning, as the assumptions and AAHU calculations make the resultant needed mitigation acreage different than that impacted. That is because the impacted reef represents combinations of different salinity regimes, while mitigation at the least or most optimal site represent a single salinity regime. An initial acreage for the restored mitigation reef was entered, and the certified AAHU calculation run, with cultch acreage shifting from zero percent in year one to 100 percent by Year 3 according to the assumption previously discussed. The results of the initial trial acreage were used to guide subsequent iterative trial and error runs, where the acreage was modified until the AAHUs restored converged in a positive value equal to the AAHUs in **Table 1**. This represents a replacement of the AAHUs lost. **Table 2** shows the full results of the mitigation calculated compared to the impacted values for mitigation at the least and most optimal sites.

Table 2 – Without versus With Mitigation Project Acres and Results

Version	Impacts (Net)		Most Optimal Site (San Leon or Dollar Reef)			Least Optimal Site (Bayport)		
			Mitigation Required		Mitigation Ratio (mitigated / impacted)	Mitigation Required		Mitigation Ratio (mitigated/ impacted)
	Acres (Net)	AAHUS	Acres	AAHUS		Acres	AAHUS	
NED Plan	88.2	73.2	85.1	73.2	0.964	93.5	73.2	1.06
Increment LPP	321.3	259.6	291.0	259.6	0.905	330.0	259.6	1.04

As shown, the mitigation ratio ranges from 0.905 to 1.06, which approximately averages a 1.0 mitigation ratio for this range.

8.0 COST EFFECTIVENESS (CE) AND INCREMENTAL COST ANALYSIS (ICA)

ER 1105-2-100 requires performing an incremental cost analysis (ICA) for recommended mitigation plans to identify the least cost mitigation plan that provides full mitigation of losses specified in mitigation planning objectives. This report section presents the last two steps of mitigation planning in the PGN, which includes a Cost Effectiveness/Incremental Cost Analysis (CE/ICA) to determine the most cost-effective and most efficient mitigation alternatives for the reef impacts associated with the recommended project. As explained in **Section 4**, the least and most optimal sites were evaluated because of the preliminary nature of the NED at this point in the SMART study process. Therefore, the two mitigation alternatives evaluated were mitigation at the least and most optimal potential sites. The mitigation at these two sites for the high end range of the potential NED impacts (the 820-foot channel option) was evaluated. These mitigation alternatives were evaluated in this CE/ICA using the USACE Institute for Water Resources (IWR) Planning Suite software, Version 1.0.11.0.

The cost-effectiveness analysis portion of the CE/ICA evaluates the relationship between the cost and environmental output (measured as AAHUs) associated with each mitigation alternative. The term cost-effective means that for a particular level of output, no other plan costs less, or that no plan yields more output for the same or less cost. The ICA compares the additional costs to the additional outputs (AAHUs) of an alternative that produces greater outputs than another alternative. In the ICA, cost effective alternatives that are most efficient in production are selected by identifying those with the lowest incremental cost per output. These alternatives, known as "best buy" alternatives, provide the greatest increase in output for the least increase in cost. The "best buy" alternative(s) represents the most efficient of the cost effective mitigation alternative(s).

8.1 Cost of Alternatives

The proposed mitigation method is to beneficially use dredged material to build relief above the surrounding bay bottom and cap it with a veneer of suitable cultch, which would provide the hard substrate for natural recruitment and settlement of oysters during the spat set season. Previously, the main technique used for restoration in this bay involved using rock or other hard substrate to build the both the base of the reef to provide relief off of bay bottom, and spat settlement cultch layer at the surface to recruit oysters. This uses a lot of hard material for non-recruitment volume at significantly more cost than beneficially using dredged material. This is explained in more detail in the Mitigation Plan at **Appendix P**.

The current estimate of costs for mitigating the NED with the proposed method were provided from the engineering analysis and cost estimation for the NED. For planning purposes, a 6-inch layer of cultch was assumed in the costs, which is consistent with the minimum cultch layer relief desired by resource agencies. The unit cost derived from the cost estimate was $65,165 per acre. Costs for the mitigated acreage at each site were calculated using this unit cost and were entered into the CE-ICA software. **Table 3** summarizes the costs and outputs of each plan.

Table 3 – Summary of Costs and Outputs of the Two Mitigation Alternatives

Plan	Acres of Mitigation	Cost $1000	Output (AAHUs)
No Action	0	0	0
NED Plan	Alternative 1 - Least Optimal Site (Bayport)		
	93.5	$31,229	73.2
	Alternative 2 - Most Optimal Site (San Leon or Dollar)		
	85.1	$238,423	73.2
LPP (Increment LPP plus NED Plan)	Alternative 1 - Least Optimal Site (Bayport)		
	423.5	$53,339	332.8
	Alternative 2 - Most Optimal Site (San Leon or Dollar)		
	376.1	$47,920	332.8

8.2 CE-ICA Results

The plan and costs were entered as a single planning set and the CE-ICA software was executed to run both the cost effectiveness and incremental cost analyses. **Table 4** shows the output report results for the Total and Average Cost Report. This report gives an indication of what the most cost-effective plan is, showing the one with the lease average cost per output first for NED Plan and for the LPP. The LPP Alternative 2 most optimal mitigation site is indicated as the best cost, as expected, because the mitigation ratio is lower when using this site.

Table 4 – IWR-Plan Total and Average Cost Report Results

Plan	Output AAHU	Total Cost $1000	Average Cost /AAHU $1000
No Action Plan	0	-	-
Alt 2 - Most Optimal Site NED Plan 85.1 acres	73.2	$28,423	$388
Alt 1 - Least Optimal Site NED Plan 93.5 acres	73.2	$31,229	$427
Alt 2 - Most Optimal Site LPP 291.0 acres	332.8	$47,920	$144
Alt 1 - Least Optimal Site LPP 330 acres	332.8	$53,339	$160

The CEICA cost and output is shown in **Figure 5**. The output is in AAHU and cost in in thousands of dollars. The “Best Buy” alternative box plot provided in **Figure 6** shows the results of the ICA portion.

The reason that only one alternative was identified among the best buy plans was because of one step in the ICA process in the IWR publication *Cost Effectiveness for Environmental Planning: Nine Easy Steps*, which is implemented in the IWR-Plan software. Step 4, which is to eliminate economically inefficient solutions by identifying the most cost effective solutions at each level of output. The level of ouput examined was replacement of 332.8 AAHUs which is the limit on the amount of mitigation required per the PGN. Alternative 2 produces the 332.8 AHHUs for less cost. Therefore the other alternatives are eliminated. LPP Alternative 2 remains as the best buy plan.

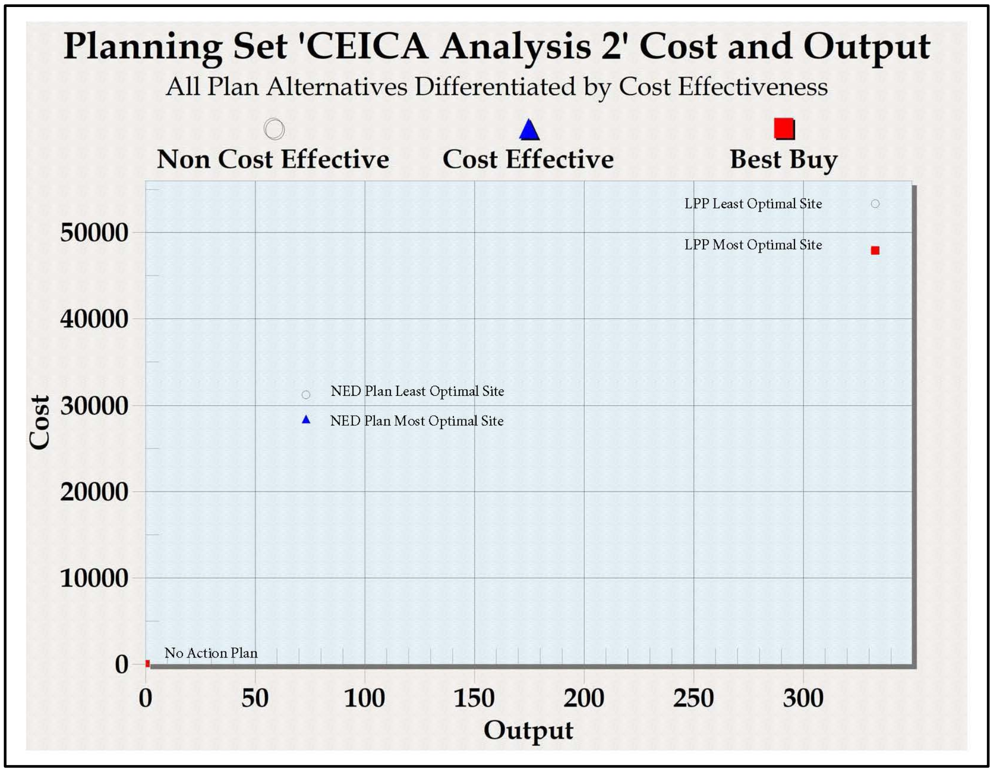

Figure 5 – CEICA Cost and Output

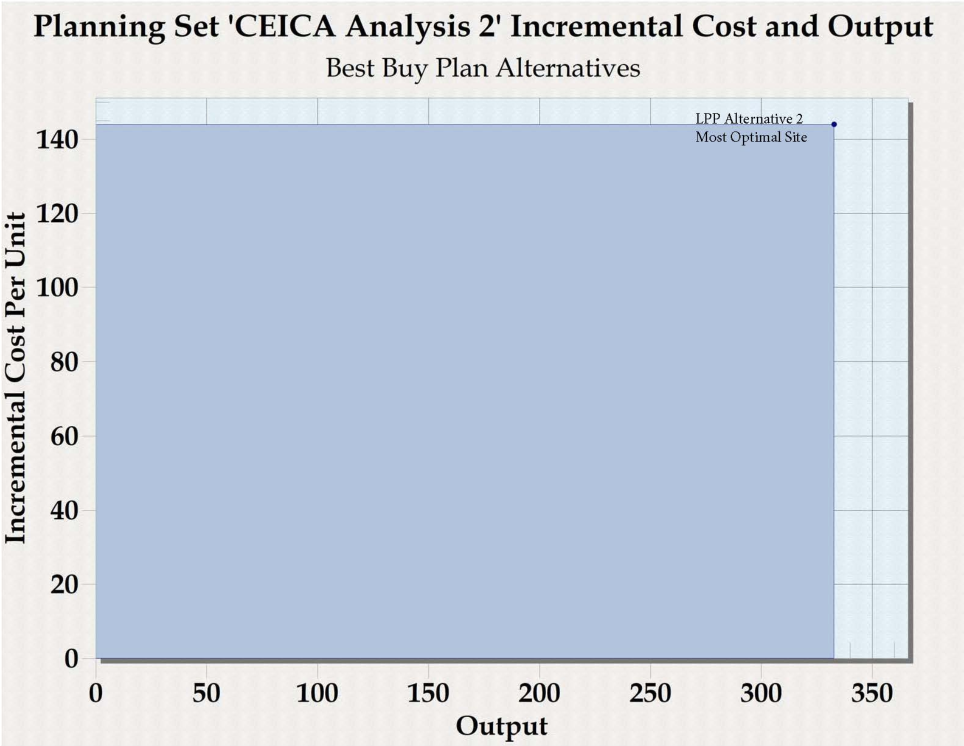

Figure 6 - IWR-Plan Best Buy Plan Alternatives Box Plot

As a result of the CE-ICA analysis, the best mitigation plan involves using the most optimal site in terms of salinity conditions, which is either constructing mitigation at the San Leon or Dollar Reef mitigation sites. Therefore, the mitigation plan for the NED Plan or the LPP will adopt construction or mitigation reef pads at these areas as the principle means of mitigation.

8.3 Dredged Material Management Plan and Mitigation Plan Modifications

During the dredged material management plan development, it was determined that areas associated with beneficial use (BU) islands could be used for oyster reef mitigation, at no additional cost to mitigation effort, employing an oyster reef wave trip shore protection concept, explained in Appendix P-1, Sections 7.3 and 7.4. These concepts were coordinated with resource agencies to also serve as oyster habitat mitigation. Two BU areas were identified: the 6-acre long bird island, and the 3-bird island BU marsh. Six-acre long bird island would be created to add 4 acres of oyster reef with an AAHU of 3.6. Three-bird island would be created to add 14.1 acres of oyster reef with an 9.9 AAHU. The BU oyster reefs would be designed to reduce the wave action around the two BU areas as part of the shoreline protection. The total of approximately 13.5 AAHU would be equally removed from the overall constructed oyster reef pad mitigation of both the NED Plan and the LPP, because the LPP plan includes the NED Plan with minor sections being removed (See Appendix P-1 for more details). Using the BU sites for oyster reef mitigation reduces the overall costs of both plans.

The modeling was conducted to determine the impacts of each plan measure impacting oyster reef, and the series of proposed mitigation features. These consisted of the following elements of mitigation:

- Oyster Reef Mitigation Pads at Dollar Reef
- Oyster Reef Mitigation Pads at San Leon
- Oyster Reef Wave Trip features at 6-acre long bird island and 3-bird island BU marsh

The OHSIM model spreadsheet was used to model the impacts and the above mitigation. These results were presented in summary in Appendix P-1, Table 6. The modeling details are provided in Attachment 1 of this Appendix O. Attachment 1 contains a summary tab up front of modeling results for each measure and the mitigation chosen for the NED Plan, The LPP increment, and sums both to give a total mitigation needed for the full LPP. The source of mitigation calculations and modeling is given as “case numbers.” The subsequent tabs contain the certified spreadsheets named for the numbered cases, and consist of two component tabs each for each case: one tab for the HIS calculation, and one tab for the AAHU calculation.

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