Appendix 7

Mitigation Plan for Oyster Habitat

This page left intentionally blank

US Army Corps of Engineers ®
Galveston District

FINAL
MITIGATION PLAN

for

Oyster Reef Habitat

Houston Ship Channel Project Deficiency Report
Houston-Galveston Navigation Channels, Texas

(Flare at the Intersection of the Houston Ship Channel and Bayport Ship Channel)

Chambers County, Texas

Prepared for:
U.S. Army Corps of Engineers, Galveston District

Provided by:
The Port of Houston Authority

Prepared by:
Starcrest Consulting Group, LLC and the Joint Venture of Turner Collie & Braden Inc. and Gahagan & Bryant Associates, Inc.

March 2016

This page left intentionally blank

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ATTACHMENTS

This page left intentionally blank

1.0 BACKGROUND

Implementation of the Preferred Alternative ("the Proposed Project") to correct the deficiencies recommended in the Houston Ship Channel (HSC) Project Deficiency Report (PDR) for the Flare at Bayport will permanently impact the oyster reef within the footprint of the proposed channel modifications. The Proposed Project will consist of channel modifications to ease (widen) the existing Flare to a radius of curvature of 4,000 feet ("the Flare Easing"), widening the HSC at the bend just south of the Flare ("the Main Channel Widener") to provide a straighter path, and relocate the existing barge lanes impacted by the Main Channel Widener, by means of an adjacent widener ("the Barge Lane Relocation".) The USACE Civil Works CECW-PC Memorandum for *Implementation Guidance for Section 2036(a) of the Water Resources Development Act of 2007 (WRDA 07) - Mitigation for Fish and Wildlife and Wetlands Losses*, dated 31 August 2009, reiterates mitigation requirements for any report being submitted to Congress for approval, but also adds the requirement for mitigation plans to comply with the mitigation standards and policies of the USACE Regulatory Program including specific mitigation plan components. The memo is applicable to Civil Works water resources projects that require specific authorization. The content and structure of this Mitigation Plan meet the requirements for Regulatory Program compensatory mitigation plans in 33 CFR 332.4(c).

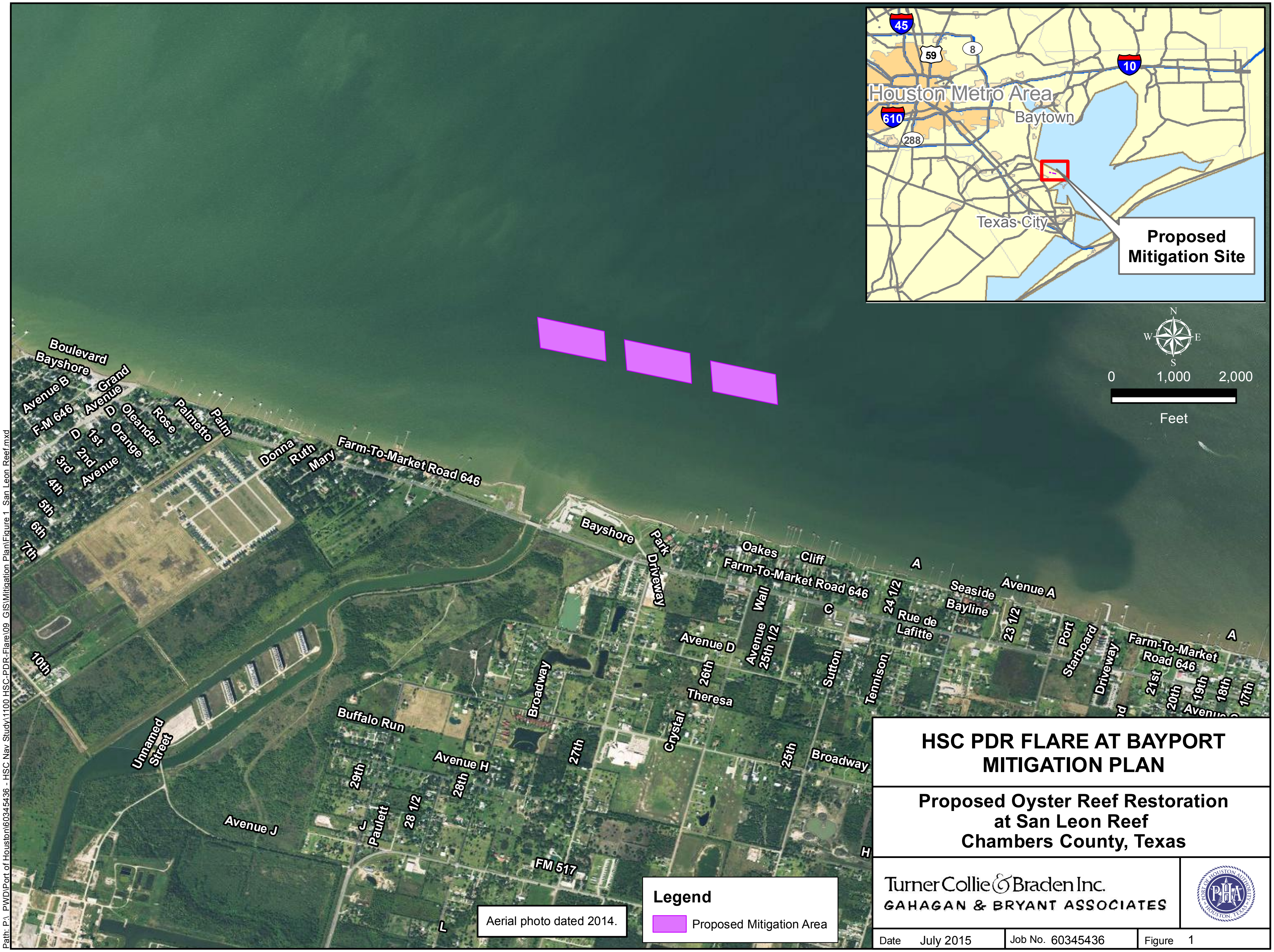
2.0 OBJECTIVES

The primary objective of the mitigation project is to replace the significant net losses of 29.16 Average Annual Habitat Units (AAHUs) of oyster reef habitat that would be removed during modifications made to the HSC for the Proposed Project through restoration of oyster habitat on San Leon Reef in the Clear Lake Embayment of Galveston Bay, Chambers County, Texas. Specifically, the mitigation plan proposes to add approximately 36,445 cubic yards (CY) of cultch to 30.1 acres on San Leon Reef to compensate for the direct impacts associated with dredging the Proposed Project. The restoration would increase the existing oyster habitat in Galveston Bay by providing 30.1 acres of hard surface area available for natural recruitment of oyster larvae. San Leon Reef was impacted by Hurricane Ike-induced sedimentation in 2008. The oyster reef restoration would replace the oyster reef that contributes important ecological benefits to Galveston Bay. Benefits include provision of aquatic habitat structure for several fish and invertebrate species, improvement of water quality and clarity as well as general re-establishment of essential fish and invertebrate habitat. The proposed site at San Leon Reef is shown in Figure 1.

3.0 SITE SELECTION CRITERIA

The San Leon Reef area was selected based on post-Hurricane Ike Texas Parks and Wildlife Department (TPWD) side-scan sonar data and sub-bottom profiling data collected by Texas A&M University at Galveston. The sub-bottom data indicated San Leon Reef was silted over by greater than 6 inches of sediment, and would be conducive to restoration by cultch placement. The reef footprint is in waters restricted for shellfish harvesting, which means the area is closed to harvesting for direct marketing. Harvesting for personal consumption would still be allowed. The San Leon Reef area was recommended by the TPWD as the preferred location for oyster reef restoration, during preliminary USACE discussions with the agency in 2012. Following

This page left intentionally blank



HSC PDR FLARE AT BAYPORT MITIGATION PLAN

Proposed Oyster Reef Restoration at San Leon Reef Chambers County, Texas

Turner Collie & Braden Inc.
GAHAGAN & BRYANT ASSOCIATES

Date	July 2015	Job No.	60345436	Figure	1

Path: P:_PWD\Port of Houston\60345436 - HSC Nav Study\1100 HSC-PDR-Flare\09_GIS\Mitigation Plan\Figure 1_San Leon Reef.mxd

This page left intentionally blank.

Hurricane Ike, the TPWD side-scan sonar surveys found that as much as 60 percent of the reefs in Galveston Bay were covered by hurricane-induced sedimentation eliminating or substantially reducing their function. This triggered an ongoing restoration effort by TPWD to reverse these losses. As the selected site is in Galveston Bay, the mitigation occurs in the same bay system that the impacts would occur in, and where restoration efforts have been planned and targeted by the resource agency with primary responsibility for oyster reef conservation. Direct on-site mitigation is not applicable in this situation as replacement reef cannot be appropriately located in the deepened navigation channel. The restoration relies on natural oyster larvae recruitment and growth, and would be self-sustaining. This method has been successfully used on past similar restoration projects in Galveston Bay and around the nation.

4.0 SITE PROTECTION INSTRUMENTS

The San Leon Reef area is located within Galveston Bay, for which, in general, the submerged land is State-owned and managed by the Texas General Land Office (TxGLO). Natural resource use or impact is subject to regulation by various governmental agencies including but not limited to TPWD, USACE, National Marine Fisheries Service (NMFS), and the U.S. Environmental Protection Agency (USEPA). In addition, natural oyster reefs are public resources managed by TPWD, and subject to compensation for losses under the Restitution and Restoration Rule, Chapter 69 of Title 31 of the Texas Administrative Code (TAC) to seek restoration of fish, wildlife and habitat loss occurring as a result of human activities, pursuant to enforcement powers in the Parks and Wildlife Code and Water Code. Any activity impacting the resources regulated by those agencies within the proposed mitigation area would be regulated by these governmental agencies. This would include development or fill of the Waters of the U.S., and oyster reefs that would be present or restored there.

5.0 BASELINE INFORMATION AND IMPACTS

Galveston Bay is characterized as a relatively large shallow bay with an extensive interconnected system of deeper navigational ship channels. With the exception of ship navigation channels and the Mid Bay constriction caused by Redfish Bar, both natural and anthropogenic oyster reefs constitute the largest physiographic feature in Galveston Bay. Remaining portions are comprised of sand, mud, silt and clay particles, and shell, with little bottom relief. Only very small portions of the Bay contain any sea grasses, limited to the West Bay and Smith’s Point area of the Bay, which excludes the area impacted and the proposed mitigation site. The project area is an example of a typical Galveston Bay habitat.

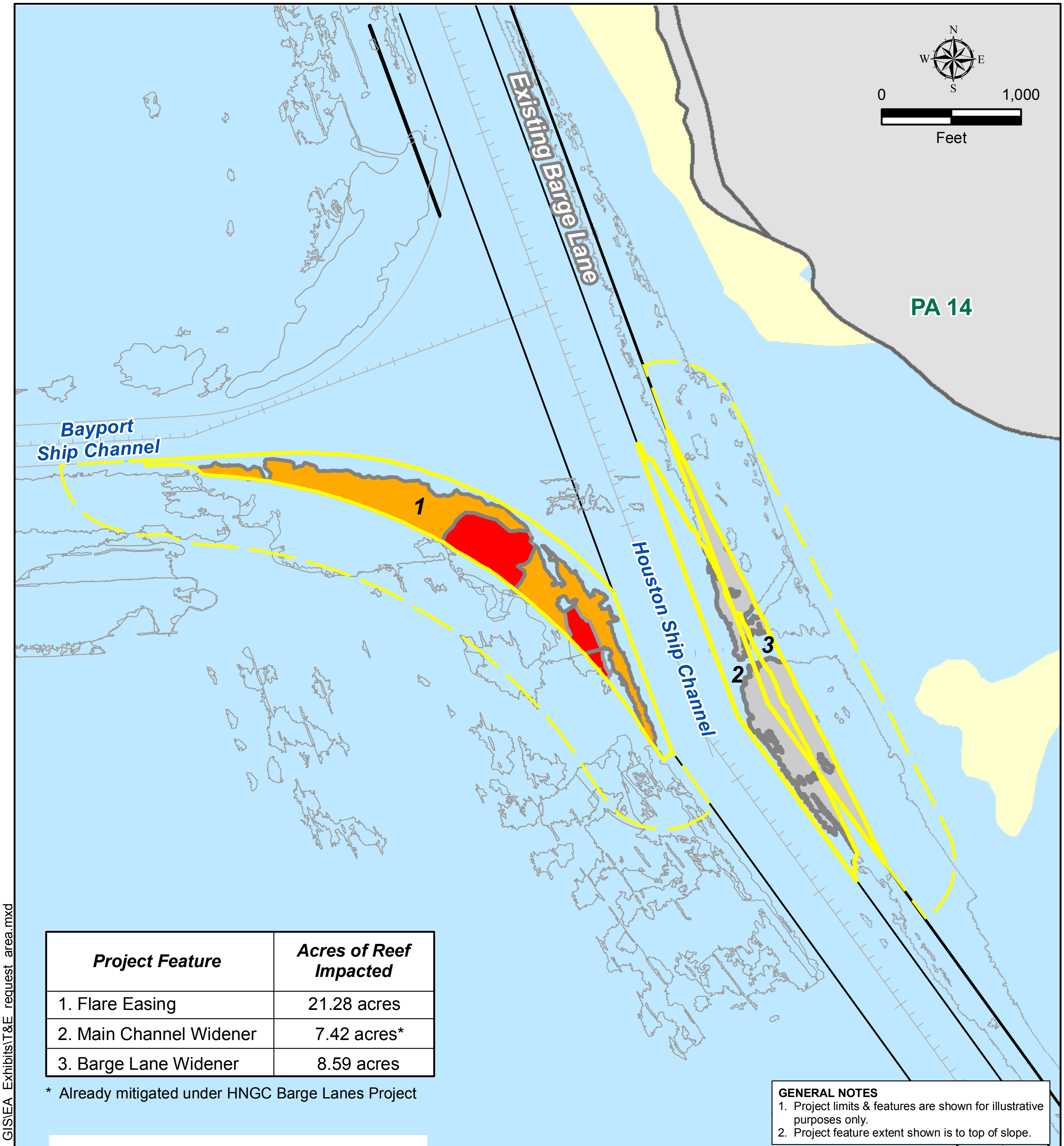
5.1 Baseline Benthic Habitat Survey

The benthic habitat was characterized for the Flare easing area of the proposed project in 2011 by side-scan sonar surveys ground truthed by aquatic science divers, as part of field investigations for the Port of Houston Authority’s (PHA) BSC Improvements Project (Department of the Army permit SWG-2011-1183). The results are detailed in the technical report *Bayport Ship Channel Improvements Galveston Bay, Texas Draft Benthic Habitat Characterization Report* dated December 2011, that was transmitted to the USACE Galveston District on April 25, 2012. Based on the survey results and observation data, the habitat was classified according to substrate density and live oyster cluster spacing. The Main Channel

Widener and Barge Lane Relocation of the proposed project were surveyed by side-scan sonar in December 2011 by the PHA's consultants during cultural resource investigations conducted for the BSC Improvements Project. This survey was not ground truthed by diver. However, based on the density of the side scan sonar image, similarity to the ground truthed Flare side scan signature, and ground truthing during the BSC Improvements Project of other reef complexes along the HSC and BSC intersection that form part of the large contiguous reef signature lining the HSC that extends to the widener area, the signature in the wideners is clearly indicative of dense reef. Based on the density and similarity of the signature to that in the Flare easing area, which was classified, the reef in the wideners is assumed to at minimum Class 3 reef. Figure 2 shows the results of the survey near the proposed channel modifications. Table 1 summarizes the habitat in the footprint of the Proposed Project and also includes the 500-foot buffer of the area of new work dredging. The Proposed Project area consists mostly of soft bottom with few areas of hard bottom, composed mostly of varying densities of dead oyster shell (hash) interspersed with varying sizes and densities of clusters of live oysters. As shown in the table, only a small percentage is consolidated reef. In May 20, 2015, an additional side scan survey was conducted at the proposed he San Leon Reef area and confirmed that the reef has not reestablished itself. Further, the area was hand probed and the former reef is covered in 1-3 feet of soft silt and mud over a harder sand, mud and shell substrate.

5.2 <u>Direct Impacts</u>

Oyster habitat within the project footprint is found in the Flare Easing, Main Channel Widener, and Barge Lane Relocation Area of new work dredging for the proposed project. The Flare Easing portion of the HSC will be dredged from approximately -10.5 ft Mean Low Lower Water (MLLW) [-9 ft Mean Low Tide (MLT)] to -46.5 ft MLLW (-45 ft MLT) and will impact 21.3 acres of oyster reef. The existing Flare adjacent to this area was previously deepened in the 1970s and mined to -52.5 feet MLLW (-51 feet MLT) in 2004. Part of the side slope of the existing Flare extends into the proposed Flare Easing area. The proposed Main Channel Widener lies within the existing barge lane that was previously dredged to -13.5 feet MLLW (-12 feet MLT) in 2005 and for which permanent reef impacts were mitigated in 2004 as part of the addition of barge lanes to the Houston-Galveston Navigation Channels Project by the USACE. The impacts from the barge lane additions are documented in 2003 *Final Environmental Assessment, Houston - Galveston Navigation Channels, Texas Project, Upper Bay Barge Lanes*. Mitigation for this area was previously accounted for, and the 7.4 acres of oyster that will be impacted are considered regrowth. It should be noted that the Barge Lanes are allowed to be perpetually dredged. The current Barge Lanes will be converted to the Main Channel Widener and will require dredging from -13.5 to -46.5 feet MLLW (-12 to -45 feet MLT) with 3:1 side slopes. The Barge Lane Relocation area will impact 8.6 acres of reef and will be dredged from an approximate depth of -9.5 to -13.5 ft MLLW (-8 to -12 ft MLT). A total of 37.3 acres of reef will be directly impacted and 29.9 of the impacted acres will be mitigated at the San Leon Reef site. The class and category descriptions of the oyster habitat to be mitigated for direct impacts, the acreages of each class, and their corresponding percentages, are shown in Table 1.



Project Feature	Acres of Reef Impacted
1. Flare Easing	21.28 acres
2. Main Channel Widener	7.42 acres*
3. Barge Lane Widener	8.59 acres

* Already mitigated under HNGC Barge Lanes Project

GENERAL NOTES
1. Project limits & features are shown for illustrative purposes only.
2. Project feature extent shown is to top of slope.

Legend

- Proposed Project Footprint
- Proposed Project Buffer
- Impacted Reef
- Other Reef in Project Area

Oyster Reef Impacted by Proposed Project

Class

- 3-High Density Shell Hash w/ & w/o Oyster Clusters
- 4-Consolidated Reef
- Reef not classified

HSC PDR FLARE AT BAYPORT MITIGATION PLAN

Surveyed Oyster Habitat Near Proposed Channel Modifications

Turner Collie & Braden Inc.
GAHAGAN & BRYANT ASSOCIATES

Date July 2015 | Job No. 60345436 | Figure 2

P:\Bayport Ch Deepen Widen 60183643\08 GIS\EA Exhibits\T&E request area.mxd

This page left intentionally blank.

5.3 Indirect Impacts

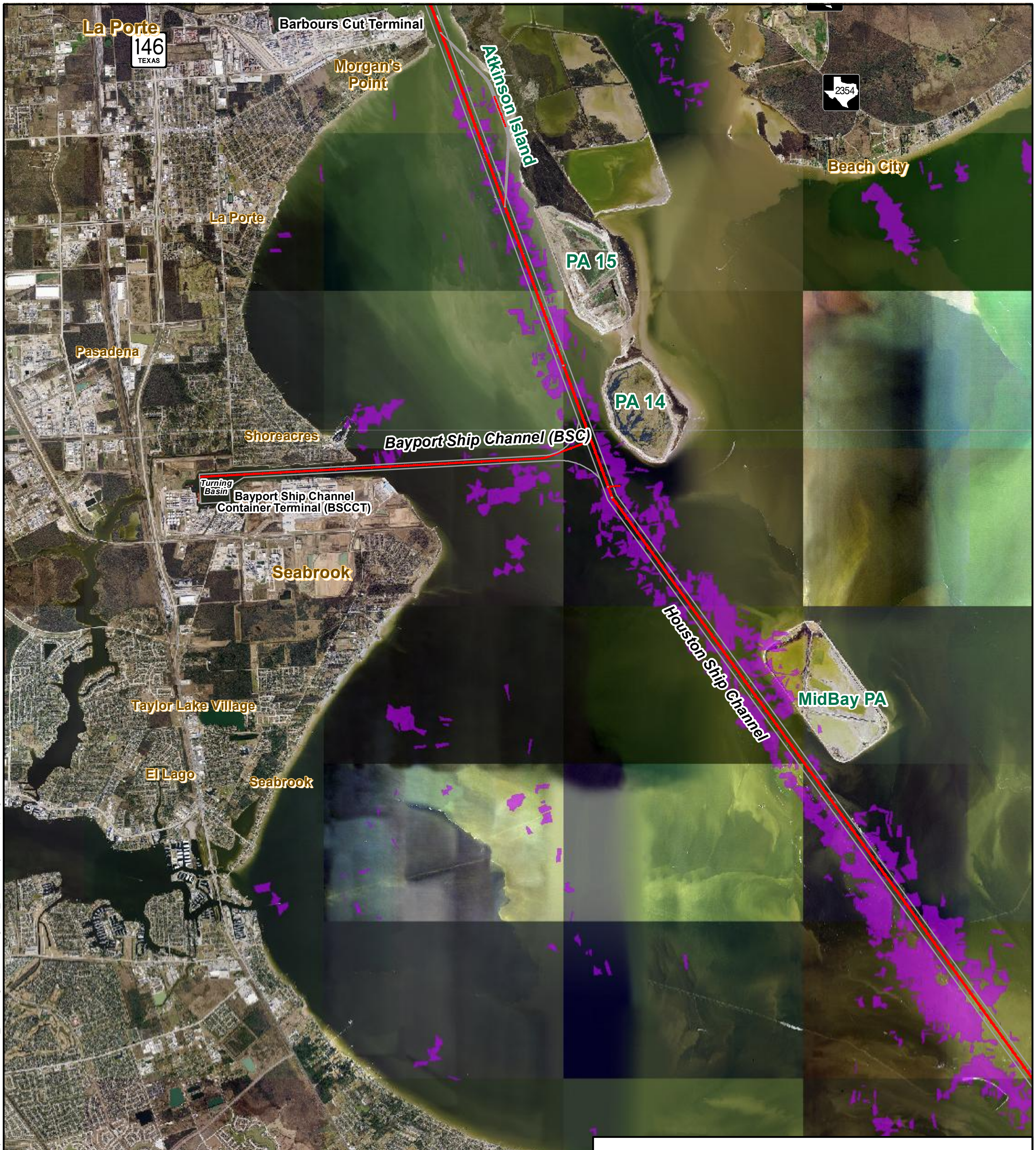
Indirect impacts to oyster from turbidity from new work dredging required for construction of the proposed project are expected to be minimal.

Numerous studies indicate that dredge-induced turbidity plumes are, more often than not, localized, spreading less than a thousand meters from their sources and dissipating to ambient water quality within several hours after dredging is completed (Higgins et al., 2004). A literature review performed for the California Coastal Commission found that most studies indicated that in almost all cases, the vast majority of re-suspended sediments resettle close to the dredge within an hour (Anchor Environmental CA L.P., 2003). Observations from this report included that sediment concentrations are greater at the bottom of the water column, and rapidly decrease with distance from the dredge. When properly operated, suspended concentration levels away from the cutterhead dissipate exponentially towards the surface with little turbidity actually reaching surface waters, and in many cases, at concentrations no greater than those generated by commercial shipping operations or during severe storms (Higgins et al., 2004). One recent study measuring total suspended solids (TSS) concentrations during dredging of the Calcasieu Channel and Pass found no discernible differences in concentrations upstream, parallel to, and downstream of the dredge, indicating the dredging operation had no influence on TSS (USACE New Orleans District 2007). Results of earlier densitometry surveys from this study indicated silt suspension during maintenance dredging was confined to the deep parts of the channel.

The vast majority of suspended particles would settle close to the dredge, which greatly reduces the volume available for re-deposition at distances from the dredge. Therefore the amount of material that would be available for resettling on reef at distance would be expected to be small and only have minimal effects in terms of covering reef. The 500-ft buffer around the proposed project features is shown in Figure 2.

With the exception of a few smaller complexes, oyster habitat within the part of Upper Galveston Bay that the project is located in, is almost exclusively located directly adjacent to the navigations channels of the HSC and BSC. This is clearly observed in the 1991 historical mapping of reef by Texas A&M University at Galveston (TAMUG) [shown in Figure 3], and was corroborated in the oyster survey side scan sonar data collected for this project and was later ground truthed by divers for the Benthic Habitat Characterization Report. The channel margins are covered with extensive reef, and the trend is observed along the HSC south of the project area. The HSC was widened and deepened under the Houston and Galveston Navigation Channel (HGNC) project between 1998 and 2008, and extensive HSC adjacent reef was still observed in the sidescan sonar data for this project in 2011. Considering the previous information discussed, and considering that these channels are periodically dredged for maintenance (which would involve higher percentages of unconsolidated fines), the new work dredging required for construction of the proposed project and subsequent maintenance dredging would not be expected to result in reef losses due to turbidity effects, only minimal impacts would occur, and pre- and post-construction monitoring for turbidity impacts is not proposed for the new work dredging.

This page left intentionally blank.



Legend

- Existing Channel Limits
- Channel Centerline
- Oyster Reefs (TAMUG 1991)

N W E S

0 7,500
Feet

HSC PDR FLARE AT BAYPORT MITIGATION PLAN

Historic Oyster reef in Upper Galveston Bay

Turner Collie & Braden Inc.
GAHAGAN & BRYANT ASSOCIATES

PORT OF HOUSTON AUTHORITY HOUSTON, TEXAS PHA

Date July 2015	Job No. 60345436	Figure 3

Path: P:_PWD\Port of Houston\60345436 - HSC Nav Study\1100 HSC-PDR-Flare\09_GIS\Mitigation Plan\Figure 3_Historic Oyster Mapping.mxd

This page left intentionally blank.

Table 1: Oyster Hardbottom Habitat

Proposed Project Site Habitat						
Habitat Classification	**Flare Easing**		**Wideners**			
			Main Channel[1]		**Barge Lane**	
	Acres	% total area	Acres[2]	% total area	Acres[2]	% total area
Class 1	0	0.0%	0	0%	0	0%
Class 2	0	0.0%	0	0%	0	0%
Class 3	15.2	71.4%	7.4	100*%	8.6	100*%
Class 4	6.1	28.6%	0	0%	0	0%
Total	**21.3**	100%	**7.4**	100%	**8.6**	100%

(1) Acreage already mitigated under the HGNC Barge Lanes Project
(2) Assumed value based on side scan survey

Class descriptions:

- Class 4-Consolidated Reef - Habitat defined as consolidated reef and/or habitat with numerous, closely spaced, large oyster clusters <15 percent visible substrate between oyster clusters if not completely consolidated reef.
- Class 3-High Density Shell Hash with or without Oyster Clusters - Habitat defined as predominantly Category III and/or Category IV shell hash substrate with or without visible oyster clusters.
- Class 2-Low Density Shell Hash with Oyster Clusters - Habitat defined as predominantly Category I and/or Category II shell hash substrate with visible oyster clusters.
- Class 1-Low Density Shell Hash without Oyster Clusters - Habitat defined as predominantly Category I and/or Category II shell hash substrate without visible oyster clusters.

Substrate categories:

- Category IV – 75-100% of the seafloor covered in oyster shell hash
- Category III – 50-<75% of the seafloor covered in oyster shell hash
- Category II – 25-<50% of the seafloor covered in oyster shell hash
- Category I - >1-<25% of the seafloor covered in oyster shell hash

6.0 CREDIT DETERMINATION METHODOLOGY

USACE Civil Works policy contained in the CECW-CP policy memo *Policy Guidance on Certification on Ecosystem Output Models*, dated August 13, 2008, requires that only standard 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 outline by the USACE. The policy memo contains a list of approved methods and models already certified, including the Habitat Evaluation Procedure (HEP), and the related HSI model for the American oyster (*Crassostrea virginica*) (Cake 1983). Reefs in Galveston Bay are predominantly American oyster. Therefore, this HSI model, in its standard form, was selected for use. A full description of the model is provided in the USFWS model literature listed in the references for this report (Cake 1983).

Through the use of this model, oyster habitat suitability over time is assumed based on variables such as substrate type, salinity, current oyster population, killing floods, and substrate firmness. Suitability ratings range from 0.0 to 1.0; 0.0 denotes unsuitable habitat, while 1.0 represents optimal habitat (Soniat and Brody, 1988). Two ecological scenarios were modeled at both the project site and mitigation site using this model; the first scenario assumes affected Habitat Units (HUs) without the proposed project, termed the without-project condition, and the second scenario assumes affected HUs with the proposed project, termed the with-project condition. Following the methodology in the HEP procedures, HUs in each scenario are then projected over a period of analysis that typically encompasses the assumed project life span to determine future with and without project conditions, and then annualized by time-weighted averaging to calculate AAHUs over the period of analysis [USFWS 1980]. For this project the period of analysis was assumed for a timeframe of 20 years. The following subsections describe the modeling detail for each scenario. Attachment 1 provides the HSI model spreadsheets showing the variable values input into the model and the results, for all project conditions discussed below.

6.1 Proposed Project Site

The following subsections describe modeling of the impacts of not dredging or dredging the proposed channel modifications at the Proposed Project site.

6.1.1 Without Project

At the Proposed Project site, the HSI Model assumes that without the dredging project, the HSI and associated HUs provided by the existing oyster reef would remain the same through the period of analysis as calculated for the existing (baseline) condition; 29.9 acres of oyster bed with a suitability index of 1.0, indicating optimal habitat. This assumes that in an uninterrupted environment of 29.9 acres of oyster bed would thrive year over year. The variable values for the baseline condition and ensuing years, were based on the following data collected or condition assumed:

- V_1 Percentage of-cultch cover on bottom – Optimal value is ≥50 %. Given that the Flare Easing reef was comprised of Class 3 and 4 which have optimal value substrate densities, and that the reef in the Barge Lane Relocation area is assumed to be Class 3 at minimum, the optimal value was assumed. It was assumed that it remained optimal through the period of analysis as oysters will be not be removed with dredging.
- V_2 Mean summer water salinity – Texas Water Development Board (TWDB) salinity data at the Red Bluff station for the available years 1991-1999, was obtained through the Estuary Monitoring (Datasonde) Program (TWDB 2012). Data is consistent with, though slightly lower than, Yacht Club and Red Bluff Reefs assessed by Soniat & Brody (1988).
- V_3 Mean abundance of living oysters – Baseline densities based on data collected during ground truthing by divers for the BSC Improvements Project. Maintained at baseline as oysters would likely increase vertically; horizontal expansion is less predictable. Observations of live oyster cluster spacing was used, along with the

transect length and width, and assumptions of typical observed adult oyster size, to estimate an areal coverage of live oysters per square meter (oysters/m2).

- V_4 Historic mean water salinity – The data source was the same as V_2. The optimum range for mean salinities in this area is 10-20 parts per thousand (ppt). Values are not likely to be found outside of this range in the upper Bay at this location.
- V_5 Mean interval between killing floods – Based on mean killing flood intervals for Yacht Club and Red Bluff Reefs assessed by Soniat & Brody (Soniat and Brody 1988) this variable is unlikely to decrease. Killing floods less than 3 years apart would require substantial freshwater inflow to reduce the salinity to 2 ppt for weeks.
- V_6 mean substrate firmness – Assumed optimal. Underlying sediments for this area are stiff clay as observed in the geotechnical data for the Proposed Project. Also, since extensive, dense growth is present in the Proposed Project footprint, this would substrate firmness is optimal.

Per the HSI Model manual, V_7 (mean predator abundance), and V_8 (mean intensity of disease) are for implementing the optional component index modifier equation used typically for oyster management (rather than solely for habitat function). This option was not used.

6.1.2 <u>With Project</u>

When dredging impacts are accounted for at the site within the model, it is assumed that the 29.9 acres of live reef and hard substrate will be removed, resulting in a suitability index of 0.0 and 0.0 HUs, indicating unsuitable habitat and loss of function. Therefore, based on this model, it is assumed that the function provided by the 29.9 acres of oyster habitat at the Proposed Project site due to dredging will be lost in Year 1 of the period of analysis, following construction. In accordance with the HEP procedure, the calculation of AAHUs for the period of analysis includes the baseline year (Year 0) score. As a result the AAHU value for the With Project scenario is 0.711 AAHU. The variable values for the With Project condition, were based on the following assumptions:

- V_1 Percentage of-cultch cover on bottom – This was assumed to be reduced to 0% as oysters will be removed with dredging.
- V_2 Mean summer water salinity – Remains unaffected by the dredging activity and the resultant channel modifications.
- V_3 Mean abundance of living oysters – This was assumed to be reduced to 0% as oysters will be removed with dredging.
- V_4 Historic mean water salinity – Assumed to be the same as the without project condition, since dredging will not alter climatic factors..
- V_5 Mean interval between killing floods – Assumed to be the same as the without project condition, since dredging will not alter climatic factors.
- V_6 mean substrate firmness - Assumed to remain optimal since bay bottom layers under the proposed dredged depths are dominated by stiff clays.

In actuality, some reef would be expected to reform within the footprint of the channel modifications, as evidenced by side-scan sonar signature collected in 2011 indicative of reef visible in the footprints of the existing barge lanes, the southern side slope of the existing BSC, and side slope of the HSC, where initial new work dredging would have been done. However, the factors which limit how far into the channel regrowth occurs are likely complex and not well-investigated, and without a time-series of sonar scans following dredging, the rate and timing of regrowth would be speculative. The American oyster has been known to occur at depths up to approximately 100 feet, but are thought to best thrive in shallower waters up to approximately 9 feet deep (SCDNR undated). However, the 2011 side-scan imagery showed signature indicative of continuous reef at locations on the BSC side slopes that would be at depths between 15 and 20 feet, and in the existing barge lane bottom that would be at approximately 12 feet of depth. Factors that have been suggested to explain reef development along the navigation channels are the presence of sidecast dredged spoil banks that provide sufficient relief to initiate growth, the saltier local isohaline contours that develop parallel to the deeper channels, higher current flows, lower turbidity, and related effects on food supply (Powell *et al.* 1997). Closer to the channel, factors limiting regrowth into the channel may be depth, proximity to the greatest magnitude of vessel return currents, and local water and sediment effects in the channel boundary. Given that there are many possible complex factors influencing the rate and extent of regrowth that have not been well-defined, and the lack of time series data to develop a reliable forecast, the reef was not assumed to regrow in the modeling of the With Project condition.

6.2 San Leon Reef Proposed Mitigation Site

The following subsections describe modeling of the impacts of not constructing, or constructing the proposed mitigation at the San Leon Reef proposed mitigation site.

6.2.1 Without Project (without Proposed Mitigation)

As a result of Hurricane Ike, the formerly exposed reef at the San Leon Reef restoration site is covered in more than 6 inches of silt, and due to the unfavorable substrate available at the bay bottom, oysters are not currently present, and the existing reef acreage is 0.0 acres. Side-scan sonar imagery performed on May 20, 2015 did not indicate any substantial reef signature. A few suspect anomalies were probed June 4 and 5, 2015, and indicated that the proposed mitigation site footprint is soft bottom devoid of oyster reef. Based on a lack of an oyster population and the unfavorable substrate for oyster growth, the current suitability index rating is 0.0. It is assumed within the model that overtime the suitability index and HUs will remain consistent at 0.0 without the addition of a suitable substrate such as cultch to allow for oyster growth at San Leon Reef. The variable values for the Without Proposed Mitigation condition, were based on the following data collected and assumptions:

- V_1 Percentage of-cultch cover on bottom – 0% as this site has been covered by silt after Hurricane Ike, corroborated by side-scan sonar and probing.
- V_2 Mean summer water salinity – Mid-Galveston TWDB data (2012). Values are consistent with but slightly higher than Soniat & Brody 1998 which was pre-HGNC deepening and widening.

- V_3 Mean abundance of living oysters – 0 live oysters/m^2, no live oysters are assumed to occur due to reef buried by Hurricane Ike.
- V_4 Historic mean water salinity – The data source was the same as V_2. The optimum range for mean salinities in this area is 10-20 ppt. Values are not likely to be found outside of this range at this location in the upper Bay.
- V_5 Mean interval between killing floods - Based on mean killing flood intervals for San Leon Reef assessed by Soniat & Brody (Soniat and Brody 1988), this variable is unlikely to decrease. Killing floods less than 3 years apart would require substantial freshwater inflow to reduce the salinity to 2 ppt for weeks.
- V_6 mean substrate firmness – As documented by TPWD the site is historically shell hash and reef. Since hurricane Ike the site has been silted over and is comprised of mostly soft sediment.

6.2.2 With Project (with Proposed Mitigation)

In order to determine the net habitat function losses that would occur to define the functional "lift" that mitigation must provide to replace those losses, the net impact at the Proposed Project site was first calculated as prescribed in the HEP procedures by subtracting the Without-Project AAHUs from the With Project AAHUs from Sections 6.1.1 and 6.1.2. The net impact is 0.711 AAHUs With Project minus 29.87 AAHUs Without Project to yield a net impact of -29.16 AAHUs, meaning a loss of 29.16 AAHUs. So a positive AAHU target of 29.16 AAHUs is what the mitigation should provide.

As part of the restoration, cultch will be placed within the San Leon Reef restoration site to provide a suitable attachment habitat. With the addition of cultch to the restoration site, and the rapid colonization within one year that can be expected, the suitability index will increase from 0.0 to 1.0 by the end of Year 1 of the period of analysis. Rapid recruitment of oyster spat on the artificial cultch is expected and was observed with the previous oyster mitigation in Galveston Bay that employed the same proposed method for the HGNC Project. Substantial growth was observed within 3 months as documented in post-construction monitoring. The live oyster density observed during post-construction monitoring for the HGNC was commensurate with the consolidated reef live oyster cluster spacing observed during the ground truthing-by-diver for this project. Consolidated growth would be expected on the mitigation cultch. Also, conversation with TPWD staff indicated that recruitment on new cultch in this Bay can be expected to be greater than 90 oysters/m^2 a year after placement. Once the optimal live oyster density is reached, the gregariousness life requirement provided, and the associated added larval production to that already occurring (which led to initial colonization), would provide a self-sustaining reef that maintains the suitability in ensuing years. The variable values for the With Proposed Mitigation condition, were based on the following assumptions:

- V_1 Percentage of-cultch cover on bottom – Starting from 0 as the site has been covered by silt; the value is increased to 100% since a solid coverage of cultch over the restoration site acreage would be added as proposed.

- V_2 Mean summer water salinity – This would remain as the Without Project condition at this site. The mitigation project, consisting of adding cultch inherently would not change the Bay's salinity.
- V_3 Mean abundance of living oysters – Increase from baseline condition of 0 to optimal value of $\geq$25 live oysters/m^2 per HGNC project experience and communication with TPWD staff as discussed above.
- V_4 Historic mean water salinity – Same as V_2
- V_5 Mean interval between killing floods – This would remain as the Without Project condition at this site. The mitigation project, consisting of adding cultch inherently would not change climatic events.
- V_6 mean substrate firmness – Starting at the assumed baseline condition indicative of soft bay bottom surface conditions, the addition of artificial cultch (crushed limestone, rock etc.) makes the value optimal by Year 1 following mitigation construction, and would remain in place in ensuing years. Cultch, by definition, provides the optimal substrate firmness.

Using the calculated HSI scores, the Excel software numerical method application Solver was used in conjunction with the model spreadsheet to converge to the required acreage value to achieve the target AAHU value, given the assumed variable values and changes described above. This resulted in 30.12 acres being required to produce 29.16 AAHUs, as shown in Attachment 1. Therefore, 30.12 acres is proposed for restoration at San Leon Reef. A summary of the habitat modeling for impacts and mitigation is provided in Table 2.

Table 2: Summary of American Oyster HSI Modeling of Without and With Project Condition

Project Location/Condition	Area (acres)	Endpoint HSI Score*	AAHUs
Proposed Project Site			
Without Project	29.9	1.00	29.87
With Project	29.9	0.00	0.71
		Net Impact	**-29.16**
San Leon Reef Mitigation Site			
Without Mitigation Project	30.1	0.00	0
With Mitigation Project	30.1	1.00	29.16
		Net Impact	**+29.16**

*HSI value once full impact of project or mitigation is achieved

As shown in Attachment 1, restoring the San Leon Reef site to the proposed acreage would restore 100% of the function of the impacted oyster beds at the Proposed Project dredging site. The mitigation site would provide for 30.1 acres of seafloor that will be covered 100% with artificial cultch, which will provide similar or more attachment surface area per acre than the impacted reef, considering it was not entirely comprised of consolidated reef. The mitigation ratio is a one to one ratio replacement of function, as measured by the appropriate functional model, and not a direct one to one replacement ratio of living oysters. However, based on HGNC project and other restoration project experience in Galveston Bay, it is assumed that the cultch material will be readily colonized by oyster larvae, and the resultant live oyster density would be expected to match if not be greater than that impacted.

7.0 MITIGATION WORK PLAN

The following are elements of the mitigation work plan:

- Geographic boundaries of the project – The project site and approximate boundaries are shown in Figure 1. The mitigation for the proposed project is shown as conceptual, since the final design for 30.1 acres of mitigation to be located within the identified 40-acre TPWD restoration site may change considering review of detailed local site condition information and consultation with TPWD staff during Preconstruction Engineering Design (PED). However, the area of cultch is not expected to change.
- Construction methods, substrate elevation, and slopes – The mitigation work plan proposes to add approximately 36,445 CY of cultch to 30.1 acres, to result in an approximate 6-inch thick layer of cultch above the bay bottom. This profile was recommended by the TPWD. The cultch would be clean limestone, crushed concrete rubble, or other suitable substrate as deemed acceptable by the TPWD. Limestone is anticipated to be used. The cultch would most likely be barged to San Leon Reef and then placed evenly on the bay bottom at San Leon Reef over the indicated acreage. For planning purposes, the cultch amount accounts for a 9-inch thick layer to account for 3 inches of settling into soft sediments to produce the desired 6-inch relief. However, based on more detailed foundation information that may be collected during design, the amount may be adjusted to better ensure the desired relief would be obtained. Proper sloping for stability will be determined for the: 1 vertical side slope ratio.
- Timing and sequence – The mitigation would be constructed either before or concurrent with the construction of the proposed channel modifications. Therefore, mitigation would be built before or at the time impacts occur. With the area and volume of material involved, it is anticipated the mitigation would be constructed in a single phase, under a single mobilization. Seasonally, the construction would be timed to target completion a short time before or during the spawning season to ensure recruitment of spat soon after the substrate is available. Spawning season is late spring to early fall in Galveston Bay. Ideally, completion would be timed before one of the two spat set peaks that typically occur in the Bay, the larger, first one being between April and June, and the second, smaller peak around August.
- Foundation – Proper analysis will be performed and measures taken to determine and ensure vertical stability of cultch material in the soft bay bottom. This will be determined after the specific cultch material is determined and local site conditions analyzed. Historic knowledge of the site indicates that suitable foundation exists, as the site is underlain by former reef. Experience during the BSC Improvements Project mitigation at Fisher's Reef, which was also former reef buried by Hurricane Ike-induced sedimentation, indicates that settlement into soft surficial sediments was less than expected, possibly due to the underlying shell from the former reef.
- Other elements considered – Other mitigation work plan elements listed in 40 CFR 230.94(c)(7), such as source of water or methods to establish the desired plant community, are not applicable.

Details for the elements of the mitigation work plan will be developed during the PED phase of the mitigation project, as part of the development of plans and specifications for the procurement of services to construct the proposed mitigation. More detailed surveys or geotechnical calculations to address foundation conditions may be performed to specify the appropriate and final cultch thickness to ensure the target relief of 6 inches above the existing bay bottom is achieved. Though 9 inches was used for preliminary planning purposes, the final vertical thickness may be adjusted to thicker dimensions, dependent on surveys or other geotechnical investigations during PED. In addition to surveys and geotechnical investigations, information and observations from other local restoration projects, such as the recently completed construction of mitigation at Fisher's Reef by the PHA, may be used to inform decisions of proposed thicknesses for construction. This information and the final design dimensions will be shared and coordinated with TPWD, and other resource agencies, as requested.

8.0 MAINTENANCE PLAN

Once the cultch has been placed on the bottom of the San Leon Reef area of Galveston Bay, no further maintenance of the project area would be required. The cultch should stay exposed for colonization by oyster larvae and other aquatic organisms. The substrate will develop on its own into mature reef with market-size oysters expected in two to three years similar to that experienced with the HGNC oyster restoration. However, other unusual events, such as another major hurricane like Hurricane Ike could cover the area, as well as natural reefs. No specific long term maintenance for these unusual events is planned.

9.0 ECOLOGICAL PERFORMANCE STANDARDS

The objective of this restoration is to replace oyster habitat function by a one to one ratio. Success would be defined as an increase in reef acreage of at least 30.1 acres. Because the USACE is required by Civil Works policy to use USACE-certified habitat models to determine mitigation, as discussed at the beginning of Section 6.0, the success should also be measured in context of the function determined by the model used to determine habitat losses. Therefore, the success criteria proposed for use is based on the American oyster HSI model. Once the mitigation site is chosen and mitigation implemented, three variables could not practically be changed by adaptive management actions, other than to relocate the mitigation entirely: V_2 Mean summer water salinity, V_4 Historic mean water salinity, and V_5 Mean interval between killing floods. These are environmental conditions determined by the Bay's salinity regime and freshwater inflows, and their values would be what were used in the modeling, since they came from data specific to San Leon Reef. Once the cultch is placed in accordance with the plans and specifications that would be developed to meet the requirements of the Mitigation Plan, V_1 Percentage of-cultch cover on bottom and V_6 mean substrate firmness, would be set to their optimal value, and remain at those optimal values with the cultch in place. Therefore, V_3 Mean abundance of living oysters would be the one variable that would be monitored to ensure the mitigation reaches the mitigation objective of 29.16 AAHUs.

Pre-restoration and post-restoration side scan-sonar data would be collected and processed into ArcGIS data layers. This will determine the acres of reef habitat available for colonization. As a structural endpoint, the restored cultch acreage would be quantified by subtracting pre-restoration hard bottom acreage from post-restoration hard-bottom acreage to determine the amount of hard bottom habitat restored that will be available for oyster recruitment. The pre-restoration side-scan sonar data was already collected on May 20, 2015 and probed on June 4 and 5, 2015, to determine pre-restoration reef was zero acres. The functional endpoint would be the model variable V_3, mean live oyster density (oysters per square meter [oysters/m^2]). Success would be defined as an average post-restoration oyster density equal to or greater than 25 oysters/m^2, which is the value at which the suitability score would be maximized (reference V_3 suitability graph, P.18 Cake 1983) to match the optimal without project condition, and result in 29.16 AAHUs being replaced. Therefore, once monitoring determines 25 oysters/m^2 has been met or exceeded, success will have been determined to be achieved, and monitoring would stop.

10.0 MONITORING REQUIREMENTS

Monitoring of the restoration sites would be conducted pre- and post-restoration to assess the success of the project. Criteria for restoration success would include one structural and one functional endpoint. The structural endpoint would be the number of reef acres restored. Oyster density, the functional endpoint, would be measured using the diver quadrat method twice a year (pre- and post-oyster harvest season) for three years or until the target live oyster density is achieved. Self-contained Underwater Breathing Apparatus (SCUBA) divers would sample random points along a transect line by placing a 0.5 square meter quadrat on the bay bottom and placing all shells and live oysters from within the quadrat into a mesh bag. All live oysters within the quadrat would be enumerated and measured for shell length. When the success criteria are met, the monitoring would cease and the mitigation project would be determined to be successful.

11.0 LONG-TERM MANAGEMENT PLAN

After the mitigation project is determined to be successful, management of the San Leon reef area would be returned to the owners of the site and regulators of the bottom of Galveston Bay, which are the various governmental agencies including but not limited to TPWD, TxGLO, NMFS, and USEPA.

12.0 ADAPTIVE MANAGEMENT PLAN

Any time during the monitoring period, if the success of the mitigation plan appears not to be meeting the success criteria; the permittee would notify the TPWD, so that the mitigation can be evaluated and measures pursued to address deficiencies of the mitigation. Discussions on meeting the success criteria would be included in each monitoring report.

13.0 FINANCIAL ASSURANCES

The USACE is a U.S. federal agency under the Department of Defense and a major Army command made up of approximately 37,000 civilian and military personnel. The USACE is one of the world's largest public engineering, design, and construction management agencies. The Corps' missions are: 1) Planning, designing, building, and operating locks and dams; 2) Design and construction of flood protection systems; 3) Design and construction management of military facilities; and, 4) Environmental regulation and ecosystem restoration. This mission is required to be accomplished in a manner that 1) complies with all applicable Federal, State, and local environmental regulations, including those for mitigation, and 2) provides sufficient funds to cover the mitigation operational expenses and capital investments. USACE Civil Works project planning policy, including Engineer Regulation (ER) 1105-2-100, Planning Guidance Notebook (PGN), and the aforementioned USACE Civil Works CECW-PC Memorandum, explicitly require that all significant losses of significant resource from a proposed USACE project be mitigated. As a matter of policy and procedure, all Civil Works projects, or portions impacting resources requiring mitigation, would not get funded unless the mitigation is also funded. Therefore, projects would not be implemented without the required mitigation as part of the project. A preliminary cost estimate for the mitigation is approximately $3.31 million, which is approximately 8 percent of the estimated $41 million cost to construct the proposed channel modifications. It is anticipated the mitigation funding source will be the same as that for the proposed project construction. It is anticipated that the project will be executed with funds appropriated by Congressional Approval of the President of the United States' Budget proposed in a given fiscal year. The USACE has a long track record of successfully participating in and funding mitigation and ecosystem restoration (e.g. beneficial use) as part of its sponsored projects.

14.0 REPORTING

The first report to TPWD would include the findings of the restored reef acreage as determined by side-scan sonar, and would be submitted no later than 90 days after placement of the reef substrate. The results of all monitoring activities would be summarized annually. The subsequent three annual reports over the 3-year monitoring period would include the oyster density findings of the SCUBA divers, including when the post-restoration oyster density success criteria was met.

15.0 REFERENCES

Anchor Environmental CA L.P. 2003. Literature Review of Effects of Resuspended Sediments Due to Dredging Operations. Technical report prepared for Los Angeles Contaminated Sediments Task Force Los Angeles, California. Anchor Environmental CA L.P., Irvine, California.

Cake, E.W. 1983. Habitat Suitability Index Models: Gulf of Mexico American Oyster. U.S. Fish and Wildlife Service (USFWS) Publication FWS/OBS-82/10.57. 37 pp. USFWS, Department of the Interior, Washington, D.C.

Higgins, C.T., C.I. Downey, and J.P. Clinkenbeard. 2004. Literature Search and Review of Selected Topics Related to Coastal Processes, Features, and Issues In California. Technical report prepared for the California Coastal Sediment Management Workgroup [CSMW]. California Geological Survey, California Department of Conservation.

Powell, E.N., J. Song, M. Ellis, and K. Choi. 1997. Galveston Bay Oyster reef Survey: Technical Reports Volume I. Galveston Bay National Estuary Program Publication GBNEP-50. Department of Oceanography, Texas A&M University.

Soniat, T.M. & M.S. Brody. 1988. Field validation of a habitat suitability index model for the American Oyster. Estuaries. 11:87-95.

South Carolina Department of Natural Resources(SCDNR). Undated. American Oyster. Ashepoo-Combahee-Edisto (ACE) Basin Species Gallery. Online resource of the SCDNR

Marine Resources Research Institute (MRRI). Available at http://www.dnr.sc.gov/marine/mrri/acechar/specgal/oyster.htm (accessed July 14, 2015)

Texas Water Development Board (TWDB). 2012. Estuary Monitoring Program. Estuarine water quality data sets available upon request from the TWDB Datasonde Program. 2012 data requested. Contact available at http://www.twdb.texas.gov/surfacewater/bays/monitoring/index.asp

U. S. Army Corps of Engineers, New Orleans District. 2007. Calcasieu Lake Suspended Solids Sampling and Analyses.

U.S. Fish and Wildlife Service (USFWS). 1980. Habitat Evaluation Procedures (HEP). Ecological Services Manual (ESM)102. USFWS Division of Ecological Services, Department of the Interior, Washington, D.C.

This page left intentionally blank.

Attachment 1

American Oyster Habitat Suitability Index Model Spreadsheets

This page left intentionally blank

Baseline and Projected HSI Scores
Without Project (Proposed Project Site)

Oyster HSI Model

			TY0		TY1		TY2		TY3		TY4		TY11		TY21	
Variable	Description	Optimal	2012 (Baseline)	SI	2016	SI	2017	SI	2018	SI	2019	SI	2026	SI	2036	SI
V_1	% bottom covered with cultch	≥50 %	100	1.00	100	1.00	100	1.00	100	1.00	100	1.00	100	1.00	100	1.00
V_2	Mean summer salinity	10-30 ppt	12.2	1.00	12.2	1.00	12.2	1.00	12.2	1.00	12.2	1.00	12.2	1.00	12.2	1.00
V_3	Live oyster/m^2	≥25	25	1.00	25	1.00	25	1.00	25	1.00	25	1.00	25	1.00	25	1.00
V4	Historic mean salinity	10-20 ppt	12	1.00	12	1.00	12	1.00	12	1.00	12	1.00	12	1.00	12	1.00
V5	Mean interval between killing floods	≥3 yrs	7	1.00	7	1.00	7	1.00	7	1.00	7	1.00	7	1.00	7	1.00
V6	Mean substrate firmness	1.0 kg/cm^2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
CI - I		$(SI_{V1} \times SI_{V2} \times SI_{V3})^{1/3}$		1.00		1.00		1.00		1.00		1.00		1.00		1.00
CI - a		$(SI_{V4} \times SI_{V5} \times SI_{V6})^{1/3}$		1.00		1.00		1.00		1.00		1.00		1.00		1.00
HSI				1.00		1.00		1.00		1.00		1.00		1.00		1.00
Acres				29.87		29.87		29.87		29.87		29.87		29.87		29.87
Habitat Units (HUs)				29.87		29.87		29.87		29.87		29.87		29.87		29.87

AAHUs						
T1	T2	HSI1	HSI2	Acres1	Acres2	Cumulative HUs
0	1	1.00	1.00	29.87	29.87	29.87
1	2	1.00	1.00	29.87	29.87	29.87
2	3	1.00	1.00	29.87	29.87	29.87
3	4	1.00	1.00	29.87	29.87	29.87
4	11	1.00	1.00	29.87	29.87	209.09
11	21	1.00	1.00	29.87	29.87	298.70
Cumulative HUs						627.27
Without Project AAHUs						29.87

Future With Out Project Variable Assumptions:

V1= assume remains 100% as oysters will be not be removed with dredging

V2, V4= Red Bluff (TWDB, 2012); data is consistent with, though slightly lower than, Yacht Club and Red Bluff Reefs assessed by Soniat & Brody (1988)

V3 = baseline densities based on PHA diver sampling; maintained at baseline as oysters would likely increase vertically; horizontal expansion is less predictable

V4=Variable is insensitive to this change, as optimum is between 10-20 ppt; mean salinities outside this range at this location in the upper bay is unlikely

V5= based on V5 for Yacht Club and Red Bluff Reefs assessed by Soniat & Brody (1988); variable is insensitive to increases; anything less than optimum (3 years) would require susbstantial FW inflow to cause salinities less than 2ppt for weeks

V6 = remains a 1 (existing reef); underlying sediments are assumed stiff clays

Baseline and Projected HSI Scores
With Project (Proposed Project Site)

Oyster HSI Model

			TY0		TY1		TY2		TY3		TY4		TY11		TY21	
Variable	Description	Optimal	2012 (Baseline)	SI	2016	SI	2017	SI	2018	SI	2019	SI	2026	SI	2036	SI
V_1	% bottom covered with cultch	≥50 %	100	1.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
V_2	Mean summer salinity	10-30 ppt	12.2	1.00	12.2	1.00	12.2	1.00	12.2	1.00	12.2	1.00	12.2	1.00	12.2	1.00
V_3	Live oyster/m^2	≥25	25	1.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
V4	Historic mean salinity	10-20 ppt	12	1.00	12	1.00	12	1.00	12	1.00	12	1.00	12	1.00	12	1.00
V5	Mean interval between killing floods	≥3 yrs	7	1.00	7	1.00	7	1.00	7	1.00	7	1.00	7	1.00	7	1.00
V6	Mean substrate firmness	1.0 kg/cm^2	1	1.00	1	1.00	1	1.00	1	1.00	1	1.00	1	1.00	1	1.00
CI - I		$(SI_{V1} \times SI_{V2} \times SI_{V3})^{1/3}$		1.00		0.00		0.00		0.00		0.00		0.00		0.00
CI - a		$(SI_{V4} \times SI_{V5} \times SI_{V6})^{1/3}$		1.00		1.00		1.00		1.00		1.00		1.00		1.00
HSI				1.00		0.00		0.00		0.00		0.00		0.00		0.00
Acres				29.87		29.87		29.87		29.87		29.87		29.87		29.87
Habitat Units (HUs)				29.87		0.00		0.00		0.00		0.00		0.00		0.00

AAHUs						
TY1	TY2	HSI1	HSI2	Acres1	Acres2	Cumulative HUs
0	1	1.00	0.00	29.87	29.87	14.94
1	2	0.00	0.00	29.87	29.87	0.00
2	3	0.00	0.00	29.87	29.87	0.00
3	4	0.00	0.00	29.87	29.87	0.00
4	11	0.00	0.00	29.87	29.87	0.00
11	21	0.00	0.00	29.87	29.87	0.00
Cumulative HUs						14.94
With Project AAHUs						0.711

Future With Project Variable Assumptions:

V1= reduced to 0% as oysters will be removed with dredging

V3 = reduced to 0% as oysters will be removed with dreding

V6 = remains a 1 as the underlying sediments are fairly stiff clays

V2, V4, V5 = same as FWOP

Baseline and Projected HSI Scores
Without Proposed Mitigation Project (San Leon Reef Site)

Oyster HSI Model

			TY0		TY1		TY2		TY3		TY4		TY11		TY21	
Variable	Description	Optimal	2012 (Baseline)	SI	2016	SI	2017	SI	2018	SI	2019	SI	2026	SI	2037	SI
V_1	% bottom covered with cultch	≥50 %	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
V_2	Mean summer salinity	10-30 ppt	16.6	1.00	16.6	1.00	16.6	1.00	16.6	1.00	16.6	1.00	16.6	1.00	16.6	1.00
V_3	Live oyster/m^2	≥25	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
V4	Historic mean salinity	10-20 ppt	16.1	1.00	16.1	1.00	16.1	1.00	16.1	1.00	16.1	1.00	16.1	1.00	16.1	1.00
V5	Mean interval between killing floods	≥3 yrs	7.00	1.00	3.00	1.00	3.00	1.00	3.00	1.00	3.00	1.00	3.00	1.00	3.00	1.00
V6	Mean substrate firmness	1.0 kg/cm^2	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
CI - I		$(SI_{V1} \times SI_{V2} \times SI_{V3})^{1/3}$		0.00		0.00		0.00		0.00		0.00		0.00		0.00
CI - a		$(SI_{V4} \times SI_{V5} \times SI_{V6})^{1/3}$		0.45		0.45		0.45		0.45		0.45		0.45		0.45
HSI				0.00		0.00		0.00		0.00		0.00		0.00		0.00
Acres (reef)				30.11		30.11		30.11		30.11		30.11		30.11		30.11
Habitat Units (HUs)				0.00		0.00		0.00		0.00		0.00		0.00		0.00

AAHUs						
TY1	TY2	HSI1	HSI2	Acres1	Acres2	Cumulative HUs
0	1	0.00	0.00	30.11	30.11	0.00
1	2	0.00	0.00	30.11	30.11	0.00
2	3	0.00	0.00	30.11	30.11	0.00
3	4	0.00	0.00	30.11	30.11	0.00
4	11	0.00	0.00	30.11	30.11	0.00
11	21	0.00	0.00	30.11	30.11	0.00
Cumulative HUs						0.00
Without Project AAHUs						0

Variable Assumptions:

V1 = 0% as this site has been covered by silt after Hurrican Ike * (TO BE VERIFIED BY PHA)

V2,V4: Mid-Galveston TWDB data (2012); consistent but slightly higher than
Soniat & Brody 1998 which was pre HGNC D/W

V3 = 0, no live oysters are assumed to occur; buried reef due to Hurricane Ike

V4=Variable is insensitive to this change, as optimum is between 10-20 ppt;
mean salinities outside this range at this location in the upper bay is unlikely

V5 = Based on San Leon Reef (=April Fool Reef) assessed by Soniat & Brody (1988)
variable is insensitive to increases; anything less than optimum (3 years)
would require susbstantial FW inflow to cause salinities less than 2ppt for weeks

V6 = Site was formerly reef/shell/shell hash or firm substrate according to TPWD

Baseline and Projected HSI Scores
With Proposed Mitigation Project (San Leon Reef Site)

Oyster HSI Model

			TY0		TY1		TY2		TY3		TY4		TY11		TY21	
Variable	Description	Optimal	2012 (Baseline)	SI	2016	SI	2017	SI	2018	SI	2019	SI	2026	SI	2037	SI
V_1	% bottom covered with cultch	≥50 %	0	0.00	100	1.00	100	1.00	100	1.00	100	1.00	100	1.00	100	1.00
V_2	Mean summer salinity	10-30 ppt	16.6	1.00	16.6	1.00	16.6	1.00	16.6	1.00	16.6	1.00	16.6	1.00	16.6	1.00
V_3	Live oyster/m^2	≥25	0	0.00	25	1.00	25	1.00	25	1.00	25	1.00	25	1.00	25	1.00
V4	Historic mean salinity	10-20 ppt	16.1	1.00	16.1	1.00	16.1	1.00	16.1	1.00	16.1	1.00	16.1	1.00	16.1	1.00
V5	Mean interval between killing floods	≥3 yrs	7.00	1.00	7.00	1.00	7.00	1.00	7.00	1.00	7.00	1.00	7.00	1.00	7.00	1.00
V6	Mean substrate firmness	1.0 kg/cm^2	0.09	0.09	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
CI - I		$(SI_{V1} \times SI_{V2} \times SI_{V3})^{1/3}$		0.00		1.00		1.00		1.00		1.00		1.00		1.00
CI - a		$(SI_{V4} \times SI_{V5} \times SI_{V6})^{1/3}$		0.45		1.00		1.00		1.00		1.00		1.00		1.00
HSI				0.00		1.00		1.00		1.00		1.00		1.00		1.00
Acres (reef)				0.00		30.115		30.11		30.11		30.11		30.11		30.11
Habitat Units (HUs)				0.00		30.11		30.11		30.11		30.11		30.11		30.11

AAHUs						
TY1	TY2	HSI1	HSI2	Acres1	Acres2	Cumulative HUs
0	1	0.00	1.00	0.00	30.11	10.04
1	2	1.00	1.00	30.11	30.11	30.11
2	3	1.00	1.00	30.11	30.11	30.11
3	4	1.00	1.00	30.11	30.11	30.11
4	11	1.00	1.00	30.11	30.11	210.80
11	21	1.00	1.00	30.11	30.11	301.15
Cumulative HUs						612.33
With Project AAHUs						29.16

Variable Assumptions:

V1 = 0 as site has been covered by silt, increased to 100% with addition of rock

V3 = Per communications w/TPWD personnel; may expect >90/m2 by year 1.

V6 = Site was formerly reef/shell/shell hash or firm substrate according to TPWD will become hard reef substrate with addition of rock and oyster recruitment

V2, V4, V5 = FWOP