

# **HOUSTON SHIP CHANNEL BENEFICIAL USE PROJECT: LESSONS LEARNED IN BUILDING THOUSANDS OF ACRES OF HABITAT WITH DREDGE MATERIAL**

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## **ABSTRACT**

The Houston-Galveston Navigation Channels, Texas (HGNC) project is the largest collection of beneficial uses sites under one project scope in Galveston Bay, Texas as well as one of the largest in the U.S. and world. But how does a project with such an enormous scope get constructed and what lessons have been learned in the nearly 10 years since construction was authorized by the U.S. Congress?

The genesis for the project came from the need to deepen and widen the existing channels to allow larger vessels to call on the existing ports in the area. The channel with the most vessel usage of the two authorized for construction, the Houston Ship Channel, allows for continued economic growth in the Port of Houston. However, at the time construction was to begin, placement of the material dredged to widen and deepen the Houston Ship Channel was to be placed in existing underwater placement areas along the channel. This practice of placing dredged material in the open bay was no longer acceptable to local environmental groups. As a result of this project, a team of eight agencies was brought together to develop a plan to beneficially use dredge material to solve placement area capacity problems, develop a scope of work to address these concerns and all agree on the path forward for the project.

The project team has also gained experience on how to fill dredge material placement sites with the dredge material to meet not only the capacity needs to support the maintenance dredging for the channel, but also how to meet the future planting and habitat needs of a marsh or upland habitat area. Additionally, the team will share their current efforts on how they are managing the filling process of the sites to potentially minimize future channel construction expenses needed to gain circulation in the marsh cells.

**Keywords:** Marsh creation, island creation, marsh construction, project management, stakeholders

## **INTRODUCTION**

The Houston-Galveston Navigation Channels project has been and continues to be a standard-setting project for the Corps of Engineers Galveston District as well as the Port of Houston Authority. When authorized by Congress in 1996, it was the largest collection of beneficial uses sites to be constructed under one project scope for Galveston Bay, Texas as well as one of the largest in the world. The project came about because the second largest port in the country (the Port of Houston) required a larger channel (deeper and wider) to facilitate safer and more efficient movements of deep draft vessels transiting the 83 kilometer (53 mile) Houston Ship Channel. The wider and deeper channel was needed to support the dramatic growth in waterborne cargo that the Port of Houston was experiencing and is projected to experience in future years.

The project team of the Port of Houston Authority and the US Army Corps of Engineers, Galveston District along with 6 local state and federal agencies developed an innovative plan to contain the material dredged from the channel by constructing 1,720 hectares (4,250 acres) of intertidal marsh and addition islands that supported vegetation and bird habitats. Existing upland placement areas are also being utilized for dredge material placement and have become part of the dredge material capacity requirement, but by beneficially using the dredge material to create marshes and islands the required capacity for the project was realized (see Figure 1 for a project map).

In order to get the project approved by local stakeholders and authorized by Congress, numerous concerns had to be addressed which include: environmental, capacity, economic and social. All of the concerns expressed were answered and initial construction (widening and deepening) has been completed. The present channel (13.7 meters deep by 161.5 meters wide (45 ft by 530 ft) is available for vessel traffic and 1,720 hectares (4,250 acres) of initial

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habitat has been started. Through the years of construction and design, numerous lessons have been learned by the project team and those will also be discussed in this paper.

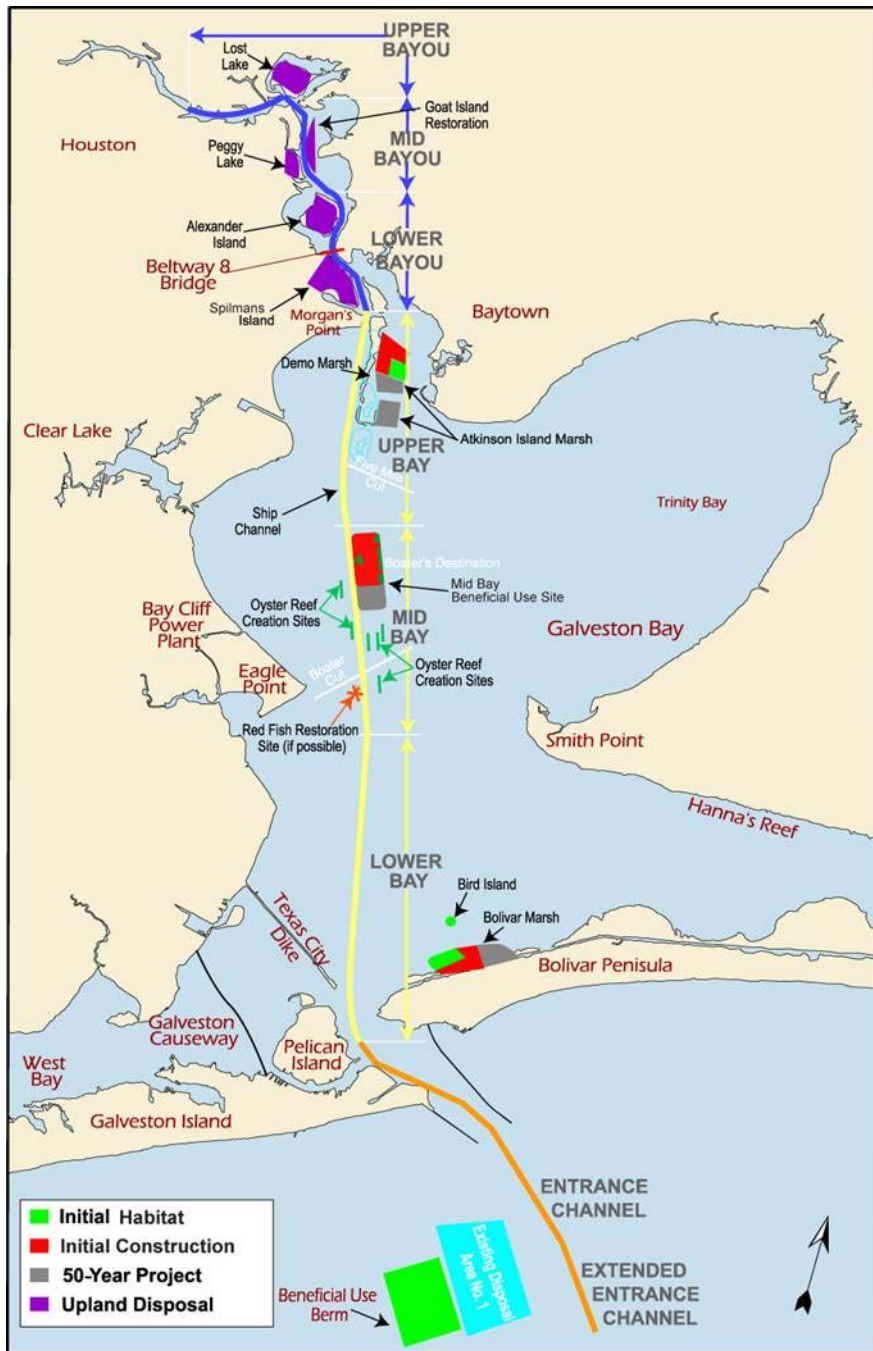


Figure 1. 50 -year project plan for Houston ship channel.

## ENVIRONMENTAL CONCERNS

Initially the plans for construction identified by the Corps of Engineers and Port of Houston Authority addressed various configurations to deepen the Houston Ship Channel, the largest configuration deepened the channel to 15.2 meters (50 feet) and widened it to 182.9 meters (600 feet) and called for all of the dredge material to be pumped next to the channel. This method of placement, which had occurred until this point in time, is referred to as open bay placement or open bay disposal. After discussions with local state and federal environmental agencies the practice

of open bay placement of dredge material was no longer going to be accepted. To address the concerns an Interagency Coordination Team (ICT) was created by the Corps' Galveston District to address open bay placement as well as other environmental concerns. The ICT for this project was the first ever initiated by the Corps of Engineers and has since become a standard practice followed in developing plans for other projects undertaken by the Corps of Engineers. Twelve agencies make up the ICT for this project: the U.S. Environmental Protection Agency (EPA), U.S. Army Corps of Engineers (Galveston District), Port of Houston Authority, U.S. Fish and Wildlife Service, U.S. National Marine Fisheries Service, Natural Resource Conservation Service, Galveston Bay Estuary Program, Texas Parks and Wildlife Department, Texas General Land Office, Texas Water Development Board, Texas Natural Resources Conservation Commission and the Port of Galveston. In order to properly address the environmental issues sensitive to the stakeholders, various subcommittees were formed. Among the subcommittees formed were the 3-Dimensional Hydrodynamic and Salinity Model Subcommittee, Ship Navigation Simulation Subcommittee, Oyster Model Subcommittee, the Contaminants Subcommittee, the Cumulative Impacts Subcommittee, the Benthic Recovery Subcommittee, the Beneficial Uses of Dredged Material Subcommittee, and the Oyster Reef Subcommittee. Each of these subcommittees, through years of discussions and meetings in addition to countless studies, were able to resolve all issues to the satisfaction of the resource agencies. Almost all subcommittees cease to meet today, with one exception.

Of all the subcommittees formed by the ICT, the one that continues to meet on a regular basis is the Beneficial Uses Group (BUG) who was originally tasked with determining where and how the dredge material could be placed in Galveston Bay without utilizing open bay placement. The BUG provided guidance to develop the 50-year plan (see Figure 1 on previous page). This plan is still in use today and the BUG continues to advise on habitat creation and management matters that are ongoing with the project. The BUG Plan includes 1720 hectares (4,250 acres) of intertidal marsh to be created over the 50-year economic life of the project. Additionally, a 2.4-hectare (6-acre) bird island has been built, Redfish Island restored, 69.6 hectares (172 acres) of oyster reef created, Goat Island restored and an offshore beneficial use berm created. At the end of the study process the BUG plan was chosen by the Corps of Engineers as the National Economic Development (NED) Plan because the original NED Plan was not constructable. This plan was approved by Congress in the Water Resource Development Act of 1996.

#### **Lessons Learned:**

- Engage environmental agencies and other stakeholders early in the process and keep them informed through all stages.

### **CAPACITY AND SAFETY CONCERNS**

The economic factors associated with the Houston Ship Channel are the ones that had generally received the bulk of the press when justification for a channel deepening and widening were discussed, but safety concerns for vessel traffic were also a key factor for the enlarged channel. Larger commercial deep draft vessels were and are continually being constructed that have deeper drafts and wider beams to make overseas transportation more efficient and affordable. In the 161.5 meter (400 foot) wide channel, there was just enough room for two modest size deep draft vessels to pass each other, however the Houston Ship Channel also has a tremendous volume of barge tow traffic in the same channel. Deep draft pilots were forced to maneuver around the many barge tows as they proceeded through the channel and then also pass deep draft vessels with very little margin to spare. To help solve this issue, the project team designed barge lanes on each side of the ship channel at a depth of 3.7 meters (12 feet) which were located along the full distance of the ship channel in the bay. These shallow channels allowed the barges to travel on the sides of the deeper channel while the deep draft vessels could travel in the center of the channel without having to make as many passing maneuvers thus increasing the safety and efficiency of the channel.

In the past, prior to the widening and deepening, the Corps was able to side-cast dredge material (open bay placement) in Galveston Bay, but that practice was no longer approved by the local environmental resource agencies predicated the need for a new method of placing dredge material in the bay. In the upper parts of the channel (landlocked reach), upland sites near the channel have historically been used and could continue to be used, but because of the extensive development along the channel, land for additional placement areas has become increasingly difficult and expensive to find. With no sign of that trend reversing, a better alternative needed to be developed. One of the key missions of the BUG was to assist in developing the plan to place over 229 million cubic meters (300 million cubic yards) of dredge material over the 50-year economic life of the project without using open bay placement. They met diligently for several years and involved many citizens and stakeholders in the process of deciding how to manage all the dredge material. Ultimately, the plan, which became known simply as the BUG Plan, was finalized. It included a mixture of upland placement where it was feasible and in the bay, where upland

placement was not feasible, 1,720 hectares (4,250 acres) of intertidal marsh cells are planned to contain the dredge material. The plan also included the creation of a 2.4 hectare (6-acre) bird island constructed with dredge material, the restoration of Goat Island and the restoration of Redfish Island.

The plan for construction was accepted by all the BUG members, but there was still one more obstacle: beneficial use sites had never been constructed to the sizes that were planned using large dredge equipment. So, with the goal of proving it could be done, the Port of Houston Authority and the Corps of Engineers constructed a 89 hectare (220-acre) demonstration marsh in 1993 using the same construction methods and equipment that would be used in the marsh construction during the project construction. A site was selected, the designs were developed and the site was built. A containment levee was pumped to capture the dredge material. The dredge material was then allowed to settle to the proper elevation for the intertidal marsh grass to grow. Various test plots were laid out and planted in the newly placed dredge material to determine which planting method would ultimately prove to be most effective and least expensive (see Figure 2). Almost all planting methods worked and some were so successful that the grass was dying because of the density. Ultimately it was decided that seeding the *spartina alterniflora* was the least costly and most effective for applications. Further lessons learned through the planting and vegetation will be covered in a later section.

#### **Lessons Learned:**

- Safety concerns are equally important and should be promoted along side economic reasons.
- Get project input from all stakeholders. They often have good ideas.



**Figure 2. Demonstration marsh test planting plots.**

#### **ECONOMIC CONCERNS**

Before the Corps of Engineers can participate in the construction of a project, the project must have a local sponsor to be authorized and the federal costs funded by the U.S. Congress for construction. In order for this authorization to take place there must be an economic benefit to the federal government and the local economy. In the case of the HGNC project, an economic evaluation was conducted by the Corps of Engineers that would factor in the 50-year costs of the project and weigh that against the projected economic gains of the added depth and width of the channel. The initial estimates for the cost of the project were \$700 million dollars and the benefit-to-cost ratio was determined to be 2.3 to 1 when all factors were considered. This ratio means that for every \$1 invested \$2.3 of benefit would be received. The key factor in the benefit-to-cost ratio for the HGNC project was that petroleum

tankers could bring in and take out more products with each vessel by having the extra 1.5 meters (5 feet) of depth that the new channel would provide.

Once Congress authorized the project, the Port of Houston Authority and the Corps of Engineers prepared a Project Cooperation Agreement (PCA). A PCA spells out the details of how the project to be constructed will be cost shared and who has the responsibility for construction. Due to the depth of the project (-13.7 meters (-45 feet Mean Low Tide datum)) the local sponsor (Port of Houston Authority) was responsible for 25% of the costs to construct. Initial estimates of construction cost indicated that the Port of Houston Authority share of the construction cost could be in excess of \$130 million to complete the initial construction phase. These funds would be provided in annual allotments to the Corps of Engineers. To provide its share, the Port of Houston Authority had to find a way to generate an enormous amount of readily available capital. They accomplished this by going to the voters of Harris County to approve bonds that would pay for the Port of Houston Authority's share of the costs for initial construction. The bonds would be paid back over time by taxes to all property owners in the county. The Harris County residents saw the benefit of a larger and wider channel and passed the bonds by a 2 to 1 margin. This bond passage gave the Port of Houston Authority the initial dollars it would need for the construction efforts.

Once a project is authorized by the Congress to begin construction all necessary dollars needed for the federal share (Corps of Engineers) of construction are not available or guaranteed. Each year, the Congress must still approve a federal budget for the project and ultimately only provide the funds needed for a given fiscal year. The delegation of Senators and Representatives for Texas and Houston needed to be continually educated on the merits of this project and the benefits it has for the local region, the state and the nation. Diligent efforts by the Port of Houston Authority to provide this information to the elected officials have proven to be effective and the project has been successful at receiving adequate funding to complete the initial construction phase.

In the summer of 2005, the Houston Ship Channel was opened to its new depth of 13.7 meters (45 feet) deep and new width of 161.5 meters (530 feet). A celebration was held and elected officials and everyone who helped along the way to secure funding attended the event. While the occasion was worthy of celebrating, it sent an inadvertent message to some of the elected officials that the project was complete and under normal conditions that means that no additional funds are required. This was not the case for this project because the event only celebrated the completion of the channel depth and the initial phase of construction on the placement areas and marshes. Since the HGNC project is a 50-year project, future dredge placement capacity is needed and Congressional funding will be required to build future sites. Not only was federal funding needed for many years to come, but a matching cost share from the local sponsor (Port of Houston Authority) is also needed. In the case of the Port of Houston Authority, the initial bond fund was exhausted through initial construction, so a continued finding mechanism needs to be identified. This funding process could occur through another bond election or through operating revenues, so continued communication and education of financial planning personnel in the organization is also critical.

### **Lessons Learned**

- Consistently educate elected officials on project funding needs over the life of the project.
- Repeatedly inform elected officials (Congress) of the importance of funding the annual budget for construction.
- Regularly inform financial planning personnel

### **SOCIAL CONCERNS**

Both the Port of Houston Authority and the Corps of Engineers that cost-share the HGNC project are public entities, so the input and opinions from citizens is critical to the approval and success of the project. Knowing this, the Corps of Engineers and the Port of Houston Authority prepared for public input and used the public opinion as an integral part of the process in developing the plan for deepening and widening of the channel and the dredge material placement plan in the bay. Even before plans and specifications of the proposed project were prepared, the Port of Houston Authority began to take the necessary steps to provide for the future funding it would need to contribute 25% of the project costs through the bond election approved by the public. This occurred in large part due to the education efforts of the Port of Houston Authority and Corps of Engineers who specifically set out to educate the population on the importance of the enlarged channel to the local economy and to thousands of local jobs.

Following the passage of the bonds to fund the Port of Houston portion of construction in 1987, plans for project construction were started. An initial concern expressed by the citizens was that the sites need to be open and available to the public after construction has completed. Additionally the citizens wanted access channels for small watercraft to be able to navigate across shallow areas in the bay and go between some of the sites thus allowing

marked access from the east side of the bay to the west side of the bay around the newly created habitat areas. This was requested at many of the public meetings that the project team held to explain to all interested citizens and groups the project construction plan. These meetings also allowed the public to voice concerns and allowed them to express ideas for the project construction plan. One such suggestion was the restoration of Goat Island, which was an area that over time had eroded and subsided to a point where the area was completely under water. The project team took that idea and further developed it into an upland habitat area.

### **Lessons Learned**

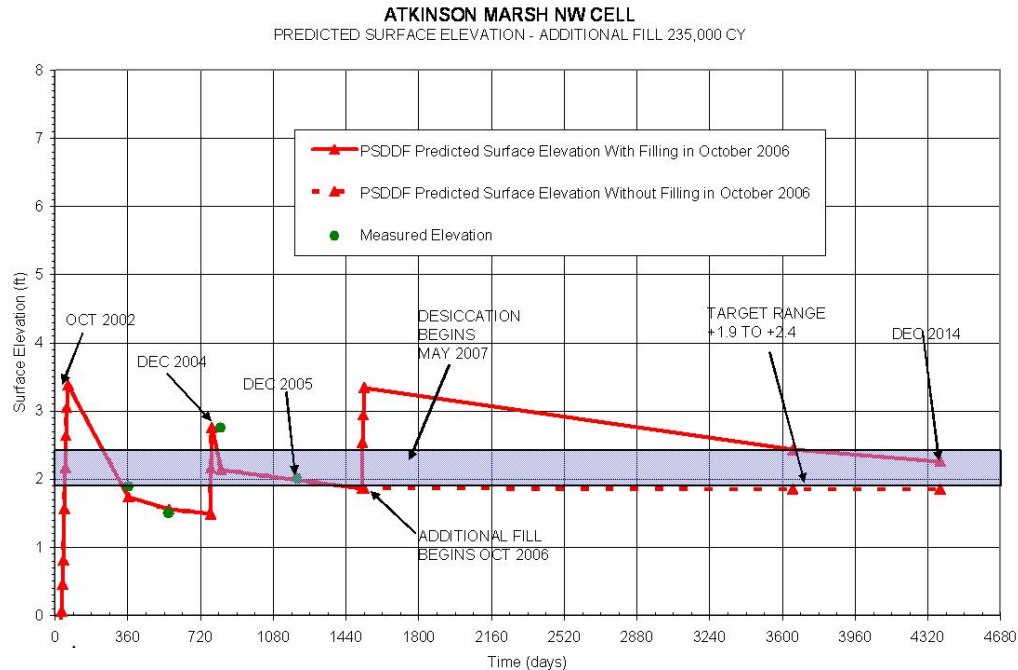
- Thoroughly educate the public on the project (particularly before any type of activity occurs, i.e. vote, construction in a given area, etc.).

### **ENGINEERING CONSIDERATIONS**

Since the HGNC project was the first of its kind with a plan to construct large beneficial use sites, the engineering behind the construction had to be tested. Most of the testing was initially performed through the demonstration marsh, but lessons are still being learned today as the marshes constructed as a result of the widening and deepening of the channel come on line.

The Corps of Engineers and the Port of Houston Authority along with some consultants assisting on the project design had years of experience dealing with putting dredge material into placement areas, but most previous placements did not required a dredge to pump in an amount that would then settle to an elevation that be between an elevation that varied only 20.3 centimeters (8 inches). Due to the silt and clay that exists in the bottom of the Houston Ship Channel the dredge material exiting the discharge dredge pipe from large dredges (76.2 centimeters (30 inches)) flowed fairly well and usually formed an elevation with only a slight slope across a 200 to 300 acres marsh cell. However, when smaller dredges were used (< 61 centimeters (<24inches)) the material had a tendency to stack up at the end of the discharge pipe since there was not sufficient power to push the dredge material across the site. To help in the filling process, later contracts included several dredge discharge locations to allow for flexibility in material placement. This allowed the size and power of dredge to vary and the resulting elevation in the cell was not impacted. Once the project team was able to control the dredge material placement the difficult prediction was to decide what elevation to fill a cell to so the material would settle to intertidal elevations conducive to marsh grass growth.

The Corps of Engineers' PSDDF settlement model was utilized and found to be quite effective at predicting the ending elevation in the marsh while taking into consideration the consistency of the material existing in the borrow (dredge) site. An example of the output that the model can provide is shown in Figure 3 below.



**Figure 3. Example of PSDDF settlement predictions.**

Geotech samples taken during and after the filling process are a key to getting useable results from the PSDDF model. Samples are taken from the existing material in the bottom of the channel prior to dredging and also taken during the filling operation. These samples give the designers an idea of how the material reacted during the dredging process and allows them to predict the amount of settlement that will take place in the marsh cell.

Prior to marsh cell construction, the project team also gathers data on the soil conditions along the proposed cell's levee alignment. This evaluation proved critical in the construction of certain project sites because of the soft bay bottom present in Galveston Bay. Along with the geotech analyses, considerable hydrographic surveying was also performed in the proposed locations for marsh cell construction to further validate the site selections and minimize any issues prior to preparation of plans and specifications for construction.

As the construction of each marsh and island site is completed the project team has come to understand more about the types of erosion protection needed to protect the marsh cell levees and how different types of protection hold up in the wave conditions of Galveston Bay and inside the cell itself. The first two marsh sites that were designed and built utilized geotubes to protect the exterior levees. It was first believed that if the levees are intended to slowly deteriorate as waves break on the geotubes, some damage could occur causing geotube deterioration. If this is acceptable, then the geotube appears to be a viable option. For sites where the levees need to withstand the elements for 10-20 years or more, the project team has found that the properly graded stone shore protection (with a geotextile filter layer) does a more effective job (see Figure 4 below). Also, since Galveston Bay has a thriving oyster population, the stone protection used on the bay side of the cells, below the water surface, serves as habitat for oysters and other aquatic species that prefer the crevices provided by the stone.





**Figure 4. Rock shore protection with geo-membrane.**

### **Lessons Learned**

- Large scale dredges (24-30 inches or 61-76 cm) can fill a marsh site to a desired elevation but may need several discharge locations.
- Detailed geotech analyses are needed to accurately place the marsh sites (particularly the levees).
- Thorough hydrographic surveying of proposed marsh sites is vital to accurate site placement.
- Aim on the high side for levee erosion protection (rock vs. geotube).

### **ECOLOGICAL CONSIDERATIONS**

Re-creating or replicating a natural marsh, can be a delicate and often tricky endeavor. Over the 13 years that this project team has been designing and constructing large man-made marshes, they have had to continually keep this concept in mind. No scientist or engineer can predict with 100% certainty how a natural system will react to man-made influences. The BUG did however provided a wealth of knowledge that helped the team create a plan with a high likelihood of success. Thus far, the BUG's influence on the construction plans has been highly successful, and there were several opportunities over the years to learn new lessons. The main focus of learning has been through the Demonstration Marsh. From its inception, the Demonstration Marsh (now renamed the Gorini Marsh) was constructed to be a living laboratory to test out the methods that were slated to be used in the overall BUG plan. One of the first ecological areas that the BUG wanted to test related to grass planting. As shown in Figure 2, plots were established to test different spacing for the planting of the *spartina alterniflora* (smooth cordgrass) sprigs and spartina seed. All the test plots grew very well and it was concluded that the seeded plots were the least expensive to plant as well as highly successful in plant growth. The seeding method has continually evolved into the preferred method of planting the large marsh cells. In late fall, seed is gathered from healthy plants, put into containers with brackish water and stored in freezers over the winter. This process is called scarification. In the early spring, the seed is ready to be spread in a cell that has reached the proper elevation for smooth cordgrass growth.





**Figure 5. *Spartina Alterniflora* (smooth cordgrass) seed after scarification.**

When seed is distributed in one of the marsh cells, the BUG has found it is generally most effective when the material is still somewhat “soupy/wet” in nature, so the seed sinks gently into the dredge material. This allows the seed to germinate easier and makes it more difficult for birds to find and eat. The placement of the seed can actually be performed before the marsh reaches its target elevation. The seed can start growing into a plant at the upper limit of the intertidal range and continue to establish itself as the elevation of the cell continues to consolidate to the lower range for intertidal growth. The BUG prefers to fill the cells to the lower elevation of the tidal range in each area of Galveston Bay. One reason for this decision is that it allows for more tidal exchange into cell thus naturally forming some of the critical marsh edge that the aquatic creatures seek. This method of construction also has the potential to reduce the cost of manually excavating creeks and channels to establish circulation. The more marsh edge available for use, the better the marsh functions. Another reason the BUG and the project team try to fill the cell to the lower range is because it minimizes the chance of overfilling a marsh cell. If a cell is overfilled additional construction effort is needed to reach the proper elevation and in turn could require costly manual excavation.

Another form of habitat that the HGNC project has created and continues to cultivate is bird habitat. One specific island was created just for birds. The 2.4 hectare (6 acre) island known as Evia Island is now home to thousands of birds during the nesting season. The island was constructed using dredge material and armored with rock shore protection with a rock breakwater forming a beach area for wading birds. The island is partially vegetated and planted with trees and shrubs to allow for the various habitat preferences of the birds that use the site. When the island was initially planted, all shrubs and grasses were planted at the same time as had typically been done at other mainland sites. Much of the vegetation started to grow, but it was primarily the low lying vegetation that began to grow rather than the large shrubs and trees. The growth of the shrubs on the inner part of the island was being impacted since the salt spray was reaching further in the island. The BUG and project team later determined that the salt spray during high wind or storm events was actually retarding the growth of the plants. An outer barrier of shrubs was then planted using more salt tolerant plants. The partially salt tolerant plants that were in the perimeter plantings have now started to take hold and provide a better barrier to the other plants. The team now realizes that a perimeter of larger plants should have been planted first. The interior shrubs and plants should then be planted after an effective wind and spray barrier is in place. Additionally on the island, Bermuda grass was introduced to prevent erosion of the island and began to rapidly spread and take up area that the BUG had initially wanted for the bare ground nesting birds. A monitoring and management plan has been established to ensure that no single plant species takes up an inordinate percentage of the island.



**Figure 6. Evia Island (2.4-hectare (6-acre) dedicated bird island).**

Many of the other beneficial use features with the HGNC project also provide acreage for birds to inhabit. Sometimes the birds utilize them and sometimes they do not do what the BUG team expects. The good news is that the bird populations continue to increase and return to many different BUG sites each year but not necessarily to the same site. The project team stopped trying to predict what the birds will like, but now provide habitat in a range of types (bare ground, grass, shrubs, etc.) so the bird populations have opportunities to nest and rest wherever they desire. Thus far this philosophy has been successful.

#### **Lessons Learned**

- Marshes can be planted with seed and does not require manually sprigging.
- Do not try to out-engineer nature.
- Aim for the lower limit of marsh creation elevation and allow tidal movement to form creeks/channels.
- Establish a wind barrier early on bird island habitats to help inner vegetation grow.
- Birds will nest and rest where they like, so focus on providing a variety of habitat.

#### **PROJECT MANAGEMENT CONSIDERATIONS**

As should be expected, a project of the size and scope of the HGNC project requires a dedicated team to manage and oversee the construction and environmental elements. The Port of Houston Authority and the Corps of Engineers are the cost-sharing partners in the project, so their involvement is guaranteed, but the group's involvement that has made a significant impact over the life of the project is the BUG. Since its inception in 1990, the BUG members have had a stake in the plan and outcome of the project. Often on projects, stakeholders are gathered prior to project construction, ideas and concerns are carefully considered and incorporated into the project construction plan rarely returning to report the outcome to the stakeholders. The BUG was integrally involved and largely responsible for the innovative plan that was constructed, but the Port of Houston Authority and Corps of Engineers insisted on their involvement through out construction and into later years particularly so the marsh and habitat areas could be properly completed and monitored for success. The BUG has generally met monthly for 16 years and continues to be a vital key to the success of the project.



**Figure 7. BUG members inspecting bird habitat area.**

The BUG has been instrumental in assisting the project team in the challenges and changes that have come up through the initial construction phase of the project. Changes are inevitable in a large-scale 50-year construction project but since the project team has involved the BUG through out the life of the project, the key stakeholders have been able to not only stay informed on the changes, but also have an active role in solving some of the issues that have arisen. The project team has developed an extensive inspection program to help identify when issues arise that need the attention of the project team and the BUG. This program has proved to be a useful tool in managing the project to ensure that the best possible habitat is created while adhering to the project budgets and site constraints.

As much as the HGNC project team and the BUG would like to think that it has strictly been science and engineering knowledge that has led to the success of the marsh and habitat creation for this project, the truth of the matter is that there is a great deal of creativity and intuition that also plays into the process. The science and engineering are absolutely critical, but they do not paint the entire picture of how a large habitat project is created. The years of experience of the BUG members and the project team have given them the additional ability to apply that experience to benefit the site construction and the wildlife that calls these habitats home.

### **Lessons Learned**

- Involve stakeholders early and keep them involved
- Changes will happen so be ready by developing an active inspection program and keep stakeholders informed
- Marsh creation is as much creativity and intuition as it is science and engineering

### **CONCLUSIONS**

The conclusions and lessons learned of the project team regarding the creation of beneficial use sites in and along the Houston Ship Channel have been included at the end of each section of this manuscript, but are also combined below:

- Engage environmental agencies and other stakeholders early in the process and keep them informed through all stages.
- Safety concerns are equally important and should be promoted along side economic reasons.
- Get project input from all stakeholders. They often have good ideas.
- Consistently educate elected officials on project funding needs over the life of the project.
- Repeatedly inform elected officials (Congress) of the importance of funding the annual budget for construction.

- Regularly inform financial planning personnel
- Thoroughly educate the public on the project (particularly before any type of activity occurs, i.e. vote, construction in a given area, etc.).
- Large scale dredges (24-30 inches or 61-76 cm) can fill a marsh site to a desired elevation but may need several discharge locations.
- Detailed geotech analyses are needed to accurately place the marsh sites (particularly the levees).
- Thorough hydrographic surveying of proposed marsh sites is vital to accurate site placement.
- Aim on the high side for levee erosion protection (rock vs. geotube).
- Marshes can be planted with seed and does not require manually sprigging.
- Do not try to out-engineer nature.
- Aim for the lower limit of marsh creation elevation and allow tidal movement to form creeks/channels.
- Establish a wind barrier early on bird island habitats to help inner vegetation grow.
- Birds will nest and rest where they like, so focus on providing a variety of habitats.
- Involve stakeholders early and keep them involved.
- Changes will happen so be ready by developing an active inspection program and keep stakeholders informed.
- Marsh creation is as much creativity and intuition as it is science and engineering.

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