DELAWARE RIVER MAIN CHANNEL DEEPENING PROJECT
SUMMARY OF SUPPLEMENTAL INFORMATION
COMPILED BY THE CORPS OF ENGINEERS
(1998-2007)

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1.0 PURPOSE

The purpose of this document is to present summaries of the supplemental data collected and analyzed by the Corps of Engineers since the completion of the Supplemental Environmental Impact Statement and the filing of the Record of Decision on the project in December 1998.

1.1 BACKGROUND

The final Feasibility Report and Environmental Impact Statement for the Delaware River Comprehensive Navigation Study Main Channel Deepening Project was completed in February 1992. Based on economic and environmental analyses, a two way, full-width channel with a depth of 45 feet below mean low water (mlw) was selected as the recommended plan of improvement. Plan features included:

- Deepening the existing 40-foot mlw main channel of the Delaware River navigation channel to a depth of 45 feet mlw. The improvement would follow the existing channel alignment and widths, which vary from 1000 feet to 400 feet from deep water in the Delaware Bay to Philadelphia Harbor and the Beckett Street Terminal, Camden, New Jersey;
- Widening of channel bends and deepening a portion of the Marcus Hook Anchorage for safety purposes; and
- Placement of dredged material in several upland dredged material disposal sites in the riverine portion of the project area and at various beneficial use sites in Delaware Bay.

The Record of Decision for the final Environmental Impact Statement dated December 17, 1992, indicated that supplementary environmental analyses were planned for the Preconstruction, Engineering and Design phase of project development to verify conclusions reached during feasibility investigations by either gathering additional data and/or using more sophisticated modeling techniques.

These analyses included:

- Three-dimensional hydrodynamic modeling of the Delaware Estuary to evaluate potential changes in salinity and circulation patterns;
- Benthic invertebrate sampling to assess habitat quality at selected beneficial use sites in Delaware Bay;

- Biological effects based testing to determine the impact of open water disposal on aquatic ecosystems;
- Detailed environmental assessments of selected upland dredged material disposal sites;
- Consultation with both the U.S. Fish and Wildlife Service and the National Marine Fisheries Service, pursuant to Section 7 of the Endangered Species Act;
- Cultural resource investigations in dredging and disposal locations; and
- Coordination with regional oil spill response teams to review the adequacy of existing Delaware River spill contingency plans.

The Corps of Engineers worked closely with Federal and State resource agencies to complete the required investigations. Pursuant to the National Environmental Policy Act, a final Supplemental Environmental Impact Statement that presented the findings of these investigations was completed in July 1997. The recommended plan of improvement remained the same as presented in the original Environmental Impact Statement, with additional details regarding beneficial use sites in Delaware Bay. The final Supplemental Environmental Impact Statement evaluated the use of Delaware Bay dredged material from initial project construction for wetland restoration at Egg Island Point, New Jersey and Kelly Island, Delaware, and for stockpiling of sand for later beach nourishment work at selected beaches in the State of Delaware. The Record of Decision for the final Supplemental Environmental Impact Statement, dated December 18, 1998, indicated that due to fishery and habitat related concerns expressed by resource agencies, the Corps would consider placement of sand directly on Delaware beaches in lieu of offshore stockpiling. This is the current recommended plan of improvement.

1.2 DATA COLLECTION/STUDIES

Since the completion of the Supplemental Environmental Impact Statement, the Corps has continued to work with various Federal and State resource agencies to collect data for two purposes:

1) To establish the baseline conditions for the extensive monitoring that would accompany the construction of the project.
2) To verify previous findings.

The data collection and studies conducted for 1) and 2) above were:

1. Studies of the Delaware Bay Oyster beds in the vicinity of the proposed restoration projects.
2. Collection of sufficient pre-construction monitoring data in the vicinity of the Kelly Island restoration project to verify and evaluate the ecological effects and benefits of the project when compared to post-monitoring data.

3. Species-specific studies (blue crab, horseshoe crab, *Sabellaria vulgaris*, shorebirds and sturgeon) that addressed habitat utilization at certain times of the year to verify previous findings.

4. Conduct of various water quality modeling efforts that provided additional information to confirm that the project would not adversely impact water quality with regard to dredging and placement.

5. Collection of additional sediment data and water quality monitoring of on-going maintenance dredging operations to provide further validation of previous findings.

Note that data collection on all of the above efforts will be utilized as appropriate for the development and conduct of any monitoring associated with the project.

2.0 SUPPLEMENTAL DATA COLLECTION/STUDIES

The following provides summaries of the additional environmental information obtained since completion of the Supplemental Environmental Impact Statement. Various environmental consultants and regional experts were used to collect, analyze the data and document their observations and findings. The information will be used as the project moves forward to insure that all practicable means to avoid or minimize adverse environmental effects have been incorporated into the recommended plan and to identify any unanticipated impacts during the construction process. To this end, the Corps will continue to work closely with all appropriate Federal and State resource agencies and has included funds in the construction cost of the project to conduct the appropriate monitoring. The following summarizes the supplemental data collected, studies conducted, findings and conclusions.

2.1 PRE-CONSTRUCTION (OYSTERS, WATER QUALITY, AND SEDIMENT) MONITORING STUDY (2000-2001)

2.1.1 REASON FOR ACTIVITY

The purpose of this effort was to develop a database on the water quality conditions and health of Delaware Bay oyster populations prior to construction of the Delaware River Main Channel Deepening Project. The data developed from the program will be used after the project is completed to monitor oyster populations in Delaware Bay to insure that no unanticipated effects occur.

2.1.2 SUMMARY OF EFFORT

Data collection and analysis was conducted by the following consultants/experts:

1. Versar, Inc. Columbia, Maryland - water quality monitoring and oyster spat production estimates

2. Rutgers University, Haskin Shellfish Research Laboratory in Bivalve, New Jersey - oyster population studies and assessment of the pre-construction health and condition of the subject oyster beds

3. Dr. Robert Diaz, Ware Neck, VA, - sediment profile reconnaissance study

Water Quality Monitoring. The water quality monitoring that was conducted as part of this effort was to provide additional physical/chemical data needed to interpret oyster population health and to provide further verification of the hydrodynamic model predictions of potential salinity changes that may result after the Delaware River channel is deepened. The model predicted that a negligible movement of the salt line would result from the deepening project. The findings from the salinity model, when analyzed with respect to the salinity changes identified and their impact on oyster resources, indicated that the predicted range of salinity changes would result in no adverse impact on oyster resources. In consultation with the New Jersey Department of Environmental Protection

(NJDEP), the Corps of Engineers agreed to collect additional data to further evaluate the potential salinity changes and any unforeseen impacts on oyster populations due to the deepening project. A monitoring plan to assess any possible effects of the project to the oyster beds will be implemented.

Nine monitoring sites were established in lower Delaware Bay centered on historic oyster beds. These sites were selected to cover a range of salinity gradients of the naturally occurring oyster beds in the States of Delaware and New Jersey. The New Jersey oyster beds from upper bay to lower bay were Arnold's, Ship John, Bennies, Nantuxent, New Bed, Egg Island, and Lease 554D. These beds are routinely sampled in October by the annual Haskin Shellfish Research Laboratory oyster seedbed survey. Two of the nine sites studied were located in the State of Delaware over known oyster seedbeds (Over the Bar and Lower Middle). All beds were natural beds except for Lease 554D. The sites covered the salinity gradient, and thus, were representative of beds typically characterized by high and low rates of natural mortality from predators and disease. The sites also covered a range of fishing pressures from high (New Bed, Bennies) to virtually non-existent (Over the Bar, Lower Middle).

Some variables, such as food supply, correlate with salinity. Fishing and salinity however, are partially confounding factors. Since some beds with limited fishing impact occur at higher salinities, yet no beds with substantial fishing impact occur at low salinities. In general, differences between beds can best be explained by the location of the bed in the salinity gradient, as that determines most of the environmental conditions present, and on the degree of fishing, as that may impact abundance and bed structural characteristics on a more local scale.

Continuous water quality monitoring was conducted for nine separate months from May through November 2000 and from March through April 2001 at each sampling location. Data were collected by deploying in-situ YSI series 6600 data loggers moored one-meter from the bottom at all nine oyster monitoring stations. Each unit collected data on temperature, pH, dissolved oxygen, salinity, turbidity, and chlorophyll concentrations. Each unit was retrieved in 2-4 week intervals and the data were logged every 15 minutes of soak time. Several data gaps occurred between deployments due to occasional malfunctions of the data loggers or excessive fouling of the water quality probes. The data logger deployed at Arnold's Bed was lost in the March 2001 deployment; therefore the data were not retrieved.

Whole water samples were collected throughout the survey period to assess the nutrient content of the water column for oyster production. Samples were collected one meter from the bottom with a submersible pump, transferred into pre-labeled jars, and shipped on ice to the analytical laboratory (Academy of Natural Science of Philadelphia). Samples were collected from the Arnold's, Ship John, New Bed, and Lease 554D monitoring sites. Once a month sampling was conducted in the cooler months but was increased to twice a month during the primary oyster-growing season (June, July, and August). Samples were analyzed for Total Suspended Solids (TSS), chlorophyll *a*, organic nitrogen (measured as Total Kjeldahl Nitrogen; TKN), proteins, carbohydrates, and lipids.

Oyster Monitoring. Each of the nine monitoring sites were defined as a 0.2' latitude *x* 0.2' longitude rectangle, about 25 acres in size. On approximately the 15th of each month (April-November, 2000; March, 2001), each site was sampled by taking three or more dredge hauls initiated at random positions within the 25-acre rectangle. Sufficient dredge hauls were made to provide 100 or more live oysters for analysis, unless total abundance was very low; however, no fewer than three hauls were made. Each haul was about one minute in duration and was tracked precisely by a Digital Global Positioning System with positions in decimal minutes to three significant digits logged every 5 seconds. The first three hauls were split into thirds and the respective thirds from each of the three hauls combined to produce three combined bushel samples. One of these bushel samples was used to provide information on oyster health, condition index, and gonadal index. The number of predators and fouling organisms were also estimated from this sample. The additional bushels were used to provide a larger sample size when the minimally required number of animals were not present in the initial one.

Spat production was monitored by deploying trays of natural oyster shell at all nine monitoring stations during the summer 2000 spawning season. A total of six deployments of spat trays were conducted. Trays were left in-situ for spat settlement for approximately two weeks. Oyster spat trays were retrieved on July 5, July 24, August 7, August 21, September 11, and September 20, 2000. Increased boat traffic or vandalism to tray markers caused a number of trays to be lost particularly in the latter part of the season. Six clean oyster shells were placed in alternating positions between two sheets of coated wire mesh that were wire tied together. For each deployment, the wire mesh trays were attached to four sides of a weighted crab pot (shell was held vertically in the water column over the pot entrances) such that 24 shells were available for settlement for each set. Upon retrieval, the shells were inspected under a dissecting microscope and all oyster spat attached to the inside surface of the shell were counted and measured (from the shell hinge to the outer lip). To express the density of spat per unit area of shell, the surface area of each shell was estimated. The surface area for each shell was measured by molding and cutting a sheet of tin foil over the inside surface of the shell. The foil was then weighed on a microbalance and the total surface area was estimated based on a regression between foil weight and surface area (e.g. 1, 2, 4, and 6 cm^2 sheets) developed for each roll of foil.

Sediment Monitoring. On September 13 and 14, 2000 a sediment profile camera survey of Delaware Bay was conducted. Sediment Profile Images (SPI) were successfully collected at 50 stations. Most stations were arranged in four transects perpendicular to the axis of the navigation channel. In order, from lower to upper bay, they were designated MM for Miah Maull Range, C for Cross Ledge Range, L for Listion Range, and A for Arnold's Range. On each transect a station was located in the center of the channel, designated 0, with five stations extending East-West, E or W, at distances of approximately 200-300, 700-1,000, 1,200-1,500, 2,200-2,400, and 4,000-4,200 feet (ft) from the channel center line. Thus, Station LE3 would be on Liston Range 1,200 to 1,500 ft east of the Delaware Bay channel. The only exception was transect A that had only four East-West stations. An additional nine stations were located in the nine oyster grounds near the channel. At each station a Hulcher Model Minnie sediment profile camera was deployed three times. The profile camera was set to take two pictures; using

Fujichrome 100P slide film, on each deployment at 2 and 12 seconds after bottom contact. Seventy-five pounds of lead were added to the camera frame to improve penetration. Both the 2- and 12-second sediment profile images were analyzed visually by projecting the images and recording all features seen into a preformatted standardized spreadsheet file. The major parameters measured were: prism penetration, surface relief, apparent color redox potential discontinuity (RPD) layer, sediment grain size, surface features, and subsurface features.

2.1.3 FINDINGS

For the above efforts, the collected data was documented and summarized in a report. The report provides a convenient source document on the general conditions observed in the pre-construction period of the deepening project. A large database now exists (maintained in an SAS database) through which potential unforeseen changes that may result from the channel deepening project can be assessed and evaluated. This information includes:

- Physical/chemical water quality parameters measured at 15 minute intervals at nine oyster beds for a one year period;

- Water column nutrient data collected 1-meter from the bottom at four oyster beds during the prime growing season;

- A detailed characterization of adult, juvenile, and spat oyster abundance, incidence of diseases, and fouling in the pre-construction period; and

- A characterization of sedimentation conditions using a sediment profile camera on the nine oyster beds and around three navigational ranges that are adjacent to oyster seed and lease beds.

Water Quality Monitoring. The physical/chemical water quality monitoring at the nine oyster bed stations using the in-situ water quality meters showed that conditions followed predictable salinity gradients from lower bay to upper bay stations. Temperature changes followed seasonal changes and were generally consistent among all sites. Dissolved oxygen concentrations were generally high at all monitoring sites and there was no evidence of anoxic conditions that typically plague deeper estuaries such as Chesapeake Bay. Turbidity and chlorophyll concentrations measured by the in-situ meters were highly variable among sites and within seasons, but due to the patchy nature of plankton and turbidity plumes, these results were not unexpected.

Measurements of total suspended solids measured at the four monitoring stations were generally low, typically averaging less than 40 mg/L. Upper bay stations closer to the source of sediment loads within the estuary were generally higher than stations sampled closer to the mouth of Delaware Bay. Whole water samples for chlorophyll resulted in highly variable concentrations similar to those recorded by the in-situ water quality meters. Concentrations averaged about 15-ug/L throughout the monitoring period, although higher concentrations were typically observed at the upper bay (Arnold's) station. Concentrations of Total Kjeldahl Nitrogen averaged about 0.5-mg/L throughout the monitoring period. Analyses of protein, carbohydrates, and lipids of the suspended material in the whole water samples revealed that concentration of lipids were typically 1 to 2 times higher that carbohydrates and protein concentrations. Over all stations and months, lipid concentrations averaged about 5-mg/L.

Oyster Monitoring. Rutgers University's Haskin Shellfish Research Laboratory prepared a report to present the results of the oyster monitoring study and the oyster dredge efficiency study. The Haskin report provides a detailed summary of oyster densities, incidence of diseases, and a general description of the condition of the nine oyster beds monitored in the pre-construction phase of the Delaware River Deepening project. These data will be used as a baseline through which oyster bed health after project completion can be assessed. Assuming that the deepening project moves forward, the studies conducted in 2000/2001 will be repeated to provide the necessary post-construction data to assess any potential unforeseen changes in oyster bed productivity caused by the deepening project. The Haskin Shellfish Research Laboratory pre-construction characterization of oyster beds monitored in 2000/2001 is summarized below.

- The abundance of oysters increased with decreasing salinity. Lowest numbers (less than 2 oysters/m^2) were observed at Lease 554D and Egg Island. Highest numbers (greater than 200 oysters/m^2) were observed at Arnold's and Ship John. Submarket sized oysters typically outnumbered market sized oysters.

- Larger oysters were typically found in higher salinities such as New Bed, Egg Island, and Lease 554D while the oysters collected in lower salinities such as Arnold's and Lower Middle were generally smaller.

- The number of spat per bushel of shell was highest at Ship John and was elevated for most of the year at all the lower salinity sites. Values ranged from 120 spat per bushel at Arnold's to over 800 per bushel at Over the Bar. Spat counts in the lower portion of the bay ranged from 100 to 200 spat per bushel.

- The Gonadal index peaked in July and August at all sites and declined to low levels after August 15, 2000. The decline in the gonadal index suggested that the main spawning in the year 2000 occurred between August 15 and September 15, 2000. The condition index followed the salinity gradient with increased values at higher salinity sites (down bay) and was highest in the April through July 2000 time frame.

- In general, the number of boxes counted at each site did not vary much over time indicating that disarticulation rates were slow. Live oysters typically outnumbered boxes in all size classes, except at lower bay stations (higher salinity). The ratio of live oysters to boxes was highest for juveniles at the lower salinity sties and frequently exceeded 10. At higher salinity sites, the ratio of live oysters to boxes tended to be higher for sub-market sized oysters. Box size frequency did not vary much over the course of the study at any of the sites.

- Both MSX (*Haplosporidium nelsoni*) and Dermo (*Perkinsus marinus*) were commonly found among the samples. Less common parasites included ciliates, *Bucephalus*, trematodes, xenomas, and rickettsial bodies. Ceroid bodies were observed in abundance. The prevalence of MSX during the year 2000 rarely exceeded 20%. MSX peaked in early spring and again in June. In contrast, the prevalence of Dermo reached 100% at all sites except Arnold's and Over the Bar. Dermo is currently the primary cause of oyster mortality in Delaware Bay. Infection patterns for both MSX and Dermo followed the norm for any particular year in Delaware Bay.

- Cumulative mortality (estimated from new boxes and gapers) ranged from 12% at Arnold's to 87% at Lease 554D. Natural mortality was lower for up bay oyster beds relative to down bay beds. The fraction of total mortality attributable to predation (oyster drills) was greater at the high salinity beds from Egg Island to Bennies (25 to 50%). Mortality computed from box counts was relatively high at the beginning of the sampling program ranging from 16% at Arnold's to nearly 80% at Lease 554D. Predation accounted for a large fraction of total mortality and the distribution of predators was consistent with higher mortality rates down bay. Predators included mud crabs, blue crabs, and drills.

- Most fouling organisms were observed on the outside of the shell; organisms on the inner surface were limited to borers (mostly *Polydora*) that had bored through the oysters. The outer shells were mostly dominated by bryozoans, encrusting polychaetes, and barnacles. A variety of other fouling organisms including egg cases, fungi, green algae, hydroids, and mollusks were also commonly observed. Total coverage of fouling organisms on the outer shell did not follow any obvious temporal trends, but fouling tended to increase with increasing salinity. One exception was the up bay Arnold's site where fouling was unusually high.

- Oyster abundance on the New Jersey seedbeds in 2000 was about average for the decade of the 1990s. Oyster abundance at Bennies, New Bed, Egg Island, and Nantuxent was lower than levels observed in seven of the twelve years from 1989-2000. Oyster abundances at Arnold's and Ship John were at historic highs, and significantly higher in six of the 11 previous years. Abundance of market-sized oysters in New Bed, Bennies, and Nantuxent beds was about average in 2000 and well below historic highs. Up bay market-size abundance was relatively high, but still well below historic levels. Spat recruitment in 2000 was among the lowest for the decade of the 1990s. Spat abundance was low throughout the bay, suggesting that adult abundance will be impacted sometime in the 2002-2003 period, even if Dermo mortality rates remain at average levels.

Sediment Monitoring. From the 50 Delaware Bay stations sampled with sediment profile imaging in September 2000 the following is a summary of the findings:

- Sediments were predominantly compact sands, being composed of fine to medium sands. Silty-clays were the second most predominant sediment type. Within station variation in sediments was minor with little variation in grain-size. Coarsest sediments, pebbles and coarse-sand, occurred in the center of the navigation channel.

- Oyster shell in the form of fine to coarse shell hash was a significant component of sediments at most stations. Whole oyster shell, in high concentrations representing oyster beds, occurred at ten stations. Blue mussels occurred at one station in lower Delaware Bay.

- Thin layers of sediment were draped over oyster shell at five of ten oyster bed stations. This fine sediment provided substrate for tube building organisms. At the other five stations there was little to no sediment deposited over shells.

- Sediment layering occurred at ten stations. Layers were primarily coarser over finer sediments at eight of ten stations, and likely represent a lens of coarser sediments transported over finer during storm events. Stations with a sandy layer over a silt-clay layer may be located near a sediment transition area of Delaware Bay. At two stations thin (<1 mm) layers of fines overlaid coarser sediments. It appeared that the fine silty layers were likely due to a recent suspension/ resuspension event.

2.1.4 CONCLUSION

As the deepening project continues, the survey performed in the 2000/2001 time frame will be repeated during construction and after construction is complete. At that time, a comparative analysis of pre-, during-, and post-construction studies will be made to assess any unforeseen changes and how they may affect the oyster populations or water quality in Delaware Bay. These studies may verify the previous modeling findings or initiate adjustments to construction operations, if needed.

3.0 SPECIES SPECIFIC STUDIES

The following details a series of specific efforts that were undertaken to provide the basis for environmental monitoring efforts during and post-construction of the deepening project as well as to verify the previous findings**.**

3.1 DELAWARE BAY WINTER CRAB SURVEY (2000/2001)

3.1.1 REASON FOR ACTIVITY

Portions of the Federal navigation channel in Delaware Bay would be dredged during the winter as part of the Kelly Island ecosystem restoration project (3.7 km or 2.3 miles of the Miah Maull Range). Concerns have been raised that dredging in the lower bay during the winter could impact the over-wintering population of female blue crabs. The prior impact assessment was based upon generalized data as to the distribution and location of the blue crabs in Delaware Bay. Site-specific data was collected to verify the previous analysis.

The blue crab supports the most valuable fishery in Delaware, with an average commercial catch of 50,000 bushels of hard shells and peelers per year; the pot fishery accounts for the majority of the total landings. A dredge fishery for blue crabs occurs from December 15 to March 30 in the lower Delaware Bay, targeting fully recruited crabs (carapace width greater than or equal to 120 mm) that over-winter in deeper waters (depth greater than 10 m) with relatively high salinity. Mature females are dominant in these waters, and make up the vast proportion of blue crabs residing in the lower Delaware Bay. At the onset of winter, mature female blue crabs migrate to the mouth of the estuary and burrow into deep-water sediments where they remain until spring. Young-of year females (carapace width less than 60 mm) and male crabs of all size classes tend to burrow near their foraging habitat in shallow water. If a large portion of the over-wintering female blue crab population utilizes the navigation channel, then dredging operations could adversely impact the winter crab dredge fishery and blue crab recruitment in the following year.

The purpose of the 2000/2001 Delaware Bay winter crab survey was to collect site-specific data to:

- Determine the density distribution of over-wintering blue crabs with respect to the Federal navigation channel;
- Assess the potential impacts of winter dredging on blue crab abundance by sex; and
- Provide an estimate of total blue crab standing stock in lower Delaware Bay for the winter 2000/2001 fishing season.

3.1.2 SUMMARY OF EFFORT

The survey was conducted in lower Delaware Bay (including the Federal navigation channel) in an area extending from river mile 0 to the N 39 degree 20' parallel, excluding tributaries and shallow waters (less than 5 m). The survey area was divided into six primary geographic strata: (1) deep water at the mouth of Delaware bay; (2) lower bay on the State of New Jersey side; (3) lower bay on the State of Delaware side; (4) upper bay on the State of New Jersey side; (5) upper bay on the State of Delaware side; and (6) the Federal navigation channel. The navigation channel was divided into four segments based on range (Liston, Crossledge, Miah Maull, and Brandywine). Sampling in the channel covered three distinct dredging categories: (1) areas previously dredged within the last 15 years for maintenance of the Delaware Bay 40-foot project; (2) areas not previously dredged but would be dredged for construction of the Delaware Bay 45-foot project; and (3) areas not previously dredged and not required to be dredged for construction of the Delaware Bay 45-foot project.

A stratified random dredge survey was conducted during January 2001 to estimate density, abundance, and size/sex composition of the blue crab population. The survey was designed to obtain separate estimates of density and abundance by sex for the Federal navigation channel, the channel bank, and the remaining areas of Delaware Bay with depths greater than 1.5 m. A total of 105 stations were sampled in the standard stratified random survey, with 30 stations allocated to the channel, and 15 stations to each of the other strata. In addition, 30 stations were sampled as a test for differences in density between the bottom of the channel and the channel bank. Sampling was conducted from a commercial fishing vessel equipped with a dredge (4.3 m wide) widely used in the Delaware winter blue crab fishery. The dredge was generally hauled for 2 minutes along the bottom at a speed of 3 knots. The towing distance (in meters) for all hauls was measured by GPS, and depth was recorded from acoustic readings. The area swept for each haul was estimated as the towing distance multiplied by the width of the dredge. For each haul, the number of blue crabs was recorded, and information on carapace width to the nearest mm, sex, maturity stage, and overall condition was collected for each specimen. Live crabs and dead crabs were tallied separately by sex to provide information on winter mortality. The Catch-Per-Unit-Effort (CPUE) for each haul was standardized to number of crabs per 1,000 square meter area swept. A bottom sediment sample was collected at each station to determine grain size.

3.1.3 FINDINGS

On average, it was estimated that 22% of the crabs present in the path of the survey dredge were caught. After statistically adjusting for the dredge catching efficiency, the density of blue crabs in the Federal navigation channel was estimated at 62.0 live crabs per 1,000 square meters (251 crabs per acre), as compared to 51.4 live crabs per 1,000 square meters (208 crabs per acre) for the entire study area. There was no significant difference between these two density estimates. The winter mortality appeared to be substantial, with dead crabs constituting about 20% of the total. The total winter population was estimated at 71.46 million live crabs for the entire study area, and 1.1

million for the section of the Federal navigation channel included in the survey. Only a small fraction (1.6% or less) of the blue crab population in lower Delaware Bay resided in the navigation channel during the survey. The absolute abundance of fully recruited crabs (120 mm and greater carapace width) in the study area was 60.2 million crabs, and 1.05 million for the navigation channel (1.7% of the total). A significant number of age 0 crabs and adult males (age 1+) are likely to over-winter in the upper Delaware Bay and its tributaries, and were not sampled effectively in this survey. This portion of the stock is unlikely to be affected by the deepening project, and therefore was not a target for the survey.

Blue crab sampling in the Federal navigation channel covered bottom habitats that have previously been subject to Corps of Engineers regular maintenance dredging, as well as areas that have not previously been dredged. Although not statistically significant, the estimated mean absolute density in previously dredged areas (2.7 crabs per 1,000 square meters) was substantially lower than the mean density in areas that have never been dredged (65.9 crabs per 1000 square meters). This suggests that frequent dredging may result in less suitable habitat for over-wintering blue crabs.

For the section of Miah Maull Range to be dredged during the winter (3.7 km in length and 1.13 square km in area), the estimated abundance of live crabs across size and sex groups was 70,038 crabs based on the mean density in the entire channel. The number of crabs in the impacted area constituted about 6% of the live crabs in the channel and 0.1% of the crabs in the entire lower Delaware Bay survey area (based on the overall mean density of crabs in the channel). Sampling stations in the Miah Maull Range alone gave an estimate of 2.3 live crabs per 1,000 square meters or a total of 2,594 live crabs in the impacted area.

3.1.4 CONCLUSION

The survey indicates that the planned winter dredging activities would have negligible impact on the over-wintering blue crab stock as only a small area with relatively low density of crabs would be affected.

3.2 DELAWARE BAY WINTER CRAB SURVEY (2002)

3.2.1 REASON FOR ACTIVITY

Concerns have been raised that dredging in the lower Delaware Bay during the winter could impact the over-wintering population of female blue crabs. A stratified random blue crab survey was conducted in January 2001 to provide information on crab density, abundance and population characteristics for the lower Delaware Bay that could be used to assess the relative importance of the navigation channel as habitat for over-wintering blue crabs. The 2001 survey concluded that only a small fraction of crabs over-winter in the Federal navigation channel, and that the dredging operation would have marginal effect on the winter crab dredge fishery and blue crab recruitment in the following year. The 2001 crab survey effort was documented in Section 3.1 above.

The purpose of the second year survey was to obtain additional data to:

- Determine the density distribution of over-wintering blue crabs with respect to the navigation channel;
- Assess the potential impacts of winter dredging on blue crab abundance by sex; and
- Provide an estimate of total blue crab standing stock in lower Delaware Bay for winter 2001/2002.

3.2.2 SUMMARY OF EFFORT

The second year survey was conducted in the same portion of Delaware Bay as the first year. The survey area was divided into the same six primary geographic strata: (1) deep water at the mouth of Delaware bay; (2) lower bay on the State of New Jersey side; (3) lower bay on the State of Delaware side; (4) upper bay on the State of New Jersey side; (5) upper bay on the State of Delaware side; and (6) the Federal navigation channel. The sampling intensity in the navigation channel was enhanced relative to the first survey; taking into account more detailed and spatially referenced information about previous and planned channel dredging. Again, sampling in the channel covered three distinct dredging categories: (1) areas previously dredged within the last 15 years for maintenance of the Delaware Bay 40-foot project; (2) areas not previously dredged but would be dredged for construction of the Delaware Bay 45-foot project; and (3) areas not previously dredged and not required to be dredged for construction of the Delaware Bay 45-foot project. The previously dredged category was further divided into three categories: (1) dredged between 1991 and 1995, (2) dredged in 1996, and (3) dredged between 1999 and 2001. These three sub-categories of the previously dredged area were of approximately equal size. In total, 25 previously dredged plots were defined for the Brandywine, Miah Maull, Crossledge and Liston navigation ranges.

As in the first year survey, a stratified random dredge survey was conducted during February 2002 to estimate density, abundance, and size/sex composition of the blue crab population for the navigation channel and the remaining areas of Delaware Bay with depths greater than 1.5 m. A total of 195 stations were sampled in the standard stratified random survey, with 120 stations allocated to the channel, and 15 stations to each of the other strata. Sampling was conducted with the same commercial fishing vessel used in the first survey, equipped with a dredge (4.3 m wide) widely used in the Delaware winter blue crab fishery. The dredge was generally hauled for 2 minutes along the bottom at a speed of 3 knots. In the Federal navigation channel, 1minute hauls were conducted to ensure that measures of abundance were obtained from the dredging categories to which the station was assigned. The towing distance (in meters) for all hauls was measured by GPS, and depth was recorded from acoustic readings. The area swept for each haul was estimated as the towing distance multiplied by the width of the dredge. For each haul, the number of blue crabs was recorded, and information on carapace width to the nearest mm, sex, maturity stage, and overall condition was collected for each specimen. Live crabs and dead crabs were tallied separately by sex to provide information on winter mortality. The CPUE for each haul was standardized to number of crabs per 1,000 square meter area swept.

3.2.3 FINDINGS

Again, it was estimated that 22% of the crabs present in the path of the dredge were caught. After statistically adjusting for the dredge catch efficiency, the density of blue crabs in the Federal navigation channel was estimated at 3.60 live crabs per 1,000 square meters, which was a significantly lower density than the estimated 21.87 live crabs per 1,000 square meters for the entire survey area. The density of blue crabs overall as well as for the Federal navigation channel was also significantly lower than the first year survey (51.4 and 62.0 live crabs per 1000 square meters, respectively). Sections of the channel that had been previously dredged had a density of 0.96 live crabs per 1000 square meters, as compared to 3.96 crabs per 1000 square meters in sections of the channel that had never been dredged. There was no significant difference between these two density estimates. Only a small fraction (0.22%) of the blue crab population in the lower Delaware Bay survey area resided in the Federal navigation channel during the winter survey (0.13% for the sections proposed for winter dredging). The winter mortality during the second year survey was negligible. The winter population was estimated at 30.37 million live crabs for the entire survey area, and 66,977 crabs for the section of the navigation channel included in the survey. The absolute abundance of fully recruited crabs (120 mm and greater carapace width) in the entire survey area was 19.77 million crabs, and 47,021 crabs for the navigation channel (0.24% of the total).

For the section of the channel proposed for winter dredging (9.86 square km in area, revised up from the first year survey) the estimated density was 4.02 crabs per 1,000 square meters, and the absolute abundance of live crabs across size and sex groups was 39,635 crabs. The number of crabs in the potentially impacted area constituted about 59% of the live crabs that were over-wintering in the Federal navigation channel, and 0.13% of all crabs over-wintering in lower Delaware Bay.

3.2.4. CONCLUSION

The second year survey provided supplemental data that further support the previous conclusion that the planned winter dredging activities would have negligible impact on the over-wintering blue crab stock as only a small area with relatively low density of crabs would be affected.

3.3 KELLY ISLAND PRE-CONSTRUCTION MONITORING STUDY IN DELAWARE BAY (2001)

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3.3.1 REASON FOR ACTIVITY

As part of the deepening project, material dredged from the channel in Delaware Bay would be used to reconstruct Kelly Island, located at the mouth of the Mahon River in Kent County, Delaware. Kelly Island has been subjected to severe shoreline erosion over many years to the extent that a significant amount of saltmarsh wetlands have been lost and commercial harbor facilities, originally occupying the protected lower Mahon River, have had to relocate farther upstream. The beneficial use of dredged material for restoring eroded beaches or creating productive saltmarsh habitat is increasingly being used as an alternative to traditional methods of dredged material placement such as confined disposal facilities. If the deepening project were implemented, dredged material from Liston, Cross Ledge, and/or Miah Maull ranges would be used to reconstruct the shoreline of Kelly Island, and restore saltmarsh wetland habitat.

The restoration project would entail the installation of a 5,000-foot dike along the Delaware Bay shoreline of Kelly Island. The dike would be constructed with a Geotextile tube core overlain and supporting approximately 1.7 million cubic yards of sand. After the dike is constructed, dredged material of approximately 200,000 cubic yards of silt and 500,000 cubic yards of sand would be placed behind the dike to create a 60-acre saltmarsh wetland. During construction, dredged material would be pumped behind the dike and de-watered through a weir discharging into Delaware Bay at the northern end of the project. The details of the plan as shown on Figure .

It is expected that the reconstruction of Kelly Island would accrue a number of ecological benefits. On the Bay shore side, a reconstructed sand beach would provide important nesting habitat for horseshoe crabs and diamondback terrapins. At present, most of this shoreline consists of eroding saltmarsh. Although there are areas of sand beach, for the most part these are broken up by hummocks of eroding saltmarsh as well. Behind the dike, saltmarsh restoration would provide habitat for shore nesting birds, and through several tidal cuts linking to the Mahon River, nursery habitat for fish and shellfish species. Further, stabilizing the Kelly Island shoreline may benefit the nearshore oyster beds by reducing sediment accumulation derived from erosion processes.

Should the Kelly Island reconstruction project proceed, a means to verify and evaluate the ecological effects of the project is necessary. To that end, the purpose of this study was to provide a baseline ecological characterization of Kelly Island habitats prior to construction activities through the implementation of a multi-aspect monitoring program. Environmental data collected from this baseline-monitoring program will be used to:

- Identify sensitive habitats and natural resources present at Kelly Island prior to construction activities;

- Verify and evaluate the ecological benefits of the project by comparing to post-reconstruction monitoring data; and

- Provide a means to guide future wetland restoration projects planned for the Delaware River.

3.3.2 SUMMARY OF EFFORT

Kelly Island is located on the western shore of Delaware Bay in Kent County, Delaware. It is bounded by Delaware Bay to the east, Simons River to the north, and Mahon River to the south and west. The Mahon River is an important port for local commercial and recreational fishermen. The reconstruction project would principally affect the lower eastern shore of the island, facing the Delaware Bay. Most of the sampling and monitoring activity for the project fell within the area bounded by the Kelly Island shoreline to the west, Mahon River mouth to the south, Simons River mouth to the north, and approximately 1.5-miles offshore toward the Delaware River main channel. Additional sampling for juvenile horseshoe crab data comparisons was undertaken along the western shore of Delaware Bay, Kitts Hummock and Broadkill beach. Shoreline erosion is occurring at an estimated rate of 20 feet per year, mostly from the loss of salt marsh. Depths in Delaware Bay waters adjacent to Kelly Island are shallow and average approximately 9 feet out to the main channel, 5 miles to the east. The beach and access road to the south of the entrance of Port Mahon is severely eroded. Construction to stabilize the shoreline has occurred in the past as evidenced by the rock, sheet bulkheads, and construction rubble placed along the shoreline. The road leading to the State of Delaware dock and ramp facilities is frequently washed out by storm events, and over time, the road has been moved farther back into the salt marsh.

Sampling Activities. Seasonal sampling was conducted in 2001 to characterize spring, summer, fall, and winter conditions at the placement site. Elements of the pre-construction survey included:

- **Water Quality Monitoring**

Continuous water quality monitoring at four Delaware Bay oyster beds near Kelly Island was conducted from May through November 2001. Oyster beds monitored were Beck's Rock, Delaware Lower Middle, Drum Bed, and Lease Bed 102. Water quality monitoring comprised continuous monitoring of physical/chemical parameters with water quality meters and analytical measures of total suspended solids. Continuous data of physical/chemical parameters were collected by deploying data logging water quality meters (YSI 6600 Sondes). At 30- minute intervals, the meters recorded temperature, specific conductivity, salinity, dissolved oxygen, pH, turbidity, and chlorophyll. Total Suspended Solids (TSS) were measured in the lower water column at the four oyster beds

11 times during the monitoring period. Whole water samples were collected one meter above the oyster bed using a submersible pump. Laboratory methods for the analysis of TSS followed U.S. EPA Method 160.2.

- **Sediment Sampling**

Estimation of sediment accumulation rates on oyster beds using sediment traps were measured in the lower water column at the four oyster beds over nine intervals during the monitoring period. Rates were calculated from the amount of sediment that was deposited over time in sediment traps. Sediment accumulation rates were calculated from sediment trap data. The accumulation rate (g/ cm^2/yr) is the measured flux of particulate matter into the traps and is composed of net sedimentation plus resuspension.

- **Oyster Monitoring**

Several types of monitoring were conducted. They are summarized below.

Summer Monitoring Of Oyster Spat Settlement. Spat settlement was investigated at five seedbeds and five lease beds in Delaware Bay near Kelly Island during 2001. The seedbeds included Delaware Lower Middle, Drum Bed, Martin's Rock, Ridge Bed, and Silver Bed. The lease beds (LB) included LB-01, LB-02, LB-05, LB-08, and LB-102. At each bed, a weighted crab pot was deployed fitted with four spat settlement trays. Spat settlement trays comprised 1- ft^2 sheet of coated wire hardware cloth folded in half and wire-tied at the margins. Each tray held six clean oyster shells placed in alternating positions, and when affixed to a crab pot, was vertical in the water column and immediately above the oyster bed bottom. In total, 24 oyster shells were presented for spat settlement at each bed during each deployment. Spat settlement trays were deployed seven times during the 2001 monitoring period. Deployment dates were July 3, July 17, July 31, August 15, August 28, September 19, and October 12. Soak time, or time deployed at an oyster bed ranged from 13 to 23 days. The last set, deployed on October 12, was retrieved on November 2. After a crab pot was retrieved, the spat settlement trays were removed and labeled for the oyster bed and deployment dates. The crab pot was refitted with new trays and then redeployed. In the laboratory, the oyster shells were inspected under a dissecting microscope. Spat settlement rate was calculated by counting the number of oyster spat that settled onto a measured area of natural oyster shell for a specific period of time.

Seasonal Oyster Bed Dredge Surveys. Oyster dredge surveys were conducted at 12 of the oyster beds near Kelly Island. Five seedbeds were dredged and included Delaware Lower Middle, Drum Bed, Martin's Rock, Ridge Bed, and Silver Bed. Because Ridge Bed and Silver Bed were much larger than the other beds, three portions of these beds were dredged, designated East, West, and Center. In total, 9 locations were dredged within the seedbeds. Seven lease beds (LB) were dredged and included LB-01, LB-02, LB-05, LB-08, LB-09, LB-10, and LB-16. Because LB-02 and LB-05 were proportionally larger than the other lease beds, two portions of these beds were dredged. In total, 9 locations were dredged within the lease beds. Surveys were conducted during early summer and fall. Oyster dredging was conducted off of the Delaware research vessel, *Ringgold Brothers,* using the same crew and gear as used in their annual survey of oyster beds. Oysters were collected with a standard oyster dredge with a 54- inch tooth-bar width and a capacity of 7 bushels. Three dredge hauls were collected at each sampling location and processed as individual replicates. During operation, the dredge was towed at a speed of approximately 2 knots for in most cases 1- minute or less (depending on recovery, dredge time was occasionally longer in some of the less productive lease beds). Location data was recorded at the start and end of each dredge tow with a GPS. The total number of bushels of material collected was recorded for each dredge haul, and one bushel was retained for oyster bed characterization. To characterize the bushel samples, the total number of live oysters present as well as categorizing them into spat (roughly less than 2-cm), small size (from 2 to 7-cm), and market size (7-cm or greater) was recorded. In addition, up to 100 randomly selected oysters in each bushel were measured to the nearest millimeter. To assess recent mortality of oysters, the number of "boxes" or articulated shells present in the bushel sample were counted. In addition, up to 100 randomly selected boxes were measured to the nearest millimeter. To assess predation due to the oyster drill, the number of boxes with oyster drill holes were counted. Additionally the number of oyster drills collected in the bushel sample were counted. Ancillary species collected by the dredge were identified and recorded.

- **Finfish and Macro-invebrate Survey**

A seasonal finfish and macro- invertebrate survey using otter trawl and beach seine was conducted to provide a site-specific characterization.

Kelly Island. Kelly Island fisheries were characterized principally by employing a seasonal trawl and seine survey. Trawling and seining surveys were conducted seasonally during 2001. Trawling was conducted in three areas adjacent to Kelly Island in Delaware Bay (South, Central, and North), reference areas were north and south of Kelly Island, and within the Mahon River. Similarly, seining was conducted at three locations along Kelly Island (South, Central, and North) and at the north and south reference locations. Trawling was conducted with a 16-ft otter trawl with ¼"-mesh cod-end liner towed for 5- minutes parallel to the shoreline in shallow water habitat. Three replicate trawls were completed at each station. Seining was conducted with a 100-foot beach seine with 6-ft depth and ¼"-mesh. Three replicate seine-hauls were completed at each station. Fish species collected from trawling and seining were identified, counted, and measured in millimeters for total length of 25 specimens. Horseshoe crabs were identified by sex, counted, and measured in millimeters for carapace width and total length. Blue crabs were identified by sex, counted, and measured in millimeters for carapace width. Diamondback terrapins were identified by sex, counted, and measured in millimeters carapace width and length.

- **Spring horseshoe crab spawning survey**

Adult horseshoe crabs were surveyed on Kelly Island and Port Mahon beaches during the spring spawning of 2001. Spawning adult horseshoe crabs were surveyed by methods instituted by the Delaware National Estuarine Research Reserve (DNERR). Horseshoe crabs were counted along two transects each (South and North) for Port Mahon and Kelly Island beaches. Transects were 50-m in length and followed the “crab- line” or the upper limit of the beach where crabs were laying most intensively. Only crabs within 1-m of the “crabline” were counted. Along the transect area border, crabs with more than half of their bodies within the area were included in the count. Male and female crabs were counted separately. Two surveyors using mechanical count recorders worked in tandem along each transect, one counting males and the other females. Transect surveys were started 20-minutes after the evening high tide. Start and end times were recorded as well as qualitative assessments of wave height and cloud cover. Port Mahon was surveyed on the new moon of May 22 and full moon of June 5. Kelly Island was surveyed only on 5 June; thunderstorms precluded working on the earlier date.

- **Summer juvenile horseshoe crab survey**

A juvenile horseshoe crab survey was conducted along the Delaware Bay shoreline during September 2001. The survey was designed to characterize juvenile crab use of subtidal habitats adjacent to known spawning beaches. Beaches surveyed included Kelly Island, Kitts Hummock, Broadkill, and in addition adjacent reference areas located 0.5-miles north and south of Kelly Island. The south reference beach was near the Port Mahon spawning beach. Two transects were surveyed at each beach. Each transect constituted twin replicate tows (8 total) of a biological dredge at distances from the mean high tide line of 50, 100, 200, and 300-ft. The dredge was towed for a distance of 30-ft as measured by an incremental tag line. The biological dredge was constructed with a rectangular framed mouth of 10 x 18- in fitted with a ¼-in mesh nylon bag. In operation, the heavy flat bar of the frame scraped along the bottom and dislodged epibenthic fauna into the collection bag. Following a tow, bottom material collected by the dredge was washed, sieved, and sorted; all juvenile horseshoe crabs were counted and measured for carapace width.

- **Sediment profiling before and after a major storm event**

Two sediment profile camera surveys were conducted off Kelly Island, Delaware Bay during 2001. On July 6, Sediment Profile Images (SPI) were successfully collected at 50 stations. The same stations were resampled on October 24 after several storm events. At four stations during the October sampling rough seas caused the profile camera to pullout of the sediment before any images could be obtained. Stations were arranged in five transects oriented East-West, they were; Reference North (RN), Kelly Island North (KN), Kelly Island Middle (KM), Kelly Island South (KS), and Reference South (RS). At each station a Hulcher Model Minnie sediment profile camera was deployed. The profile camera was set to take two pictures, using Fujichrome 100P slide film, on each deployment at 2 and 12 seconds after bottom contact. Seventy-five pounds of lead were added to the camera frame to improve penetration. Both the 2- and 12-second sediment profile images were analyzed visually by projecting the images and recording all features seen into a preformatted standardized spreadsheet file. The major parameters measured were: prism penetration, surface relief, apparent color redox potential discontinuity (RPD) layer, sediment grain size, surface features, and subsurface features.

- **A Fall Seasonal Benthic Infaunal Survey**

Benthic sampling was conducted off Kelly Island on October 4, 2001. Benthic samples were collected at nine locations that coincided with sediment profile imagery sites. Sampling locations were 2,000, 3,000, and 4,000 feet along the three transects, KI South, KI Central, and KI North, that radiated in an easterly direction from Kelly Island and toward the main channel. At each location, four replicate benthic samples were collected with a Young grab-sampler, which samples an area of 440-cm^2 to a depth of 10-cm. A total of 36 benthic samples were collected and processed individually. Each sample was sieved in the field on a 500-µm mesh screen, transferred to a pre-labeled sample container, and preserved with 10% buffered formalin stained with “Rose Bengal”. At each sampling location, a fifth sediment grab was taken and a surface subsample was collected for grain-size and organic content analysis. In the laboratory, benthic macroinvertebrates were sorted from the sample material under dissecting microscope, identified, and enumerated. Each organism was sorted and identified to the lowest taxon practicable depending on the maturity or physical condition of the specimen. To calculate biomass, organisms were combined at higher taxonomic levels and processed for Ash-Free Dry Weight (AFDW). AFDW was measured by drying the organisms to a constant weight at 60ºC and then ashing them in a muffle furnace at 500ºC for four hours. Sediment subsamples were analyzed for grain-size by the standard method ASTM D2487, excepting that the hydrometer portion of the test was not included. The minimum grain size category, or silt, was defined as that passing through U.S. Standard Sieve No. 200 at 63-µm. Total organic carbon (TOC) of sediments was measured by loss on ignition.

- **Hydroacoustic Survey of Oyster Bed Size**

An Acoustic Seabed Classification Survey (ASCS) was conducted in Delaware Bay adjacent to Kelly Island in July and August 2001. The survey grid was located between 39.16297 and 39.23674 degrees N and 75.34837 and 75.38928 degrees W (decimal degrees). The ASCS survey was conducted over four days between July 21-28, 2001. Sixteen principal transects were spaced 200 m apart over the entire extent of the survey. In the northwest corner of the survey, where oyster seedbeds are located, transect spacing was decreased to 100 m. All transects were oriented north - south. Individual bottom interrogations (pings) were spaced between 6 - 9 m apart, depending on vessel speed over ground. A total of 26.66 km^2 of bottom was surveyed. The dataset generated from the ASCS survey was field validated with a tethered video sled on August 1 and 10. After completion of video and physical validation, a number of habitat classes were established which best reflected habitat variability within the population dataset. Once the acoustic classes were validated, the spatial dataset was imported into ArcView GIS to create an “interpolated” polygon representation of the bottom features. Polygons were created with the Spatial Analyst software using iterations of neighborhood statistics on a gridded version of the original ASCS chart.

3.3.3 FINDINGS

Water Quality. Continuous water quality monitoring on oyster beds off Kelly Island provided an overview of the seasonal patterns for water temperature, specific conductivity, salinity, dissolved oxygen, pH, turbidity, and chlorophyll. Water temperature increased from 17ºC in May to a high of 26ºC in August, and decreased thereafter to 12ºC in November. Specific conductivity increased uniformly over the monitoring period from 23-mS/cm in May to 33-mS/cm in November. Likewise, salinity increased over the same interval from 14 to 21-ppt. Dissolved oxygen, correlating negatively with temperature, decreased from 7.5-mg/L in May to a low of 5- mg/L in August and increased thereafter to 9-mg/L in November. Measures of pH were relatively stable over the monitoring period averaging about 7.7. Turbidity was also consistent at about 100-NTU. Chlorophyll was highest in May averaging about 50-µg/L, and declined thereafter to about 10-µg/L by November. Periodic monitoring of total suspended solids indicated variability over the monitoring period but most measures ranged less than 100-mg/L. Sediment accumulation rates averaged about 250-g/cm^2/year over the monitoring period. Spat settlement rates generally ranged less than 0.1-spat/100-cm^2/day over the settlement period from July to September, but ranged as high as 0.4-spat/100-cm^2/day. The temporal pattern of settlement suggested that oyster spawning might be attuned to a lunar cycle. Seasonal dredge surveys of oyster beds indicated that oysters were relatively abundant on the seedbeds, however, most were small or below market size. In contrast, oysters were infrequent to absent on most lease beds. Oyster mortality, as indicated by empty box shells, appeared to be reflective of the overall population throughout. Predation by oyster drills appeared to affect more of the smaller sized oysters.

Finfish And Macro-invertebrates. Thirty-one species of fish were collected by trawl and seine during seasonal sampling along Kelly Island and in the Mahon River; all species were typical for the nearshore estuarine habitats. In spring, the most abundant fish were spotted hake, striped cusk-eel, and hogchoker. In summer, Kelly Island appeared to offer important nursery habitat for weakfish. Juvenile fish were abundant in the Mahon River and were collected at all sampling locations along the nearshore of Kelly Island. In fall, juvenile Atlantic croaker was the most abundant species with more than 1,000 fish collected at each sampling location. Although to a lesser degree, croaker was most abundant during winter. Also at this time, the abundances of white perch and striped bass peaked, most likely because of the presence of the juvenile croakers on which they prey. Horseshoe crabs were most abundant during spring and were collected incidentally as they attempted to spawn and nest along the shoreline of Kelly Island. Blue crabs were most abundant during fall and for the most part comprised juveniles. Diamondback terrapins were only occasionally collected during spring sampling, but were commonly observed in nearshore waters. Most likely, terrapins nest on Kelly Island during late spring and early summer.

A survey of spawning adult horseshoe crabs suggested that, relative to Port Mahon Beach, Kelly Island might offer less suitable spawning habitat. However, in comparison with a bay-wide survey run by the United States Geological Service (USGS), both Kelly Island and Port Mahon may be among the most important beach spawning sites along the

Delaware shoreline of Delaware Bay. More data needs to be collected for the Kelly Island and Port Mahon beaches using USGS survey methods before their relative importance can be gauged. A survey of juvenile horseshoe crabs in late summer indicated low abundance throughout the study range.

Sediment Profile. For the sediment profile imaging the following summary applies:

- Sediments were predominantly silty-clays. Fine- to medium- sands were the second most predominant sediment type. There was little variation in sediments between July and October with 46 of 50 stations having the same sediment type.

- An oyster bed, whole shell and coarse shell hash, occurred at one station (KM-10) in both July and October.

- Thin flocculent layers of sediments from recent resuspension events occurred at 10 stations. Thicker layers of uniformly colored lighter sediments indicative of major resuspension/deposition events occurred at 13 stations.

- Sediment grain-size layering occurred at 11 stations. Layers were primarily sandy over silty sediments (seven stations), and likely represent lens of coarser sediments transported over finer during storm events. Stations with sandy layer over silt-clay layer may be located near sediment transition areas. At four stations silty overlaid clayey sediments.

- Processes structuring surface sediments appeared to be physical at all stations in October and all but five in July. At these five stations biological process were dominant in structuring surfical sediment fabric.

- Overall, community succession appeared to be primarily pioneering Stage I with evidence of intermediate Stage II fauna at five stations.

Benthic Organisms. Benthic organisms identified from sediment samples collected offshore Kelly Island were typical for the nearshore estuarine habitats. Overall, the most abundant organisms comprised the oligochaete worms. For the most part, indices of species diversity were similar throughout the study area including mean number of taxa, Shannon-Wiener Index, and Simpson's Diversity Index. Total abundance and total biomass were variable over the study area, but did not appear to be spatially dependent. An invasive species of isopod was found to be pervasive in the study area. Sediment characterization of benthic samples indicated bottom sediments of mostly silt-mud and less than 12% total organic carbon.

Oyster Habitat. Extensive oyster habitat (identified by the presence of exposed shell and related epi-fauna) is present in the region associated with oyster seed beds. Because of generally poor visibility it was difficult to determine quantities of live oysters in these beds. Oyster lease areas to the south did exhibit limited regions of shell bottom, but were generally dominated by non-shell surface habitat. Excluding oyster shell habitat, three other principal habitat types were found in the survey region. Two of these were composed of sand-silt substrate being segregated by the presence or absence of shell bits or pieces in the matrix. The final bottom type was defined by a biogenic component although the bottom character did appear different from the sand-shell types. This bottom type was dominated by epi-fauna/flora, presumably tubeworms.

3.3.4 CONCLUSION

This study provided a baseline ecological characterization of Kelly Island habitats prior to construction, which will be used to verify and evaluate the ecological benefits of the project by comparing to post-construction monitoring data.

3.4 PRE-CONSTRUCTION SHOREBIRD MONITORING AT KELLY ISLAND WETLAND, AND PORT MAHON AND BROADKILL BEACH (2001)

3.4.1 REASON FOR ACTIVITY

Delaware Bay is recognized as one of the most critical stopovers worldwide for shorebirds migrating from their wintering grounds in Central and South America to their Arctic and Sub-Arctic breeding grounds. Each spring shorebirds arrive by the hundreds of thousands on their staging grounds along the Delaware Bay to fuel up for the last leg of their northward journey. Their stopover coincides with the peak of horseshoe crab spawning. The millions of horseshoe crab eggs laid in the sand along bay shore beaches comprise an important food source for the migrants. Previous studies have called attention to apparent declines in the numbers of several shorebird species on their staging grounds and point to the importance of habitat protection in the conservation of these species.

For the deepening project, material dredged from the Delaware Bay channel is proposed for shoreline restoration, including a restoration project at Kelly Island. Other projects propose sand placement at Broadkill Beach and Port Mahon. Shoreline beaches on Delaware Bay are known to attract high numbers of shorebirds. In order to determine whether the shoreline restoration projects will benefit migratory shorebirds, it is necessary to collect and analyze quantitative and qualitative baseline data on shorebird use of the sites prior to construction. This effort provided baseline data completed during May and June 2001. Principal emphasis was on documenting usage by shorebirds at the locations proposed for restoration, and in one case (Prime Hook), at a comparable abutting location not slated for restoration. Rapid assessments also were made of common invertebrate animals in the same areas.

3.4.2 SUMMARY OF EFFORT

Migratory shorebird surveys were conducted at four locations on the Delaware coast during May 2001. Bird surveys were made with binoculars and a 20x telescope, and were conducted from vantage points that caused minimal disturbance to birds along the shoreline. Counting focused mostly on shoreline habitats, but flight-line counts of shorebirds moving between shoreline and nearby marshland habitats also were made near Port Mahon. Each shoreline section was divided into 25-31 subsections and marked. Counts were kept for each subsection.

Knowing what tidal stage is best for counting shorebirds is important to designing sequel studies. Between two and eight shoreline surveys were made at each location each week. Shorebirds were counted at predicted mid-tide times (roughly half way between low and high tides) on each day that counts were made. A second count also was made either 3 hr before or 3 hr after the predicted mid-tide time, i.e. at approximately the time of predicted low or high tide. Correlation analysis was used to describe overall relationships between counts made at mid- versus low tide, and between counts made at mid- versus high tides. Analysis of variance was used to compare counts between the 4 study areas.

The methodology of the shoreline surveys closely followed that used by The Nature Conservancy and Manomet Center for Conservation Sciences for shorebird monitoring at Port Mahon in 1997 and 1999. The study areas were as follows:

- Kelly Island (proposed for restoration): this area extends north along the shoreline from the mouth of the Mahon River for about 1.6 km to Deepwater Point;

- Port Mahon (proposed restoration site): the area is a 1 km stretch of shoreline just south of the mouth of the Mahon River where Port Mahon Road runs parallel to Delaware Bay;

- Broadkill Beach (proposed for restoration): the study area is a 4.4 km stretch of shoreline from Arizona Avenue south to the end of the paved road; and

- Prime Hook Beach: an equivalent area of habitat similar to Broadkill Beach was surveyed as a future control site.

The study areas on Port Mahon and Broadkill beaches were divided into linear sections and marked. Similar linear segments were measured on Kelly Island and Prime Hook Beach. Marker locations were also GPS-located for future reference.

To assess the levels of shorebird use of marshlands proximate to the study beaches, birds were counted moving between the marsh and the shore during peak migration weeks. These surveys were made near the north end of the Port Mahon study site for 10 minutes at dawn and/or dusk, times when shorebirds are expected to be moving to and from roosting sites.

At each of the 4 study locations (at the tideline in transect 1,10, 20, and 25), core samples were collected during visits to the study sites after May 15th. Samples were sorted with a standard 1 mm screen to identify macro-invertebrate taxa. Fifty-two samples were assessed. Cores were collected on site, screened in the field, and washed with salt water into suitable containers marked for date and location, refrigerated, and sorted within 36 hours.

Invertebrates were identified as follows:

- Gastropods and bivalves to genus (or better)
- Amphipods and polychaete worms to family (or better)
- Shrimps to genus (or better)
- Crabs to genus (or better)
- Insects and spiders to order (or better)
- Scarce invertebrates (occurrence $< 5\%$ by head count) to class.

3.4.3 FINDINGS

The shoreline at Port Mahon is highly eroded and has been extensively affected by human efforts to fortify the shoreline against erosion. Natural shoreline substrates are sand (or marsh peat in some areas) on higher sections of the beach and unconsolidated mud at lower tide locations. The vestiges of remaining sand beach are littered with rock, cement blocks, and other materials that historically were used in attempts to control erosion. Little beach remains exposed at high tides, leaving little habitat for foraging or resting birds and little material suitable for nesting horseshoe crabs, many of which become trapped in rocks and other erosion-control materials. Note that more intertidal mud exists on the unarmored section of shoreline south of Port Mahon Rd.

Kelly Island is immediately north of Port Mahon, and also is slated as an environmental restoration site. The Kelly Island shoreline is substantially eroded, with some sections having a thin, sandy beach near the high tide line, and other sections having an eroded marsh peat shoreline. Mud is the principal substrate in the lower tidal reaches. Because little sand remains on the Kelly Island shore, there is little habitat for horseshoe crab nesting, and so it is not a key feeding area for shorebirds during May. On the other hand, the shoreline of Kelly Island is difficult for people to access, and so it is little disturbed, and serves shorebirds well as a resting area.

Prime Hook and Broadkill beaches are close to the mouth of Delaware Bay and are about 20 miles from the Port Mahon/Kelly Island locations. The bayshore in the Prime Hook region has much more extensively developed (wider) beaches than shorelines farther up the bay, and so provide better substrates for nesting horseshoe crabs. Beaches fronting the Broadkill community have groins built in efforts to control sand erosion. Sections of the beach that are less populated by people provide good potential foraging areas to shorebirds during the May and early June migration period, as do nearshore, intertidal sandflats. In addition, banks of marsh peat are sometimes exposed in eroded sections of beach (more so on the Prime Hook than the Broadkill section), which can provide good shorebird foraging and roosting habitat.

In addition, the researchers that participated in this effort provided the following findings: This project was oriented to provide baseline information on shorebird use of three areas proposed for environmental restoration on the Delaware Bay shore. An additional area (Prime Hook) where no restoration is planned also was also evaluated with hopes that 'before' and 'after' studies could be made of a restored and an abutting 'unrestored' site. The premise underlying this design was that the Prime Hook site would act as a 'control' in comparisons that would be made after restoration efforts were completed.

We believe that the bird counts from May/June 2001 provide a good basis for describing the numbers of shorebirds using the 4 shoreline sections. The counts at the southern (Broadkill/Prime Hook) location were similar to each other, and the northern counts (Port Mahon/Kelly Island) were similar to each other. In contrast, the northern pair of sites had much higher counts than the southern pair.

The level of invertebrate sampling that we were able to collect was insufficient to reliably quantify differences of the invertebrate animal populations between the sites, but it is clear that horseshoe crab eggs were far and away the most available food item, and that they were apparently more abundant at Port Mahon than at the other three locations. A more quantitative evaluation would be needed to verify this.

Field time also was inadequate for documenting activities of shorebirds, including prey selection, while they were being counted. But it was clear that for most species Kelly Island was used principally as a roosting site whereas the other three areas were used primarily as foraging sites. If Kelly Island was used principally for roosting, we would expect greater numbers of shorebirds to have been counted there at times when foraging habitats were restricted or inaccessible, i.e. during high tides. We have only limited samples for evaluating this, and they show the expected pattern; however, the differences are not statistically significant, perhaps due to the small sample sizes.

Ideally the pairs of sites we selected for this work would have been identical with respect to bird numbers, species composition, activity budgets of the birds, and accessibility of prey populations. This, of course, was not the case. Perhaps the most important disparity was the difference of foraging activities between the Port Mahon and the Kelly Island restoration sites. It remains to be seen whether this difference will be maintained after restoration work is completed, i.e. whether Kelly Island will continue to be principally used by shorebirds as a roosting site or whether alterations to it will make it an attractive foraging site. Another consideration is human activity at the sites. Human activities were not comparable between the two sites at both the northern and the southern locations. The Port Mahon site is substantially more accessible to human activities than the Kelly Island restoration site; this did not appear to be a major issue in 2001 with respect to numbers of birds counted. However, human activities may have contributed to the lower counts at the Broadkill versus Prime Hook locations, but we had insufficient data to analyze for this.

3.4.4 CONCLUSION

The shorelines at Port Mahon and Kelly Island are highly eroded and provide limited habitat for horseshoe crab nesting, thus limited foraging habitat for shorebirds. Because the Kelly Island shoreline receives little disturbance from people, it does provide resting habitat for shorebirds. Prime Hook and Broadkill beaches are wider and provide good potential foraging areas for shorebirds. Human activity can limit shorebird use. Areas less populated by people provide the best habitat.

3.5 PRE-CONSTRUCTION HORSESHOE CRAB EGG DENSITY MONITORING AND HABITAT AVAILABILITY AT KELLY ISLAND, PORT MAHON, AND BROADKILL BEACH STUDY AREAS, STATE OF DELAWARE (2001)

3.5.1 REASON FOR ACTIVITY

Several species of migratory shorebirds and resident laughing gulls feed extensively on eggs of the horseshoe crab, *Limulus polyphemus* L., during its spring spawning season. For some shorebird species migrating to their arctic nesting grounds, the stopover on Delaware Bay beaches to feed on *Limulus* eggs may represent the most critical part of their annual reproductive cycle. Migrating shorebirds have been shown to make body weight gains of 40%, or more, during their two to three-week stopover on Delaware Bay beaches in May.

In Delaware Bay, most *Limulus* spawning occurs from April through July, with May and June being the peak months of activity. Female *Limulus* spawn near the high tide line beneath the beach surface in “nests”, where they produce one or more clusters of adhering eggs. Clusters are deposited below the feeding zone of shorebirds. However, many of these clusters become dissociated before the eggs hatch, and their constituent eggs are dispersed through beach sediments, toward the surface. A simple census, for egg clusters only, can underestimate actual egg numbers present on a beach. Several studies have sampled beaches to determine the populations of horseshoe crab eggs present in beach sediments. Researchers examining *Limulus* spawning behavior have taken a variety of approaches. However, no standardized sampling method for determining densities of *Limulus* eggs dispersed in beach sediments has emerged from the literature. Such a method would facilitate a variety of comparisons that would be especially useful in making coastal and estuarine management decisions. Examples include: quantification of dispersed-egg population densities on beaches most heavily used by migrating shorebirds, comparisons of dispersed-egg populations in heavily used beaches with egg populations of less-used beaches, comparison of annual variations in spawning activity on a particular beach, and investigation of the effects of beach erosion or beach replenishment on *Limulus* spawning.

Material dredged from Delaware Bay for construction of the deepening project would be used for shoreline restoration projects at Kelly Island, Port Mahon, and Broadkill Beach, areas on the Delaware Bay known to attract shorebirds and spawning horseshoe crabs. These projects are expected to increase the amount and quality of horseshoe crab spawning habitat, significantly improving the habitat quality for both horseshoe crabs and shorebirds. In order to determine whether the completed shoreline restoration has benefited these species at the site, it is necessary to collect and analyze quantitative and qualitative baseline data on horseshoe crab egg density prior to construction.

Currently an environmental window exists that prevents construction (i.e. sand placement) to take place from April 15 to August 31 to prevent impacts to spawning horseshoe crabs. This window follows the recommendations of the Atlantic States Marine Fisheries Commission's *Interstate Fishery Management Plan for Horseshoe Crab.* These projects will be extremely difficult to build if no construction is done during this period. It may not be possible to complete the Kelly Island wetland restoration. The Delaware Department of Natural Resources and Environmental Control (DNREC) has stipulated that unless the Corps of Engineers can provide site specific information to indicate that 1) the site is not being used as a horseshoe crab nursery area or 2) that horseshoe crab spawning and egg incubation has ceased for the year, then the above window would be applied. Site-specific information will be needed for confirmation of these conditions if sand placement is requested within the general April 15 to August 31 closure window.

A study was conducted during 2001 to estimate the amount of potential horseshoe crab spawning habitat that exists at each site, to:

- Sample horseshoe crab egg densities at these sites,
- To compare those egg densities to egg densities on other horseshoe crab spawning areas examined on the Delaware Bay coast in Delaware during the same period.
- The study was conducted on Kelly Island, Port Mahon (both in Kent County), and Broadkill (Sussex County) beaches, in Delaware during the summer of 2001.

3.5.2 SUMMARY OF EFFORT

The following summarizes the efforts conducted.

Kelly Island. Kelly Island is not actually an island, but rather a marshy peninsula lying between the Mahon River and Delaware Bay. The southern part of Kelly Island, near the mouth of the Mahon River, is the area considered for restoration. The shoreline runs more-or-less true north. At low tide, most of the shoreline consists of irregular, vertical peat "cliffs", ranging in height from ca. 0.5–1.3 meters above low water. The high ground consists of compacted mud and peat. There are few locations where the sandy areas of upper beach grade smoothly down to the low water line. The upper edge of the beach is separated from the background marsh by a variable wrack line, consisting mostly of coarse vegetable detritus, deposited during periods of storm flooding. Bayward from this storm wrack line, and running irregularly along beside it, is a discontinuous band of wave-deposited sand of varying depth, covering the mud and peat substrate. Depth of this band ranges from approximately 40 cm at the upper edge to 2 cm at the lower edge. The band ranges in width from 2.1 m (7 ft) to 8.5 m (28 ft), and in all but a few narrow places, is discontinuous with the tide flats, being separated from the low water line by variable expanses of mud and peat substrate which are well above the low water line. All egg clusters and eggs found on this beach were in this band of sand. The two study transects sampled on Kelly Island during the 2001 study were "North", and "South", whose upper (high beach) ends were located at N39°12.679', W075°23.913' and N39°12.431', W075°23.849', respectively. Approximate distance between the two transects was 418 m (1,373 ft). These transects were selected, after a preseason site assessment, as being representative of the other sandy sections examined along that shoreline. Owing to an error in communication, both transects were located beyond the northern boundary of the proposed restoration project. This was not discovered until after samples had all been collected and processed.

Port Mahon Port Mahon beach has a northeasterly-oriented Delaware Bay shoreline. A sand road closely parallels the shoreline. The southern midsection of the beach has several sections of vertical metal breakwater, which persist from early attempts to protect the roadway. Breakwater sections parallel the shoreline 1–2 m out past the low tide line. The road is separated from the water by a variable band of riprap, which consists principally of boulders in the 30 – 120 cm (1 – 4 ft) size range. The lower edge of the riprap runs variously up and down through the intertidal area. In some places the lower edge of the riprap reaches out nearly to the low tide line. In other cases the lower edge rises somewhat above the middle part of the intertidal area. At lunar tides, water rises completely over some sections of riprap, and wave action erodes the roadway. As a result, the road is subject to continual grading and repair, with additional sand being added several times each year. Sand from this erosion and subsequent replenishment migrates downslope through the riprap, to create the sections of sandy beach upon which the horseshoe crabs spawn. On the bay side of the riprap, the beach contains varying amounts of smaller (£ brick size) miscellaneous chunks of macadam, masonry rubble, etc., applied long ago in attempts to stabilize and maintain the road. This trash material, together with random layers of shell, is variably covered with sand. The color and size uniformity of the sand particles along the riprapped beach areas suggest that most sand present is the result of erosion from the material used to repair the road. Much of what appears to be sandy beach is actually shallow sand underlain by clay hardpan, dense layers of shell, or miscellaneous trash material, and is generally unsuitable for spawning. Female horseshoe crabs seldom spawn in situations where the sand is not at least deep enough to nearly cover their bodies, approximately 10 cm (4in). The two study transects sampled on Port Mahon during the 2001 study were “North”, and “South”, whose upper (high beach) ends were located at N39°11.114', W075°24.071' and N39°10.794', W075°24.297', respectively. Approximate distance between the two transects was 671 m (2,203 ft). These transects were used for the study because they have been sampled in similar studies each year since 1998. They were selected in 1998 because they had the deepest, most uniform layers of sandy sediment along the Port Mahon shoreline.

Broadkill Beach. Broadkill Beach differs from the other beaches studied, being a wide, continuous band consisting almost entirely of clean sand and small (<2 cm) gravel. Sediment depths are greater than 30 cm in most sections. The beach is currently protected by a series of regularly-spaced breakwater structures extending from high on the beach, out into the water at right angles to the shoreline. Shoreward, the beach is backed by varying widths of sparsely vegetated dunes, and a dense residential area. This beach is the southernmost of the beaches studied and is approximately 42 km (26 miles) from Port Mahon. The two study transects sampled on Broadkill beach during this study were “North”, and “South”, whose upper (high beach) ends were located at N38°49.961', W075°12.958' and N38°49.713', W075°12.692', respectively. Approximate distance between the two transects was 577 m (1,894ft). These transect sites were selected after a preseason assessment of the entire beach frontage. They were visually representative of all frontage examined, and were reasonably close to public access points.

In Delaware Bay, *Limulus* spawning activity seems to be more intense during the full and new moon tides. During the 2001 spawning season, full moon tides were on May 7, June 5, and July 5, and new moon tides were on April 23, May 22, and June 21. Beaches were sampled 2–4 days after each of these tides. For each sampling date, two transects which were at right angles to the waterline were sampled. Upper (high beach) transect endpoints were located by reference to permanent visual markers, and recorded as GPS readings, and the same section of beach was sampled on each date. All transects were within the intertidal zone, where spawning activity is more concentrated.

On sample dates, 25 evenly-spaced core samples were collected along each transect. Each transect spanned 83% of the distance from the nocturnal high tide wrack line down toward the foot of the beach, where the flat began. The nocturnal high tide wrack line was used as the upper end of transects because nocturnal tides around the new and full moons (when spawning is believed to be heaviest) are higher on the beach than diurnal high tides of the same period. Although intertidal beach spans varied at the points where transects were located, the 25 sample cores along each transect were kept evenly, thus proportionally, spaced across the sample distance by use of transect lines made from bungee cord. These lines were marked off into 25 equal units of distance. Bungee cord lines can be stretched to fit beaches of varying widths, and since the marks spread apart at the same ratio as the line is stretched, cores are always equally spaced across the span to be sampled.

Sample cores consisted of beach sediment cores, 5.7 cm (2.25in) in diameter x 20 cm (8in) deep. The 20 cm depth of the sample cores spans the reported range at which most egg clusters are placed during spawning. Surface area (cross section) of each core was 25.65 cm2, giving a total cross section of the 25 cores taken per transect of 641 cm2. After each core was lifted, it was separated into two fractions: 0–5 cm and 5–20 cm depth. This was done by sliding a sheet metal divider through a transverse slit in the corer, located 5 cm from its top end. The divider was held in place until the lower, 5–20 cm, portion of the core had been dumped through a screen into a sample bucket, and then was removed so the 0–5 cm portion could be put through a screen into a second bucket. These core fractions are of interest because shorebirds forage in the surface sediments, while the clusters are deposited somewhat deeper. Knowledge of egg numbers present in the 0–5 cm part of a beach is therefore useful in estimating how many *Limulus* eggs are potentially available for shorebird use. Core sample fractions from each transect were combined into the appropriate bucket as they were collected, and all sediment material collected was processed to extract the eggs. When *Limulus* eggs are laid, they adhere together in tight clusters, and they continue to adhere tightly to each other during the first weeks of development. One, or more, tight aggregations of eggs was recorded as a single cluster. Thus, a single 20 cm core could have up to two clusters: one each from the 0–5 cm and 5–20 cm fractions. After being recorded, clumps were broken apart into the appropriate sample container, and their component eggs included in the final egg volume values. The 25 sample cores from a single transect (0–5 cm and 5–20 cm fractions, considered together) had a total volume of approximately 13.3 liters (3-1/2 gallons).

Samples were processed at the Delaware National Estuarine Research Reserve Center, on Kitts Hummock Road, south of Dover, DE. Eggs were separated into smaller, greenish undeveloped eggs ("eggs") and larger, visibly embryonated eggs ("embryos"). Only viable eggs were quantified. It is not necessary to also quantify embryos and trilobite larvae, because the eggs take sufficient time to develop that they are present in the beach for at least two sample periods before they hatch. When sample egg numbers were small, direct counts were made. When egg numbers were too great for direct counting to be efficient, the extracted eggs were measured volumetrically, using standard graduated cylinders, and a total egg count was estimated using an average egg value of 178 eggs per ml.

3.5.3 FINDINGS

The following provides the project leader for this effort, Dr. Weber's thoughts and assessment of the situation at each location based upon the supplemental information gathered as a result of the the 2001 monitoring:

Kelly Island. Larvae of several species of flies and beetles (personal observation) attack *Limulus* egg clusters in the beach from approximately the middle of the intertidal zone up to the nocturnal wrack line. Most such infestations are found in the upper part of this span, and <5% of egg clusters seem to be infested (personal observation). When their development is complete, larvae pupate in the beach sediment near where they fed and grew. When adults emerge from the pupal stage, they burrow to the surface during low tide, leaving characteristic exit holes on the beach surface. Exit holes above the current tide range persist until destroyed by rain, lunar tides, human footprints, etc. Thus, presence of these insect emergence holes on the surface is evidence of *Limulus* egg clusters below, and, by extension, indicates sections of beach frontage where spawning has taken place. On Kelly Island, I used the presence of these insect emergence holes as indicators of frontage where *Limulus* spawning had occurred.

I walked 2,203 m (7,234ft) of frontage on this shoreline, to determine the amount of spawning habitat present. I began at the southern tip of Kelly Island, at the first section of sand with sufficient depth for spawning (N39°11.577', W075°23.781'), and continued northward along the storm wrack line to N39°12.872', W075°23.855. I used a GPS unit to record the lengths of sand stretches having sufficient depth for spawning. Center widths of these stretches were measured with a tape, so estimates of their surface areas could also be calculated. There were 901 m (2,957ft) of spawning habitat along this 2,203 m (7,234') of bay frontage. This represents 40.8% of the length I examined. The combined area of these sections of spawning habitat was 0.39 hectare (0.96 acre). The 2001 estimated egg load for the 901 m spawning frontage of the 2,203 m examined was 3.2 x 109 eggs.

Owing to the error mentioned earlier, the span of shoreline I examined extended from near the present south tip of Kelly Island to considerably north of the proposed restoration project. It was possible to calculate the percentage of spawning habitat that was within the limits of the proposed project. There were 933 m (3,062ft) of shoreline from the southern tip of Kelly Island to the northern limit of the proposed project. Within this span, there were 466 m (1,531ft) of spawning habitat. This represents 49.9% of the span I examined that was within the limits of the proposed project. The combined area of the sections of spawning habitat within this span was 0.20 hectare (0.49 acre). The 2001 estimated egg load for the 466 m spawning frontage of this part of the shoreline was 0.83 x 109 eggs.

The finished bay frontage of the proposed project would be approximately 1,522 m (5,000ft). Length of bay shoreline of the completed project would then be 1.6 times greater than the length of shoreline south of the project boundary in 2001. When the project is completed, the spawning frontage would no longer consist of intermittent shallow sandy sections separated by variable spans of peat, as in 2001. Instead, the 466 m (1,531ft) of intermittent spawning habitat present in 2001 would be replaced with approximately 3.25 times as much *continuous* spawning frontage, comprised of sand deeper than ca. 1 m.

This is the first time Kelly Island has been evaluated as a *Limulus* spawning site. Judging from the evidence of a rapidly eroding shoreline—both on-site, from aerial photographs, and from the relevant USGS Quadrangle (1956)—the spawning habitat I evaluated in 2001 will very likely be altered by erosion before the next spawning season. Indeed, the impression gained from repeated sampling on the beach, and walking along the storm wrack line, is that this shoreline is not at all a constant or consistent spawning area. Some indication of recent changes along this shoreline can be obtained by simply noting the westward displacement of the sandy spawning areas I found in 2001 from the stretches of sand shown in a 1997 aerial photograph. The rate of erosion along this frontage has been variable, as shown by the varying distances between lines indicating 2001 spawning habit, and the sandy stretches present in 1997.

At my request, personnel with the Philadelphia office of the U.S. Army Corps of Engineers examined their aerial photographs and records of this area to provide me with an estimate of the rate at which this shoreline has been eroding. Their estimate is that the Bay shore of Kelly Island has been eroding westward for at least the last 100 years, at an average rate of 6 m (20ft) per year. The earliest aerial photograph of the area in their files was made in 1926. During the 75 years since, the shoreline has eroded westward approximately 457 m (1,500ft). By comparison of the 1926 aerial photograph with aerial photography of the same area done in 2001, their estimate is that the tip of Kelly Island has eroded northward approximately 487 m (1,600ft) during the same period.

It seems likely that some stretches of the Kelly Island shoreline with sand deep enough to be suitable for spawning in 2001 will still have enough sand next year. However, it is also likely that some stretches of shoreline suitable for spawning in 2001 will not be suitable next year. Further, some sections without any sand, or without a suitable depth of sand in 2001, could possibly have enough sand next year to support spawning. These are reasonable beliefs when the stretches of spawning habitat I found in 2001 are compared to the stretches of sand visible on the 1997 aerial photograph upon which they are plotted. Stretches of spawning habitat appear and disappear in response to continuing erosion of the shoreline. With reference to the 1997 photograph, in some places long stretches of sand present then are now gone. Other sandy spawning areas I found along those same sections of shoreline in 2001 are reduced in total length from stretches of sand visible in the photograph. Along some other sections of the shoreline, where no sand was visible in 1997, there was enough sand present in 2001 that spawning occurred.

Such comparisons must be made tentatively because the sandy stretches visible in the 1997 photograph were not checked to see how much spawning occurred on them. For Kelly Island, there is only the 2001 *Limulus* egg sampling and spawning habitat evaluation data, coupled with the understanding that spawning only occurs on sandy substrates. I have not observed *Limulus* to spawn in mud or peat substrates on any beach I have studied in Delaware. My experience in sampling Delaware beaches over the past five years is that they also do not spawn on beaches with only a shallow layer of sand (< 10 cm) over mud or peat. For this reason, stretches of sand shown in an aerial photograph do not necessarily indicate suitable spawning habitat.

Port Mahon. The spawning habitat along the Port Mahon shoreline is discontinuous, being interrupted by stretches of riprap and rubble. Along much of the shoreline, the high tide wrack line either falls within the area spanned by riprap, or actually reaches onto the roadway. Thus, it was not possible to use insect emergence holes to verify that spawning had occurred on a particular section. Instead, for this beach I relied on observations made during low tides over the 2001-spawning season. These included stranded males, “buried” pairs, and “nests” left when females dug out after spawning. These observations were easily made each time I sampled the beach, since the roadway parallels the high water line over most of the beach’s length. I verified these observations by walking all sandy sections.

I examined the entire 1,672 m (5,491ft) frontage of the beach at low tide, to determine the amount of spawning habitat present. I began at the southern end of the beach (N39°10.654' W075°24.491') where a culvert passes under the road, and continued northerly to N39°11.358', W075°23.909' at the bait store. I used a GPS unit to record the waterline lengths of sand stretches with sufficient depth for spawning. Center widths of these stretches were measured with a tape, so their approximate surface areas could be calculated. There were 450 m (1,478ft) of spawning habitat along the beach. This represents 26.9% of the total length of Port Mahon beach. The combined area of these lengths of habitat was 0.44 hectare (1.08 acre). The amount of spawning habitat on this beach has remained essentially the same since I examined it in 1999. At that time, total area of spawning habitat was 0.39 hectare (0.96 acre), and 28.5% of total beach length. The 2001 estimated egg load for the 450 m spawning frontage of this beach was 22.3 x 109 eggs.

Typically, Port Mahon transects have been among the top transects for total numbers of *Limulus* eggs. Season total egg numbers for the beach have ranged between 400,000 and 500,000, while per-transect season total values have been 174,000 or higher. The 2001 total egg values from Port Mahon transects S and N, 268,000 and 233,000 respectively, were considerably higher than from any other transect sampled in a parallel study of other Delaware beaches done that same season. The next highest 2001 egg total observed was from Kitts Hummock S (135,000 eggs). In 2000, total egg values from Port Mahon transects N and S were 174,000 and 229,000, respectively. These were less than the value observed on Ted Harvey S (312,000) that year. The 1999 Port Mahon transect totals were both higher than any others, with the next highest 1999 total being Ted Harvey S (140,000).

Comparing the *Limulus* egg data from Port Mahon beach with similar data collected on other beaches sampled in this, and earlier, studies is problematic. For example, the approximately mile long frontage of Port Mahon contains a rather small percentage of shoreline where there is sufficient sand to allow spawning, and where coupled *Limulus* pairs come up to the water's edge. While other beaches generally provide a meter of spawning beach for each meter of shoreline, this is definitely not the case at Port Mahon. It seems probable that female *Limulus* in the waters along Port Mahon beach are forced to concentrate into the few areas where they can spawn. This seems unlikely to be the case on most other beaches where shoreline and suitable spawning habitat are essentially equal. While the N and S transects typically have high cluster and total egg counts, these may be high simply because individuals spread along the Port Mahon shoreline are forced to come to the same few locations suitable for spawning. This could account for the high cluster counts and total egg numbers observed there. However, this concentration effect is partly offset by the fact that *Limulus* are legally harvested from Port Mahon beach two days a week, during the spawning season.

Personal observations, and discussions with those harvesting, suggest that females coming onto the beach to spawn are the primary catch. These potential spawners are taken before they have a chance to lay eggs, since females full of eggs are more desirable as bait, their intended use. No data are available on the percentage of spawning females harvested from this beach each season, but the favored places to harvest are the few spawning areas, which include areas surrounding both the N and S transects. A further confounding factor for Port Mahon spawning areas is the fact that large numbers of *Limulus* adults, of both sexes, become accidentally wedged into interstices between rocks of the riprap shoreline erosion barrier. Some individuals are trapped during each spawning event. Many of these animals become so firmly wedged between rocks that they cannot get free. Gulls prey on the more accessible individuals; the others die of exposure or starvation.

Broadkill Beach. The entire length of this beach is one continuous, unbroken stretch that is visually similar with regard to sediment size, slope, and exposure to the Bay. For this reason, I equated spawning habitat with shoreline length. On this beach it was not possible to utilize insect emergence holes as indicators of spawning because apparently too few clusters were spawned there to attract flies. Even if heavy spawning had occurred, and flies had emerged in considerable numbers, the human foot traffic along the upper part of this beach would have obliterated them from many areas.

The area I evaluated began at N38°50.347', W075°13.493' and continued southward to N38°48.408', W075°11.397', at the boundary with Beach Plum Island Nature Reserve. Total frontage length, 4,723 m (15,506'), was determined by measurements taken from beach restoration project plans provided by USACE personnel. At 13 locations distributed along the frontage, I measured beach width from the nocturnal tide wrack line down to the foot of the beach slope. Widths for Broadkill beach ranged from 11.9 m (39') to 16.1 m (53ft), with an average width of 14.4 m (47ft). Frontage length of the beach was multiplied by the average width value to estimate the amount of spawning habitat present. The full length of shoreline consisted of sandy sediments, which appeared suitable for *Limulus* spawning. The potential spawning habitat on the beach was 6.4 hectares (15.8 acres). The 2001 estimated egg load for the 4,723 m of spawning frontage on this beach was 0.25 x109 eggs.

In terms of beach slope and sediment size distribution, the entire shoreline of Broadkill beach appears to be equally suitable for spawning. However, only low numbers of eggs were found there during this study. It is unclear why this is so, although I usually found the wave height, and corresponding surf, to be greater than found on more northerly Delaware beaches on the same day, and within an hour or two. Waves from onshore wind reduce, or prevent spawning. This surf difference I observed may be due to influence of ocean waves. On more northerly Delaware Bay beaches, *Limulus* spawning does not take place when onshore winds create waves over ca. 30 cm (12 in) (personal observation). Waves observed on Broadkill during sampling periods were frequently over 30 cm high, and on several occasions, were ca. 50 cm (20 in) high. Whatever the cause of the low egg numbers on Broadkill beach, the extremely low numbers indicate that it currently receives very little *Limulus* spawning.

3.5.4 CONCLUSION

Kelly Island, Port Mahon and Broadkill beaches varied widely from each other in their total egg numbers for the sampling season. Season egg totals (the sums of all eggs found on both transects of each study beach) were compared to the season egg totals (also the sums of all eggs found on both transects of each beach) observed on Kitts Hummock, Pickering, and North Bowers beaches, also studied during 2001, in a parallel study. Port Mahon had approximately twice as many total eggs as the next most populous beach, Kitts Hummock (248,000). In turn, Kitts Hummock and Pickering (201,000) beaches each yielded more eggs than did Kelly Island. Pickering was approximately twice as productive as Kelly Island (104,000). North Bowers had approximately half as many eggs as Kelly Island (55,000). Broadkill beach had a season total, both transects combined, of 431 eggs.

3.6 PRE-CONSTRUCTION HORSESHOE CRAB MONITORING: EGG ISLAND, NEW JERSEY AND KELLY ISLAND, DELAWARE WETLAND RESTORATION AREAS (2004)

3.6.1 REASON FOR ACTIVITY

To complete the deepening project in Delaware Bay, approximately 7.3 million cubic yards of primarily good quality sand would be dredged and used for shoreline reconstruction, beach replenishment and habitat enhancement. Proposed projects include Kelly Island, Delaware and Egg Island Point, New Jersey. Both sites are subject to severe shoreline erosion. Reconstruction would not only replace lost habitat but shore up the coastal margins to prevent future degradation. The projects are expected to yield substantial ecological benefits by restoring beach habitat for horseshoe crab (*Limulus polyphemus*) spawning.

The Delaware Bay shoreline provides spawning habitat to horseshoe crabs, which are endemic to the Atlantic coast seaboard. From April to July, crabs that have migrated from the Atlantic continental shelf emerge along the bayshore to spawn near the high tide line of primarily sandy beaches. The peak of spawning activity usually occurs during May and June, and coincides with the highest spring tides associated with full and new moon events. At these times, female crabs, attended by several males, lay clusters of eggs up to 20-cm deep within the beach sands. The eggs develop over a minimum of two weeks and hatch into trilobite larvae, the free-swimming stage of the horseshoe crab. Because of the intensity of spawning activity throughout the spawning period and the lengthy term of development, large numbers of eggs can become dislodged from their clusters and end up exposed on the beach surface. This abundance of eggs provides critical food resources for a number of species of migratory shorebirds during a brief springtime stopover period in Delaware Bay.
.
After hatching, juvenile horseshoe crabs make their way into the bay where they spend the remaining spring and summer developing. For the most part, the crabs occupy shallow water inshore habitats, where they undergo several molts before heading to deeper water at the end of the warm season. Not much is known of the ecology of juvenile horseshoe crabs during this phase of growth, such as habitat preference or local movement patterns, as they are very small and difficult to sample.

At present, the Atlantic States Marine Fisheries Commission (ASMFC) advises against implementing shoreline construction projects in the mid-Atlantic region between April 15 and August 31, specifically to avoid adverse impacts to horseshoe crabs. However, ASMFC also provides that specific seasonal restriction dates should be based on site-specific information for any particular area. Given operational and scheduling constraints, the reconstruction projects for Egg Island and Kelly Island may be jeopardized if they are held to the restricted interval in its entirety.

The objective of this study was to evaluate horseshoe crab use of Egg and Kelly Islands as spawning habitat, and similarly for near shore areas, as nursery habitat for juvenile crabs. The study was conducted to provide baseline information of horseshoe crab use of the islands prior to reconstruction and to provide a means to compare post-construction conditions to gauge the effectiveness of the beneficial use of sediments. Furthermore, as the monitoring period spans the ASMFC window of constraint on construction, the study was designed to identify with greater precision the critical use of the two sites by horseshoe crabs. Finally, as other species of fishes and invertebrates inhabiting nearshore habitats might be affected by the reconstruction, baseline data on these species were collected off Egg and Kelly Islands in conjunction with the juvenile horseshoe crab surveys.

3.6.2 SUMMARY OF EFFORT

During 2004, from late April to July, egg count surveys were conducted at spawning beaches on Egg Island and East Point, New Jersey and Kelly Island, Delaware. The methods used to sample horseshoe crab eggs differed somewhat between New Jersey and Delaware, and followed protocols developed independently by researchers in each state. Monitoring of horseshoe crab spawning by these researchers is ongoing and covers much of the Delaware Bay. By duplicating their respective sampling methods, it was possible to compare these egg counts with other monitoring studies and place the spawning effort observed at Egg Island and Kelly Island in to perspective with other parts of the Delaware Bay. Horseshoe crab eggs in New Jersey were sampled using methods developed by Drs. Mark Botton and Robert Loveland in Delaware Bay (primarily supported by New Jersey Sea Grant, New Jersey Department of Environmental Protection, and Public Service Electric & Gas Company). Delaware horseshoe crab egg counts followed survey protocols that have been implemented by Dr. Richard Weber of the Delaware National Estuarine Research Reserve (See procedure described for the 2001 horseshoe crab survey). Horseshoe crab egg samples collected from Delaware Bay beaches in New Jersey and Delaware were processed in a benthic laboratory. Sample material was washed on a 1 mm sieve to remove the formalin fixative. The material was transferred to sorting trays and inspected under a magnifying lamp. All viable horseshoe crab eggs were counted (blue-green in color) and totaled for each sample.

Juvenile horseshoe crab surveys were conducted in Delaware Bay in nearshore habitats adjacent to spawning beaches. Beaches surveyed in New Jersey and Delaware included the principal study beaches, West Egg Island, East Egg Island and Kelly Island, as well as reference beaches, East Point, Port Mahon, Kitts Hummock and North Bowers Beach. The surveys were conducted monthly from July to October during 2004. Two types of gear were used to collect juvenile crabs, a suction dredge assembly and a modified fish trawl. A survey area was delineated adjacent to each spawning beach. The survey areas were divided into 3 transect corridors, positioned parallel to shore and approximately 0.2 nautical miles in breadth. In order of proximity to shore, the corridors were defined as nearshore, midshore, and offshore habitats. Along the center of each corridor, 4 station targets were positioned at equal distances of approximately 0.2 NM apart. In total, 12 stations were defined for each beach. When sampling, the station targets were visually tracked using a Differential Global Positioning System (DGPS) during the deployment of gear. In this way, sample tows could be conducted within habitat corridors. In each of the four months of the survey period, 84 station targets were surveyed using both suction-dredge and trawl methods (7 beaches x 3 transects x 4 stations).

For suction dredging, a target station was approached while moving with the tide; when in position, the dredge was allowed to sink to the bottom. A centrifugal pump was started, and the outlet hose was monitored for sediment suspended in the discharge. As soon as the discharge was gauged acceptable, the outlet hose was directed into a catch-basin, while a 50 meter tagline was deployed over the side to standardize distance towed. At the end of the tow, the outlet hose was removed from the catch-basin, boat speed was increased to raise the dredge from the bottom, the discharge was monitored for clarity, and lastly the centrifugal pump was switched off. In this way, the suction dredge was kept from fouling. Juvenile horseshoe crabs collected by the suction dredge were sorted by hand from material within the catch-basin. Each crab was inspected for viability (many shell casts closely resembling live crabs were also collected). Most crabs passed through the dredge and pump apparatus without suffering physical damage. Up to 30 crabs were measured for prosomal width (i.e., helmet width), and any additional crabs were counted. Following sample processing, all live crabs were released overboard.

Trawl sampling was conducted using a 16-foot semi-balloon otter trawl with 1.5-inch stretch mesh in the wings and body, and 0.5-inch stretch mesh liner in the cod end. This is the same equipment used by the Delaware Division of Fish and Wildlife in their surveys for juvenile horseshoe crabs. Two-minute tows were conducted at each station. Up to 30 live horseshoe crabs, juvenile and adult, were measured for prosomal width, and released overboard. Fish collected as by-catch were identified, counted, and up to 30 were measured for total length (mm). Blue crabs collected as by-catch were measured for carapace width for up to 30 crabs, additional crabs were counted.

At the 84 stations surveyed for juvenile horseshoe crabs, samples of bottom sediment were collected during August. Sediment samples were collected using a petite-ponar benthic grab-sampler. For each station, material representing surface sediment was placed in a container labeled for station location, date, and time. Sediment samples were kept in a cooler on wet ice until they could be transferred to an analytical laboratory where they were stored in a freezer. Sediment samples were analyzed for grain size, percent silt-clay content, and total organic carbon (TOC) using ASTM Method D422-63.

The water quality parameters, salinity (ppt) and temperature (ºC), were measured during the juvenile horseshoe crab surveys for each month of sampling. Most times, surface and bottom measures of the parameters were recorded midway through suction dredge sampling at each of the seven nearshore survey areas. Water quality was not measured at West Egg Island during the August/September survey period. Bottom water quality was not measured during the October/November survey period. Salinity and temperature were measured with a pre-calibrated YSI water quality monitoring probe.

3.6.3 FINDINGS

The principal objective of this study was to evaluate horseshoe crab spawning on Egg Island, New Jersey and Kelly Island, Delaware. The evaluation was based on comparing spawning intensity as measured by egg counts with other regional spawning beaches. The information from this study was necessary to provide a baseline measure of spawning prior to reconstruction, and to better define the spatial and temporal spawning characteristics along the affected beaches. A second objective was to evaluate juvenile horseshoe crab presence in nearshore habitats adjacent to the spawning beaches.

Horseshoe crab spawning at Delaware Bay beaches along the shores of Egg Island and Kelly Island followed an expected pattern during 2004. The onset of spawning in the spring was characteristically sudden and egg-laying by adult crabs was most intense during the months of May and June. Spawning of horseshoe crabs is usually synchronized with high (spring) tides associated with full or new moon phases. Survey methods for adult spawning crabs are usually scheduled around these times on the evening high tide. As our sampling schedule roughly followed 2-week intervals, we could not directly gauge the intensity of spawning, however on a number of occasions coupled adults were noted off spawning beaches, particularly at times near high tide.

Horseshoe crab spawning at Egg Island beaches was markedly different between the east and west sides of the Island. Egg counts along the west shore of Egg Island were the least productive among the New Jersey beaches. More than likely, this is in part due to the nature of the intertidal zone along this shore. In many parts, the intertidal zone leading up to the high beach is very broad and punctuated with clumps of decaying salt marsh. In effect, these might serve as obstacles to adult crabs trying to reach the higher beach to spawn. This observation is reinforced by sampling event 3 (28 May) on west Egg Island that produced high numbers of eggs. This event followed an extremely high tide that may have provided spawning adults access to this particular beach that was consistently unproductive at all other times. Spawning along the east side of Egg Island was much more prolific. Egg counts at the two beaches surveyed were comparable to those at East Point, the reference beach historically known for spawning. The east side of the island presents a more favorable habitat for spawning. The beaches have a more gradual slope and the high beach area preferred for egg-laying is much closer to the low tide mark. The spawning evaluation for Egg Island and the reference beach of East Point would benefit from a comparison with regional beaches surveyed using the same methods. At this time, comparative data are not available.

Horseshoe crab spawning at Kelly Island in Delaware was comparatively low during 2004. Egg counts from the island ranked among the lowest of 6 beaches sampled by DNERR, and several times lower than the proximal beach, Port Mahon. This last point is encouraging for the future of spawning on Kelly Island as it indicates that a fair number of crabs already spawn nearby. Spawning along the Delaware shore generally follows a consistent pattern with respect to location. For the past three years, a comparison among the 6 DNERR beaches by the total number of eggs collected has produced the same rankings. The intertidal zone at Kelly Island is interrupted in many places by a steep face of decaying salt marsh that might prevent horseshoe crabs from reaching optimal spawning beaches except during the highest tides that surmount the marsh.

Juvenile horseshoe crabs were successfully collected in nearshore habitats adjacent to New Jersey and Delaware spawning beaches. The suction dredge provided a quantitative means by which to survey the youngest of crabs. The juvenile crabs were most abundant in the nearshore habitats during July and August. This is consistent with previous descriptions of juvenile habitat preference for intertidal flats near breeding beaches. Although it is suggested that they remain there for their first and second summers, juvenile crabs from our survey appeared to be moving farther from shore and to locations further down the bay by the end of summer. The impact of the reconstruction project on juvenile horseshoe crabs is not expected to be as great as that for the eggs. Shortly after hatching and reaching the bay, crab larvae molt into the juveniles capable of motility. In that regard, they at least have the ability to disperse into extensive intertidal habitat in the Delaware Bay. Given the success of the survey method employed for this study, it would be worthwhile to conduct a bay-wide survey for juvenile crabs following the spawning season to further elucidate patterns of dispersal and habitat preference.

Bottom sediment characterization of nearshore habitats did not correlate with the abundance of juvenile horseshoe crabs, suggesting that the juveniles were not selecting a specific sediment type. However, a limitation of this element of our study was point sampling for sediment in the vicinity of the track towed during suction dredging which sampled crabs 25 feet to either side of the station. If the bottom habitat was more heterogeneous around the station point with respect to sediment type, this would obfuscate potential correlations. An alternative method would have been to take benthic grabs over a broader area. For example, a high count of 300 crabs was obtained in an individual tow. This reflects 6 crabs/m2 assuming 100% efficiency of the gear. By replicate sampling within these high catch areas, crab density might be better correlated to bottom sediment type.

Trawl studies also highlighted several patterns of seasonal fish usage of inshore habitats in the vicinity of the reconstruction areas. Foremost, weakfish and Atlantic croaker (drum species) are abundant during early summer and late summer, respectively. Impacts from reconstruction may also occur for these species, but are less likely given their free-swimming abilities. Blue crabs were also frequently found in the nearshore habitats but are also capable of avoidance. The information from trawl studies will provide a comparative data set for surveys conducted post construction that will better assess the beneficial use of dredged materials for reconstruction.

3.6.4 CONCLUSION

The reconstruction of Egg and Kelly Island will likely span over a year, and therefore overlap with time of spawning for horseshoe crabs. Once the construction project is initiated, it must be carried on until completion so as to minimize the impact of uncontrollable factors such as weather and tide on its progress. By this circumstance, impacts to horseshoe crabs will be unavoidable for at least one spawning season. In broader scope however, the reconstruction of Egg and Kelly Islands stands to offer horseshoe crabs a much greater enhancement of spawning than would be lost by a single season by constructing suitable beaches.

Continued monitoring after the restoration is completed will be needed to confirm that newly constructed beaches are in fact providing suitable spawning habitat. Based on results of the current study, gently sloping beaches with no physical barriers and high tide lines approximately 20 feet from the water edge appear optimal (i.e., similar to the slopes found at the eastern Egg Island sampling stations).

3.7 PRE-CONSTRUCTION SABELLARIA VULGARIS BASELINE MONITORING AT BROADKILL BEACH SAND PLACEMENT SITE, SUSSEX COUNTY, DELAWARE (2001)

3.7.1 REASON FOR ACTIVITY

The sandbuilder worm or “reefworm,” *Sabellaria vulgaris* Verrill 1873 is a tube-building, annelid polychaete worm common on the Mid-Atlantic coastline of the USA. This species ranges from Cape Cod to Georgia, occurring from low in the intertidal zone to shallow subtidal in waters with salinity above 15 ‰ (parts per thousand). Their life cycle includes a planktonic larval stage, and the larvae settle gregariously on a wide variety of substrata, including rocks and cobbles, clamshells, oyster bars, horseshoe crab carapaces, other worm tubes and pilings.

Sandbuilder worm tubes are built of sand grains cemented together into a hard encrustation or rock-like structure. For feeding and tube construction, the worms protrude their crown of tentacles from the tube openings. Worm tubes may be found singly or in small clusters attached to various substrata. In Delaware Bay, sandbuilder worms are also found in dense aggregations where the tubes grow in straight, parallel, spaghetti-like bundles that completely cover the substratum. These bundles may extend 20 cm or more above the substratum and be firm enough to walk on, often forming worm reef. The surface of the reef is of brown, honeycomb-like tube openings, each representing an individual sandbuilder worm. Reef development appears to be a unique characteristic of Delaware Bay populations, although masses were described on a shipwreck in North Carolina that closely resemble Delaware reefs in consistency, morphology and tidal elevation. Sandbuilder reefs form a habitat that is far more physically stable and ecologically diverse than would otherwise be found on bare rock or sand substratum. Thus, their reef structure and associated invertebrates are likely to provide food for fish and therefore represent a productive nearshore marine habitat.

For the deepening project, material dredged from the Delaware Bay channel is proposed for shoreline restoration, including beach nourishment at Broadkill Beach. This area has been known historically and recently to have sandbuilder worm reefs. Since shoreline restoration has the potential to bury and disrupt these reefs, it is necessary to determine the extent and location of present reefs as baseline data prior to construction activities. The purpose of this study was to document the presence, extent and locations of

Sabellaria vulgaris colonies at Broadkill Beach in summer, 2001, with respect to habitat type, tidal stage, and other environmental factors.

3.7.2 SUMMARY OF EFFORT

A survey of the sandbuilder worm colonies at the Broadkill Beach sand placement site was conducted in July 20 and 21 2001. Within an hour of the afternoon low water, the beach was walked by the contractor and his associates in two segments: on July 20, from the north end at California Avenue south to Route 16, and on July 21, from the boundary of Beach Plum Island State Park north to Route 16. These dates were chosen to be near the lowest spring tides of the month and represent the best opportunity for the colonies to be observed and measured in the intertidal and nearshore subtidal zones along this beach. The following operational definitions were used: a colony is defined as an aggregation of worm tubes, usually small in size (< 1 m across) and somewhat isolated from other worm tubes. A reef is defined as a larger structure, a meter or more across, with 5 cm or more of vertical worm tube growth.

Where sandbuilder colonies or reefs were observed, their location was determined with a handheld GPS (Garmin model GPSMAP 76) and associated with nearby streets or landmarks. The dimensions of the colony or reef, along the shore and distance seaward from the beach-slope break, were determined with a measuring tape. Various digital photographs of the whole reef, as well as close-up sections, were made to document the reef shape and structure. An on-site determination of the overall condition of the reef was made as indicated by new tube growth (tubes with a "flare" or "porch,"), tube erosion, over-settlement by mussels or tube worms, crab burrows, *et cetera.*

Reef observations and notes were recorded in the field on data sheets and additional observations were made on the study area shoreline, especially where rock, cobbles and gravel were present at the tidal level typically associated with sandbuilder reefs. At the *Sabellaria* reefs and other sites along Broadkill Beach, additional measurements were made to more fully characterize environmental conditions in the study area. These included: seawater temperature and salinity (handheld YSI model 30 meter), beach slope (inclinometer), and sediment grain size (standard dry sieving methods).

3.7.3 FINDINGS

In a July, 2001 survey of Broadkill Beach, sandbuilder worm colonies were found in reef-like masses at three locations: two on the rock groins at Alabama and at Georgia Avenues, and the largest on the Old Inlet Jetty south of Route 16 and north of the Beach Plum Island boundary. At each location, sandbuilder reefs were associated with large rocks comprising the groins and jetty. No colonies were found along the beach near the beach slope break, low in the intertidal zone where they presently occur at nearby beaches in the lower Delaware Bay. In comparison with other sites studied by the contractor, sand beaches at Broadkill Beach lack the stable, cobble-sized or larger substratum to which colonies attach at nearby beaches. All colonies at Broadkill Beach are associated with large rocks on artificial structures.

Sandbuilder worms have a life cycle with a planktonic larval stage that permits broad dispersal. Larval settlement occurs over extended periods in the summer and early fall and is often gregarious. Stable substratum, for example gravel and rock of sufficient size not to be overturned by wave action, placed near mean low water should provide favorable habitat for sandbuilder worm settlement and reef development.

3.7.4 CONCLUSION

Sandbuilder worms are epifaunal and require water flow and wave action to provide food particles, oxygen and sand grains for tube building. While they have some capability to withstand burial under thin layers of sand, shoreline restoration would be expected to bury the present reefs at Broadkill Beach resulting in a substantial loss of this habitat. This impact could be compensated by placing suitable substratum, large rock in groins or jetties or cobble-sized gravel on sand beaches at mean low water during the summer or early fall following shoreline restoration. Other possibilities include removing current reef masses to new shoreline locations to reconstruct or reseed from enhanced larval settlement on the restored reefs.

3.8 PRE-CONSTRUCTION SABELLARIA VULGARIS MONITORING AT BROADKILL BEACH AND PORT MAHON SAND PLACEMENT SITES, KELLY ISLAND AND SLAUGHTER BEACH (CONTROL) (2004)

3.8.1 REASON FOR ACTIVITY

The purpose of the study was to document the presence, extent and locations of *Sabellaria vulgaris* colonies and reefs at Broadkill Beach, Kelly Island, and Port Mahon with respect to habitat type, tidal stage, and other environmental factors for both intertidal and subtidal colonies. Colonies at Slaughter Beach were surveyed as a control site, and various substrates at Broadkill and Slaughter Beaches were monitored for colonization over several months.

3.8.2 SUMMARY OF EFFORT

A survey of the intertidal sandbuilder worm colonies and reefs at Broadkill Beach, Slaughter Beach, Port Mahon and Kelly Island was conducted on the spring tides in late June and early July 2004. The basic methodology used was identical to that employed previously in the July 2001 survey of Broadkill Beach.

Following the intertidal surveys, settling plates were deployed at Broadkill and Slaughter Beaches and monitored monthly on low spring tides. These plates were replicate pairs of numbered stone pavers of slate and quartzite stone material placed on or adjacent to the reef in accessible locations. Deployment coincided with noticeable new, small *Sabellaria* tubes visible at both sites. These plates were monitored for *Sabellaria* settlement and tube growth through December 2004. Additional plates were deployed in September, October and December as needed to monitor for additional settlement. Recovered plates were photographed and measured in the field, and then either returned to their location in the field or in some cases returned to the laboratory for further analysis. In addition to photographing the natural reef on monthly site visits, additional water column and sediment measurements were made.

3.8.3 FINDINGS

Sabellaria colonies and reefs were widely distributed at Broadkill Beach, Slaughter Beach and Port Mahon, but no colonies were found on the Kelly Island shoreline. This distribution is explained by the availability of stable substratum near mean low water. Favorable substrata for sandbuilder worm settlement and reef development appears to be any material of sufficient size not to be overturned by wave action. Natural substrata include gravel and rip rap rock, but colonies were also found on wood groins, horseshoe crab carapaces, and discarded tires. Smaller colonies, formed by settlement in situ or by fragmentation are present near the large reefs. While these smaller colonies were in some cases observed to have live worms and exhibit active tube growth, the longevity of these colonies is uncertain. Some colonies with low vertical relief appear susceptible to burial by natural sedimentation.

Monthly monitoring of settlement plates confirmed the suitability of two different rock substrata for settlement and tube growth, and plates deployed in late August or early September appear most favorable for tube growth in the form that results in reef formation. Tube growth rates of a centimeter or more per month were observed. Timing of available bare substratum appears to be more important than the type of material.

3.8.4 CONCLUSION

Construction impacts to *Sabellaria* could be compensated by placing suitable substratum, large rocks in groins or jetties or cobble-sized gravel on sand beaches at mean low water during the late summer or early fall settlement period following shoreline restoration. The above may be incorporated into the deepening project.

3.9 DELAWARE RIVER ADULT AND JUVENILE STURGEON SURVEY WINTER (2005)

3.9.1 REASON FOR ACTIVITY

The Delaware River Basin Fish and Wildlife Management Cooperative has established dredging restrictions for the protection of fisheries resources that restricts blasting in the Delaware River to the winter months (December 1 to March 15). This restriction was primarily imposed to protect springtime anadromous spawning fish and summer spawning and nursery activity in the river. The deepening project requires blasting to remove rock outcrops located in the Marcus Hook, Chester, Eddystone and Tinicum ranges of the channel. While blasting in the winter months should protect most fish species that use the Delaware River in the spring and warmer months, Atlantic sturgeon

(*Acipenser oxyrinchus*) and shortnose sturgeon (*Acipenser brevirostrum*) may be susceptible to blasting mortality if they use this area during the winter.

The purpose of this study was to determine if sturgeon adults and juveniles inhabit the Marcus Hook to Tinicum reach of the Delaware River during the winter blasting period, and if so, to evaluate the abundance of sturgeon in the project area relative to that in known upriver over wintering habitats near Trenton, New Jersey.

3.9.2 SUMMARY OF EFFORT

Little historical data on sturgeon use of this part of the river exists, particularly during winter. The lack of information on sturgeon populations in the Marcus Hook region is partially a function of the difficulties that the physical conditions of the area pose to routine fisheries survey techniques (i.e., trawling and gillnetting). The Delaware River near Chester, Pennsylvania is subject to high tidal currents (4-5 knots), and heavy commercial tanker traffic, and has rocky bottom features and other snags that make trawling with nets and other traditional sampling devices extremely difficult and dangerous.

Surveys for the presence of Atlantic and shortnose sturgeon were conducted between March 4 and March 25, 2005 primarily using a Video Ray® Explorer submersible remotely operated vehicle (ROV). The Video Ray® was attached to a 1.0 x 1.0 x 1.5 meter aluminum sled which was towed over channel bottom habitats behind a 25-foot research boat. All images captured by the underwater camera were transmitted through the unit's electronic tether and recorded on 60-minute Mini Digital Video Cassettes with a Sony GV-D1000 NTSC Digital Video Cassette Recorder. The recorded images were captured through the video monitor feed on the control unit of the ROV. A total of 43 hours of bottom video were collected on 14 separate survey days. Twelve days of survey work were conducted in the project area, specifically the Marcus Hook, Eddystone, Chester, and Tinicum ranges, while two separate days of survey work were conducted up river near Trenton, New Jersey, at an area known to have an over wintering population of shortnose sturgeon.

After deploying the sled and bottom contact was confirmed, the recording of digital video was initiated. The sled was generally towed on the bottom parallel to the centerline of the channel and into the current at 0.8 knots. Tows were attempted with the current to reduce the amount of "snow" created in the recordings from passing particles. This tow method was abandoned after hanging the sled up on debris and determining that the speed over the bottom could not be properly controlled. Tow track logs were maintained throughout the survey and any fish seen on the ROV monitor was noted. Boat position during each video tow was recorded every five minutes with the vessel's Furuno GPS. The Sony digital recorder recorded a time stamp that could be matched with the geographic coordinates taken from the on-board GPS.

Digital tapes were reviewed in a darkened laboratory at normal or slow speed using a high quality 28-inch television screen as a monitor. When a fish image was observed the tape was slowed and advanced frame by frame (30 images per second were recorded by the system). The time stamp where an individual fish was observed was recorded by the technician. Each fish was identified to the lowest practical taxon (usually species) and counted. A staff fishery biologist reviewed questionable images and species identifications. Distances traveled by the sled between time stamps were calculated based on the GPS coordinates recorded in the field during each tow. Total fish counts between the recorded coordinates within a particular tow were converted to observed numbers per 100 meters of tow track.

Limited 25-foot otter trawling and gillnet sets were conducted initially to provide density data, and later to provide ground truth information on the fish species seen in the video recording. Large boulders and other snags that tore the net and hung up the vessel early on in the study prompted abandoning this effort for safety reasons given the high degree of tanker traffic in the lower Delaware River. The trawl net was a 7.6-m (25-foot) experimental semi-balloon otter trawl with 44.5-mm stretch mesh body fitted with a 3.2-mm stretch mesh liner in the cod end. Otter trawls were generally conducted for five minutes unless a snag or tanker traffic caused a reduction in tow time. Experimental gillnets were periodically deployed throughout the survey period in the Marcus Hook area. One experimental gillnet was 91.4-m in length and 3-m deep and was composed of six 15.2-m panels of varying mesh size. Of the six panels in each net, two panels were 50.8-mm stretch mesh, 2 panels were 101.6-mm stretch mesh and two panels were 152.4-mm stretch mesh. Another gillnet was 100 m in length and consisted of four 25 x 2-m panels of 2.5-10.2-cm stretched monofilament mesh in 2.5 cm increments. Gill nets were generally set an hour before slack high or low water and allowed to fish for two hours as the nets had to be retrieved before maximum currents were reached.

3.9.3 FINDINGS

Turbidity in the Marcus Hook region of the Delaware River limited visibility to about 18 inches in front of the camera. However, despite the reduced visibility, several different fish species were recorded by the system including sturgeon. In general, fish that encountered the sled between the leading edge of the sled runners were relatively easy to distinguish. The major fish species seen in the video images were confirmed by the trawl and gillnet samples. In the Marcus Hook project area, a total of 39 survey miles of bottom habitat were recorded in twelve separate survey days. Eight different species were observed on the tapes from a total of 411 fish encountered by the camera. White perch, unidentified catfish, and unidentified shiner were the most common taxa observed. Three unidentified sturgeon were seen on the tapes, two in the Marcus Hook Range, and one in the Tinicum Range. Although, it could not be determined if these sturgeon were Atlantic or shortnose, gillnetting in the Marcus Hook anchorage produced one juvenile Atlantic sturgeon that was 396 mm in total length, 342 mm in fork length, and weighed 250 g.

Water clarity in the Trenton survey area was much greater (about 6 feet ahead of the camera) and large numbers of shortnose sturgeon were seen in the video recordings. In a total of 7.9 survey miles completed in two separate days of bottom imaging, 61 shortnose sturgeons were observed. To provide a comparative measure of project area density (where visibility was limited) to up river densities (where visibility was greater), each of the 61 sturgeon images were classified as to whether the individual fish was observed between the sled runners or whether they were seen ahead of the sled. Real time play backs of video recordings in the upriver sites indicated that the sturgeon did not react to the approaching sled until the cross bar directly in front of the camera was nearly upon it. Thirty of the 61 upstream sturgeon images were captured when the individual fish was between the runners. Using this criterion, approximately 10 times more sturgeon were encountered in the upriver area relative to the project site near Marcus Hook where three sturgeons were observed. Using the number of sturgeon observed per 100 meters of bottom surveyed, the relative sturgeon density in the project area was several orders of magnitude less than those observed in the Trenton area. The relative density of unidentified sturgeon in the Marcus Hook area was 0.005 fish per 100 meters while the densities of shortnose sturgeon between the sled runners in the upriver area was 0.235 fish per 100 meters.

3.9.4 CONCLUSION

The results of the video sled survey in the Marcus Hook project area confirmed that sturgeons are using the area in the winter months. However, sturgeon relative densities in the project area were much lower than those observed near Trenton, New Jersey, even when the upriver counts were adjusted for the higher visibility (i.e., between runner sturgeon counts). The sturgeons seen near Trenton were very much concentrated in several large aggregations, which were surveyed in multiple passes on the two sampling dates devoted to this area. The lack of avoidance of the approaching sled seen in the upriver video recordings suggests that little to no avoidance of the sled occurred in the low visibility downriver project area. Video surveys in the downriver project area did not encounter large aggregations of sturgeon as was observed in the upstream survey area despite having five times more sampling effort than the upstream area. This suggests that sturgeons are more dispersed in the Marcus Hook region of the Delaware River. Although the video survey data suggests that large aggregations of sturgeon do not exist in the blasting area, impacts to even a small number of shortnose or Atlantic sturgeon may not be acceptable to fisheries agencies. Measures to move fish away from the blast zone or otherwise protect them from the blast may be required.

4.0 GENERAL AIR CONFORMITY ANALYSIS (2004)

4.1 REASON FOR ACTIVITY

The proposed deepening project extends from the Ports of Camden, New Jersey and Philadelphia, Pennsylvania to the mouth of Delaware Bay, and follows the alignment of the existing federally authorized channel. In addition to the channel deepening, several berths at the various oil refineries and port facilities along the Delaware River will also be deepened. A majority of the oil refinery berths and port terminals are located in the upstream reaches of the river near the Philadelphia/Camden area. The project is scheduled to be constructed over a period of 5 years for the channel deepening and an additional year for the completion of the adjacent berth deepenings. An emissions analysis needed to be performed to determine if the deepening project would exceed air quality standards and, if so, how to mitigate so that the project could reach conformity.

The U.S. Environmental Protection Agency's (EPA) Office of Air Quality Planning and Standards has set National Ambient Air Quality Standards (NAAQS) for six principal pollutants, called "criteria" pollutants. They are carbon monoxide (CO), ozone [which is composed of nitrogen oxides (NOx) and volatile organic compounds (VOC)], lead (Pb), particulates (PM2.5 and PM10), and sulfur oxides (SOx). The 1990 Federal Clean Air Act Amendments directed EPA to develop two federal conformity rules. Those rules (promulgated as 40 CFR Parts 51 and 93) are designed to ensure that federal actions do not cause or contribute to air quality violations in areas that do not meet the NAAQS. The rules include transportation conformity, which applies to transportation plans, programs, and projects; and general conformity, which applies to all other projects, which would include the proposed deepening project.

Under EPA rules, each state may promulgate its own conformity regulations. State conformity regulations must be consistent with EPA's regulations for state programs (40 CFR 51, Subpart W), but can be more stringent than federal regulations, provided the more stringent requirements apply equally to federal and non-federal entities (40 CFR 51.851(b)). Delaware, Pennsylvania, and New Jersey do not have more stringent regulations than the federal requirements.

4.2 SUMMARY OF EFFORT

Conformity determination is a two-step process: (1) applicability analysis and (2) conformity analysis. Applicability analysis is achieved by comparing the project's annual emissions to de minimis pollutant thresholds outlined in the conformity rule.

The emission sources for the deepening project consist of marine and land-based mobile sources that will be utilized during the six-year Project construction period (five years for the project and one year for the berthing areas). The marine emission sources include the various types of dredges (clamshell, hydraulic, and hopper) as well as all support equipment. The land-based emission sources include both off-road and on-road equipment. The off-road equipment consists of the heavy equipment utilized to construct and maintain the disposal sites. The on-road equipment is made up of employee vehicles and any on-road trucks utilized for the project. The marine emission sources and off-road equipment consist primarily of diesel-powered engines. The on-road vehicles are a combination of gas and diesel-powered vehicles.

Once the operational information for the various engines was obtained from the project cost estimates, the engine load factors and emission factors were determined using EPA guidelines. The air emissions were determined on an annual basis for each piece of equipment. The emissions were then totaled on an annual basis for all equipment (regardless of where construction was taking place). The annual emissions for the project were then compared to the de minimis threshold level for the combined non-attainment area. Since the project area is in severe non-attainment for ozone (composed of NOx and VOC), the de minimis level for each is 25 tons per year. Since the project area is in a maintenance area for CO, the de minimis level is 100 tons per year.

4.3 FINDINGS

Detailed modeling of the emissions resulting from the channel deepening project predicts that releases of VOCs would be below the de minimis threshold. However, engine pollutant releases during construction of the channel deepening project would exceed the de minimis levels for NOx (during all years of construction) and CO (Year 4). Mitigation of the NOx and CO emissions will be necessary for the federal action to meet the GC requirements.

The General Conformity ruling (40 CFR 93.158(a)(2)) states that once a project has exceeded the established de minimis threshold(s), emissions from the project must be reduced "so that there is no net increase in emissions of that pollutant." Consequently, the Project is required to reduce or offset its annual emissions of CO (year 4 only) and NOx (all years) to zero.

The analysis conducted clearly demonstrates that several viable options exist to allow the Project to achieve GC compliance for CO (Year 4) and NOx. The analysis evaluated the effectiveness and related cost impacts of both on-site and off-site emission reduction opportunities. Three-emission reduction plans were developed that achieve GC and a preferred plan selected. More detailed information is available in the *General Conformity Analysis and Mitigation Report* prepared by Moffatt & Nichol, February 2004. Results of this analysis have been coordinated with all appropriate Federal, state and local agencies and Metropolitan Planning Organizations (MPO) as well as the public under the General Conformity Rule of the Clean Air Act (40 CFR 93, Subpart B).

Construction contracts advertised for the Project will require the installation of Selective Catalytic Reduction equipment on all hopper dredges, hydraulic dredges and booster pumps used in connection with the project. Alternatively, the contractor should be afforded the opportunity to achieve the emission reduction benefits required by the project through other emission control methods as long as the net result of these methods meets or exceeds the reductions specified in the selected emission reduction plan. The Corps Philadelphia District will ensure that these reductions have been attained by conducting emissions testing to verify emissions reductions.

The Corps Philadelphia District will pursue converting maintenance dredging activities to electric power at recurring maintenance dredging sites. Details will be developed as part of the plans and specifications for implementing this portion of the plan. Specifications to ensure that these methods are used will be coordinated with appropriate federal, state and local agencies and MPOs and added to the appropriate contracts.

The Corps hopper dredge *McFarland* will be utilized as part of the mitigation plan. The vessel will be retrofitted and used during Years 3 through 6 of construction of the proposed channel deepening project.

The offsets will occur contemporaneously with the project emissions such that there is no net increase in emissions as required by 40CFR 93.153(b)(2). The Corps commits not to begin construction activities until the emission reduction measures are actually in place. The Corps will release additional notification if the construction plan changes significantly or the mitigation plans need to change and will coordinate with all appropriate Federal, state and local agencies and MPOs to ensure offsets occur contemporaneously with project emissions.

4.4 CONCLUSION

The project's annual emissions were calculated and compared to de minimis pollutant thresholds outlined in the Clean Air Act conformity rule. Annual emissions exceeded threshold levels for CO (year 4 only) and NOx (all years). A mitigation plan was developed that would reduce these emissions to zero, which would bring the project into compliance with the Clean Air Act.

The off-site mitigation opportunities contained within the preferred plan offer additional environmental benefit beyond that captured by this Project. Since the standard engine life for large marine diesel engines is 20 to 25-years, replacing the engines will provide air quality benefits for at least 14-years beyond the Project construction period. Although these ancillary benefits have not been taken into consideration in the analysis, these far-reaching benefits should not be overlooked.

5.0 SUPPLEMETNTAL INFORMATION FOR THE STATE OF DELAWARE

As a result of discussions between the Philadelphia District of the U.S. Army Corps of Engineers and the Delaware Department of Natural Resources and Environmental Control (DNREC), the Corps applied for a Delaware Subaqueous Lands and Wetlands Permit for the Delaware River Main Channel Deepening Project on April 19, 2001. During the permit application process, DNREC asked for supplemental information on a variety of issues. The studies conducted in 2001 and their results are described below.

5.1 NEAR-FIELD WATER QUALITY MODELING OF DREDGING OPERATIONS IN THE DELAWARE RIVER

5.1.1 REASON FOR ACITIVITY

In 2001, DNREC requested that the Corps evaluate the near-field concentrations of metals and PCBs released during dredging operations. The purpose of this evaluation was to ensure that potential sediment contaminants that may be released during dredging were not likely to exceed applicable water quality criteria. These evaluations were conducted for cutterhead hydraulic dredging in the shipping channel and for a bucket dredge in berthing areas. In addition, a separate analysis was conducted to assess impacts to human health criteria. That analysis was conducted as is discussed under the heading of "***PCB Mobilization During Dredging Operations and Seqestration by Upland Confined Disposal Facilities***".

5.1.2 SUMMARY OF EFFORT

The model selected for the water quality evaluation was the DREDGE model, developed for the Corps of Engineers for a near-field (i.e., within a 200-foot mixing zone) evaluation of dredging operations. DREDGE was developed to assist in making a-priori assessments of environmental impacts from proposed dredging operations. DREDGE estimates the mass rate at which bottom sediments become suspended into the water column as the result of hydraulic and mechanical dredging operations and the resulting suspended sediment concentrations. These are combined with information about site conditions to simulate the size and extent of the resulting suspended sediment plume. DREDGE also estimates particulate and dissolved contaminant concentrations in the water column based upon sediment contaminant concentrations and equilibrium partitioning theory.

Bulk sediment contaminant data previously collected from the Marcus Hook Range of the Delaware River navigation channel and the Sun Marcus Hook Berth were used to represent the expected level of contamination in the sediment to be dredged. These locations are in the immediate vicinity of the State of Delaware line.

5.1.3 FINDINGS

The results of the DREDGE model indicated the following, using environmentally conservative assumptions. Neither dissolved metals nor total dissolved PCBs released during cutterhead hydraulic dredging would exceed acute or chronic water quality criteria outside of the mixing zone, using the model. Even using a more conservative estimation approach, none of the metals would exceed water quality criteria at the edge of a 60-meter mixing zone except mercury and then only within 0.1 meters of the bottom. Given the conservative nature of these predictions, actual contaminant concentrations are expected to be considerably lower than predicted.

None of the dissolved metal or total PCB concentrations predicted to be released to the water column as a result of bucket dredging were above the Delaware River Basin Commission (DRBC) acute or chronic water quality criteria, even using the maximum sediment metal concentration measured in the area to be dredged. Even with a more conservative metals partitioning estimation approach, no metals with measurable sediment concentrations would exceed chronic or acute water quality criteria.

5.1.4 CONCLUSION

Metals and PCBs would not exceed DRBC water quality criteria in the vicinity of a working cutterhead hydraulic dredge or a bucket dredge during construction of the deepening project.

5.2 PCB MOBILIZATION DURING DREDGING OPERATIONS AND SEQUESTRATION BY UPLAND CONFINED DISPOSAL FACILITIES

5.2.1 REASON FOR ACTIVITY

Based on PCB contamination concerns in the Delaware estuary, the Corps reviewed data and conducted various studies to understand how PCBs are distributed in the estuary and how dredging and dredged material disposal activities might affect the movement of PCBs. Work efforts included testing channel sediments for PCBs using high resolution congener specific techniques, reviewing similar data from a study conducted in shoal areas of the Delaware River, and developing mass balance analyses for PCBs entering and leaving active CDFs during dredging operations. Four conclusions were drawn from this work: (1) PCB concentrations tend to be higher in shoal areas than in the navigation channel; (2) PCB concentrations are lower in Delaware Bay than in the Delaware River; (3) the vast majority of PCBs present in dredged sediments are retained in upland confined disposal facilities (CDFs); and (4) PCB concentrations in CDF weir discharges are not vastly greater than background river PCB concentrations. To evaluate potential PCB impacts associated with the deepening project, previously collected data was used to (1) conduct a mass balance analysis for the entire deepening project and (2) determine the potential for exceeding the human health water quality criteria established for the Delaware River (0.0448 ng/L for freshwater and 0.0079 ng/L for marine waters) as a result of dredging and dredged material disposal activities.

5.2.2 SUMMARY OF EFFORT

To conduct a PCB mass balance analysis for the entire deepening project, previously collected PCB sediment data collected from various reaches of the channel were matched with up-to-date estimates of the volume of material to be removed from each reach. The previously collected PCB data was obtained from sediment cores collected in the channel. In that study, the top three inches of the core was tested and the bottom 57 inches of the core was tested. For this analysis, weighted PCB concentrations were calculated for each core. Average weighted concentrations for areas that had more than one core were calculated to provide one estimate of total PCB concentration per dredging reach. The total volume of material to be dredged was converted in to total grams of material assuming the density of the material was 1.33 gm/cc. Average reach PCB concentration was then multiplied by the total grams in the reach to estimate the total kg of PCBs that may be removed from the channel for the entire deepening project. Based on efficiency studies conducted at the Pedricktown North, Killcohook and Oldmans CDFs, the total kg of PCBs returned to the river through the weir was estimated assuming an efficiency of 99.9%.

A mathematical equation was developed to estimate PCB concentrations in the Delaware River resulting from construction of the deepening project. The equation combined a sediment source strength factor (the quantity of sediment placed in the water column per unit of time by the working dredge) and the average PCB sediment concentration to calculate a PCB release rate. The dissolved fraction of PCBs in the water column was estimated by selection of a reasonable partition coefficient for PCBs. The dredging production rate combined with the volume of material to be removed provided an estimate of the time over which the dredging operation would occur. The total and dissolved PCB release rate combined with the time required for completing the excavation provided an estimate of the mass of total and dissolved PCBs that may be released into the water column during the dredging project. Human health criteria were applied under a complete-mix condition, which is defined as the material released per unit of time into the mean harmonic flows in the different reaches. These were extrapolated from the mean harmonic flow at Trenton, NJ. The water column concentrations of total and dissolved PCBs were calculated and compared with PCB human health criteria for the Delaware River.

5.2.3 FINDINGS

Nearly 423 kilogram (kg) of total PCBs would be removed during dredging operations in the Delaware River navigation channel for the deepening project; this amount represents about 1.5% of the total PCBs in the Delaware estuary. This material would be placed in upland confined disposal facilities where at least 99.9% would be retained, resulting in a release back to the estuary of only about 0.42 kg of PCBs. During the dredging process itself, between 0.07 and 0.23 kg of total PCBs could be released to the water column, using environmentally conservative or worst-case estimates of physical and chemical processes, which occur during dredging. The dissolved fraction of PCBs, which might be released during dredging, is estimated to be between 0.036 and 0.117 kg, again using worst-case assumptions. In the most contaminated reach of the estuary, this dissolved fraction could result in water column concentrations that are between 13 and 43% of the PCB human health criteria using these worst-case assumptions.

5.2.4 CONCLUSION:

Human health criteria established for PCBs in the Delaware River would not be exceeded.

5.3 REEDY POINT SOUTH WATER QUALITY MODELING

5.3.1 REASON FOR ACTIVITY

The exiting Corps placement site at Reedy Point South is one of the placement sites that will be used to store dredged material from the deepening project. This site is located on the south side of the Chesapeake and Delaware Canal at its confluence with the Delaware River, in the State of Delaware. Material would be dredged from the Reedy Island Range of the Delaware River navigation channel and placed in the Reedy Point South. At the request of the DNREC, water quality was modeled to determine the potential levels of exposure for aquatic organisms to contaminants mobilized into the water column by dredging activities in this area. Mobilization of contaminants into the water column can occur at two points of exposure, the point of dredging and the point of weir discharge from an upland placement site. Unlike particulate substances bound to sediment, dissolved substances are available for potential uptake by aquatic organisms.

5.3.2 SUMMARY OF EFFORT

The equilibrium partitioning model was used to predict levels of contaminants that may become dissolved in the water column at the point of dredging. Equilibrium partitioning theory is a simple mathematical method of estimating the proportion of a chemical sorbed to sediment to the chemical dissolved in water. With a known concentration of chemical per unit weight of sediment, and a known weight of total sediment, this method can be used to determine the concentration of the chemical in the water. Assuming linear relationships between sediment concentration, fraction of organic carbon, and the octanol/water partition coefficient, the concentration of a chemical in sediment can be multiplied by a factor to yield a concentration of that chemical in the water column. Bulk sediment contaminant data previously collected from the Reedy Island Range were used to represent the expected level of contamination in the sediment to be dredged. Because of a lack of organic contaminants in this area, modeling was limited to inorganic heavy metal parameters (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver and zinc).

The Cornell Mixing Zone Model (CORMIX) was used to predict dissipation of contaminants discharged from the weir at Reedy Point South. CORMIX is used to predict how contaminants dissolved in the water column will behave as mixing and tidal action disperses them from their source. CORMIX is intended as a first-order screening/design model. It does not carry out detailed hydrodynamic calculations using the exact geometry of the discharge location, nor does it explicitly handle dynamic ambient currents (i.e., tides). It uses a simplified representation of the physical conditions at the discharge location to approximate the fundamental behavior of the plume. Dissolved contaminant concentrations in the Reedy Point South weir discharge were conservatively assumed to be equal to dissolved contaminant concentrations predicted by the equilibrium partitioning model at the point of dredging. This assumption is considered to be conservative because this is the maximum dissolved contaminant concentration that would occur, and does not account for processes that may reduce the aqueous contaminant load within the placement site.

5.3.3 FINDINGS

The results of the equilibrium partitioning model indicate that four contaminants, copper, lead, mercury, and nickel may exceed water quality criteria near the point of dredging and at the weir discharge. These results are based on the assumptions of the model, including the conservative assumption that 80% of the sediment-bound contaminants will dissolve into the water column and that TSS concentrations would be 250 mg/l. A June 2001 study of the Corps Oldmans placement site indicated that the equilibrium partitioning model may overestimate dissolved metals concentrations. This study also showed that it is likely that TSS concentrations will be lower than 250 mg/l, resulting in no exceedances of water quality criteria.

Even given the conservative nature of the equilibrium partitioning model and the TSS concentration of 250 mg/l, only copper may exceed acute water quality criteria, which range from 2.4 ug/l for NJDEP to 5.3 ug/l for DRBC. None of the other contaminants were projected to exceed acute water quality criteria near the point of dredging or at the weir discharge. Once mixing is considered at the weir, it was determined that at flood and ebb tides, all water quality criteria would be met within 2 meters of the weir. While water quality during slack tide may exceed chronic criteria for lead, mercury, and nickel, and acute criteria for copper, to a distance of nearly 44 meters, slack tide only lasts for a half hour and the plume is located within 0.2 meters of the surface. At the point when the tide begins to flood or ebb, the slack tide plume will dissipate in a short period of time, likely less than an hour. This limited affected area would not substantially impact water quality.

5.3.4 CONCLUSION

Water quality impacts at the point of dredging and in the vicinity of the weir of the Reedy Point South confined disposal facility would be minimal during construction of the deepening project.

6.0 DELAWARE RIVER PHILADELPHIA TO THE SEA MAINTENANCE DREDGING WATER AND SEDIMENT QUALITY INVESTIGATIONS (1998-2006)

The existing 40-foot Federal navigation channel from Philadelphia to the Sea is routinely maintained by the Corps of Engineers. Approximately 3 million cubic yards are dredged annually to maintain the 40-foot depth. This maintenance dredging is reviewed by NJDEP as part of the water quality certification process. Data on sediment quality and placement area(s) discharges are analyzed as part of this process. The method of dredging, the location of the samples taken and the monitoring are all within the proposed 45-foot channel deepening project area. This data provides further verification, to some degree, of the analysis done for that project.

6.1 REASON FOR ACTIVITY

In accordance with NJDEP water quality certification for maintenance of the existing Delaware River Philadelphia to the sea project, the quality of water discharged from Confined Disposal Facilities (CDFs) during maintenance dredging operations was monitored on an annual basis from 1998 through 2006. Inlet slurry samples, a mixture of dredged sediment and water from the Delaware River that is pumped through pipes into the CDF, and water samples from the weir, discharge plume, and background locations were analyzed for inorganics, volatile organic compounds, semi-volatile organic compounds, pesticides, and high resolution or arochlor PCBs. Water samples were compared to DRBC water quality criteria for the protection of aquatic life. In addition, sediment samples from 45 sediment core locations in the navigation channel were collected and analyzed for bulk concentrations of contaminants. The results were compared to NJDEP residential and non-residential sediment quality criteria.

6.2 FINDINGS

Water quality criteria for inorganic elements defined by the DRBC are intended for comparison to dissolved metals concentrations. Dissolved inorganics are biologically available to aquatic organisms, whereas particulate inorganics are not likely to be taken up. Since dredged material disposal operations are short-term events, comparison of sample data to acute water quality criteria is more relevant than chronic. Some of the water quality criteria are hardness based. To calculate these criteria the average hardness was determined over all sampling events and divided in half to be conservative. The lower the hardness the lower the criteria. A total of 71 water samples have been collected at the point of CDF discharge and analyzed over the last nine years. Of these 71 samples, none exceeded DRBC freshwater acute water quality criteria for arsenic, cadmium, lead, mercury, nickel, selenium or silver. Three samples exceeded the acute criterion for aluminum, four samples exceeded the acute criterion for copper and 17 samples exceeded the acute criterion for zinc. A total of 70 samples have been collected within approximately 100 yards of where the CDF discharges back to the adjacent water body. These samples represent water quality with some initial mixing. After initial mixing, three samples exceeded the acute criterion for aluminum, two samples exceeded the acute criterion for copper and eight samples exceeded the acute criterion for zinc. Based on these minimal exceedences, the impact of CDF operation on water quality is considered small.

Water samples collected at the point of CDF discharge have also been analyzed for a variety of organic contaminants. Only one sample had a concentration of an organic contaminant (endrin ketone) above an acute freshwater quality criterion (0.15 parts per billion compared to the criterion of 0.09 parts per billion).

A total of 45 sediment samples were collected from the navigation channel in 2003 and 2005 and analyzed for a variety of inorganic and organic contaminant parameters. The results were compared to NJDEP residential and non-residential sediment quality criteria. For inorganic parameters only thallium (28 samples) and arsenic (2 samples) were over the residential and non-residential criteria of 2 parts per million and 20 parts per million, respectively. The thallium exceedences are not considered to be true readings. Laboratory analysis for thallium can be troubled by interference problems, where other elements are detected and reported as part of the total thallium concentration. Thallium is not a contaminant of concern in the Delaware Estuary. For organic contaminants, three of the 45 samples had contaminant concentrations above NJDEP criteria. All three samples had concentrations of some polyaromatic hydrocarbons above the NJDEP criteria. One sample had a PCB concentration above the criteria.

6.3 CONCLUSION

Water quality impacts associated with operation of upland confined disposal facilities for construction of the channel deepening project would be minimal.

Bulk contaminant concentrations in the channel sediments are low and suitable for beneficial use of dredged material. The number of detections have been low and previous sediment characterizations at existing CDFs have shown all parameters to be below criteria and suitable for beneficial use.

This data has been recently reviewed by the NJDEP and a new water quality certificate for continued maintenance of the existing channel was issued in September 2007.