8. Cost Attainment Analysis

8.1. Cost Attainment Curve – DO Water Quality Standard Attainment Basis

Using the estimated conceptual project cost data and water quality projections for each evaluated alternative presented in the previous sections, cost-attainment curves were prepared. These curves show conceptual project cost for each alternative versus percent attainment with NYSDEC dissolved oxygen water quality standards. Cost attainment curves were prepared for treatment, outfall relocation, bay modifications as well as combination alternatives (figures 8-1 through 8-16). Cost attainment curves were prepared showing annual average and summer average attainment with current NYSDEC DO water quality standards, both baywide and for Grassy Bay only.

Figure 8-1 Treatment Alternatives; Annual Average Baywide % Attainment with NYSDEC DO WQS, indicates that LOT at 4 WPCPs only provides 2% improved attainment over existing conditions (about 96%) and diminimus additional improvement over LOT at the Jamaica and 26th ward WPCPs. The figure also indicates that the most cost effective treatment alternative is Level 2 BNR (modified flow split; partially oxic) at Jamaica WPCP + Contract 12 at 26th Ward WPCP, providing 97% attainment.

Figure 8-2 Treatment Alternatives; Annual Average Grassy Bay % Attainment with NYSDEC DO WQS indicates that LOT at 4 WPCPs only provides 8% improved attainment over existing conditions (82%) and diminimus additional improvement over LOT at the Jamaica and 26th ward WPCPs. The figure also indicates that the most cost effective treatment alternative is Level 2 BNR (modified flow split; partially oxic) at Jamaica WPCP + Contract 12 at 26th Ward WPCP, providing 87% attainment.

Figure 8-3 Treatment Alternatives; Summer Average Baywide % Attainment with NYSDEC DO WQS indicates that LOT at 4 WPCPs only provides 8% improved attainment over existing conditions (87%) and diminimus additional improvement over LOT at the Jamaica and 26th ward WPCPs. The figure also indicates that the most cost effective treatment alternative is Level 2 BNR (modified flow split; partially oxic) at Jamaica WPCP + Contract 12 at 26th Ward WPCP, providing 90% attainment.

Figure 8-4 Treatment Alternatives; Summer Average Grassy Bay % Attainment with NYSDEC DO WQS indicates that LOT at 4 WPCPs provides 32% improved attainment over existing conditions (35%) and diminimus additional improvement over LOT at the Jamaica and 26th ward WPCPs. The figure also indicates that the most cost effective treatment alternative is Level 2 BNR (modified flow split; partially oxic) at Jamaica WPCP + Contract 12 at 26th Ward WPCP, providing 52% attainment.

Figure 8-5 Outfall Alternatives; Annual Average Baywide % Attainment with NYSDEC DO WQS indicates that outfall relocation to the ocean of all 4 WPCPs only provides 3% improved attainment over existing conditions (96%) and diminimus additional improvement over relocation of the Jamaica and 26th ward WPCPs to the Rockaway Inlet. The figure also indicates that the most cost effective outfall relocation alternative is relocation of the Jamaica WPCP and 26th Ward WPCP outfalls to the Rockaway Inlet by gravity, providing 99% attainment.

Figure 8-6 Outfall Alternatives; Annual Average Grassy Bay % Attainment with NYSDEC DO WQS indicates that outfall relocation to the ocean of all 4 WPCPs only provides 18% improved attainment over existing conditions (81%) and diminimus additional improvement over relocation of the Jamaica and 26th ward WPCPs to the Rockaway Inlet. The figure also indicates that the most cost effective outfall relocation alternative is relocation of the Jamaica WPCP and 26th Ward WPCP outfalls to the Rockaway Inlet by gravity, providing 96% attainment.

Figure 8-7 Outfall Alternatives; Summer Average Baywide % Attainment with NYSDEC DO WQS indicates that outfall relocation to the ocean of all 4 WPCPs only provides 12% improved attainment over existing conditions (87%) and diminimus additional improvement over relocation of the Jamaica and 26th ward WPCPs to the Rockaway Inlet. The figure also indicates that the most cost effective outfall relocation alternative is relocation of the Jamaica WPCP and 26th Ward WPCP outfalls to the Rockaway Inlet by gravity, providing 97% attainment.

Figure 8-8 Outfall Alternatives; Summer Average Grassy Bay % Attainment with NYSDEC DO WQS indicates that outfall relocation to the ocean of all 4 WPCPs provides 59% improved attainment over existing conditions (36%) and diminimus additional improvement over relocation of the Jamaica and 26th ward WPCPs to the Rockaway Inlet. The figure also indicates that the most cost effective outfall relocation alternative is relocation of the Jamaica WPCP and 26th Ward WPCP outfalls to the Rockaway Inlet by gravity, providing 86% attainment.

Figure 8-9 Bay Modifications Alternatives; Annual Average Baywide % Attainment with NYSDEC DO WQS indicates that recontour alternatives do not provide appreciable improvement in attainment ver existing conditions (96%). Aeration is shown to achieve the highest attainment (about 99%).

Figure 8-10 Bay Modifications Alternatives; Annual Average Grassy Bay % Attainment with NYSDEC DO WQS indicates that recontour of Grassy Bay to 4 ft. below mean low water only provides a 9% improvement over existing conditions (81%), but does not provide appreciable improvement in attainment over recontour of Grassy Bay to 8 ft. below mean low water. Aeration is shown to achieve the highest attainment (about 99%).

Figure 8-11 Bay Modifications Alternatives; Summer Average Baywide % Attainment with NYSDEC DO WQS indicates that recontour of Grassy Bay to 4 ft. below mean low water only provides a 2% improvement over existing conditions (87%), but does not provide appreciable improvement in attainment over recontour of Grassy Bay to 8 ft. below mean low water. Aeration is shown to achieve the highest attainment (about 95%).

Figure 8-12 Bay Modifications Alternatives; Summer Average Grassy Bay % Attainment with NYSDEC DO WQS indicates that recontour of Grassy Bay to 4 ft. below mean low water provides a 19% improvement over existing conditions (35%), and a 11% improvement in attainment over recontour of Grassy Bay to 8 ft. below mean low water. Aeration is shown to achieve the highest attainment (about 98%).

Figure 8-13 Annual Average Baywide % Attainment with NYSDEC DO WQS indicates that neither LOT at all 4 WPCPs or relocation of all 4 WPCP outfalls to the ocean can attain the dissolved oxygen standard 100% of the time and both only provide a diminimus improvement over existing conditions (96%). The alternative of is Level 2 BNR (modified flow split; partially oxic) at Jamaica WPCP + Contract 12 at 26th Ward WPCP and filling Grassy Bay and North Channel to 8 ft. below mean low

water, offer a cost effective alternative for the Department, considering the costs for recontouring are borne by others.

Figure 8-14 Annual Average Grassy Bay % Attainment with NYSDEC DO WQS indicates that neither LOT at all 4 WPCPs or relocation of all 4 WPCP outfalls to the ocean can attain the dissolved oxygen standard 100% of the time and provide a range of improvement of 10 to 19% over existing conditions (81%). The alternative of is Level 2 BNR (modified flow split; partially oxic) at Jamaica WPCP + Contract 12 at 26th Ward WPCP and filling Grassy Bay and North Channel to 8 ft. below mean low water, offer a cost effective alternative for the Department (91% attainment), considering the costs for recontouring are borne by others.

Figure 8-15 Summer Average Baywide % Attainment with NYSDEC DO WQS indicates that neither LOT at all 4 WPCPs or relocation of all 4 WPCP outfalls to the ocean can attain the dissolved oxygen standard 100% of the time and provide a range of improvement of 8 to 12% over existing conditions (87%). The alternative of is Level 2 BNR (modified flow split; partially oxic) at Jamaica WPCP + Contract 12 at 26th Ward WPCP and filling Grassy Bay and North Channel to 8 ft. below mean low water, offer a cost effective alternative for the Department (93% attainment), considering the costs for recontouring are borne by others.

Figure 8-16 Summer Average Grassy Bay % Attainment with NYSDEC DO WQS indicates that neither LOT at all 4 WPCPs or relocation of all 4 WPCP outfalls to the ocean can attain the dissolved oxygen standard 100% of the time and provide a range of improvement of 32 to 61% over existing conditions (35%). The alternative of is Level 2 BNR (modified flow split; partially oxic) at Jamaica WPCP + Contract 12 at 26th Ward WPCP and filling Grassy Bay and North Channel to 8 ft. below mean low water, offer a cost effective alternative for the Department (70% attainment), considering the costs for recontouring are borne by others.

8.2. Cost Attainment Curve – DO Volume Basis

In developing the ambient water quality criteria for Chesapeake Bay and its tidal tributaries, the USEPA considered the issue of determining attainment of the criteria both on a temporal and spatial extent. One of the methodologies developed to evaluate attainment with the appropriate water quality criterion was the use of DO volume-days. The concept of DO volume-days is developed in the following manner. First, assessment of attainment is performed spatially by dividing the bay into geographic regions or segments. In the case of using computations from the JEM model, the spatial segmentation is the computational grid used in JEM (Figure 2-1). The spatial resolution of the JEM grid is 1,000 ft x 1,000 ft (or 10^6 ft^2) in the open-waters of the bay. The water column is also segmented vertically into six layers. The volume of any cell is, then, the surface area of the cell (10^6 ft^2) multiplied by the daily-averaged thickness or depth of the computational cell. Since the JEM model computes the daily-averaged concentrations of dissolved oxygen for every cell, one can determine for any given day, the total volume of the bay that meets or attains a certain water quality criterion, i.e., the volume of the bay that exceeds 5 mg DO/L. One can perform that calculation on a daily basis and then sum the daily attainment volume for the assessment period of interest (e.g., a summer period or on a yearly basis) to determine the total volume-days of attainment. This concept is shown on Figures 8-17a and b.

Figure 8-17a shows a grid that is 15 x 10 cells with no vertical segmentation and, in addition, indicates that 24 of the 150 cells fail to meet the criteria. If the volume of each of the cells was equal to one million cubic feet (1 MCF) and if all cells meet the attainment criteria (of say 5 mg DO/L) every day for a month, then the DO volume-days would be equal to 150 x 1 MCF x 30 days or 4,500 MCF-days. Again referring to Figure 8-17a, which indicates that 24 of the 150 cells did not meet the criteria and assuming that this is the case for each day of 30 days, then the volume-days would be equal to 126 x 1 MCF x 30 days or 3,780 MCF-days or 84% attainment of the total volume-days for the month. Figure 8-17b shows how the spatial attainment is integrated over time. Using this methodology, cost-attainment curves were developed. These curves are shown in Figures 8-18 through 8-21.

Figure 8-18 Annual Baywide - DO Volume Days indicates that Level 2 BNR (modified flow split; partially oxic) at Jamaica WPCP + Contract 12 at 26th Ward WPCP and filling Grassy Bay and North Channel to 8 ft. below mean low water achieves a high level (>99%) of time-volume dissolved oxygen attainment with 5.0 mg/L.

Figure 8-19 Annual Grassy Bay - DO Volume Days indicates that Level 2 BNR (modified flow split; partially oxic) at Jamaica WPCP + Contract 12 at 26th Ward WPCP and filling Grassy Bay and North Channel to 8 ft. below mean low water achieves a high level (>97%) of time-volume dissolved oxygen attainment with 5.0 mg/L.

Figure 8-20 Summer Baywide - DO Volume Days indicates that Level 2 BNR (modified flow split; partially oxic) at Jamaica WPCP + Contract 12 at 26th Ward WPCP and filling Grassy Bay and North Channel to 8 ft. below mean low water achieves a high level (>98%) of time-volume dissolved oxygen attainment with 5.0 mg/L.

Figure 8-21 Summer Grassy Bay - DO Volume Days indicates that Level 2 BNR (modified flow split; partially oxic) at Jamaica WPCP + Contract 12 at 26th Ward WPCP and filling Grassy Bay and North Channel to 8 ft. below mean low water achieves a high level (>90%) of time-volume dissolved oxygen attainment with 5.0 mg/L.

9. Ecosystem Considerations

A review of the cost-attainment curves provided in Chapter 8 identifies the alternative "26thWard WPCP at Contract 12 Upgrades with Jamaica WPCP at Level 2 with modified flow split, partially oxic", as the most cost-effective treatment alternative for improving water quality in Jamaica Bay. On an annual baywide basis, this alternative alone would attain the current NYSDEC DO water quality standard of 5.0 mg/L, 97.3 percent of the time. When this treatment alternative is combined with the filling of Grassy Bay and North Channel to a depth of 8 feet below mean low water, the percent attainment with water quality standards increases to 98.0 percent. This compares to an attainment of 99.3 percent associated with the relocation of the 26th Ward and Jamaica WPCPs to the Rockaway Inlet via gravity.

A similar review was performed for summer attainment in Grassy Bay only. As noted on the cost-attainment curve, the treatment alternative "26th Ward WPCP at Contract 12 Upgrades with Jamaica WPCP at Level 2 with modified flow split, partially oxic", attains DO water quality standards 47.8 percent of the time. When linked with the filling of Grassy Bay and North Channel to a depth of 8 feet below mean low water, attainment increases to 70.5 percent. This compares to an 86.1 percent attainment with DO water quality standards associated with the relocation of the 26th Ward and Jamaica WPCPs to the Rockaway Inlet via gravity.

On an annual baywide Volume Day basis, the alternative "26th Ward WPCP at Contract 12 Upgrades with Jamaica WPCP at Level 2 with modified flow split, partially oxic", would result in possible total volume days greater then or equal to 5.0 mg/L of 99 percent. When this treatment alternative is combined with the filling of Grassy Bay and North Channel to a depth of 8 feet below mean low water, the percent DO Volume Days greater than or equal to 5.0 mg/L increases to 99.4 percent. This compares to percent DO Volume Days greater then or equal to 5.0 mg/l of 99.9 percent associated with the relocation of the 26th Ward and Jamaica WPCPs to the Rockaway Inlet via gravity.

On an summer Grassy Bay Volume Day basis, the alternative "26thWard WPCP at Contract 12 Upgrades with Jamaica WPCP at Level 2 with modified flow split, partially oxic", would result in possible total volume days greater then or equal to 5.0 mg/L of 83.5 percent. When this treatment alternative is combined with the filling of Grassy Bay and North Channel to a depth of 8 feet below mean low water, the percent DO Volume Days greater than or equal to 5.0 mg/L would increase to 90.3 percent. This compares to percent DO Volume Days greater then or equal to 5.0 mg/l of 97.8 percent associated with the relocation of the 26th Ward and Jamaica WPCPs to the Rockaway Inlet via gravity.

As noted in the above examples, the vast impacts of the dredging of Grassy Bay and North Channel on the attainment of DO water quality standards constrain the viability of cost-effective wastewater treatment options.

The Department initiated an Ecosystem Analysis within the open waters of Jamaica Bay to observe the differences in marine communities within areas of the bay whose water quality attains and does not attain DO water quality standards to identify the ecosystem benefits that might be realized with increased attainment with DO water quality standards. This study, as well as the development of an Ichthyoplankton Transport Model will be further discussed in this chapter.

9.1. Ecosystem Finding as Input to Comprehensive Jamaica Bay Report

9.1.1. Background on Jamaica Bay Ecosystem

Jamaica Bay is a shallow urban estuary comprised of a complex network of channels, islands, and marshes. Although the Bay has characteristics of classical estuarine systems, the limited input of fresh water, primarily as treated effluent discharged into the eastern portion of the North Channel, and relatively poor exchange of water with the ocean, results in a relatively long water residence time for the system (7 to 10 days on average for Grassy Bay and 20 to 30 days on average for the bay as a whole). In the deeper areas of the system created by removal of sediments for nearby construction projects, the water residence times may be longer. These factors, coupled with extremely high nutrient loading and natural biogeochemical process encompassing the production and consumption of organic matter in the water and sediments of the system, have led to poor water quality conditions over large portions of the system. The key water quality concerns are the low levels of dissolved oxygen (DO) and high levels of unionized ammonia that occur during the summer.

Methods to improve the water quality conditions are currently under evaluation. Decisions regarding the best alternatives, require information on the short and long term variability in the water quality conditions, the spatial and temporal influence from present and future nutrient loading, and a clear understanding of the potential environmental improvements that could be realized under the various restoration alternatives. Available data and water quality modeling, have characterized the spatial extent and seasonal variability of poor water quality in the deeper portions of the Bay (which experience restricted flushing) and shallower waters of the North Channel proximal to the main source of nutrient loading. However, other areas of the bay that have highly restricted circulation and long flushing times, but are distant from the main nutrient source, can also have poor water quality primarily during summer months, when water temperature is high.

Available information also documents that water quality conditions vary on daily, weekly, monthly and seasonal scales. These data and water quality model results suggest there should be gradients in the water quality conditions of the system. This is in part due to the influence of tidal flow, wind patterns, temperature, light, water depth, and variations in freshwater input.

Because the water column, sediments, and biogeochemical processes are linked in time and space, water quality data address only a portion of a system's status. A full understanding of nutrient loading impact and projecting acceptable restoration conditions requires an understanding of sediment quality and how water quality affects the sediment quality. Moreover, because sediments are a long-term repository and generally less physically dynamic than the water column, they tend to integrate short-term, highly variable water column conditions, and respond more slowly to changes in the system. As a result, conditions in the sediment and water respond on different time scales and gradients between them are established.

9.1.2. Ecosystem Study and Design Findings

In Jamaica Bay, there is an incomplete understanding of the linkages between nutrient loading and water and sediment quality relative to alternative approaches for improving ecosystem function. The 2005 and 2006 Ecosystem Study characterizes many linkages to anticipate how benthic habitat and community might respond to water quality improvements.

The study was designed to map water quality conditions, benthic habitat gradients, and benthic community distributions to:

- Characterize spatial and temporal variability of key water quality parameters – especially DO and unionized ammonia;
- Quantify water and sediment quality gradients throughout Jamaica Bay;
- Examine the linkages between water quality and benthic habitat quality;
- Examine the degree of biological stress based on measurements available (Figure 9-1);
- Examine the potential toxicity of sedimentary ammonia on benthic organisms; and
- Integrate observations to enable reasoned projections of potential ecosystem responses to reductions in duration or extent of hypoxic conditions or elevated unionized ammonia concentrations.

The fundamental premise of the study design was to investigate whether differences in ecosystem functions can be observed across regions of Jamaica Bay that experience varying levels of DO and unionized ammonia. Central to this premise was obtaining data that characterize the system before and after poor water quality conditions develop, thus sampling occurred in spring and late summer.

Multiple lines of evidence suggest ecosystem changes are likely to occur in segments of Jamaica Bay borrow pits and channels if water quality stressors decrease. Channel segments that may respond are referred to as transitional regions based on observed gradients in water quality and benthic conditions. Benthic habitat and community statistics in transitional regions (i.e., reduced abundance, species numbers, differences in species composition, total organic carbon levels, RNA:DNA ratio shifts, and SPI indices) were consistent with those typically ascribed to several environmental stressors, including low DO conditions or high contaminant loads.

The magnitude and severity of benthic effects were large in the deep, poorly mixed regions of Grassy Bay and Grass Hassock, where low DO conditions may persist longer than in other regions of the bay. Multivariate statistical analyses showed a distinct separation from the stations in the deep areas of Grassy Bay and those in eastern North Channel/western Grassy Bay. The distinction between the latter set of stations and those in North Channel was apparent in SPI images, but less clear in infaunal measures. The magnitude and severity of benthic effects decrease in the transition zones of the Jamaica Bay channels where low DO conditions were less frequent or of shorter duration.

The Jamaica Bay ecosystem shows distinct regions with clear differences in habitat conditions that would likely respond individually to potential changes in water quality. The ichthyoplankton survey findings revealed some associations between DO levels and abundance and diversity. However, sampling yields make the statistical determinations less definitive than benthos at this time.

The benthic faunal patterns observed along the channels of Jamaica Bay suggest that ecosystem functions can be sustained in Jamaica Bay where DO conditions do not dip below hypoxic levels for extended periods. The scientific literature makes clear that benthic habitats will benefit from high DO levels. Southwest regions of Jamaica Bay appear to follow typical annual successions. Some ecosystem indicators in borrow pit regions appear to shift slightly during the year, albeit on the very degraded end of the continuum. Of importance to this plan, there appear to be transitional regions where ecosystem health indicators shift back and forth along a series of continuum pertaining to ecosystem stress. Sampling in the channels suggests that these transitional regions, which make up approximately 5% of Jamaica Bay, may benefit demonstrably from incremental improvements to water quality. However, improvements are likely to be less consequential than changes that could stem from remedies which increase mixing between the water column and benthic habitats of Jamaica Bay.

The benthic habitats in Jamaica Bay will likely improve in response to improved DO conditions and it is reasonable that improved benthic communities eventually will result. However, the recovery process will be complex (e.g., appearance and disappearance of species as conditions change) and will depend on the interplay among several factors. For example, sites showing some "recovery" and higher diversity in May 2006 were being colonized by very few animals characterized as opportunistic species which can indicate a stressed site not necessarily a richly diverse benthic community. Benthic recovery in Jamaica Bay may take a relatively long time (e.g., a few to several years) for biological recolonization following the geochemical processes that consume labile carbon, which presently creates such a high sediment oxygen demand. Conceptually of coarse, capping this carbon inventory would reduce the need to consume the sediment oxygen demand (SOD) prior to recolonization.

The various lines of evidence suggest that it will be especially important to decrease the duration of low DO events, that is, it is vital that protracted episodes of low DO be avoided because just one protracted episode can decimate a benthic community for the season even if average DO levels increase on an annual basis. Additional study is needed to more clearly understand the temporal aspect of benthic community tolerance for low DO events. Sublethal effects of water quality non-attainment were observed, which appear reversible or tolerable to the surviving biota, based on RNA:DNA observations of *Ampelisca* specimens.

It is not clear how much water quality needs to improve in absolute terms, or in duration. However, it is conceptually possible to anticipate a threshold, or "tipping point," amongst the benthic geochemical and biological processes beyond which incremental gains in water quality could promote ecosystem conditions that further improve water quality through reductions in sediment oxygen demand and increases in denitrification. The lack of benthic community complexity in the severely impacted areas, means that recolonization must proceed through numerous phases via the immigration of opportunistic animals from other areas of Jamaica Bay, or by larval recruitment into the newly improved habitats. In the Grassy Bay depression and Grass Hassock, recruitment via migration, whether direct or indirect, seems likely to be a slow process because of the distance from suitable sources of fauna and the relatively poor bedload transport.

9.1.3. Water Column Mixing Processes are Key to Ecosystem Health

The ongoing assessment of the Jamaica Bay ecosystem functions and patterns has definitively shown that water column mixing is the primary controlling factor by which most other processes are driven. Nutrient levels and availability are directly proportional to the waterbodies' proximity and exchange with Rockaway Inlet flows. Total organic carbon, particularly labile carbon concentrations, driving sediment oxygen demand are found to be highest in channels and borrow pits with diminished vertical mixing or tidal exchange. Substantial differences between the main body of Jamaica Bay versus Grassy Bay were observed via continuous monitoring of variations in water quality levels both vertically and over tidal cycles. Clearly, hydrodynamics in Jamaica Bay create varied amounts of water column mixing, which enable drastically different ecosystem conditions. Any proposed remedy to improve ecosystem function in Jamaica Bay needs to ensure adequate mixing regimes for optimal benthic communities and ichthyoplankton.

9.1.4. Water Quality Non-Attainment Episodes

The 2005 fieldwork captured the temporal sequence after the onset of hypoxic conditions in two portions of the bay. The results showed that by late July 2005, Grassy Bay, eastern North Channel, and Grass Hassock DO levels were less than 3mg/L. Certain regions appeared to have been hypoxic for at least two months. Other regions experienced episodic reductions. The spatial extent of hypoxia decreased between July and October 2005, with most areas having DO concentrations greater than 5 mg/L by late September. Dissolved oxygen values less than 5 mg/L were measured in Grassy Bay and Grass Hassock in October 2005. Dissolved oxygen levels were relatively high from November 2005 to May 2006 peaking in January coincident with a major phytoplankton bloom. The first occurrence of hypoxic DO levels in Grassy Bay was measured in the bottom waters in late May 2006. Although not directly comparable, the observation of hypoxic conditions (late May 2006 and September 2005) in Grassy Bay bottom waters suggests that hypoxic conditions can occur intermittently during the period between May and September. The complete mooring record from 2006 will provide a detailed record of the magnitude, duration and frequency of hypoxic events in North Channel and Grassy Bay bottom waters.

During the more complete temporal record of Spring and Summer 2006 (Figure 9-2), hypoxic DO levels in the bottom waters were episodic and of varying duration in Grassy Bay and North Channel. The continuous mooring data (MGB, MNC in Figure 9-3) and high-resolution in-situ water quality sampling show much more variability in the North Channel relative to Grassy Bay. This is primarily due to tidal effects and mixing in North Channel data versus the limited tidal influence and less mixing in Grassy Bay. It will be important to learn more about the resident biota's tolerance for extended periods of low DO. Benthic infaunal evidence discussed below suggest that communities in North Channel can either tolerate or recover from some protracted episodes of low DO. Grassy Bay and Grass Hassock communities experience longer periods when bottom waters have low DO than other communities within the bay, which reduces their ability to recover.

Unionized ammonia concentrations were very high during the survey conducted in late July 2005 with a study maximum unionized ammonia concentration of 0.239 mg NH_3/l measured in eastern North Channel. In August 2005, Grassy Bay, North Channel and Broad Channel had unionized

ammonia UIA levels greater than 0.035 mg/L. The maximum unionized ammonia concentration (0.19 mg/L) was observed in Grassy Bay during early August. There was high variability in the data and clear gradients were apparent. The area of high unionized ammonia UIA was generally consistent with the region of elevated nutrients, although most levels were below those expected to cause negative impacts on biota. By early September 2005, unionized ammonia concentrations had decreased to less than or equal to 0.025 mg NH_3/L. From late October 2005 to early May 2006, unionized ammonia concentrations were very low (less than 0.0001 mg NH_3/L). During the May 19 survey, unionized ammonia levels had begun to increase again, but were still less than 0.0005 mg NH_3/L. The data suggest that unionized ammonia levels might only be an issue during the warmest months of the year, July and August.

9.1.5. Benthic Ecosystem Function and Status

The benthic habitat quality mapping conducted in late summer 2005 revealed a region of low sediment quality (32 of 46 stations) primarily from evidence of low DO inferred from the sediment profile images. Benthic habitat specialists used four parameters (apparent redox potential depth, methanogenesis, evidence of low DO, and biological activity) to calculate an Organism Sediment Index for sites throughout Jamaica Bay (Figure 9-4), which was used to evaluate habitat quality. The worst habitat quality occurred in deeper areas of Grassy Bay and in Grass Hassock. Poor habitat quality was found in Grassy Bay near North Channel and the northern part of Broad Channel. The best habitat quality, which still showed signs of stress, was in western North Channel and southeastern Grass Hassock Channel. The images collected in May 2006 showed substantial improvements, or shifts, in sedimentary habitats bay-wide, and particularly in "transitional" areas identified near Grassy Bay, although many areas still showed evidence of stress.

Under oxygen-stressed conditions, sediments can act as a biogeochemical feedback mechanism that exacerbates the effects of eutrophication by increasing the efflux of ammonium (NH_4) from the sediment to the water column. Elevated rates of NH_4 efflux were measured at all stations sampled in August 2005, but only at two in Grassy Bay in September 2005. In addition, the efficiency of denitrification in Jamaica Bay was high even for a highly eutrophic environment with the highest efficiencies found at stations with populations of the benthic amphipod, *Ampelisca*. These data provide an interesting insight into this system because if infauna become more abundant after improved water quality, their presence would increase bioturbation in surface sediments. Similarly, higher oxygen levels will also increase denitrification efficiency. If these conditions were to develop, a positive feedback could be established leading to further improvements through more effective use of the organic load to the sediments and by burning off excess organic material in the sediments.

The abundance of benthic infauna species varied substantially across Jamaica Bay (Figure 9-5). Two major groups of organisms, annelid worms and amphipod crustaceans, dominated the communities. Very few organisms were found in samples from Grassy Bay and Grass Hassock regardless of the sampling date. Variability between the August and September sampling events was evident at some stations, although without a general trend. A spatial trend of declining species numbers was observed from the eastern end of North Channel through a transition area into Grassy Bay. In contrast, species numbers increased from Grassy Bay out to Broad Channel and into Grass Hassock Channel. As in Grassy Bay, abundance in the deeper areas of Grass Hassock was low or zero. Samples collected in May 2006 at the transition areas near Grassy Bay showed increased numbers of species compared to 2005, but the increase was primarily from the influx of rare species, that is, those represented by only one or a few individuals per sample. Some increases in abundance were also noted for the

transitional areas, but these were primarily attributable to colonization by an opportunistic polychaete worm that masked important decreases in abundance of other key species in the areas.

There was a clear threshold-type association between total abundance and total species numbers and sediment total organic carbon (TOC). Significant associations were not found with bathymetry. At TOC values of greater than 5.5%, organism abundance and species numbers declined steeply, with azoic conditions reached where TOC was greater than 7% in late summer 2005. Although TOC levels in these areas decreased slightly by May 2006, sediments there continued to be azoic or severely depauperate. In 2005, the association between total infauna abundance and DO concentration was ambiguous at the normoxic stations, but where DO concentrations were less than 2 mg/L (Grassy Bay and Grass Hassock) the benthos was very depauperate or azoic. This limited data set also suggests although the water quality at the azoic stations had improved from mid to late August 2005 and to May 2006, fauna generally had failed to colonize the stations. The timing of the water quality recovery and life cycles of the organisms is a key element to understanding how incremental improvements in the water quality will affect the overall recovery of this system. However, it is also clear that some areas of the bay, such as the Grassy Bay depression and deeper parts of Grass Hassock will not respond quickly to changes in water quality improvements, if they improve at all.

Gray *et al.* (2002) and Wu (2002) stressed that the quality of the organic load in a system is more important in determining the potential for eutrophication and subsequent hypoxia than the total load itself. High quality organic material has more potential to lead to eutrophication than low quality. Organic material quality was evaluated in May 2006 by determining the C:N ratios in sediments. These data showed that most of the sediments contained high quality organic material that is likely to contribute to hypoxia as microbes process the material. The data also showed a few areas that had low quality organic material likely derived from macrophyte (*Ulva*) detritus exported from shallow to deep waters. Several occurrences of loose Ulva detritus were observed in SPI images from May 2006 and measuring C:N ratios in late summer 2006 will help determine whether or not that material becomes incorporated into the sediments.

Generally, even though the unionized ammonia levels measured during the summer 2005 surveys were higher than the USEPA chronic standard levels, they were substantially lower than those known to cause acute impacts to benthic fauna. unionized ammonia concentrations during the fall, winter and spring were orders of magnitude lower indicating that the summer values measured in 2005 represent likely peak unionized ammonia concentrations. Thus, it seems unlikely that unionized ammonia levels have impacted benthic communities in Jamaica Bay. Moreover, the similarities between Grassy Bay and Grass Hassock benthic stations suggest that stressors other than unionized ammonia may be influencing conditions in Grass Hassock. Potential linkages between unionized ammonia levels and benthic effects would be better investigated with measurements of unionized ammonia within the sediment, as contrasted with the near-bottom readings available from the water column samplers.

9.1.6. Sediment Toxicity Assessment

The results of the ammonia toxicity tests with the infaunal amphipod *Ampelisca abdita*, clearly demonstrate that ammonia is a significant toxicant in Jamaica Bay sediments. However, the laboratory results are difficult to completely reconcile with the observed infaunal community patterns where some biota appear to survive in spite of stressful water quality. This incongruity was also

observed in Jamaica Bay field samples where resident fauna remain active in spite of being exposed to levels which, in the literature, would have been expected to cause deleterious effects. In general, the treatments having the highest *Ampelisca*- survival (greater than 85%) in the laboratory tests were from stations shown to have well-developed infaunal communities. One station that had poor amphipod survival (56%) also had a poorly developed infaunal community in May 2006 that was characterized by low faunal abundance with infauna consisting primarily of the opportunistic polychaete *Capitella capitata*. However, some of the results were enigmatic, as stations with moderate infaunal communities had relatively poor to very poor *Ampelisca* survival. Also, sediments from stations in Grassy Bay and Grass Hassock that had very poorly developed or azoic infaunal communities often showed surprisingly high *Ampelisca* survival in the laboratory (69–78%). The relatively high A*mpelisca* survival observed during the acute bioassay for sediment from stations known to be severely depauperate or azoic could indicate that the poor infaunal community condition is the result of chronic stress and/or the severe hypoxia that both areas encounter each year.

9.1.7. Ichthyoplankton Background

Ichthyoplankton (fish eggs and larvae) abundance and diversity were the primary ecosystem characteristics investigated in this ongoing fieldwork (July 2005 – July 2007) via biological collections and sampling of dissolved oxygen (DO), ammonia and nutrients. Most marine biota utilize oxygen that is dissolved in the water column. Many of these organisms are sensitive to dissolved oxygen concentrations and suffer when levels are less than ~ 5mg/L. As reported by Howell and Simpson (1994), "Although individuals may show sensitivity to low oxygen in the laboratory, mobile species may move out of hypoxic areas, and both sessile and mobile populations may develop behavioral or metabolic adaptations when chronically exposed to hypoxia". The USEPA (2000) has determined values of dissolved oxygen that will cause acute and chronic effects on aquatic life in the region of the Virginian Province (Cape Cod, MA to Cape Hatteras, NC). Chronic effects are those that negatively impact growth, and reproduction, whereas acute effects cause death. The recommended criteria define limits of dissolved oxygen based on continuous and cyclic (diel, tidal, episodic) exposure to hypoxic conditions. Hypoxia is defined by many regulatory agencies as DO less than3 mg/L, the level below which many finfish and benthic species experience stress (Anderson and Taylor, 2001). The proposed New York State Department of Environmental Conservation (NYSDEC) standard for acute exposure is never less than 3.0 mg/L, and for chronic exposure the standard is a duration exposure curve ranging between 1 day at 3.0 mg/L and up to 60 days at 4.6 mg/L. This study seeks to observe ecosystem functions as ambient levels of DO vary relative to these criteria.

Because of the toxicity of ammonia to aquatic life, the USEPA has developed criteria for ammonia concentrations and calculated mortality estimates for a variety of finfish and invertebrate species (mostly freshwater, some marine). Impacts of temperature and pH on un-ionized ammonia have also been evaluated by the USEPA. Based on their findings, the toxicity of ammonia can depend on ionic composition, pH and temperature. This study monitored the multiple parameters necessary to accurately report the ambient levels of ammonia at numerous locations and time periods.

Nitrogen was considered the limiting nutrient in Long Island Sound Study and most coastal marine systems (Riley and Conover, 1967). Current theory supports the view that excess nitrogen creates eutrophic conditions fueling phytoplankton growth, which in turn is decomposed by bacteria, a process that depletes oxygen and leads to hypoxia. A "new conventional wisdom" has arisen based

on the theory that "excess nitrogen stimulates the microbial loop and net phytoplankton biomass and production, which in turn stimulates microcrustacean biomass and production and fecal release; both significantly fuel hypoxia and likely stimulate gelatinous zooplankton production." This study was designed to monitor a variety of nutrients in order to create a more complete understanding of cycling and variations over time.

Jamaica Bay experiences eutrophication resulting from increased nitrogen inputs. During the late summer/early fall, areas of Jamaica Bay experience low DO levels as a result of high nutrient loads and temperature increases causing stratification of the water column. When these DO levels fall below established NYSDEC standards, the areas are considered 'non-compliant.' The Ecosystem Analysis was designed to observe ecosystem differences between compliant and non-compliant areas of the bay, as well as to observe the nature and extent of non-compliance within the period of high-frequency water quality sampling.

This study was also designed to act as an extension of the Use and Standards Attainment (USA) Project and the Jamaica Eutrophication Project. In particular, this project gathered additional biological and water quality data that will further explore the relationship between biological impacts and ecosystem health. While the USA project focused on the tributaries (with some stations in the Bay), this study focused on the open waters of the Bay (Figure 9-6).

9.1.7.1. Ichthyoplankton Survey

Biological monitoring of marine systems is an important tool used to assess anthropogenic impacts on ecosystems. Fish assemblages are used as indicators of habitat quality since their composition is known to change as habitats are modified. Long-term variations in fish abundance provides an important framework to assess the influence of water quality trends on fish assemblages (Araujo *et al.*, 2000). Numerous studies have cited temperature and dissolved oxygen as the most significant environmental variables affecting estuarine fish species distributions.

This study is currently in the process of receiving additional funding to continue the study and report on multiple (three) years of data. This will allow for a comparison of interannual variations in the data. The general locations of the ichthyoplankton transects are shown on Figure 9-3

This project was designed to gain an understanding of the spatial distribution and the seasonality of pelagic habitat usage of Jamaica Bay by early life stages of important species across a range of ambient DO and ammonia levels. A sequence of bi-monthly and monthly surveys were implemented over a 12 month period during which a series of transects were sampled for ichthyoplankton and ambient water quality. This study was designed to be qualitative and to provide data to make relative comparisons between non-compliant and compliant areas of Jamaica Bay, for that point in time when sampling occurred.

The ichthyoplankton surveys were designed to act as an extension of the Department's Use and Standards Attainment (USA) Project. Specifically, this study collected additional biological and water quality data that further explored the relationship between biological impacts as they relate to the NYSDEC's water quality standard for dissolved oxygen.

Previously, baseline information on finfish, macroinvertebrates, benthos and water quality was collected from Jamaica Bay during the years 2000-2001 as part of the USA project. While the USA project focused on the tributaries of Jamaica Bay (with some stations in the Bay proper), this study focused on regions of the open waters throughout Jamaica Bay, with particular focus on Grassy Bay and locations that contrast Grassy Bay water quality conditions.

Beginning in February 2006, the Norton Basin/Little Bay region of Jamaica Bay was added to the current ecosystem study. Norton Basin/Little Bay are two embayments located on the north shore of the eastern Rockaway Peninsula of Jamaica Bay. Four additional stations in the Norton Basin-Little Bay region were added to the study in order to supplement data previously collected from this region by a joint study of the U.S. Army Corps of Engineers, NYSDEC and the Port Authority of New York/New Jersey.

9.1.7.2. Ichthyplankton Methods

Sampling was conducted from July 2005 through July 2006. Sampling was conducted twice per month from May through October (when most fish are spawning) and once per month from November through April. This study will continue for two additional years. At the time of report writing, sampling has been ongoing to continue data gathering in order to prevent any gaps in data collection. This report presents findings from the first year of the study, the time period of July 2005 through July 2006. Samples were collected at seven stations in DO and ammonia compliant zones and five stations in DO and ammonia non-compliant zones from July 2005 through January 2006. An additional four stations were added to the ichthyoplankton sampling protocol beginning in February 2006.

Sampling was conducted throughout Jamaica Bay focusing on key areas such as Grassy Bay and North Channel. Both of these areas have been dredged in the past and experience some of the lowest dissolved oxygen levels in Jamaica Bay. Stations were selected based upon known trends (from previous studies) in DO and ammonia distributions in non-compliant areas. At each station, *in situ* data was collected on dissolved oxygen, temperature, salinity, pH, chlorophyll *a* fluorescence and light transmission concurrent with the ichthyoplankton sampling. When possible, water quality measurements were recorded continuously throughout the water column. Discrete depth water samples were collected from surface and near bottom waters for analysis of dissolved inorganic nutrients (NH_4, NO_3+NO_2, PO_4, and SiO_4) and chlorophyll. The latter analysis provided data for calibrating the *in situ* fluorescence sensor. Quality Assurance procedures for collection, processing, and analysis of the water quality samples are described in the QAPP for this study which was reviewed by the NYSDEC (Battelle and EEA, Inc., 2005).

9.1.7.2.1. Community Analyses

Data were analyzed to make comparisons of fish community structure at the twelve sampling stations in Jamaica Bay. Species abundance was tabulated for each station. Shannon's Diversity Index (H') and Pielou's Evenness Index (J') were computed to facilitate comparisons. The Shannon's Index generally increases as the number of species in a sample increases and as the population sizes become more alike. Pielou's Index relates the Shannon's Index to that which would occur if there were a

perfectly even distribution. Pielou's Index reflects Shannon's Index as a proportion of its maximum possible value. Pielou's Index ranges between 0 and 1 and permits easier comparison of communities between stations.

Similarities between stations were compared using the Bray-Curtis Similarity Index (B-C). The Bray-Curtis Similarity Index compares two stations and measures the proportion of the total number of fish in the two stations that are present at both stations. The Bray-Curtis Index ranges from 0 to 1, with 0 indicating no species in common and 1 indicating that all species are present in the same number at both stations. Results of the Bray-Curtis comparisons were reported in a matrix display of pair-wise species associations. Based on the results of the Bray-Curtis Index, cluster analysis was used to group the sampling stations.

The RNA/DNA ratio, describing fish condition at each station, was calculated as the average value of the RNA determination divided by the average value of DNA determination. Estimated growth using the RNA/DNA ratio was analyzed for two species at four stations in July and August. With a non-normal distribution, Kruskal-Wallis One Way Analysis of Variance on Ranks was used to determine if there was a difference in mean values among sampling units.

9.1.7.2.2. Comparison to Environmental Conditions

To provide visual trends in the data, abiotic factors (dissolved oxygen, ammonia, temperature) were included in the matrix view of species abundance at each station (as noted above). In addition, diversity and mean RNA/DNA ratio were plotted against each environmental variable.

Regression analysis was performed to relate community characteristics to the environmental conditions, dissolved oxygen and ammonia. Since neither dissolved oxygen nor ammonia is an independent variable under our control, the situation reflects a model II regression, for which we used a Robust Line Fit. The correlation between dissolved oxygen and ammonia was explored to determine the extent of collinearity to determine the usefulness of multiple regression. For significant results, the regression analysis is reported as a regression equation that represents the functional relationship between the variables, and a significance value (p).

9.1.7.3. Ichthyoplankton Results

This section of the report describes results from the first year of the ichthyoplankton survey. Eighteen surveys were conducted between July 2005 and July 2006 (Table 9-1). Twelve stations in Jamaica Bay proper were sampled, three repetitions per station, during each survey. All samples were collected during each survey. To date, all repetition one samples have been identified and enumerated for fish eggs and larvae.

9.1.7.3.1. Ichthyoplankton Distributions and Abundance

Ichthyoplankton data were analyzed by describing characteristics of the fish communities, relating community structure to environmental conditions (dissolved oxygen and ammonia) and contributing to inferences regarding the health of Jamaica Bay ecosystem functions. The data were analyzed

separately for both fish eggs and larvae. Biological ichthyoplankton data were analyzed with selected environmental variables to make inferences on the health of Jamaica Bay as an ecosystem and determine survivability of fish eggs and larvae.

9.1.7.3.2. Community Analysis

A total of 211,674 eggs and 23,620 larvae were collected between July 2005 and July 2006 in Jamaica Bay. Fourteen taxonomic groups of eggs and 28 larval fish taxa were identified in the samples. Table 9-2 lists the common and scientific names for all species collected. *Anchoa mitchilli* was the dominant species in the egg collections outranking other species by an order of magnitude. *Anchoa mitchilli* and Gobiidae were the dominant species of larval fish collected outnumbering other taxa by at least an order of magnitude, in most cases two to three orders of magnitude.

In general, the average number of egg taxa were similar across all stations, ranging from 8 taxa at stations Y8, Y9 and Y10 to 13 taxa at stations Y6 and Y11 (Table 9-3). Average yearly egg densities, ranged from 147.64 to 739.49 eggs/100m^3. The lowest average densities were collected at stations Y9 (Grassy Bay), Y10, Y1 (near Rockaway Inlet) and Y12, while the highest densities were at stations Y2 (Broad Channel), Y3 (Island Channel) and Y11 (Beach Channel). Shannon's Diversity Index (H') (a measure of species richness) ranged from 0.5363 (Y2) to 1.8696 (Y1). Higher diversity indices were observed at stations Y1, Y12, Y3, Y5, Y6 and Y7. Those stations are located near the Rockaway Inlet and North Channel. Lower diversity indices were observed at stations Y2 (the Raunt), Y4, Y8, Y9, Y10 and Y11 (in Grassy Bay, Beach and Broad Channels).

Pielou's Index (J') is a measure of distribution evenness. Values of Pielou's Index ranged from 0.2158 to 0.7797. The lowest Pielou indices were observed at stations Y2, Y4 and Y11 (Beach and Broad Channels and Pumpkin Patch). The highest Pielou indices were observed at stations Y1 (near Rockaway Inlet) and Y12. Overall, stations Y5 and Y6 are lowest in diversity, lowest in evenness and the furthest from other stations, from the perspective of community distribution.

In general, the average number of larval fish taxa was variable across all stations, ranging from 8 taxa at station Y8 to 20 taxa at station Y3 (Table 9-4). Average yearly larval fish densities were variable ranging from 18.31 to 210.39 larvae/100m^3. The lowest larval densities were observed at stations Y8 and Y9 in Grassy Bay and Y2 (the Raunt). The highest larval fish densities were observed at Y6 in North Channel. At this location, larval densities were an order of magnitude higher than those observed at the other stations. Shannon's Diversity Index (H') ranged from 0.6724 (Y5) to 1.5998 (Y1). Higher diversity indices were observed at stations Y1, Y2 and Y4. Lower diversity indices were observed at stations Y5 and Y6 in the North Channel. Pielou's Index (J') ranged from 0.2560 to 0.6198. The lowest Pielou indices were observed at stations Y5 andY6 in North Channel while the highest Pielou indices were observed at stations Y1, Y2 (Rockaway Inlet and Broad Channel) and Y9 (Grassy Bay).

9.1.7.3.3. Water Quality and Species Distribution

The employed statistical tests compared the number of organisms, number of taxa, and Shannon's Index to water quality conditions measured as dissolved oxygen and ammonia. Because of the large

number of sampling stations, the temporal intensity of the program and the number of abiotic (water quality) factors, the results of the study are quite complex.

9.1.7.3.4. Overall Summary of Results

There are various ways to view complex data sets and draw valid conclusions. One method is to look at the data set as a whole including all stations, samples, abiotic factors for the entire twelve month span and attempt to draw broad brush conclusions. Another method is to look at the data on a more micro level drawing inferences from specific time periods, selected abiotic factors and/or station locations. Both methods have been employed herein.

From a broader perspective, the Shannon Index, which takes into account both species numbers and abundance was applied to the entire ichthyoplankton data set. The results indicated no correlation between abiotic factors and diversity and abundance over the coarse of a full year (Tables 9-5 and 9-6). Locations in some back areas of the Bay exhibited similar indices to areas near the inlet. The implication of this are discussed below.

9.1.7.4. Ichthyoplankton Discussion and Conclusions

It is argued that excess nutrient loadings to estuaries can stimulate algal production that leads to hypoxia and subsequently reduces recruitment and/or survival of finfish and shellfish. Abundance and diversity of biological organisms can be used to indicate the health of an ecosystem. The first year of this study evaluated the monthly presence of ichthyoplankton (fish eggs and larvae) throughout Jamaica Bay. Ichthyoplankton abundance, diversity and condition are compared in areas that experience compliant and non-compliant conditions for dissolved oxygen and ammonia. The primary goal of this study is to determine if ichthyoplankton distributions are being affected by eutrophication in Jamaica Bay.

The more diverse a community, the healthier a community is said to be because a greater variety of species are able to withstand the environmental conditions. Some of the statistical tests indicate that those sections of Jamaica Bay that are more compliant with dissolved oxygen and ammonia standards support a greater species diversity and numbers at certain times of the year. However, when the data were viewed from a broad perspective, there did not appear to be a correlation between station location (e.g., compliant vs. non-compliant) and the results of the Shannon's Index on a comparative basis when applied over a full year.

While this result may seem counter intuitive at first, there are other factors operating. First, while the non-compliant stations tend to be in the eastern and northern sections of the Bay, they are also the deepest stations and therefore have a reasonably deep layer of oxygenated water that allows for fish survival and reproduction even though the deeper layers may be showing depressed DO. A second factor is the temporal duration of spawning. Most fish spawn from late winter through early summer, although a few species spawn outside this period. The depressed DO events occur mainly in late summer when fewer species are spawning. Therefore, the lower number and diversity of ichthyoplankton during the depressed DO periods may be due to natural cycles. Third, the areas of

depressed DO, when corrected for volumes of water and temporal duration may not be large enough to be major influence on phytoplankton community in the bay as a whole.

9.2. Ichthyoplankton/Larval Transport

In November of 2000, the USEPA released ambient aquatic life water quality criteria for dissolved oxygen in marine waters (USEPA, 2000). The criteria developed by the USEPA are meant to be protective of different life stages of marine aquatic life in the waters of the Virginian Province (southern Cape Cod, MA to Cape Hatteras, NC). The criteria have been developed to protect juvenile and adult organisms from mortality and to protect aquatic organisms from mortality during their larval life stages. In addition, criteria have been developed that provides for protection from unacceptable effects on growth and development. NYSDEC is considering implementing a revised form of the USEPA criteria as water quality standards for dissolved oxygen in the marine waters of New York State. In particular, the State is giving consideration to adopting an acute fish survival dissolved oxygen standard of not less than 3.0 mg/L as a daily average and a chronic fish propagation dissolved oxygen standard based on the duration-exposure curve shown on the figure below. (the USEPA larval survival criteria is also shown for reference).

Attaining the USEPA larval survival criteria or the proposed NYSDEC chronic water quality standard is actually a limit based on the number of days a continuous exposure can occur with the cumulative fraction of allowable days above a daily mean dissolved oxygen not to exceed 1.0, or

$$\sum \frac{t(actual)}{t(allowed)} \leq 1.0 \qquad (5)$$

For example, based on the curve presented in Figure 9-7, larvae may be exposed to a concentration of dissolved oxygen of 4.0 mg/L for up to 16 days and still meet compliance if all other concentrations are greater than 4.7 mg/L. Similarly, larvae could be exposed to a dissolved oxygen concentration of 4.2 mg/L for up to 18 days and still meet compliance if all other concentrations are greater than 4.7 mg/L. However, in the case where larvae are exposed to a dissolved oxygen concentration of 4.0 mg/L for 10 days and a concentration of 4.2 mg/L for 10 days, then compliance would not be attained, per Equation 5, since, 10/16 + 10/18 = 0.625 + 0.556 = 1.181 greater than 1.0

Analysis of JEM model computations for compliance with the proposed chronic water quality standards for dissolved oxygen can be performed in one of two ways: (1) assuming that the ichthyoplankton or larvae are "caged" or immobile within each water quality segment in the model grid (as has been presented earlier in this report), or (2) recognizing that the larvae are moved throughout Jamaica Bay under the influence of tidal currents and freshwater inputs to the system and keeping track of their exposure to different levels of dissolved oxygen as they move throughout the Bay. This section summarizes the approach developed and used to analyze for attainment of the proposed NYSDEC water quality standards for dissolved oxygen using the latter approach, i.e., larval transport.

Before the ichthyoplankton/larval transport approach was developed, discussions were held with Mr. Glen Thursby (USEPA Office of Water) one of the key authors of the Virginian Province criteria document. During these discussions the approach and algorithms to be developed for modeling the effects of exposure to varying levels of dissolved oxygen were reviewed and Mr. Thursby generally thought that the proposed approach was reasonable. However, as this portion of the analysis was completed, the Project Team contacted Mr. Thursby for another review. Mr. Thursby provided some initial feedback and expressed some concerns about the protocols for determining larval survival, but was not able to complete his review before the report was completed.

9.2.1.Computational Approach

As part of the Jamaica Eutrophication Study, a coupled hydrodynamic/water quality model (JEM) of the Bay was developed and calibrated against observed field and laboratory data. The details of the JEM model have been presented by HydroQual (2002) and presented earlier in this report. Numerical computations of water speed and direction are available from the JEM hydrodynamic model on an hourly basis. In addition, the daily average concentrations of dissolved oxygen are also available for every model cell for every day of the year for the base calibration/validation as well as all treatment alternatives evaluated as part of developing the comprehensive plan.

The hydrodynamic model used in the JEM study, ECOMSED, has a capability to track particle movement as the hydrodynamics are being computed. It is this "particle-tracking" algorithm that forms the basis for the ichthyoplankton/larval transport model. It is assumed that the "particles" released and tracked during the hydrodynamic model computations represent ichthyoplankton or larvae and that these larvae have no independent motility of their own, i.e., that they just move with the currents and cannot move horizontally or vertically in the water column, independent of the water currents. This may be considered to be a conservative assumption, as Bejda et al. (1987) and Breitburg (1994) have shown that larvae are aware of and capable of avoiding low dissolved oxygen concentrations.

As the ichthyoplankton/larval move throughout the JEM model domain on an hourly basis, each ichthyoplankton or larval organism's cumulative exposure to varying concentrations of dissolved oxygen is computed on a daily basis, as per equation 6,

$$DO_{ave} = \sum_{i=1}^{24} DO_i \Delta t \qquad (6)$$

where

DO_{ave} = daily average dissolved oxygen, (mg/L),
DO_i = dissolved oxygen concentration, (mg/L),
t = exposure time of 1 hour or $1/24^{th}$ of a day.

The 66-day record of daily exposure concentrations is then evaluated for attainment using the proposed NYSDEC chronic curve presented above. Furthermore, the approach used in this analysis evaluated a cohort of ichthyoplankton/larvae released during each day from a period beginning in mid-May (beginning of sub-4.8 mg DO/L levels of dissolved oxygen computed by JEM for the base case) through mid-September (when dissolved oxygen levels increased above 4.8 mg/L). The results

to be presented later in this section represent the summer-average ichthyoplankton/larval "survival" for the ensemble population.

Two additional assumptions were made as part of the overall evaluation: (1) residence within Jamaica Bay and (2) exposure levels in the Bay's tributaries. Under the residence within the Bay assumption, it was decided that any "particle" or ichthyoplankton or larval organism that was transported out of the computational model domain of Jamaica Bay (i.e., export from the Bay via the Rockaway Inlet on outgoing tides) was lost from the system. The assumption is that during the remaining three hours before the tides turn-around and a new flood cycle begins ichthyoplankton/larvae will be transported away from the mouth of Jamaica Bay and will be under the influence of larger scale New York Bight circulation processes such that they would not be available to return to the Bay on the next flood cycle. If, however, the model computations indicate that an individual(s) ichthyoplankton/larval organism was to have suffered mortality before exiting the Bay then it is included in the survival/non-survival statistics. Those "particles" or ichthyoplankton/larval organisms that exit the Bay during the last three hours of tidal ebb are assumed to return to the Bay on the next flood cycle and continue to be included in the ichthyoplankton/larval population.

The second assumption considers ichthyoplankton/larval survival in the tributaries. At this point in developing a comprehensive plan for nitrogen control in Jamaica Bay, the primary emphasis has been on the open waters and non-CSO tributaries (Shellbank Basin and Mill and East Mill Basins). Currently, the Department is also conducting a Long Term Control Plan (LTCP) for CSOs. Current water quality, in particular levels of dissolved oxygen, in the Bay's tributaries is adversely impacted by CSO discharges. Since, at the time of this report, the LTCP had not been completed, it was decided to evaluate larval survival with (1) existing conditions in the tributaries and (2) assuming that the LTCP would attain compliance with the proposed NYSDEC dissolved oxygen water quality standards. Therefore, ichthyoplankton/larval survival was evaluated under both conditions. The way this analysis proceeded was to perform duplicate computations, in one case using model computed dissolved oxygen concentrations in the tributaries under the specific alternative being evaluated and in the second case assuming that water quality standards would be attained (i.e., daily averaged dissolved oxygen concentrations greater than 4.6 mg/L) in the tributaries.

9.2.2. Results

Results from the ichthyoplankton/larval transport computations are presented in Table 9-7 comparing summer-averaged larval survival both bay-wide and specific to Grassy Bay. In the latter case, any "particle" or ichthyoplankton/larval organism that is transported into Grassy Bay from any point in the model domain (including initial spatial distribution at time 0.0 of the spawning event) at any point within the 66-day maturation (ichthyoplankton/larval phase to juvenile phase) for a period as short as an hour is included in the "Grassy Bay" survival statistics, as well as the bay-wide statistics. These survival statistics are compared to the water quality standards attainment plots and tables reported on in earlier sections of this report.

As can be seen comparing attainment with the proposed chronic standards (looking at bottom segments only, i.e., assuming "caged" organisms) with "larval" survival using the ichthyoplankton/larval transport model, indicates that a much higher level of "attainment" would be computed if an organism's movements throughout the bay and its exposure to differing levels of dissolved oxygen as it moves throughout the bay is considered. For example, looking at the baseline

(permit condition) alternative, larval survival for Grassy Bay ichthyoplankton/larvae may be as high as 86% as compared to 37% if one assumes that the ichthyoplankton/larvae are permanently resident in the bottom water segments of Grassy Bay during the critical summer period of low dissolved oxygen.

It is recommended that NYSDEC give consideration to utilizing the ichthyoplankton/larval transport modeling approach for evaluating compliance with proposed water quality standards. The approach employs the proposed chronic duration/exposure curve presented in this section, but recognizes that ichthyoplankton and larvae move throughout the bay, subjected to tidal currents, during their life cycle and that as a result are exposed to differing levels of dissolved oxygen.

9.3. Basis for Separate Designated Use

9.3.1. Attainability of Designated Use from Ichthyoplankton Modeling Analysis

As described in Section 1.2, the open waters of Jamaica Bay are classified by NYSDEC as Class SB, with best usage of primary and secondary contact recreation and fishing. This classification also requires that Jamaica Bay be suitable for fish propagation and survival. It is this latter use which can be affected by nitrogen discharges to the open waters of Jamaica Bay resulting in eutrophication and depressed dissolved oxygen in portions of the bay, Grassy Bay in particular.

The ichthyoplankton model and larval transport analysis described in Section 9.2 provides a procedure to place a perspective on the attainment of the fish propagation and survival use designation for Jamaica Bay. As described, the analysis is based on detailed bay circulation and transport modeling and utilizes the most recent marine dissolved oxygen criteria to assess the impacts of depressed dissolved oxygen on fish propagation and survival, in particular, larval survival. The analysis recognizes that larvae are not static in receiving waters to be exposed only to local dissolved oxygen conditions, but are transported throughout the bay with general circulation, and are therefore exposed to various environments and differing dissolved oxygen levels. Further, the analysis includes the fact that marine fish larvae have adapted to survive under temporarily depressed dissolved oxygen below ideal levels for some periods of time. The survival of the larvae of marine fish depends upon the duration and the severity of dissolved oxygen exposure below the ideal. The larval transport analysis more realistically incorporates these factors as compared with numerical assessments of attainment in static environments which assumes unchanging organism exposure to never-less-than dissolved oxygen objectives.

The ichthyoplankton model analysis demonstrates that larvae are continuously transported throughout Jamaica Bay with tidal circulation and exposed to a variety of dissolved oxygen environments. On this basis, it is considered more appropriate, from a fish propagation and survival standpoint, to view the Jamaica Bay ecosystem not as individual locations for use attainment purposes, but rather as broader geographic areas for ecological assessment, e.g., the Grassy Bay area and Jamaica Bay in its entirety. From an overall assessment standpoint, given the bay's tidal circulation and larval transport characteristics, considering Jamaica Bay as a whole for the fish survival and propagation standpoint is probably more meaningful. As shown in Table 9-7 in the previous section, the expected summertime larval survival for nitrogen reduction upgrades at the 26th Ward (Contract 12) and Jamaica (Level 2;

modified flow split; partially oxic) WPCPs is very high, significantly in excess of what is inferred from considering attainment of the numerical dissolved oxygen criteria in near bottom waters.

On this basis, it is considered that this treatment alternative for nitrogen reduction will result in practical attainment of the water use of fish propagation and survival.

9.3.2. Attainability of Class SB Numerical Dissolved Oxygen Criteria

From the standpoint of attainability of the numerical requirements of the Class SB designation for Jamaica Bay, dissolved oxygen not less than 5.0 mg/L at any time, modeling calculations indicate less than full attainment for the cost effective treatment alternative (26th Ward WPCP at Contract 12 plus Jamaica WPCP at Level 2 BNR with modified flow split, partially oxic; "cost-effective treatment"). Tables 9-2 and 9-3 show projected levels of attainment and minimum dissolved oxygen conditions in Jamaica Bay under summer and annual conditions for the Baseline conditions, cost-effective treatment and cost-effective treatment with bay recontouring to 8 ft MLW. Projected attainment in Grassy Bay and Bay-wide are shown. Table 9-3 shows expected levels of attainment during the summer of 47.8% and 70.5% with the Class SB dissolved oxygen criterion in Grassy Bay for cost-effective treatment and cost-effective treatment with bay recontouring, respectively, less than full attainment. On a Bay-wide basis, Table 9-2 shows greater than 90% attainment Bay-wide, for both alternatives, a relatively high level of attainment considering the Jamaica Bay ecosystem in its entirety.

Table 9-9 shows expected conditions on an annual basis in both geographical areas. Annually, in Grassy Bay, the two alternatives are expected to achieve 85.0% to 90.9% attainment as shown. On a Bay-wide basis, cost-effective treatment and cost-effective treatment with bay recontouring are projected to attain 97.3% to 98.0% attainment of the Class SB dissolved oxygen criterion. This is considered a high level of attainment considering the Jamaica Bay ecosystem as a whole over the extended 10 to 11 month larval spawning season. The minimum dissolved oxygen expected annually in the Grassy Bay area of Jamaica Bay is 2.9 mg/L, sufficient for protection for juvenile fish survival according to EPA's marine dissolved oxygen criteria.

9.3.3. Effect of Bay Alterations on Attainability of Numerical Dissolved Oxygen Criteria

Although Jamaica Bay dissolved oxygen water quality standards can be expected to be achieved with a high level of confidence bay-wide and annually, periodic excursions below the Class SB criterion can be expected for the alternatives considered. If attainment of the numerical dissolved oxygen criterion alone, rather than together with larval transport considerations is to be considered in assessing attainment with the fish propagation and survival water use, the improvement alternatives considered in Tables 9-8 and 9-9 may be considered as non-attaining and a further regulatory evaluation is warranted.

It is noted from Tables 9-8 and 9-9 that projected attainment of the dissolved oxygen criterion improved and the minimum expected dissolved oxygen increased in all cases with the addition of bay recontouring to 8 ft MLW. As noted in Section 6, the recontouring of Grassy Bay was developed as an alternative to counter the negative environmental impacts associated with the human alterations which have occurred in Jamaica Bay during the 20th Century. As described in Section 1.1.2, extensive channelization was conducted in Jamaica Bay at various times in the last century for

navigation improvements and potential industrial and port development. In addition, extensive sand mining operations were conducted as part of the construction of Idlewild (John F. Kennedy) Airport and Floyd Bennett Field. As a result of these operations, the bay's geomorphology and bathymetry were significantly altered from 19th Century historic conditions.

The increase in bay depth, in particular, has an important effect on bay dissolved oxygen resources. The ability of atmospheric oxygen to be transferred to Jamaica Bay waters is strongly related, in an inverse manner, to bay depth. A doubling of bay depth decreases the rate of atmospheric oxygen transfer by a factor of almost three (O'Connor, 1958).

An analysis was undertaken to assess further the significance of the human alterations of Jamaica Bay on the dissolved oxygen response of selected control alternatives. Tables 9-10 and 9-11 present the results of this model sensitivity analysis for projected attainment with dissolved oxygen criteria for a number of conditions, for the summer period and annually, respectively. As observed from the tables, some of the responses shown are calculated for a condition where the depth in Grassy Bay was assumed to be approximately 4 ft MLW for model sensitivity purposes. This depth was chosen to be representative of maximum historic depths in Grassy Bay. Figure 1-2 shows the Grassy Bay area from a U.S. Coast and Geodetic Survey nautical chart of Jamaica Bay. The bathymetry was performed between 1877 and 1888. The soundings shown indicate maximum depths in Grassy Bay of approximately 4 ft MLW with many measurements of around 1 ft MLW. For purposes of sensitivity, a bay-wide average depth of 4 ft MLW was selected. It is probable that the historic depth was even less.

Table 9-10 shows the projected effect of modifying the Grassy Bay bathymetry from its current depth of 30 to 40 ft MLW to 4 ft MLW. The table indicates that, under Baseline conditions, summer attainment of the current Class SB dissolved oxygen criterion in Grassy Bay would increase significantly from 32.4% to 64.9%. On a bay-wide basis, the equivalent attainment values are 85.5% and 95.0%, respectively. The significant improvement resulting in the bay with more historic depth levels shows the effect of past alterations to the bay's bathymetry, although the bay at historic depth levels would not achieve the Class SB dissolved oxygen criterion in Grassy Bay under Baseline conditions.

Table 9-10 also shows the projected effect of Limit of Technology (LOT) nitrogen reduction at all four Jamaica Bay WPCPs. It is noted that baseline load reduction by LOT improves both summer and annual attainment of the Class SB dissolved oxygen criterion, but even the maximum level of nitrogen load reduction achievable by advanced treatment is not projected to attain the Class SB dissolved oxygen level at all times in Grassy Bay. Attainability numbers using the USEPA larval survival level of protection of the marine dissolved oxygen criteria are shown for comparison.

Table 9-11 presents projected evaluations similar to those shown on Table 9-5 but for annual conditions instead of summer. As shown, neither bay at historic depths nor LOT alone is projected to completely attain any of the dissolved oxygen criteria. As before, the importance of the historic bathymetric depth alterations to Grassy Bay on impacting the attainability of dissolved oxygen criteria is evident.

Table 9-12 presents projected summer and annual attainability results in Grassy Bay and Bay-wide with the Class SB and EPA marine DO criteria for cost-effective treatment with historic depths in Grassy Bay and for cost-effective treatment with bay recontouring to 8 ft MLW in Grassy Bay and

North Channel. As shown previously, the shallower historic depth results in greater attainability values for all criteria. The table also shows, that although cost-effective treatment at the proposed bay recontouring depth will not totally achieve the Class SB criterion, annual attainment values using EPA criteria are projected as 94% to 99%, respectively, for Grassy Bay and Bay-wide. Considering the Jamaica bay open waters ecosystem in its entirety, the annual attainment of 99% achieved by cost-effective treatment with bay recontouring for the EPA criteria indicates that the fish propagation and survival water use is attained although the Class SB criterion is not. In addition, as these results are restricted to near bottom waters which are the most severely impacted portions of the water column, criteria and aquatic life protection use attainment would be even greater considering Jamaica Bay at all depth levels.

9.3.4. Basis for a Separate Designated Use

The larval transport analysis in the ichthyoplankton model and the overall level of annual attainment with the EPA marine dissolved oxygen criteria in the open waters of Jamaica Bay as a whole indicate that the fish propagation and survival use is achieved by cost-effective treatment and bay recontouring. Yet, attainment of the numerical dissolved oxygen criterion of the Class SB water quality designation is not achieved at all times in all areas, particularly in Grassy Bay. However, Federal and State regulations provide for a procedure whereby non-attainment of numerical water quality criteria may be justified. It is considered that, under regulations, those areas of Grassy Bay and other affected portions of Jamaica Bay which may show periodic depressions below the Class SB dissolved oxygen criterion after plan implementation may be considered for a separate designated water use under the following bases:

(1) Historical human alterations of the bathymetry of Jamaica Bay significantly affect the attainability of current dissolved oxygen criteria;

(2) Current Class SB dissolved oxygen criteria in Jamaica Bay are not attainable by treatment plant-based nitrogen load reduction to Limit of Technology levels;

(3) Restoration to 4 ft MLW is not practicable nor desirable as it would promote the proliferation of the nuisance species, *Ulva*; LOT nitrogen is not cost-effective nor necessary as cost-effective treatment with recontouring (8 ft MLW) will achieve high levels of dissolved oxygen criteria attainment and achieve the fish propagation and survival water use;

(4) The human alteration of Jamaica Bay and the inability to attain the current Class SB dissolved oxygen criteria are justifications under Federal and State Use Attainability Analysis regulations to provide for a Separate Designated Use for Grassy Bay and other affected areas of Jamaica Bay which allows for periodic exceedence of dissolved oxygen criteria.

Given the technical, engineering and regulatory obstacles which exist for full attainment of the current dissolved oxygen standard, NYSDEC may wish to consider a Separate Use Designation and classification for Grassy Bay and other affected areas of Jamaica Bay. It is considered that such a regulatory procedure can be supported by an approvable Use Attainability Analysis. On a preliminary basis, it is considered that two of the six Federal and State UAA criteria can be demonstrated for areas of Jamaica Bay: Factor (3) – "human caused conditions... prevent attainment of the standard..." and Factor (5) – "physical conditions related to the natural features... preclude attainment of the standard..."

It is recommended that cost-effective treatment (Contract 12 at 26th Ward WPCP and Level 2 BNR with modified flow split, partially oxic) be approved as proposed with possible bay recontouring as appropriate. However, modeling calculations project periods when dissolved oxygen levels in Grassy Bay and the North Channel will fall below the Class SB criteria, with cost-effective treatment implementation; only near complete removal of the current loadings as a Water Quality Based Effluent Limit (WQBEL) would achieve attainment. Therefore, NYSDEC may wish to consider an application for cost-effective treatment in accordance with the Comprehensive Jamaica Bay Report recommendations in accordance with Section 702.17 of the Water Quality Regulations. If approved, as cost-effective treatment is executed, a long term post construction water quality monitoring program can be implemented in Jamaica Bay to assess resulting dissolved oxygen conditions and the need for a Separate Use Designation and a Use Attainability Analysis.

9.3.5. Potential Revisions to Water Quality Standards

In addition to, or as an alternative to, the Jamaica Bay Use Attainability Analysis for Separate Designated Use and WQBEL variance procedure as described above, it is recommended that consideration be given to possible modification of NYSDEC Water Quality Regulations. Specifically, it is recommended that consideration be given to the following:

(1) Modification of dissolved oxygen criteria to reflect recent research findings as documented in EPA's marine dissolved oxygen criteria for the Virginian Province. Consideration can be given to allowable excursions of dissolved oxygen below a desired endpoint for biologically acceptable periods of time in place of the current "never-less-than" values;

(2) Allowance for seasonally and spatially varying dissolved oxygen criteria. Connecticut has modified its State marine dissolved oxygen criteria to allow for water column (depth) specific objectives to accommodate the naturally occurring vertical stratification that occurs in locations such as Long Island Sound. EPA and the States surrounding Chesapeake Bay have modified dissolved oxygen criteria to reflect seasonal vertical stratification of the water column and the requirements of targeted biological species;

(3) The development of a cumulative frequency distribution-based approach to define criteria attainment. For example, EPA and the States in the Chesapeake Bay area have developed various approaches to define allowable periods of time when criteria exceedences are acceptable in space and/or time based upon policy decisions, biological effects-based data and/or technical uncertainty. The procedure allows for some acceptable level of criteria exceedence without materially affecting the desired water use.

10. Agency Coordination

10.1. General

During the development of the *Comprehensive Jamaica Bay Report*, several meetings were held with those regulatory agencies having jurisdiction or interest in the bay. These included the NYSDEC, US Army Corp of Engineers (USACE), National Park Service (NPS) and Port Authority of New York and New Jersey (PANYNJ). Additionally, the New York City Office of Management and Budget (OMB) convened a Value Engineering workshop to review and discuss all treatment and non-treatment alternatives evaluated as part of the Comprehensive Report.

This section provides a synopsis of the issues discussed at these meetings as well as the NYC OMB Value Engineering considerations.

10.2. NYSDEC

Beginning in July 2005, the Department initiated discussions with the NYSDEC concerning the protocol and methodology to be used in the Ecosystem Study of Jamaica Bay. This included the NYSDEC's review of the Quality Assurance Project Plan associated with this Study.

In the fall of 2005, two meetings were held with the NYSDEC. These included meetings between the Department and NYSDEC Commissioners, as well as with Department and NYSDEC technical staff. At these meetings, the Department informed NYSDEC officials, that the Grassy Bay borrow pit and dredging of the North Channel had a major impact on the attainment of dissolved oxygen water quality standards in the open waters of Jamaica Bay and limited the effectiveness of nitrogen reduction through conventional treatment alone. The cost-effective option of recontouring the bay, in combination with cost-effective nitrogen reductions at the treatment plants was discussed. Specifically, the idea of using the ongoing Norton Basin/Little Bay recontouring project as a pilot for a broader application to Grassy Bay was introduced.

In December 2005, an additional meeting was held with the NYSDEC jointly with other stakeholder agencies including the US Army Corps of Engineers (USACE). The idea of using Norton Basin/Little Bay as a pilot for broader application to a long term Grassy Bay solution was further explored. At this meeting, the Department also agreed to fund water quality and sediment transport modeling associated with the Norton Basin/ Little Bay Restoration Project being performed by the NYSDEC and USACE. The Department also agreed to expand the Ecosystem Study to include finfish sampling within Norton Basin and Little Bay.

Additionally, in January 2006, a meeting was held with USACE and NYSDEC personnel to discuss salt march restoration projects within Jamaica Bay. At this meeting, the Department agreed to share in the cost associated with restoration of Elders Point and Yellow Bar Hassock.

Finally, a meeting was held in August of 2006 with personnel from the NYSDEC's Division of Water and Division of Marine Science to discuss the interim findings of the *Comprehensive Jamaica Bay*

Report. All alternatives evaluated were discussed and it was noted that the recontouring of Grassy Bay and the North Channel, together with BNR upgrades at the Jamaica and 26th Ward WPCPs had emerged as the most cost-effective alternative to improve water quality in the bay. At this meeting, the interim findings of the Ecosystem Study were also discussed as well as the DO Volume Day alternative approach (discussed in Section 8.) to determine attainment with applicable DO water quality standards.

10.3. National Park Service (NPS)

The Department convened several meetings with the National Park Service to discuss various issues related to improving water quality within the open waters of Jamaica Bay. At a January 2006 meeting, the Department agreed to share information with the NPS once US Geological Survey to study historic nitrogen loading to Jamaica Bay. Additionally, at a second meeting with NPS personnel in March 2006, the Department discussed the limitations of wastewater treatment to achieve water quality standards due to the altered bathymetry of Grassy Bay and the North Channel.

At this meeting, NPS personnel informed the Department that they would not be in favor of the aeration of Grassy Bay as it was not NPS policy to support correcting man-made problems with man-made solutions. NPS personnel also noted that NPS would support recontouring of Grassy Bay and North Channel with clean sand only. Finally, NPS expressed an interest in the findings of the Ecosystem Study and its merits with regards to moving away from strictly using percent attainment of water quality standards as a judge of water quality.

10.4. Port Authority of New York and New Jersey (PANYNJ)

At a March 2006 meeting with PANYNJ, representatives suggested that the recontouring of Grassy Bay and the North Channel should be proposed on its own merits and not linked to the USACE Harbor Dredging Project. Port Authority personnel also noted that the Department could not mandate nor fund the recontouring of Grassy Bay and the North Channel, unilaterally.

10.5. NYC Office of Management and Budget Value Engineering Workshop

The New York City Office of Management and Budget convened a Value Engineering (VE) Program to review the alternatives evaluated as part of the *Comprehensive Jamaica Bay Report*. To this end, an orientation meeting was convened on July 11, 2006, with a value engineering workshop held from July 24 through July 28, 2006. In addition to OMB personnel, the make-up of the VE team and their area of expertise were as follows:

- Bayard Bosserman -Mechanical/Pumping
- Mike Domenica -Water Quality Planning
- John DeRugeris -Dredging
- Alexander Lazarev -Electrical
- Rod Reardon -BNR Process
- Greg Sherry -Tunneling

- Don Stafford -Water Quality Planner
- Ian Taylor -Cost Estimating
- David Yozzo -Marine Science Specialist
- Sean Zhang -Water Quality Modeling

Following an extensive presentation of treatment and non-treatment alternatives, JEM, the Ecosystem Study and discussion on the DO Volume Day approach, the VE team met to discuss possible improvements to the alternatives evaluated and a summary of recommendations was proposed.

Recommendations received from the VE consultants dealt with characterization of life cycle costs, definition of plan components, plan acceptance, informational gaps and approach justification.

10.5.1. Characterize Life Cycle Costs

Recommendations included presenting an estimated range for the various plan components and cost per unit of increase in DO Volume Days.

10.5.2. Define Plan Components

Recommendations included documenting the impacts of JFK International Airport of Jamaica Bay, considering piloting of various types of aerators within Grassy Bay, use of dredge material from the New York Harbor Deepening Project with final capping using clean fill and the use of various decision making software programs to assist in the selection of the final plan.

As discussed within the *Comprehensive Jamaica Bay Report*, the National Park Service will not approve of the recontouring of Grassy Bay and the North Channel with anything but clean sand. Additionally and as previously discussed, the NPS will not approve of the installation of aerators within Grassy Bay. Therefore, these alternatives have been dismissed from further evaluation.

10.5.3. Gain Plan Acceptance

The VE design team noted that the use of volume DO days might be a more accurate method to represent water quality. They also recommended that the *Comprehensive Jamaica Bay Report* convey the idea that nitrogen is not the only impediment to improving water quality in Jamaica Bay. It was also recommended that the report recommend an adaptive management approach.

10.5.4. Resolve Informational Gaps

The VE consultants suggested that additional information be obtained to fill existing data gaps. These included; the implementation of a groundwater monitoring program around Jamaica Bay to determine if groundwater is impacting water quality within the bay; better defining the DO vertical profile in Grassy Bay and North Channel; increase the spatial resolution of JEM by using a finer grid; perform a formal risk assessment of all evaluated alternatives; revisit tidal marsh dry/wet element treatment and sediment transport; and present JEM output as ranges rather than specific numbers.

10.5.5. Justify Approach

The VE consultants recommended that an adaptive management approach be implemented.

11. Findings and Recommendations

On the basis of the efforts described in this report, the following general and key findings are presented and recommendations are made to improve water quality in Jamaica Bay.

11.1. Summary of General Findings

- The Jamaica Bay watershed has been extensively developed and urbanized with a population of approximately two million persons residing within the drainage area. The bay's geomorphology and bathymetry have been extensively altered, especially during the development period of the last century. Grassy Bay has been deepened from approximately 2 feet below mean low water (MLW) to 40 feet below MLW during that time.

- Jamaica Bay is eutrophic with high levels of algal productivity particularly in the Grassy Bay and North Channel areas. Water quality measurements show that the phytoplankton activity is a result of the over enrichment of the bay by the nutrient, nitrogen. Bay dissolved oxygen concentrations are subsequently seasonally depressed. The most severe oxygen depression is confined to the lower layers of the Grassy Bay borrow pit and the deeper portions of the dredged North Channel during the summer period.

- On the basis of ichthyoplankton and benthic infauna sampling to date, Jamaica Bay's ecosystem appears to be productive and resilient, yet seasonally stressed in specific locations. The fishery is productive with larval diversity and density consistent with another productive area near Long Island. Ichthyoplankton taxa numbers appear unrelated to water quality, although taxa shifts appear to be related to seasonal dissolved oxygen depression. Infaunal abundance and species numbers are associated with bathymetry, water quality and bottom sediment composition. The characteristics of shallower and well mixed regions of the bay were found to be markedly different from those in the deep borrow pit and channel areas.

- Modeling and water quality sampling investigations demonstrate that the seasonal water quality depression in Jamaica Bay is related to the discharge of treated wastewater to the bay which is exacerbated by the historical human alterations of the bay's bathymetry, particularly in Grassy Bay and the North Channel. The four Water Pollution Control Plants (WPCPs) which discharge to the bay contribute approximately 90 percent of the total nitrogen input. Of these plants, the most important in terms of water quality impact are the 26th Ward and Jamaica WPCPs.

- Various engineering alternatives demonstrate differing levels of effectiveness in terms of reducing eutrophication impacts and improving oxygen resources in affected areas, particularly Grassy Bay and the North Channel. Advanced wastewater treatment, and non-treatment alternatives such as outfall load relocation, coarse bubble instream diffuser aeration and bathymetric restoration of Grassy Bay and the North Channel via recontouring were considered. Combinations of these alternatives were also evaluated for cost-effectiveness. The alternatives considered varied in capital construction cost from $65 million to $5.5 billion in 2006 dollars.

11.2. Summary of Alternatives; Conclusions

- Advanced wastewater treatment at the 26th Ward and Jamaica WPCPs, is effective in reducing the total nitrogen load discharged to the open waters of the bay and improves the seasonal dissolved oxygen levels in Jamaica Bay. However, even conventional limit of technology nitrogen reduction at all four WPCPs discharging to Jamaica Bay will not attain the dissolved oxygen water quality standard of 5.0 mg/L at all times and in all locations under current bay altered bathymetry. Similar improvements to dissolved oxygen can be achieved at less stringent levels of nitrogen reduction due to the existing bathymetry of the bay.

- Relocation of the four Jamaica Bay WPCP outfalls to the Atlantic Ocean or Rockaway Inlet would also improve eutrophic and water quality conditions within the open waters of Jamaica Bay to a degree greater than from Limit of Technology nitrogen reductions. As with advanced treatment, most improvement would be realized by relocation of the 26th Ward and Jamaica WPCP outfalls. However, load relocation would not attain the current dissolved oxygen standard in the lower water column of Grassy Bay during the summer due primarily to historical bathymetric alterations. Additionally, the outfall relocation alternatives will be difficult to implement and permit due, in part, to strong public opposition to wastewater disposal to or near the ocean. Further, the removal of the main source of non-saline water to the bay may have negative impacts to the existing ecosystem that are difficult to predict and quantify at the present time.

- A coarse bubble seasonal in-stream diffuser aeration system is cost-effective in attaining the dissolved oxygen standard in Grassy Bay. However, an extensive diffuser field would need to be constructed within Grassy Bay. The National Park Service, which has jurisdiction over the bay as well as underwater land under the bay, has informed the Department on several occasions that man-made solutions of this type, to correct man-made problems would not be acceptable.

- Modeling and water quality sampling demonstrates that the dissolved oxygen levels of Jamaica Bay in Grassy Bay and the North Channel are significantly impacted by the historical alterations of the bay's bathymetry for sand mining. It is projected that restoration of the bathymetry in these areas would achieve improvements in bottom dissolved oxygen similar to that attained by advanced wastewater treatment. The projected improvements in bottom dissolved oxygen concentration attained by bathymetric restoration could be further enhanced in performed in conjunction with treatment.

11.3. Comprehensive Report Recommendations

- In view of the complexities of Jamaica Bay's ecosystem and the historical human-caused alterations of the bay's watershed, receiving waters and bathymetry, the Department recommends a phased approach for adaptive management of needed environmental improvements. The approach would consist of cost-effective treatment reductions for nitrogen, and continued ecosystem evaluation and post-construction monitoring to assess the effectiveness of controls. The Department would also work closely with other stakeholder agencies to monitor progress and seek interagency cooperation to improve the bay's environment and ecosystem as appropriate.

- Of the various treatment and non-treatment alternatives that have been evaluated, the most readily implementable option from a Departmental control and regulatory approval standpoint is nitrogen reduction by advanced wastewater treatment. Modeling and engineering analysis show that nitrogen reduction at the 26th Ward and Jamaica WPCPs are most water quality effective of the four Jamaica Bay WPCPs. It is recommended that the Department complete implementation of Contract 12 nitrogen load reduction at the 26th Ward WPCP as currently planned, and obtain approval for design and construction of Level 2 with modified flow split, partially oxic nitrification at the Jamaica WPCP.

- It is projected that this level of Nitrogen load reduction will achieve eighty five percent annual attainment (days) of the current dissolved oxygen standard in the most severely impacted lower water column of Grassy Bay area on a time basis. On a more representative and complete ecosystem-based volume and time weighted basis, dissolved oxygen standards attainment of 83 percent (volume days) is projected for Grassy Bay, even during the more critical summer period. This level of attainment could increase to ninety percent with the restoration of Grassy Bay and the North Channel to a depth of 8 feet below mean low water.

- The Department proposes to extend its current water quality and ecosystem monitoring program, with NYSDEC oversight, for an additional two years to further understand existing ecosystem functions and establish baseline statistics. The Department will provide a detailed report on this program to NYSDEC upon its completion. The Department would also cooperate with NYSDEC to develop and implement a post-construction water quality and ecosystem monitoring program which would be implemented after proposed 26th Ward and Jamaica WPCP upgrades are constructed and placed into operation.

- The Department will also be completing, under the Citywide Long Term Control Plan (CSO) Project, development of the Jamaica Bay Watershed/Sewershed Protection Plan, which is now in progress. This plan will evaluate and recommend additional steps that the Department and possibly other City agencies can consider to reduce runoff and inflows into the sewer systems to further reduce loadings to Jamaica Bay and its tributary waterways.

- The engineering and scientific work conducted during this project demonstrates the significant adverse impacts produced by the human alterations of Jamaica Bay's geomorphology, bathymetry and hydrodynamics. The deepening of the Grassy Bay area in particular, as well as the North Channel, reduces dissolved oxygen resources and otherwise adversely impacts demersal and benthic aquatic life. It is therefore recommended that NYSDEC continue and extend its leadership role in Jamaica Bay restoration projects to seek interagency cooperation for the bathymetric restoration of Grassy Bay and the North Channel.

- Given the technical, engineering and regulatory obstacles which exist for full attainment of the current dissolved oxygen standard, DEP would like to suggest that it may be beneficial for both the City and DEC to jointly assemble another third party review of this proposed plan be conducted. In the meantime, DEP will share the information from the weeklong Value Engineering workshop that was held in July 2006, including all recommendations that were made.

11.4. Implementation Schedule

The Department's proposed implementation schedule is shown on Figure 11-1. As noted therein, a key element of the recommended plan is currently being implemented by the Department. This element is the Contract 12 upgrades at the 26th Ward WPCP. The proposed implementation schedule calls for initiation of design activities associated with Level 2 upgrades at the Jamaica WPCP by October 2008, initiation of construction of Level 2 BNR upgrades at the Jamaica WPCP by November 2012 and completion of construction activities by November 2016.

Another key element of the Comprehensive Report Recommendations, the post-construction ecosystem monitoring study, will be initiated June 2016 with a report submitted to the NYSDEC by July 2019

Also noted on the schedule is initiation of a program, to be considered by the NYSDEC, to further investigate, develop relationships and form alliances with potential stakeholders and move forward with the restoration of Grassy Bay and North Channel.