4. Treatment Alternatives for the Jamaica Bay Water Pollution Control Plants

This section of the Comprehensive Jamaica Bay Report details the evaluation performed on the impact of implementing advanced wastewater treatment processes for nitrogen removal at the four Jamaica Bay WPCPs on baywide water quality. The four WPCPs and their design flow capacities are:

- 26th Ward – 85 mgd
- Coney Island – 110 mgd
- Jamaica – 100 mgd
- Rockaway – 45 mgd

Figure 1-4 shows the locations of these WPCPs in relation to each other and Jamaica Bay.

It is believed that nitrogen from the WPCPs is a contributing factor to the low dissolved oxygen (DO) concentration in specific portions of the bay. The goal of the treatment alternative evaluations is to develop various BNR upgrade options for the WPCPs that will enhance nitrogen removal.

The Department approved design guidelines for BNR facilities were utilized in the development of conceptual designs for each WPCP upgrade. Once the conceptual designs were complete, the *BioWin* process model, used by the Department for evaluation of Biological Nitrogen Removal (BNR) processes, was used to project the effluent total nitrogen concentration from each of the Jamaica Bay WPCPs. Parallel to the modeling effort, a conceptual cost estimate was developed in order to develop the cost attainment curves further discussed in Section 8.0 of this report.

4.1. Description of Levels of Treatment

This section will discuss and describe the various pathways to achieve greater means of nitrogen removal at the Jamaica Bay WPCPs. The Citywide Advanced Wastewater Treatment (AWT) program, in conjunction with ongoing full-scale operational experience and the Department's Applied Research Program, developed a variety of advanced wastewater treatment upgrades that provide different levels of projected effluent total nitrogen. The levels of treatment, and their projected effluent total nitrogen concentrations are:

- Low Level (Level 1): 12 mg/L – 16 mg/L
- Mid Level (Level 2): 9 mg/L – 13 mg/L
- High Level (Level 3): 5 mg/L – 9mg/L
- Limit of Technology: 4.1 mg/L – 4.4 mg/L

Each of the levels of treatment described herein relies upon nitrification and denitrification processes. Nitrification is the process by which ammonia and organic nitrogen is oxidized (by bacteria), to nitrites (NO_2) and further oxidation of nitrites to produce nitrates (NO_3). The process requires oxygen

to be provided in the process reactors, as well as a source of alkalinity, either that existing in the wastewater stream, or by supplemental carbon addition. Denitrification is the process by which nitrates or nitrites are reduced by bacteria resulting in the release of nitrogen gas to the atmosphere. This process occurs most readily under anoxic conditions and requires a source of readily biodegradable carbon, such as is found in the influent wastewater stream, or can be provided by the addition of a carbon source such as methanol, ethanol or acetic acid. These processes are the basis for the various treatment upgrades conceptually designed for this analysis.

Conceptual designs for each treatment options were developed for each of the four Jamaica Bay WPCPs by each plant's engineer of record.

4.1.1. Low Level (Level 1) BNR Treatment

Level 1 BNR treatment refers to a treatment upgrade level that will provide some degree of nitrogen removal at a minimal cost. This upgrade level is similar in nature to those performed at the Upper East River WPCPs in the mid-1990's to comply with the *Phase II* requirements of the Long Island Sound Study (LISS). Specifically, the Level 1 BNR upgrades include:

- Construction of Baffle Walls in the Aeration Tanks
- Installation of Mixers in the Anoxic Zones
- Construction of Froth Control Hoods

The process schematic and upgrades associated with this level of treatment are shown on Figure 4-1. Baffle walls are installed in the Level 1 BNR upgrade to create distinct zones for nitrification and denitrification to occur. For the Level 1 BNR upgrade, the baffles would be installed one third the distance from the head of each pass, in order to create a boundary between anoxic and oxic zones (Figure 4-2).

Mixers would be installed in the anoxic portion of each pass. The purpose of these mixers is to keep solids in suspension within the mixed liquor, not allowing settling to occur in the anoxic zones.

Froth control hoods would be placed across the width of Pass A and Pass B of the aeration tanks in two locations. These hoods will spray a chlorine solution in order to prevent and suppress froth outbreaks. These hoods are required, as excess froth accumulation can have a detrimental impact on the BNR process, and can create aesthetic issues.

4.1.2. Mid Level (Level 2) BNR Treatment

Level 2 BNR treatment is consistent with the upgrades planned and discussed in the *Modified Phase I BNR Facility Plan for the Upper East River and 26th Ward WPCPs* (October, 2005) prepared by the Department as a submittal under the Nitrogen Consent Judgment (CJ). This provided a familiar and recent upgrade design as the backbone for this potential level of treatment. Specifically, the Level 2 BNR upgrades include:

- Construction of Baffle Walls

- Installation of Mixers
- Limited Flow Splitting
- Upgrade to Process Air Capacity Based on Existing Footprint, Credit for Denitrification, Assimilation, Primary Settling Tank Attenuation and Refractory TN
- Return Activated Swage (RAS) System Upgrades Based on Existing Footprint
- Separate Centrate Treatment in an Existing Aeration Tank with Alkalinity Addition, (where feasible), with Nitrified Centrate to Pass A
- Multiple Lines of Defense for Froth Control (Hoods, RAS Chlorination, Surface Wasting)
- Switch Zones/Pre-Anoxic Zones
- Limited Instrumentation and Automation
- Pass D Wet Weather Optimization in Aeration Tanks

The process schematic and upgrades associated with this level of treatment are shown on Figure 4-3. Baffle walls in the aeration tanks are required to effectively separate the different process zones, which require different operating conditions for optimal performance (Figure 4-4). Within each switch zone and pre-anoxic zone, mixers should be installed to keep the mixed liquor solids in suspension and prevent the formation of stagnant pockets. At the same time, mixed liquor in the switch zones must not be re-aerated by surface turbulence.

Flow distribution and control is an important process parameter that has a direct impact on the nitrogen removal performance of the BNR process. Level 2 flow distribution upgrades are based on the existing plant-specific flow splitting limitations at a reduced level of monitoring and control. Due to the significant advantage in wet weather operations, providing automation, such as local motorized operators to increase the flow to Pass D, is recommended.

The existing WPCP aeration systems were designed for Biochemical Oxygen Demand (BOD) removal only, and have the same number of diffusers throughout the aeration tank. The increased air required for nitrification compounded with the reduced oxic volume makes it necessary to reevaluate and potentially redesign the aeration system. Specifically, sufficient air must be provided in the oxic zones for carbon removal and nitrification without allowing dissolved oxygen bleed-through into the anoxic zones.

Under the Level 2 BNR upgrade, the recommended aeration system expansion will be tailored to fit within available site constraints. The design intent is to provide maximum capability to remove nitrogen under current loading conditions with minimal infrastructure modifications. It is possible that existing blowers and facilities may have sufficient capacity to meet the aeration requirement associated with the Level 2 BNR improvements. The upgrade capacity at each WPCP was identified given the existing infrastructure limitations. Pollutant loads that are that are not oxidized, such as taking credit for denitrification, unbiodegradeable TKN and assimilated nitrogen were also evaluated. The WPCPs were also evaluated to consider installation of a new tapered diffuser system along with the repair of existing blowers, motors, headers and droplegs. The installation of more efficient fine bubble diffusers in plants that presently have tube diffusers was also considered.

With proposed Level 2 upgrades, solids loading to the final clarifiers are anticipated to be slightly higher than for Level 1 upgrades. Therefore, there is a slightly higher recommended level of operational flexibility for the plant return activated sludge (RAS) system. This will result in higher RAS pump capacity within the existing plant infrastructure. Based on earlier work performed by the

Department, the system should be able to operate at RAS flows of about 50 to 60% of the design flow.

The Level 2 BNR upgrades allow for increased sludge age to achieve nitrification in the mainstream treatment system. Biologically induced foaming is relatively common at higher sludge age BNR. Frothing organisms tend to be hydrophobic in nature, and when present in sufficient numbers, they attach to air bubbles and rise to the surface in aeration tanks as froth. Once at the surface, the froth tends to collect, causing operational problems. In order to control and mitigate froth problems, several control measures are recommended:

- Froth Control Hoods – Similar to Level 1 upgrade
- RAS Chlorination – Chlorine is added to the RAS line to effectively kill nuisance bacteria, while operational changes are made to select for more desirable organisms that possess better settling characteristics and have less frothing potential
- Surface Wasting – Provide for the continuous ability to waste froth and mixed liquor from the surface of Pass A of each aeration tank

The Level 2 BNR upgrade also includes the flexibility to distribute centrate and operate with separate centrate nitrification in an existing aeration tank (where feasible) and feed the nitrified centrate to Pass A of the mainstream BNR aeration tanks. In addition, supplemental alkalinity will be supplied to the separate centrate treatment process in order to maintain an optimal pH in the system.

An analysis was performed as a subset of Level 2 BNR treatment for Jamaica WPCP. The assumption includes the construction of the Level 2 BNR upgrades at the Jamaica WPCP, but changes and modifications to the operation of the facility.

Normally, in reference to Level 2 BNR, the primary effluent (PE) flows are split 0-33-33-33 among passes A through D of the aeration tanks. However, based on discussions with BioWin modeling and process experts, an operating scenario was developed where no flow would be passed through the D Pass with the intention that this would increase the amount of nitrification occurring and thus, spur ammonia removal. This modified flow splitting was then modeled in a mode where the aeration tanks were operated either 'fully oxic' or 'partially oxic'. The 'fully oxic' scenario would maximize the amount of ammonia removed from the process. However, it would not provide a pathway for denitrification, so an overall minimal decrease in total nitrogen would be expected. The 'partially oxic' scenario would involve the use of switch zones in the anoxic mode. This would enhance the denitrification process and provide a balance for the increased production of nitrates from the nitrification process.

4.1.3. High Level (Level 3) BNR Treatment

The Level 3 BNR upgrades are a more conservative approach to BNR and provide some additional facilities above Level 2 upgrades that will further reduce nitrogen discharges. The Level 3 BNR upgrades include:

- Construction of Baffle Walls
- Installation of Mixers

- Flow Control to Each Aeration Tank and Aeration Tank Pass
- Upgrade Process Air Blowers for 100% Nitrification of maximum day influent TN load (N+1+1), without credit for Denitrification, Assimilation, Primary Settling Tank Attenuation and Refractory TN
- Improvements to Final Settling Tanks
- RAS System for 100% Design Flow (N+1+1)
- Separate Centrate Treatment (Where Feasible)/Raw Centrate to Pass A
- Froth Control Systems (Hoods, Surface Wasting, RAS Chlorination)
- Switch Zones/Pre-Anoxic Zones
- Full Instrumentation and Semi-Automated Controls
- Alkalinity and Carbon Addition Systems

The process schematic and upgrades associated with this level of treatment are shown on Figure 4-5. Baffles would serve the purpose identical to the previous two levels of treatment (Figure 4-6). Similar to previous levels of treatment, mixers are required to keep solids in suspension and prevent the formation of stagnant pockets. Flow splitting is also an important process parameter in Level 3 BNR treatment and can have an additional impact on the nitrogen removal performance of the BNR process. Flow splitting to each aeration tank and each aeration tank pass is recommended under Level 3 treatment. Increased monitoring of the flow split is important in order to maximize nitrification, maximize the inherent carbon used for denitrification and maintain control of solids inventory.

In Level 3 BNR treatment, sufficient air would be supplied in order to provide for both carbon removal and complete nitrification under peak carbon and nitrogen load conditions. In addition, in order to optimize the removal of nitrogen, the control of dissolved oxygen levels between oxic and anoxic zones is crucial as well as the distribution of aeration tank influent between passes.

In order to promote the growth of nitrifiers, a higher process mean cell residence time (MCRT) is required compared to Level 1 and Level 2 BNR upgrades. This will result in higher mixed liquor concentrations in the aeration tanks, which will result in higher solids loading to the final settling tanks. Therefore, the design features for the final settling tanks under the Level 3 BNR upgrades include:

- Baffling of the mixed liquor flow to distribute it across the settling tank
- Considering the use of dedicated bioflocculation zones to enhance floc formation
- Access to and mechanism to remove entrapped foam/scum
- Providing a mechanism to collect and remove RAS without interfering with the settling tank flow pattern or resulting in the resuspension of settled solids

The Level 3 BNR upgrades recommend that the RAS pumping of 100% of the design dry weather flow be provided for optimal operational flexibility for future BNR operations. This flexibility provides the ability to optimize secondary settling tank operation under varying operating conditions.

The Level 3 BNR strategy is for the use and implementation of independent separate centrate treatment facilities at the two Jamaica Bay WPCPs that operate sludge dewatering facilities, the 26th Ward and Jamaica WPCPs. The Coney Island and Rockaway WPCPs will continue to send digested sludge to the 26th Ward WPCP for dewatering.

Froth control systems for Level 3 BNR are identical to the Level 2 BNR upgrades, providing multiple lines of defense.

The general Level 3 BNR process control strategy includes automation of critical process control parameters. In order to optimize resources and process performance, while minimizing required operator attention and equipment adjustment, flow paced controls are recommended. Specifically, the critical on-line analyzers would include:

- Dissolved oxygen probes
- Alkalinity meters
- pH probes
- Ammonia probes
- Nitrate probes

Since the alkalinity of NYC wastewater is relatively low and significant alkalinity consumption occurs in nitrification, supplemental alkalinity may be required to maintain optimal nitrification conditions. The optimal location for alkalinity addition is at the head of Pass A or to the RAS after the waste line.

NYC wastewater also has relatively low biodegradable carbon content. To optimize the Level 3 BNR upgrades and denitrification performance, supplemental carbon addition will be required. Therefore, new chemical feed storage and distribution systems would be necessary to optimize or stabilize Level 3 BNR operations via the addition of alkalinity or carbon.

4.1.4. Limit of Technology (LOT) BNR

Beyond the three levels of treatment described above, a limit of technology (LOT) option was also investigated. The goal of these LOT technologies is to deliver an effluent total nitrogen concentration of approximately 4.4 mg/L, less than convention BNR processes can achieve at the existing WPCPs. Two processes were evaluated in this effort:

- Denitrification filters
- 2 Stage Biological Aerated Filter (BAFs)

The denitrification filter option combines elements of Level 3 BNR treatment with this add-on process. The goal of this LOT process is to provide full nitrification in the main plant aeration tanks and allow for add-on denitrification filters to perform the denitrification process. The use of supplemental carbon is also required for this process. Since this process is an add-on, it will be designed for those Jamaica Bay WPCPs with available space. For this study, the 26th Ward WPCP and the Rockaway WPCP LOT BNR alternative was based upon the addition of a denitrification filter at each WPCP. The process schematic and upgrades associated with this level of treatment are shown on Figure 4-7.

In addition to add-on denitrification filters, a two-stage Biological Aerated Filter (BAF) option was considered for those WPCPs where additional land is not available, such as the Jamaica and Coney

Island WPCPs. The BAFs consist of a first stage, where nitrification/denitrification will occur. The second stage is one where denitrification solely will occur. The use of supplemental carbon and alkalinity will be required for this process. The process schematic and upgrades associated with this level of treatment are shown of Figure 4-8.

The installation of BAF technology will require that existing secondary treatment infrastructure at the Jamaica and 26th Ward WPCPs be completely demolished and the BAF process be constructed on that site. The cost estimates prepared for the LOT BNR alternative includes process equipment to allow for enhanced primary settling during the period when the WPCPs secondary processes are not in service.

4.2. BioWin Model and Modeling Results

4.2.1. Background

As part of WPCP evaluations, the Advanced Wastewater Treatment Program Assistance Team performed *BioWin* modeling in order to determine the projected effluent total nitrogen concentration for each level of treatment. The projected effluent quality was then used to project water quality improvements using JEM. The results of that analysis are discussed in section 7 of this report.

In addition, *BioWin* modeling runs were used to identify various levels of nitrogen upgrades at the Jamaica WPCP. This section describes the difference in the Jamaica WPCP nitrification scenarios and the Level 2 and Level 3 BNR upgrades.

The Jamaica nitrification scenario involved upgrading the Jamaica plant to provide near full nitrification on a year round basis without major infrastructure changes. The modeling work and its purpose were to minimize the effluent ammonia concentrations, with minimal denitrification. This modeling was performed to address the need to improve both dissolved oxygen and ammonia toxicity attainment. A modification was made in the modeling work to the flow splits in each aeration tank in order to limit the flow to the D Pass in each tank. The modeled flow splits were 20-40-40-0. The flow split allows sufficient time for nitrification to occur, even during winter operating temperatures.

The Level 2 BNR upgrades involves the installation of facilities to provide nitrification/denitrification in the main aeration tanks and the construction of a separate sidestream centrate nitrification system to treat the estimated one million gallons per day of centrate produced by the Jamaica WPCP dewatering facility based upon projected 2045 influent wastewater flows. The modeling effort performed under this scenario assumed the existing flow split of 0-33-33-33 was maintained post-upgrade. This is not an optimal flow split for achieving nitrification in the winter months, which is evident in poor nitrification performance at the lowest modeled temperature.

The Level 3 BNR upgrade involves the construction of a new full size aeration tank at the Jamaica WPCP. The detention times and operating mixed liquor concentrations required to operate at Level 3 BNR require additional aeration tank volume for nitrification. The modeled flow splits for this level of BNR treatment were 10-40-30-20. This flow split was determined in the coarse of the Department Applied Research Program to be optimal for this level of nitrification/denitrification. In this scenario, however, the centrate is conveyed from the dewatering building to Pass A of each of five aeration

tanks. The centrate then is treated along with the main plant flow. However, when averaged out, the winter modeling results also show limitations in terms of the nitrification, as evidenced by higher concentrations of ammonia.

4.2.2. BioWin Model Setup

The assumptions used in the *BioWin* runs for the four WPCPs are listed in Appendix B and are briefly described in this section.

Raw Plant Influent:

The influent BOD, Total Suspended Solids (TSS), and Total Kjeldahl Nitrogen (TKN) values used in the *BioWin* runs were taken from the Department fiscal year 2001-2003 data and altered by subtracting 30% BOD, 30% TSS, and 10% TKN to account for Primary Settling Tank removal. The 2045 projected influent flows, gravity thickener overflow, and storm flows were used to calculate the influent flow values.

Centrate Influent:
Centrate was only modeled for the 26th Ward and Jamaica WPCPs. The influent BOD, TSS, and TKN values used in the *BioWin* runs were taken from the April 2003 AWT Revised Program Guidance. The 2045 centrate flow projections were used to calculate the influent flow values.

Temperature:
Each alternative was run at four different temperatures, representing summer, spring, fall, and winter, with the temperatures taken from NCFP.

Kinetic Autotrophic Parameters and Temperature Dependencies:
Default parameters were used except in the case of the Mu Max and Ba, which were set to 0.8 and 0.17, respectively, in order to reflect recent WERF research.

Stoichiometric Autotrophic Parameters:
Default parameters were used.

Kinetic Heterotrophic Parameters and Temperature Dependencies:
Default parameters were used.

Stoichiometric Heterotrophic Parameters:
Default parameters were used.

Switching Functions:
Default parameters were used except in the case of the SND DO Limit which was set to 0.2.

Wastewater and Centrate Characteristic Fractions:
Default parameters for the primary effluent were used for the Coney Island, Jamaica, and Rockaway WPCPs. Centrate parameters for the Jamaica WPCPs were taken from the Centrate Characteristic Fractions used for the Bowery Bay WPCP in the UER *BioWin* analysis because both Jamaica and Bowery Bay do not receive visitor sludge. The 26th Ward primary effluent and centrate parameters were taken from an average of the Centrate Characteristic Fractions used in the Upper East River *BioWin* runs.

Certain changes were made to the infrastructure of each plant according to the level of treatment being modeled. For each alternative, the *BioWin* runs were optimized to lower final effluent total nitrogen (TN) concentrations.

For the Limit of Technology (LOT) alternative, based on the physical characteristics of each plant, it was decided that the current activated sludge basins followed by denitrification filters would be applied at 26th Ward and Rockaway. Limitations on space at the Coney Island and Jamaica WPCPs resulted in the option to demolish the aeration tanks and secondary clarifiers, and replace them with two-stage BAFs. In order to estimate final effluent TN concentrations for LOT, assumptions were made regarding the effects of the denitrification filters and the BAFs regarding the effluent quality. Ammonia (NH_3-N) levels were assumed to range from 0.5 to 1.0 mg/L for 26th Ward and Rockaway WPCPs and equal to 0.5 mg/L for Coney Island and Jamaica. Nitrate (NO_3-N) levels were assumed to equal 2.0 mg/L for all four plants. TSS levels were assumed to equal 3.0 mg/L for 26th Ward and Rockaway WPCPs, and to equal 10.0 mg/L for the Coney Island and Jamaica WPCPs.

These effluent total nitrogen concentrations were then utilized in JEM in order to evaluate the improvement in water quality. The results of the water quality modeling are further discussed in Section 7.0.

4.3. Alternative Cost Estimates

Construction cost estimates were prepared based on the information contained within the conceptual design reports for each of the Jamaica WPCPs for each level of treatment. The methodology used in the estimating the conceptual project cost was developed as part of a Department effort to standardize the cost estimating process. Table 4-1 shows the estimated non-factored and factored construction cost as well as Total Conceptual Project Cost for each WPCP upgrade alternative.

As noted therein, total project costs includes probable construction cost which includes a ten percent construction reserve to cover change orders during construction, soft costs other costs. Soft costs include fees associated with environmental assessments and permitting, engineering/architecture, construction management and other professional fees, cost associated with performing fixed asset surveys and staff training and development. Other costs include land acquisition and an allowance for the Setaside for the Arts program.

As the cost estimates were originally prepared in March of 2004, they were escalated to March 2006 dollars using an escalation rate of 8.5 percent per year, in accordance with Department cost estimating procedures. Additionally, contractor overhead and profit, originally calculated at thirteen percent, was increased to twenty-one percent in the final estimation of the Total Conceptual Project Cost.

5. Outfall Relocation

5.1. General

Concept level designs and associated cost estimates were developed for conveying treated effluent from the Jamaica, 26th Ward, Coney Island and Rockaway WPCPs to either the Atlantic Ocean or Rockaway Inlet via outfall tunnels. Currently, treated effluent from the 26th Ward, Jamaica and Rockaway WPCPs discharge into Jamaica Bay either directly or indirectly through tributaries to the bay. The Coney Island WPCP discharges directly to Rockaway Inlet.

The first stage of the study identified twelve concepts for connecting various combinations of WPCPs to an outfall discharging to either the Atlantic Ocean or the Rockaway Inlet. These alternative concepts are summarized on Table 5-1 for Ocean Outfalls and Table 5-2 for Rockaway Inlet Outfalls designed to convey WPCP effluent via pumping, and Table 5-3 for gravity flow alternatives. Figures 5-1 through 5-12 show a conceptual plan and profile of the alternatives.

For evaluated alternatives, where outfall relocation to Rockaway Inlet or the Atlantic Ocean is based on conveying treated effluent volumes at two times design dry weather flow, (Rockaway and Coney Island WPCPs) or two times design dry weather flow plus 50 million gallons (26th Ward and Jamaica WPCPs), effluent pumping would be necessary to convey peak flows at high tidal stages. For those alternatives where outfall relocation to either the Atlantic Ocean or Rockaway Inlet is based on gravity flow, a peaking factor one and one-half times design dry weather flow was used and effluent pumping was not included.

Under the gravity flow alternatives, WPCP flows in excess of one and one half times design dry weather flows would be discharged, via the existing WPCP outfalls. Based upon landside modeling, it has been projected that approximately 99 percent of WPCP influent flow would be conveyed to the ocean at 1988 tidal and meteorological conditions for the alternative Jamaica, 26th Ward and Rockaway WPCPs to the ocean via gravity. To ascertain the effects of increased tide on this alternative, two feet was added to the 1988 tidal condition and the results showed that approximately 96.5 percent of WPCP influent flow would be conveyed to the ocean.

Additionally, for the alternative of Jamaica, and 26th Ward WPCPs to the ocean via gravity, it has been projected that approximately 98.9 percent of WPCP influent flow would be conveyed to the ocean at 1988 tidal and meteorological conditions. To ascertain the effects of increased tide on this alternative, two feet was added to the 1988 tidal conditions and the results showed that approximately 97 percent of the WPCP influent flow would be conveyed to the ocean.

Finally, for the alternative of Jamaica, and 26th Ward WPCPs to Rockaway Inlet via gravity, it has been projected that approximately 98.4 percent of WPCP influent flow would be conveyed to the Rockaway Inlet at 1988 tidal and meteorological conditions. To ascertain the effects of increased tide on this alternative, two feet was added to the 1988 tidal conditions and the results showed that approximately 97 percent of the WPCP influent flow would be conveyed to the Inlet. Water quality modeling results for the gravity flow alternatives account for flows greater than 150 percent of design dry weather flow that are shown to discharge via the existing WPCP outfalls.

The alternatives selected for evaluation are based on the following general concepts:

- Conveying treated effluent via tunnels to the Rockaway Inlet
- Conveying treated effluent via tunnels to the Atlantic Ocean
- Conveying Jamaica WPCP treated effluent only
- Conveying Jamaica and 26th Ward WPCPs treated effluent
- Conveying Jamaica and Rockaway WPCPs treated effluent
- Conveying Jamaica, 26th Ward and Rockaway WPCPs treated effluent
- Conveying Jamaica, 26th Ward and Coney Island WPCPs treated effluent
- Conveying Jamaica, 26th Ward, Coney Island and Rockaway WPCPs treated effluents

Each alternative that included pumping of treated effluent to either the Atlantic Ocean or the Rockaway Inlet included sub-alternatives as to the type of effluent pumps used. These included:

- Submersible pumps located in WPCP Chlorine Control Tanks (CCT)
- Submersible pumps located in wet pit/dry pit pumping station
- Centrifugal mixed flow pumps located in trench type wet well
- Effluent pumps located in a landside tunnel shaft located at either Barren Island or in proximity to the Rockaway WPCP

Lastly, three alternatives were evaluated for gravity flow only (no effluent pumps). A matrix of alternatives is shown in Table 5-3.

The alternatives analyses was based on several general engineering and technical concepts, summarized as follows:

- Alternatives 1 through 9 are based on conveying treated effluent at two times design dry weather flow (DDWF) (Coney Island and Rockaway WPCPs) and two times (DDWF) plus fifty million gallons (26th Ward and Jamaica WPCPs)
- Alternatives 10 through 12 (gravity) are based on conveying WPCP effluent at one and one-half times DDWF, with flow above that amount discharged to the bay or Rockaway Inlet via each respective WPCP's current outfall
- Ocean outfalls include diffuser length of 4,100 linear feet for all outfall alternatives with the exception of 5,000 linear feet for the Jamaica and 26th Ward WPCPs to the ocean alternative
- Rockaway Inlet outfalls include diffuser length of 810 linear feet
- Ocean outfall discharge location is based on placing the diffuser at a depth necessary to trap treated WPCP effluent below the pyncnocline. For the Jamaica WPCP to the ocean alternative, the design depth was fifty-six feet. For the Jamaica and 26th Ward WPCPs to the ocean alternative, the design depth was seventy -five feet. For the Jamaica and Rockaway WPCPs to the ocean alternative, the design depth was sixty-six feet. For the Jamaica, 26th Ward and Rockaway WPCPs to the ocean alternative, the design depth was eighty-five feet, and for all WPCPs to the ocean, the design depth was one hundred and five feet.
- For all Rockaway Inlet alternatives, the design depth was twenty-eight feet
- The worst case hydraulic condition exists when peak WPCP flows two times DDWF, two times DDWF plus 50 million gallons or one and one-half time DDWF as applicable) must be conveyed to the discharge point when the Ocean (or Rockaway Inlet) are at high/high tide elevation

- Total shaft/tunnel/diffuser hydraulic losses should not exceed approximately 70 ft TDH.
- Tunnel minimum velocity 2 (fps); tunnel maximum velocity 7.5 fps

General engineering and technical assumptions, related to the shafts and tunnels are summarized as follows:

- Tunnel alignments would be limited to publicly-owned rights-of-way
- Tunnel alignments would avoid foundations for bridges, where possible
- Tunnel alignments would by-pass large public or commercial structures
- All ocean outfall alternatives would pass through a shaft to be constructed adjacent, and to the west of the Rockaway WPCP site
- All tunnel alignments to the Rockaway Inlet Outfall would pass through a shaft located on the Southeast shoreline of Barren Island
- Tunnel radii would be no less than 700 feet
- Tunnel invert gradients are maintained at 0.05% for drainage during tunnel construction
- The tunnel crown would be a minimum of 40 feet below ocean or bay bottom
- The geology consists of glacio-fluviatile sediments such that soft ground tunnel conditions would prevail
- The conceptual designs would be based on USGS NAVD 1988 datum

The concept of discharging treated WPCP effluent to Rockaway Inlet or the Atlantic Ocean generally consists of the following major components:

5.2. Tunnel Alignments

5.2.1. Tunnel Alignments to Ocean Outfalls

There are six alternatives that would convey treated effluent at a peak flow rate of two times DDFW or two times DDFW plus 50 million gallons from combinations of WPCPs to various depths of the Atlantic Ocean. All of the six alternatives share a common shaft located adjacent and to the west of the Rockaway WPCP site. These alternatives are identified as Alternatives 1, 2, 3, 4, 5, and 9 as summarized in Table 5-1 and further described below.

Alternative 1- Jamaica WPCP to Ocean

All tunneling operations would begin at the Rockaway shaft site located west of the Rockaway WPCP across Beach 108th Street on a vacant lot along the Rockaway Freeway. The northern portion of the tunnel would proceed from the Rockaway shaft north into Jamaica Bay, below the Broad Channel, Cross Bay Boulevard and the city subway. The alignment curves slightly west and continues northerly to the Bergen Basin, along the western side of the John F. Kennedy International Airport. The alignment follows the northeasterly curvature of the basin and would terminate at the Jamaica WPCP shaft which is located on the northwestern corner of the Jamaica WPCP site, adjacent to the Nassau Expressway. The southern portion of the tunnel would begin at the Rockaway shaft and proceed southeasterly into the Atlantic Ocean and terminates at the ocean outfall shaft location. This

alternative would convey treated effluent from the Jamaica WPCP to the ocean. Refer to Figure 5-1 for tunnel plan, profile and section.

Alternative 2- Jamaica and 26th Ward WPCPs to Ocean

Tunneling operations for the first portion of the tunnel would begin at the 26th Ward WPCP shaft site. The first portion of the tunnel would proceed from the 26th Ward WPCP shaft northeast along the Belt Parkway, and terminate at the Jamaica WPCP shaft located on the northwestern corner of the Jamaica WPCP site, adjacent to Nassau Expressway. Tunneling operations for the second and third portions of the tunnel would begin at the Rockaway shaft located to the west of the Rockaway WPCP. The second portion of the tunnel would begin at the Rockaway shaft and proceed northwesterly into Jamaica Bay, below the Beach Channel, North Channel, along Hendrix Creek and terminate at the 26th Ward WPCP shaft site. The third portion of the tunnel also would begin at the Rockaway shaft and proceed southeasterly into the Atlantic Ocean and terminate at the ocean outfall shaft location. This alternative would convey treated effluent from the Jamaica and the 26th Ward WPCPs to the ocean. Refer to Figure 5-2 for tunnel plan, profile and section.

Alternative 3 – Jamaica and Rockaway WPCPs to Ocean

All tunneling operations would begin at the Rockaway shaft site. The northern portion of the tunnel would follow the same alignment as Alternative 1 and terminate at the Jamaica WPCP shaft site. The southern portion of the tunnel would begin at the Rockaway shaft and proceed southeasterly into the Atlantic Ocean and terminate at the ocean outfall shaft location. This alternative would convey discharge treated effluent from the Jamaica and Rockaway WPCPs to the ocean. Refer to Plan Figure 5-3 for tunnel plan, profile and section.

Alternative 4 – Jamaica, 26th Ward and Rockaway WPCPs to Ocean

The tunnel alignment for this alternative is identical to Alternative 2 with the exception that the southern portion of the tunnel to the ocean outfall shaft is longer. Additionally, the effluent flow from the Rockaway WPCP would be conveyed to the Rockaway shaft site. This alternative would convey treated effluent from the Jamaica, 26th Ward and Rockaway WPCPs to the ocean. Refer to Figure 5-4 for tunnel plan, profile and section.

Alternative 5 – Jamaica, 26th Ward, Rockaway and Coney Island WPCPs to Ocean

The tunnel alignment for this alternative, north of the Rockaway shaft, is identical to Alternative 2 and Alternative 4. There would be an additional tunnel from the Rockaway shaft west into Jamaica Bay, below Barren Island to the Coney Island shaft site located along the northern Sheepshead Bay shoreline south of the Belt Parkway. The shaft site selected is currently owned by the Department and is located between the two existing Coney Island outfall conduits. The southern portion of the tunnel would begin at the Rockaway shaft and proceeds southeasterly into the Atlantic Ocean and terminates at the ocean outfall shaft location. This alternative would convey treated effluent from the Jamaica, 26th Ward, Coney Island and Rockaway WPCPs to the ocean. Refer to Figure 5-5 for tunnel plan profile and section.

5.2.2. Tunnel Alignments to Rockaway Inlet Outfalls

There are three alternatives that convey treated effluent at a peak flow rate of two times DDWF or two times DDWF plus 50 million gallons from combinations of WPCPs to the Rockaway Inlet. All of these alternatives share a common central shaft location at Barren Island. These alternatives are identified as Alternatives 6, 7, and 8 as summarized on Table 5-2 and further described below.

Alternative 6 – Jamaica WPCP to Rockaway Inlet

All tunneling operations would begin at the Barren Island shaft site located on the southeast shoreline of Barren Island on property owned by the U.S. Department of Defense. The northern portion of the tunnel would proceed from the Barren Island shaft, northeast into Jamaica Bay, below the Island Channel, Runway Channel, Horse Channel, Black Wall Channel, Cross Bay Boulevard and the city subway. The alignment would curve slightly west and continue northerly to the Bergen Basin, along the western side of the John F. Kennedy International Airport. The alignment would follow the northeasterly curvature of the basin and terminate at the Jamaica WPCP shaft which is located on the northwestern corner of the Jamaica WPCP site, adjacent to the Nassau Expressway. The southern portion of the tunnel would begin at the Barren Island shaft and proceed southwesterly into the Rockaway Inlet and terminate at the Rockaway Inlet outfall shaft location approximately two miles off the southwest shoreline off Barren Island. This alternative would convey treated effluent from the Jamaica WPCP to the Rockaway Inlet. Refer to Figure 5-6 for tunnel plan, profile and section.

Alternative 7 – Jamaica and 26th Ward WPCPs to Rockaway Inlet

Tunneling operations for the first portion of the tunnel would begin at the 26th Ward WPCP shaft site. The first portion of the tunnel would proceed from the 26th Ward WPCP shaft, northeast along the Belt Parkway and terminate at the Jamaica WPCP shaft which is located on the northwestern corner of the Jamaica WPCP site, adjacent to Nassau Expressway. Tunneling operations for the second and third portions of the tunnel would begin at the Barren Island shaft site. The second portion of the tunnel would begin at the Barren Island shaft and proceed north into Jamaica Bay, below the Island Channel, Canarsie Pol, North Channel, Pennsylvania Avenue Landfill and Belt Parkway and terminate at the 26th Ward WPCP shaft site. The third portion of the tunnel would also begin at the Barren Island shaft and proceed southwesterly into the Rockaway Inlet and terminate at the Rockaway Inlet outfall shaft location approximately two miles off the southwest shoreline off Barren Island. This alternative would convey treated effluent from the Jamaica and 26th Ward WPCPs to the Rockaway Inlet. Refer to Figure 5-7 for tunnel plan, profile and section.

Alternative 8 – Jamaica, 26th Ward and Rockaway WPCPs to Rockaway Inlet

Tunneling operations for the first portion of the tunnel would begin at the 26th Ward WPCP shaft site. The first portion of the tunnel would proceed from the 26th Ward WPCP shaft, northeast along the Belt Parkway and terminate at the Jamaica WPCP shaft which is located on the northwestern corner of the Jamaica WPCP site, adjacent to the Nassau Expressway. Tunneling operations for the second and third portions of the tunnel would begin at the Barren Island shaft site. The second portion of the tunnel would proceed north into Jamaica Bay, below the Island Channel, Canarsie Pol, North Channel, Pennsylvania Avenue Landfill and Belt Parkway and terminate at the 26th Ward WPCP shaft site. The third portion of the tunnel would proceed southwesterly into the Rockaway Inlet and terminate at the Rockaway Inlet Outfall shaft location approximately two miles off the southwest

shoreline off Barren Island. The fourth portion of the tunnel would proceed easterly to the Rockaway shaft. This alternative would convey treated effluent from the Jamaica, 26th Ward and Rockaway WPCPs to the Rockaway Inlet. Refer to Plan Figure 5-8 for tunnel plan, profile and section.

Alternative 9 – Coney Island and Jamaica WPCPs to 26th Ward WPCP Via Open Cut Force Main; 26th Ward WPCP to Ocean

This alternative is similar to Alternative 4 with the exception that the conveyance of treated effluent from the Coney Island and Jamaica WPCPs to the 26 Ward WPCP is via an open cut force main running along the Belt Parkway to the site of the drop shaft at the 26th Ward WPCP. Refer to Figure 5-9 for tunnel plan, profile and section.

5.2.3. Gravity Tunnel Alignments

There are three alternatives that would convey treated effluent at one and one half times DDWF from combinations of WPCPs to the Atlantic Ocean or Rockaway Inlet via gravity. These alternatives are identified as Alternatives 10, 11, and 12 as summarized on Table 5-3 and further described below.

Alternative 10 – Jamaica, 26th Ward and Rockaway WPCPs to Ocean via Gravity

Tunneling operations for the first portion of the tunnel would begin at the 26th Ward WPCP shaft site. The first portion of the tunnel would proceed from the 26th Ward WPCP shaft northeast along the Belt Parkway and terminates at the Jamaica WPCP shaft which is located on the northwestern corner of the Jamaica WPCP site, adjacent to the Nassau Expressway. Tunneling operations for the second and third portions of the tunnel would begin at the Rockaway shaft site located west of the Rockaway WPCP. The second portion of the tunnel would begin at the Rockaway shaft and proceeds northwesterly into Jamaica Bay, below the Beach Channel, North Channel, along Hendrix Creek and terminates at the 26th Ward WPCP shaft site. The third portion of the tunnel would also begin at the Rockaway shaft and proceed southeasterly into the Atlantic Ocean and terminate at the ocean outfall shaft location. This alternative would convey treated effluent from the Jamaica, Rockaway and the 26th Ward WPCPs to the ocean. Refer to Figure 5-10 for tunnel plan, profile and section.

Alternative 11 – Jamaica and 26th Ward WPCPs to Ocean via Gravity

Tunneling operations for the first portion of the tunnel would begin at the 26th Ward WPCP shaft site. The first portion of the tunnel would proceed from the 26th Ward WPCP shaft northeast along the Belt Parkway and terminates at the Jamaica shaft which is located on the northwestern corner of the Jamaica WPCP site, adjacent to the Nassau Expressway. Tunneling operations for the second and third portions of the tunnel would begin at the Rockaway shaft site located west of the Rockaway WPCP, across Beach 108th Street on a vacant lot along the Rockaway Freeway. The second portion of the tunnel would begin at the Rockaway shaft and proceed northwesterly into Jamaica Bay, below the Beach Channel, North Channel, along Hendrix Creek and terminates at the 26th Ward WPCP shaft site. The third portion of the tunnel would also begin at the Rockaway shaft and proceed southeasterly into the Atlantic Ocean and terminates at the ocean outfall shaft. This alternative would convey treated effluent from the Jamaica and 26th Ward WPCPs to the ocean. Refer to Figure 5-11 for tunnel plan, profile and section.

Alternative 12 – Jamaica and 26th Ward WPCPs to Rockaway Inlet via Gravity

Tunneling operations for the first portion of the tunnel would begin at the 26th Ward WPCP shaft site. The first portion of the tunnel would proceed from the 26th Ward WPCP shaft northeast along the Belt Parkway and terminates at the Jamaica WPCP shaft which is located on the northwestern corner of the Jamaica WPCP site, adjacent to the Nassau Expressway. Tunneling operations for the second and third portions of the tunnel would begin at the Barren Island shaft site. The second portion of the tunnel would begin at the Barren Island shaft and proceeds north into Jamaica Bay, below the Island Channel, Canarsie Pol, North Channel, Pennsylvania Avenue Landfill and Belt Parkway and terminates at the 26th Ward WPCP shaft site. The third portion of the tunnel would also begin at the Barren Island shaft and proceeds southwesterly into the Rockaway Inlet and terminate at the Rockaway Inlet outfall shaft location approximately two miles off the southwest shoreline off Barren Island. This alternative would convey treated effluent from the Jamaica and 26th Ward WPCPs to the Rockaway Inlet. Refer to Figure 5-12 for tunnel plan, profile and section.

5.3. Tunnel Lining

Based on the geology to be encountered, which consists of sands, and construction below the water table, it is envisioned that the bored tunnel lining system will consist of pre-cast reinforced concrete segments that will be bolted and gasketed. The one-pass system will provide both stabilization of the tunnel opening during construction and a permanent service lining that will keep the tunnels watertight. The bolted, gasketed segments would be designed and detailed to match the configuration of the single bored tunnel. Fabrication of the segments would be accomplished at an off-site fabrication plant and shipped to the site for installation. The segments would then be transported to the site on barges and stored at the site.

Since the one-pass system acts as the initial and final lining of the tunnel, the segments must be capable of supporting the anticipated external loads due to overburden, surcharge, and groundwater. The segment will provide a smooth bore for flow. The segments must be able to withstand handling and erection loads and all loads due to jacking forces in advancing the shield, as well as any internal hydrostatic pressures. As the tunnel advances, grout will be injected into the annulus between the outside of the concrete segment and the excavated soil surface. This will minimize subsidence and aid in developing uniform external pressure around the segments.

The typical depths of the tunnel are such that a minimum of two tunnel diameters of ground cover over the crown of the tunnel is provided. The tunnel depth and weight of segments will also be sufficient to resist floatation forces.

5.4. Tunneling Method

The geotechnical investigation for this phase of the project has indicated the subsurface conditions for the Jamaica Bay CSO tunnel will generally consist of saturated sands. Therefore, it is envisioned that a pressurized face type Tunnel Boring Machine (TBM) will be required. Pressurization of the face can be accomplished by either earth pressure balance or slurry machine. The first method requires an Earth Pressure Balance Machine (EPBM) and the second method requires a "slurry machine". Both types of TBMs stabilize the face to prevent water infiltration into the tunnel. Contractors have

embraced these types of machines since they eliminate the need for compressed air method while mining below the water table.

5.4.1. Earth Pressure Balance Machine

The EPBMs resist the earth and water pressure at the face by keeping the interior of the EPBMs pressure chamber filled with a mixture of excavated earth and additives if required. Face stability is achieved by controlling earth pressure in the pressure chamber.

Excavation in sands, which do not contain sufficient clay or silt particles underneath the groundwater table may not be possible without additives or ground conditioning agents, as the soil will be too permeable to resist the hydrostatic pressures. Ground conditioning results in a creation of plastic, impermeable and flowable mass of soil. Typically, the ground is conditioned utilizing bentonite, polymer or foam conditioning agents, or their combination. Plastic flowability of the excavated muck filling the excavation chamber and screw conveyor is necessary to provide support of the excavation face and to allow for removal of muck through the screw conveyor without pressure losses.

As the excavation progresses, the pressure at the heading is maintained by adjusting the speed of muck removal and thrust of the machine. To control the face stability, the pressure of the excavated soil and water within the mixing chamber must be maintained within the required range required for face stability. The plasticity of the excavated soil has to be controlled at all times so that the screw conveyor can be used to control the pressures within the excavation chamber. The thrust force of the machine will vary according to the ground conditions encountered.

In EPBMs, the handling of excavated material is less complex than with slurry machines, as it does not require slurry and soil separation in a separation plant. The muck mixed with slurry can result in higher handling and disposal costs. Major face collapses are essentially impossible, as the face is constantly supported by a "soil plug" in the excavation chamber, provided that the hydrostatic pressure is controlled.

The cutterhead of the EPBM will be equipped with drag teeth suitable for excavating soft ground. Each EPBM will be equipped with a jack propulsion system located in the tail of the machine. The machine will be advanced by jacking-off the previously installed segmental lining.

Initially, EPBMs were designed to operate in soils with relatively high content of fines, resulting in a plastic soil mass with low permeability. They were not suitable for use in permeable sands where slurry machines were typically utilized. Introduction of soil conditioning agents greatly expanded the range of soils that can be excavated with EPBM. Currently, with the employment of suitable additives, the EPBMs can be employed for excavation in sands underneath the groundwater table.

5.4.2. Slurry Machine

The second type of TBM that can be utilized for construction of the outfall tunnels is a slurry machine. Slurry shields incorporate a watertight bulkhead behind the excavator head, which completely seals off the excavation face from the completed sections of the tunnel. Pressurized slurry

supplied to the front of the bulkhead keeps the excavation face stable, ensuring safe and efficient tunneling even under unstable ground conditions such as running sands and high water pressure. The slurry pressure is regulated at the face to counterbalance the encountered ground conditions.

Introduction of an air pressure cushion or a so- called "air bubble" in the excavation chamber allows for better control of slurry pressure. The excavated muck is transported in fluid form to a slurry separation plant on the surface where the slurry and soil are separated. Then, the slurry is recirculated to the tunnel heading again, forming a closed system. Impermeable sands, a filter cake must be created at the excavation face to prevent the slurry from infiltrating into the sands ahead of the machine.

Currently, there are also mixshield machines available. Mixshield machines allow for switching from earth pressure balance operation to slurry operation while mining underground. This type of a machine allows more flexibility in dealing with varying ground conditions.

Both EPBMs and slurry machines may be outfitted with the equipment necessary to allow ground improvements ahead of the machine utilizing either grouting or ground freezing techniques.

5.4.3. Additives/Soil-Conditioning Agents

Soil conditioning alters and enhances the properties of the tunneling medium by transforming soils into plastic, flowable, and relatively impermeable material. Soil conditioning is generally utilized with EPBM machines and only in certain applications with slurry machines. With slurry machines, the typical use of additives occurs when mining in permeable soils, where slurry alone is not enough to form a filter cake at the excavated face. Then, some additives may be used to increase the density of the slurry to facilitate creation of filter cake and reduce slurry losses into surrounding ground.

Without additives, the EPBM machines can only excavate, as a rule of thumb, in soils with liquid limit in excess of 30%. Soil conditioning greatly expands the range of soils that the machine can excavate, including cohesionless soils below the groundwater table.

The most common conditioning agents are bentonite slurries, foams and polymers, or their combination. Excavation in sandy soils underneath the water table is typically conducted with dense bentonite slurry mixed with polymers, but foams with polymer addition may also be considered. Bentonite slurry is a liquid, while foam is essentially a gas consisting of approximately 90% air and 10% liquid. Generally foam is preferred over the bentonite slurry as it produces very little of additional material for disposal. However, foams are not stable and with time, they will dissipate. It is important to know the length of time during which the foam could be kept stable, to plan for contingencies like unexpected work stoppage. The disadvantage of bentonite slurry is that it requires a slurry separation plant on the surface, which will separate slurry and spoils. Even though most of the slurry is recirculated, the amount of slurry required will be considerable. For mining in coarse material, the amount of slurry needed may be as much as fifty percent of the volume of excavated soil.

In summary, utilization of soil conditioning agents allows the formation of a "sand plug" in EPBM machines by increasing the plasticity and reducing the permeability of the excavated material. It allows better control of hydrostatic pressure and flow of the spoils through the screw conveyor. In addition, lubrication provided by foams or slurries reduces torque required to turn the cutting wheel,

wear and tear of the cutting bits, and reduces the friction between the shield and the ground. In fact, because of the beneficial influence of conditioning agents on reduction of wear and friction, they may be used, even if not required by ground conditions.

5.4.4. Muck Removal and Disposal

The muck removal method depends on the type of TBM used for mining the tunnel. With slurry machines, the cuttings are mixed with slurry and transported, in liquid state, from the excavation chamber to the surface through system of pipes and pumps. After reaching the surface, the mix of muck and slurry enters the slurry separation plant where slurry is separated and recirculated back to the heading. The separation process is faster for granular, sandy spoils than for fine materials. The spoils are similar to those resulting from a slurry wall construction operation.

With EPBM machines, the muck from the excavation chamber first passes through the screw conveyor. Then, depending on the flowability, the muck is loaded on the conveyor belt or into the muck cars for transportation out of the tunnel. If the soil was subjected to heavy conditioning it may be too liquid for conveyor belt removal. In addition, for smaller diameter tunnels, there may not be enough space for installation of conveyor system. Regardless of the muck removal system, trains would still have to be utilized in the tunnel for transportation of segments and agitator cars for grouting. Muck removed from the tunnel will be temporarily stored at the designated site prior to shipping, by barges, from the job site.

Spoil disposal may become a very costly aspect of tunneling if the muck is contaminated. The boring and testing program conducted as for the Jamaica Bay CSO project, indicates that tunneling will be conducted in non-contaminated ground. Therefore, it is very critical that all soil-conditioning additives be non-toxic and biodegradable. The same requirement applies to agents that may be introduced during the slurry separation process.

Utilization of non-toxic soil conditioning agents assures that the resulting spoils are environmentally friendly. If the in-situ ground is not contaminated, the resulting muck will have the same non-contaminated status, after the application of conditioning additives. In the New York metropolitan area, soil mixed with slurry, non-toxic foam or polymers can be disposed of at any landfill accepting construction debris without the need for any special permits.

The Department does not consider muck, mixed with bentonite slurry a regulated material. Spoils containing bentonite slurry, which is essentially clay, are impermeable and are often used to seal the bottom of the landfills. Disposal of the tunnel spoils can be accomplished by ocean dumping, providing proper permits are secured. No detrimental effects to the marine life are anticipated, as slurry walls utilizing bentonite have been constructed in marine environments for decades.

5.4.5. Grouting

The cutting wheel of the machine excavates a tunnel diameter slightly larger than the shield to reduce friction and accommodate guidance in the tunnel curves. Grout must be injected into the annulus between the excavation and the tunnel segmental lining as excavation progresses to insure that settlements do not occur, and to avoid distortion of the segments. The grouting will be conducted

simultaneously with the TBM advancement. The grout mix may consist of cement, flyash, sand, bentonite, water, and water-reducing additives. The mix will have to have a set time of at least several hours allowing enough time for transportation from the surface to the tunnel heading and for conducting of grouting operations. Grout will be mixed at the plant at the surface and transported in agitator cars to the heading. Grouting will start after commencement of the next shove of the TBM and injected continuously into the annulus to keep the void completely filled at all times.

5.5. Shafts

All tunneling would begin at the work shaft for each tunnel alignment. Each alignment alternative has one or more designated work shafts dependent upon the number of WPCP to be serviced. Finally, two types of construction shaft were identified. Work shafts were assumed to be 35 feet in diameter to accommodate tunnel machine insertion, muck removal, and liner delivery. Their proximity to water was desirable to gain economy of transport for muck and liner segments. Exit shafts were assumed to be 20 feet in diameter since their only purpose would be for machine removal. The exit shafts also require less acreage for temporary equipment, machinery and related facilities. Using these criteria, exit shafts were selected for the Jamaica and Coney Island WPCP shaft and work shafts were chosen for the remaining sites. The outfall shaft, in the Atlantic Ocean or at the Rockaway inlet, is based on an inside diameter of 20 feet. Shaft invert elevations were dictated by minimum tunnel crown cover, assumed mining direction, invert gradient and ocean water depth. In total there are three work shaft sites designated as work shafts as described below.

5.5.1. 26th Ward WPCP Work Shaft

The 26th Ward WPCP Shaft has been designated as the work shaft for Alternatives 2, 4, 5, 7, 8, 10 11 and 12, and would have an inside diameter of 35 feet. The shaft will provide means of access to the tunnel during construction of portions of the different tunnel alignments for the TBM placement, muck removal, materials delivery, and will serve as an exit for some equipment upon completion of construction. The proposed shaft is located at the southeast corner of the 26th Ward WPCP site.

A muck conveyor system would exit at the northeast side of the shaft, crossing over the access road, then running southeast along the western shore of Hendrix Creek to the muck storage area. The concrete tunnel segments will be brought into Hendrix Creek on barges and docked along the western shore at the concrete segment storage area. The concrete segments will then be transported on the access road to the work site storage area.

The barges used for transporting the concrete segments and removing muck will be staged at a temporary wharf structure that will be constructed along the western shore of Hendrix Creek. An alternative to the temporary wharf structure would be to provide a temporary storage site within the Pennsylvania Avenue landfill property to minimize the size of the wharf structure along Hendrix Creek. The use of the landfill property, if allowed, would also minimize the cost of the temporary wharf structure.

5.5.2. Rockaway Work Shaft

The Rockaway Shaft has been designated as the work shaft for Alternatives 1, 2, 3, 4, 5, 9, 10, 11 and 12 and will have an inside diameter of 35 feet. The shaft will provide means of access to the tunnel during construction of portions of the different tunnel alignments for the TBM placement, muck removal, materials delivery, and will serve as an exit for some equipment upon completion of construction. The proposed shaft is located on the northeast corner of a vacant parcel of land west of the Rockaway WPCP on the northern side of the intersection of Beach 108th Street and the Rockaway Freeway.

A muck conveyor system exits at the southwest side of the shaft, through the shaft site and crossing over Beach Channel Drive to the southern shore of Jamaica Bay to the muck storage area. The concrete tunnel segments will be brought into Jamaica Bay on barges and docked along the southern shore at the concrete segment storage area. The concrete segments will then be transported across Beach Channel Drive to the work site storage area.

The barges used for transporting the concrete segments and removing muck will be staged at a temporary wharf structure that will be constructed along the southern shore of Jamaica Bay across from the shaft site.

5.5.3. Barren Island Work Shaft

The Barren Island Shaft has been designated as the work shaft for Alternatives 6, 7, 8 and 12 and will have an inside diameter of 35 feet. The shaft will provide means of access to the tunnel during construction of portions of the different tunnel alignments for the TBM placement, muck removal, materials delivery, and will serve as an exit for some equipment upon completion of construction. The proposed shaft is located on the eastern side of a parcel of land located on the southeast shoreline on United States Department of Defense.

A muck conveyor system exits at the southeast side of the shaft, through the shaft site to the southern shore of Jamaica Bay to the muck storage area. The concrete tunnel segments will be brought into Jamaica Bay on barges and docked along the southern shore at the concrete segment storage area. The concrete segments will then be transported to the work site storage area. The barges used for transporting the concrete segments and removing muck will be staged at a temporary wharf structure that will be constructed along the southern shore of Jamaica Bay across from the shaft site.

5.5.4. Shaft Construction and Parameters

The shaft depths at the work and exit shafts vary for each tunnel alignment. The bottom of the shaft excavation was determined based upon two factors. The first is to keep a minimum of two tunnel diameters of ground cover above the crown of the tunnel at the lowest ground elevation along the tunnel alignment. The tunnel slopes downgradient 0.05% from the exit shaft to the work shaft to allow for tunnel drainage during construction. The shaft invert elevation was determined using the low point along the tunnel alignment with the tunnel slope. Once the shaft invert elevation was known, the shaft weight was calculated to determine the additional weight needed to resist floatation.

This is the second factor controlling the shaft depth. The thickness of the shaft slab is determined to provide the additional weight to prevent flotation.

Due to the high groundwater table at the shaft sites, it is envisioned that ground-freezing techniques will be utilized to provide temporary support of the excavation, as well as control of groundwater. Brine refrigerant, or liquid nitrogen, is circulated through the pipes installed around the perimeter of the shaft, thereby creating a freezewall. The ice becomes a bonding agent, fusing together adjacent particles of soil to increase the combined strength and make them impervious. Excavation of the shaft can then proceed inside the barrier of frozen earth until initial supports are installed. The excavation for the shafts will be performed utilizing mechanical means. The process of ground freezing does not affect the existing water table or water quality. When refrigeration is discontinued, the ground thaws. The earth then returns to its original condition with no detrimental effects to the soil or groundwater at the site.

5.6. Effluent Pumping

5.6.1. General

A hydraulic analysis was conducted to calculate the hydraulic head losses that would result from conveying peak treated effluent flow from the WPCPs to the Ocean or Rockaway Inlet for each alternative. The hydraulic losses include calculated head losses from the effluent of each plant's chlorine contact tank through the shafts, tunnels and effluent diffuser.

Conceptual designs were prepared for three type of effluent pumping station for each alternative as follows:

- Submersible pumps located in WPCP Chlorine Contact Tank (Figure 5-13)
- Submersible pumps located in a wet pit/dry pit pumping station located adjacent to the WPCP's Chlorine Contact Tanks (Figure 5-14)
- Centrifugal mixed flow pumps located in a trench type wet well adjacent to the WPCP Chlorine Contact Tank (Figure 5-15)
- Centrifugal mixed flow pumps located in a tunnel shaft located either at Barren Island or adjacent to Rockaway shaft sites (Figure 5-16)

The type of pumps, number of pumps and pump capacities associated with each alternative is summarized in Tables 5-1 and 5-2 for the ocean outfall and Rockaway Inlet outfall alternatives, respectively. The Conceptual Designs for the pumping alternatives are summarized herein.

5.6.2. Effluent Pumps located in Chlorine Contact Tanks (CCT)

The concept level designs for effluent pumping utilizing submersible pumps located in WPCP chlorine contact tanks was prepared for all four Jamaica Bay WPCP's. The pumping design concept is shown on Figure 5-13

The system at each site include the following major elements:

- N+2 pumps
- Submersible pumps located in the CCT's such that the tank acts as a wet well
- Peak pumping capacity at two times DDWF at Coney Island and Rockaway WPCPs and two times DDWF plus 50 million gallons at 26th Ward and Jamaica WPCPs
- Common pump header discharging to a proposed pipeline which interconnects the existing plant effluent with the tunnel drop shaft
- Hydraulic control structure and gates that can divert treated plant effluent to the current outfall or the proposed tunnel outfall
- Hydraulic control gate(s) which allow the plant effluent to flow by gravity to the ocean outfall diffuser when flow rate and ocean elevation allow gravity flow or act as a pressure system when a combination of high flow and high tides require effluent pumping
- A one story masonry, pile supported control building sized to enclose effluent pump electrical switchgear, pump variable frequency drives (VFDs), pump control panels, hydraulic power pack for valve operators, programmable logic controllers (PLC) equipment and heating, ventilation and air conditioning (HVAC) equipment
- An exterior pile supported concrete pad size to support transformers, primary switchgear, 2 fifty percent emergency power generators, and diesel fuel tank and paralleling switchgear

5.6.3. Effluent Pumps located in Wet Pit/Dry Pit Pumping Stations

The concept level design for effluent pumping utilizing submersible pumps located in wet pit/dry pit pumping station was prepared for all four Jamaica Bay WPCPs. The design pumping concept is shown on Figure 5-14. The system at each site include the following major elements:

- N+2 pumps
- Centrifugal pumps located in a wet well/dry well type pumping station structure
- Peak pumping capacity of two times DDWF at Coney Island and Rockaway WPCPs and two times DDWF plus 50 million gallons at 26th Ward and Jamaica WPCPs
- Common pump header discharging to a proposed pipeline which interconnects the pumping station with the tunnel drop shaft
- Hydraulic control structure and gates at each WPCP, that can divert plant effluent to the current outfall or the proposed pumping station
- Hydraulic control gate(s) which allow the plant effluent to flow by gravity to the ocean outfall diffuser when flow rate and ocean elevation allow gravity flow or act as a pressure (purged) system when a combination of high flow and high tides require effluent pumping
- A one story masonry, pile supported superstructure building sized to enclose effluent pump electrical switchgear, pump VFDs, pump control panels, hydraulic power pack for valve operators, PLC equipment and HVAC equipment
- An exterior pile supported concrete pad size to support transformers, primary switchgear, 2 fifty percent emergency power generators, and diesel fuel tank and paralleling switchgear

5.6.4. Centrifugal Mixed Flow Pumps located in Trench Wet Well Pumping Stations

The concept level designs for effluent pumping utilizing centrifugal mixed flow pumps located trench wet wells was prepared for all four Jamaica Bay WPCP's. This design pumping concept is shown in Figure 5-15. The system at each site include the following major elements:

- N+2 pumps
- Centrifugal (vertical mixed flow type) pumps located in the concrete trench type wet well.
- Peak pumping capacity of two times DDWF at Coney Island and Rockaway WPCPs and two times DDWF plus 50 million gallons at 26th Ward and Jamaica WPCPs.
- Common pump header discharging to a proposed pipeline which interconnects the pumping station with the tunnel dry shaft.
- Hydraulic control structure and gates at each WPCP, that can divert plant effluent to the current outfall or the proposed pumping station.
- Hydraulic control gate(s) which allow the plant effluent to flow by gravity to the ocean outfall diffuser when flow rate and ocean elevation allow gravity flow or act as a pressure (purged) system when a combination of high flow and high tides require effluent pumping.
- A one story masonry, pile supported control building sized to enclose effluent pump electrical switchgear, pump VFD's, pump control panels, hydraulic power pack for valve operators, PLC equipment and HVAC equipment.
- An exterior, pile supported concrete pad size to support transformers, primary switchgear, 2- fifty percent emergency power generators, diesel fuel tank and paralleling switchgear.

5.6.5. Effluent Pumps located in Tunnel Shafts

The concept level design for effluent pumping utilized centrifugal mixed flow type pumps centrally located at either the Rockaway shaft or at Barren Island shaft site. This design-pumping concept is shown on Figure 5-16.The system at each site include the following major elements:

- N+2 pumps
- Peak pumping capacity of two times DDWF at Coney Island and Rockaway WPCPs and two times DDWF plus 50 million gallons per day at 26th Ward and Jamaica WPCPs
- Hydraulic control structure and gates that can divert plant effluent to the current outfall or the proposed tunnel outfall
- Hydraulic control gate(s) which allow the plant effluent to flow by gravity to the ocean outfall diffuser when flow rate and ocean elevation allow gravity flow or act as a pressure (purged) system when a combination of high flow and high tides require effluent pumping.
- A one story masonry, pile supported control building sized to enclose effluent pump electrical switchgear, pump VFD's, pump control panels, hydraulic power pack for valve operators, PLC equipment and HVAC equipment
- An exterior pile supported concrete pad size to support transformers, primary switchgear, 2-fifty percent emergency power generators, and diesel fuel tank and paralleling switchgear

5.7. Alternative Cost Estimates

Construction cost estimates were prepared based on the information contained within the conceptual design drawings for each of the outfall relocation alternatives. The methodology used in the estimating the conceptual project cost was developed as part of a Department's effort to standardize the cost estimating process. Table 5-4 shows the estimated non-factored and factored construction cost as well as Total Conceptual Project Cost for each outfall alternative.

As noted therein, total project costs includes probable construction cost which includes a ten percent construction reserve to cover change orders during construction, soft costs other costs. Soft costs include fees associated with environmental assessments and permitting, engineering/architecture, construction management and other professional fees, cost associated with performing fixed asset surveys and staff training and development. Other costs include land acquisition and an allowance for the Setaside for the Arts program.

As the cost estimates were originally prepared in March of 2004, they were escalated to March 2006 dollars using an escalation rate of 8.5 percent per year, in accordance with Department cost estimating procedures. Additionally, contractor overhead and profit, originally calculated at thirteen percent, was increased to twenty-one percent in the final estimation of the Total Conceptual Project Cost.

5.8. Permits

A listing of those permits requires to allow the construction of an ocean/inlet outfall is provided on Table 5-5.

5.9. Critical Habitat and Endangered Species

5.9.1. Rockaway Inlet Outfall

A preliminary critical habitat and endangered species study was performed and focused on near field impacts associated with outfall relocation to Rockaway Inlet. Battelle conducted this study with findings included in the report entitled Critical Habitat Study and Preliminary Ecological Assessment for Rockaway Inlet Alternatives, dated May 2004. The preliminary assessment consisted of two tasks:

(1) Identifying target species and supporting habitats
(2) Conducting a preliminary analysis of potential ecological impacts

Species identified within are found in Table 5-6. These species are those that frequently use the study area, or the area is within their critical habitat, there is the potential that adoption of the alternatives will have a direct impact on the species. According to Battelle, "These concerns must be taken into account, but are not fatal flaws for any of the alternatives."

Primary productivity within the Jamaica Bay estuary is high compared to other temperate estuaries in the United States. Summer averaged chlorophyll-*a* concentrations have been increasing since the

1980s. The high chlorophyll *a* levels restrict net oxygen production to surface waters within the estuary.

Critical Areas - The project area lies within the New York Bight adjacent to numerous significant habitat areas for target species, fishing and for sand. Below is a summary of significant areas within or adjacent to the project area.

The project area lies within the Jamaica Bay & Breezy Point US Fish and Wildlife Service (USFWS) Significant Water Habitat and Land Habitat Complex #16 and a New York State Department of State (NYSDOS) designated Significant Coastal Fish & Wildlife Habitat. Both of these habitats are more inclusive than the project area extending further east to encompass all of Jamaica Bay and its islands. However, the areas end at Rockaway Point and do not extend to the ocean side.

Analysis of the NYSDOS and USFWS information, note that the study area includes protected species and potential target species which led to the identification of areas that serve as critical habitat for many target species. These areas include:

- Breezy Point, Marine Parkway Bridge, Jacob Riis Park
- Floyd Bennett Field
- Ruffle Bar Island in Jamaica Bay

One of the main reasons for relocating the present WPCPs outfalls is to reduce the high nutrient inputs to the bay. These nutrient loads are responsible for increased phytoplankton production that ultimately leads to hypereutrophic conditions at certain times of the year.

The following is a description of the issues related to physical and biogeochemical impacts associated with this activity

Construction Activities – Outfall construction could potentially pose short-term, local perturbations to a number of receptors. However, due to the local nature of the process, and the likelihood of strict operational procedures and mitigation rules, construction is considered a minor impact on most receptors. Impact on the benthos is considered substantial due to the nature of outfall construction. However, it is assumed that negative influences would be local and not necessarily permanent; benthic communities within the zone of influence would likely recover over time.

Erosion and Sediment Transport – Erosion and sediment transport is associated with possible changes in the spatial distribution of sediment delivery from the proposed outfall and local and regional hydrodynamics. The potential impact is minor with respect to most receptors. If depositional and transport patterns were to change locally, then substantial impacts could be experienced by Submerged Aquatic Vegetation (SAV) and salt marsh communities where habitat quality is directly linked to sediment balances and quality.

Water Residence Time – Water residences time directly affects the relationship between nutrient loads and availability to primary producers. The shorter the residence time, the less available nutrients are to phytoplankton and microalgae. Similarly, rapidly flushed systems tend to export phytoplankton standing stock prior to their ability to propagate within the system. Slowly flushed systems like Jamaica Bay tend to have higher phytoplankton standing stocks because of then greater availability of growth-limiting nutrients. Model runs suggest that an e-folding residence time

(defined as the natural logarithmic decay of mass or conservative concentration over time; approximately 63% initial mass removed) for Jamaica Bay is 21 days. Simulations of the bay without the WPCPs suggest a new e-folding residence time of 27 days. These simulations apply to the entire bay and do not reflect local conditions (i.e., individual tributaries or borrow pits).

Salinity – The combined four WPCPs comprise approximately 75% of the total annual freshwater flow to Jamaica Bay. (JABERRT, 2002) Many of the tributaries do not receive regular freshwater flow, but rather periodical discharge of stormwater and CSOs. Preliminary model runs suggest a baseline in the Rockaway Inlet of 27 to 28 parts per thousand (ppt) to 23 ppt near Grassy Bay. The Rockaway Inlet outfall simulation suggests increased salinities in the mid- and inner- bay to 26-27 ppt.

Stratification – Because stratification is typically limited to inner areas of Jamaica Bay and not Rockaway Inlet, most receptors are not considered to be impacted by the outfall relocation.

Temperature - The outfall relocation should not change general temperature regimes within Jamaica Bay

Nutrients – Preliminary results of model runs support the hypothesis that relocating the outfall to the Rockaway Inlet would alleviate the degree of eutrophication in the inner regions of Jamaica Bay. If nutrient reductions are sufficient, the main effect will be to reduce phytoplankton. However, it is important to consider that there may be additional, secondary effects, which may not be desirable. A reduction in nutrients in a system may ultimately contribute to a decreased population of desirable species. In the case of Jamaica Bay, high primary production has contributed to high secondary production of benthic fauna, particularly amphipods (*Ampelisca)* which leads to higher production of benthic-feeding fish such as juvenile winter flounder.

Biochemical Oxygen Demand and Dissolved Organic Carbon – Increases or spatial and temporal alterations in the delivery of BOD can have pronounced effects on local system metabolism (recognized as low DO events) and, coupled with increased delivery of organic matter to the benthos, increased risk to benthic communities.

Contaminants - The WPCPs outfall relocation may not have a substantial impact on contaminant loads in Jamaica Bay because a large part of the contaminant load is historical.

Floatables - The WPCPs outfall relocation should not change the impacts of floatables to Jamaica Bay inhabitants.

5.9.2. Atlantic Ocean Outfall

The alternative involves combining up to four WPCPs into one outfall located approximately five miles south of Jamaica Bay in the Atlantic Ocean. A preliminary critical habitat study and ecological assessment was performed and focused on near field impacts on Jamaica Bay. Battelle prepared this study in a report entitled Critical Habitat Study and Preliminary Ecological Assessment for the Offshore Alternative, dated May 2004. The preliminary assessment consisted of two tasks:

(1) Identify target species and supporting habitats

(3) Conduct a preliminary analysis of potential ecological impacts

Species identified for the treatment alternatives are found in Table 5-7. These species are those that frequently use the study area, or the area is within their critical habitat, there is the potential that adoption of the alternatives will have a direct impact on the species. According to Battelle, "the potential impacts on those species of concern are most likely to be short-lived." Moreover, "These concerns must be taken into account, but are not fatal flaws for any of the alternatives." (Battelle, 2004)

One of the main reasons for relocating the present WPCP outfalls is to reduce the high nutrient inputs to the bay. These nutrient inputs are responsible for increased phytoplankton production that ultimately leads to hypereutrophic condition at certain times of the year. Primary productivity within the Jamaica Bay estuary is high compared to other temperate estuaries in the United States. Summer averaged chlorophyll-*a* concentrations have been increasing since the 1980s. The high primary production rates and chlorophyll *a* levels restrict net oxygen production to surface waters within the estuary and contribute to organic loading to the bottom waters. This transfer of organic material to the sediments in turn is a primary driver of sediment oxygen demand and hypoxic DO levels in the bottom waters of the bay.

The influence of the Hudson River on water quality and physical characteristics in the ocean outfall study area is obvious in the data collected during the surveys. What is less clear, yet more important to the task of understanding the assimilative capacity of the waters in the study area, is how the environment would change with the transfer of Jamaica Bay effluent to an offshore outfall. At present, a substantial quantity of the nutrients discharged by the WPCPs into Jamaica Bay is already making its way to the ocean. Preliminary model runs calculated that seventy-five to eighty percent of the total nitrogen load that is discharged into Jamaica Bay is exported. The existing nitrogen loading from the WPCPs is approximately 36,000 lb/day. An additional 1,000-2,000 lbs/day comes from other sources. The same model runs estimate that the export from Jamaica Bay constitutes ten to fifteen percent of the total nitrogen load in the Hudson River plume.

Preliminary model runs indicate that there could be instances under high flow conditions where the offshore outfall discharge plume would break through the pycnocline and bring nutrients to surface waters. The problem being that this pulse of nutrients could lead to deleterious impacts in the summer when stratified conditions contribute to nutrient limited conditions in the surface waters. However, the data indicates that the Hudson River is already bringing a much larger total nitrogen load to the surface waters of the area. The impact of sporadic pulses of nutrients from high flow events is likely to be minor in comparison to that associated with the nutrient load from the Hudson River.

5.9.3 Feasibility of Offshore Siting

Part of the Department's environmental assessments was an evaluation of the feasibility of siting an ocean outfall in an area south of Jamaica Bay. The approach taken for the feasibility study was to conduct reconnaissance surveys to address spatial variability in this coastal environment. The assessment evaluated spatial variability and gradients in the water column and phytoplankton community in the area of interest as well as physical oceanographic conditions and water quality

characteristics. The results of this study are included in the Long Outfall Feasibility Study: 2003 Interpretative Report, prepared by Battelle, dated 2004.

During the offshore study planning process, reconnaissance objectives and goals were defined to ensure the measurement program focused on obtaining appropriate data and information to serve as a starting point for quantitative assessments of the basic questions regarding feasibility of an outfall. These discussions identified the capacity of the system to assimilate effluent constituents as a primary consideration toward the relocation of effluent into the coastal waters of New York Bight Apex. It was also determined that while a full understanding of assimilative capacity may require modeling, particularly in the area of nutrient discharge, the reconnaissance surveys would at least provide an indication of the present status of this area, early insight into the present assimilative capacity, and data to assist the design of the modeling studies. The goals of the feasibility study were as follows:

Goal 1: Validate assimilative capacity of offshore environment
- Locate and forecast onshore transport potential
- Characterize nearfield dissolved oxygen and nutrients
- Assess boundary inputs of dissolved oxygen and nutrients.

Goal 2: Assess variability for change detection in benthos
- Characterize benthic community status
- Characterize benthos spatial variability
- Look for benthic gradient at Nassau outfall

Goal 3: Assess variability for change detection in water column
- Optimize spatial grid size to detect water quality change
- Examine boundary conditions

The reconnaissance fieldwork performed in 2002 and 2003 (Figure 5-17) addressed the goals listed above and identified the need for additional studies in the region. Under Goal 1, the physical oceanographic conditions for the study period (Sep-Oct 2002) were well characterized for the potential outfall area, but the water column had already begun to mix in the fall of 2002 and there was no information collected under summer stratified conditions. Likewise, water quality conditions in fall 2002 were well described, but the need for more information during other seasonal conditions was noted. Coherency of water quality parameters between upstream or 'boundary' stations to the east (farfield) and stations within the study area (nearfield) was observed in 2002 and as a result the summer 2003 efforts concentrated on the nearfield.

The objectives under Goal 2 were partially addressed as the sediment type and benthic community status were characterized and clear gradients were noticed in both the nearfield and the farfield at the Nassau outfall. A more detailed characterization of the benthic infaunal community and sediment chemistry may be necessary in the future if the outfall relocation to the ocean alternative is selected. The physical oceanographic and water quality data collected in 2002 also addressed the objectives under Goal 3. Based on the 2002 results, recommendations for the 2003 surveys focused on the nearfield with an emphasis on gathering data on ocean currents over a larger area to understand the extent of the nearfield mixing and the homogeneity or heterogeneity in the current regime, better characterizing the inshore to offshore gradients in water quality parameters, and also investigating the variability in the phytoplankton community. The phytoplankton analysis component of the surveys also served to provide information on the overall condition of the receiving water environment.

Fieldwork conducted during Summer 2003 determined that the non-tidal motions at all three offshore current meter stations had no preferred direction, however, the dominance of the tidal flow at station D1 (up to 80% of the current variance) results in a much more coherent flow than at the other two stations. Despite water column stratification present during summer months, the current measurements indicate strong vertical mixing together with large horizontal dispersion produced by strong water column shear. Upwelling and downwelling appeared to play a smaller role in vertical mixing than water column shear. Horizontal mixing estimated from pseudo drifters was on the order of 10 kilometers in two tidal cycles. The water column was strongly stratified over the summer period encompassed by the three surveys. There was a gradient in stratification with the shallower inshore waters being the least stratified while the westernmost stations and deeper offshore waters the most stratified. Both temperature and salinity contributed to the density gradient in the study area. Within the area of the Hudson River plume, the density gradient was primarily due to salinity with bottom water salinity being up to 50% higher than the fresher surface waters in some cases. At the offshore stations, the density gradient was predominately driven by temperature with surface temperatures about double those measured in the bottom waters.

The most prominent patterns observed in the offshore water quality data were due to the influence of the Hudson River (Figure 5-18) and the deep, offshore bottom waters. Trends in nutrient, chlorophyll, and dissolved oxygen concentrations were related to a combination of river inputs, stratification, and biological processes. The Hudson River plume transported nutrient rich waters into the study area along with, and contributing to, elevated phytoplankton biomass. The water column was strongly stratified across the study area for most of the summer period (early indications of mixing at the inshore stations in August) and there was little communication between surface and bottom waters. The surface waters were often depleted in nutrients along the eastern extent of the study area as the nutrients supplied by the Hudson River were rapidly utilized by the relatively abundant and stable phytoplankton community. The isolation of the bottom waters resulted in trends of decreasing dissolved oxygen and increasing nutrient concentrations from June to August as elevated rates of respiration led to lower DO concentrations and regeneration of nutrients particularly ammonia.

6. Bay Modification and Combination Alternatives

6.1. General

The Grassy Bay and North Channel sections of Jamaica Bay (Figure 6-1) present a challenge for achieving water quality goals as these areas receive relative little though flow and Grassy Bay and North Channel have been substantially made deeper than most other areas of the Bay due to dredging. In that regard, several non-treatment alternatives were evaluated for improving water quality. These included:

- In basin aeration of Grassy Bay with existing bathymetry (Figure 6-2)
- In basin aeration of Grassy Bay with re-contouring to a uniform depth of 28 ft (Figure 6-3)
- Re-contouring the Grassy Bay borrow pit to a depth of 4 feet below mean low water (Figure 6-4)
- Re-contouring the Grassy Bay borrow pit to a depth of 8 ft below mean low water (Figure 6-4)
- Re-contouring the Grassy Bay borrow pit and dredged North Channel to a depth of 8 feet below mean low water. (Figure 6-5)

6.2. Aeration of Grassy Bay

6.2.1. Introduction

This section presents an evaluation related to the aeration of the waters of Grassy Bay. This section provides a development of potentially applicable alternatives and an evaluation of those alternatives, as well as conceptual project cost estimates.

6.2.2. Technologies and Basis of Design

In an attempt to evaluate how to deal with the problem of seasonal dissolved oxygen depressions below the standard, a preliminary screening of aeration technologies was performed. Based on the screening of technologies with the potential to add oxygen to Grassy Bay, two alternative approaches were selected for further evaluation. These included coarse bubble diffuser aeration based on the existing bay bottom contours and coarse bubble aeration based on cutting and filling (re-contouring) the bay bottom such that a generally flat surface is achieved.

6.2.2.1. Oxygen Requirements

The major factors affecting the dissolved oxygen levels in Grassy Bay include the existing bathymetry of the Grassy Bay borrow pit which results in semi-stagnant conditions, the discharge of treated effluent from the 26th Ward and Jamaica WPCPs and the existing muck layer on the floor of Grassy Bay. It is important that these factors be taken into consideration in the determination of the oxygen input required to maintain a minimum dissolved oxygen level that meets the current NYSDEC dissolved oxygen water quality standard. Weather, temperature, tidal activity and a

number of other variables also play a part in the dissolved oxygen levels. Based on modeling of Grassy Bay, the daily oxygen input required to meet the minimum dissolved oxygen level of 5 mg/L in the water column of Grassy Bay was projected at 100,000-lbs/day oxygen.

6.2.2.2. Technology Description

Based on an initial screening of aeration technologies, which included the use of surface aerators, oxygen injection via a floating barge and coarse bubble diffuser aeration, one technology was selected for further evaluation and use in the development of alternatives. As it was unlikely that the National Park Service would find surface aerators acceptable throughout Grassy Bay, this technology was dropped from further consideration. The use of a barge carrying liquid oxygen for injection into Grassy Bay was also dropped from further consideration as it is unlikely that the Port Authority of New York and New Jersey, National Park Service and local stakeholders would accept this technology, especially in light of its proximity to JFK International airport. Therefore, the aeration technology selected was coarse bubble diffused aeration. This technology is described and discussed below.

6.2.2.2.1. Coarse Bubble Diffuser Aeration

Aeration of water is the supply of air to a water body. Coarse bubble diffuser aeration utilizes compressors to supply air, and a network of pipes and diffusers located beneath the water surface to distribute the air. A standard coarse bubble diffuser system might consist of an air intake structure, compressors to transport the pressurized air through supply piping, the mains and headers to convey the air to its point of delivery and a network of diffusers. At the diffusers, the compressed air is released to the water column in the form of coarse bubbles. These bubbles rise to the water surface, transferring oxygen to the water as they rise. Coarse bubble diffuser aeration is a proven means of transferring oxygen to a water body and is more efficient in moderate to deep waters than the surface aeration technologies screened.

Coarse bubble diffusers come in a variety of styles. The type chosen for evaluation in Grassy Bay was the simple orifice type. The simple orifice type diffuser used in the alternatives development consists of an engineered network of one quarter inch openings drilled in high-density polyethylene (HDPE) piping.

The air for coarse bubble diffusion would be supplied using compressors. Multistage centrifugal compressors, or rotary positive displacement units, are often used to achieve the airflow and pressure required. The compressors are designed to develop sufficient pressure to overcome static head and friction losses of the supply piping, while delivering air at the required flow rate to the diffuser network.

A coarse bubble diffused aeration system for Grassy Bay has advantages as well as disadvantages. The advantages of coarse bubble diffusion aeration is that it is a proven aeration system used in many wastewater treatment systems and has been used in the Cardiff Bay Project to improve dissolved oxygen within the man-made escarpment. Typically, these systems are relatively easy to operate once installed, with all mechanical parts located on shore for ease of repair and maintenance.

The disadvantages of coarse bubble diffusers are the difficulty of installation as well as inspection and maintenance of the system in Grassy Bay. Diffuser networks are installed relatively level in order to achieve even distribution of air to all diffuser ports and to prevent diffuser port bypass. Grassy Bay has very poor underwater visibility caused by high turbidity, as well as a bottom covered by a muck layer that varies in thickness. The turbidity will make leveling the large diffuser networks extremely difficult while the muck may cause anchor movement (sinking), which will increase t leveling difficulties. These issues will further effect any under water equipment inspection and repairs required.

6.2.2.3. Basis of Design Summary

Based on the above discussions, the following basis for the evaluation and preliminary design of aeration options were developed:

- Depth: 0 to 40 ft
- Influent Temperature: 32-85°F
- Current Minimum DO 0 mg/L
- Minimum DO Required 5 mg/L

6.2.3. Alternatives Evaluation

The aeration systems evaluated included:

- Coarse bubble diffuser aeration with existing bathymetry (Alternative 1A)
- Coarse bubble diffuser aeration with leveling of the bay bottom to establish a single depth of aeration (Alternative 1B)

Conceptual level design drawings were developed for the coarse bubble aeration system based upon existing Grassy Bay bathymetry as well as a level bay bottom.

6.2.3.1. Coarse Bubble Diffuser Aeration with Existing Bathymetry

Under Alternative 1A, coarse bubble diffusion would be utilized to aerate Grassy Bay without any changes to the existing bathymetry. The coarse bubble diffusion system would be comprised of a network of diffusers located in the water body relying on compressed air injected into the water column. The diffused air system consists of compressors, air mains, headers, and perforated pipe diffusers. Aeration of Grassy Bay, utilizing coarse bubble diffusion, requires compressors totaling approximately 6,000 horsepower (hp). A combination of one 1,750 hp, one 1,500 hp, two 1,000 hp and one 700 hp compressors were used to meet the air supply requirements. Two 1,750 hp compressors would be supplied to meet the Department's redundancy requirements of one spare with one unit down for service. This will result in a system comprised of a total of seven compressors. These compressors are designed to deliver 57,835 standard cubic feet per minute (scfm) of air to Grassy Bay. Compressors and controls would be housed in a blower building located approximately 12,000 ft from Grassy Bay adjacent to what was once the Edgemere Landfill.

Five air distribution networks would be required to deliver the air at five different water column depths. Five levels were chosen to deal with the varied bathymetry of Grassy Bay, in order to achieve adequate air distribution at different depths. Four 24 inch diameter and one 18 inch diameter ductile iron mains would be used to convey the air, under pressure, to the diffuser networks at 22, 25, 30, 32 and 35 feet of depth.

Air mains would be installed in a trench from the compressor building to the diffuser network constructed at the bottom of Grassy Bay. The main piping will enter the bay area from the southwest corner of Grassy Bay. The sub-aqueous pipe trenches would be five and a half (5-1/2) feet deep and pipes would have a minimum cover of three (3) feet. The risers will be constructed of HDPE pipe and will connect the main piping to the diffuser networks. The coarse bubble diffuser networks, also constructed of HDPE pipe, would be anchored along the bottom of Grassy Bay and leveled to the noted design depths.

In order to minimize the re-suspension of the existing bottom muck, the diffuser network would be anchored five feet above the existing bottom of Grassy Bay.

6.2.3.2. Coarse Bubble Diffuser Aeration with Leveled Bay Bottom

Under Alternative 1B, the bay bottom of Grassy Bay would be re-contoured and coarse bubble diffusion would be utilized to aerate the water.

As noted in the discussion above, five different aeration networks would be required to meet the different depths for aeration if the current bathymetry of Grassy Bay is maintained. By leveling the bottom via cutting and filling, it might be possible to reduce the number of compressors, mains and provide more uniform diffuser grids, as the coarse bubble diffuser network will be set at a common depth.

Equipment similar to that used in dredging would be used to move bottom sediments from areas less then 28 feet in depth to deeper areas. In some cases the bottom of Grassy Bay would be leveled by means of dragging bottom soils and sediment across the floor, and in this manner filling the low areas in the bay. The intent is to create a relatively uniform bay floor at 28 feet.

Aeration of Grassy Bay, utilizing coarse bubble diffusion given a uniform bottom depth of 28 feet, requires compressors totaling 6,000 Horsepower (hp). Two 3,000 hp, compressors are used to meet the air supply requirements. Two 3,000 hp compressors would be supplied to meet the Department's redundancy requirements of one spare with one unit down for service. This will result in a system comprised of a total of four compressors. These compressors would be designed to deliver 57,000 (scfm) of air to the bottom of Grassy Bay. Compressors and controls will be housed in a building located approximately 12,000 ft from Grassy Bay in the vicinity of the Edgemere Landfill.

One distribution network would be used to deliver the air to the water column. One 42-inch diameter ductile iron main would be used to convey the air under pressure to the diffuser network at 28 feet of depth. The air mains will be installed in a trench from the compressor building to the risers, a distance of more then 12,000 feet. The main piping will enter the bay area from the southwest corner of Grassy Bay. The sub-aqueous pipe trenches will be seven feet deep and pipes will have a minimum cover of three (3) feet. The risers will be constructed of HDPE pipe and will connect the

main piping to the diffuser networks. The coarse bubble diffuser networks, also constructed of HDPE pipe, would be anchored along the bottom of Grassy Bay and leveled to the design depth.

Installation of the air main within the subaqueous trench and the installation and maintenance of the diffuser networks within Grassy Bay are important considerations for this alternative. Installation and maintenance of the diffuser system within Grassy Bay will also require the use of divers to place and level the diffusers and perform necessary annual inspections and repairs to the system.

6.3. Recontouring of Grassy Bay

Two alternatives were evaluated for the recontouring of Grassy Bay borrow pit with clean sand. These include the recontouring of Grassy Bay to a depth of either 4 feet or 8 feet below mean low water. Additionally, sub alternatives were evaluated for each recontouring alternative based upon the leaving in-place or removal of the muck that is currently deposited along the bottom of Grassy Bay. These sub alternatives account for multiple mobilization/demobilization to account for seasonal restrictions that may be placed on recontouring operations.

In order to develop recontour quantities, bathymetric survey data prepared by Ocean Surveys, Inc. dated October 31, 1996 was reviewed. The mapping also included information on bottom soils based on jet probes taken at the site. Using this information and taking transects across Grassy Bay, the total fill volume was calculated.

Based upon this analysis, the volume of fill required to recontour Grassy Bay to an elevation of 4 feet below mean low water was estimated at approximately 34 million cubic yards assuming the bottom muck is not removed. Additionally, a factor of ten percent was applied to allow for sand compaction during filling operations resulting in an overall fill requirement of approximately 37.4 million cubic yards.

In order to calculate the volume of fill necessary to recontour Grassy Bay to an elevation of 4 feet below mean low water with muck removal, the volume of bottom muck was calculated based on the results of the jet probes taken as part of the bathymetric survey of Grassy Bay performed by Ocean Surveys, Inc. Based upon the removal of approximately 16.6 million cubic yards of muck, a total of 50.7 million cubic yards of clean sand would be required.

A similar analysis was performed to calculate the volume of clean sand required to recontour Grassy Bay to an elevation of 8 feet below mean low water. Using the methodology described above, the fill volume was estimated at approximately 28 million cubic yards assuming the bottom muck is not removed. Additionally, a factor of ten percent was applied to allow for sand compaction during filling operations resulting in an overall fill requirement of approximately 30.8 million cubic yards.

In order to calculate the volume of fill necessary to fill Grassy Bay to an elevation of 8 feet below mean low water with muck removal, the volume of bottom muck was calculated based on the results of the jet probes taken as part of the bathymetric survey of Grassy Bay performed by Ocean Surveys, Inc. Based upon the removal of approximately 16.6 million cubic yards of muck, a total of 44.5 million cubic yards of clean sand would be required.

The source of clean sand would be the borrow area located one mile off of the Rockaways. A cutter dredge would be used to mine the clean sand and convey it through a pipeline, with booster station to Grassy Bay. In order to facilitate crossing of the Rockaways, four, four-foot diameter bores would be driven under the Rockaways. The clean sand would then be deposited within Gassy Bay using a tremmie pipe with deflector plate to minimize turbulence during the fill placement operation. Should it be determined to leave the muck in place, the clean sand would be uniformly placed in lifts along the bottom of Grassy Bay in order to minimize resuspension of the muck layer during filling operations.

6.4. Recontouring of Grassy Bay and North Channel

This alternative includes the recontouring of Grassy Bay and North Channel to an elevation of 8 feet below mean low water (Figure 6-3). Using a similar process discussed in section 6.4, and using the National Oceanographic Atmospheric Administration (NOAA) navigational chart for Jamaica Bay, the total volume required to recontour Grassy Bay and North Channel, without muck removal was estimated at 48.9 million cubic yards.

The source of clean sand would be the borrow area located off of the Rockaways. A cutter dredge would be used to mine the clean sand and convey it through a pipeline, with booster station to Grassy Bay. In order to facilitate crossing of the Rockaways, four four-foot diameter bores would be driven under the Rockaways. The clean sand would then be deposited within Gassy Bay using a tremmie pipe with deflector plate to minimize turbulence during the placement operation. Should it be determined to leave the muck in place, the clean sand would be uniformly placed in lifts along the bottom of Grassy Bay in order to minimize resuspension of the muck layer during filling operations.

6.5. Alternative Combinations

In addition to WPCP upgrade, outfall relocation and bay modification alternatives, combination alternatives were also evaluated. These alternatives included combinations of outfall relocation with bay recontouring and aeration alternatives, WPCP BNR upgrades with bay recontouring and WPCP BNR upgrades with aeration and outfall relocation alternatives.

6.6. Probable Construction Costs

Construction cost estimates were prepared based on the information contained within the conceptual design drawings for each bay modification and combination alternative. The methodology used in the estimating the conceptual project cost was developed as part of a Department effort to standardize the cost estimating process. Tables 6-1 and 6-2 shows the estimated non-factored and factored construction cost as well as Total Conceptual Project Cost for each bay modification and combination alternative, respectively.

As noted therein, total project costs includes probable construction cost which includes a ten percent construction reserve to cover change orders during construction, soft costs other costs. Soft costs include fees associated with environmental assessments and permitting, engineering/architecture,

construction management and other professional fees, cost associated with performing fixed asset surveys and staff training and development. Other costs include land acquisition and an allowance for the Setaside for the Arts program.

As the cost estimates were originally prepared in March of 2004, they were escalated to March 2006 dollars using an escalation rate of 8.5 percent per year, in accordance with Department cost estimating procedures. Additionally, contractor overhead and profit, originally calculated at thirteen percent, was increased to twenty-one percent in the final estimation of the Total Conceptual Project Cost.

6.7. Critical Habitat and Endangered Species

6.7.1. Open Waters of Jamaica Bay

A preliminary critical habitat study and ecological assessment was performed and focused on near field impacts within the open waters of Jamaica Bay. This study was prepared by Battelle with findings included in a report entitled "Critical Habitat Study and Preliminary Ecological Assessment for Three Alternatives in Jamaica Bay" dated June 2004. The preliminary assessment consisted of two tasks:

(1) Identify target species and supporting habitats
(2) Conduct a preliminary analysis of potential ecological impacts

Species identified for the treatment alternatives are found in Table 6-3. These species are those that frequently use the study area, or the area is within their critical habitat, there is the potential that adoption of the alternatives will have a direct impact on the species. According to Battelle "These concerns must be taken into account, but are not fatal flaws for any of the alternatives."

As previously discussed, a substantial amount of material was dredged from Grassy Bay and North Channel. One of the alternatives being considered to improve water quality in Jamaica Bay is to fill in the borrow pit in Grassy Bay and North Channel.

The following is a description of the issues related to physical and biogeochemical impacts by activity.

Construction Activities – The filling activities will cover the existing benthic community in Grassy Bay, and North Channel, but the impact is expected to be relatively minor because of poor habitat quality and poor benthic community that currently exists. Filling Grassy Bay will also cause some re-suspension of material, including bottom sediments and the material use to fill the borrow pit, increasing water column turbidity. This effect should be short-lived as the material is expected to settle out of the water column very quickly. Increased vessel traffic during the material placement may temporarily interrupt use of Grassy Bay by sea turtles, marine mammals, and perhaps sea birds.

Erosion and Sediment Transport – A potential cause of salt marsh decline include the deepening of several parts of Jamaica Bay to dredge navigation channels that may have started an erosion cycle by increasing tidal current strength. It was also noted by Hartig, et al, 2002 that the borrow pits in the

bay, which includes Grassy Bay may serve as suspended sediment sinks thus removing sediment that would have been available for distribution among shallow water habitats in the bay. Filling the Grassy Bay borrow pit and North Channel may allow more suspended sediment to be transported around the bay. Recontouring might also have the benefit of both removing sediment sinks (deep borrow pits) and potentially providing a new source of suspended sediments (shallower depth, sand-silt fill material).

Salinity – Filling Grassy Bay and the North Channel should not change salinity regimes within Jamaica Bay.

Stratification – Filling Grassy Bay and the North Channel will change or eliminate stratification within these water bodies. Any impact of re-contouring on stratification on areas outside of Grassy Bay and North Channel is unlikely.

Temperature – Filling of Grassy Bay and North Channel should not change general temperature regimes within Jamaica Bay.

Water Column Clarity – Filling Grassy Bay and North Channel will have short-term adverse conditions for water clarity during the placement of material.

Nutrient Dynamics – Filling Grassy Bay and North Channel should not change nutrients into Jamaica Bay.

Biochemical Oxygen Demand and Dissolved Organic Carbon – Recontouring of Grassy Bay and North Channel should not change the biochemical oxygen demand within Jamaica Bay. However, burial of the rich organic sediments currently in these areas would greatly reduce sediment oxygen demand.

Contaminants – Recontouring of Grassy Bay and North Channel should not change the input of contaminants to Jamaica Bay. Moreover, contaminants that may currently present in the sediments of Grassy Bay and North Channel will be buried and isolated from the ecosystem under the recontouring alternative.

Floatables - Filling Grassy Bay and North Channel should not change the impacts of floatables to Jamaica Bay inhabitants.

6.7.2. Background on Recontouring

As part of this report, issues associated with borrow pit restoration, in particular recontouring borrow pits for habitat restoration, were investigated. The findings summarized below reflect a wide range of cases with varying levels of applicability to Jamaica Bay. Findings are based on literature review, web searches and personal communications.

Lessons learned from bathymetric recontouring cases outside of Jamaica Bay may be the best means of anticipating feasibility considerations that will be pertinent to Grassy Bay recontouring. Each case had unique characteristics reflecting site-specific considerations. Key technical facets, including geophysics, water quality and biology were examined. Consideration of political, regulatory or public acceptability factors can drive the implementability of recontouring alternatives.

6.7.3. Recontouring General Conclusions

No projects were found to reveal technical problems that could not be mitigated relative to the conceptual plan to recontour Grassy Bay and North Channel. It should be noted that dozens of additional sites nationally are considering borrow pit restoration as a viable means of restoring habitat. However these projects are not yet far enough along to offer lessons learned.

6.7.4. Suspended Sediment From Recontouring

Suspended sediment was a potential issue at almost every borrow pit restoration project identified. It can occur at multiple stages:

- during deposition as dredged material passes through the water column;
- creation of a plume during settling and upon impact with the seafloor; or
- over time as hydrodynamic forces resuspend unconsolidated sediment.

Each project successfully addressed their respective suspended sediment concerns. Some of the projects used engineering solutions, such as placement techniques, advection controls or capping. Other projects relied on scheduling to help mitigate seasonal issues.

In general, proposed and ongoing projects adjacent to submerged aquatic vegetation (SAV) beds, or in areas with fisheries concerns, were required to address suspended solids and sediment resuspension because it might be detrimental to SAV and fish growth/survival. Two projects identified used turbidity curtains, a weighted geotextile barrier, during dredge and infill operations to protect existing SAV beds. The Barnegat Bay recontouring project was required to use a turbidity curtain during dredge and infill operations to protect adjacent SAV beds from suspended sediment. Strong currents in November and December rendered the curtain ineffectual and the regulatory agencies have not proposed nor required alternative turbidity control measures for this project.

The proposed Port of Oakland project intends to create shallow bay and shoreline habitats with the primary goal of restoring eelgrass. This project will address turbidity during construction and will monitor turbidity post-construction. The permit for this project requires the use of turbidity curtains to protect existing SAV beds, spawning herring and least tern foraging habitat. A turbidity curtain and an environmental dredge bucket, may be required based on seasonality (for spawning) and turbidity levels. Turbidity monitoring after construction will likely focus on cap integrity and eelgrass health. It is not clear whether their post-construction monitoring will include event-driven sampling to observe resuspension as storm events occur within the recontoured habitat.

6.7.5. Water Quality Improvement After Recontouring

Borrow pits, by definition, are manmade alterations to the bathymetry that usually create a region that is significantly deeper than the adjoining waterbody. Although the hydrodynamic circulation in each borrow pit will be unique, borrow pits commonly have reduced circulation and protracted residence times, which can lead to degraded water quality. Compromised biological assemblages, either pelagic or benthic, are often observed in association with the degraded water quality conditions of borrow pits.

Complete recontouring of borrow pits results in at least two changes. Recontouring eliminates the geomorphic forces that contribute to degraded water quality. Recontouring also eliminates the deeper water habitat. Only a few borrow pit recontouring projects were initiated primarily to improve water quality conditions. These include:

- The Tampa Bay Dredged Hole Habitat Assessment Project, which appears to be the most ambitious pursuit of water quality improvement in borrow pits. Tampa Bay has not yet recontoured any pits.
- NOAA was a strong advocate for consideration of recontouring that occurred at the Morris Cove site in New Haven, Connecticut due to chronically low dissolved oxygen levels.
- Corps of Engineers modeling showed that borrow pit recontouring is amongst the most promising management actions that can be taken, in association with nutrient load reduction, to improve water quality in the San Juan Bay estuary.

Most dredged material management scientists interviewed agreed that improved water quality conditions was a reasonable expectation following borrow pit restoration. However, water quality monitoring was not commonly part of post-construction assessments. The Central Long Island Sound dredged material disposal site (not a borrow pit) received dredged material and a cap in 1995. Follow up monitoring one year later observed improved dissolved oxygen levels and continued benthic recolonization. Water quality improvements realized after borrow pit recontouring elsewhere support the notion that recontouring may improve dissolved oxygen levels in Grassy Bay and the North Channel.

6.7.6. Pre-Construction Usage of Pits By Fish, Plants or Invertebrates

As part of the Tampa Bay Dredged Material Management Strategy, the USACE is investigating infilling existing dredged holes (~15' deep) with dredged material as a beneficial reuse project with the long-term goal of habitat restoration. Evaluation of the existing habitat value of the holes found that many of the holes currently provide good habitat or temporary refuge for fish and invertebrates (even though they are man-made).

Barnegat Bay, New Jersey is in the process of recontouring one dredged pit from 33 feet to 18 feet with clean fill in order to restore habitat. Examination of the pits revealed that fish, especially juveniles and adult weakfish (*Cynoscion regalis*), utilized the intermediate depths of the pits as a refuge area. The protection of fisheries resources and SAV beds dictated the design of the project to recontour to18 feet. For benthic community health, the USACE had originally proposed infilling the pits to surrounding water depths but this design was altered to reflect fisheries and SAV concerns. Construction was completed and while post-construction biological monitoring is desired, funding has not been secured.

6.7.7. Post-Construction Recolonization by Plants or Invertebrates

The rate and extent of recolonization is unique to each borrow pit recontouring project investigated. There are no inherent factors that constrain eventual recolonization of a recontoured seafloor. Factors that can influence recolonization in the short term include:

- sediment characteristics (grain size, mineralogy, organic content and texture);
- regional benthic community present for recruitment;
- short term physical alteration (settling, consolidation, dewatering, de-gassing); and
- short term erosion of unstable sediment surfaces.

In general, the effort to restore or create eelgrass habitat and benthic habitat has been successful where the proper elevations and contours have been achieved and the proper substrate is placed as the new seafloor. Extensive benthic surveys were conducted within some of the borrow pits recontoured as part of the Boston Harbor Navigation Improvement Project. Recolonization was observed at varying levels across borrow pit stations. Generally, the diversity observed was already similar to those seen in Boston Harbor and Western Long Island Sound.

Initial recolonization has been observed even before the geophysical and geochemical makeup of the recontoured seafloor reaches its new equilibrium. Borrow Pit East (BPE) was recontoured with what was assumed to be clean material in association with development of the Chek Lap Kok airport in Hong Kong. A reconnaissance survey of BPE just 3 months after recontouring revealed recolonization had already begun in some portions of the former borrow pit. In the Boston Harbor borrow pits it appeared that recolonization began within days or weeks of deposition.