Nitrogen

Based on the performance of well developed marsh systems to the north of this region, it is predicted that restored marshes around the Pelham Bay Landfill will remove approximately 40 lbs of nitrate per acre per year (Valiela & Teal 1979a; 1979b; DeLaune et. al. 1989; White & Howes 1994). By extrapolation, this would lead to 1,200 lbs nitrate removal for 30 acres each year. While nitrate reducers are common in well developed salt marshes and in silty sediments, they do not readily develop in more porous media such as sand because of porosity and oxygen inhibition (Thompson, et. al. 1995; Currin et. al. 1996; Zedler et. al.). This was noted by early researches on nitrogen metabolism in marshes (Kaplan, W. I. Valiela, & J.M. Teal. 1979: Valiela, I. & J.M. Teal. 1979), but has not been tested developmentally with a specific focus on nitrate removal. Royal Marina sediments contain little or no sand, and do contain silts and clays, so these should support denitrifying microbial communities.

Carbon: Biochemical Oxygen Demand/Dissolved Organic Carbon.

Dissolved organic carbon, and especially biochemical oxygen demand or BOD have been characterized in many wetlands (Hammer et. al. 1993; Kaklec & Knight 1996), and in salt marsh environments. While removal rates vary, since BOD metabolism largely depends on aerobic microbes, removal rates develop relatively more quickly, and remove much higher qualities per area of marsh, than can occur with nitrate removal. Expected removal capacity would be in the range of tons of BOD per acre per year. Measures of an increasing number of constructed wetlands fall in this range.

	BOD (mg/L)	total loading kg BOD/d	treatment area in m2	removal rate in lbs/acre/d	removal rate in tons/acre/yr	removal rate tons/30 acres/yr
influent	110.80	90.00	3,600.00	132.63	24.20	726.13
effluent	6.10	36.00				
% removal	90.40					Hammer et. al. 1993.

These data indicate what appears in many reports on BOD removal rates. While these can be quite variable, well designed or well structured wetlands often achieve order of magnitude reductions, and these facilities can remove tons per acre per year. While these are freshwater systems, microbial counts suggest that saltmarshes should have equivalent or higher performance values.

The Arcata marsh in Humbolt County, California, was divided into ten cells, with varying hydraulic loadings and detention times. These behavior of these cells indicates an expected range of behavior for constructed marshes generally which are working with lower loadings:

hydraulic loading rate in m3/m2/d	hydraulic loading rate in ml/m2/d	total BOD removed in mg per m2	total BOD removed in kg/m2/d	total BOD removed in lb/acre/d	total BOD removed in tons/ acre/yr	BOD removed tons/30 acres per year
0.24	240,000.00	3,792.00	3.79	33.57	6.13	183.79
0.06	60,000.00	996.00	1.00	8.82	1.61	48.27

The extrapolation for a thirty acre marsh is given to indicate what may be expected in terms of water quality enhancement from the building of the whole Pelham Project. In round numbers, a marsh of this scale could remove between 50 and 200 tons of BOD per year at loading rates of tens of parts per million BOD, which may be expected in Western Long Island Sound. A marsh of this scale behaving at this level would measurably improve water quality in and around Eastchester Bay.

Hydrocarbons

"Microorganisms can degrade any organic compound"(Atlas 1978). This statement is true, in general, as applied to hydrocarbons, although, as the author notes "In reality, there are many complex hydrocarbon structures that are either recalcitrant or at least very resistant to microbial degradation" (Atlas 1978). Under the right biogeochemical conditions of nutrient availability, redox state, and microbial community structure, however, even recalcitrant molecules can be mineralized through a number of steps (DeLaune et. al. 1980; Gambrell et. al. 1981; Evans & Fuchs 1988; Gambrell & Patrick 1988; Heitkamp, MA. & CE Cerniglia 1988; Cerniglia 1992; Wilson & Jones 1992; Lee & Banks 1993; Rielley et. al. 1996).

More hydrocarbons are moved through the Port of New York and New Jersey than any other harbor in the world. This activity, plus the thousands of miles of roadway, and tens of millions of car and truck miles logged daily on City streets and highways inputs substantial quantities of hydrocarbons into the estuaries surrounding New York. Three major sinks for these materials are photooxidation, soils, and sediments. Each of these provide some treatment capacity, and while some work has addressed each of these, the majority of research to date has probably occurred in soils (Dragun 1988;). More than fifty different microbially mediated biochemical transformation and cleavage reactions of hydrocarbons in soils have been identified in categories including methylation, ether formation, N-acylation, nitration, nitrosation, and dimerization (Dragun 1988; Lee & Banks 1993). It is likely that most of these reactions also occur in sediments, and especially in the dynamic, heterogeneous rhizosphere environments afforded by salt marsh development.

With such great quantities of the material being moved, crude oil spills affecting estuaries during loading and unloading and other accidents occur with some frequency. Where concentrations are not too high, breakdown rates in sediments can be substantial. The table below is based on the rates of crude oil mineralization on sand columns. By extrapolation, it suggests that about a tenth of a ton of crude oil can be metabolized on a acre of biogeochemically active sediments.

	degradation rate in mg of oil per m2 per day	degradation rate in grams of oil per m2 per yr	degradation rate in lbs of oil/acre/yr	rate in tons of oil/30 acres/yr
Kuwait crude oil	90.00	32.85	290.80	4.36

(Johnston 1970, as reported in Atlas 1981).

Lighter fraction petrochemical components of gasoline, other fuels, and solvents also find their way into the estuary. A number of these materials can cause cellular damage in metazoans, and pose potential risk through inhalation or skin contact. This has led researchers to characterize breakdown rates for toluene and xylene under sulfate reducing conditions, which are typical of salt marsh and mudflat systems. Breakdown rates for these potentially problematic compounds where measured in terms of removal per milliliter of sediment. In order to apply these findings to natural systems capacities, it was assumed that only one cubic centimeter per square centimeter behaved with the capacities reported in this mesocosm study. Given these assumptions, a salt marsh would have the capacity remove toluene and xylene in the pounds to hundreds of pounds per acre range, or in the tenth of a ton to ton range for tens of acres, as indicated in the table below.

toluene & xylene	degradation rates in mg/l	degradation capacity/top lbs/acre/yr	degradation capacity- tons/ 30 acre/yr
lowest rate	0.10	8.08	0.12
highest rate	1.50	121.17	1.82

(Edwards et. al. 1992)

These results indicate that salt marsh microbial communities mineralize certain toxic benzene derivatives. This suggests that actual rates of mineralization on salt marshes is similar to earlier work on sand columns noted above. Thus these systems afford protection to human health and ecological integrity.

Polynuclear aromatic hydrocarbons (PAHs) are ubiquitously distributed molecules in the New York/New Jersey Harbor Estuary. These chemicals of concern are also one of the warning signs vis a vis the disposal of dredgings, since they are relatively refractory, and can be mobilized into food chains and food webs. Nonetheless, PAHs can be mineralized under biogeochemical regimes found in salt marshes. In a case study of an oil spill on a Georgia salt marsh, phenanthrene, chrysene, and fluoranthene were spiked in sediments. Concentrations remained high, around a hundred parts per billion, for about 45 days, followed by a rapid decrease over the next hundred days. Reduction by a factor of three to an order of magnitude occurred with these three compounds, with phenanthrene showing the greatest reduction, and fluoranthene the least in this timeframe, as indicated in the table below (Lee et. al. 1981).

PAHs	initial concentration ng/g sediment	concentration on day 150 ng/g sediment	removal ng/g sediment	removal rate g/acre/year	removal rate g /30 acre/year
phenanthrene	115.00	0.50	114.5	4.60	138.05
chrysene	105.00	15.00	90	3.62	108.51
fluoranthene	75.00	20.00	55	2.21	66.31

These inferred removal rates are about two orders of magnitude lower than rates for benzene derivatives given above. It is interesting to note that the initial concentrations in this study are at the same an order of magnitude as the EPA Region 3 screening level (US EPA 1991a; US EPA 1991b; US EPA 1991c), while concentrations after microbial activity are below these screening levels.

The removal rates given may, in fact, be underestimating actual breakdown. The reason for this is that bacteria consume easily metabolized materials first, and thereafter, enzyme induction must occur to metabolize the more refractory materials (Cookson 1995). Much of the literature of bioremediation in fact shows this classic pattern from biochemistry where a lag occurs after introduction of nutrients until simpler metabolites are no longer available, and the induction of specific enzymatic groups is completed by the populations or consortia of microbes involved in the biogeochemical work. This can be seen in the above data, where active metabolic activity was not initiated until day 45. Thereafter, the half life of the PAHs was about 50 days.

Where enzymes are already induced, total PAH metabolism can be much greater. Chrysene was spiked into sediments which had already been contaminated with oil, where enzyme activity had presumably been induced prior to the chrysene addition. As noted in the table below, by extrapolation of these data on metabolism of chrysene, about a pound would be removed by each acre of marsh each year.

	breakdown rate ng/g sediment per day	removal nanograms m2 sediment per day	removal g/acre per year in top cm of sediment	removal lbs/acre per year in top cm of sediment	removal lbs/30 acres/ year in top cm of sediment
chrysene	35.00	350,000.00	513.43	1.13	33.93
control	5.00	50,000.00	73.35	0.16	4.85

While some of the higher molecular weight PAHs may persist in some sediments over time (Herbes & Schwall 1978), breakdown rates of the lighter fractions appear to be high enough to reduce concentrations of hundreds of parts per billion to levels of a third to a hundredth or less of this concentration (Herbes & Schwall 1978; Edwards et. al. 1992).

16.The extensive body of knowledge on the treatment of pollutants by natural and constructed wetlands has by now contributed many thousands of peer reviewed papers in the US alone. Even landfill leachate is now regularly treated with constructed and restored wetlands.[1] The burden of proof now lies with anyone attacking these peer-reviewed publications to prove that these findings are false, or non-replicable. This is unlikely at this juncture in the development of the science.

Recognizing this, however, we nonetheless agree with the assessment that any assumptions regarding how restored or constructed wetlands will behave vis a vis specific pollutant loadings in Eastchester Bay are, in essence, unsupported unless and until the Pelham Project is built and the tests actually carried out. The Pelham Project was, in fact, specifically designed to fill hydrodynamic, geophysical, biological, ecological, hydrodynamic, and geochemical gaps in the knowledge base of ecosystem restoration. It can only do this by resting firmly on prior work. For example, the abbreviated bibliography of the Technical Appendix contains more than ten references to hydrocarbon degradation by biogeochemical systems. The Gaia Institute database contains more than a hundred more. Together with those in the prior footnote, these references

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1<u>Constructed Wetland for the Treatment of Landfill Leachate</u>, ed. by G. Mulamoonil, E. McBean, and F.A. Rovers. 1998. Lewis Publishers, Boca Raton, FL. Leachate Treatment System Using Constructed Wetlands, Town of Fenton Sanitary Landfill, Broome County, New York. 1993. Energy Authority Report 94-3 (dated November 1993). Energy Research and Development Authority. <u>Constructed Wetlands for Water Quality Improvement</u>, ed. by G.A. Moshiri, Chapts 50, 51, & 52. Lewis Publishers, Boca Raton, FL.

themselves contain many hundreds to thousands of references from peer reviewed literatures describing hydrocarbon mineralization under various circumstances. These facts, however, are as yet unsupported by tests in constructed marshes on dredged sediments around the Pelham Bay Landfill. Such specific tests are the purpose of the Pelham Project, which aims to provide rigorous evaluation of physical and biogeochemical processes through continuous and real time monitoring of inputs and outputs. Existing literature has thus been pressed into the service of a general predictive framework on the behavior of biogeochemical systems vis a vis specific pollutants and toxics. Since the existing literatures lack the requisite specificity and interdisciplinary syntheses necessary to predict input and output behavior of developing intertidal marsh and microbial communities, the Pelham Project will utilize before and after measures, as well as the closely monitored dynamic behavior of these environments to put their description on a much more rigorously defined foundation.

Pathogens

Stormwater runoff, combined sewer discharges, as well as discharges from water treatment plants all contribute pathogens to the receiving waters. Because these organisms require a host for reproduction, their existence and half life in receiving waters is limited by the biogeochemical filtration rates of these waters. Because wetlands increase the probability of contact between pathogens and biogeochemical surfaces, they increase the removal rate, and decrease the half life of pathogens.

location		system influent	performance effluent	% removal
Santee, CA	bulrush			
Winter season (Oct- Mar)				
Total coli no./100 ml.		50,000,000	100,000	99.80%
Bacteriophage, PFU/ml		1,900	15	99.21%
Summer season (Apr-Sept)				
Total coli no./100 ml.		65,000,000	300,000	99.54%
Bacteriophage, PFU/ml		2,300	26	98.87%
Iselin, PA	cattails & grasses			
Winter season (Nov-Apr)				
Total coli no./100 ml.		1,700,000	6,200	99.64%
Summer season (May-Oct)				
Total coli no./100 ml.		1,000,000	723	99.93%
Arcata, CA	bullrush wetland			
Winter season				
Total coli no./100 ml.		4,300	900	79.07%
Summer season				
Total coli no./100 ml.		1,800	80	95.56%
Listowell, ONT	cattails			
Winter season				
Total coli no./100 ml.		556,000	1,400	99.75%
Summer season				
Total coli no./100 ml.		198,000	400	99.80%

(Bastian & Hammer. 1993).

As can be seen from these data, constructed wetlands reduce pathogens by one to three orders of magnitude.

This is likely to be an underestimate of pathogen removal for intertidal wetlands, however, since filter and suspension feeders are often a major component of these communities, and since a strip of mussels 2 feet wide and 250 feet long can completely filter the three acre feet of water (≈ one million gallons) that covers acre of tidal marsh each day. Ribbed and black mussels (*Geukensia demissa* and *Mytilus edulis*), as well as soft shell clams (e.g. *Mya avenaria*), are often major components of the salt marsh fauna in and around Eastchester Bay. Where rocky or piling habitat is available, barnacles are also present in large numbers. Mussel densities can be quite high. A square yard of mussel bed yielded 1612 *Mytilus* individuals (p396 Between Pacific Tides, E.F. Ricketts & J Calvin, Stanford Univ. Press, 4th ed., 1968), which comes to about 180 per square foot, similar to mussel numbers in specific areas of salt marshes in Pelham Bay Park (PS & JA Mankiewicz, unpublished data).

Mussels have been found to filter water at rates of around 250 cm3 (g soft tissue)-1 h-1 or (in some experiments) rather faster". (p311 The Invertebrates R. McNeill Alexander Cambridge 1979). This means it would take roughly 1,300 grams of mussels to filter 2000 gallons in one day, or about 9 grams per square inch, a density found in many mussel beds.

A mussel 70 mm (about 2 1/2 inches) long filters, at some 60% efficiency, the plankton and suspended detritus out of 60 liters of water a day, or 22,000 liters of water a year". (p396 Between Pacific Tides, E.F. Ricketts & J Calvin, Stanford Univ. Press, 4th ed., 1968). This would require some 130 mussels of this size per square foot (about one per square inch in the foot square area) to filter 2000 gallon per day. Pumping water at this rates, it would take about 500 $ft.^2$ of mussel beds to filter the three acre feet of water over a one acre salt marsh.

Metals

Metals are of concern in estuaries, and rates of metal sequestering have been studied under different loading conditions. In Great Sippissiwisset Marsh in Cape Cod, metals were loaded onto quadrats in the marsh, and measurements were taken of metals retained in sediments, taken up by plants and animals, and exported from the marsh. Loadings were generally in the tens to hundreds of milligrams per square meter range, or tens to hundreds of parts per million per square meter, while sediment quantities varied into the hundreds of parts per million. The variability of the sewage sludge applied as a metal source, and the intrinsic variability in marsh components constitute serious methodological defects in the Giblin et. al. 1983 study. Sequestering rates were in the milligrams to tens of milligrams per meter squared per year. Percent sequestered is given below.

Cadmium	Iron	Manganese	Zinc	Chromium	Copper	Lead
15%	24%	27%	28%	45%	49%	60%

More recent work on fully contained mesocosms have shown some similarities to this earlier work. More carefully controlled and measured inputs and output, however, have led to better documentation of system behavior. As the mesocosm work of Sinicrope et. al. 1992 indicates, sequestering rates for most metals may be lower than that reported in earlier work, and, in the case of copper, under some conditions, there may be little sequestering of this metal in estuarine systems.

	Cadmium	Chromium	Zinc	Lead	Nickel	Copper
% sequestered	75%	75%	75%	84%	55%	
loadings mg/m3/d 96 l/day (low) Aug-Dec 1990	13.20	18.90	56.70	56.70	56.70	11.3
loading in mg/l	0.07	0.10	0.30	0.30	0.30	0.06
loadings mg/m3 110 l/day (high) Jan-Aug 1991	16.00	18.90	572.00	68.70	68.70	275
loading in mg/l	0.07	0.10	2.50	0.30	0.30	1.2
Aug-Dec'90 load	2376	3402	10206	10206	10206	2034
Jan-Aug'91 load	2880	3402	102960	12366	12366	49500
Annual load-mg	5256	6804	113166	22572	22572	51534
Annual sequestering capacity						
in g/m3	4	5	85	19	12	0
in g/m2*	0.59	0.77	12.72	2.84	1.86	0.00

According to these findings, where loadings are in the tens of milligrams of metals per cubic meter of sediment per day, removal / sequestering rates may be relatively high. Since sediments in contact with the rhizosphere are prone to redox changes and metal mobilization, it should be recognized that these areas may be regulators of metal movement, but not ultimate sinks for the metals tested here. On the other hand, direct and indirect measures indicate that marshes and sediments are resistors and regulators of the movement of metals, and as such, afford some protection to human health and to surrounding food chain and food webs. These data indicate, however, that marshes act as regulators of metals at the tens of parts per billion level. At higher concentrations, marshes may become sources for metal release into estuaries. In sedimentary environments, however, marshes may be expected to accrete metals, especially lead, over time. Migration of some metals from sediments containing parts to tens of parts per million should also be regulated or suppressed in a sedimentary environment. Arsenic, cadmium, chromium, copper, lead, nickel, and zinc occur in the Royal Marina sediments in this range, and will be investigated as to mobilization.

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* if sediment sampling depth to 15 cm, as implied but not stated in paper.

4.2 Any adverse environmental effects which cannot be avoided should the proposal be implemented;

Dredging resuspends some sediments. While this can be mitigated, to some extent, by using silt curtains to contain the distribution of materials in suspension, there are limits to the efficacy of these measures. One reason for this is physical. A coarse silt particle 0.01 mm in diameter settles at 1/10,000 of a meter per second, or, a meter in about three hours (Peavy et. al. 1985, p131). Fine clay particles may take as much as a day to settle 1 meter. Silt curtains would therefore have to be left up for one to several weeks for these particles to fully settle out.

Some resuspension is also likely to occur while placing the sediments in the containment facility. While the exact mitigation steps to minimize negative impacts have not been yet worked out for this operation, the rock armor of the containment facility, and finer rock of the central core (if the facility is constructed in this way), would act to minimize suspended sediment dispersal because quiescent waters in the interstices between armor and gravel are from part of an inch to a few inches in diameter at a maximum. For the particles left suspended within these spaces, settling rates would be relatively large compared to the dimensions of these spaces and forces acting to move water out of these interstices. Similarly, gravitational and viscous forces on these intersticial spaces would be large compared to pressure differences acting to move water through these openings. While finer silts, clays, and organic colloids may settle only a meter or less in a year, other mechanisms such as coagulation with algae, bacteria, larger organic and inorganic particles, and adhesion to surfaces act to remove these materials from the water column.

With silt curtains around the perimeter of the entire 600' length and 270' width of the Royal Marina, to an average depth of 6', effects would be limited to about a million cubic feet, or about seven million gallons of water. By way of comparison, this quantity of water is about one three hundredths of surrounding Eastchester Bay, or about one third of one percent.

To compare this adverse environmental impact in terms of the effects of the Pelham Project's restoration of salt marsh, about ten acres of tidal marsh would filter out the fines in about a million cubic feet of water in one tidal cycle. So while the initial dredging of 20,000 yards of sediments from Royal Marina will increase the load of suspended solids in about a million cubic feet of water, a one and one half acre marsh constructed with these sediments would physically filter a million cubic feet of water in about a week, and continue in perpetuity to filter about 50 times this quantity each year. Using similar projections as hypotheses, the Pelham Project aims to quantify these filtration and sedimentation rates in constructed and control marshes.

4.3 Alternatives to the proposed action;

With two possible actions of dredging or non-dredging, and wetland construction vs no wetland construction, there are only four possible outcomes: no dredging and no wetland construction; dredging with no wetland construction; no dredging with wetland construction; and dredging and wetland construction.

<u>No Action Plan: No Dredging and No Wetland Construction.</u>
If the sediments at the Royal Marina are left in place, contaminants will not necessarily remain 'locked in the sediments'. Natural forces are likely to intervene, and resuspend sediments in the water column through storm surges or wind driven wave action from the southwest. From

anthropogenic causes, sediments will also be resuspended by the 30 to 40 foot per second scour of inboard and outboard motor thrust. While shallower slips are often less costly, they may leave power boats unusable during parts of the tidal cycle. Vessels of all sizes have utilized 'hydraulic dredging', turning up the throttle while docked to resuspend sediments to deepen slips and dockage, creating negative impact on the surrounding estuary. It is likely that such activities usually occur without regard for windows of least impact on fish or shellfish life cycles. Dredging, on the other hand, would be done as a staged activity, in a regulated fashion, with due regard to spawning periods of fish and shellfish, larval settlement, juvenile sensitivities, and other key parameters of the life cycles of the biota in the surrounding waters .

The no action plan would have other impacts, as well. While dredging can add value to a marina, any potential for water based uses will be irretrievably lost without dredging. Derelict properties adjacent to the Royal Marina attest to the financial difficulties of water based economic activities in recent years. The non-dredging scenario will inevitably lead to consideration of other, non-water based uses of these waterfront properties. Commercial developments presently under consideration include a crematorium, and shops and condominums. The latter would add stresses on existing infrastructure, from crowded roadways, to crowded classrooms. In other words, the no action plan would have irretrievable effects in the immediate and the long term future of water based economic activity of City Island, and concomitant negative effects on the Long Island Sound coastal communities of Queens, the Eastern Bronx, and surrounding coastal counties in general.

Dredging Without Building Local Wetlands.
Sediments may be removed from the Royal Marina and disposed of upland or below the waterline without the construction of intertidal marsh habitat. While this reflects past disposal options, this is now possible only in theory, since there are no cost-effective disposal means which would be affordable for the Royal Marina or other similar facilities. While dredging alone would alleviate short and mid term problems of slip depth, allowing access of deeper draft vessels through all parts of the tidal cycle, it does not address the problem which bulkhead and seawall infrastructure have created in channelizing flow and eliminating shallow, depositional, productive marsh environments. Also, disposing of sediments rather than incorporating these in habitats which remove BOD, nitrate, and suspended solids does not benefit water quality in the region where the dredging occurs. Neither can upland or deep water disposal support fin fish habitat creation and production. Finally, these alternative disposal means do not in any way rectify the local loss of more than a thousand acres of salt marsh, rocky intertidal, and rocky subtidal habitat or the historic net loss of 45,000 acres (90% to 99%) of tidal wetlands in the whole of New York City.

Since the cost of dredging itself may account for one to several years of profit from a marina, disposal costs are key to maintaining water based activities on coastal properties. Since even the cost of testing sediments may be a substantial fraction of a years profits, low cost local disposal is a necessary inducement to do such testing, since sediment testing may not otherwise be perceived to be a good investment for marina owners. Since time and distance set certain costs in any dredging job, local disposal of local dredging projects provides efficiencies which otherwise are not available.

Building Local Wetlands Without Dredging. Building wetlands serves water quality goals, and increases fisheries production. Since each acre of tidal wetland has been valued at $75,000 as a water treatment facility (Miller Living in the Environment, p 150), the thirty acre wetland proposed in the Pelham Project would be worth about $2,250,000. The same source has valued commercial and recreational fisheries production by an acre of wetland at about $8,000/acre/yea (more broad based approach by Costanza et. al. 1997, arrives at a figure between $4,000 and about $9,000/acre/year for similar contributions to ecosystem services) For the proposed 30 acre wetland, this adds up to about a quarter million dollars per year in perpetuity. Wetland construction alone could also contribute to the settlement of legal disputes. For example, a law suite has been filed against New York State by the State of Connecticut for polluting western Long Island Sound. In this context, marshes play a major regulating role in the nitrogen cycle, facilitating particulate organic nitrogen deposition in marshes, warm weather nitrification of ammonia, and 40 lbs/acre/year nitrate removal. Thus constructing marsh systems may then be considered, with other point and non-point pollution programs, as a means of meeting agreed upon standards (Valiela & Teal 1979a; 1979b; DeLaune et. al. 1989; White & Howes 1994). Denitrification along could account for half a ton per year nitrate removal by 30 acres of marshland, and the cost of building such wetlands may be one of the mitigation steps considered as a cost-effective means of meeting interstate water quality goals.

Coupling Local Dredging with Local Wetland Restoration Projects. While salt marshes would be of value to build for themselves for pollutant removal and fisheries production. But for whatever purpose they may be constructed, such marshes need to utilize specific size classes of sediments. These materials are available at Royal Marina and at other sites in local channels and docking areas. Using these sediments adds value to the rest of the local, regional, and New York State water based economy by allowing greater use of the surrounding waterways, and, where incorporated into intertidal marshes, by removing two causes of hypoxia and concomitant fish kills, BOD and nitrate, while increasing fish habitat size, contiguity, and complexity (Bohnsack et. al. 1991; Irlandi & Crawford 1997) and thus adding to commercial and recreational fisheries. Using these specific sediments also diminishes the cost of marsh construction, precisely because they are locally available.

21. Alternative disposal options & costs, upland and in-water: As the closure of many marinas over the past decade indicates, maintenance dredging costs have become, in many cases, prohibitive. The following four upland and two subaqueous cases provide direct examples of the kinds of cost multipliers of maintenance which are diminishing the viability of the water based economy.

Available disposal costs:

OENJ site:	$56/cubic yard
SeaLand Site	$47/cubic yard
SK Koppers Koke	$47/cubic yard
New Bayonne (OENJ)	mid 30s, + dredging, probably $40-$42/cubic yard
Newark Bay subaqueous pit	$29 + dredging, $34/cubic yard
HARS- unrestricted	≈$10/cubic yard

These pricing translates into dredging costs which are comparable in scale to major capital investments in marinas. The dredging cost for a twenty thousand yard job thus ranges from about two hundred thousand to more than a million dollars.

disposal cost/cu yd	cost/20,000 cu. yds

Pennsylvania mines (estimated)	$70	$1,400,000
OENJ Site	$56	$1,120,000
SeaLand Site	$47	$940,000
SK Koppers Koke-Kearney	$47	$940,000
New Bayonne (OENJ) Site	$40	$800,000
Newark Bay Subaqueous pit	$34	$680,000
HARS-unrestricted (low volume)	$12	$240,000
HARS-unrestricted (high volume)	$9	$180,000

These dredging and disposal costs can be measured against annual marina income streams. Yearly charges for boats are about a hundred and ten dollars per foot. This covers both summer dockage and winter storage. The contribution of this major income stream is limited by the number of boats which can be accommodated. The figures below indicate the number of boat customers necessary to cover these dredging costs:

	disposal cost/cu yd	cost/20,000 cu. yds	cost in terms of number of 30' boats stored at $110/ft/yr.
Pennsylvania mines (estimated)	$70	$1,400,000	424
OENJ Site	$56	$1,120,000	339
SeaLand Site	$47	$940,000	285
SK Koppers Koke-Kearney	$47	$940,000	285
New Bayonne (OENJ) Site	$40	$800,000	242
Newark Bay Subaqueous pit	$34	$680,000	206
HARS-unrestricted (low volume)	$12	$240,000	73
HARS-unrestricted (high volume)	$9	$180,000	55

Noting that the Royal Marina, one of the larger facilities on City Island, can service about a hundred boats, it is apparent that the highest dredging and disposal costs would eliminate all income from this stream for three to four years. The lower dredging and (subaqueous pit) disposal costs would eliminate income for about two years, while even HARS disposal would eliminate most of a years income. Since this dredging would also defer any profits for five to ten plus years, from a fiscally responsible business perspective, dredging could not be justified.

4.4 The relationship between local short-term uses of the environment and the maintenance and enhancement of long-term productivity;

Where sediments are not incorporated into depositional environments, the historic pattern in the Hudson River Estuary and Long Island Sound, development of intertidal habitats which increase ecological productivity, water quality, fisheries production, and environmental health is suppressed. Where such depositional environments become intertidal, they develop increasing capacities to remove chemicals of concern, including dissolved organic carbon (BOD fraction), nitrogen in the form of nitrate, hydrocarbons, and some metals.

In both short and long term, regional New York City and local Eastern Bronx coastal environments have lost most of their biochemical and geochemical buffering capacity, as well as the majority of shoreline erosion and flood control protection they previously afforded. Channelization, bulkheading, and straightening the coastline all proceeded by in filling in the majority of these wetlands. Evaluated against present measures of marsh capacity, these losses are very large, probably amounting to the removal of 90 to 99% of prior biogeochemical buffering capacity and perhaps a similar reduction in fisheries production. In essence, human built infrastructure has largely eliminated the physical processes in estuaries which had previously incorporated sediments into the productive capacities of estuaries. The coastal environmental has been structured to largely eliminate intertidal depositional environments and the critical habitat these areas provided. The development and accretion of marshes and flats in this manner has been arrested. Human built infrastructure has thus reduced or eliminated long term water quality enhancement from the development of these natural systems.

In the short term, the economy of the Port of New York, together with regional and local economies dependent on water based activities are either declining, or growing at a lower rate than well developed maritime infrastructure would allow. Economic components of the Port are thus suppressed in the short and long term, as are those populations and ecological communities of the estuary dependent on depositional areas, together with the ecosystem services they provide for environmental quality enhancement and fisheries production. This will continue indefinitely into the future under the no action plan.

4.5 Any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented.

The major irreversible and irretrievable change involved in the proposed action should it be implemented is the covering of sedimentary benthic habitat, due to the placement of dredge materials to bring the salt marsh restoration to the proper grade. As discussed above, this loss of sedimentary benthic habitat is balanced by production of equal or greater quantities of rocky tidal and subtidal habitat, which was historically more prevalent in this area than it is now.

In terms of commitments of material resources to build the facility, the Pelham Project aims to quantify how well contaminants in sediments can be effectively broken down or sequestered in constructed salt marshes within containment facilities. To do this, it will be necessary to modify the coastline so that it once again supports larger intertidal marsh communities, as the geomorphology of the coast did in historic times. The capital resources involved in this change are quite modest, even including the cost of initial and on-going studies. The material resources, rock armor for the containment facility together with harbor sediments, are already geo-physical and geo-chemical components of the ecological systems of the estuary. Since it is necessary to move sediments to make the Port of New York viable, and since sediments, and the rock armor to contain them, are essential components of intertidal salt marsh and rocky habitat, the aim of this project is to restore coastal communities which, to this moment, have been irretrievably lost to bulkheading and channelization.

In this case, the environmental impact of the no action plan will lead to the irreversible and irretrievable loss of the competitive viability of the Port of New York, and to a continuance of the status quo of relative economic decline of the water based economies of the region. On the other hand, constructing wetlands on sediments dredged from nearby piers and channels to create salt marshes will incrementally serve local, regional, and national economies by lowering the costs of water based activities and transport while increasing water quality in the process.

5.0 Clean Water Act

Under the Clean Water Act guidelines, and in compliance with the Clean Water Act (CWA), a Joint Application for Permit was filed with the New York Department of Environmental Conservation and the United States Army Corps of Engineers, New York District for approval. The Pelham Project may uniquely fit the intent of the congressional declaration on the Clean Water Act, which addresses the following goals (headings as given in CWA):

> •(a) "Restoration and maintenance of chemical, physical and biological integrity of Nation's waters; national goals for achievement of objective The objective of this chapter is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters....
>
> •(2) "it is the national goal that wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water...;
>
> •(3) "it is the national policy that the discharge of toxic pollutants in toxic amounts be prohibited;
>
> •(6) "it is the national policy that a major research and demonstration effort be made to develop technology necessary to eliminate the discharge of pollutants into the navigable waters, waters of the contiguous zone, and the oceans; and
>
> •(7) "it is the national policy that programs for the control of nonpoint sources of pollution be developed and implemented in an expeditious manner so as to enable the goals of this chapter to be met through the control of both point and nonpoint sources of pollution.

On all of these points, the Pelham Project is specifically structured to reach the water quality and ecological goals in question.

- •(a) The objective of the Pelham Project is the restoration of physical, chemical and biological integrity and activity in order to restore the ecosystem services of lost wetland, intertidal and benthic habitat.

- •(2) This project aims to increase the habitat diversity, biodiversity, ecological productivity, and essential fish and waterfowl habitat in and around Eastchester Bay, increasing the value of this area for fishing, boating, and swimming in the process;

- •(3) The Pelham Project aims to remove toxics and pollutants from Eastchester Bay, especially BOD, nitrate nitrogen in stormwater and combined sewer overflow, and landfill leachate from these waters to improve water quality and diminish the potential for fish kills and hypoxia;

- •(6) It is the mission of the Pelham Project is to demonstrate the feasibility, long term stability, and advantages of engineered constructed wetlands for dredge material treatment and disposal. This research and development program aims to integrate questions from engineering, hydrodynamics, geophysics, biology, and geochemistry to address the removal of chemicals of concern through the ecosystem services provided by wetlands constructed on dredged materials. This research program aims to quantify the pollutant removal by the ecologically based technology of wetland construction and restoration.

•(7) The construction of wetlands around the Pelham Bay Landfill and the southern tier of Pelham Bay Park has the specific goal of removing pollutant inputs from point and non-point sources including storm water, combined sewer overflow, and landfill leachate, while removing or sequestering contaminants in dredged sediments.

The Pelham Project strongly supports the essence of the "no net loss" concept of the Clean Water Act and wetland protection by serving to enhance and expand Eastchester Bay intertidal wetlands including salt marsh and rocky habitat, together with rocky benthic habitat. This also fits the requirements of more recent regulatory aims to enhance Essential Fish Habitat while increasing the beneficial functions and values of these habitats, including, but not limited to, sediment decontamination.

This project reflects the "no net loss" objectives while at the same time moving to protect human health. Because the Pelham Project aims to improve water and sediment quality by enhancing water based economic activity, it provides opportunities for coordination and cooperation between regulatory agencies, applicants, public and private conservation organizations, and investors in water based economic activities to increase wetland diversity and acreage, protect and purify fresh water inputs into estuaries, and support the biota that rely on these waters. This project has the potential to become a state and national model which combines environmentally and ecologically sound engineering principles with community-based improvement efforts and environmental protection regulatory directives. It exhibits a more proactive, value-added approach to obtaining "no net loss" of present and historic wetlands through dredging and harbor maintenance. While directly supporting all aspects of the Clean Water Act, the Pelham Project also encompasses the components of a sustainable environmental and economic development program. With the local support the project has received from SoundWatch, the Bronx Council for Environmental Quality, the City Island Civic Association, BayKeeper, and other environmental and community groups, the project further promotes the US EPAs commitment to develop community-based environmental projects.

6.0 REFERENCES

Alexander, R. McNeill. 1979. The Invertebrates. Cambridge University Press, NY.
Atlas, RM. 1981. Microorganisms and Petroleum Pollutants. BioScience, 28(6): 387-391.

Atlas, RM. 1981. Microbiological Degradation of Petroleum Hydrocarbons: an Environmental Perspective. Microbiological Reviews, 45(1): 180-209.

Bastian, RK., & DA.Hammer. 1993. The use of constructed wetlands for wastewater treatment and recycling. *In* Constructed Wetlands for Water Quality Improvement, ed. by G.A. Moshiri. Lewis Publishers, Boca Raton, FL.

Batiquitos Lagoon Enhancement Project in the City of Carlsbad 1986. "Agreement Among the City of Los Angeles, the City of Carlsbad, the California Department of Fish & Game, the California State Lands Commission, the National Marine Fisheries Service, the US Fish & Wildlife Service. To Establish a Project for Compensation of marine Habitat Losses incurred by Port Development Landfills within the Harbor District of the City of Los Angeles by Marine Habitat Enhancement at Batiquitos Lagoon.

Bergen, Andrew, Michael Levandowsky, Thomas Gorrell and Carl Alderson. 1996. *Restoration of a heavily oiled saltmarsh using* Spartina alterniflora *seedlings and transplants: effects on petroleum hydrocarbon levels and soil microflora*, in Contaminated Soils, Volume 1. edited by E.J. Calabrese, P. T. Kostecki and M. Bonazountas. Amherst Scientific Publishers, Amherst, Massachusetts.

Bertness MD & AM Ellison. 1987. Determinants of Pattern in a New England Salt Marsh Plant Community. Ecological Monographs 57(2): 129-147.

Bertness, MD 1992. The ecology of a New England salt marsh. Amer. Scientist 80:260-68.

Bohnsack, JA, DL Johnson, & RF Ambose. 1991. Ecology of artificial reef habitats and fishes. Chapter 4 *in* Artificial Habitats for Marine and Freshwater Fisheries. Academic Press. New York.

Cairns, J. Jr. & A.L. Buikema Jr. eds. 1982. Restoration of Habitats Impacted by Oil Spills. Butterworth Publishers, Woburn, Massachusetts.

Cerniglia, CE. 1992. Biodegradation of polycyclic aromatic hydrocarbons. Biodegradation 3: 351-368.

Dame, RF. 1987. The new flux of inorganic matter by an intertidal oyster reef. Cont. Shelf. Res. 7: 1421-1424.

Dragun, J. 1988. Microbial degradation of petroleum products in soil. *In* Soils Contaminated by Petroleum, ed. by EJ Calabrese & PT Kostecki, Wiley, NY.

CA Rich Consultants, Inc. 1985. Hydrogeologic assessment of Pelham Bay Park, Bronx, New York for the Pelham Bay Park Management Study and the City of New York Department of Parks and Recreation. October 1985.

Chipps, SR., DH. Bennett, & TJ Dresser, Jr. 1997. Patterns of fish abundance associated with a dredged disposal island: implications for fish habitat enhancement in a large reservoir. North American Journal of Fisheries Management 17: 378-386.

Currin, CA, SB Joye, & HW Paerl. 1996. Diel rates of N2-fixation and denitrification in a transplanted Spartina alterniflora marsh: implications for N-flux dynamics. Estuarine, Coastal and Shelf Science (1996) 42: 1-20.

Cookson, JT. 1995. Bioremediation Engineering: Design and Application. McGraw Hill, Inc. New York.

Costanza, R., R. d'Arge, R. De Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeen, R.V. O'Neill, J. Paruelo, R. Raskin, P. Sutton, & M. van den Belt. 1997. The value of the worlds ecosystem services and natural capital. Nature 387 (15 May 1997):253-260.

DeLaune, RD., GA. Hambrick, III, & WH. Patrick, Jr. 1980. Degradation of hydrocarbons in oxidized and reduced sediments. Marine Pol. Bul. 11: 103-106.

DeLaune, RD., TC. Feijtel, & WH. Patrick, Jr. 1989. Nitrogen flows in Louisiana Gulf Coast salt marsh. Spatial considerations. Biogeochemistry 8:25-37.

Di Toro, DM; Mahony, JD; Hansen, DJ; Scott, KJ; Carlson,AR;; & GT Ankley. 1992. Acid volatile sulfide predicts the acute toxicity of cadmium and nickel in sediments. Environmental Science and Technology 26(1): 96-101.

Di Toro, DM; Mahony, JD; Hansen, DJ; Scott, KJ; Hicks, MB; Mayr, SM; & MS Redmnd. 1990. Toxicity of cadmium in sediments: the role of acid volatile sulfide. Environmental Toxicology and Chemistry 9: 1487-1502.

Edwards, E.A., L.E. Wills, M. Reinhard, & Grbic-Galic. 1992. Anaerobic degradation of toluene and xylene by aquifer microorganisms under sulfate-reducing conditions. Applied and Environmental Microbiology, Vol. 50, No. #. March 1992, p 794-800.

Evans, WC. & G. Fuchs. 1988. Anaerobic degradation of aromatic compounds. Ann. Rev. Microbiol. 42: 289-317.

Gambrell, RP., CN. Reddy, V. Collard, G. Green, & WH. Patrick, Jr. 1981. Behavior of DDT, kepone, and permethrin in sediment - water systems under different oxidation-reduction and pH conditions. US EPA Research and Development EPA-600/S3-81-038 July 1981.

Gambrell, RP & WH. Patrick, Jr. 1988. The influence of redox potential on the environmental chemistry of contaminants in soils and sediments. *In* The Ecology and Management of Wetlands, vol. 1. ed. by DD. Hook et. al.

Gearheart, RA., F. Kloop, & G. Allen. 1989. Constructed free surface wetlands to treat and receive wastewater: pilot project to full scale. *In* Constructed Wetlands for Wastewater Treatment: Municipal, Industrial and Agricultural, ed. by D.A. Hammer. Lewis Publishers, Chelsea, MI.

Giblin, A.E., I. Valiela, & J.M. Teal. 1983. The fate of metals introduced into a New England salt marsh. Water, Air, & Soil Pollut., 20: 81-98.

Grove, RS, CJ. Sonu, & N. Nakamura. 1991. Design and Engineering of Manufactured Habitats for Fisheries Enhancement. *In* Artificial Habitats for Marine and Freshwater Fisheries, ed. by W. Seaman, Jr., & LM Sprague. Academic Press, NY

Hamilton, WA. 1981. Sulfate-reducing bacteria and anaerobic corrosion. In Biology of Nitrogen and Sulfur, ed. by Bothe, H, & A. Trebst. Springer-Verlag, NY.

Hammer, DA. 1989. Constructed Wetlands for Wastewater Treatment: Municipal, Industrial and Agricultural. Lewis Publishers, Chelsea, MI, 1989.

Hammer, DA., BP. Pullin, TA. McCaskey, J. Easton, & VWE. Payne. 1993. Treating livestock wastewaters with constructed wetlands. *In* Constructed Wetlands for Water Quality Improvement, ed. by G.A. Moshiri. Lewis Publishers, Boca Raton, FL.

Havens, KJ., LM. Varnell, & JG. Bradshaw. 1995. An assessment of ecological conditions in a constructed tidal marsh and two natural references tidal marshes in coastal Virginia. Ecological Engineering 4 : 117-141.

Herbes, SE. & LR Schwall. 1978. Microbial transformation of polycyclic aromatic hydrocarbons in pristine and petroleum-contaminated sediments. Applied and Environmental Microbiology. Feb. 1978: 306-316.

Heitkamp, MA. & CE Cerniglia. 1988. Mineralization of polycyclic aromatic hydrocarbons by a bacterium isolated from sediment below an oil field. Applied and Environmental Microbiology 54 (6): 1616-1614.

Irlandi, EA. & MK Crawford. 1997. Habitat linkages: the effects of intertidal saltmarshes and adjacent subtidal habitats on abundance, movement, and growth of an estuarine fish. Oecologia (1997) 110:222-230.

Johnston, R. 1970. The decomposition of crude oil residues in sand columns. J. Mar. Biol. Assoc. U.K. 50: 925-937.

Wilson, SC. & KC. Jones. 1992. Bioremediation of soil contaminated with polynuclear aromatic hydrocarbons (PAHs): a review. Environmental Pollution 81 (1993):229-249.

Kaklec, RH. & RL. Knight. 1996. Treatment Wetlands. CRC Press, Lewis Publishers, Boca Raton, FL.

Keck, R, D. Mauer, & L. Watling. 1973. Tidal stream development and is effects on the distribution of the American oyster. Hydrobiology 42: 369-379.

Kennish, MJ. 1992. Ecology of Estuaries: Anthropogenic Effects. CRC Press, Boca Raton
Kucnerowicz, F. & W Verstraete. 1983. Evolution of microbial communities in the activated sludge process. Water. Res. 17(10):1275-79.

Kirby, R. 1995. Tidal flat regeneration- a beneficial use of muddy dredged material. In Proceedings of the Fourteenth World Dredging Congress: Dredging Benefits, Vol. 1., Amsterdam, 14-17 November 1995.

Lee, E. & MK. Banks. 1993. Bioremediation of petroleum contaminated soil using vegetation: a microbial study. J. Environ. Sci. Health, A28(10): 2187-2198.

Lee, RF., B. Dornseif, F. Gonsoulin, K. Tenore, & R. Hanson. 1981. Fate and effects of heavy fuel oil spill on a Georgia salt marsh. Marine Environmental Research 5 (1981):125-143.

McAuliffe, CD. 1977. Dispersal and alteration of oil discharged on a water surface. Chapter 3 *in* Fate and Effects of Petroleum Hydrocarbons in marine Ecosystems and Organisms. D. A. Wolfe , editor. Pergamon Press, NY.

Miller, GT Jr., 1996. Living in the Environment: Principles, Connections, and Solutions. 9th ed. Wadsworth Publishing Company, Belmont, CA.

Mitsch, WJ. & JG. Gosselink. 1993. Wetlands, 2nd edition. Van Nostrand Reinhold, New York.

Montgomery, R.L. 1978. Methodology for design of fine grained dredged material containment areas for solids retention. U.S. Army Corps Engineers Tech Rep. D-78-56. Vicksburg, MS.

Moshiri, G.A., ed. 1993. Constructed Wetlands for Water Quality Improvement, Lewis Publishers, Boca Raton, FL.

National Academy of Sciences. 1972. Accumulation of Nitrate. National Academy of Sciences, Washington, D.C.

National Research Council 1992. Restoration of Aquatic Ecosystems. National Academy Press, Washington.

Nixon, SW. 1981. Between Coastal Marshes and Coastal Waters- A Review of Twenty Years of Speculation and Research on the Role of Salt Marshes in Estuarine Productivity and Water Chemistry. *In* Estuarine and Wetland Processes, Hamilton, P & B MacDonald, eds. Plenum, New York.

Okada, M., JG Lee, & W. Nishijima. 1997. A comparative study of the structure and function of natural and man-made tidal flat ecosystems. US-Japan Experts Meeting on the Management of Bottom Sediments Containing Toxic Substances, 4-7 November 1997, Kobe, Japan.

Peavy, HS., DR Rowe, & G. Tchobanoblous. 1985. Environmental Engineering. McGraw Hill, Inc. New York.

Rielley, KA., MK. Banks, & AP Schwab. 1996. Organic chemicals in the environment: dissipation of polycyclic aromatic hydrocarbons in the rhizosphere. J. Environ. Qual. 25: 212-219.

Ricketts, EF. & J. Calvin. 1968. Between Pacific Tides, 4th ed., Stanford Univ. Press, Palo Alto, CA.

Simpson, RL., RE. Good, R. Walker & B. R. Frasco. 1983. The Role of Delaware River freshwater tidal wetlands in the retention of nutrients and heavy metals. J. Environ. Qual. 12(1): 41-48.

Sinicrope, T.L., R. Langis, R.M. Gersberg, M.J. Busnardo, and J.B. Zedler. 1992. Metal removal by wetland mesocosms subjected to different hydroperiods. Ecological Engineering. 1 (1992) 309-322.

Surface, J.M., J.H. Peverly, T.S. Steenhuis, and W.E. Sanford. 1993. Effect of season, substrate composition, and plant growth on landfill leachate treatment in a constructed wetland. *In* Constructed Wetlands for Water Quality Improvement, ed. by G.A. Moshiri. Lewis Publishers, Boca Raton, FL.

Thompson, SP., HW. Paerl, & MC. Go. 1995. Seasonal patterns of nitrification and denitrification in a natural and a restored salt marsh. Estuaries 18 (2): 399-408.

United States Department of Agriculture - Soil Conservation Service (USDA-SCS). Undated. Interpretive Soils Report - County Soils Survey and Water Conservation.

United States Environmental Protection Agency (USEPA). 1991a. Proposed Sediment Quality Criteria for the Protection of Benthic Organisms - Acenaphthene. Office of Water & Office of Research and Development.

United States Environmental Protection Agency (USEPA). 1991b. Proposed Sediment Quality Criteria for the Protection of Benthic Organisms - Flouranthene. Office of Water & Office of Research and Development.

United States Environmental Protection Agency (USEPA). 1991c. Proposed Sediment Quality Criteria for the Protection of Benthic Organisms - Phenanthrene. Office of Water & Office of Research and Development.

Valiela, I. & JM. Teal. 1979a. Inputs, outputs and interconversions of nitrogen in a salt marsh ecosystem. ch. 25 *in* Ecological Processes in Coastal Environments, R.L. Jefferies & A.J. Davy editors. Blackwell Scientific Publications, Oxford.

Valiela, I. & JM. Teal. 1979b. The nitrogen budget of a salt marsh ecosystem. Nature 280(5724): 652-656

White, DS. & BL. Howe. 1994. Long-term ^{15}N-nitrogen retention in the vegetated sediments of a New England salt marsh. Limnol. Oceanogr., 38(8): 1878-1892.

Woodward-Clyde Consultants, Inc. 1993. Remedial Investigation Report. Pelham Bay Landfill, Bronx, New York. April - June 1993. Woodward-Clyde, New York.

Young, L.Y., & M.M. Häggblom. 1990. The anaerobic microbiology and biodegradation of aromatic compounds. Biotechnology and Biodegradation 4:3-17.