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Engineering

Gowanus Canal
Ecological Investigation Report

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List of Acronyms

All possible regression	APR
Benzo[a]pyrene	BAP
Sum of benzene, toluene, ethyl benzene, and xylene	BTEX
Canonical Correspondence Analysis	CCA
Capture per Unit Estimate	CPUE
Chi-squared automatic interaction detection	CHAID
Combined sewer outfall	CSO
Dissolved oxygen	D.O
Effects Range-Low	ERL
Effects Range-Median	ERM
Environmental Monitoring Assessment Program	EMAP
Equilibrium partitioning	EP
Exploratory data analyses	EDA
GEI Consultants, Inc./Chadwick Ecological Division	GEI
Geographic information system	GIS
GIS using sediment profiling imagery	SPI
Hester-Dendy	H-D
New York City Department of Environmental Protection	NYCDEP
New York Department of Environmental Conservation	NYDEC
New York State Codes, Rules and Regulations	NYCRR
Parts per thousand	PPT
Polychlorinated biphenyl's	PCBs
Polycyclic aromatic hydrocarbons	PAHs
Principal components analysis	PCA
Quality assurance and quality control	QA/QC
U.S. Army Corp of Engineers	USACE
Semi-volatile organic compounds	SVOCs
Site-specific sediment criteria	SSSC
Total organic carbon	TOC
Toxicity Quotient"	TQ
Water quality	WQ
U.S. Environmental Protection Agency	EPA
U.S.EPA's Regional Environmental Monitoring and Assessment Program	REMAP
Volatile organic compounds	VOCs
Wastewater Treatment Plant	WWTP

1.0 Introduction

At the request of KeySpan Corporation, GEI Consultants, Inc. (GEI) conducted an ecotoxicological investigation to determine whether and what water and/or sediment contaminants were affecting the aquatic biological community observed in the Gowanus Canal. To perform this task we analyzed and interpreted the relationship between biotic and abiotic variables from current GEI sampling and previous studies conducted on the Gowanus Canal. Our ecotoxicological findings were the following:

1. Gowanus Canal sediment and water quality appears to be adversely impacted by multiple chemical and physical stressors largely unrelated to contaminants associated with former manufactured gas plant (MGP) operations.

2. Canal sediments were toxic to sediment dwelling organisms in controlled laboratory exposures with sewage-related contaminants, including ammonia being the drivers of the toxicity.

3. Current canal benthic invertebrate communities are inherently impoverished due to the chemical stressors related to combined sewer outfall (CSO) discharges and other sources. As a result, the benthic communities consist of organisms tolerant to organic pollution associated with sewage, the distribution of which seems to be driven by physical habitat variability.

1.1 Gowanus Canal – A Class SD Waterbody

The State of New York Department of Environmental Conservation (NYDEC) has established a number of classes of waters (New York State Water Quality Regulations Surface Water and Groundwater Classifications and Standards New York State Codes, Rules and Regulations [NYCRR) Title 6 Chapter X Parts 700-7006 Department of Environmental Conservation). The general classes relevant to waters like Gowanus Canal are listed below:

1. Class I saline surface waters- The best usages of Class I waters are secondary contact recreation and fishing. These waters shall be suitable for fish propagation and survival (6 NYCRR §701.13).

2. Class SA saline surface waters - The best usages of Class SA waters are shellfishing for market purposes, primary and secondary contact recreation and fishing. These waters shall be suitable for fish propagation and survival (6 NYCRR §701.10).

3. Class SB saline surface waters - The best usages of Class SB waters are primary and secondary contact recreation and fishing. These waters shall be suitable for fish propagation and survival (6 NYCRR §701.11).

4. Class SC saline surface waters - The best usage of Class SC waters is fishing. These waters shall be suitable for fish propagation and survival. The water quality shall be suitable for primary and secondary contact recreation, although other factors may limit the use for these purposes (6 NYCRR §701.12).

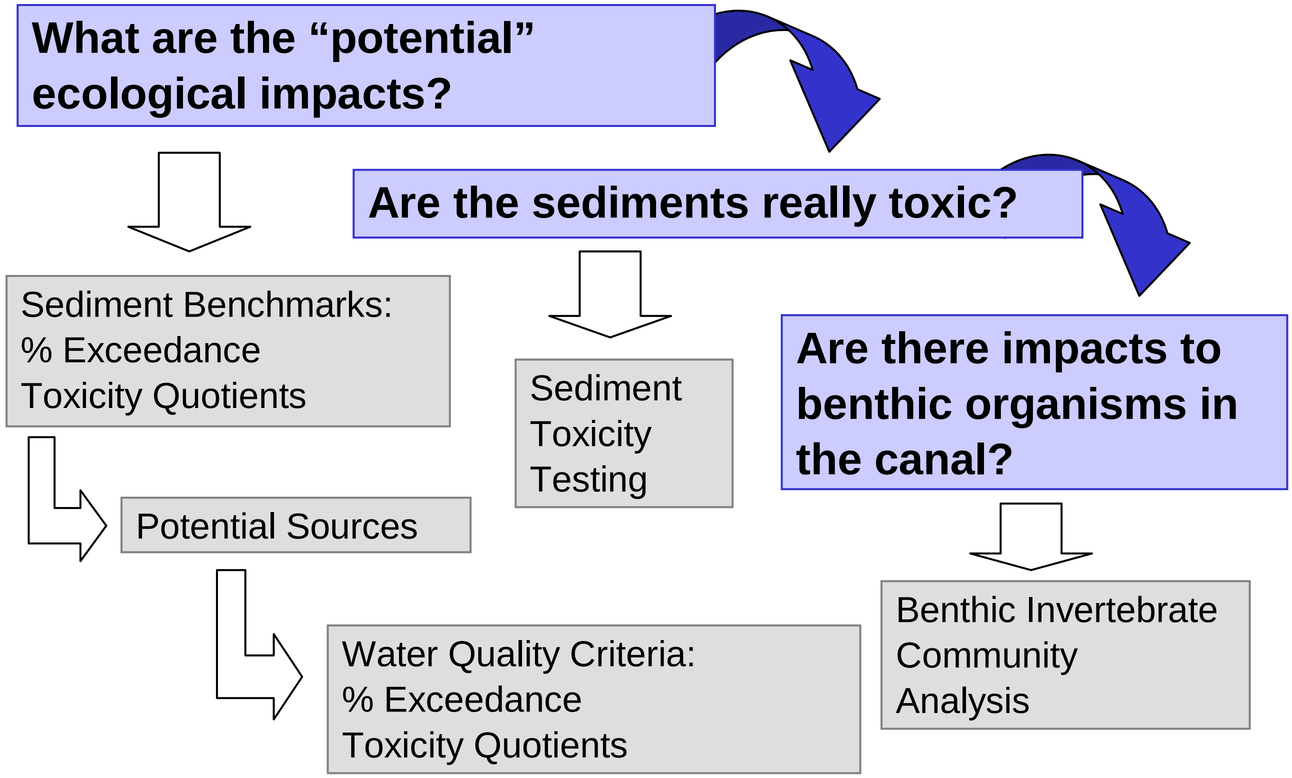
5. Class SD saline surface waters - The best usage of Class SD waters is fishing. These waters shall be suitable for fish survival. This classification may be given to those waters that, because of natural or man-made conditions, cannot meet the requirements for primary and secondary contact recreation and fish propagation (6 NYCRR §701.14).

Gowanus Canal is classified as Class SD. As such, it is not suitable for fish propagation or contact recreation. This classification acknowledges the historic contamination of the canal.

1.2 Ecotoxicology Study Approach

This evaluation was conducted in a number of steps (see diagram below). First, we evaluated the potential aquatic community impacts by comparing sediment and water quality data collected by GEI to sediment ecological screening benchmarks and Class SD water quality standards or guidance values. Next, potential sediment contamination sources, such as permitted and unpermitted outfalls, were evaluated. Sediment toxicity testing data from U.S. Army Corp of Engineers (USACE, 2003) studies were used to validate predicted chemical stressor impacts and identify relationships with specific contaminants that might influence sediment toxicity. Finally, biological data collected by the USACE was analyzed with respect local reference conditions, sediment contamination, and physical habitat data.

Diagram of Conceptual Approach Used to Evaluate Gowanus Canal



2.0 General Methods

A total of eight unique datasets were evaluated for this ecotoxicological investigation of the Gowanus Canal, as follows.

- 2006 GEI Sediment data
- 2006 GEI Water Quality Data
- 2006 GEI Outfall Water Quality Data
- 2005 USACE Sediment Data
- 2005 USACE Sediment Toxicity Data
- 2003 USACE Ponar Data
- 2004 Lawler Hester-Dendy (H-D) Data
- 2003/2004 USACE Ichthyoplancton, Fish, and Crab Data

These datasets were used in all statistical analyses and to create tables and figures. An analyte matrix, listing all potential contaminants that were investigated with respect to each data source, can be found in Appendix A. Below is a brief description of how each dataset was prepared for report analyses. Detailed descriptions of database preparation and the resulting data can be found in Appendix A (Figure A-1).

2.1 2006 Sediment Data

The 2006 sediment data were collected by GEI along transects established in the Gowanus Canal (Keyspan, 2005). These data were collected at all sediment depths. Because we are interested in ecological effects of sediment exposure, only surficial sediments (0-3 ft) were analyzed. Benthic (bottom-dwelling) organisms would not be expected to inhabit deeper sediments. The 0 to 3 ft sediment sampling depth interval is consistent with reference burrowing depths for deep burrowing organisms (Kropp and Diaz, 1995).

Non-detect values were carefully examined and unreasonably high non-detect values were deleted from further analyses. After screening the non-detect values, all remaining contaminant values from all samples were condensed into single values for each respective transect Detailed methods for developing the databases used for analysis, as well as the resulting screened and organized 2006 sediment data, can be found in Appendix A.

2.2 2006 Water Quality Data

The 2006 water quality data were collected by GEI along the same transects established in the 2006 sediment dataset. These data were collected at two depths, surface and at the sediment water column interface. The 2006 water quality datasets are presented in Appendix A.

2.3 2005 Sediment Data

The 2005 sediment data were collected on behalf of the USACE by DMA, Inc (2006). Site locations ranged from the upstream portion of the Gowanus Canal to below the Carrol Gardens/Public Place MGP site (but above the Metropolitan former MGP site). Samples were analyzed for metals, semi-volatile organic compounds (SVOCs), polychlorinated biphenyl's (PCBs), pesticides, grain size, and total organic carbon (TOC) (See contaminant matrix in Appendix A).

These sediment data were then organized into transects and matched to the nearest GEI transect. Non-detect values were screened using the same method as the GEI sediment data. These sediment datasets are presented in Appendix A.

In addition, we investigated, but did not use, analytical sediment data collected by the USACE in 2003. Once categorized into depth categories, we found that only two samples were collected from surficial sediments and was too limited to be used in our investigations.

2.4 Outfall Water Quality Data

Outfall water quality (WQ) data were collected by GEI during a dry weather period between August 2 and 11 2006. Only samples from 11 actively flowing outfalls discharging into the canal above the waterline (including one CSO) were used in our analysis. Each sample was matched to the nearest GEI transect.

2.5 Sediment Toxicity Tests

Sediment toxicity tests were conducted on behalf of the USACE by AquaSurvey, Inc. (2005), as presented in the DMA (2006) report, for sediments collected in September 2005. Testing was conducted using the amphipod *Ampelisca abdita* in a 10 day exposure whole sediment bioassay. Toxicity test results, water quality conditions, and notes are summarized in the toxicity test dataset found in Appendix A.

2.6 Biological Data

Three separate biological datasets were available for our investigations into Gowanus Canal ecology. These datasets included data from benthic invertebrate communities, water column 'epibenthic' invertebrate communities, and limited data from fish trawls and fish/crab trap sampling efforts. A brief summary of each of the four datasets are provided below.

Benthic invertebrates were sampled in April 2003 using a petite Ponar benthic sampler by USACE (2003) at 28 stations with two replicates per site. Station locations ranged though the entire length of the canal from the flushing tunnel to Gowanus Bay. Latitude/longitude coordinates used to identify site locations were matched to 15 GEI transects. Limited water quality parameters were recorded by the USACE at each sample location. These data on the biological community of the canal form the primary basis of our ecotoxicological analysis.

The second dataset was created from H-D epibenthic community sampling. Epibenthic community invertebrates were sampled by Lawler, Matusky, and Skelly Engineers, LLP, for the USACE at five locations in the Gowanus Canal and Bay using H-D style samplers (Lawler et al. 2004). These data were limited and did not lend themselves to detailed comparisons to sediment or water quality and were not evaluated further.

The third dataset was a combination of the ichthyoplankton, adult fish, and crab trap data collected on behalf of the USACE in 2003 through 2004 using trap nets and trawl nets (Lawler et al. 2004). Since these data were collected at fewer locations and could not be easily matched to the GEI transects or abiotic datasets, only qualitative summary results are presented.

2.7 Data Quality Assurance and Quality Control

Due to the quantity of data and the large number of calculations which had to be performed for data analysis, a quality assurance and quality control (QA/QC) protocol was established. All efforts were made to be as easily understandable as possible when creating all of the analyses datasets and details are provided in Appendix A.

2.8 Statistical Analyses

Multiple parametric and non-parametric statistical analyses were performed in our ecotoxicological evaluation of the Gowanus Canal. Statistical tests are explained in greater detail when presented in the report and in Appendix A. As part of every parametric statistical analysis, the assumptions of equal variance and normality were tested and data was transformed, when appropriate. For all analyses, significance was set with an alpha level of 0.05 (i.e., only a 5 percent chance of a statistical difference occurring by chance). All statistical data analyses were conducted using NCSS 2004, SPSS 15.0, and CANOCO for Windows 4.5 software packages.

3.0 Evaluation of Potential Ecotoxicological Impacts

3.1 Sediment Quality

For many contaminants, low and median toxic effect estimates derived from field studies across the nation were used as surrogate sediment screening benchmarks. Effects range estimates were established to indicate levels of sediment contamination that can be tolerated by the majority of benthic organisms (Long et al. 1995) for contaminants in marine and estuarine sediments, as presented in Tables 3 and 4 of the New York State Department Environmental of Conservation (NYSDEC) Technical Guidance Document (NYSDEC, 1999). If the concentration is greater than the Effects Range-Median (ERM), the sediment is "contaminated" and significant harm to benthic aquatic life is anticipated (NYSDEC, 1999).

A number of contaminants do not have ERM values for evaluation of potential toxicity. The NYSDEC has developed a contaminated-sediment screening technical guidance document (NYSDEC, 1999) to develop sediment criteria based on the U.S. Environmental Protection Agency (EPA) equilibrium partitioning (EP) model. The role of EP-based sediment criteria is for screening potentially contaminated sediments and providing an initial assessment of possible adverse impacts to aquatic biota from those sediments.

EP-based sediment criteria are tied to water quality standards and guidance values. Therefore, within the framework of New York State water quality regulations, sediment criteria were derived according to the primary levels of protection for available Class SD water quality standards or guidance values presented in Division of Water TOGS 1.1.1 (1998). Because these criteria are scaled to sediment TOC, EP-based criteria can be thought of as site-specific sediment criteria (SSSC). SSSC were derived using available Class SD water quality standards or guidance values.

The affinity of non-polar organic compounds to organic carbon ultimately defines bioavailability and exposure to sediment dwelling organisms. Other compounds such as metals exhibit many properties in water that largely depend on the form or species in which the metal occurs. The toxicity and bioavailability of metals in water and sediment are highly influenced by environmental conditions such as pH, alkalinity, REDOX potential, and availability of complexing ions or ligands. Additionally, the complexity of metals behavior in sediments makes accurately predicting levels at which toxic effects will occur difficult. These caveats need to be kept in mind when evaluating the significance of an exceedance of these thresholds.

In our screening analysis of Gowanus Canal sediments, SSSC or ERM guidance values for marine and estuarine sediments were used as toxicity benchmarks. When both SSSC and an ERM were available, the ERM benchmark was given priority over the water quality criteria derived sediment benchmark since it is derived from measured sediment-biology relationships. The ERM was chosen over the Effects Range-Low (ERL) as the benchmark criteria because this would be the most appropriate standard for a Class SD waterbody based on protection categories established by the state for Class SD waters (i.e. fish survival).

The potential for ecological impacts from sediment contamination were evaluated two ways. The first was to determine how often the sediment thresholds (ERM or SSSC) were exceeded (i.e., the frequency, or percent of values over the threshold). The second approach was based on the magnitude of sediment benchmark exceedances, based on the *ratio* of the measured values to the threshold, also called a "Toxicity Quotient" or TQ. TQs > 1 would be predictive of toxicity (i.e., measured concentrations are greater than the threshold). Because aquatic biota are only expected to be exposed to surficial sediments, only samples collected within the top 3 feet of sediment cores were evaluated in our analysis.

3.1.1 Sediment Benchmark Exceedances

Twenty-six ERM values were available to develop 26 ERM-based TQs. Fourteen Class SD WQ standards, seven guidance values, and three default sediment screening values were available to develop a total of 24 SSSC-based TQs for this analysis. In total, 50 specific contaminants or contaminant class totals (i.e., total PCBs) were available for development of percent exceedance and TQs, with respect to transect results.

3.1.1.1 Exceedance Analyses

Of the 50 contaminants for which a criteria benchmark was available, only eight were found at levels below respective benchmarks or detection limits. In contrast, 18 contaminants were above the benchmarks in 100 percent of the measured transect values. Most of these 18 contaminants were polycyclic aromatic hydrocarbons (PAHs), PCBs, and pesticides. All transects exceeded at least 20 sediment toxicity benchmarks. Figure 1 presents the transect-specific benchmark exceedance rates with all contaminants combined. No clear-cut patterns of exceedances were noted among transects and results indicated that sediments in all areas of the Gowanus Canal are potentially toxic to aquatic life.

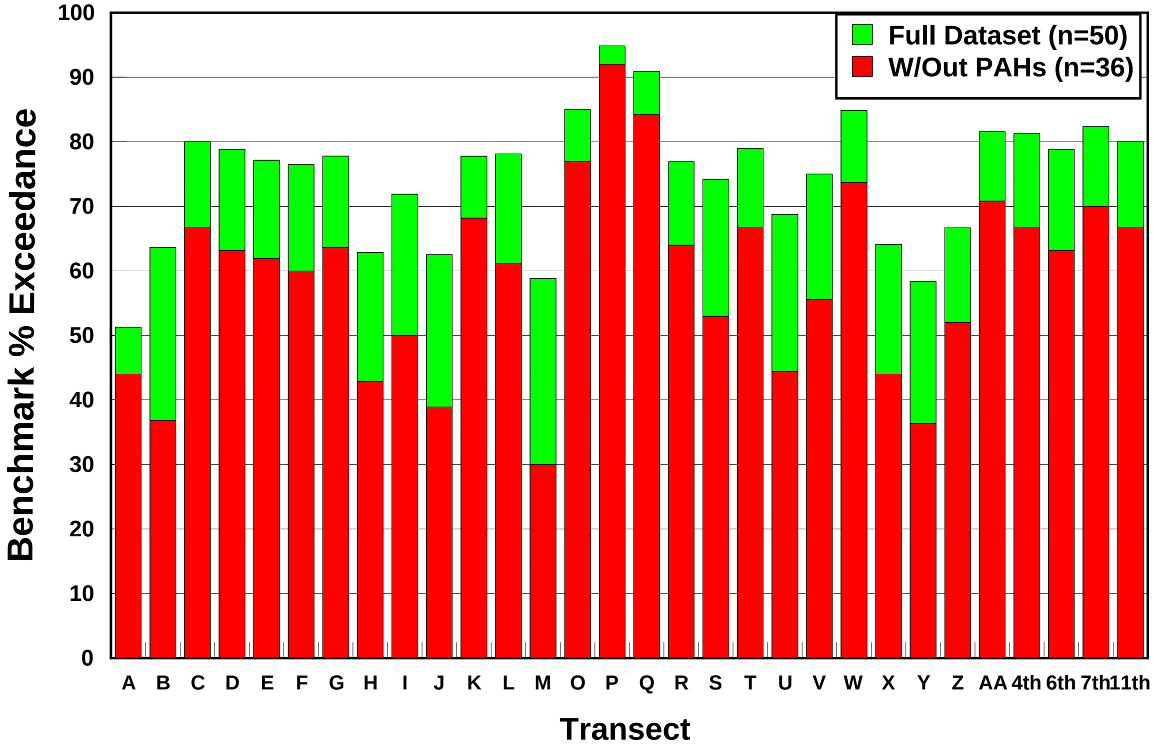


Figure 1: Cumulative sediment criteria benchmark exceedance rates for each transect. Exceedance rates derived using the full dataset contained 50 contaminants. Exceedance rates derived using the full dataset minus polycyclic aromatic hydrocarbon (PAH) contaminants contained 36 contaminants.

To explain the influence of PAHs in exceedance rates, we removed all PAHs and re-analyzed the data (Figure 1). Fourteen PAHs were removed allowing an examination of exceedance rates for the remaining 36 contaminants (including SVOCs, volatile organic compounds [VOCs], PCBs, pesticides, and metals). Even after removing PAHs, the minimum number of exceedances was 30 percent, with most transects having 50 percent or greater frequency of exceedances. From this figure it is clear that the spatial patterns of exceedances are similar between the two datasets; with a substantial percentage of exceedances for each transect even with PAHs removed.

3.1.1.2 Toxicity Quotient Analyses

To investigate the magnitude of sediment benchmark exceedances, we derived cumulative TQs for each contaminant category and transect (Figure 2). From this analysis it can be seen that cumulative PAH, PCB, pesticide, and metal TQs are greater than one (zero on the log10 scale) for each transect in the canal. Cumulative VOC TQs, including the sum of benzene, toluene, ethyl benzene, and xylene (BTEX), were greater than one in just over a third of all of the transects. The greatest cumulative TQs were derived for PAHs; although this only accounts for roughly half the total toxicity at any one transect. These results indicate that sediment quality is greatly impacted by multiple contaminant stressors. Additionally, the cumulative impact of all non-PAH contaminants is at least similar to PAH impacts. In summary, Gowanus Canal sediments are greatly impacted by multiple chemical stressors. When analyte results were compared to sediment screening benchmarks, high exceedance rates and TQs were derived for each transect.

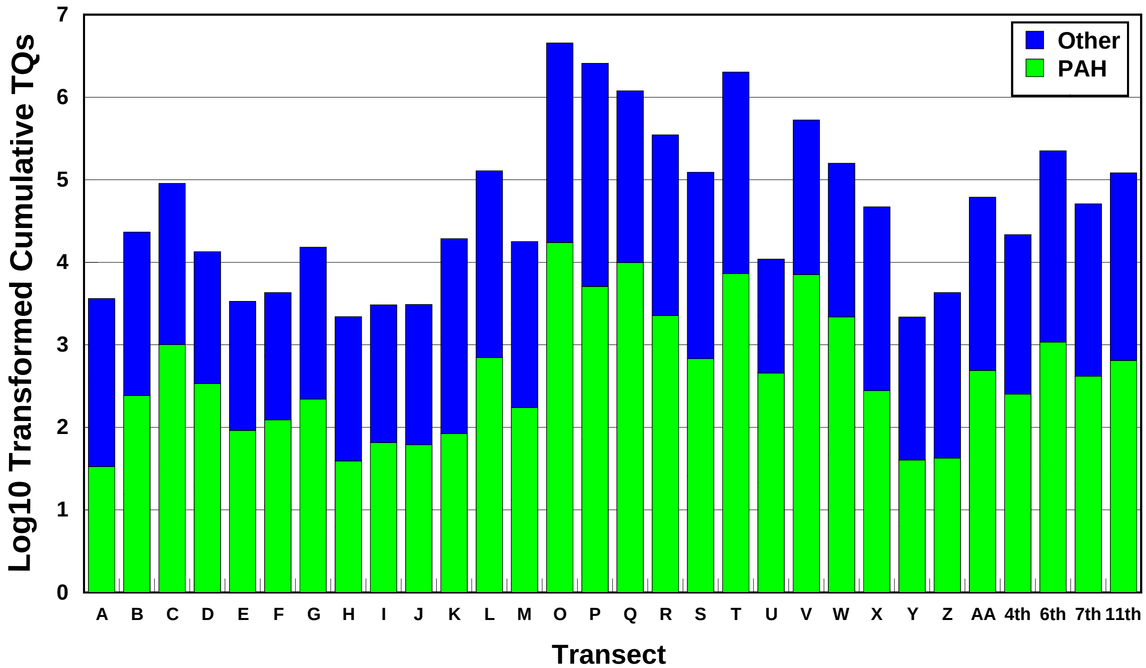


Figure 2: Cumulative log transformed sediment benchmark Toxicity Quotients (TQs) for polycyclic aromatic hydrocarbons (PAHs), and other contaminants, primarily polychlorinated biphenyls, pesticides, metals, and volatile organic compounds, which included benzene, toluene, ethyl benzene, and xylene (BTEX).

3.2 Evaluation of potential sediment contamination sources

After establishing the frequency and magnitude of benchmark exceedances, we identified that active outfalls were a potential source of surficial sediment contamination within the canal. To identify outfall sources, active CSOs and outfalls discharging unknown effluents were sampled by GEI. Collected effluent samples were analyzed for similar contaminants as performed in sediment analyses. When an analyte was measured in the outfall effluent it was matched to the analyte-transect matched sediment value. These pairs (outfall/sediment results) were separated into contaminant classes and regressed (Figure 3).

When each contaminant class-paired effluent/sediment data were regressed, the relationship between outfall and sediment analytes identified a statistically significant positive relationship between the outfall data and paired sediment quality for metals (slope = 0.71) and combined pesticides, PCBs, and VOCs (slope = 0.68). The BTEX regression resulted in a slightly positive slope (slope = 0.06) that was not statistically significant (Table 1). No relationship was noted between PAH concentrations in outfall effluents and sediments within the same transect (slope < 0.001). These results indicate that outfalls are a potential source of sediment contamination in terms of metals, pesticides, PCBs, VOCs, and to a lesser extent BTEX.

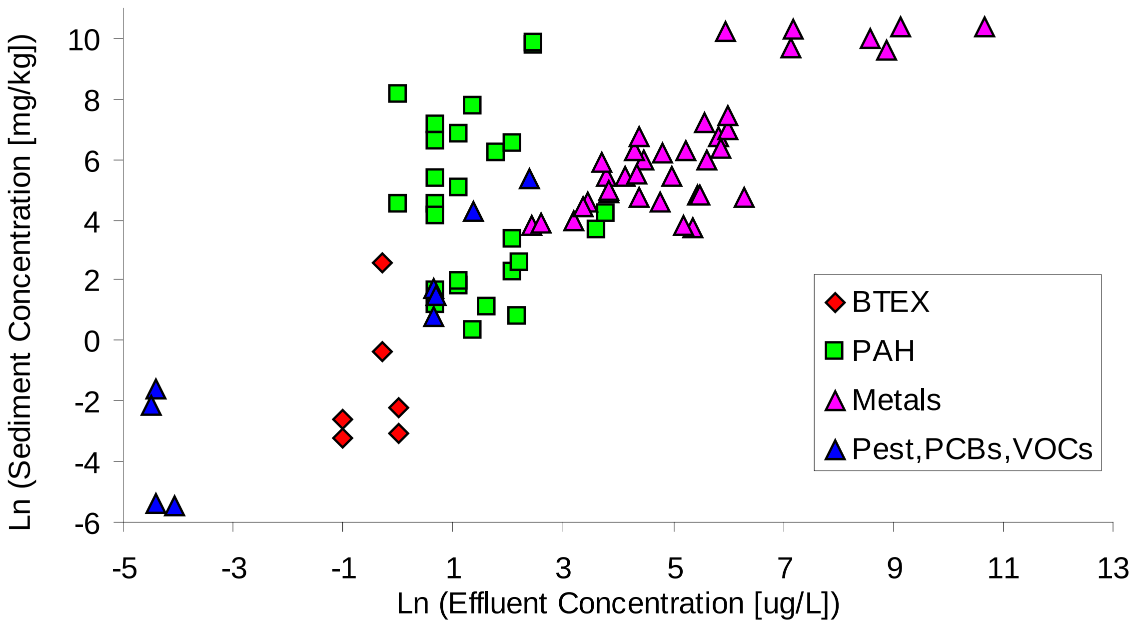


Figure 3: Scatter plot of paired effluent/sediment contaminant results. Paired contaminant results were plotted according to contaminant categories. The contaminant categories included benzene + toluene + ethyl benzene + xylene (BTEX), polycyclic aromatic hydrocarbons (PAHs), metals, pesticides (PEST), polychlorinated biphenyls (PCBs), and volatile organic compounds (VOCs).

Similar to sediment quality analyses, we can determine the predicted toxicity of active outfall effluents using the same TQ approach. Figure 4 shows the cumulative log transformed outfall effluent specific TQs for PAHs, PCBs, pesticides, and metals.

Analysis of respective TQs showed that active outfalls throughout the Gowanus Canal are discharging potentially significantly toxic concentrations of several contaminants. Overall, these outfalls represent unknown sources. It is important to note that TQs derived for VOCs, which included BTEX, were less than one, indicating that during outfall sampling these contaminants were not being discharged at potentially toxic levels.

Table 1: Paired effluent/sediment data summary and regression results. Numbers in parentheses indicate the number of paired observations for each contaminant. The pooled slope = 0.6310* (95% CI = 0.5109 - 0.7512).

BTEX	PAHs	METALS*	OTHERS*
Toluene (3)	Acenaphthene (2)	Aluminum (2)	Aldrin (2)
Total BTEX (3)	Anthracene (1)	Barium (7)	Alpha-BHC (1)
	Fluoranthene (3)	Chromium (2)	Delta-BHC (1)
	Fluorene (1)	Copper (2)	Bis(2-ethylhexyl)phthalate (2)
	2-Methylnaphthalene (1)	Iron (5)	Butyl benzyl phthalate (1)
	Phenanthrene (3)	Lead (1)	Aroclor 1242 (1)
	Pyrene (3)	Manganese (8)	Total PCBs (1)
	Total Noncarc.PAHs (3)	Nickel (5)	Acetone (1)
	Benzo[a]anthracene (1)	Vanadium (2)	Cyanide (1)
	Benzo[a]pyrene (1)	Zinc (3)	
	Chrysene (2)		
	Total Carc. PAHs (2)		
	Total PAHs (3)		
Slope = 0.06	Slope = < 0.00	Slope = 0.71	Slope = 0.68

* = Statistically significant relationship between outfall and sediment paired results (alpha=0.05)

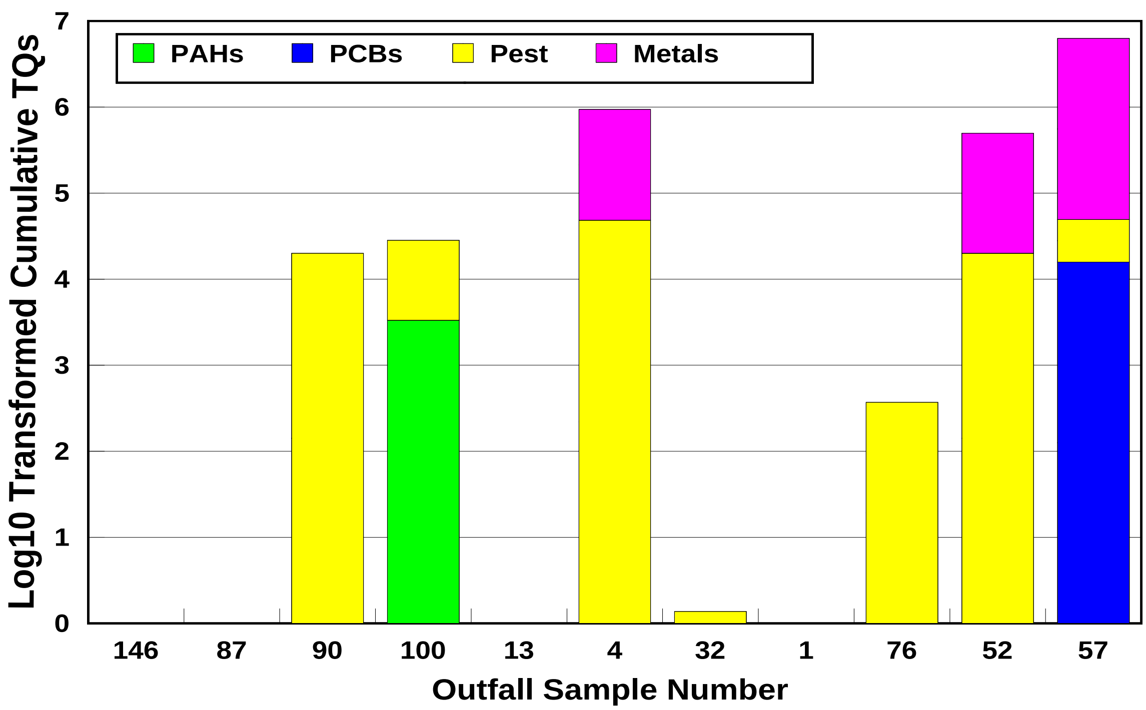


Figure 4: Cumulative log transformed outfall specific Toxicity Quotients (TQs) for polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pesticides (PEST), and metals.

Only one active CSO (Outfall sample number 146) was available for analysis. Examination of effluent from this outfall indicated that only three contaminants were identified and measured at concentrations greater than the non-detection limits. These contaminants included barium, manganese, and fecal coliform; none of which have a toxicity benchmark needed to derive respective TQs. The large PAH cumulative TQ identified in outfall sample number 100 (GC-OF-100) was almost entirely due to benzo[a]pyrene (BAP). The outfall, GC-OF-100, is not permitted under NYDES SPDES or EPA NPDES. The exact source of that outfall effluent is uncertain. Active discharge was observed. The discharge had moderate petroleum-like odor and sheen was observed in the effluent sample (GEI, field observations). BAP was also found in surface water samples near this outfall (see below). Interestingly, the transect corresponding to this outfall (Transect H) had the greatest BAP water column analyte results at concentrations that were roughly five fold that of the next greatest measurement.

3.3 Water Quality

To investigate potential chemical stressors in the canal, water column analyte data were evaluated using a toxicity benchmark or criteria screen. Class SD water quality standards or guidance values served as toxicity benchmarks and were used to predict potential ecological harm when compared to measured contaminant values. New York State defines water quality standards with respect to classification of surface waters. Gowanus Canal is classified as Class SD saline surface water; therefore, canal waters should be suitable for fish survival or "no acute toxicity." It is important to note that Class SD waters are not intended to protect for more sensitive chronic toxicity endpoints such as fish propagation, although a few Class SD standards are set according to more sensitive endpoints. For water quality screening purposes, 15 Class SD standards, 10 guidance values, and four narrative standards were compared to transect condensed measured water column analyte concentrations. From these comparisons the frequency and magnitude, measured as TQs, of exceedances were developed as discussed above.

We compared transect condensed water quality results to available standards or guidance values to develop transect specific TQs for each contaminant (Table 2). The NYSDEC also provides narrative standards for Class SD waters outlined in 6 NYCRR §703.2 Narrative Water Quality Standards. Additionally, water quality standards for dissolved oxygen (D.O.), odor, color and floatables, are provided in 6 NYCRR §703.3. The appropriate narrative standard for oil and floating substances states that "No residue attributable to sewage, industrial wastes or other wastes, nor visible oil film nor globules of grease." The Class SD standards for D.O. "Shall not be less than 3.0 milligrams per liter (mg/L) at any time." Observational accounts of sampling locations and conditions were used to screen narrative water quality standards. The averaged transect specific D.O. results were used to determine respective standard adherence. Because of the narrative nature of these additional water quality standards, TQs could only be derived for D.O. Exceedance rates were developed for each narrative standard.

Table 2: Class SD standards, guidance values, and narrative standards used to derive percent exceedance and Toxicity Quotients.

Contaminant	Class SD WQ Standards (µg/L)	Class SD WQ Guidance Values (µg/L)	Narrative Class SD WQ Standards	Comments
Benzene	10 a	670 b		Guidance value used over standard due preference for fish survival endpoint
Toluene	6000 a	430 b		Guidance value used over standard due preference for fish survival endpoint
Ethylbenzene		41 b		
Xylene		170 b		
Acenaphthene		60 b		
Fluorene		23 b		
2-Methylnaphthalene		38 b		
Naphthalene		140 b		
Phenanthrene		14 b		
Benzo[a]pyrene		0.0006 a		
Aldrin	0.001 a			
Alpha-Benzenehexachloride (BHC)	0.002 a			
Beta-BHC	0.007 a			
Delta – BHC	0.008 a			
Epsilon – BHC	0.008 a			
Gamma-BHC	0.008 a			
Alpha-Chlordane	0.00002 a			
Trans-Chlordane	0.00002 a			
DDT, DDE, DDD (sum)	0.000011 e			
Dieldrin	0.0000006 a			
Endosulfan	0.034 b			
Endrin	0.002 a			
Heptachlor	0.0002 a			
Heptachlor epoxide	0.0003 a			
Toxaphene		0.07 b		
PCBs total	0.00012 e			
Copper	7.9 b			
Lead	204 b			
Mercury	0.0026 d			
Nickel	74 b			
Zinc	95 b			
Dissolved Oxygen (D.O.)			Shall not be less than 3.0 mg/L at any time.	
Odor			None in amounts that will adversely affect the taste, color or odor thereof, or impair the waters for their best usages.	

Contaminant	Class SD WQ Standards (µg/L)	Class SD WQ Guidance Values (µg/L)	Narrative Class SD WQ Standards	Comments
Clarity			None in amounts that will adversely affect the taste, color or odor thereof, or impair the waters for their best usages.	
Floatables			No residue attributable to sewage, industrial wastes or other wastes, nor visible oil film nor globules of grease	

a = Human consumption of fish (saline waters)
b = Fish survival (saline waters)
c = Fish propagation (saline waters)
d = Aesthetic (saline waters)
e = Wildlife protection (saline waters)

Water quality standards for the state's waters are compiled in the Division of Water Technical and Operational Guidance Series 1.1.1 (Division of Water, 1998). This document provides ambient water quality standards and guidance values for toxic and non-conventional pollutants derived under the authority of Article 17 of the Environmental Conservation Law and 6 NYCRR Parts 700-706, Water Quality Regulations. A standard value is a numeric concentration value that has been promulgated and placed into regulation. A guidance value may be used where a standard for a substance or a group of substances has not been established. Standards and guidance values are the maximum allowable concentration for a defined water classification.

3.3.1 Water Quality Exceedances

Seventeen Class SD water quality standards, 10 guidance values, and four narrative standards were available for analytical results comparisons (Appendix A). Surface water samples from near the surface and bottom of the water column were analyzed separately and combined when comparing water quality standards. Due to laboratory methods, analytical detection limits were often greater than Class SD water quality standards, but when a concentration above the detection limit was obtained, a percent exceedance or TQ value was derived. We compared the Class SD water quality standards and guidance values to transect specific results and used a pass/fail logical test to screen exceedance rates between transects and contaminants or narrative standards. The Class SD water quality standards and guidance values were used to derive TQs for each transect. The TQs were derived as the ratio of each measured value over each transect's specific criteria. These TQs were combined.

3.3.1.1 Exceedance Analyses

Of the 25 contaminants for which a standard or guidance value was available, 11 contaminants were found at levels below respective criteria benchmarks or detection limits. In 11 other contaminants, 100 percent of measured values were found above respective criteria benchmarks - most of these were pesticides. The number of numeric criteria exceedances ranged from 53 percent to zero exceedances (Figure 5).

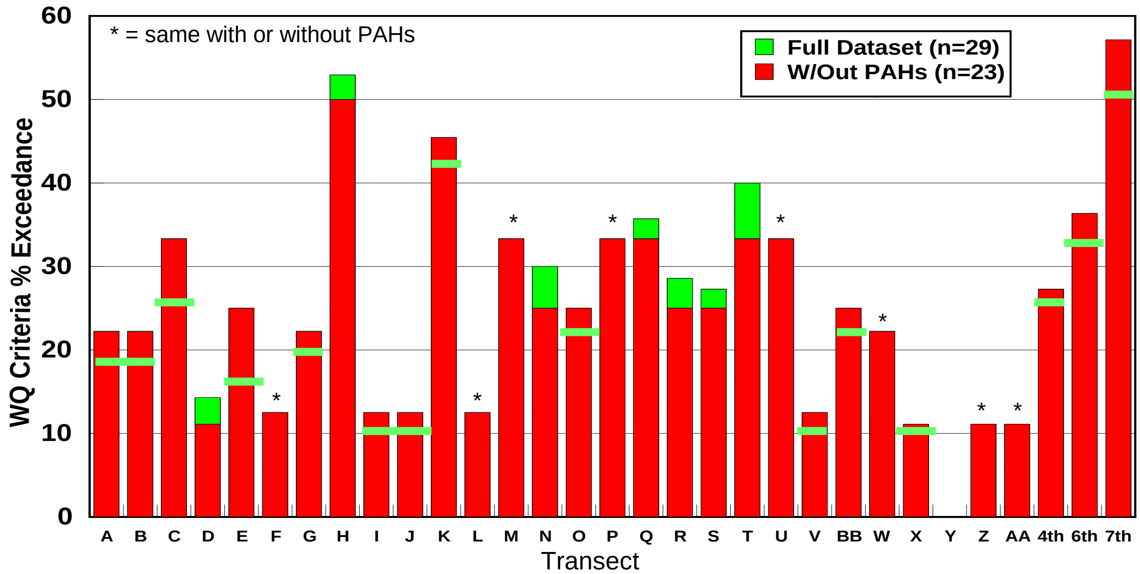


Figure 5: Transect specific Class SD water quality (WQ) standard, guidance value, and narrative standard exceedance rates for the full dataset and the full dataset without polycyclic aromatic hydrocarbons (PAHs).

Four narrative standards were also assessed in conjunction with numeric criteria. There were no notable differences in D.O., odor, or floatables narrative standard exceedances between surface and bottom collected samples. The D.O. Class SD criterion (3 mg/L) was not met in 35 percent of the surface sampled transect results and 39 percent of bottom sampled results. D.O. measured in surface water samples from above sediment surface ranged 1.6 mg/L to 12.4 mg/L and the median value was 3.3 mg/L, indicating surface sediments are also most likely anoxic. Twenty percent of the surface collected samples exceeded the color narrative standard “No increase that will cause a substantial visible contrast to natural conditions.” The Class SD odor narrative standard “None in amounts that will adversely affect the taste, color or odor thereof, or impair the waters for their best usages” was exceeded in 6 percent and 13 percent of the surface and bottom transect results, respectively. The “No residue attributable to sewage, industrial wastes or other wastes, nor visible oil film nor globules of grease” standard was exceeded in 81 percent of the surface and 68 percent of the bottom collected samples. The majority of these exceedances were associated with spotty sheens and observed fecal matter within the Canal.

When the surface and bottom water column results were condensed, the 6th and 7th Street turning basins had the greatest number of narrative standards exceedances (75 percent) and Transect L had zero narrative exceedances.

To investigate numeric and narrative exceedance rates with respect to PAHs, we analyzed analyte results with and without PAHs. Figure 5 presents exceedance rates for the two datasets. From this figure it can be seen that only 7 transects have a fewer exceedances without PAHs. Interestingly, 15 of the transects have a greater proportion of exceedances *after* PAH results were removed. Eight transects have the same proportion of exceedances with or without PAHs. The minimal difference between each dataset for most transects, and increased rates in many others, indicates that PAHs are not appreciably contributing to the respective total number of water quality exceedances in the canal.

3.3.1.2 Toxicity Quotient Analyses

To investigate the magnitude of Class SD water quality standard or guidance value exceedances, we derived cumulative TQs for each contaminant category and transect (Figure 6). The PAH category represents cumulative TQs for each PAH contaminant, except benzo[a]pyrene (BAP). BAP was removed from the water quality analysis due to it being measured at concentrations greater than the aqueous solubility and a low Class SD standard to protect human consumption of fish. This combination resulted in a biologically insignificant inflated TQ that confused results comparisons.

With BAP removed, Transect H had the greatest cumulative TQ due to high pesticide and PAH TQs. Pesticide TQs were also elevated in Transects P, Q, 6th and 7th Street basins. Potential sources for these pesticides at these transects is uncertain. Cumulative metal TQs were greater than 1 (zero on the Log10 scale) in 7 transects, with the greatest value observed in Transect G. When measured above the minimum detection limits, in Transects T, U, and 7th St, total PCBs TQs were very high. Transects T and U are located immediately downstream of the 9th street bridge. For 7th street basin, an active unpermitted discharge found at outfall GC-OF-057 contained PCBs, Although BTEX compounds were measured at each transect, results were far below respective benchmarks; thus, TQs were less than one and are not presented.

In summary, BTEX compound results were substantially less than Class SD guidance values. Evaluation of all other water quality results with respect to water quality criteria were complicated by detection limits that were often greater than Class SD water quality standards or guidance values. However, when measured above the detection limits, BAP, total PCBs, chlordane, and heptachlor results were greater and chromium, nickel, and zinc results were less than screening criteria. D.O. was below the minimum criteria to protect fish survival in over 40 percent of the transects and aesthetic narrative standards were not met at most sites due to oil surface sheens.

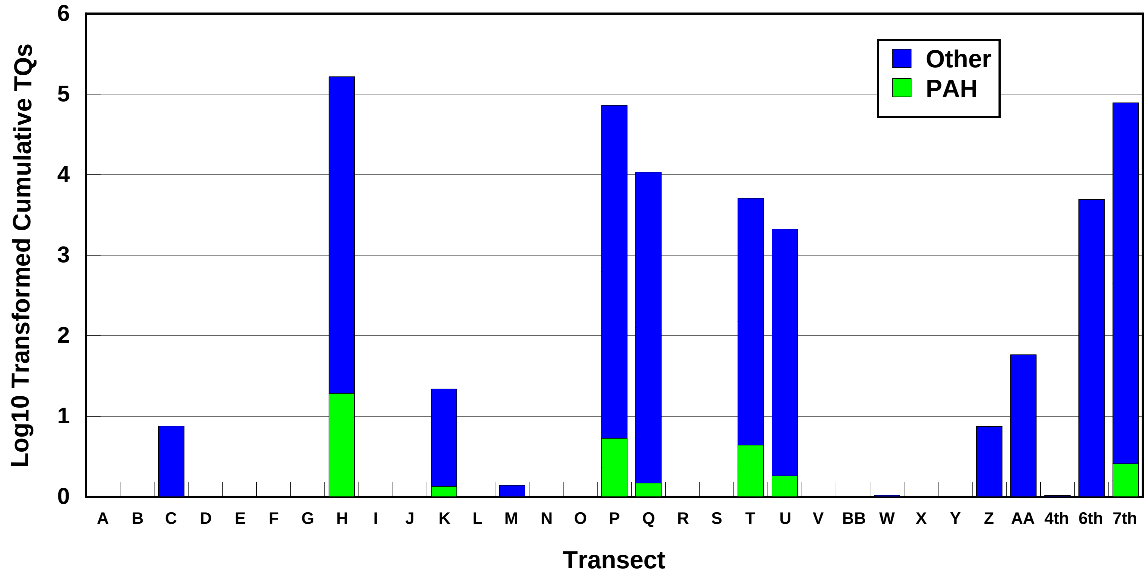


Figure 6: Log10 transformed cumulative water column Toxicity Quotients (TQs). The “other” category represents the cumulative TQs for four contaminant categories; pesticides, metals, polychlorinated biphenyls (PCBs), and benzene + toluene + ethyl benzene + xylene (BTEX). The polycyclic aromatic hydrocarbon (PAH) category represents cumulative TQs for each PAH contaminant, except benzo[a]pyrene (see text).

This water quality analysis identified the frequency and magnitude of Class SD criteria exceedances with respect to condensed transect analytical results. These results indicate that multiple contaminants are predicted to be contributing to the degraded water quality condition of the Gowanus Canal, primarily as a result of non-PAH contaminants.

3.4 Analysis Limitations

In general, data limitations fall into two categories, issues related to non-detect values and the availability (or lack thereof) of potential toxicity benchmarks Deleting unreasonably high non-detect values from further analyses could introduce some selection bias. The direction of this selection bias would be towards lowering the potential magnitude of contamination, since unreasonably high non-detection values were not used in working datasets. In sediment analyses the physical matrix of each sample influences the respective analyte detection limits; therefore, the magnitude of non-detect values can be variable even within a single contaminant between samples. We felt that is was important to retain as much data as possible by carefully screening non-detection values when enough additional data was available to screen the magnitude of respective analyte results. This methodology is consistent with EPA data usability guidance (EPA, 1990; Smith, 1991). The main objective for these data manipulations was to critically retain as much data as possible for use in potential impact analyses. Detailed methods for developing the databases used for analysis, as well as the resulting screened and organized datasets can be found in Appendix A.

Of the 108 potential sediment contaminants, 31 contaminants had non-detection analyte results that were manipulated. The degree of non-detect manipulation was not equal among these 31 contaminants. The greatest number of non-detect manipulations occurred in BTEX, 2-methylnaphthalene, and gamma-chlordane analyte datasets (see Appendix A 2006 - sediment datasets). Perhaps the most influential data manipulations were for two PAHs, dibenz[a,h]anthracene and benzo[k]fluoranthene. In these contaminants non-detection values in samples from Transects O, T, and V were deemed too high and subsequently deleted from the working datasets. Implications of these deletions were most noticeable in our benchmark analyses with dibenz[a,h]anthracene, where TQs for Transect O, T, and V could not be derived. Benzo[k]fluoranthene did not have a sediment benchmark; therefore, deletion results only lowered total PAH estimates.

Of the potential water quality contaminants, only 6 contaminants had non-detection analyte results that were manipulated. As in the sediment dataset the greatest number of non-detect manipulations occurred of BTEX analytes. The relatively small number of contaminants in which non-detection manipulations were performed was dependent on the fact that few contaminants had actual measured results at most transects. Because we could not critically compare the non-detection results to measured analyte concentrations, few contaminant non-detects were manipulated. It is important to note that effluent water quality results were not manipulated and data was used, as is, for all respective analyses.

The second data limitation issue involved the availability of potential toxicity benchmarks. Since our percent exceedance and TQ analyses depended on the availability of ERM or Class SD water quality standard/guidance values, our potential toxicity estimation scope of inference was limited. Of the 108 sediment contaminants that were analyzed, toxicity benchmarks were only available for 50 contaminants. Even fewer water quality benchmarks were available, because ERM benchmarks are not intended for use in water quality screens. Even though benchmarks were not available for all contaminants, exceedance rates and magnitude of toxicity was potentially captured in respective total contaminant "class" categories. For example, potentially toxic PAHs that had no sediment benchmarks were potentially characterized in the total PAH benchmark. This is the reason why total PAH and PCB benchmark analysis results were included with individual analyte benchmark results.

4.0 Evaluation of Sediment Toxicity

Since benchmark/analyte result comparisons only *predict* potential toxic effects in aquatic biota, it was important to follow up our analyses with results from recently conducted sediment toxicity testing. The USACE conducted sediment toxicity tests using a sensitive benthic invertebrate species exposed to canal sediments (AquaSurvey, Inc., 2005; DMA, Inc., 2006).

Results showed significant sediment toxicity to the test organisms after 10 day exposures (Table 3). Additional data provided in toxicity test results included pore water ammonia concentrations for each sediment sample. Ammonia is potentially toxic to invertebrates. Sediment test guidelines state that ammonia has to be lowered before test initiation and this was done via static renewal of overlying water prior to 10 day exposures. The source of ammonia in test sediments was likely due to the decay of nitrogenous organic matter from the CSOs. Ammonia is a common suspect in failed sediment toxicity tests (Moore et al. 1996). Although a positive relationship was found between both initial pore water and test ammonia concentrations and percent mortality, neither was statistically significant.

Table 3: Summary of the amphipod *Ampelisca abdita* sediment toxicity test results, initial test sediment pore water ammonia concentrations, and test water ammonia concentrations. Test water ammonia concentrations were the geometric mean of the initial and final ammonia concentrations. Percent mortality results are an average of replicate tests.

Nearest Transect	Percent Mortality	Pore Water Ammonia Conc. (mg/L)	Toxicity Test Ammonia Conc. (mg/L)
A	30%	109	9.5
E	100%	--	8.9
H	5%*	70.6	3.5
J	35%	57.5	8.6
L	100%	42.8	8.4
R	100%	44	9.1
U	22%	59.3	4.1
4th Street basin	100%	68.4	5.6
6th Street basin	81%	109	5.3
7th Street basin	96%	72	2.6
Control	1%	--	<0.5

* = Not statistically different from control

In addition to toxicity testing, USACE also chemically analyzed a subsample of toxicity test sediments. When analyte concentrations were compared to toxicity test results (Figure 7), a significant relationship was found between concentration and percent mortality for specific contaminants, none of which were PAHs (Table 4). Compared to their respective ERMs, copper, lead, nickel and zinc were found at potentially toxic concentrations, with average TQs ranging from 1.89 for copper to 859 for lead.

Table 4: List of 2005 sediment contaminants that demonstrated a statistically significant positive relationship between natural log transformed concentration and sediment toxicity test percent mortality.

Contaminant (natural log transformed)	p value	Contaminant (natural log transformed)	p value
Bis(2-ethylhexyl)phthalate	0.0356	Copper	0.0332
Total PCBs	0.0430	Lead	0.0261
Arsenic	0.0497	Nickel	0.0318
Cadmium	0.0377	Zinc	0.0414
Chromium	0.0386		

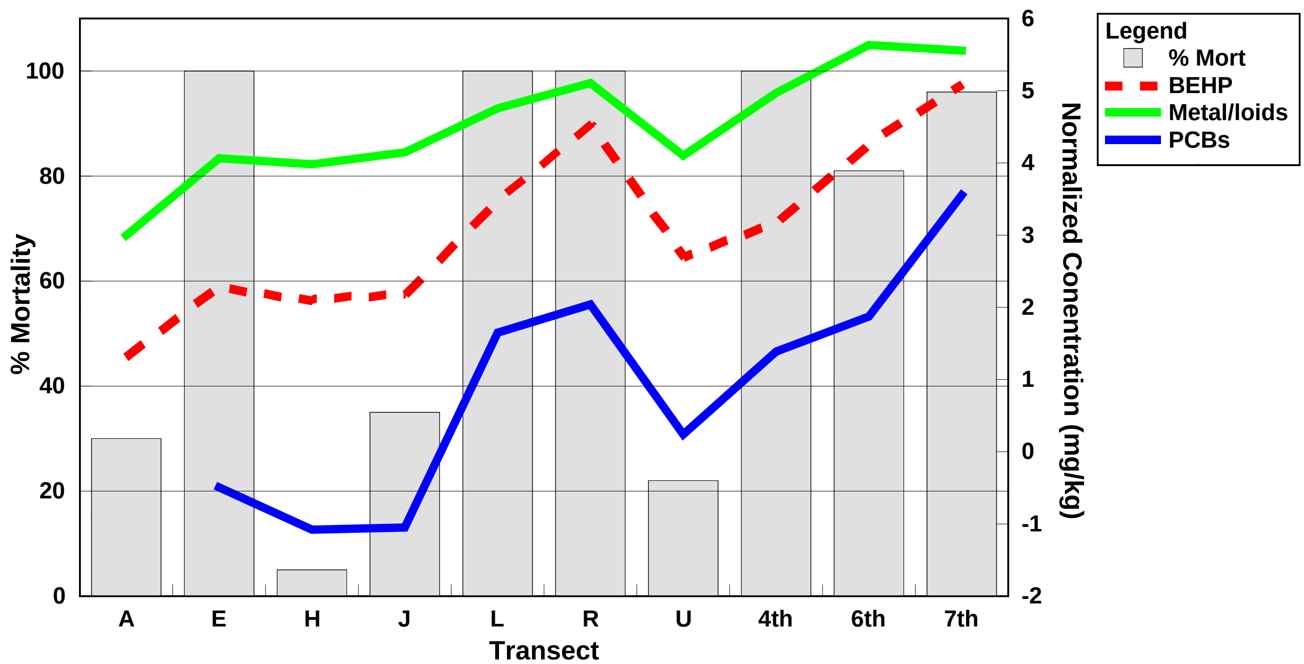


Figure 7: Summary of the amphipod *Ampelisca abdita* sediment toxicity test results, with comparisons to contaminants showing significant relationship to organism mortality. BEHP = Bis(2-ethylhexyl)phthalate, PCBs = polychlorinated biphenyls,

After demonstrating that the Gowanus Canal sediments were potentially toxic using toxicity benchmark derived TQs, toxicity testing confirmed that the sediments are toxic to standard test organisms. When 2005 sediment analytical results were compared to toxicity test results, bis(2-ethylhexyl)phthalate (a relatively non-toxic plasticizer that is ubiquitous in the environment (Agency for Toxic Substances and Disease Registry [ATSDR], 2002), PCBs, and seven metals were significantly correlated with amphipod mortality. These are common municipal contaminants and, in the previous section, were found to have a significant effluent/sediment relationship. Additionally, the high ammonia pore water concentrations, measured in toxicity test sediments, also support that CSOs could be the source of acute ammonia toxicity in canal sediments.

5.0 Evaluation of the Aquatic Biological Populations

The invertebrate community from the Gowanus Canal, as represented by samples taken with the Ponar and H-D samplers, included a total of 47 taxa in six phyla (Table 5) with most taxa preferring mesohaline environments. A few species which can exist in freshwaters were found, including scuds or side swimmers (*Gammarus)* sp., and a shrimp (*Palaemonetes vulgaris)* (Voshell, 2002; Bousfield, 1973; Foster, 1976; Smith 2001).

5.1 Benthic Community

Biological data were used to further characterize the extant Gowanus Canal aquatic community with respect to sample/transect location within the canal, local reference conditions, sediment contamination, and physical habitat. Results indicated that the current ecological condition is being stressed by multiple chemical and physical stressors. Organic pollution tolerant organisms dominated the invertebrate community. Species richness was lower than referenced stressed New York Harbor communities, which included a sewage impacted site. Although no clear cut chemical/invertebrate community metrics relationships were found, physical habitat characteristics such as sediment particle size, temperature, salinity, and D.O. seemed to drive the extant invertebrate distribution within the canal.

Benthic data provided a robust dataset that was used to investigate relationships within and between transects with respect to local reference conditions and sediment contamination. Invertebrate population metrics used to evaluate community condition included species richness and percent pollution tolerant taxa. These metrics were compared to Hudson Estuary reference conditions. These reference condition data originated from EPA's Regional Environmental Monitoring and Assessment Program (REMAP) data (Adams et al. 1998). Although the benthic samples and GEI sediment collections were temporally disconnected, correlations between benthic macroinvertebrate abundances and analyte concentrations were also investigated.

Overall, the benthic invertebrate community strongly represents an estuarine community highly tolerant of organic pollution, with most taxa preferring mesohaline environments. A few species which can exist in freshwaters were found. Nematoda, which were abundant throughout the canal, as a group are nearly ubiquitous in their distribution with widespread ecological preferences and pollution tolerance. Likewise, the freshwater aquatic worms (i.e., Oligochaeta) and flatworms (i.e., Platyhelminthes) are ubiquitous in their distribution, and as a group prefer soft substrates and are fairly tolerant of high levels of organic matter. A few species which can exist in freshwaters were found, including scuds or side swimmers

(*Gammarus*) and a shrimp (*Palaemonetes vulgaris)* (Voshell, 2002; Bousfield, 1973; Foster, 1976; Smith, 2001).

Table 5: List of taxa collected in Ponar and Hester-Dendy (H-D) samples in Gowanus Canal.

Phylum/Class	Class/Order	Family	Taxon	Type of Sample
Nematoda			Nematoda	Both
Annelida	Oligochaeta		Oligochaeta	Ponar
	Polychaeta		Polychaeta	H-D
		Capitellidae	Capitellidae	H-D
			Capitella sp.	H-D
			Capitella capitata	Ponar
			Mediomastus sp.	Ponar
		Cossuridae	*Cossura longocirrata*	Ponar
		Cirratulidae	*Caulliriella* sp.	Ponar
		Glyceridae	*Glycera Americana*	Ponar
		Nereididae	Nereididae	H-D
			Nereis sp.	H-D
			Neanthes succinea	Ponar
		Orbiniidae	*Leitoscoloplas robustus*	Ponar
		Polynoidae	*Harmothoe* sp.	Ponar
		Sabellidae	Sabellidae	H-D
			Fabricia sabella	Both
		Spionidae	*Polydora cornuta*	Ponar
			Polydora ligni	H-D
			Stroblospio bendicti	Both
		Phyllodocidae	*Eteone heteropoda*	Ponar
			Eumida sanguinea	H-D
		Paraonidae	Paraonidae	H-D
Mollusca	Neogastropoda	Nassariidae	*Nassarius obsoletus*	Ponar
		Mytilidae	*Mytilus edulis*	Both
Arthropoda	Isopoda	Limnoriidae	*Limnoria lignorum*	H-D
		Cirolanidae	*Politana polita*	H-D
		Sphaeromatidae	*Sphaeroma* sp.	H-D
	Amphipoda	Aoridae	Aoridae	H-D
			Leptocheirus pinguis	H-D
			Unciola sp.	H-D
		Amphithoidae	Amphithoidae	H-D
		Corophiidae	Corophiidae	H-D
			Corophium sp.	H-D
			Corophium insidiosum	Ponar
		Gammaridae	*Gammarus mucronatus*	Ponar
			Gammarus sp.	H-D
		Ischyroceridae	*Jassa marmorata*	Ponar
			Jassa falcata	H-D
		Melitidae	Melitidae	H-D
			Melita netida	H-D
	Thoracica	Balanidae	*Semibalanus balanoides*	H-D
	Mysida	Mysidae	*Neomysis americana*	Ponar
	Decapoda	Palaemonidae	*Palaemonetes vulgaris*	Ponar
		Xanthidae	*Dyspanopeus sayi*	H-D
Bryozoa			Bryozoa	H-D
Platyhelminthes			Platyhelminthes	H-D

5.2 Epibenthic Community

Epibenthic invertebrates were sampled at five locations in the Gowanus Canal and Bay using H-D style samplers (Lawler et al. 2004). Ten of the 15 H-D samplers were recovered and invertebrates identified after three collection periods that spanned 224 days. There was considerable variability in densities among reaches, with a total of 29 taxa collected, including polychaetes, crustaceans (amphipods, decapods, isopods, thoracica (barnacles), bryazoans, mollusca, nematode, and platyhelminthes (Table 5). All of these species are common throughout the harbor.

The greatest densities were reported after 7 months of exposure. The plates retrieved in December had relatively few settled organisms compared to those collected in other months. Highest densities occurred in June after 7 months of exposure, and successive patterns of colonization were demonstrated in all reaches. Taxa in the H-D samplers included primarily amphipods, which generally prefer to build mud tubes on hard substrates. Nearly all of the taxa collected prefer shallow waters <20 m in depth (Bousfield, 1973). Tube dwelling amphipods and polychaetes were the dominant organisms in all reaches.

Species abundance was low in comparison to a typical epibenthic community in the open waters of the harbor, and the community was dominated by opportunistic species that are common in disturbed habitats and are considered organic pollution tolerant. The absence of the amphipod *Ampelesca abdita* on the plates indicates that epibenthic community is degraded. This species is common in the harbor but is susceptible to pollution and has limited mobility. Lawler et al., 2004 concluded the epibenthic community living in the canal is an impoverished community with low complexity and diversity when compared to established epibenthic communities inhabiting hard surfaces in the East River. D.O. is a critical factor for the establishment of epibenthic community. Extended periods of decreased D.O. can limit species diversity. The D.O. levels have been observed below 3 mg/L during the GEI investigation and by Hazen and Sawyer, 2001.

5.3 Fish and Crab Community

Lawler et al. (2004) provided seasonal data on adult fish, ichthyoplankton, and invertebrate communities from October 2003 to June 2004. From these data general species assemblages were identified.

Adult fish were sampled throughout five reaches within the Gowanus Canal and Bay over four seasonal sampling periods from October 2003 through June 2004 (Lawler et al. 2004). Fish were sampled via trap nets at the three upstream reaches, and by otter trawl tows in the two downstream reaches. Fish were identified and enumerated, to provide Capture per Unit Effort (CPUE) data. All or a minimum of 20 fish from each species at each site were measured. Ten species were collected: white perch, Atlantic silversides, striped bass, cunner, American eels, northern puffer, winter flounder, bay anchovies, spotted hake, and Atlantic tomcod. Blue crabs were also collected. All were collected at low abundances. Species richness values were generally greater in the bay versus the canal. Striped bass were the most common fish species collected. Average monthly fish CPUE ranged from 0 to 77.24 (all species combined).

Ichthyoplankton were sampled throughout five reaches within the Gowanus Canal and Bay by plankton net over four seasonal sampling periods from October 2003 to June 2004 (Lawler et al. 2004). All fish larvae and eggs collected were identified, assigned a life stage (when possible), and enumerated. Twenty samples were collected with 14 species identified (bay anchovy, Atlantic menhaden, windowpane, labridae, grubby, Atlantic herring, Atlantic mackerel, weakfish, Atlantic croaker, winter flounder, unidentified gadid, tautog, northern pipefish, and Atlantic silversides). Dominant egg and yolk sac larvae species collected was bay anchovy. Post yolk sac larvae had the highest species diversity of all life stages, with 12 species collected (winter flounder were most abundant in March, and bay anchovies were the most abundant in June). Monthly average ichthyoplankton densities ranged from 0 to 8,635/1000 m^3. Limited spawning occurs in the Canal, with more likely occurring in the Bay. The few eggs collected in the Canal were dominated by pelagic species, indicating that the eggs likely drifted, possibly by being drawn into the Canal from the Buttermilk Channel through the flushing tunnel or from the bay via the incoming tide. No winter flounder eggs were collected, only post sac larval stages, so it is unclear if winter flounder are spawning in the canal or if those collected were transported from the Bay or flushing tunnel.

In summary, the fish collected were dominated by migratory species that are common in the Harbor and Mid-Atlantic estuaries, with few resident fish (cunner, tautog) collected; indicating that the habitat necessary to support a resident fish community may not be present. The canal has undergone extensive urbanization/industrialization, which has resulted in loss of aquatic habitat and poor water quality. Urbanization of the canal has created abiotic obstacles (e.g., low D.O., high temperatures) to the establishment of a resident fish community.

Eighteen crab pots were retrieved. The most abundant taxa of crabs, the Pacific shore crabs, are opportunistic omnivores that can tolerate wide ranges of temperatures and salinities. It is a potential competitor for other native species common to the area, as well as the non-native green crab. Other species collected included green crabs and bay mud crabs. Several fish were also collected in the crab traps, including winter flounder, black sea bass, cunner, American eels, northern searobins, and mummichogs. No crabs were collected in Reaches 2 and 3 and none were collected during fall and spring surveys.

Due to the limited number of ichthyoplankton, adult fish, and crab sites we did not quantitatively investigate relationships between sampling results and physical/chemical stressors. Additionally, data were collected using multiple methods that could bias results and affect statistical assumptions. Regardless, general conclusions on the distribution can be made using the available data. Generally, transects near the lower (Gowanus Bay) and upper (flushing tunnel) canal reaches had the greatest densities of ichthyoplankton, adult fish, and crab. The greatest number of adult fish species (3) were found in transects near Gowanus Bay and in Transect N. Additionally, the greatest relative adult fish density (measured by respective CPUE) was found in upper reaches of the canal. The greatest crab diversity and density was found in Transect C, which is relatively close to the flushing tunnel.

These results support that the Gowanus Bay and flushing tunnel could be potential sources for larval and adult fish sampled in the canal. However, these results also support that except for the bay, the ecological community is dependant upon the operation of the flushing tunnel. Additionally, improvements in water quality associated with tidal or tunnel exchange could influence distribution of mobile fish and crab species within the canal. These results are similar to those made by other researchers, which concluded that D.O. levels are thought to be a limiting factor in the epibenthic macroinvertebrate populations.

5.4 Analyses of Trends in the Benthic Community

5.4.1 Cluster Analyses

Cluster analysis (group average of Euclidean distances) was performed on community composition (presence/absence) data (Hintze, 2003) using only the Ponar collected dataset. The H-D dataset was not separately analyzed due to the limited number of canal sites sampled that could be matched to GEI transects.

When only the benthic invertebrate data from benthic samples were clustered, results effectively demonstrate that the benthic invertebrate community can be broken into 5 distinct clusters, with dissimilarity between clusters $\geq$55 percent (Figure 8). These five clusters were further evaluated to determine if additional trends within the invertebrate community could be identified.

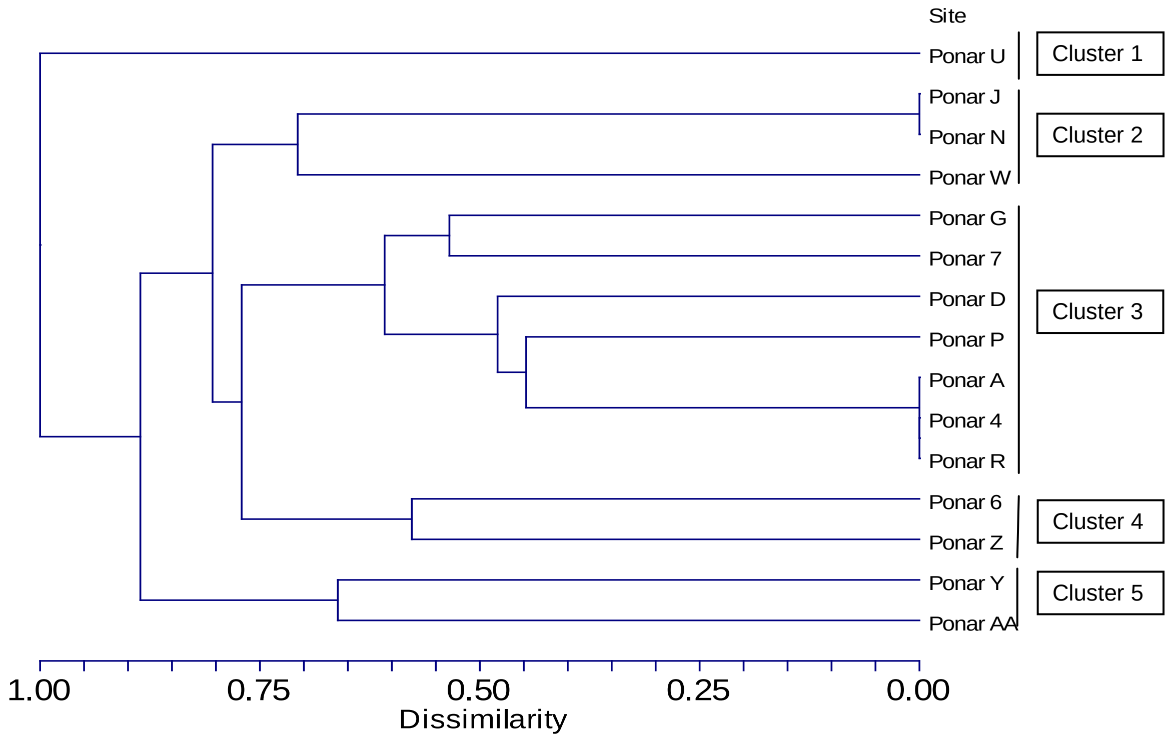


Figure 8: Cluster analysis, based from benthic invertebrate presence/absence data, of transects from benthic samples collected in Gowanus Canal. Five distinct clusters were identified with respect to dissimilarity between clusters ≥55%.

Cluster 1 contained only one transect. No invertebrates were found in samples from Transect U making it the least diverse of all clusters. Cluster 2, which included Transects N, J, and W, had few Nematoda and Oligochaeta, with no other taxa. Cluster 3 contained more transects than any other cluster, Transects A, D, G, P, R, 4th St, and 7th St. This cluster had more Nematoda and Oligochaeta than Cluster 2, but included *Capitella capitata* (Polychaete) and three species of amphipods, which were not identified at any other transects. This was the second most diverse cluster. Transect Z and the 6th Street basin was represented in Cluster 4. Cluster 4 was dominated by Nematoda, Oligochaeta, and Polychaeta (multiple species). More nematodes and oligochaetes were identified in Cluster 4 transects than any other cluster. Organic matter and sand (30 percent) is present at the 6th street basin and may be responsible for the community composition. The USACE sampled adjacent to the pier at Transect Z and therefore more marine polychaetes would be expected. Cluster 5 was most diverse. When Transects Y and AA were condensed, 15 taxa were identified. Most of these taxa were Nematoda, Oligochaeta, and Polychaeta, but a few Mollusca (mussels/snails) and Decapoda (crabs) were also found. In summary, transects were grouped (clustered) with respect to increasing species or taxa richness.

Using the clustered invertebrate communities we investigated trends in chemical and physical datasets that matched the grouped transects. No clear cut relationships were identified between cluster condensed metrics and chemical stressors in the sediments, possibly a result of the already low number of taxa present and indicating a stressed community.

Although chemical stressor relationships were poor, clustered results seemed to be correlated with physico-chemical conditions (Figure 9), such as temperature, salinity, D.O., and substrate particle size. These data were collected concurrently with invertebrate sampling and best reflect the physical condition of the Gowanus Canal when invertebrate communities were sampled. Clusters 3 and 5, which had the greatest species richness, also contained gravel sized particles. Cluster 5 contains transects closest to Gowanus Bay. Cluster 1, which had no species present, had high percent silt and clay relative to the more diverse sites. Lower temperature, higher salinity, and higher D.O. were all associated with greater species richness. In total, these results indicate that within the impoverished, organic pollution tolerant invertebrate community able to inhabit Gowanus Canal, physical habitat condition has more of an influence on resulting species richness than chemical stressors.

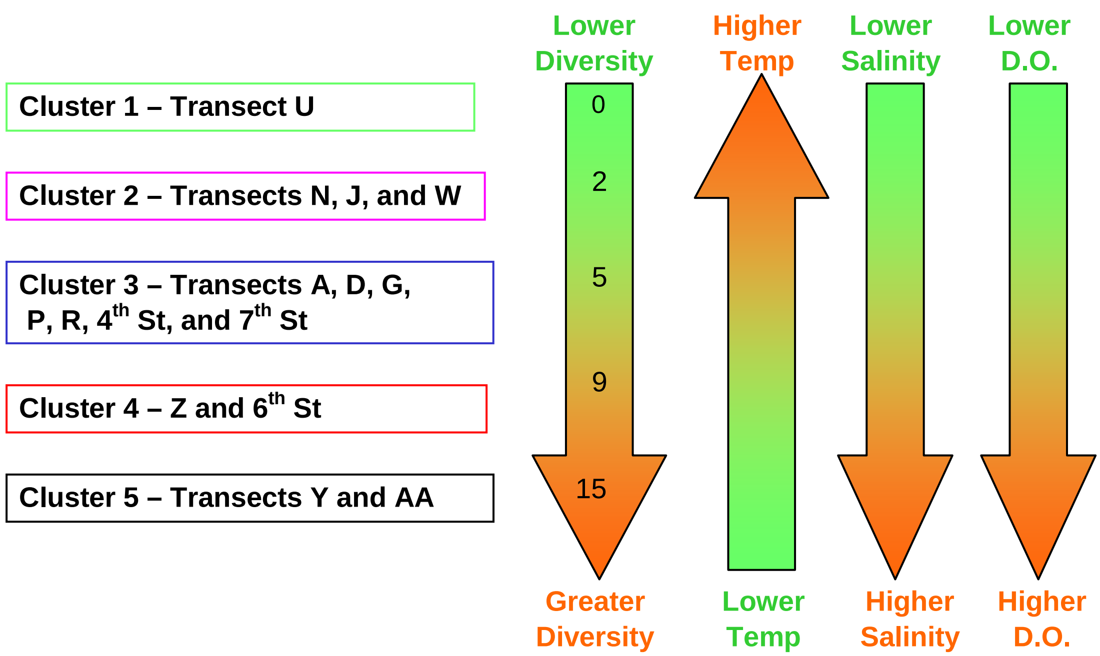


Figure 9: Comparison of species richness (combined number of taxa) of cluster analysis groupings with concurrently based water quality data.

5.5 Comparison to Gowanus Canal "Flushing Tunnel Study"

The flushing tunnel was re-activated in early March of 1999. To measure the effectiveness of the flushing tunnel on restoring the canal's benthic community, benthic organisms were collected monthly from March 1999 through February 2000 by Hazen and Sawyer (2001) on behalf of the New York City Department of Environmental Protection (NYCDEP). The benthic sampling locations included Station 1) head of the canal, 2) 4th Street Turning basin, 3) Hamilton Avenue, and 4) mouth of Gowanus Bay. USACE data, represented by GEI Transects A, J, and W/X, directly correlate to the NYCDEP Stations 1, 2, and 3 sampled in 1999. However, the USACE study did not place a transect in Gowanus Bay; therefore, no comparisons is made to NYCDEP Station 4. USACE collected benthic organisms in April of 2003. Therefore, the February 2000 results of the NYCDEP survey were compared to the USACE results to provide before and after comparison survey.

The NYCDEP results indicated that polychaete worms comprised 100 percent of the organisms collected at Stations 2 and 3. Approximately 97 percent of the polychaete worms were *Capitella capitata*. Approximately 3,600 organisms/m^2 were collected at Station 3, consisting of 8 species of polychaete worms (65 percent *Capitella capitata*). At Station No. 1, 15 percent of polychaete worms comprised the community in April 1999. The NYCDEP survey concluded that the canal did not have a stable benthic community as of February 2000, in terms of the number of organisms and species. The presence of *Capitella capitata* and *Streblospio benedicti* in high numbers represented a successional benthic community.

The macroinvertebrate results of the NYCDEP 1999-2000 survey were compared to USACE study conducted in 2003, as summarized above. The purpose was to assess if the benthic communities exhibited signs of recovery 5 years after the flushing tunnel's re-activation. Both NYCDEP and USACE sampling events used the same equipment, a petite Ponar grab sampler. The processing of the benthic macroinvertebrate samples was also similar between the NYCDEP survey and USACE 2003 sampling event. One difference between the studies was the number of replicates sampled per site (two replicates for the USACE study vs. five replicates in the NYCDEP study).

The mean number of benthic macroinvertebrate species (taxa) identified at the stations in the 2003 USACE sampling was again lower compared to 5 years earlier (Figure 11). However, the USACE only collected two replicates per transect or benthic sample. At each NYCDEP station, five replicate samples were collected. The number of replicates may account for a portion of the temporal difference in canal species richness measurements.

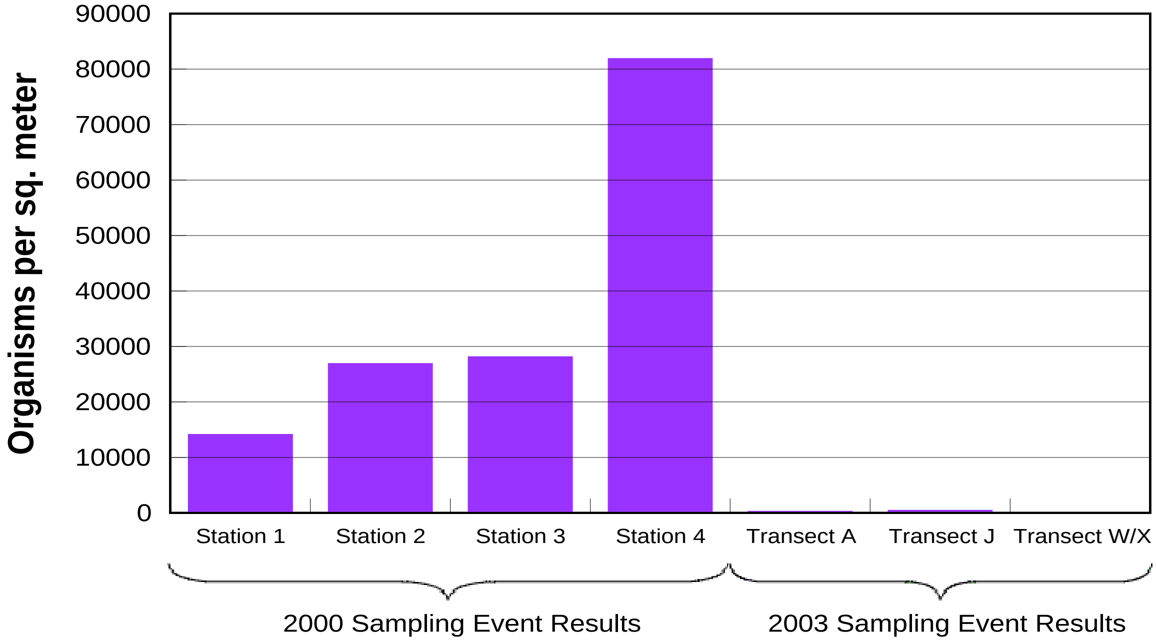


Figure 10: Comparisons of density of benthic organisms (numbers per square meter) sampled at the New York City Department of Environmental Protection stations to the corresponding USACE (per GEI transects) data from 2003.

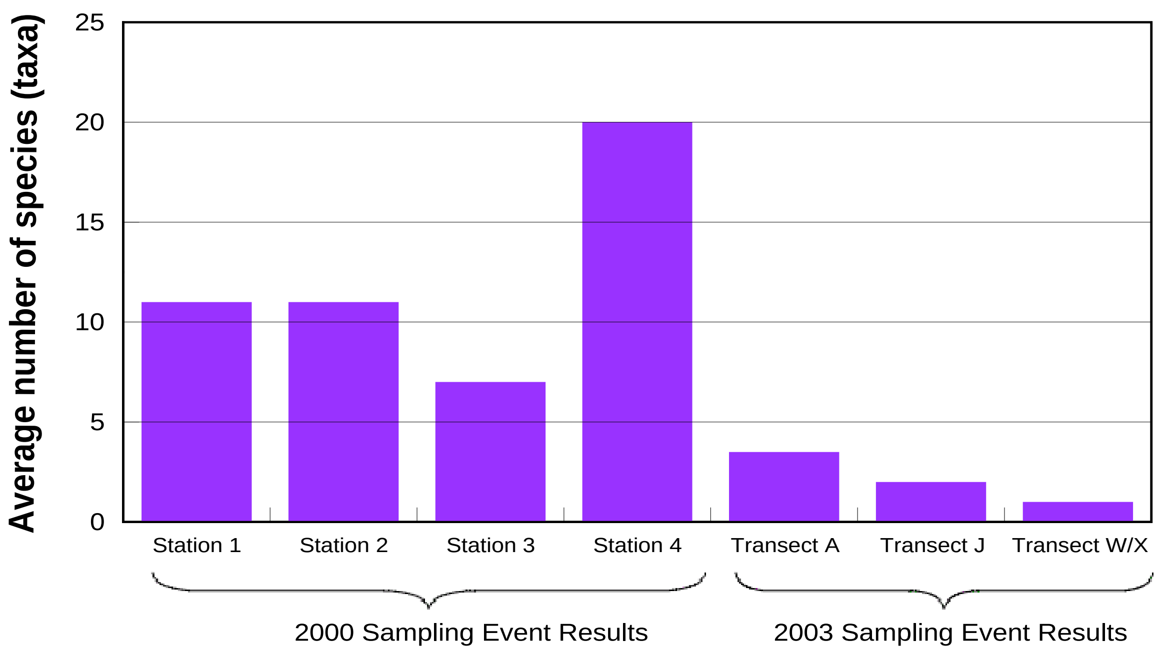


Figure 11: Comparisons of mean number of species (taxa) for benthic organisms sampled at the New York City Department of Environmental Protection stations to the corresponding USACE (per GEI transects) data from 2003.

In 2003, there was approximately a 50 percent decrease in the percentage of polychaetes at Transect A when compared to Station 1 sampled in February 2000 (Figure 12). No polychaetes were present in samples from the two other USACE 2003 transects in contrast to February 2000, when polychaetes comprised a substantial proportion of the relative density.

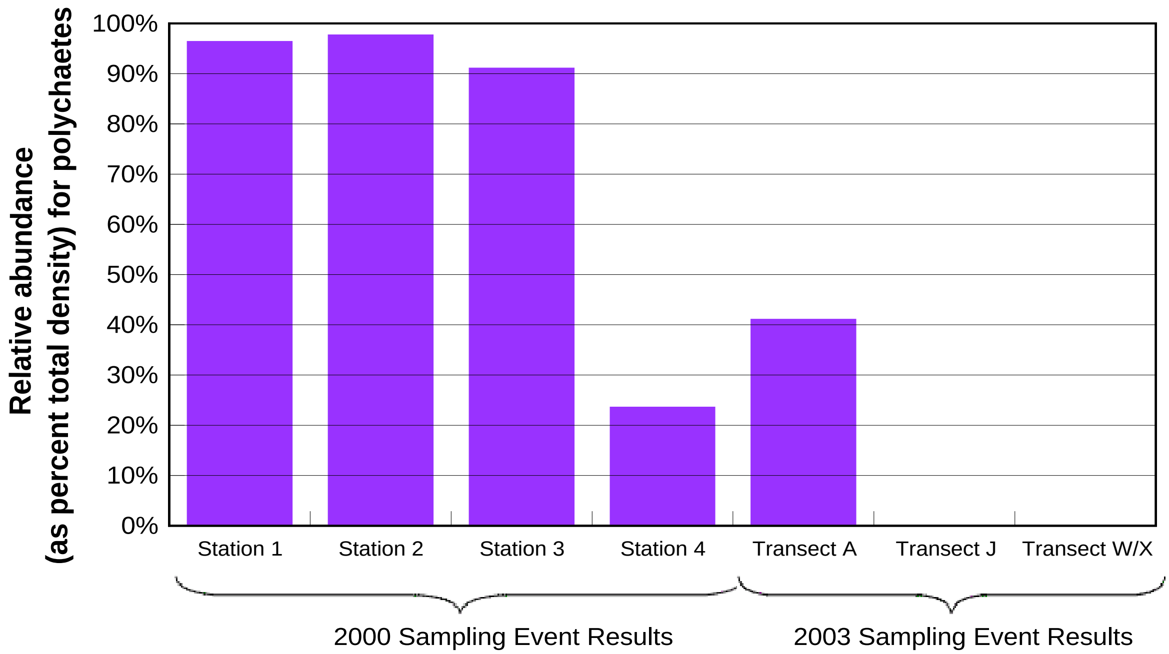


Figure 12: Comparisons of the relative abundance of polychaetes (as % total density) for samples from the New York City Department of Environmental Protection stations to the corresponding USACE (per GEI transects) data from 2003.

When comparing USACE 2003 benthic data to the NYCDEP February 2000 data using 3 benthic community metrics, the benthic macroinvertebrate communities throughout the canal are not showing signs of recovery and it appears the communities have further degraded since February 2000.

5.5.1 Comparisons to Other Regional Benthic Community Studies

Benthic invertebrates communities found in the Gowanus Canal were compared to other regional studies that assessed the benthic communities within New York Harbor and nearby waters. The objectives were to:

1. Identify if there are any similarities between the canal communities with other impaired or stressed communities in the New York Harbor system in terms of species composition or biotic metrics measuring impacts to the communities.

2. Determine if the impairment to the NY Harbor benthic communities were attributed to chemical stressors or physical habitats that were documented in sediments.

3. Make interferences with other harbor studies that investigated the effects of organic enrichment associated with sewage on marine benthic communities.

GEI's evaluation of the benthic invertebrate community structure using the USACE species data revealed that the communities are impaired to various degrees. Observations of the Gowanus Canal benthic communities included:

- Oligochaeta was the most abundant family found in the USACE benthic samples. This family is ubiquitous in distribution and as a group prefers soft substrates (Barnes, 1978). Oligochaetes are an important indicator of pollution because of their tolerance to organic enrichment. In enriched or oxygen-deficient areas, there are typically high densities of oligochaetes. Virginian Province Environmental Monitoring Assessment Program (EMAP) uses the number of oligochaetes per sampling event to assess environmental stress (EPA, 2000).

- In GEI's benthic community analysis, *Streblospio benedicti* was primarily found in Cluster 4 and *Capitella* was found in Cluster 3 and 4. EMAP also considers *Capitella* as a pollution indicative organism (EPA, 2000). Capitellids are particularly tolerant to organic pollution (Olson and Fredick 1967). In the canal, species richness was comprised primarily of polychaete worms. These invertebrates generally prefer the soft, muddy substrates. Polychaete distributions and dominance patterns are used as indicators of pollution (Olson and Fredick, 1967).

- Nematods are nearly ubiquitous in their distribution in the canal and have widespread ecological preferences and pollution tolerances.

Causes for the impairment within the five different clusters identified in Figure 8 using cluster analysis, which included elevated ambient water temperature, low D.O. in water (Figure 9), and poor substrate for colonization (high silt content and total organic carbon). These results are similar to findings from studies of nearby systems, as summarized below.

5.5.1.1 Adams et al., 1998 Sediment Quality of the NY/NJ Harbor System

As noted earlier, GEI's assessment demonstrated that non-PAH chemicals exceeded sediment benchmarks at a significantly higher frequency than PAHs (Figure 1) in Gowanus Canal. Additionally, benthic community compositions within the canal showed that sewage/organic pollution tolerant organisms dominate the canal benthic communities.

Because only impaired communities were found in the canal, a reference community was not available to directly evaluate the possible causal relationships between sediment contamination and benthic community metrics in the Gowanus Canal. However, as part of a EPA REMAP study, Adams et al. (1998) identified non-impaired benthic communities in the NY Harbor system. They determined that 3 benthic metrics, abundance (decrease), species richness (decrease), and percent pollution tolerant species (increase), could be correlated to sediment chemistry when 6 or more chemicals exceeded National Oceanic Atmospheric Administration ERMs. This was observed throughout the entire NY harbor system and each of three subbasins (Upper Harbor, Lower Harbor, Jamaica Bay). This relationship was most often found for 3 contaminants: chlordane, PCBs, and mercury.

A multi-metric benthic index of biotic integrity was developed for the NY Harbor and used to determine benthic impacts. The six metrics used included species richness, species diversity, biomass, percent abundance as pollution sensitive taxa, percent of abundance as pollution-tolerant taxa, and percent of abundance as carnivores/omnivores. Measurable benthic impacts were most widespread in Upper Harbor and Jamaica Bay. The distribution of individual stations with impacted benthos shows the most highly impacted sites were in the backbay of Jamaica Bay.

REMAP noted that pollution tolerant species were common in the backbay portion of Jamaica Bay, which is in the vicinity of 26th Ward Point Waste Water Treatment Plant. The REMAP's Jamaica Bay results showed evident pollution influence on benthic structure was associated with total organic carbon. Figure 13 compares the average number of taxa measured for Gowanus Canal transects compared to the 3 REMAP basins.

When the relative numbers of pollution tolerant taxa are compared to REMAP sites (Figure 14), Gowanus Canal is quite similar to two of the three REMAP sites, including Jamaica Bay. Together these results indicate that the number of species in the Gowanus invertebrate community is very low, even when compared to local impaired communities, while the species that are present have a similar pollution tolerance.

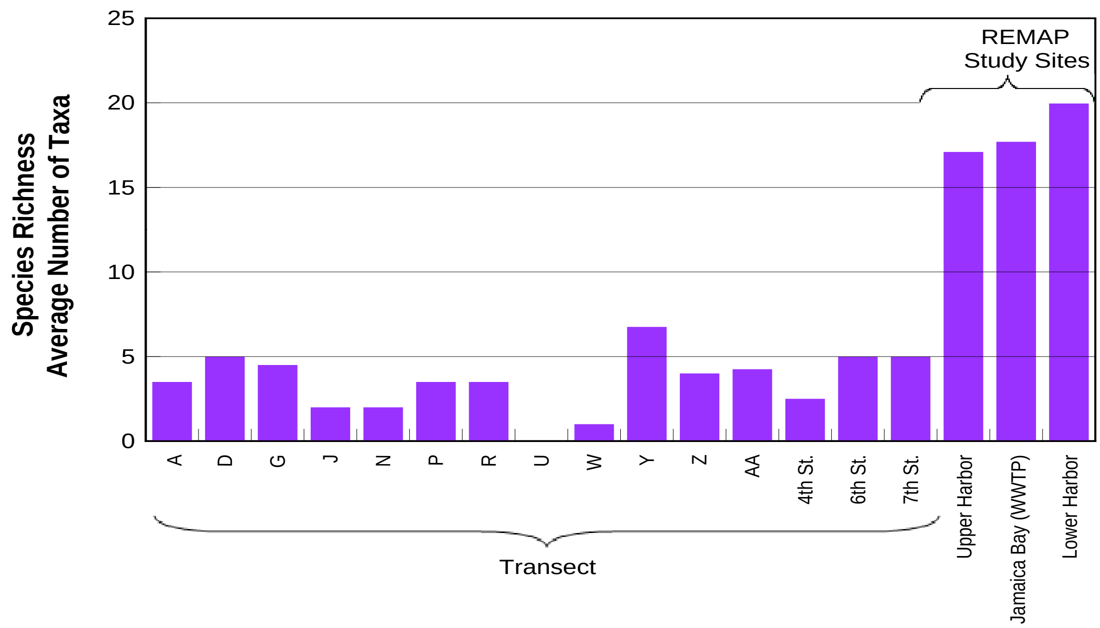


Figure 13: Gowanus Canal transect specific average number of taxa compared to local communities. The upper New York Harbor, lower New York Harbor, and Jamaica Bay Wastewater Treatment Plant (WWTP) data from the EPA's Regional Environmental Monitoring and Assessment Program (REMAP) study.

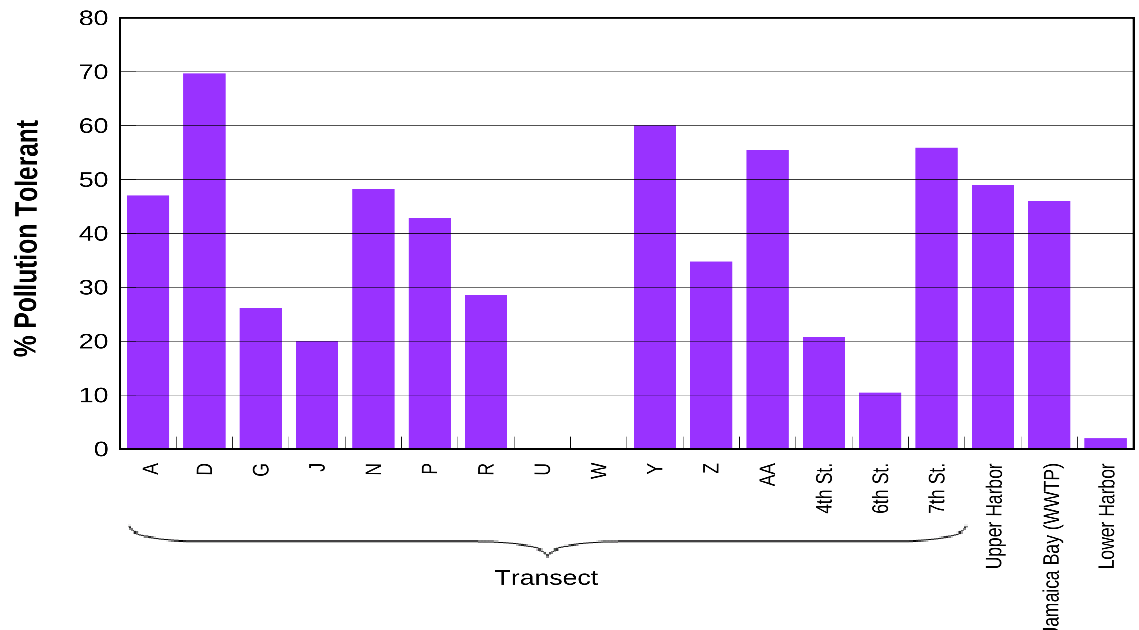


Figure 14: Gowanus Canal transect specific percent pollution tolerant taxa compared to local communities. The upper New York Harbor, lower New York Harbor, and Jamaica Bay Wastewater Treatment Plant (WWTP) data from the EPA's Regional Environmental Monitoring and Assessment Program (REMAP) study.

REMAP found that the estimated prevalence of high toxicant concentrations (i.e., sediments with one or more toxicant concentrations exceeding ERM values) was consistent with the estimates of areas with impacted benthos. However, sediments from only a relatively small area of the Harbor (15 percent) caused reduced laboratory survival of *A. abdita*. The REMAP study found that metals present at > ERM were most often associated with *A. abdita* toxicity for the Harbor system. GEI conducted a similar evaluation using USACE *A. abdita* toxicity testing results (percent survival) and 2005 sediment data. Nine natural log transformed variables, mostly metals, demonstrated a statistically significant negative relationship with percent survival (Table 1).

The REMAP studies indicated that the sediment toxicity test was a less sensitive indicator of sediment quality than ERM sediment chemistry concentration evaluations or invertebrate community structure. These findings indicated that benthic structure was measurably impacted, and was predictable by chemical contamination, before acute toxicity of *A. abdita* became evident. Given both ERM exceedances and *A. abita* toxicity were significant in Gowanus Canal, this confirms the findings of impaired benthic communities in the canal.

5.5.1.2 Benthic Habitats of New York/ New Jersey Harbor

A survey of benthic habitats was conducted in Jamaica Bay, Upper Bay, Newark Bay, Bowery Bay, and Flushing Bay (Iocco, et al. 2000). The objective of the survey was to map benthic (bottom) habitats in New York/New Jersey Harbor in a geographic information system (GIS) using sediment profiling imagery (SPI) and grab sampling. The maps developed identified benthic habitat types and their distribution, and were used to document habitat variability.

In October 1994, the USACE began collecting these data using traditional benthic sampling methods and SPI remote sensing techniques. The habitat classification system was developed for New York/New Jersey Harbor and was based on sediment type and observed faunal assemblages. Twenty-one habitat classes were identified in this study. Figure 15 compares species richness per Gowanus Canal transect to the 4 bays that were sampled in the benthic habitat study. The species richness found at the canal transects were less than the species richness for all 4 bays.

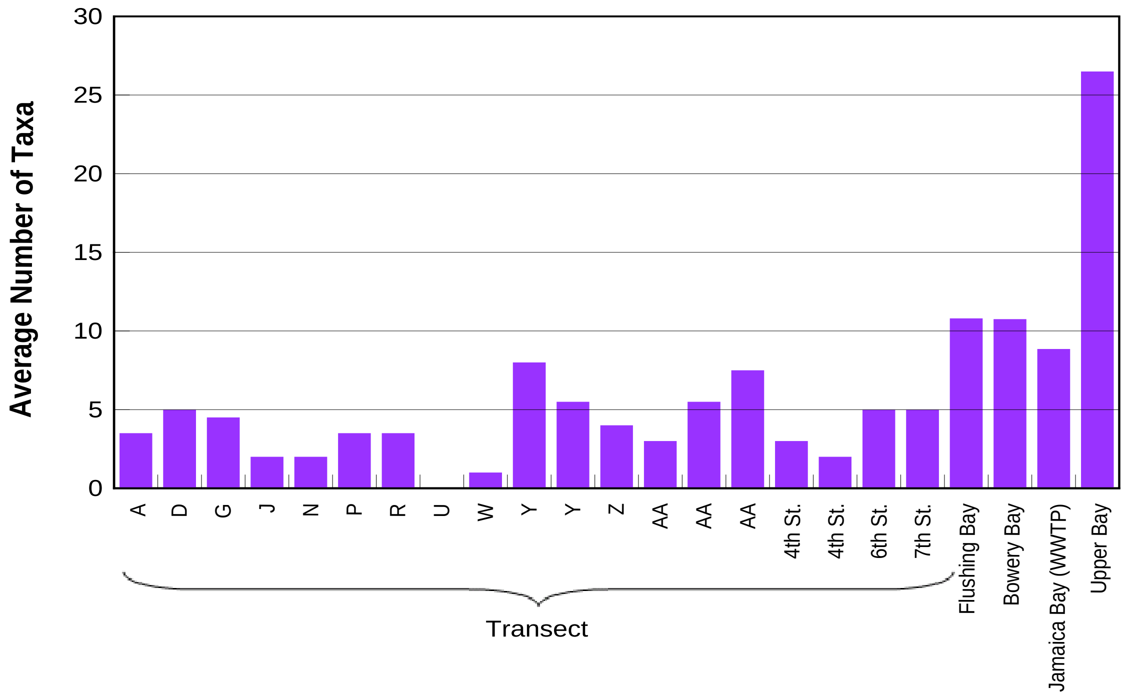


Figure 15: Comparison of species richness at transects in Gowanus Canal with New York/New Jersey Harbor bays sampled by USACE in 1994 (Iocco et al, 2000).

In general, the benthic habitat survey found that benthic habitats in each bay were dominated by opportunistic or organic pollution tolerant species. Oligochaetes were often identified in the survey and are an indicator of pollution because of their tolerance to organic enrichment. They were also living in the sediment of the Gowanus Canal. The average number of oligochaetes was calculated for each of the 4 bays (Flushing Bay, Bowery Bay, Jamaica Bay, and Upper Bay) and compared to the canal (Figure 16). Nine transects within Gowanus Canal had stations where oligochaetes were more abundant when compared to the four bays.

Because *Streblospio benedicti* was one of the polychaetes species identified both the NY/NJ harbor survey and in Gowanus Canal, GEI compared the abundances of *S. benedicti* found at the different canal transects to the abundances of this species reported in the 4 bay areas (Figure 17). The polychaete worm, *S. benedicti*, can survive in highly enriched sediments because it has gills that protrude a few hundred micrometers (µm) from the sediment-water interface. The data indicates that some individuals of *S. benedicti* have been able to colonize some sections of the canal, but not all. The number of individuals in the canal is still lower than the four other bays. In the NY/NJ harbor survey, polychaete distributions and dominance patterns were often used as indicators of pollution, as many species (including *S. benedicti*) are relatively tolerant to high levels of pollution. Pollution-tolerant polychaetes remain in areas where more sensitive species have left or died. Recolonization by most polychaetes can occur in less than a month, but some studies have indicated that several months to a year may be needed.

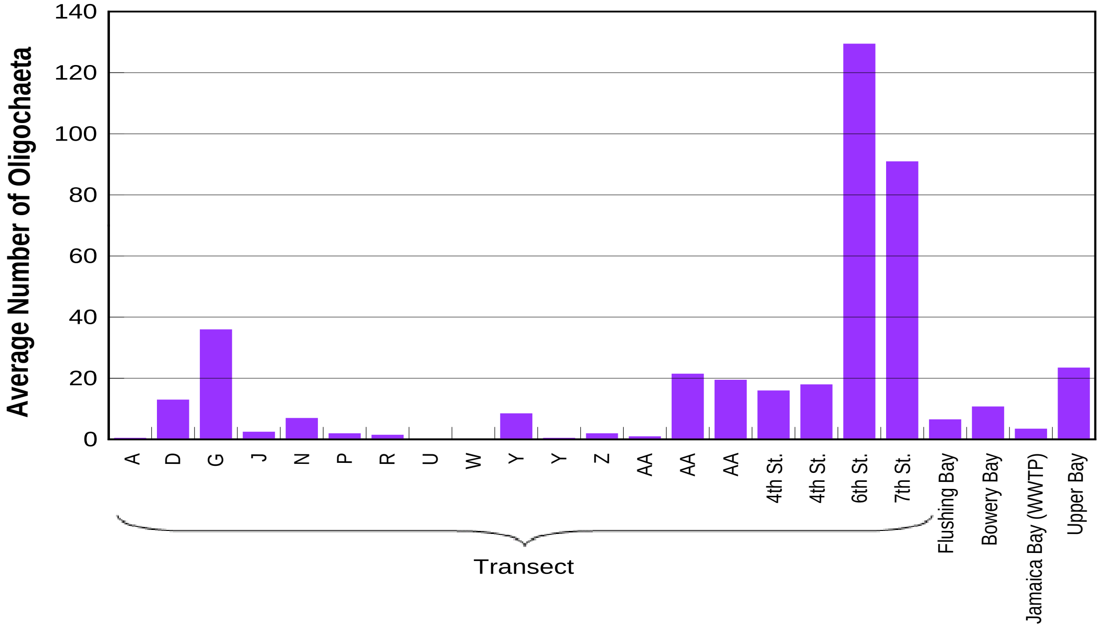


Figure 16: Comparison of numbers of oligochaetes at transects in Gowanus Canal with New York/New Jersey Harbor bays sampled by USACE in 1994 (Iocco et al, 2000).

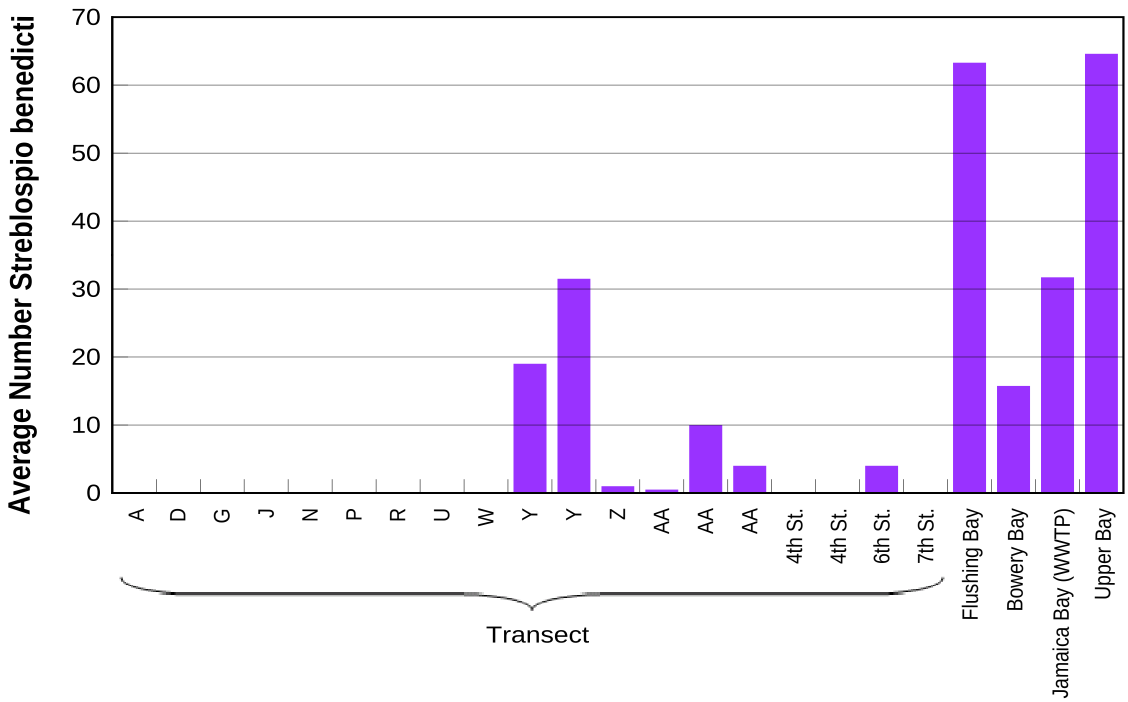


Figure 17: Comparison of numbers of the polychaete worm, *Streblospio benedicti,* at transects in Gowanus Canal with New York/New Jersey Harbor bays sampled by USACE in 1994 (Iocco et al, 2000).

5.5.1.3 Gallagher, 1998 Organism-Sediment-Contaminant Interactions in Boston Harbor

Benthic community monitoring is being conducted by Massachusetts Water Resource Authority as part of its outfall monitoring program. A study was conducted that investigated benthic communities of Boston Harbor and their relationship to contaminants and organic enrichment observed in the harbor. The major effect of pollution on Boston Harbor community structure is that species, normally found only in intertidal or low salinity habitats, dominate Boston Harbor's contaminated subtidal habitats. In addition, the most contaminated sediments contain high frequency of several polychaete worms (*Capitella*). *Capitella* were found in only the most organically enriched sediments. Many subtidal areas of Boston Harbor were dominated by oligochaete worms, and the spionid polychaetes, *S. benedicti* and *Polydora cornuta*. This would be a typical benthic community if salinities were low (15 to 20 parts per thousand [ppt]) or variable, but it is highly atypical for the high salinities (about 28 ppt) found in Boston Harbor.

A high frequency of *Capitella* or *S. benedicti* in Boston Harbor's sub tidal sediments is a strong indicator of organic enrichment or contamination. In Gowanus Canal, *Capitella* was present at 13 of 28 transects sampled by USACE. *Capitella* rarely occurs in high numbers with other species; thus, the other 15 transects where *Capitella* was not present might be due to competition by other species such as spionids. The polluted end point of organic enrichment gradient is identified by either highly organic, fine sediment with low numbers of organisms (i.e., Cluster 1 at Transect U of the canal noted above) or a community dominated with high frequency of *Capitella* (Clusters 3, representing Transects A, D, G, P, R, 4th St, and 7th St, and Cluster 4, representing Transect Z and the 6th Street basin). The next successional stage in organically enriched in subtidal areas that will replace *Capitella* include *S. benedicti*, *P. cornuta*, and oligochaetes.

5.6 Comparisons to Sediment Contaminants

To investigate trends in the extant invertebrate community with respect to chemical stressors, invertebrate metrics were compared to GEI sediment data. No biologically significant conclusions could be made when invertebrate metrics were compared to GEI sediment data. Nematode and Oligochaete abundances drove most all of the invertebrate metric endpoints and most trends were positive, indicating that the increasing concentrations of contaminants were correlated to *greater* invertebrate density and species richness. These contradictory results might be due to the low invertebrate richness resulting from the chemical stressors noted earlier, limiting identification of a true response. Species that are present are tolerant to organic pollution and it is likely that the community does not respond to contamination in the same manner as would a more diverse and sensitive assemblage.

A total of 54 contaminants and 7 habitat variables from the 2006 GEI sediment sampling analyte results were regressed against total density, diversity (H'), number of taxa, nematode abundance, oligochaete abundance, and Capitellidae abundance. For this analysis, both benthic and epibenthic invertebrate communities were combined and normalized to the "family" level of identification to allow use of the most diverse list of taxa. Contaminant and physical parameter results were natural log normalized to better meet normality assumptions.

Diversity and total number of taxa were positively correlated with BTEX compounds, and Capitellidae abundance was negatively correlated. Total density, number of taxa, nematode abundance, and oligochaete abundance were *positively* correlated with every PAH. The relationship was statistically significant for number of taxa vs. PAH results only. Diversity was negatively correlated with all of the PAHs, but none were statistically significant. Total density, nematode abundance and oligochaete abundance were positively correlated with sediment metal results, but this relationship was only statistically significant between select metals and oligochaete abundance. Nematode and oligochaete abundance were positively correlated with PCBs and pesticides. No clear or consistent patterns were identified in diversity and Capitellidae abundance with respect to metal concentration.

In summary, nematode and oligochaete abundances appear to be driving the total density and number of taxa biological endpoints, as all four metrics show similar relationships with contaminant results. Nematode and oligochaete seem to be tolerant of most all contaminants, with the exception of benzene. On the other hand, Capitellidae abundance seems to be the least tolerant of most all of the contaminants, with the exception of a few PAHs and metals. Diversity seems to be sensitive to PAHs, but no consistent patterns were identified with other contaminants.

To investigate physical habitat influences on the extant invertebrate community, we also compared abundance of abundant invertebrate taxa to 2006 matched transect data. The Corophiidae and the Capitellidae abundances were positively correlated with percent sand. Average number of taxa was negatively correlated with fine grained sediments (percent silt and clay). Interestingly, the opposite relationship was found between density and fine sediments. These results are consistent with REMAP comparisons, in that the invertebrate species richness is independent from species abundances. Gravel was rarely observed in Gowanus sediments, but at transects in which it was measured species richness was generally greater. These relationships between physical habitat and invertebrate metrics support our cluster analysis results that identified habitat conditions as the probable drivers in Gowanus Canal invertebrate communities.

6.0 Summary and Conclusions

In conclusion, results from this study support that sediments are toxic due to multiple chemical stressors. These stressors include metals, PCBs, pesticides, and to a lesser extent PAHs. Using water quality standards and sediment benchmarks, established to protect fish survival, we were able to identify the frequency and predict the magnitude of toxicity of water column and surficial sediments to aquatic organism. Although PAHs had little impact on water quality, the magnitude of potential impacts in sediments from chemical stressors was substantial, even without considering PAHs. Outfalls were also identified as a potentially significant source of sediment contamination from metals, pesticides, and PCBs. The predicted toxicity of canal sediments was validated in laboratory toxicity testing, with clear relationships seen between test organism mortality and non-PAH contaminants. Analyses investigating invertebrate abundance and richness metrics with respect to reference sites from other waters, sediment contamination, and habitat revealed that the Gowanus Canal invertebrates are severely limited.

Fish and crab were also observed in the canal. The fish community was dominated by migratory species that are common in the Harbor and Mid-Atlantic estuaries, suggesting that the habitat necessary to support a non-migratory resident fish community may not be present. The distributions of larval fish, adult fish, and crabs within the canal seemed to correlate with proximity to the flushing tunnel or Gowanus Bay. This observation supports that the Gowanus Bay and flushing tunnel could be potential sources for larval and adult fish sampled in the canal. Additionally, improvements in water quality associated with tidal or tunnel exchange could influence distribution of mobile fish and crab species within the canal. These results are similar to those made by original researchers, which concluded that D.O. levels are thought to be a limiting factor in the epibenthic macroinvertebrate populations.

To establish the ecological condition of the Gowanus Canal with respect to temporal, local, and regional data, we compared our results to referenced conditions reported by other researchers. When we investigated potential flushing tunnel benefits it was clear that the benthic macroinvertebrate communities throughout the canal are not showing signs of recovery and it appears the communities have further degraded since February 2000. When Gowanus canal sites were compared to local impaired REMAP sites, results indicated that the number of species in the Gowanus invertebrate community is very low while the species that are present have a similar pollution tolerance. When Gowanus Canal benthic macroinvertebrate communities were compared to regionally conducted surveys, successional distributions of oligochaetes and polychaetes were identified. High numbers of oligochaetes and low numbers of polychaetes further support that organic enrichment from sewage/CSO discharges in the canal results in a opportunistic or pollution tolerant invertebrate community.

In summary, the current Gowanus Canal ecology is very limited by a combination of chemical contamination, organic (sewage) pollution, and poor physical habitat, much of which could be artifacts of CSO effluent impacts.

7.0 References

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Appendix A

Data Sources and Management Protocols.

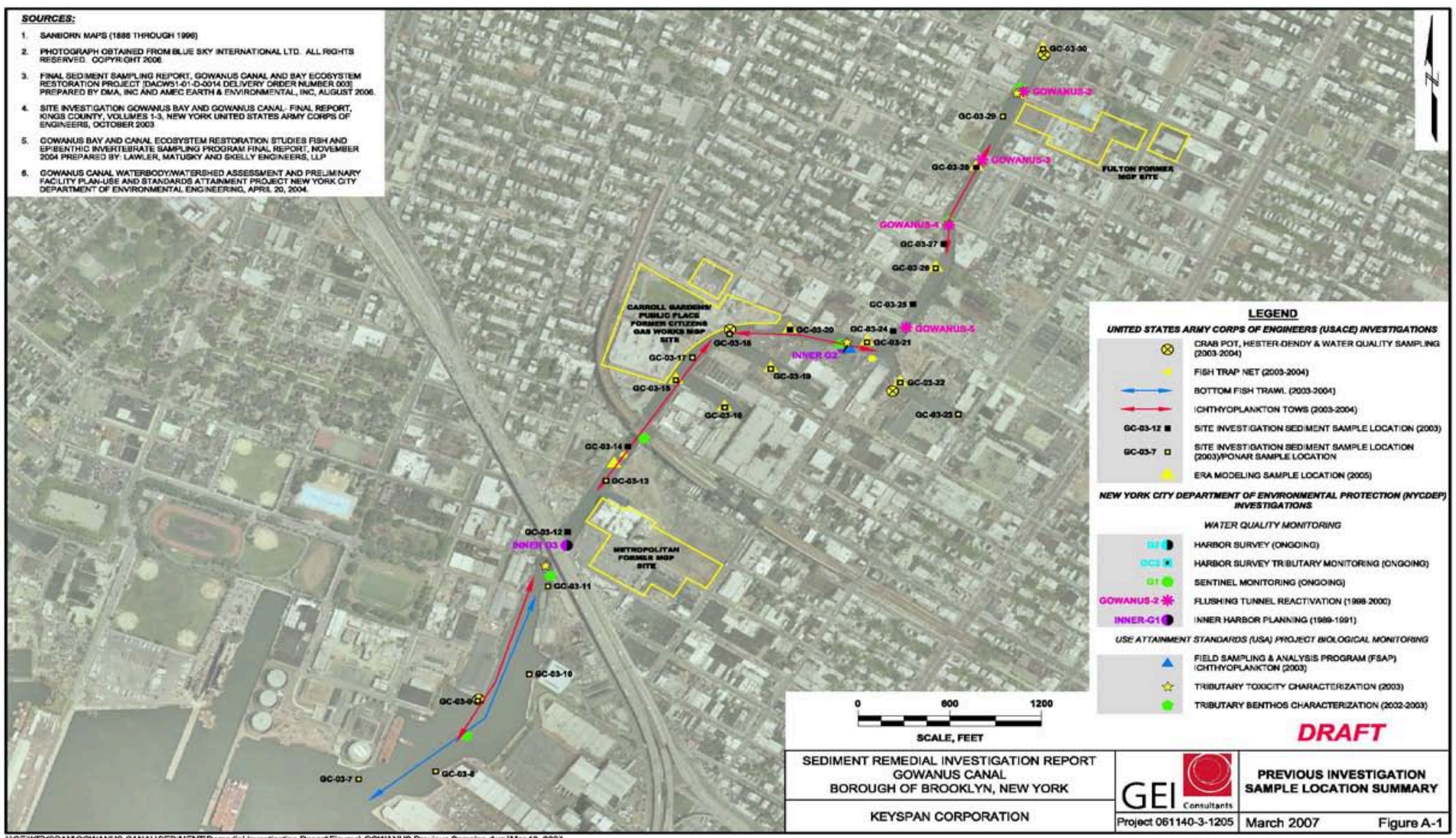

Figure A-1: Previous Investigation Sample Location Summary.

2006 Sediment Data

The 2006 sediment data was collected by GEI along transects established in the Gowanus Canal. These data were collected at all sediment depths. Because we are interested in ecological effects of sediment exposure, only surficial sediments (0-3 ft) were analyzed. Benthic (bottom-dwelling) organisms would not be expected to inhabit deeper sediments. The 0 to 3 ft sediment sampling depth interval is consistent with reference burrowing depths for Boston Harbor deep burrowing organisms (Kropp and Diaz, 1995).

To extrapolate surficial sediments from the entire 2006 sediment dataset, we averaged the lower and upper sediment sample depth that was recoded for samples 1 through 103. Using this average depth value, each sediment sample was coded into three depth categories (1 = 0-3 ft, 2 = 3.1-11 ft, and 3 = > 11.1 ft).

Once the 0 to 3 ft interval surficial sediment dataset was extracted, data identifiers were managed. For example, coded text data identifiers define if the results were an estimated value (J) and/or undefined (U). To develop a working dataset with measured values we removed the U, J, and UJ codes when in the same cell as the analytical results. The data with J identifiers ("estimated value") were deleted from working datasets, but were kept in raw datasets. All data with UJ and U codes were changed to have a "less than" (<) symbol. Modified identifiers were placed into a separate column (labeled "Sign") directly to the left of the respective contaminant value column. Duplicate sediment results were averaged so that one set of contaminant results represented a single sample station. There were 7 duplicate water quality samples in the 2006 sediment dataset.

To produce a robust dataset with measured values for as many variables and sites as possible, we performed a screening protocol. Screening consisted of manipulating non-detect values and deleting unreasonably high non-detect values from further analyses. Because this screening process involved the consideration of measured values found within a particular contaminant, only non-detects from significantly robust contaminants were manipulated. Robust contaminants consisted of measured values for most of the samples. It was important to identify the range in which contaminants were being measured to justify manipulating non-detect values. If a non-detect value was found reasonable, with respect to other measured values, it was retained, divided in half, and an H was placed in the "sign" column next to the new value. If the value was unreasonably high when compared to measured values, even after dividing in half, it was deleted and a D was placed into the respective "sign" column. Results from these data screens provided a subset of significant (or "data robust") variables with measured results that spanned all transects. It is important to note that manipulating non-detect values was not performed on all contaminants, but only for contaminants that were found at measurable levels at most sites.

After screening the database and transforming non-detect values, all remaining contaminant values from all samples were condensed into single values for each respective transect. This consisted of averaging the two-to-three samples taken from each transect into a single transect value. Because this methodology involved condensing measured, estimated, or retained non-detect values, a condensation protocol was developed. All measured values were averaged. If all values for a particular contaminant were non-detects, the average non-detect value was used for respective contaminant/transect entries. When one or more measured values were found along with non-detect values for a contaminant within a transect, the non-detect value was ignored and the measured value or average of each measured value was represented in the transect. This method of condensing the raw data into a single value for each transect yielded the most robust dataset with respect to measured values. Additionally, spatially normalizing all data to a specific transect was needed to successfully compare historic sediment, water quality, toxicity test, and biological datasets.

Screened and organized 2006 sediment data can be found in the attached tables. Two datasets are presented. The non-condensed surficial sediment dataset shows all UJ's and U's that were changed to a "<" and transformed non-detect value denoted with an “H”. The second is a working dataset that contains transect-condensed results, without the identifier codes, and has a value in each transect for robust contaminants.

2006 Water Quality Data

The 2006 water quality data was collected by GEI along the same transects established in the 2006 sediment dataset. These data were collected at two depths, surface and at the sediment water column interface. The 2006 water quality data was screened and organized similar to the 2006 sediment data, with respect to screening and condensation into single values for each transect. For the water quality data, however, surface and bottom collected samples were kept separate. The 2006 water quality datasets are presented in the attached tables, similar to the 2006 sediment dataset.

2005 Sediment Data

The 2005 sediment data was obtained from available published reports. DMA, Inc. (2006) collected sediment cores on behalf of the U.S. Army Corps of Engineers (USACE) using a Vibracore device. Samples were collected at 10 locations within the canal in September 2005, with locations chosen to fill data gaps in the understanding of sediment quality. Site locations ranged from the upstream portion of the Gowanus canal to below the Carrol Gardens/Public Place MGP site (but above the Metropolitan MGP site). Nine of the sites were previous (2003) USACE locations. Samples were analyzed for metals, semi-volatile organic compounds (SVOCs), polychlorinated biphenyl’s (PCBs), pesticides, grain size, and total organic carbon (TOC) (See contaminant matrix, attached).

The 2005 sediment data from DMA, Inc (2006) were entered into an Excel spreadsheet. These historic sediment data were then organized into transects and matched to the nearest GEI transect. When more than one sample was placed into a single transect, analytical results were averaged similarly to that described above, except that no transformation of non-detect results was performed when preparing the datasets. Additionally, the 2005 sediment dataset results were converted from parts per billion (micrograms per kilogram [µg/kg]) to parts per million (milligrams per kilogram [mg/kg]) units, to normalize all datasets to similar measurement units. Similar to the GEI sediment and water quality datasets, two 2005 sediment datasets are presented below. The raw dataset comprises the data entered into the Excel file as organized in the original report. The second is a working dataset, with results matched to GEI transect locations and normalized to like measurement units.

We investigated, but did not use, analytical sediment data collected by the USACE in 2003. Those sediment data were sampled at multiple depths. Once categorized into depth categories, we found that only two samples were collected from surficial (0-3 ft) sediments. Due to this limited surficial sampling results, the 2003 USACE sediment data was not used in our investigations.

Outfall Effluent Data

Outfall effluent water quality data were collected by GEI during a dry weather event between August 2 and 11, 2006. After reconnaissance to locate potential outfalls, combined sewer outfalls (CSOs) and unmarked outfalls were sampled. A total of 56 outfalls were sampled. When an outfall was actively discharging into the canal above the waterline, a water sample was collected. This sample is representative of effluent. When an outfall discharged below the water line, its activity was unknown. Even though a snap jar was used to collect a subsurface water sample directly in the zone of effluent, the sample may have still represented a mix of effluent and canal water, if the outfall was flowing. Because of these uncertainties, only data from actively flowing outfalls sampled above the waterline were used in our analyses. This greatly reduced our database size to 11 outfalls, one of which was a CSO.

Using location notes and field technician assistance, each sample was matched to the nearest GEI transect. These data were organized and presented in the attached tables as for all other datasets. It is important to note that it was not necessary to screen results and all data is presented as original measured values.

Sediment Toxicity Tests

Sediment toxicity tests were conducted on behalf of the USACE by AquaSurvey, Inc. (2005) and are presented in the DMA (2006) report. AquaSurvey, Inc. tested the toxicity of the sediments collected in September 2005 using the amphipod *Ampelisca abdita* in a 10-day exposure, solid phase (whole sediment) bioassay. Five replicate chambers with 20 organisms each were used to characterize the toxicity of each sediment sample. Control sediments and test organisms were obtained from a reference site, Sandy Hook, Atlantic Highlands, NJ. The overlaying water was obtained from the Manasquan Inlet, Manasquan, NJ. Because of initially high pore water ammonia concentrations, 9 of the 10 samples needed to be purged via static renewal of overlying water until concentrations were below 20 mg/L.

A series of four static or static renewal tests were run, with one test conducted as a static exposure test and the remaining three as static-renewal exposures. After 10 days of exposure, live count data were documented, as well as water quality and physical parameters. It is important to note that there was a discrepancy in the sediment toxicity testing report where the site identification code for GC-26 was presumably mislabeled as GC-23. This was corrected in our final toxicity test dataset, so that each site was matched to the same sediment sample analytical results.

Toxicity test results, water quality conditions, and notes are summarized in the toxicity test dataset found in the attached tables. Information on each of the 10 toxicity tests was recorded into the dataset.

Biological Data

Three separate biological datasets were utilized in our investigations of the Gowanus Canal ecology. These datasets included data from 1) benthic, or bottom-dwelling, invertebrate communities, 2) water-column colonizing, or epibenthic invertebrate communities, and 3) fish trawl and fish/crab trap sampling efforts. Similar to the 2005 sediment data, raw data were obtained from published Gowanus Canal sampling reports. A brief summary of each of the datasets are provided below.

Benthic Invertebrate Community

A total of 29 Gowanus Canal and Bay benthic macroinvertebrate sampling sites were established by the USACE (2003). Station locations were recorded by GIS technology and latitude/longitude coordinates were provided. Sampling was conducted on April 29 and 30 2003. Invertebrates were collected using a petite Ponar benthic sampler. Two replicate benthic grab samples were taken at by 28 Gowanus Canal or Bay stations and one control sample (no location given). Each sample was sealed in a 5 gallon bucket and sent to Atlantic Reference Centre, New Brunswick, Canada, for analysis. Limited Hydrolab measured water quality parameters were recorded at each sample location.

Results for each sample were provided. Values represented sample abundances for each taxon. Provided latitude/longitude coordinates were used to identify site locations with respect to GEI established transects locations. A total of 19 USACE sites were matched to

15 GEI transects. Gowanus Bay and unidentified site locations were not matched to transects and were discarded from further analyses.

For community cluster analyses, results from each replicate and sites within each transect were added. Few transects contained data from more than one site. Transect AA contained data from three USACE sites, Transect Y from two sites, and Transect 4th Street Turning basin from two sites. The remaining 12 transects contained data from only one USACE sites. Since clustering was done on a presence/absence basis, summed abundances from more frequently sampled transect locations did not bias results but provided species assemblages occurring at each transect location.

For all other analyses sample and replicate abundances were averaged. Therefore, each transect invertebrate value is an average abundance for a representative benthic grab within the transect location. Resultant values were kept as is (i.e. fractions) and were not rounded to the nearest whole number.

Colonizing/Fouling Invertebrate Community

The second dataset was created from H-D colonized fouling community sampling. Fouling community invertebrates were sampled at five locations in the Gowanus Canal and Bay using H-D style samplers (Lawler et al. 2004). These artificial substrate samplers were set up in October 2003 and collected at four time intervals (Table A-1). Three samplers placed at each location, with one collected during each retrieval period to provide species identifications and densities.

Each H-D sampler consisted of nine 3 x 3 inch settling plates separated by two, three, or five 1 inch diameters spacers. Samplers were suspended from the shoreline or a bulkhead below the low tide mark. On the first survey in October, three samples were placed in each of the five fixed stations. On each subsequent survey (December, March, and June) one sampler from each station was retrieved, placed on ice, and returned to the laboratory for analysis.

Table A-1: Quarterly sample dates for the aquatic resource sampling component of the Gowanus Bay and Canal Ecosystem Restoration Studies, October 2003 to June 2004 (Lawler et al. 2004).

Seasonal Sampling Period	Sampling Dates	# of Exposure Days
1	October 22 – 23	0
2	December 16 – 17	55
3	March 31 – April 1	161
4	June 2 – 3	224

Once in the laboratory each H-D sampler was immediately taken apart and plates were placed in 10 percent formalin Rose Bengal solution for preservation. Each plate was scraped clean and only whole organisms or parts with heads attached were counted. Organisms were identified to the lowest taxonomic level practicable. Final abundance values were reported as densities (number/m^2).

Each H-D sampler site location was identified with respect to GEI established transect locations. The five sampler locations were matched to four Gowanus Canal transects. The remaining sampler location was in Gowanus Bay; therefore, it could not be matched to any GEI transects. Since each sampler was exposed to canal water for different durations, data were condensed into a single transect result. When H-D data were used in cluster analyses total densities for each taxon were added within respective transects. Since cluster analyses were conducted on a presence/absence basis, condensation results represented the total number of species that colonized the sampler over the course of the three exposure durations. As described above, clustering was done on a presence/absence basis; therefore, summed abundances did not bias results but provided species assemblages occurring at each sample location.

Fish and Crab Community

The third dataset was a combination of the ichthyoplankton (larval fish suspended in the water column), adult fish, and crab trap data collected in 2003 through 2004 using trap nets and trawl nets (Lawler et al. 2004). Results presented by the authors were matched to respective transects. Similar results found for fish metrics between multiple transects indicate that a trawl path covered more than one transect location. Crab traps were set for 24 hour period to provide catch per unit estimate (CPUE) data and species identifications. Since these data were less robust and could not be easily matched to individual transects or abiotic datasets, only qualitative summary results are presented.

Data Quality Assurance and Quality Control

Because extensive manipulation of raw data into working datasets was necessary, a quality assurance and quality control (QA/QC) protocol was established. Raw data from GEI analytical analyses was assumed to be correct. Data identifiers were left in this Appendix dataset so proofreaders could follow our data manipulation steps. Data manipulation steps were left as Excel formulas so that data condensation manipulations could be easily checked. Spot checks were conducted for roughly 20 percent of the data. If data discrepancies were identified, then further spot checking and data validation steps were employed. Before and after data were organized into statistical datasets, results were also subject to a QA/QC. For data that were re-entered from report tables into Excel datasets, additional steps were taken to ensure translation accuracy. This included double checking every entered value. These protocols were performed by personnel that were not directly involved with creating the datasets. All efforts were made to be as transparent as possible when creating all of the report analyses datasets.

Statistical Analyses

Parametric and non-parametric statistical analyses were performed in our ecotoxicological evaluation of the Gowanus Canal. The exact test or analysis conducted is explained in greater detail when presented, but general guidelines are discussed here. As part of every parametric statistical analysis, an "assumptions check" was conducted. The assumption of equal variance and/or normality was often violated (graphically analyzed) and improved upon after transformation of data. Data were assumed to be independent, within and between groups being analyzed. Data were not randomly collected; therefore, our scope of inference could not be extrapolated to processes occurring outside of the study area. For all analyses, significance relies on a sample distribution test statistic and sample size, with an alpha level of 0.05 used. All data analyses were conducted using NCSS 2004, SPSS 15.0, and CANOCO 4.5 for Windows software packages.

In conjunction with specific statistical comparisons, we performed extensive exploratory data analyses (EDA). These EDA were important in initial data investigation and organization due to the large number of multivariate parameters associated with investigating relationships between complex datasets.

Principal components analysis (PCA), all possible regression (APR), and Chi-squared automatic interaction detection (CHAID) were all used to reduce respective dataset variables to those that contribute the most variance, while retaining characteristics of the dataset. First, PCA was used to find surrogates for variables that moved together. A list of 10 sediment and water quality variables were identified (Table A-2) as surrogates for removed contaminant variables (this analysis is important in reducing covariance between respective dependent variables).

Table A-2: Variables identified by PCA as potential surrogates to explain the most variability in each data set.

Biological	Sediment	WQ	Habitat
Oligochaeta	Fluoranthene	BTEX	Sed Depth
Capitellidae	CarcPAHs	Nitrate/Nitrite	Sed Density
Spionidae	PCBs	Salinity	
Total Density	Chlordane		
Average # of Sp	Cadmium		
H'	Vanadium		

APR was used to confirm PCA results by examining the variability that is explained by addition of model parameters (model parameters were selected according to PCA results). Regressions were performed for each robust invertebrate family or metric. CHAID was used to find possible subsets or contingent relationships within the data. This analysis was not robust to the limited invertebrate data and was not useful. The above PCA and APR analyses were run two times, once with separate iterations for each dataset separately and once using a combined sediment/WQ dataset. A Pearson Correlation coefficient matrix was created for identified variables. Results backed up CCA results in identifying positive relationships between Nematode/ Oligochaete abundance and identified variables and the opposite relationship between other invertebrate metrics. It is important to note that potentially significant relationships identified from EDA were backed up with appropriate parametric tests before being presented in report results.

Exploratory Data Analyses - CCA

Canonical Correspondence Analysis (CCA) was used to analyze invertebrate family response to sediment and WQ results. CCA results indicated that most all of the contaminant classes are behaving similarly in the canal (i.e., all PAHs were similarly distributed with respect to transect locations). CCA is a multivariate direct gradient analysis that is robust to skewed species distributions, with quantitative noise in species abundance data, with samples taken from unusual sampling designs, with highly intercorrelated environmental variables, and with situations where not all of the factors determining species composition are known. Results from this nonparametric multivariate screening analysis are in the form of bi-plots. Interpretation of invertebrate family response to sediment and WQ results were made from using bi-plot graphics.

CCA identified unique correlations between nematodes and oligochaetes, but not the other invertebrate families or metrics. Many contaminants were positively correlated with nematode and oligochaete abundance and the other invertebrate families showed little inverse correlation between abundance and contaminant concentration (e.g., total invertebrate abundance, nematodes, *Gammarus*, and oligochaetes were least sensitive to changes in carcinogenic PAH concentrations and all other invertebrates were negatively correlated with carcinogenic PAHs). These results directed our benthic invertebrate/contaminant statistical analyses when investigating relationships between nematodes, oligochaetes, or similarly robust invertebrate abundances and contaminant concentrations.

Derivation of Sediment Thresholds

For many contaminants, low and median toxic effect estimates derived from field studies across the nation were used to as surrogate sediment screening benchmarks. The Effects Range-Low (ERL) and Effects Range-Median (ERM) were established to indicate levels of sediment contamination that can be tolerated by the majority benthic organisms. Long et al. (1995) provide sediment threshold values for contaminants in marine and estuarine sediments, as presented in Tables 3 and 4 of the New York State Department of Environmental Conservation (NYSDEC) Technical Guidance Document (1999). Briefly, if the concentration is greater than the ERL but less than the ERM, the sediment is considered to be “contaminated,” with moderate impacts to benthic life expected. If the concentration is greater than the ERM, the sediment is “contaminated” and significant harm to benthic aquatic life is anticipated (NYSDEC, 1999).

A number of contaminants do not have ERM values for evaluation of potential toxicity. New York is unique in that the state's Department of Environmental Conservation has developed a contaminated-sediment screening technical guidance document (NYSDEC 1999). This document developed sediment criteria based on the EPA equilibrium partitioning (EP) model. The role of EP-based sediment criteria is for screening potentially contaminated sediments, providing an initial assessment of possible adverse impacts.

EP-based sediment criteria are tied to water quality standards and guidance values. Therefore, within the framework of New York State water quality regulations, sediment criteria were derived according to the primary levels of protection for available Class SD water quality standards or guidance values presented in Division of Water (1998). Application of EP-based sediment criteria derivation is only suitable for non-polar organic compounds, since derivation incorporates partitioning coefficient and organic carbon normalization methodology. Because these criteria are normalized to sediment total organic carbon (TOC), EP-based criteria can be thought of as site-specific sediment criteria (SSSC). SSSC were derived using available Class SD water quality standards or guidance values. The same chemical-specific Class SD values used in our water quality analyses were multiplied by respective chemical octanol/water partitioning coefficients and an organic carbon conversion factor to derive a TOC-normalized sediment criterion for each transect. Identification of octanol/water partitioning coefficients ($K_{o/w}$) was performed for each non-polar organic compound using reference values primarily found in Schwarzenbach et al. (2003) and the NYSDEC Technical Guidance Document (1999).

After applying the SSSC methodology we noticed unreasonably high Toxicity Quotients (TQs) associated with chlordane, aldrin, and dieldrin results. For example the TQs for dieldrin ranged from 2,227 to 298,687. These unreasonably high results might be an artifact of low Class SD water quality standards that were used to derive the SSSC. Fortunately, the NYSDEC Technical Guidance Document provided EPA ambient water quality criteria derived default sediment criteria for these three pesticides. The default sediment standard for chlordane (0.05 µg/gOC) was for acute toxicity protection of benthic aquatic life. The aldrin/dieldrin default (0.1 µg/gOC) was for protection human health bioaccumulation. These values were used in place of the $K_{o/w}$ derived SSSC to derive TQs for these contaminants. Application of these sediment standards did not change the number of transect results that were over the criteria, but only changed the magnitude of respective TQs. These criteria derived default TQs were integrated into the TQ datasets used in subsequent statistical analyses. For a complete list and derivations steps of SSSC please refer to the accompanying tables in this Appendix.

Derivation of Water Quality Thresholds

Class SD water quality standards or guidance values served as toxicity benchmarks for the water quality data and were used to predict potential ecological harm when compared to measured contaminant values. New York State defines water quality standards with respect to classification of surface waters. Gowanus Canal is classified as Class SD saline surface water; therefore, canal waters should be suitable for fish survival or "no acute toxicity." It is important to note that generally Class SD waters are not intended to protect for more sensitive chronic toxicity endpoints such as fish propagation. For water quality screening purposes, 15 Class SD standards, 10 guidance values, and four narrative standards were compared to transect condensed measured water column analyte concentrations (Table A-3). From these comparisons the frequency and magnitude, measured as TQs, of exceedances were developed as above.

Table A-3: Class SD standards, guidance values, and narrative standards used to derive percent exceedance and Toxicity Quotients.

Contaminant	Class SD WQ Standards (µg/L)	Class SD WQ Guidance Values (µg/L)	Narrative Class SD WQ Standards	Comments
Benzene	10 a	670 b		Guidance value used over standard due preference for fish survival endpoint
Toluene	6000 a	430 b		Guidance value used over standard due preference for fish survival endpoint
Ethylbenzene		41 b		
Xylene		170 b		
Acenaphthene		60 b		
Fluorene		23 b		
2-Methylnaphthalene		38 b		
Naphthalene		140 b		
Phenanthrene		14 b		
Benzo[a]pyrene		0.0006 a		
Aldrin	0.001 a			
Alpha-Benzenehexachloride (BHC)	0.002 a			
Beta-BHC	0.007 a			
Delta – BHC	0.008 a			
Epsilon – BHC	0.008 a			
Gamma-BHC	0.008 a			
Alpha-Chlordane	0.00002 a			
Trans-Chlordane	0.00002 a			
DDT, DDE, DDD (sum)	0.000011 e			
Dieldrin	0.0000006 a			
Endosulfan	0.034 b			
Endrin	0.002 a			
Heptachlor	0.0002 a			
Heptachlor epoxide	0.0003 a			

Contaminant	Class SD WQ Standards (μg/L)	Class SD WQ Guidance Values (μg/L)	Narrative Class SD WQ Standards	Comments
Toxaphene		0.07 b		
PCBs total	0.00012 e			
Copper	7.9 b			
Lead	204 b			
Mercury	0.0026 d			
Nickel	74 b			
Zinc	95 b			
Dissolved Oxygen (D.O.)			Shall not be less than 3.0 mg/L at any time.	
Odor			None in amounts that will adversely affect the taste, color or odor thereof, or impair the waters for their best usages.	
Clarity			None in amounts that will adversely affect the taste, color or odor thereof, or impair the waters for their best usages.	
Floatables			No residue attributable to sewage, industrial wastes or other wastes, nor visible oil film nor globules of grease	

a = Human consumption of fish (saline waters)
b = Fish survival (saline waters)
c = Fish propagation (saline waters)
d = Aesthetic (saline waters)
e = Wildlife protection (saline waters)

Water quality standards for the state's waters are compiled in the Division of Water Technical and Operational Guidance Series 1.1.1 (Division of Water, 1998). This document provides ambient water quality standards and guidance values for toxic and non-conventional pollutants derived under the authority of Article 17 of the Environmental Conservation Law and 6 NYCRR Parts 700-706, Water Quality Regulations. A standard value is a numeric concentration value that has been promulgated and placed into regulation. A guidance value may be used where a standard for a substance or a group of substances has not been established. Standards and guidance values are the maximum allowable concentration for a defined water classification.

For Class SD waters, standards and guidance values are presented for protection of human consumption of fish, fish survival, wildlife protection, and aesthetics. If more than one protection categories are listed for a particular contaminant then the most stringent limitation should be applied. We compared transect condensed water quality results to available standards or guidance values to develop transect specific TQs for each contaminant.

The NYSDEC also provides narrative water quality standards for Class SD waters outlined in 6 NYCRR §703.2 Narrative water quality standards. Additionally water quality standards for dissolved oxygen (D.O.), odor, color and floatables, are provided in 6 NYCRR §703.3. The appropriate narrative standard for oil and floating substances states that "No residue attributable to sewage, industrial wastes or other wastes, nor visible oil film nor globules of grease." The Class SD standards for D.O. "Shall not be less than 3.0 mg/L at any time." Observational accounts of sampling locations and conditions were used to screen narrative water quality standards. The averaged transect specific D.O. results were used to determine respective standard adherence. Because of the narrative nature of these additional water quality standards TQs could only be derived for D.O. Exceedance rates were developed for each narrative standards.

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