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Anthropogenic PAH distribution in the sediments found within Gateway NPS as Determined by Thermal Extraction GC/MS

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Introduction

Polyaromatic hydrocarbons (PAH) are ubiquitous products of organic matter combustion and are often associated with the incomplete combustion of fossil fuels. They are present in a variety of fossil fuels including gasoline, diesel fuels, and heating oils. Because some of them have been used in manufacturing processes they are frequently associated with industrial wastes and landfills. Once released into the environment they can persist in the atmosphere and be deposited into the aquatic environment by rain, snow, or particulate fallout. They quickly adsorb onto sediments and other types particulate matter. This property is allows these molecules to bioconcentrate in the aquatic food chain.

The goal of this study was to map broadly the areas of surfacial PAH contamination and identify those which require either additional study or special management. Analysis was performed by thermal extraction / pyrolysis followed by Gas Chromatography / Mass Spectroscopy. All values in this report are in units of mg/kg (PPM).

Scope

This project involved surface sediment samples from three locations within the Gateway National Recreation Area. One set of samples came from the inshore side of Sandy Hook. Samples from Staten Island were taken at the Great Kills and at the Arthur Kill. The majority of samples came from Jamaica Bay. This report will focus only on PAH concentrations and distribution. More detailed geochemical investigations will be published separately.

Sampling Site Locations

Table one lists the locations of the sample points.

Site Description – Jamaica Bay

Jamaica Bay is a shallow tidal estuary on the southern shore of Long Island. The eastern portion of the Bay is in the Borough of Brooklyn and the western portion is in the Borough of Queens. The bay measures approximately 52 square kilometers (20 square miles.) (Jackson, p. 611) The bay's watershed includes portions of Brooklyn and Queens as well as portions of the towns of Hempstead and North Hempstead in Nassau County. (Watershed Protection Plan, p. 15)

The bay is roughly semicircular with the opening on the southern shore of Long Island. The Rockaway Spit is a sandy peninsula extending westward along the coastline and separating the bay from the Atlantic.

This peninsula contains the residential neighborhoods of Edgemere, Far Rockaway, Neponsit, and Rockaway Point. The Rockaway Inlet is the only opening of the bay to the Atlantic. It is located at the western end of the peninsula separating it from Coney Island and Brooklyn.

Since 1972, most of bay and the islands inside it, have been administered by the Jamaica Bay Unit of the Gateway National Recreation Area, National Park Service. The bay contains many diverse habitats, including coastal shoals, mudflats, sand bars, open water (littoral zone), intertidal zones (low and high marshes), and upland areas. Navigation channels in the bay have been dredged to depths of approximately 10 meters. Jamaica Bay provides prime habitat for migratory birds and the intertidal mudflats are recognized as important feeding grounds for migratory shorebirds such as Black Skimmers, knots, and plovers. (Hartig 2002)

The current National Recreation Area encompasses the shoreline east and south of the Belt Parkway between Plum Beach and Spring Creek Park, the islands and marshes in the bay and the waters of the bay. The National Recreation Area does not include the communities on Broad Channel Island, most of the mainland in Queens County, Brooklyn, and developed portions of the Rockaway peninsula. (Black, p. 1)

Jamaica Bay has eight tributaries of various sizes, Sheepshead Bay, Paerdegat basin, Fresh Creek, Hendrix Creek, Spring Creek, Shellbank Basin, Bergen Basin, and Thurston Basin. (Watershed Protection Plan, p. 36)

The north shore of Jamaica Bay is dominated by John F. Kennedy International Airport. The airport's southern boundary is Grassy Bay and the Bergen Basin forms its western edge. In Bergen Basin an aviation fuel tank farm is served by four fuel handling wharves. Two of these facilities were active as of 1999. (1999 USACE Port Series)

As of 2007, six water pollution control plants (WPCP) operate in the Jamaica Bay watershed. These are the Jamaica WPCP (adjacent to Bergen Basin), Rockaway WPCP (Beach Channel Drive in Park), 26th Ward WPCP (Flatlands Ave in the Spring Creek section of Brooklyn), Coney Island WPCP (Adjacent to Shell Bank Creek near Sheepshead Bay), Spring Creek Auxiliary WPCP (located at the head end of Old Mill Creek providing hold overflow for the 26th Ward WPCP), and Cedarhurst WPCP (located at Peninsula Boulevard, Cedarhurst, discharges into Mott Creek). (Watershed Protection Plan, p. 40) New York City's secondary WPCPs are the major source of freshwater for Jamaica Bay, discharging approximately 258 million gallons per day (MGD).

Six smaller, privately operated WPCPs also operate in

the watershed. These are the JFK Airport (discharges to Bergen Basin), Lefferts Oil Terminal, Queens (discharges to Bergen Basin), Keyspan Generation (Far Rockaway Power Station, discharges to Motts Basin), Carbo Industries (Nassau County, discharges into Jamaica Bay), Exxon Mobile (Inwood, Nassau County, discharges into Head of Bay.) (Watershed Protection Plan, p. 40) Some researchers consider the private WPCPs as only a minor source of wastewater. (Benotti 2005)

Tidal mixing provides the majority of water circulation. Each tidal cycle exchanges approximately one-third of the bay's water although the degree of mixing varies over time. Freshwater inputs account for only 0.5% of the water in Jamaica Bay. As of 1990 two-thirds of freshwater inputs were from secondary wastewater treatment plants and 10% were from combined sewer overflows (CSO's). (Bopp, 1993) As of 2005, there were 26 CSO's discharging into Jamaica Bay. (Benotti 2005)

Water circulation is largely inhibited by the salt marsh islands. Mixing is generally restricted to tidal exchanges through the navigable channels. (Benotti 2005) Areas within the bay's tributaries and dead end basins have reduced water quality due to contaminated surface runoff and poor flushing. (Watershed Protection Plan, p. 29)

There are about fifteen named marshes forming islands

in the bay. These marshes are one to three meters thick and overlie sandy substrates. Shrubs and thickets dominate the uplands on many of the larger islands. Some islands contain peat-rich marshes with meandering tidal channels. Other islands such as Rulers Bar Hassock, have a sandy shore tidal marsh with limited channel inlets. (Hartig 2002)

Property developers almost entirely filled the marshes on the perimeter of Jamaica Bay during first decades of the twentieth century. The construction of the Belt Parkway in the 1930s and development of parkland along the bay shores necessitated additional land reclamation. After the Second World War much of the refuse being used as fill was being sent instead to the Fresh Kills Landfill on Staten Island. (Miller) Before 1900 the area of the bay was 10,100 ha and in large part to land filling and bulkhead construction along the perimeter, the area had shrunk to 5,260 ha by 1971. (Benotti 2005)

Three modern landfills were operated on the bay shores until the 1980s and 1990s. The Pennsylvania Avenue and Fountain Avenue landfills were located on the Brooklyn shore of the bay. The Edgemere Landfill was on the eastern end of the Rockaway Peninsula.

The 110-acre Pennsylvania Avenue Landfill was opened in 1956. Originally intended to accept residential and commercial wastes the site has also received sewage

sludge and demolition debris. At the time that the landfill was closed in 1979, it was receiving 1000 to 2000 tons of trash each day. Investigators estimate that there are between 6 and 12 million gallons of waste oil buried on the site. Oily leachate has been observed leaking into Jamaica Bay. (Goldstein & Izeman, p. 13) The 287-acre Fountain Avenue landfill operated between 1961 and 1985. It took in commercial and residential trash, asbestos, and incinerator ash. During its last year of operation, the Fountain Avenue Landfill received 8,200 tons of trash per day. (Goldstein & Izeman, p.13)

The 173-acre Edgemere Landfill forms a peninsula extending northwards into Jamaica Bay. It is located between the Norton Basin and the Somerville Basin. Between its opening in 1938 and closing in June of 1991, the landfill received more than 9 million cubic yards of waste. In 1982 more than 3,000 buried chemical drums were discovered in the landfill. (Goldstein & Izeman, page 13) (Rhoads, p. 36)

The most heavily industrialized sections of the waterfront are located in the Bergen Basin and on the eastern side of the bay. The US Army Corps of Engineers lists nine petroleum handling facilities as of 1999 of which seven were active. Eight of the nine facilities are on channels extending inland from the east half of the bay. The greatest concentration is four facilities on a channel named Head of Bay. (1999

USACE Port Series)

Located entirely in the western half of the bay are three wharfs where sewage sludge is loaded onto ships for transport out of the city. They are all are on the shores of Jamaica Bay proper as opposed to channels leading off of it. (1999 USACE Port Series)

Three sand, gravel, cement, and stone handling facilities are located on the eastern half of the bay, one in Head of Bay, one in Mott's Basin, and the third on Rockaway Peninsula.

Jamaica Bay Sediment Characteristics and Contamination

Sediment composition varies with location in the bay.

Sediments in the western portion of the Bay, defined as the area between the Cross Bay Boulevard and the Rockaway Inlet, generally have up to 80% sand. The western portions of the bay have approximately 10% silt but this proportion increases farther to the east. In Grassy Bay, adjacent to Kennedy International Airport, the silt increases to 20 to 30%. Clay particles show a similar distribution, they comprise less than 10% of the sediments in the Rockaway Inlet and up to 50% in Grassy Bay. (Watershed Protection Plan, p. 62)

Sediments from the Raunt have been determined to

consist of 50 to 60% sand and 20 to 40% clay. Sediments from the Grass Hassock Channel contain approximately 25% sand and between 30 to 50% clay. The mean proportion of the silt-clay fraction over the entire bay has been estimated to be between 30.3 and 37.5%. About 50% of Jamaica Bay can be characterized as mud. (Watershed Protection Plan, p. 62)

Another important sediment property is the percentage of total organic carbon (TOC). The mean TOC concentration in the bay was determined to be 2.6%. About 40% of Jamaica Bay sediments had less than 0.5% TOC and another 40% had TOC concentrations greater than 3.5%. When measured in 1985, Jamaica Bay sediments with less than 0.5% TOC appeared clean and yellowish brown to gray. Sediments with 0.5 to 1.0% TOC appeared "dirty" with black organic content. Those with 1.0% or higher were a black, "frothy" mud with an hydrogen sulfide odor. (Watershed Protection Plan, p. 62)

In the sandier western, central, and southern portions of the bay, sediments contained less than 0.5% TOC. Sediment TOC increases to 0.5 to 1.0% at Nova Scotia Bar (near Mill Basin) near JoCo Marsh, and the western side of the Rulers Bar Hassock. TOC concentrations between 1.0 and 3.0% are found outside Spring Creek and Fresh Creek as well as areas around Grassy Bay and Grass Hassock Channel. The highest TOC concentrations (>3.0%) were found in Grassy Bay,

French and Hendrix Creeks, and near broad channel. (Watershed Protection Plan, p. 63)

Much of the recent sedimentation research in Jamaica Bay has focused on the wetlands losses observed since 1974. The larger island marshes have lost as much as 38% of their vegetative cover and the losses on some of the smaller islands have been as high as 78%. (Hartig 2002) At the present time, the wetlands loss appears to be attributable to a combination of factors. These include subsidence of the land (1.2 mm/year), rising sea levels (1.5 mm/year), and a marsh accretion rate that is not keeping pace. (Hartig 2002) As early as 1977 it was noted that the sediment deposition rate in the bay's marshes was 0.8 cm/year and in the sandy channels was 0.5 cm/year. (Watershed Protection Plan p. 64)

Under pre-industrial conditions replacement sediments would have entered the Bay via the tributaries along the shoreline. However with almost the entire watershed built over, this source has largely been shut off. What sediments do enter the bay have largely settled in the deeper areas where current velocities are low. (Watershed Protection Plan p. 64)

Earlier research on a pair of matched sediment cores from Grassy Bay have established particle accumulation of 1.4 cm / year from the mid 1960s to the end of the 1980s and 1.6 cm / year between mid 1950s and late

1980s. The sediments in the area where these cores were taken are dominated by silt and clay. (Bopp 1993)

Based on data collected in 2002 and 2003 the major sources of total organic carbon in Jamaica Bay have been identified as WPCPs 32,800 lbs/day, CSO's 5,600 lbs/day, storm water 1,050 lbs/day, atmospheric deposition 630 lbs/day, and landfills 320 lbs/day. (Watershed Protection Plan vol 1page 44)

Generally speaking most of Jamaica Bay's pollutants have been found in proximity to WPCP outfalls, CSOs, storm sewers, and landfills. (Watershed Protection Plan p. 63)

There has been a somewhat limited study of PAH concentrations in Jamaica Bay except in small areas where an Environmental Impact Assessments have been required for a specific wetlands restoration or channel dredging project.

As of 1987 there were an estimated 10 metric tons of Naphthalene entering the bay each year. The main source of this material was the 320 million gallons per day of treated effluents from four swage treatment works with other inputs from runoff, urban fallout, pleasure boats, marine oil transportation, airport runway runoff, and landfill leachates. Tanacredi measured concentrations of substituted Naphthalenes

in sewage effluent ranging from 3 to 43 ppb and 10.8 to 18.9 ppb in 30% of the sediment samples tested. (Tanacredi 1977)

In a 2001 environmental impact assessment for the Norton Basin / Little Bay restoration project included a data from a 1995 study of pollution levels in the bay and in the tissues of its wildlife. Total PAH concentrations were reported for surfaced sediments. The highest concentrations were found inside a containment boom at the JFK outflow pipe number two, 11,800ppb. The highest levels of PAH contamination were identified at the two JFK outflow pipes (101 ppb, 337 ppb, 3130 ppb, and 11,8000 ppb). The other area of high concentrations was Grassy Bay's southeast side (9440 ppb) and southwest side 515 ppb). The remaining areas of Grassy Bay, East Broad Channel, Ruler's Bar, and Black Bank Marsh had total PAH levels under 100ppb. The lowest PAH concentrations were found in the Rockaway Inlet (4.2 ppb). (Rhoads p. 38)

Site Description Great Kills (Staten Island)

Great Kills Park comprises 580 acres of open space. It is situated on a peninsula in Staten Island that features an inlet harbor and barrier ocean beach. Visitor amenities include ocean bathing, fishing, nature trails, and the Nichols Marina. Great Kills Park is the only osprey nesting site on Staten Island.

Since 1927 the Army Corps of Engineers has maintained a navigable channel 10 feet deep, 150 feet wide, and 1.9 miles in length. A 138 acre anchorage is dredged to a depth of 8 feet. The most recent dredging operation in the channel was in 2003 and removed 124,000 cubic yards of sand. This material was used for beach replenishment. (USACE 2008)

The Staten Island samples were taken in the following locations.

Gateway 100 Sandy mud, Great Kills Harbor at end of creek
Gateway 101 mud flat, Oakwood Beach, Fox Creek tidal marsh
Gateway 102 mud flat, Saw Mill Creek

Site Description – Sandy Hook

All Sandy Hook samples were taken from the inland side of the peninsula.

Sandy Hook 1, Salt marsh
Sandy Hook 2, Salt marsh
Sandy Hook 3, Salt marsh

Sandy Hook MSU 1, Salt marsh at low tide line
Sandy Hook MSU 3, Sand bar intertidal zone

Experimental

All samples were taken by Dr. Mark Ringenary, Natural Resources Specialist - National Park Service. After sampling the materials were oven dried at 40c by NPS personnel. The dried samples were shipped to Montclair State University for analysis.

A semi-qualitative version of EPA thermal extraction method 8275a was employed. Milligram quantities of dried sediments were spiked with 5 uL of a solution containing deuterated naphthalene (D-Naphthalene), deuterated anthracene (D-anthracene), and deuterated pyrene (D-Pyrene). The spike concentration was manipulated such that each injection introduced 24.50 ng of D-Naphthalene and 27.00 ng of D-Anthracene into the chromatographic system. D-Pyrene was not used for quantization.

The spiked sediments were then heated for 20 seconds under an inert atmosphere to 610c which removes organic molecules from sediment particles. A CDS model 1500 thermal extraction system was used. The extracted molecules are swept onto the GC column by a stream of helium gas. The GC column was a Restek 60 meter, Dimethylpolysiloxane stationary phase, 0.25 mm ID (Restek catalog number 13326.) The GC temperature program began at 50c for 5 minutes and

rose at a rate of 5c per minute until reaching 300c and holding for 25 minutes. Gas pressure at the column head was 33 psi with a split ratio of 1 to 25.

When operated in the full scan mode the mass spectrometer was set to 50-550 Da, 1.08 scans/sec., 70eV ionization voltage. In the SIM mode the MS was also set to 70eV ionization voltage and identification was based on a combination of molecular weight and retention time window for each of the PAHs.

Concentrations of pollutant PAH molecules were estimated using the following formulas:

$$\text{ng sample} = \frac{\text{ng internal std}}{\text{area counts internal std peak}} \text{ (area counts PAH peak)}$$

$$\text{ppm PAH} = \frac{\text{ng PAH}}{\text{mg dried sample}}$$

Samples were examined by eye and roughly grouped by grain size into course sand, fine sand, and fine-organic rich sediments.

Results and Discussion

Concentrations at every sample point for each of the 16 PAH molecules identified by the USEPA as priority pollutants are presented in appendix one. Appendix two contains the average concentration of the priority

pollutant PAH molecules in each area of the park. All results are reported in parts per million. Appendix three contains the original Total Ion Chromatograms.

It should be noted that it has been the practice at Montclair State University to combine the peak areas of Benzo[b]fluoranthene and Benzo[j]fluoranthene and then report the value as one number for Benzo[b+j]fluoranthene.

In analyzing the results of the GC/MS runs it quickly became apparent that both of the full scan and SIM mass spectrometer methods had their strengths and weaknesses. The full scan method allows the study of numerous biomarker molecules, petroleum products, and sewage decomposition products. But the full scan method was not particularly sensitive to PAH molecules, especially those with five rings. Many of the sediments were so rich in organic matter that low concentration PAH peaks were often indistinguishable from the background. The SIM method proved to be far more reliable in detecting PAH contaminants in this situation but did not provide data on any other type of compounds. (see table 2)

Reproducibility for the SIM method was determined by running replicate analyses of a sediment sample from the Gowanus Canal in Brooklyn, New York. The contaminants in this sample were measured by an EPA laboratory with a conventional solvent extraction

followed by GC/MS analysis. The coefficients of variation for these multiple analyses are shown in table 3.

It is likely that heating the sediment to 610c during thermal extraction would pyrolyze organic carbon in the sediment and artificially inflate the values for two and three ring PAH molecules. Experience has shown that the three-ring and larger PAH concentrations are sufficiently close to values obtained through conventional solvent extraction for the purposes of large scale screening over a wide geographic area.

A side by side comparison of results obtained by pyrolysis and conventional solvent extraction is given in table 4. The sediment sample used for this comparison was provided by the US Army Corps of Engineers from their Bridgeport, Connecticut, sediment remediation project. The laboratory performing the PAH analysis by solvent extraction did not report all of the 16 PAH priority pollutants.

Results of the PAH analysis were evaluated using the guidance of the 1999 NOAA Screening Quick Reference Tables or NOAA SQRT. These documents were developed originally for the agency's Coastal Protection and Restoration Division and set screening levels. They do not embody official NOAA policy or attempt to set clean up levels. In the case of sediments NOAA has incorporated multiple screening concentrations that

have been associated with "various probabilities of adverse biological effects." (NOAA SQURT 1999)

For the polyaromatic hydrocarbons the probabilities are divided into five levels. In increasing contaminant concentration these are: Threshold Effects Level (TEL), Effects Range - Low (ERM), Probable Effects Level (PEL), Effects Range - Medium (ERM), and Apparent Effects Threshold (AET). It should be noted that the AET is often, but not always, the highest number. The effects levels have been computed for individual PAH molecules and do not take into account any synergistic effects.

For the purposes of this report, only data obtained from the SIM analysis of Jamaica Bay samples will be considered. Furthermore, only the Effects Range - Low (ERM), Probable Effects Level (PEL), and Effects Range - Medium (ERM) will be considered. Generally speaking, some adverse biological effects from PAH contamination can be expected in Jamaica Bay. Exactly 78% of all the samples had one or more PAH concentrations greater than the PEL. But for nine samples, at least 75% of the PAH concentrations were below the PEL and in four cases at least 50% of the PAH concentrations were above the PEL.

The cleanest samples, those in which 92% of the observations were below the ERL and the remaining 8% were between the PEL and the ERM, were numbers 5

and 6 from the Rockaway Inlet and 18 from JoCo Marsh. The results of samples 5 and 6 were not surprising given the fact that the Rockaway Inlet has always been subject to flushing by swift currents and tidal circulation. Generally speaking the eastern part of the bay, especially Grassy Bay where JoCo marsh is situated, has been more stagnant with lower water quality. (National Academy of Sciences, p. 44) Thus the result from sample 18 is harder to explain.

Another factor which governs the distribution of PAH molecules is the size and nature of the sediment grains. PAHs are not readily soluble in water and tend to adhere to particulate matter. PAHs stuck to small particles may be found in the surface micro layer, but those adhering to larger particles will become part of the sediments.

PAH concentration in sediments is linked to the organic matter content. Those PAH molecules with low aqueous solubilities and high affinity for carbon rich particulates will typically be found associated with high levels of organic carbon. However there is not always a clear correlation between the enrichment of a particular PAH molecule, organic carbon, and grain size. (Stange, 1997)

Generally speaking however, in this study there was a strong correlation (between 60 and 80% depending on the calculation) between the total PAH content of a particular sample and the sediment grain size. Thus

the samples from the Rockaway Inlet were both the sandiest and had the lowest PAH concentrations.

Areas with the highest PAH concentrations were those with fine grain sizes and organic rich sediments. In table three, it will be seen that even among samples that are grouped by grain size, there is variation of PAH content. Sandy samples had a relatively narrow range of 0.39 to 1.94 ppm total PAH content while the fine, organic rich samples range from 2.1 to 19.6 ppm.

The same observation has been reported for other pollution studies in Jamaica Bay. Contamination was strongly correlated with the TOC content of the sediment. (Watershed Protection Plan p. 63)

The most contaminated sample in the entire study was from the Norton Basin (NB) where 64% of observations were above the PEL (Acenaphthene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Benzo[a]anthracene, and Chrysene) and 18% were above the ERM (Acenaphthylene and Benzo[a]pyrene). Both the Norton Basin (NB) sample and sample 13a were taken near the Edgemere Landfill. This landfill was not closed until 1998 (*Civil Engineering* 1998) and forms a peninsula with the Sommerville Basin (site of sample 13a) on the west and the Norton Basin on the east. The NB sample was taken off the northeast corner of the peninsula where the Norton Basin meets the Grass Hassock Channel. Sample 13a was somewhat less

contaminated with 46% of observations above the PEL (Acenaphthene, Fluorene, Phenanthrene, Benzo[a]anthracene) and only Acenaphthylene above the ERM.

Contamination was generally higher in samples taken from the basins and shoreline of the northern portion of the bay. Between 18 and 73% of the observations were above either the PEL or the ERM for samples 24, 26, 27, and 29. Sample 24 was taken from Grassy Bay along the shoreline by the airport. Only Acenaphthylene exceeded the ERM. Exceeding the PEL were Fluorene, and Anthracene. Sample 26 was from Head of Bay which is the site of active fuel oil terminals. No result on sample 26 exceeded the ERM, but the PEL was exceeded for Acenaphthylene, Fluorene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Benzo[a]anthracene, and Chrysene. Hendrix Creek, site of sample 27, has two Combined Sewer overflows (CSO's), the Pennsylvania Avenue and Fountain Avenue Landfills at its entrance and is the site of a restoration project. In this sample only Pyrene exceeded the ERM but Acenaphthylene, Acenaphthene, Phenanthrene, Anthracene, Fluoranthene, Benzo[a]anthracene, and Chrysene all exceeded the PEL. Sample 29 was taken from Bergen Basin where there is a jet fuel depot serving the airport and is the site of the Jamaica Water Pollution Control Plant which processes sewage. It contained Acenaphthylene and Pyrene above the ERM while Acenaphthene,

Phenanthrene, Anthracene, Fluoranthene, Benzo[a]anthracene, and Chrysene were above the PEL.

Previous sediment contamination studies have also reported the highest levels of contamination along the northern and eastern portions of the bay. Contamination was especially pronounced in Grassy Bay and the northeastern side of Nova Scotia Bar. (Watershed protection plan page 63)

The ratios of selected PAH molecules can be used to determine if a particular sample is dominated by compounds that are the result of combustion as opposed to those of petrogenic origin. (Budzinski 1997, Yunker 200287) If the ratio of Anthracene / (Anthracene + Phenanthrene) is greater than 0.10, then the materials are most probably pyrogenic in origin. Similarly, if the ratio of Fluoranthene / (Fluoranthene + Pyrene) is greater than 0.40, then the materials are most probably pyrogenic in origin. The Fluoranthene / (Fluoranthene + Pyrene) ratio allows some additional source determinations. A ratio below 0.4 is thought to reflect petrogenic origins, 0.4 to 0.5 from the combustion of liquid fossil fuels, and greater than 0.5 from combustion solid fuels including coal, wood, or grass. (Budzinski 1997, Yunker 2002)

The Anthracene – Phenanthracene ratio is greater than 0.1 for each of the samples, ranging from 0.11 to 0.93 with a mean value of 0.36. Only one sample was close

to a value of 0.1, sample 16 from the Pumpkin Patch Channel between some of the islands in the middle of the bay.

The Fluoranthene – Pyrene ratio also points to a pyrogenic origin for most of the PAH contamination of the bay. Samples 5, 8, 13a, and 23 could all be classified as petrogenic by this ratio but in the case of 13a, a value of 0.38 is very close to the 0.4 petrogenic / pyrogenic border line. Sample 8 was taken in an area where petroleum products have unloaded from barges. Among the samples with pyrogenic origins, the PAH content of 8 of these can be attributed to liquid fossil fuels combustion and that of 6 to solid fuels combustion. Table 5 shows the results of these ratio calculations for Jamaica Bay and table 6 shows the results for Sandy Hook and the Staten Island sites.

In 2006 Yan et al published their results from carbon-13 ratios in New York Harbor sediment cores. They concluded that between 1970 and 2000 combustion provided an increasingly important source of PAH contamination throughout the entire harbor. (Yan 2006) The predominance of pyrogenic PAH contamination in Jamaica Bay is entirely consistent with these results.

Conclusions

The majority of PAH molecules in Jamaica Bay appear

to be the productions of combustion. Although there are some locations in Jamaica Bay where PAH concentrations may cause concern, on the whole many areas of the bay are relatively free of these materials. As might be expected, the sandier portions of the bay have less PAH contamination as do areas where there is more flushing action from tidal flows. Large scale remediation efforts must therefore be focused on areas where there are fine, organic rich sediments, and restricted flow regimes.

The proximity to former landfills and CSOs in Jamaica Bay seems to be a factor in PAH enrichment and serves as a reminder about the importance of continued monitoring at these locations. However the source apportionment process did not suggest that the PAH enrichment was due to petroleum products leaching from these landfills or running off from the streets. Possibly, restricted flows in the creeks alongside the landfills prevented tidal action from removing contaminants deposited from the atmosphere.

Table one, Decimal latitude and longitude locations of the sampling points

Sample Point	Lat	Long
Gateway 100	40.5462	74.13607
Gateway 101	40.54882	74.11399
Gateway 102	40.60828	74.188896
Jamaica Bay 1	40.56736	73.93529
Jamaica Bay 3	40.582333	73.933445
Jamaica Bay 4	40.584471	73.902597
Jamaica Bay 5	40.577706	73.870286
Jamaica Bay 6	40.58201	73.856054
Jamaica Bay 8	40.597972	73.924756
Jamaica Bay 9	40.604798	73.900527
Jamaica Bay 10	40.597852	73.870668
Jamaica Bay 12		
Jamaica Bay 11	40.595603	73.825911
Jamaica Bay 13	40.60171	73.77528
Jamaica Bay 13a	40.59879	73.78885
Jamaica Bay 16	40.62384	73.83859
Jamaica Bay 18	40.611389	73.801417
Jamaica Bay 22	40.634734	73.849788
Jamaica Bay 23	40.643734	73.834962
Jamaica Bay 24	40.637497	73.810692
Jamaica Bay 26	40.628833	73.75667
Jamaica Bay 27	40.64854	73.87505
Jamaica Bay 29	40.652448	73.823524
Jamaica Bay NB	40.60872	73.7728
Sandy Hook 1	40.4048	73.9793
Sandy Hook 2	40.42401	73.98576
Sandy Hook 3	40.44884	73.9993
Sandy Hook MSU 1	40.448875	73.999072
Sandy Hook MSU 3	40.448694	73.999136

Table 2, Comparison of full scan and SIM method results for sample number 102.

Staten Island 102 Mode	SIM	FULL
Naphthalene	1.11	0.60
Acenapthylene	0.16	0.35
Acenaphthene	ND	ND
Fluorene	0.45	ND
Phenanthrene	0.71	0.43
Anthracene	0.44	0.42
Fluoranthene	0.49	0.86
Pyrene	0.58	1.04
Benzo[a]anthracene	0.25	0.21
Chrysene	0.33	0.36
Benzo[b+j]fluoranthene	0.95	0.61
Benzo[k]fluoranthene	0.09	0.09
Benzo[a]pyrene	0.26	0.19
Dibenzo[a,h]anthracene	ND	ND
Indino[1,2,3-cd]pyrene	ND	ND
Benzo[g,h,i]perylene	ND	ND

All results in mg/kg (ppm)

Table 3, Coefficient of Variation for SIM detection, Thermal Extraction GC/MS method (PPM)

Naphthalene	0.23
Acenaphthylene	0.24
Acenaphthene	0.48
Fluorene	0.33
Phenanthrene	0.26
Anthracene	0.13
Fluoranthene	0.27
Pyrene	0.17
Benzo[a]anthracene	0.20
Chrysene	0.19
Benzo[b+j]fluoranthene	0.28
Benzo[k]fluoranthene	0.47
Benzo[a]pyrene	0.37
Indeno[1,2,3-cd]pyrene	0.67
Benzo[g,h,i]perylene	0.69
Average	0.33

Table 4, Conventional extraction and pyrolysis analysis.

	Solvent extract	Pyrolysis 610 c
Napththalene	<510 ND	1,000
Acenaphthylene	<510 ND	ND
Acenaphthene	not reported	ND
Fluorene	<510 ND	190
Phenanthrene	700	850
Anthracene	<510 ND	470
Fluoranthene	1,200	2,100
Pyrene	2,000	2,200
Benzo[a]anthracene	1,000	1,100
Chrysene	not reported	1,600
Benzo[b]fluoranthene	1,700	SEE NOTE
Benzo[b+j]fluoranthene	SEE NOTE	3,000
Benzo[k]fluoranthene	not reported	250
Benzo[a]pyrene	1,200	1,200
Dibenzo[a,h]anthracene	not reported	ND
Indino[1,2,3-cd]pyrene	not reported	ND

All Results in PPB. Note: It has been the practice at Montclair State to report the combined value of Benzo[b]fluoranthene and Benzo[j]fluoranthene as one number.

Table 5 Jamaica Bay petrogenic v pyrogenic source determination based on Anthracene – Phenanthracene and Fluoranthene – Pyrene ratios

	an/(an+ph)	Interpretation
Gateway 1	0.20	Pyrogenic
Gateway 3	0.38	Pyrogenic
Gateway 4	0.30	Pyrogenic
Gateway 5	0.25	Pyrogenic
Gateway 6	0.51	Pyrogenic
Gateway 8	0.24	Pyrogenic
Gateway 9	0.30	Pyrogenic
Gateway 10	0.52	Pyrogenic
Gateway 11	0.93	Pyrogenic
Gateway 13a	0.44	Pyrogenic
Gateway 16	0.11	Pyrogenic
Gateway 18	0.19	Pyrogenic
Gateway 23	0.42	Pyrogenic
Gateway 24	0.38	Pyrogenic
Gateway 26	0.34	Pyrogenic
Gateway 27	0.23	Pyrogenic
Gateway 29	0.37	Pyrogenic
Gateway NB	0.32	Pyrogenic

	fl/(fl+py)	Interpretation
Gateway 1	0.46	Liq fossil fuels
Gateway 3	0.49	Liq fossil fuels
Gateway 4	0.44	Liq fossil fuels
Gateway 5	0.16	petrogenic
Gateway 6	0.59	Grass, wood or coal
Gateway 8	0.28	petrogenic
Gateway 9	0.46	Liq fossil fuels
Gateway 10	0.52	Grass, wood or coal
Gateway 11	0.52	Grass, wood or coal
Gateway 13a	0.38	petrogenic
Gateway 16	0.50	Liq fossil fuels
Gateway 18	0.44	Liq fossil fuels
Gateway 23	0.22	petrogenic

Gateway 24	0.52	Grass, wood or coal
Gateway 26	0.45	Liq fossil fuels
Gateway 27	0.52	Grass, wood or coal
Gateway 29	0.50	Liq fossil fuels
Gateway NB	0.47	Liq fossil fuels

Table 6 Sandy Hook and Staten Island petrogenic v pyrogenic source determination based on Anthracene – Phenanthracene and Fluoranthene – Pyrene ratios

	an/(an+ph)	Interpretation
Sandy Hook 1	0.43	Pyrogenic
Sandy Hook 2	0.44	Pyrogenic
Sandy Hook 3	0.53	Pyrogenic
Sandy Hook_MSU_1	0.53	Pyrogenic
Sandy Hook_MSU_3	ND	N/A
Gateway 100 (Staten Isl)	0.52	Pyrogenic
Gateway 101 (Staten Isl)	0.45	Pyrogenic
Gateway 102 (Staten Isl)	0.49	Pyrogenic

	fl/(fl+py)	Interpretation
Sandy Hook 1	0.47	Liq fossil fuels
Sandy Hook 2	0.58	Grass, wood or coal
Sandy Hook 3	0.49	Liq fossil fuels
Sandy Hook_MSU_1	ND	Grass, wood or coal
Sandy Hook_MSU_3	0.50	Liq fossil fuels
Gateway 100 (Staten Isl)	0.53	Grass, wood or coal
Gateway 101 (Staten Isl)	0.55	Grass, wood or coal
Gateway 102 (Staten Isl)	0.45	Liq fossil fuels

Notes

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APPENDIX ONE: PAH CONCETRATIONS AT INDIVIDUAL SAMPLE POINTS

Sample Name	Jamaica Bay 1
Matrix	sand
Mode	SIM
Naphthalene	0.60
Acenaphthylene	0.23
Acenaphthene	0.07
Fluorene	0.07
Phenanthrene	0.24
Anthracene	0.06
Fluoranthene	0.23
Pyrene	0.27
Benzo[a]anthracene	0.10
Chrysene	0.10
Benzo[b+j]fluoranthene	0.33
Benzo[k]fluoranthene	0.04
Benzo[a]pyrene	0.12
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	0.04
Benzo[g,h,i]perylene	0.04

All results in mg/kg (ppm)

Sample Name	Jamaica Bay 3
Matrix	muck
Mode	SIM
Naphthalene	0.37
Acenaphthylene	0.13
Acenaphthene	0.14
Fluorene	0.08
Phenanthrene	0.31
Anthracene	0.19
Fluoranthene	0.33
Pyrene	0.35
Benzo[a]anthracene	0.08
Chrysene	0.11
Benzo[b+j]fluoranthene	0.05
Benzo[k]fluoranthene	ND
Benzo[a]pyrene	ND
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	0.09
Benzo[g,h,i]perylene	0.23

All results in mg/kg (ppm)

Sample Name	Jamaica Bay 4
Matrix	muck
Mode	SIM
Naphthalene	1.71
Acenaphthylene	0.17
Acenaphthene	0.14
Fluorene	0.22
Phenanthrene	0.44
Anthracene	0.19
Fluoranthene	0.51
Pyrene	0.65
Benzo[a]anthracene	0.30
Chrysene	0.37
Benzo[b+j]fluoranthene	1.57
Benzo[k]fluoranthene	2.25
Benzo[a]pyrene	0.63
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	ND
Benzo[g,h,i]perylene	0.15

All results in mg/kg (ppm)

Sample Name	Jamaica Bay 5
Matrix	sand (course)
Mode	SIM
Naphthalene	ND
Acenaphthylene	0.03
Acenaphthene	ND
Fluorene	0.02
Phenanthrene	0.12
Anthracene	0.04
Fluoranthene	0.05
Pyrene	0.27
Benzo[a]anthracene	0.08
Chrysene	0.07
Benzo[b+j]fluoranthene	ND
Benzo[k]fluoranthene	ND
Benzo[a]pyrene	ND
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	ND
Benzo[g,h,i]perylene	ND

All results in mg/kg (ppm)

Sample Name	Jamaica Bay 6
Matrix	mixed sand / muck
Mode	SIM
Naphthalene	0.30
Acenaphthylene	0.51
Acenaphthene	0.13
Fluorene	0.07
Phenanthrene	0.14
Anthracene	0.06
Fluoranthene	0.13
Pyrene	0.19
Benzo[a]anthracene	0.10
Chrysene	0.11
Benzo[b+j]fluoranthene	0.15
Benzo[k]fluoranthene	0.02
Benzo[a]pyrene	0.07
Dibenzo[a,h]anthracene	0.06
Indino[1,2,3-cd]pyrene	0.03
Benzo[g,h,i]perylene	0.02

All results in mg/kg (ppm)

Sample Name	Jamaica Bay 8
Matrix	muck
Mode	SIM
Naphthalene	0.50
Acenaphthylene	0.12
Acenaphthene	0.43
Fluorene	0.30
Phenanthrene	0.66
Anthracene	0.21
Fluoranthene	0.18
Pyrene	0.46
Benzo[a]anthracene	0.09
Chrysene	0.18
Benzo[b+j]fluoranthene	0.04
Benzo[k]fluoranthene	0.01
Benzo[a]pyrene	0.05
Dibenzo[a,h]anthracene	0.02
Indino[1,2,3-cd]pyrene	0.11
Benzo[g,h,i]perylene	0.09

All results in mg/kg (ppm)

Sample Name	Jamaica Bay 9
Matrix	muck
Mode	SIM
Naphthalene	0.01
Acenaphthylene	0.49
Acenaphthene	0.18
Fluorene	0.07
Phenanthrene	0.55
Anthracene	0.24
Fluoranthene	0.80
Pyrene	0.93
Benzo[a]anthracene	0.18
Chrysene	0.22
Benzo[b+j]fluoranthene	ND
Benzo[k]fluoranthene	ND
Benzo[a]pyrene	ND
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	ND
Benzo[g,h,i]perylene	ND

All results in mg/kg (ppm)

Sample Name	Jamaica Bay 10
Matrix	muck
Mode	SIM
Naphthalene	0.30
Acenaphthylene	0.12
Acenaphthene	0.06
Fluorene	0.04
Phenanthrene	0.29
Anthracene	0.11
Fluoranthene	0.42
Pyrene	0.39
Benzo[a]anthracene	0.17
Chrysene	0.19
Benzo[b+j]fluoranthene	0.25
Benzo[k]fluoranthene	0.01
Benzo[a]pyrene	0.05
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	0.06
Benzo[g,h,i]perylene	0.08

All results in mg/kg (ppm)

Sample Name	Jamaica Bay 11
Matrix	sand
Mode	SIM
Naphthalene	0.17
Acenaphthylene	0.28
Acenaphthene	0.08
Fluorene	0.03
Phenanthrene	0.01
Anthracene	0.02
Fluoranthene	0.13
Pyrene	0.12
Benzo[a]anthracene	0.06
Chrysene	0.08
Benzo[b+j]fluoranthene	0.14
Benzo[k]fluoranthene	ND
Benzo[a]pyrene	0.05
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	0.27
Benzo[g,h,i]perylene	0.02

All results in mg/kg (ppm)

Sample Name	Jamaica Bay 12
Matrix	muck
Mode	Full scan
Naphthalene	ND
Acenaphthylene	ND
Acenaphthene	ND
Fluorene	ND
Phenanthrene	3.89
Anthracene	2.87
Fluoranthene	7.55
Pyrene	5.35
Benzo[a]anthracene	3.01
Chrysene	3.37
Benzo[b+j]fluoranthene	ND
Benzo[k]fluoranthene	ND
Benzo[a]pyrene	ND
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	ND
Benzo[g,h,i]perylene	ND

All results in mg/kg (ppm)

Sample Name	Jamaica Bay 13_A
Matrix	muck
Mode	SIM
Naphthalene	8.79
Acenaphthylene	1.19
Acenaphthene	0.19
Fluorene	0.16
Phenanthrene	0.67
Anthracene	0.53
Fluoranthene	1.09
Pyrene	1.79
Benzo[a]anthracene	0.71
Chrysene	0.80
Benzo[b+j]fluoranthene	2.57
Benzo[k]fluoranthene	0.20
Benzo[a]pyrene	0.78
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	0.06
Benzo[g,h,i]perylene	0.06

All results in mg/kg (ppm)

Sample Name	Jamaica Bay 13
Matrix	muck
Mode	Full scan
Naphthalene	ND
Acenaphthylene	ND
Acenaphthene	ND
Fluorene	ND
Phenanthrene	ND
Anthracene	0.17
Fluoranthene	0.19
Pyrene	0.15
Benzo[a]anthracene	ND
Chrysene	ND
Benzo[b+j]fluoranthene	ND
Benzo[k]fluoranthene	ND
Benzo[a]pyrene	ND
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	ND
Benzo[g,h,i]perylene	ND

All results in mg/kg (ppm)

Sample Name	Jamaica Bay 16
Matrix	sand
Mode	SIM
Naphthalene	0.17
Acenaphthylene	0.28
Acenaphthene	0.09
Fluorene	0.03
Phenanthrene	0.08
Anthracene	0.01
Fluoranthene	0.04
Pyrene	0.04
Benzo[a]anthracene	0.02
Chrysene	0.02
Benzo[b+j]fluoranthene	0.03
Benzo[k]fluoranthene	ND
Benzo[a]pyrene	0.01
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	0.03
Benzo[g,h,i]perylene	0.01

All results in mg/kg (ppm)

Sample Name	Jamaica Bay 18
Matrix	sand
Mode	SIM
Naphthalene	0.02
Acenaphthylene	0.02
Acenaphthene	0.02
Fluorene	0.01
Phenanthrene	0.13
Anthracene	0.03
Fluoranthene	0.07
Pyrene	0.09
Benzo[a]anthracene	0.01
Chrysene	0.01
Benzo[b+j]fluoranthene	ND
Benzo[k]fluoranthene	ND
Benzo[a]pyrene	ND
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	ND
Benzo[g,h,i]perylene	ND

All results in mg/kg (ppm)

Sample Name	Jamaica Bay 22
Matrix	muck
Mode	Full scan
Naphthalene	0.64
Acenaphthylene	0.13
Acenaphthene	ND
Fluorene	ND
Phenanthrene	ND
Anthracene	ND
Fluoranthene	0.15
Pyrene	0.11
Benzo[a]anthracene	ND
Chrysene	ND
Benzo[b+j]fluoranthene	ND
Benzo[k]fluoranthene	ND
Benzo[a]pyrene	ND
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	ND
Benzo[g,h,i]perylene	ND

All results in mg/kg (ppm)

Sample Name	Jamaica Bay 23
Matrix	sand
Mode	SIM
Naphthalene	0.34
Acenaphthylene	0.28
Acenaphthene	0.06
Fluorene	0.05
Phenanthrene	0.14
Anthracene	0.10
Fluoranthene	0.09
Pyrene	0.32
Benzo[a]anthracene	0.12
Chrysene	0.14
Benzo[b+j]fluoranthene	0.13
Benzo[k]fluoranthene	0.02
Benzo[a]pyrene	0.05
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	ND
Benzo[g,h,i]perylene	ND

All results in mg/kg (ppm)

Sample Name	Jamaica Bay 26
Matrix	muck
Mode	SIM
Naphthalene	1.29
Acenaphthylene	1.19
Acenaphthene	0.02
Fluorene	0.16
Phenanthrene	0.45
Anthracene	0.28
Fluoranthene	1.24
Pyrene	1.14
Benzo[a]anthracene	0.63
Chrysene	0.69
Benzo[b+j]fluoranthene	1.51
Benzo[k]fluoranthene	0.12
Benzo[a]pyrene	0.17
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	ND
Benzo[g,h,i]perylene	ND

All results in mg/kg (ppm)

Sample Name	Jamaica Bay 26
Matrix	muck
Mode	SIM
Naphthalene	0.07
Acenaphthylene	0.35
Acenaphthene	0.06
Fluorene	0.47
Phenanthrene	1.07
Anthracene	0.54
Fluoranthene	1.61
Pyrene	1.99
Benzo[a]anthracene	1.48
Chrysene	1.72
Benzo[b+j]fluoranthene	4.96
Benzo[k]fluoranthene	0.25
Benzo[a]pyrene	0.86
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	ND
Benzo[g,h,i]perylene	ND

All results in mg/kg (ppm)

Sample Name	Jamaica Bay 27
Matrix	muck
Mode	SIM
Naphthalene	0.11
Acenaphthylene	0.34
Acenaphthene	0.25
Fluorene	0.09
Phenanthrene	1.37
Anthracene	0.42
Fluoranthene	4.53
Pyrene	4.23
Benzo[a]anthracene	1.23
Chrysene	1.98
Benzo[b+j]fluoranthene	4.01
Benzo[k]fluoranthene	0.17
Benzo[a]pyrene	1.21
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	ND
Benzo[g,h,i]perylene	ND

All results in mg/kg (ppm)

Sample Name	Jamaica Bay 29
Matrix	muck
Mode	SIM
Naphthalene	0.18
Acenaphthylene	1.51
Acenaphthene	0.37
Fluorene	0.12
Phenanthrene	0.76
Anthracene	0.44
Fluoranthene	3.32
Pyrene	3.26
Benzo[a]anthracene	1.53
Chrysene	1.74
Benzo[b+j]fluoranthene	5.82
Benzo[k]fluoranthene	0.12
Benzo[a]pyrene	0.87
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	ND
Benzo[g,h,i]perylene	ND

All results in mg/kg (ppm)

Sample Name	Jamaica Bay NB
Matrix	muck
Mode	SIM
Naphthalene	3.09
Acenaphthylene	1.21
Acenaphthene	0.20
Fluorene	ND
Phenanthrene	0.57
Anthracene	0.27
Fluoranthene	1.54
Pyrene	1.75
Benzo[a]anthracene	0.85
Chrysene	1.06
Benzo[b+j]fluoranthene	4.48
Benzo[k]fluoranthene	0.35
Benzo[a]pyrene	1.62
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	0.23
Benzo[g,h,i]perylene	0.13

All results in mg/kg (ppm)

Sample name	Sandy Hook_1
Mode	Full Scan
Naphthalene	0.31
Acenaphthylene	ND
Acenaphthene	ND
Fluorene	ND
Phenanthrene	0.13
Anthracene	0.10
Fluoranthene	0.21
Pyrene	0.24
Benzo[a]anthracene	0.08
Chrysene	0.14
Benzo[b+j]fluoranthene	0.25
Benzo[k]fluoranthene	0.05
Benzo[a]pyrene	0.07
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	ND
Benzo[g,h,i]perylene	ND

All results in mg/kg (ppm)

Sample name	Sandy Hook_2
Mode	Full Scan
Naphthalene	ND
Acenaphthylene	ND
Acenaphthene	ND
Fluorene	ND
Phenanthrene	0.19
Anthracene	0.15
Fluoranthene	0.43
Pyrene	0.31
Benzo[a]anthracene	0.11
Chrysene	0.18
Benzo[b+j]fluoranthene	0.21
Benzo[k]fluoranthene	0.02
Benzo[a]pyrene	0.08
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	ND
Benzo[g,h,i]perylene	ND

All results in mg/kg (ppm)

Sample name	Sandy Hook_3
Mode	Full Scan
Naphthalene	1.28
Acenaphthylene	ND
Acenaphthene	ND
Fluorene	ND
Phenanthrene	1.20
Anthracene	1.34
Fluoranthene	3.15
Pyrene	3.33
Benzo[a]anthracene	1.04
Chrysene	1.40
Benzo[b+j]fluoranthene	2.25
Benzo[k]fluoranthene	0.17
Benzo[a]pyrene	0.25
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	ND
Benzo[g,h,i]perylene	ND

All results in mg/kg (ppm)

Sample name	Sandy Hook_MSU_1
Mode	Full Scan
Naphthalene	ND
Acenaphthylene	ND
Acenaphthene	ND
Fluorene	ND
Phenanthrene	1.05
Anthracene	1.19
Fluoranthene	ND
Pyrene	ND
Benzo[a]anthracene	1.17
Chrysene	1.66
Benzo[b+j]fluoranthene	2.93
Benzo[k]fluoranthene	0.51
Benzo[a]pyrene	0.77
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	ND
Benzo[g,h,i]perylene	ND

All results in mg/kg (ppm)

Sample name	Sandy Hook_MSU_3
Mode	Full Scan
Naphthalene	ND
Acenaphthylene	ND
Acenaphthene	ND
Fluorene	ND
Phenanthrene	ND
Anthracene	ND
Fluoranthene	2.55
Pyrene	2.55
Benzo[a]anthracene	ND
Chrysene	ND
Benzo[b+j]fluoranthene	2.06
Benzo[k]fluoranthene	0.15
Benzo[a]pyrene	0.29
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	ND
Benzo[g,h,i]perylene	ND

All results in mg/kg (ppm)

Sample Name	Staten Island 100_b_P
Mode	Full scan
Naphthalene	0.37
Acenaphthylene	0.06
Acenaphthene	ND
Fluorene	ND
Phenanthrene	0.21
Anthracene	0.23
Fluoranthene	2.89
Pyrene	2.53
Benzo[a]anthracene	1.83
Chrysene	2.41
Benzo[b+j]fluoranthene	3.37
Benzo[k]fluoranthene	0.28
Benzo[a]pyrene	0.97
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	0.16
Benzo[g,h,i]perylene	0.25

All results in mg/kg (ppm)

Sample Name	Staten Island 101_a_P
Mode	Full scan
Naphthalene	2.73
Acenaphthylene	ND
Acenaphthene	ND
Fluorene	ND
Phenanthrene	0.93
Anthracene	0.75
Fluoranthene	2.43
Pyrene	1.97
Benzo[a]anthracene	0.64
Chrysene	1.18
Benzo[b+j]fluoranthene	1.18
Benzo[k]fluoranthene	0.15
Benzo[a]pyrene	0.06
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	ND
Benzo[g,h,i]perylene	ND

All results in mg/kg (ppm)

Sample Name	Staten Island 102_a_P
Mode	Full scan
Naphthalene	0.60
Acenaphthylene	0.35
Acenaphthene	ND
Fluorene	ND
Phenanthrene	0.43
Anthracene	0.42
Fluoranthene	0.86
Pyrene	1.04
Benzo[a]anthracene	0.21
Chrysene	0.36
Benzo[b+j]fluoranthene	0.61
Benzo[k]fluoranthene	0.09
Benzo[a]pyrene	0.19
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	ND
Benzo[g,h,i]perylene	ND

All results in mg/kg (ppm)

APPENDIX TWO: MEAN PAH CONCENTRATIONS

Gateway Unit concentrations)	Jamaica Bay (Mean	
Matrix	sand	muck
Naphthalene	0.26	1.34
Acenaphthylene	0.19	0.57
Acenaphthene	0.06	0.18
Fluorene	0.03	0.16
Phenanthrene	0.12	0.86
Anthracene	0.04	0.47
Fluoranthene	0.10	1.57
Pyrene	0.19	1.52
Benzo[a]anthracene	0.06	0.80
Chrysene	0.07	0.96
Benzo[b+j]fluoranthene	0.15	2.31
Benzo[k]fluoranthene	0.02	0.35
Benzo[a]pyrene	0.06	0.63
Dibenzo[a,h]anthracene	0.00	0.04
Indino[1,2,3-cd]pyrene	0.11	0.10
Benzo[g,h,i]perylene	0.03	0.11

All results in mg/kg (ppm)

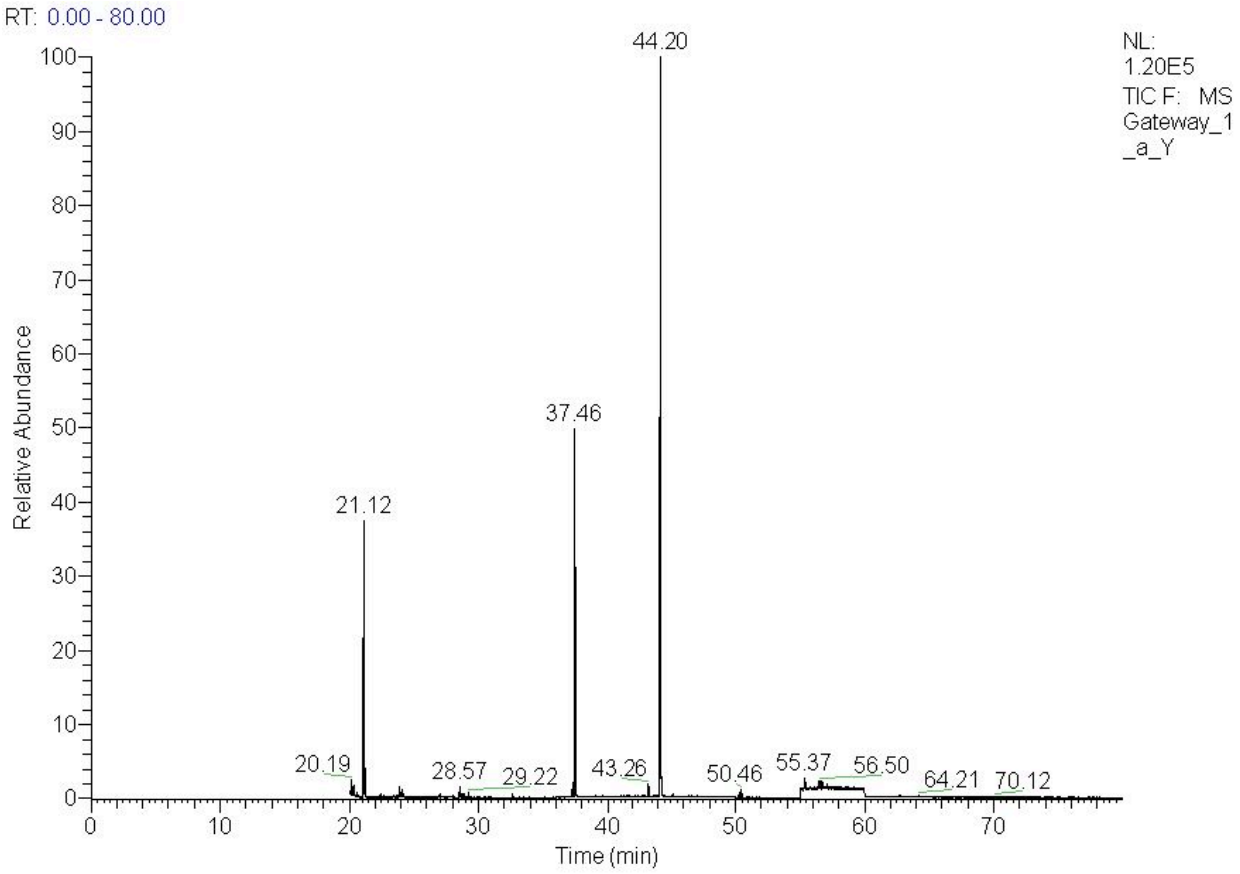
Gateway Unit	Sandy Hook (mean concentrations)
Mode	Full scan
Naphthalene	0.80
Acenaphthylene	ND
Acenaphthene	ND
Fluorene	ND
Phenanthrene	0.64
Anthracene	0.70
Fluoranthene	1.58
Pyrene	1.61
Benzo[a]anthracene	0.60
Chrysene	0.84
Benzo[b+j]fluoranthene	1.54
Benzo[k]fluoranthene	0.18
Benzo[a]pyrene	0.29
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	ND
Benzo[g,h,i]perylene	ND

All results in mg/kg (ppm)

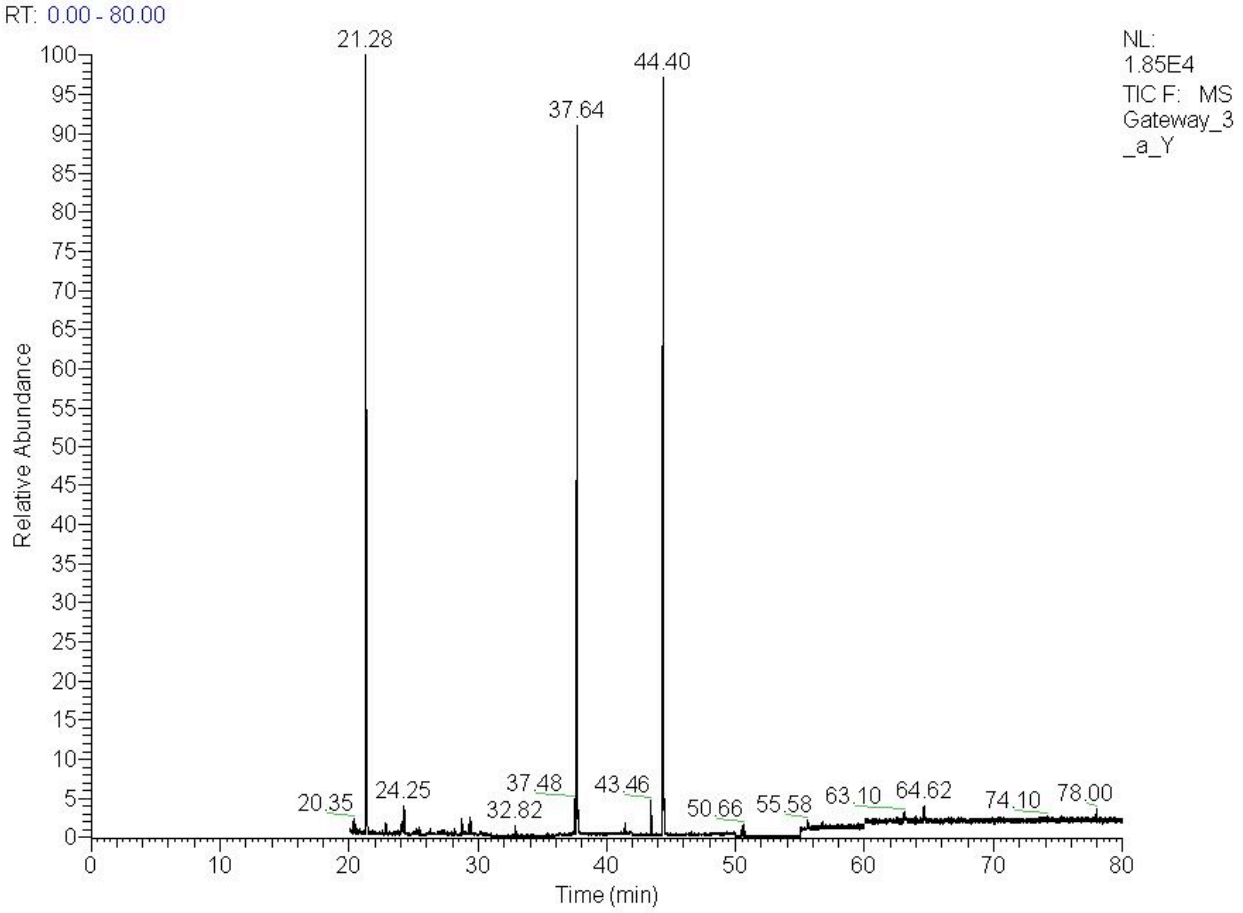
Gateway Unit	Great Kills (mean concentrations)
Mode	Full scan
Naphthalene	1.23
Acenaphthylene	0.21
Acenaphthene	ND
Fluorene	ND
Phenanthrene	0.52
Anthracene	0.47
Fluoranthene	2.06
Pyrene	1.85
Benzo[a]anthracene	0.89
Chrysene	1.32
Benzo[b+j]fluoranthene	1.72
Benzo[k]fluoranthene	0.17
Benzo[a]pyrene	0.40
Dibenzo[a,h]anthracene	ND
Indino[1,2,3-cd]pyrene	0.16
Benzo[g,h,i]perylene	0.25

All results in mg/kg (ppm)

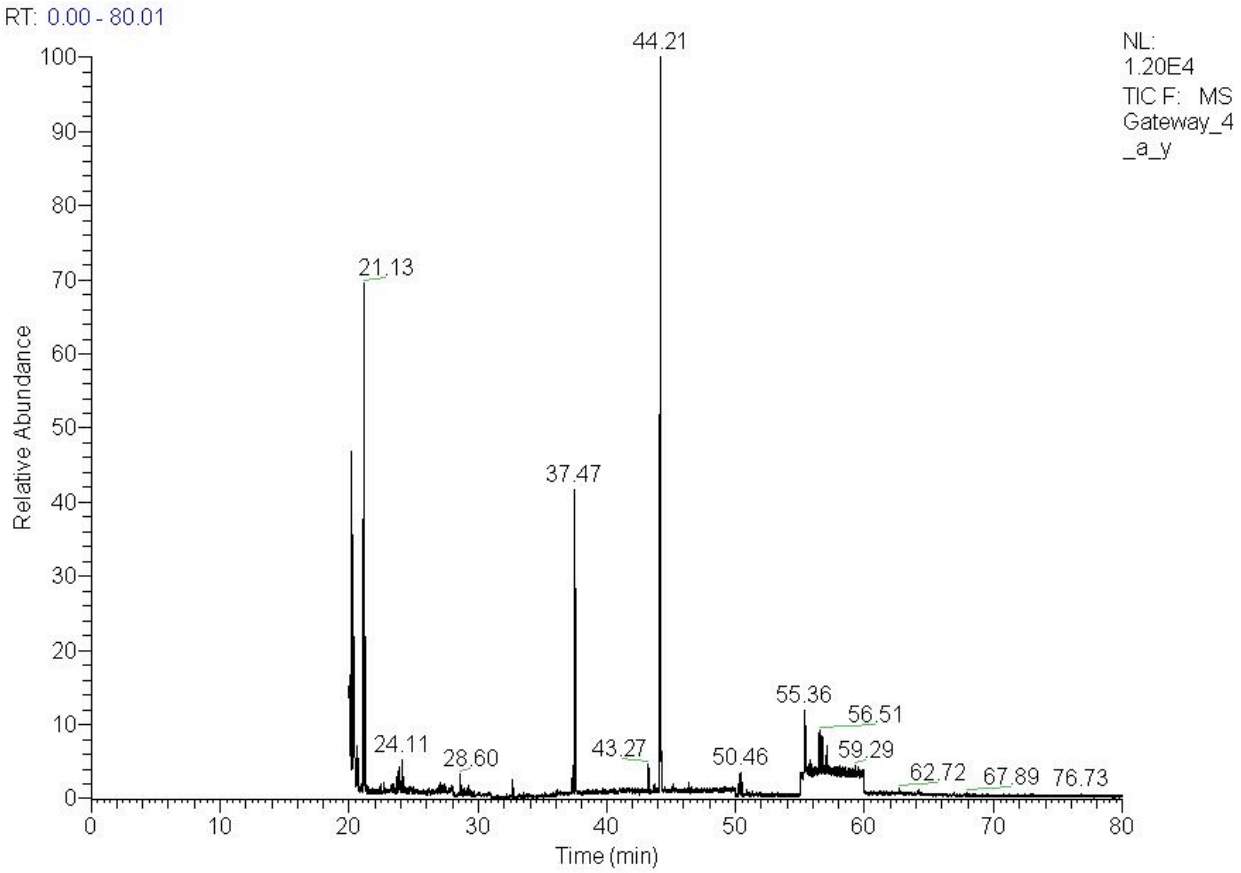
APPENDIX THREE: CHROMATOGRAMS



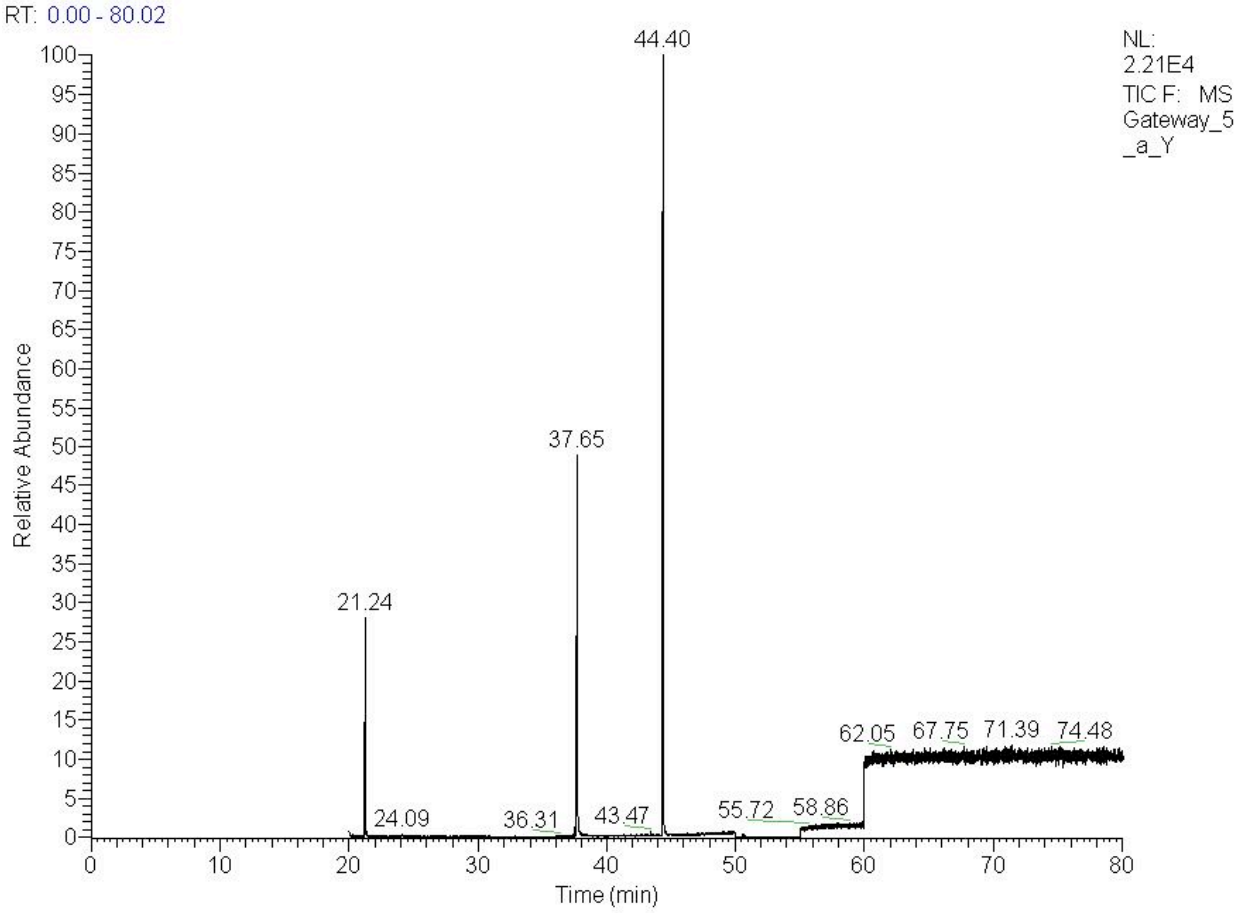
Jamaica Bay
Sample point 1
SIM method



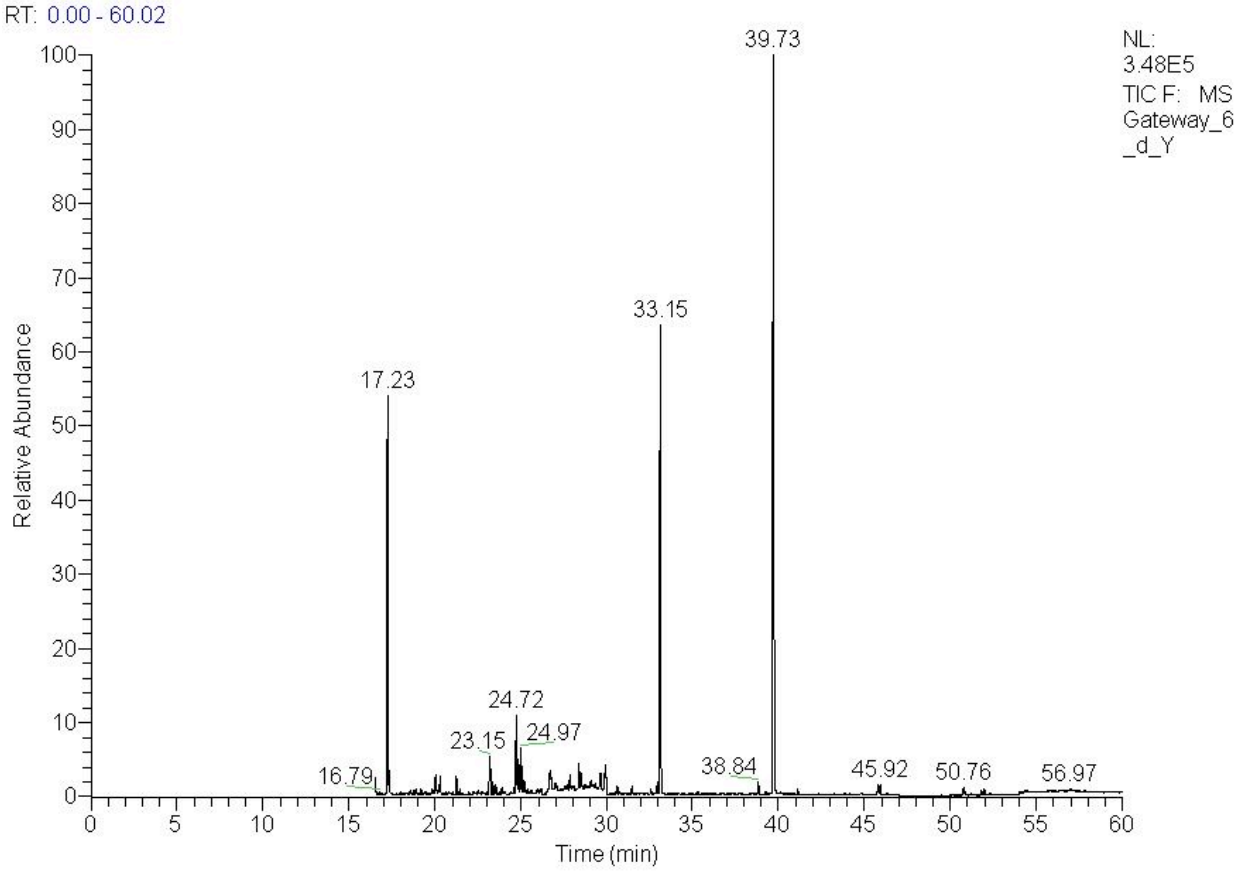
Jamaica Bay
Sample point 3
SIM method



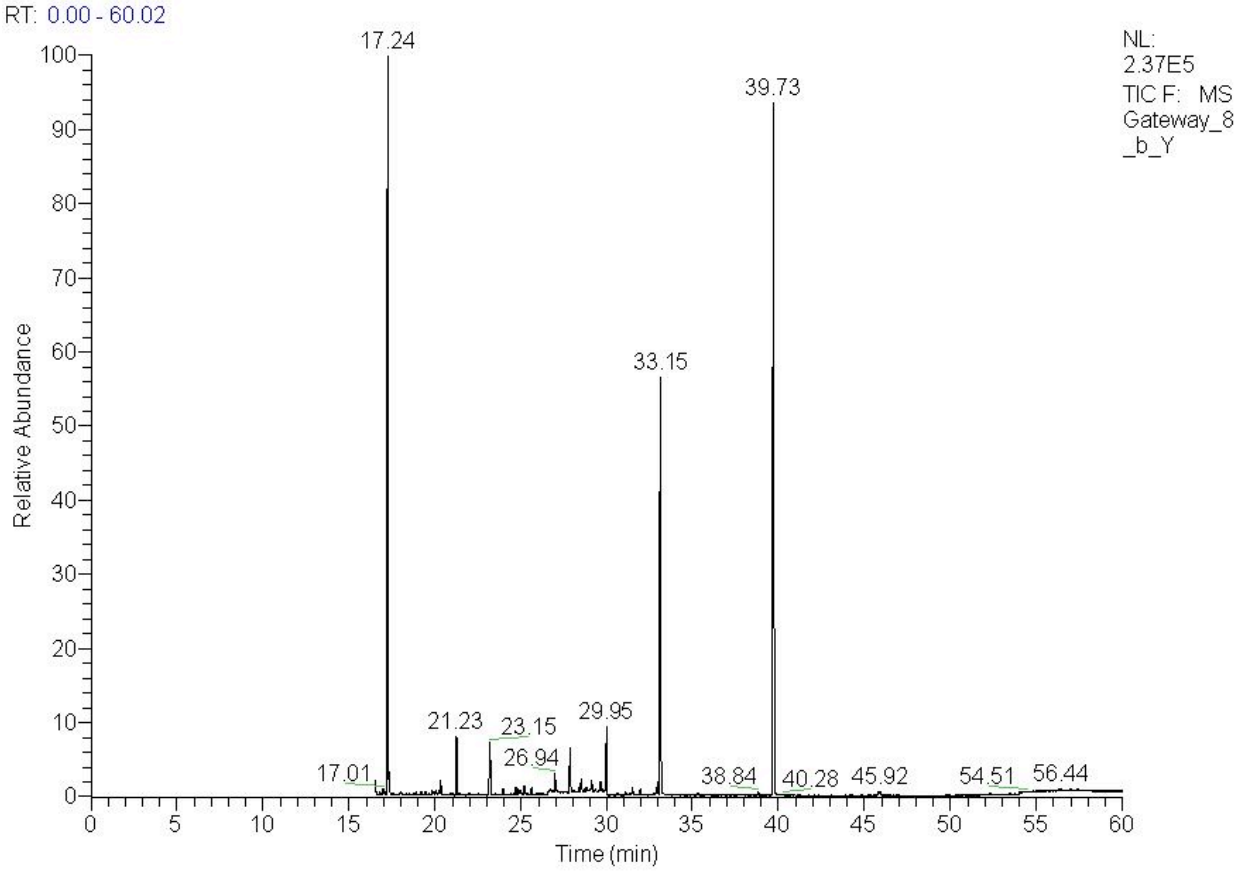
Jamaica Bay
Sample point 4
SIM method



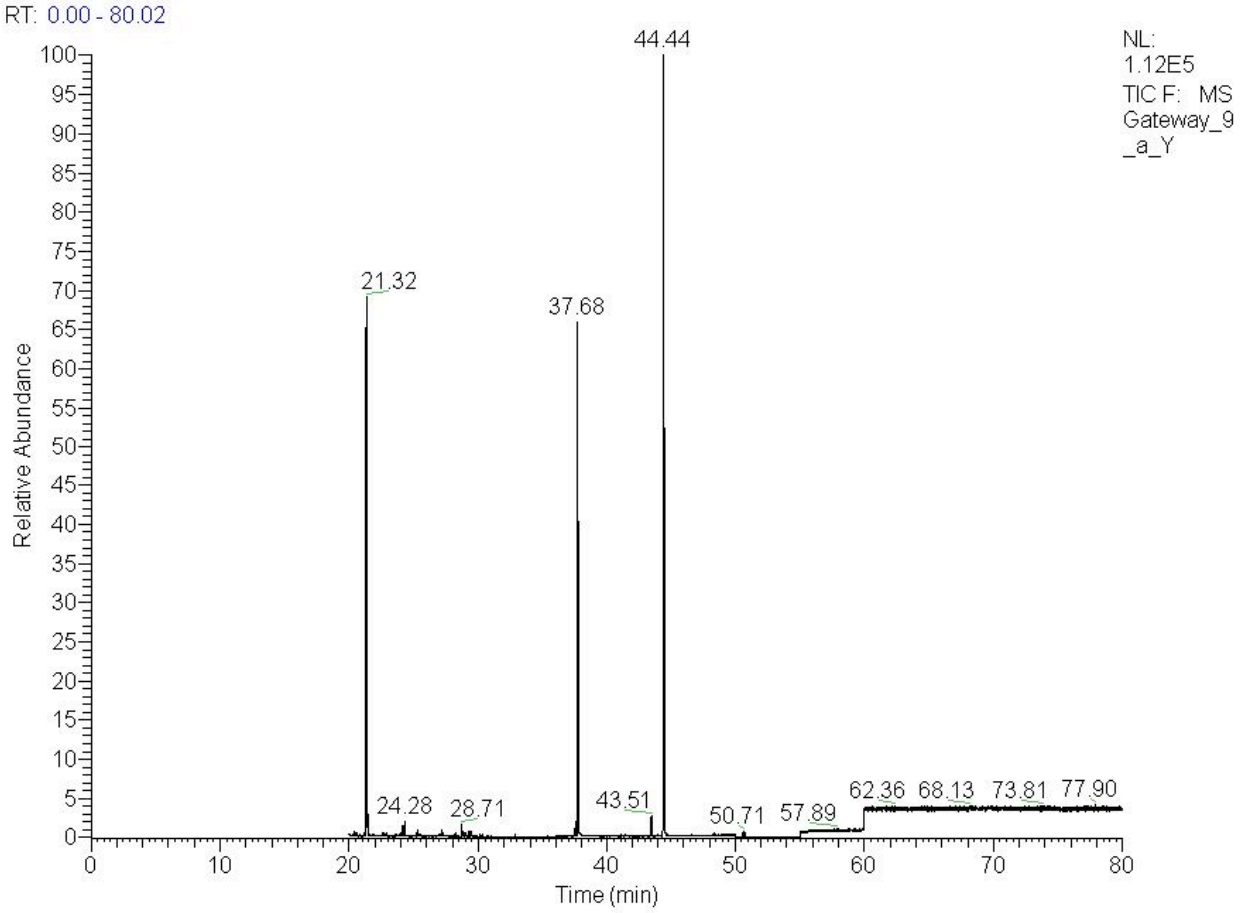
Jamaica Bay
Sample point 5
SIM method



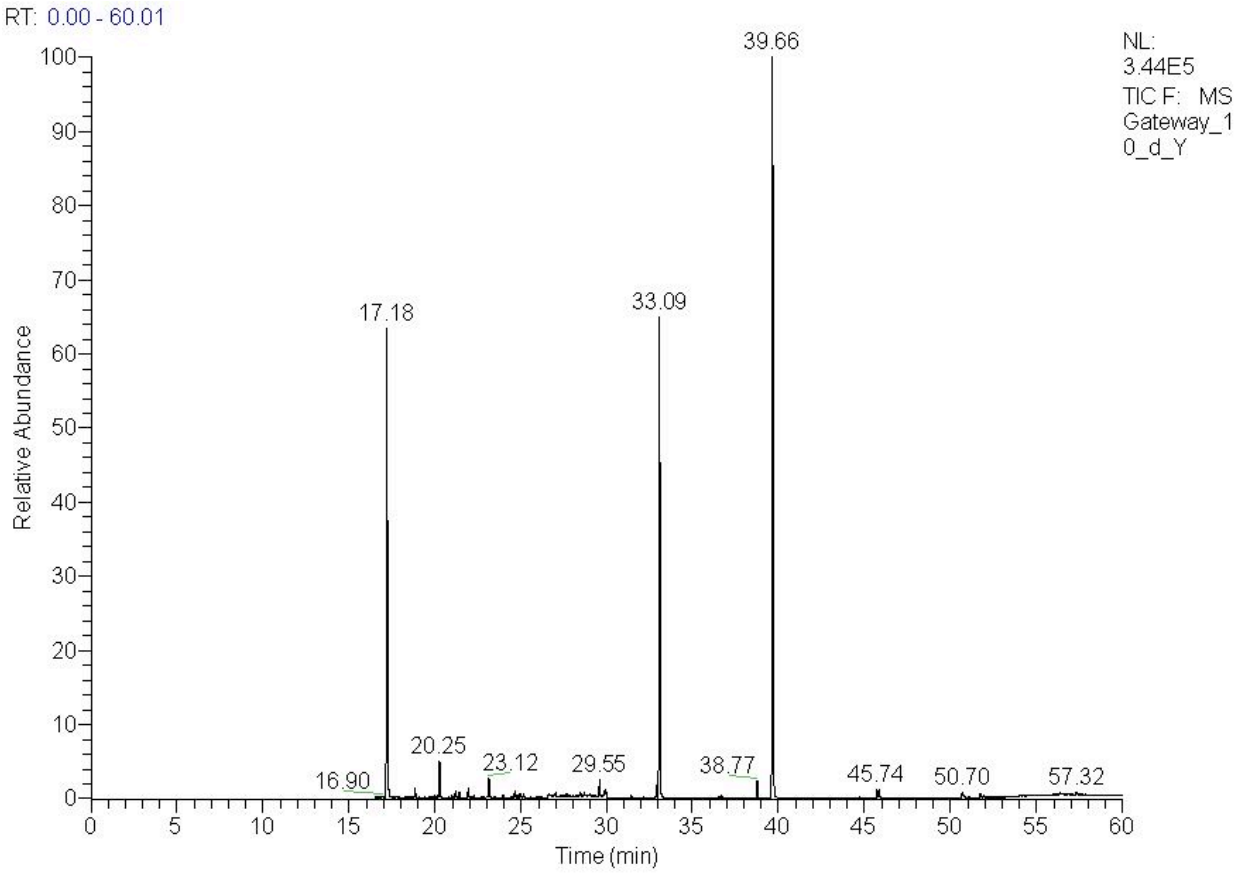
Jamaica Bay
Sample point 6
SIM method



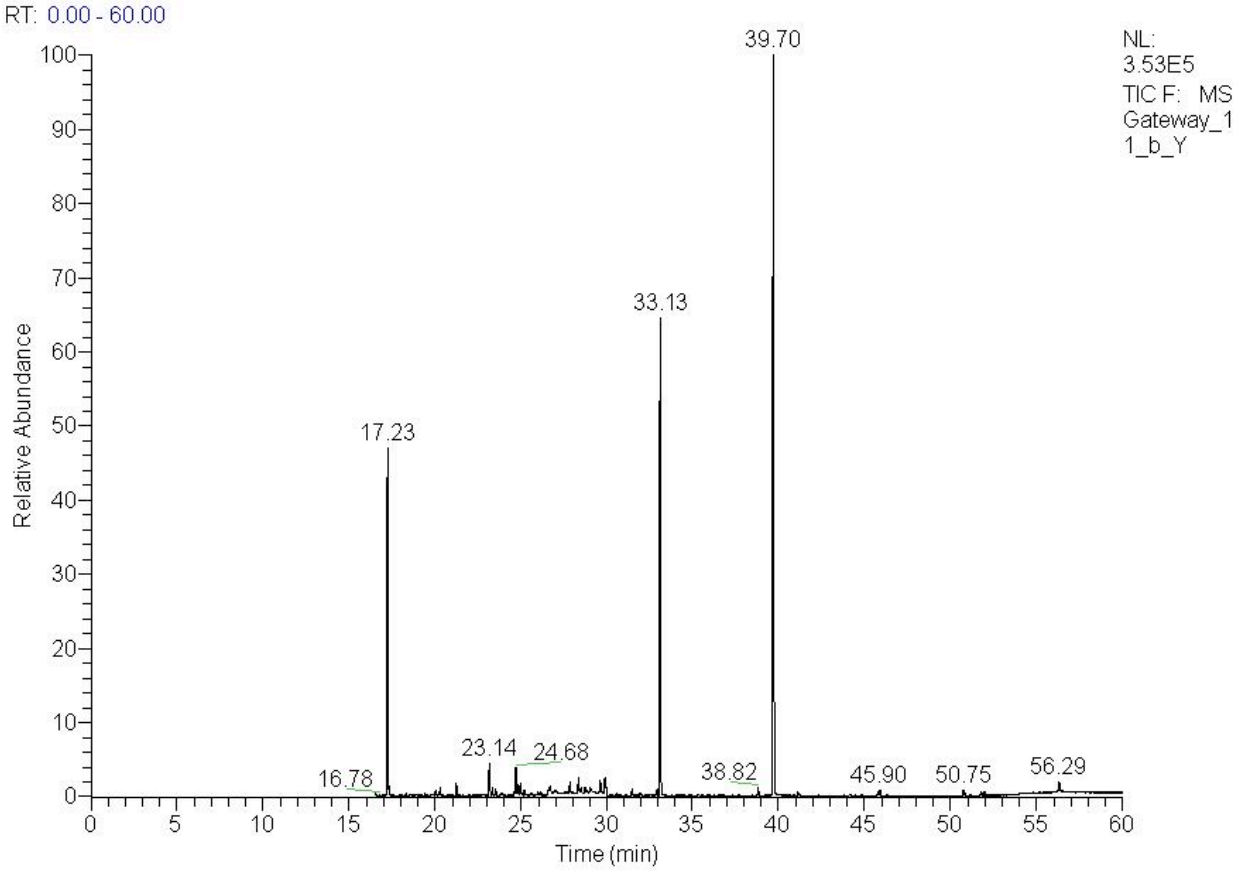
Jamaica Bay
Sample point 8
SIM method



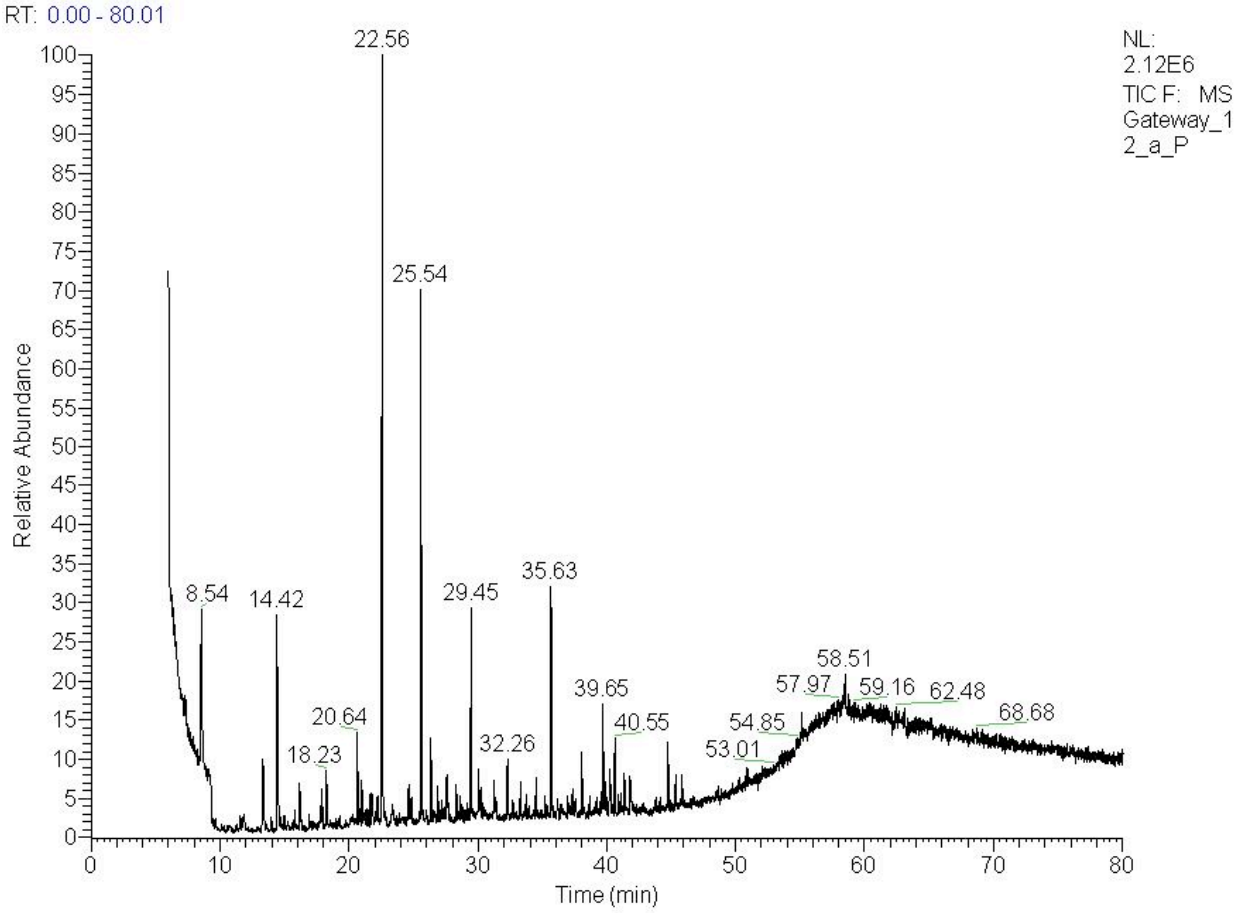
Jamaica Bay
Sample point 9
SIM method



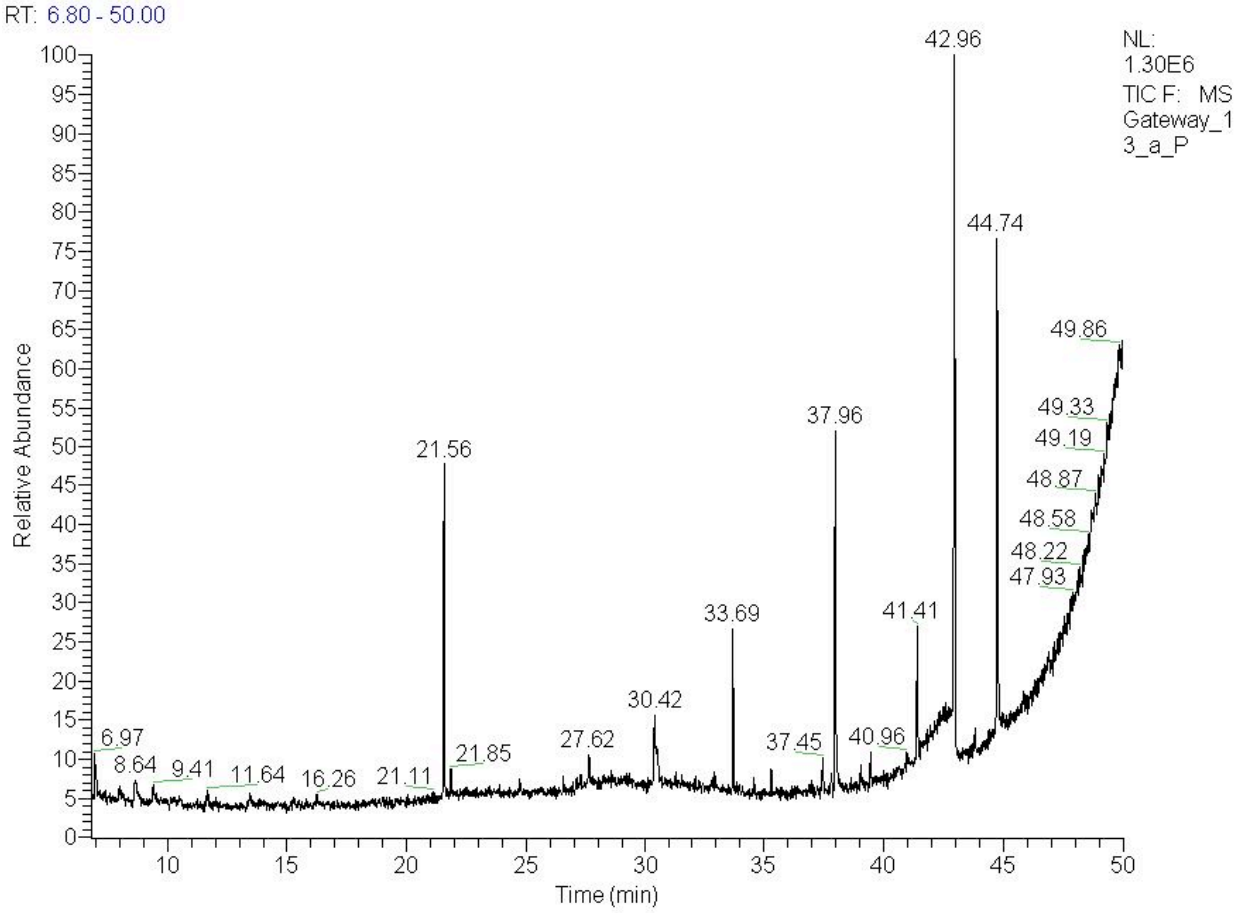
Jamaica Bay
Sample point 10
SIM method



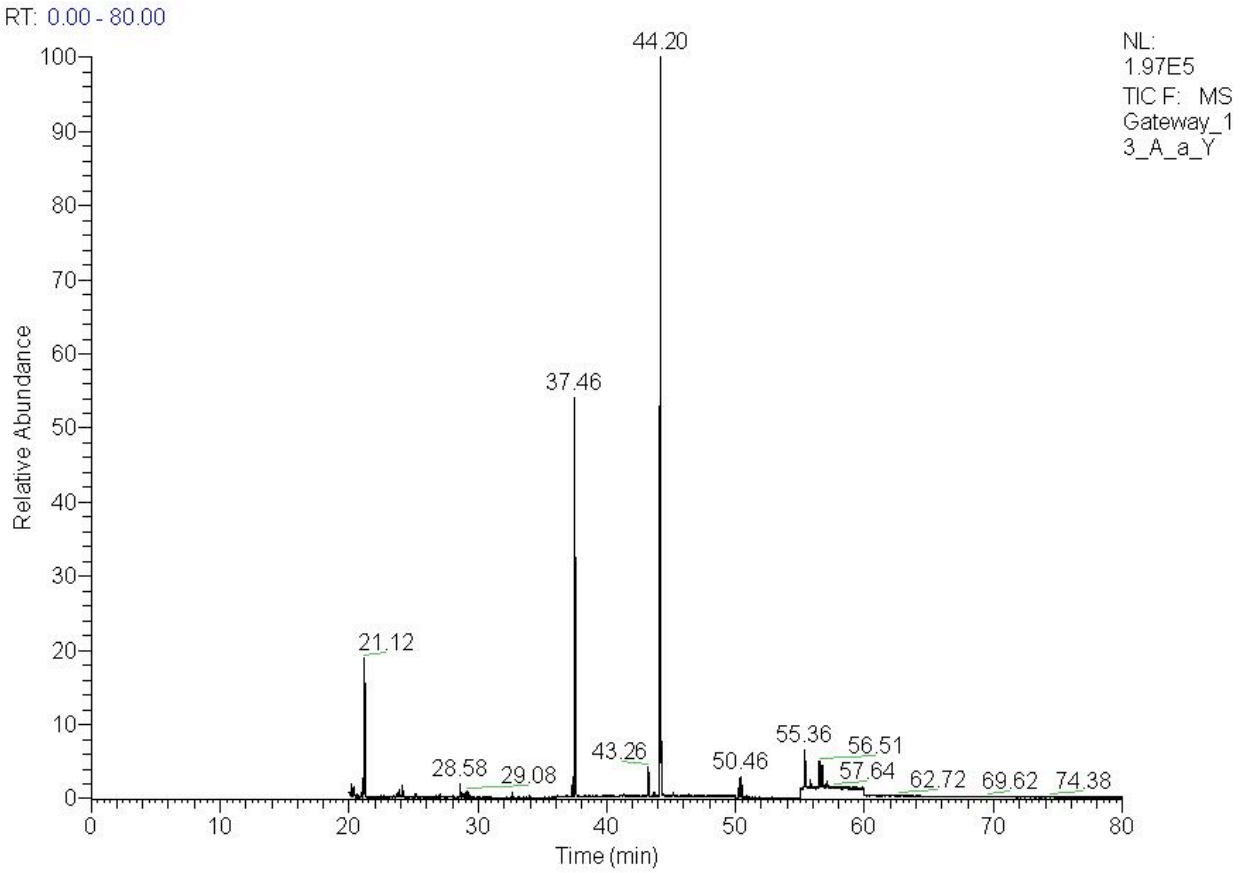
Jamaica Bay
Sample point 11
SIM method



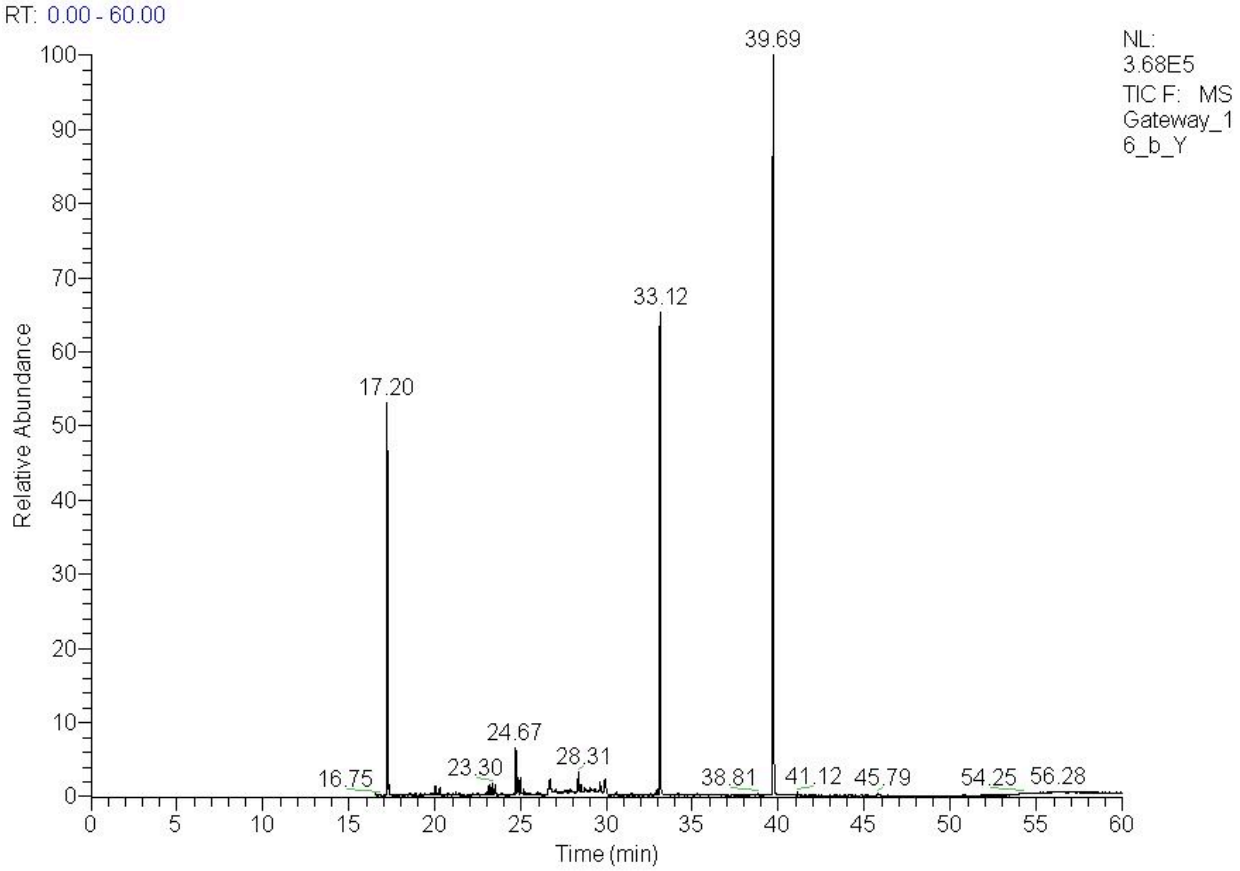
Jamaica Bay
Sample point 12
Full Scan method



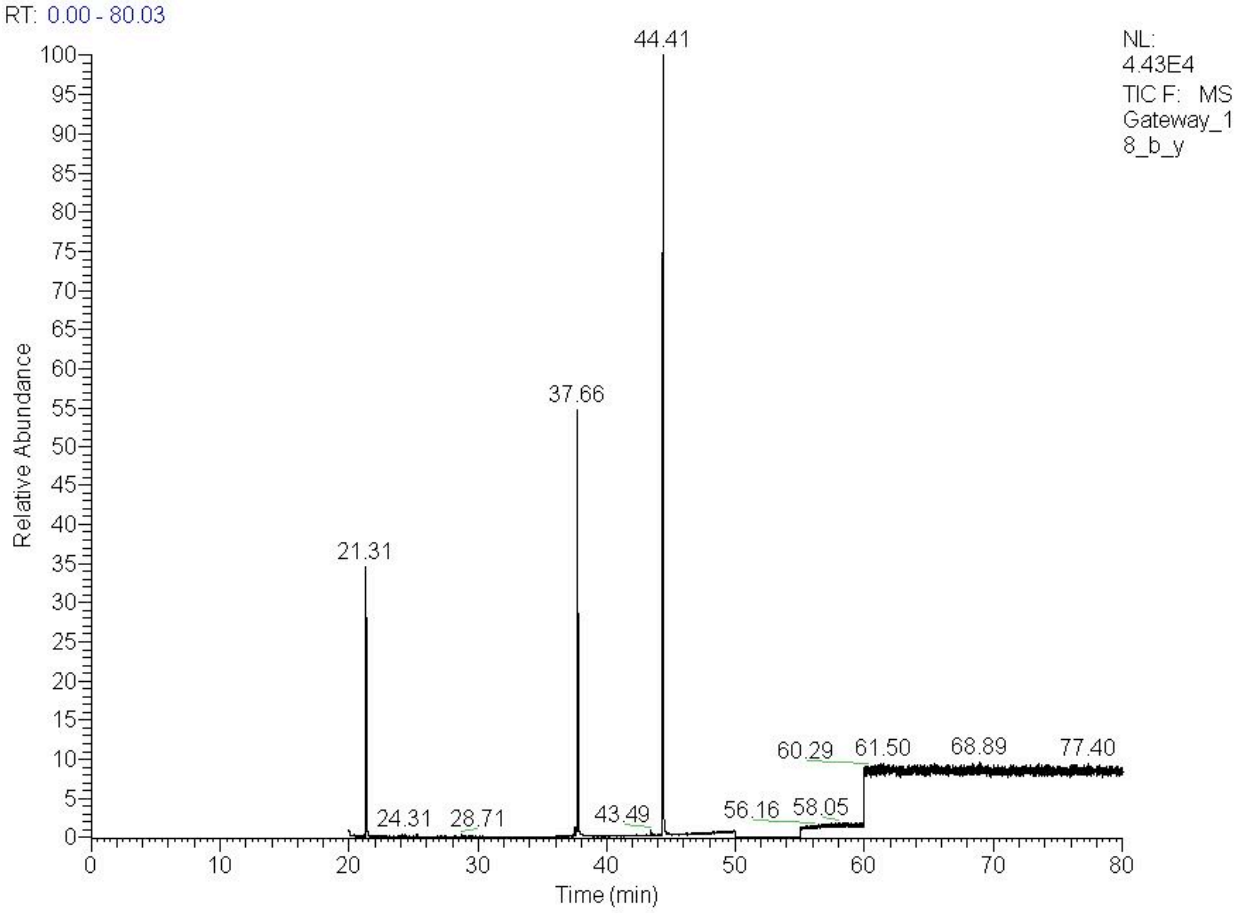
Jamaica Bay
Sample point 13
Full Scan method



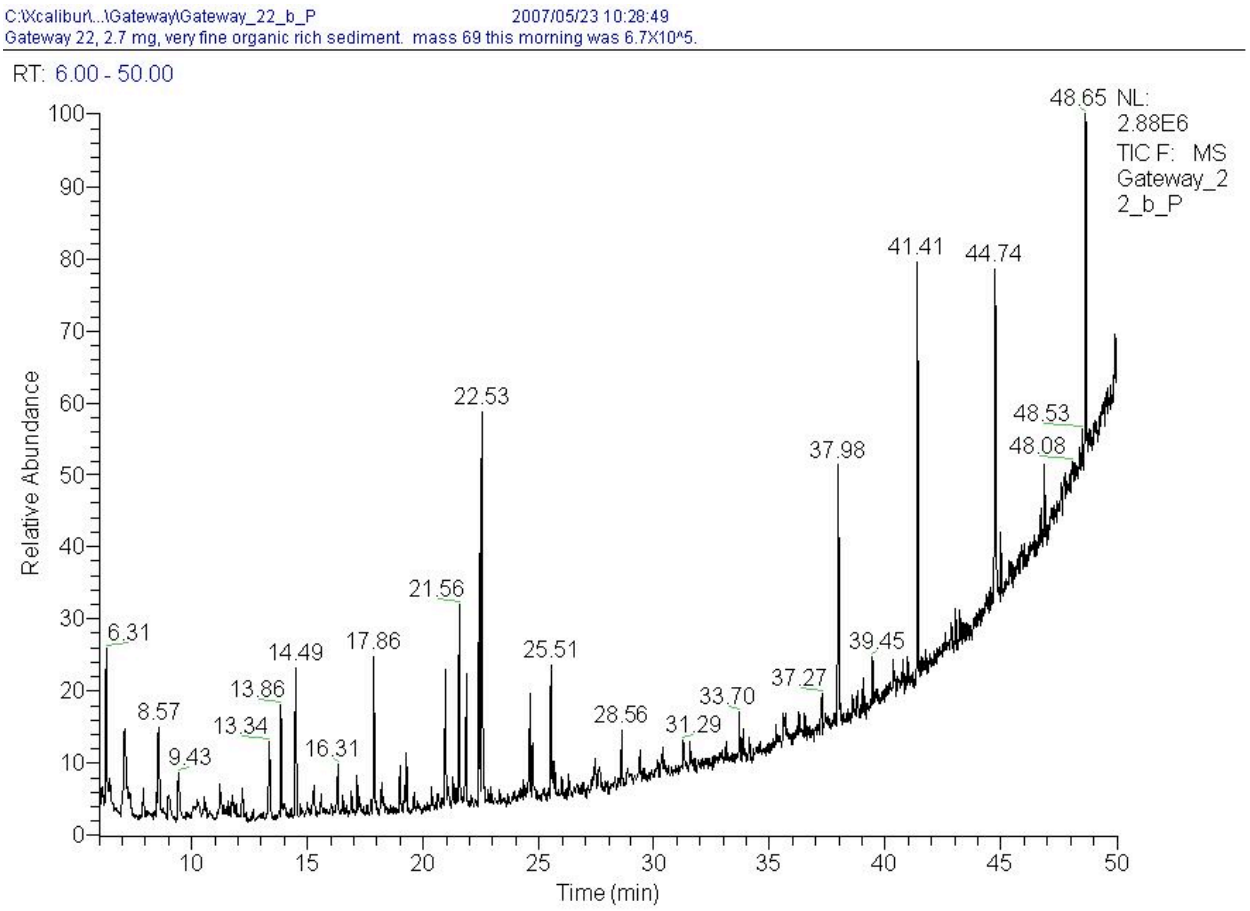
Jamaica Bay
Sample point 13A
SIM method



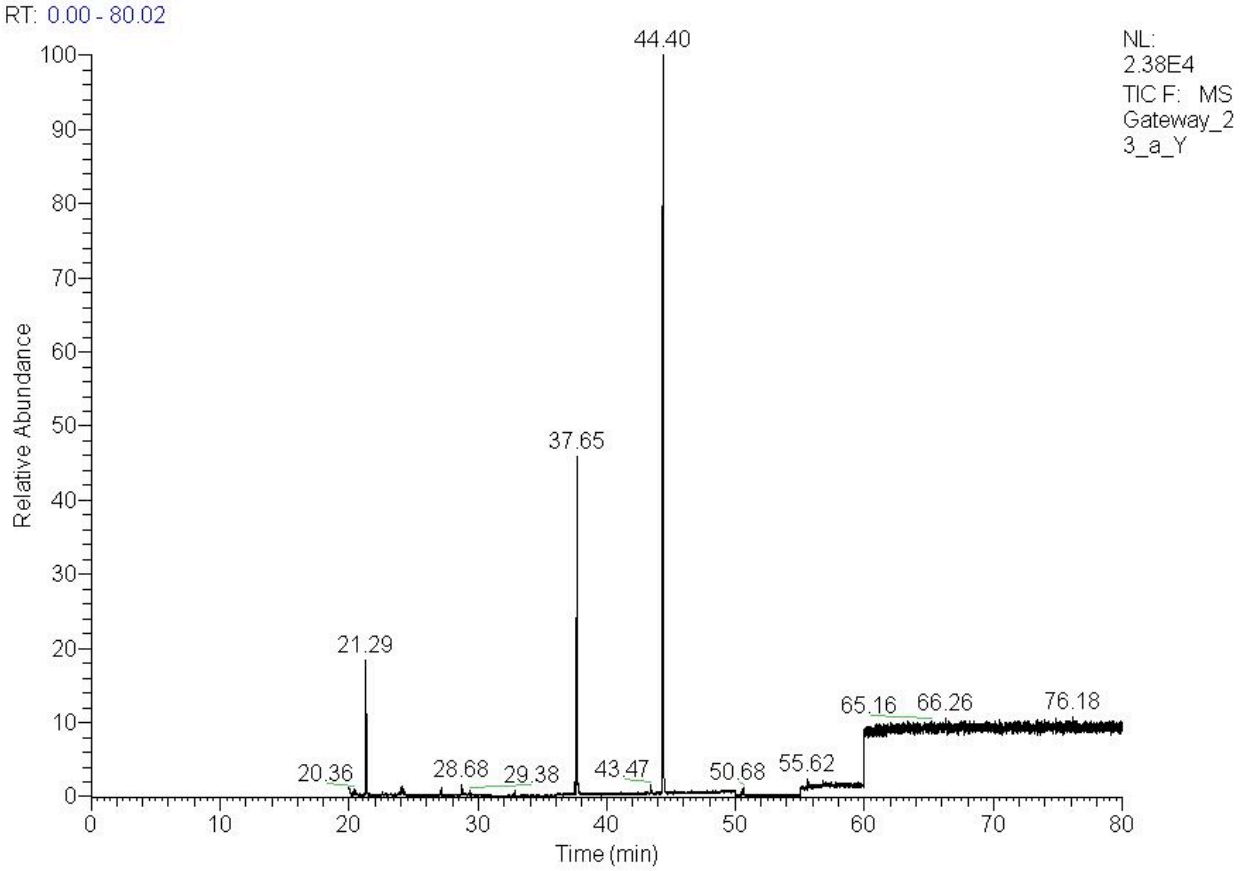
Jamaica Bay
Sample point 16
SIM method



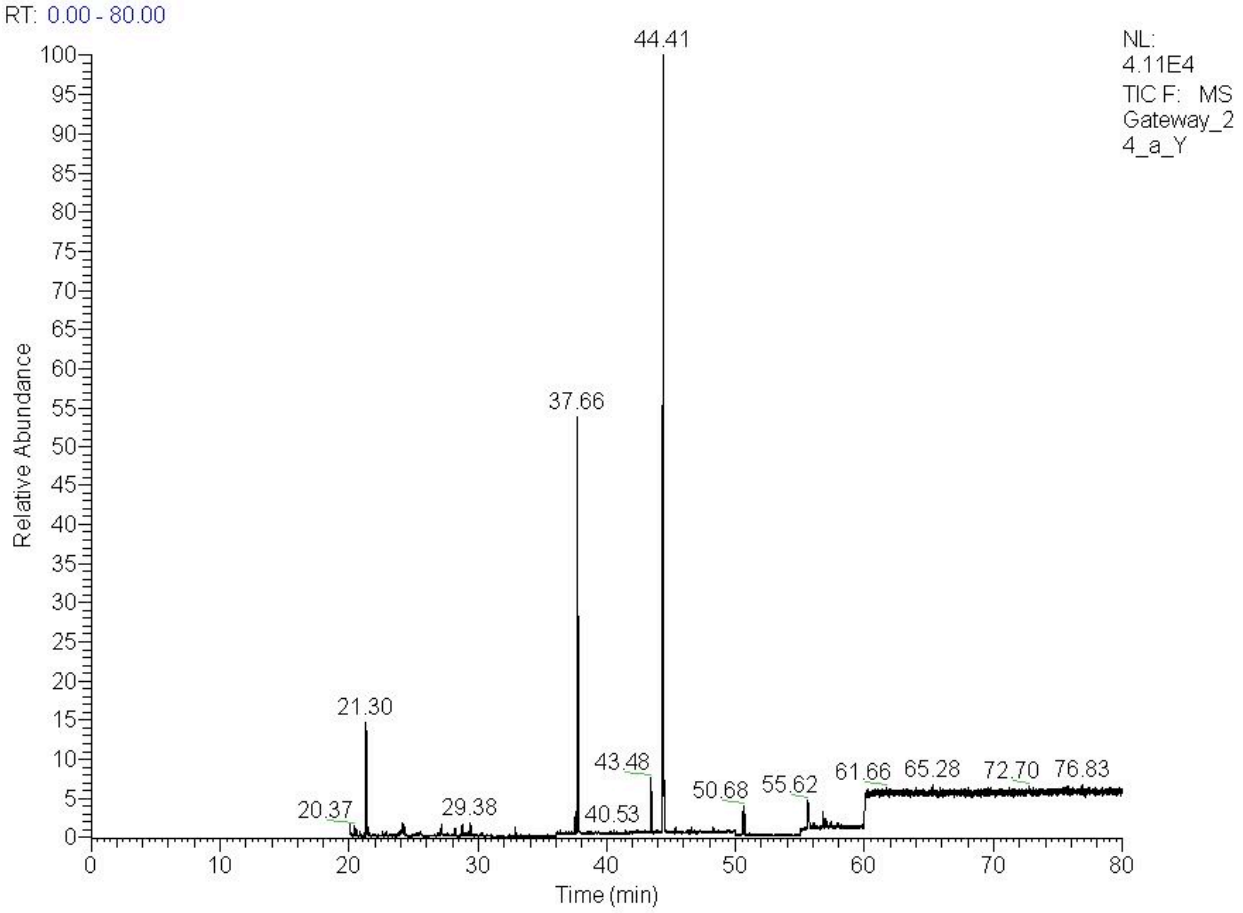
Jamaica Bay
Sample point 18
SIM method



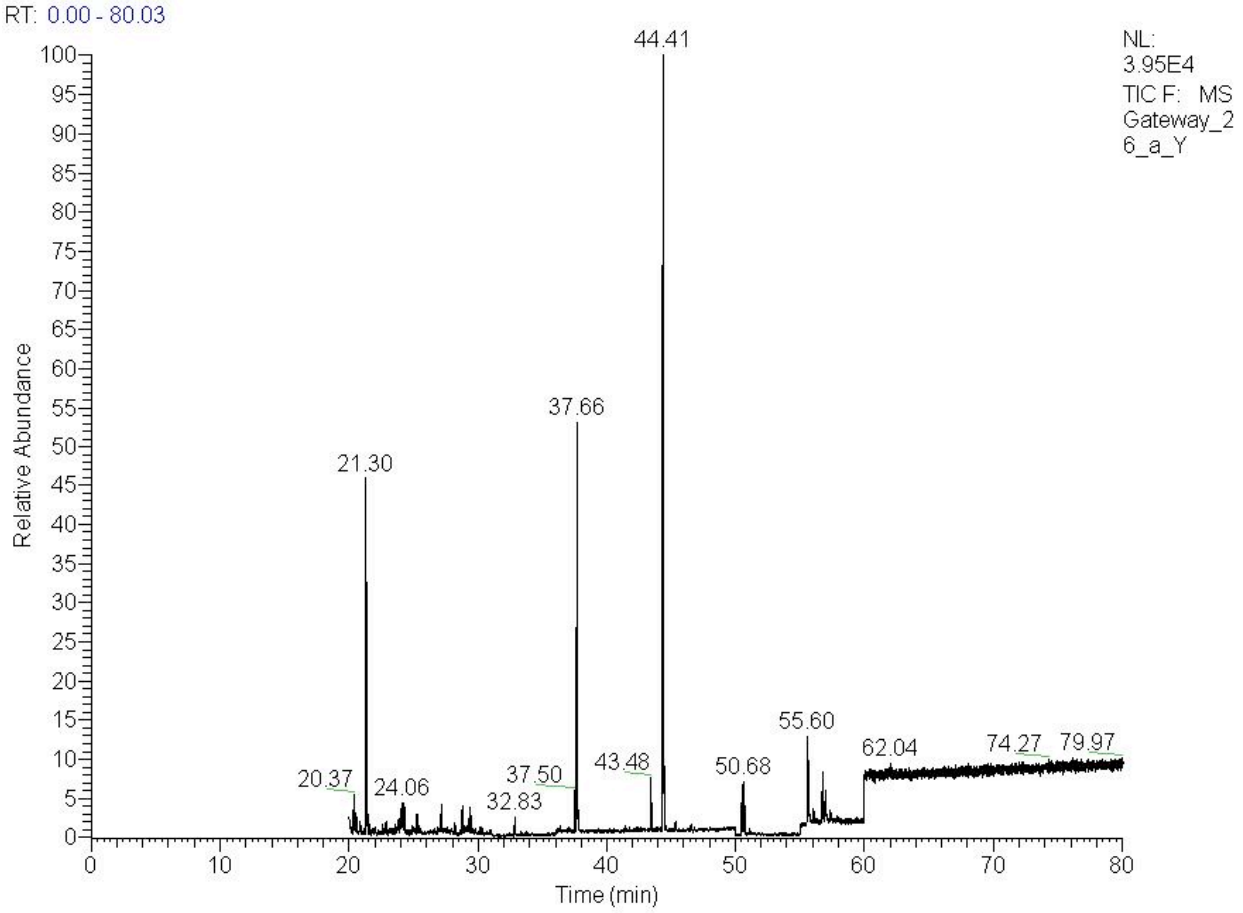
Jamaica Bay
Sample point 22
Full Scan method



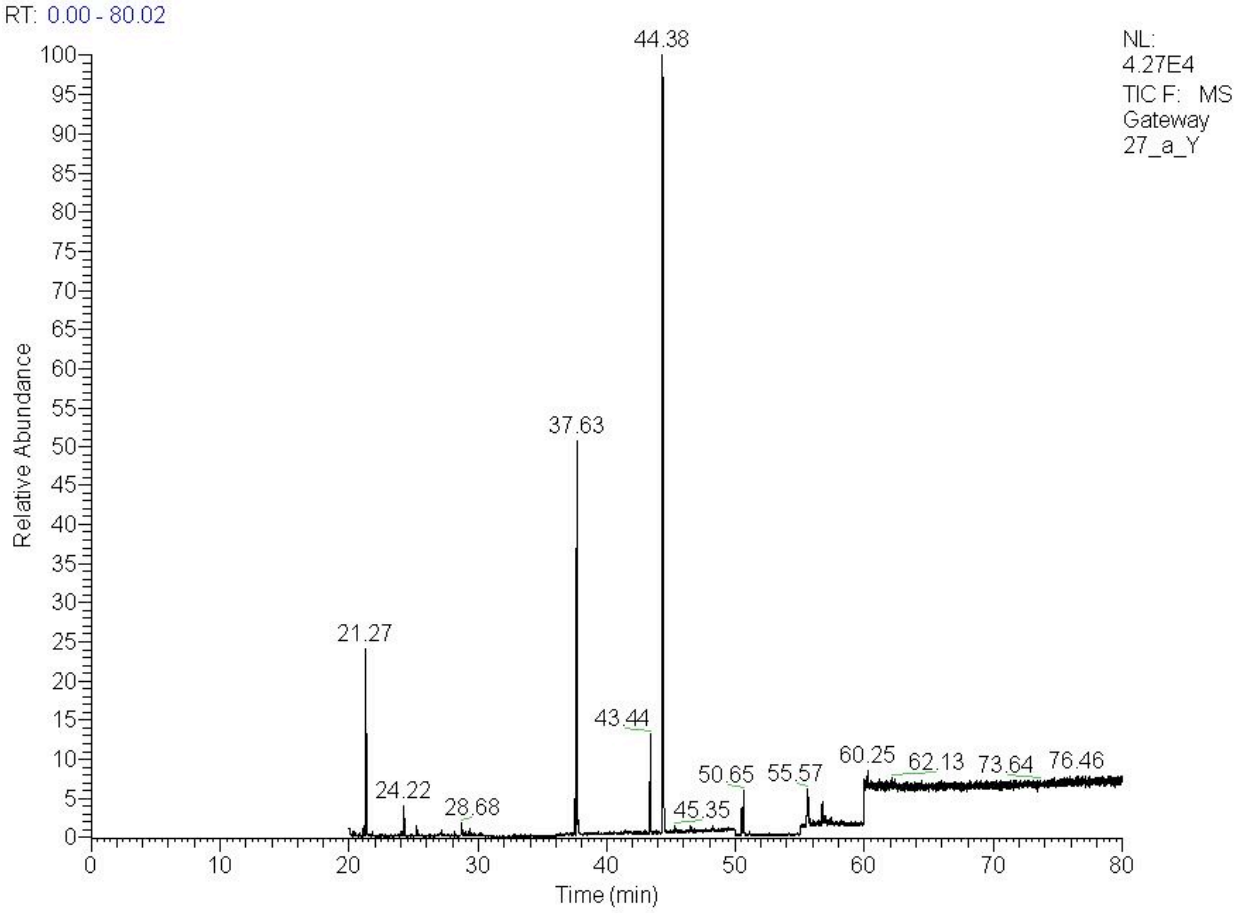
Jamaica Bay
Sample point 23
SIM method



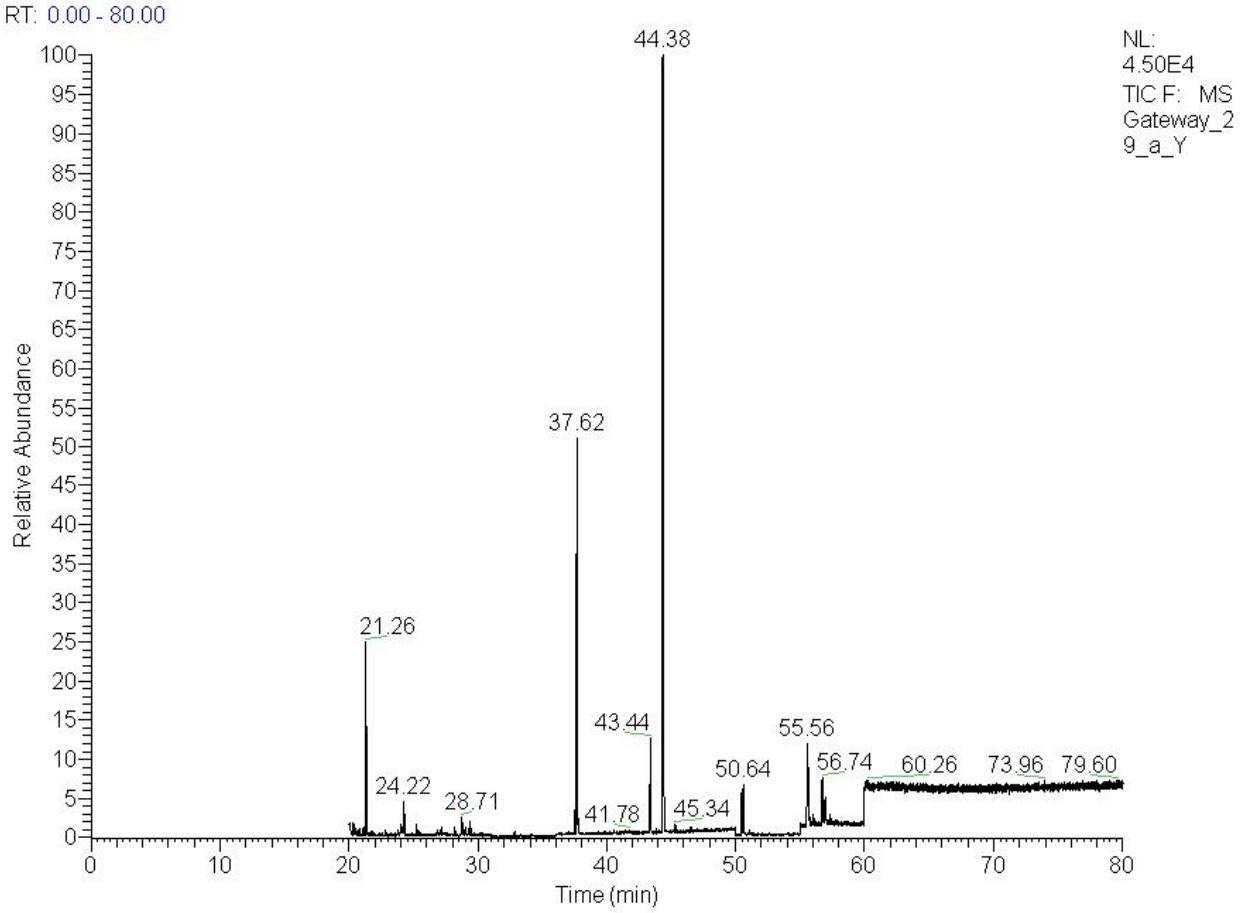
Jamaica Bay
Sample point 24
SIM method



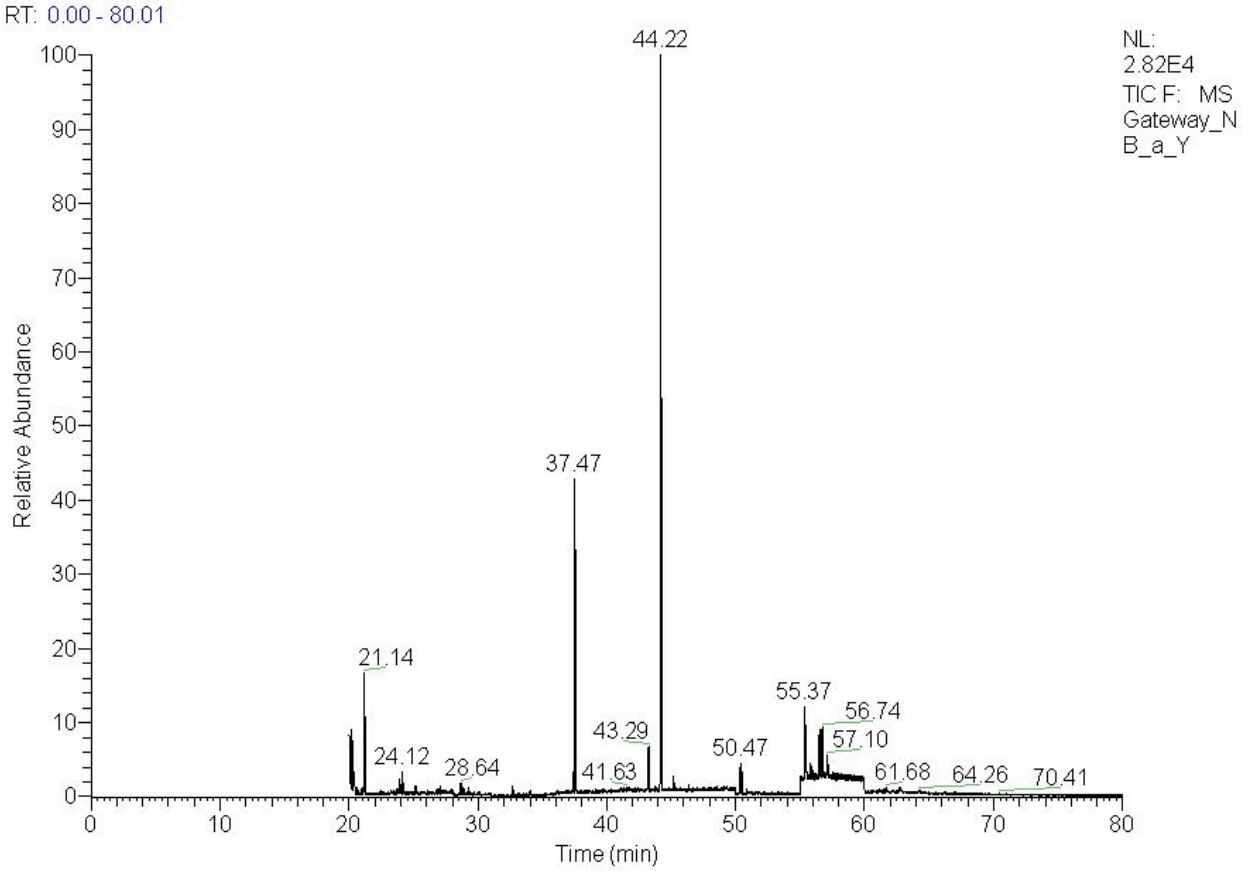
Jamaica Bay
Sample point 26
SIM method



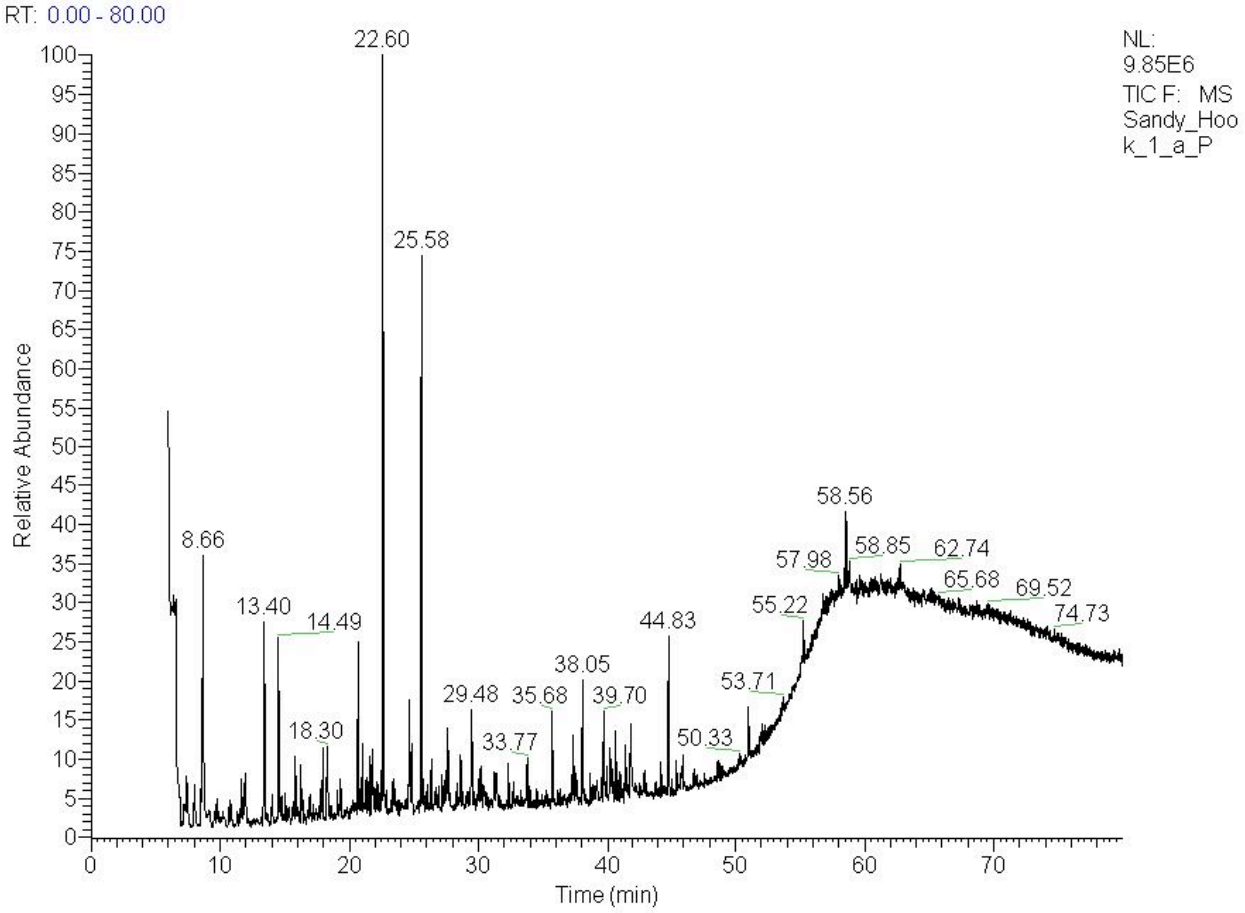
Jamaica Bay
Sample point 27
SIM method



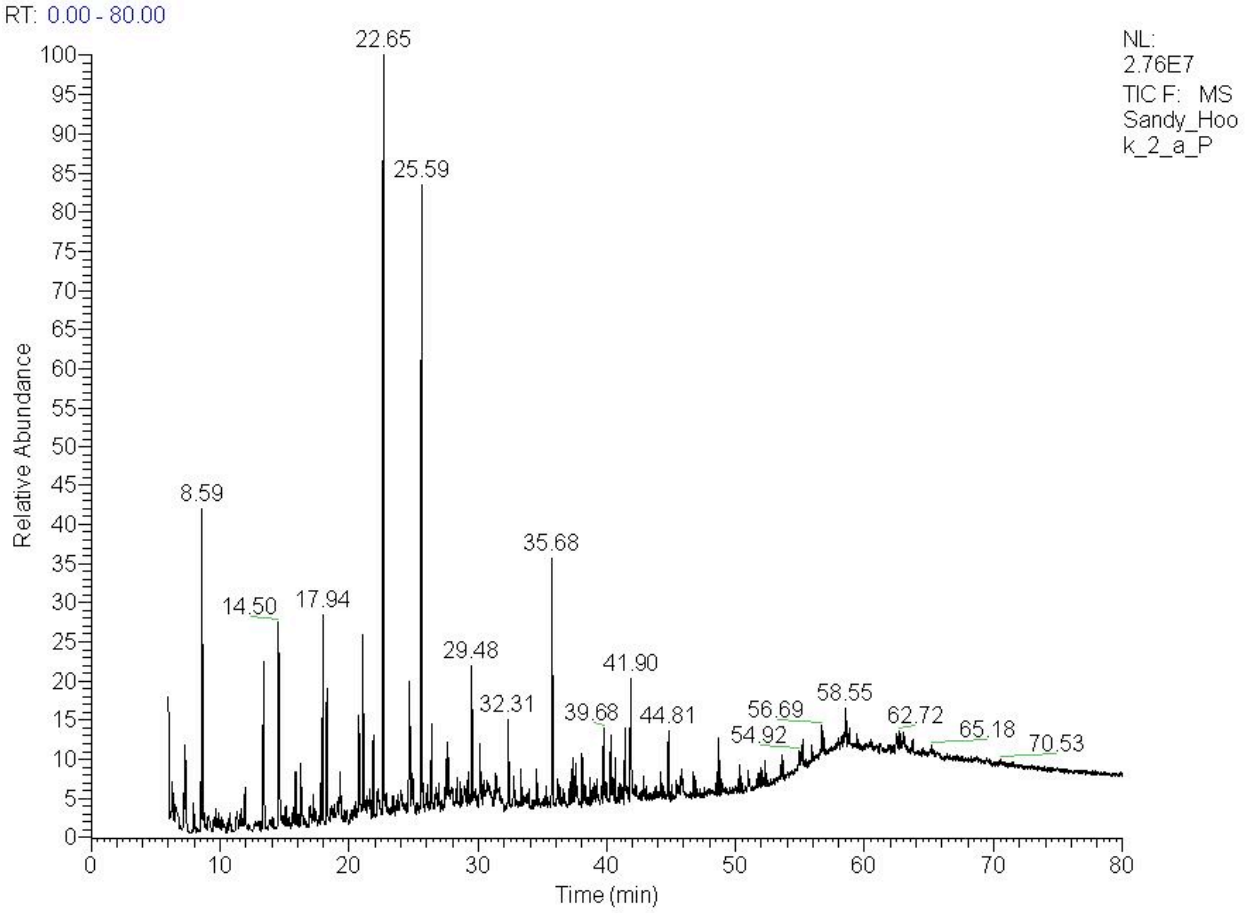
Jamaica Bay
Sample point 29
SIM method



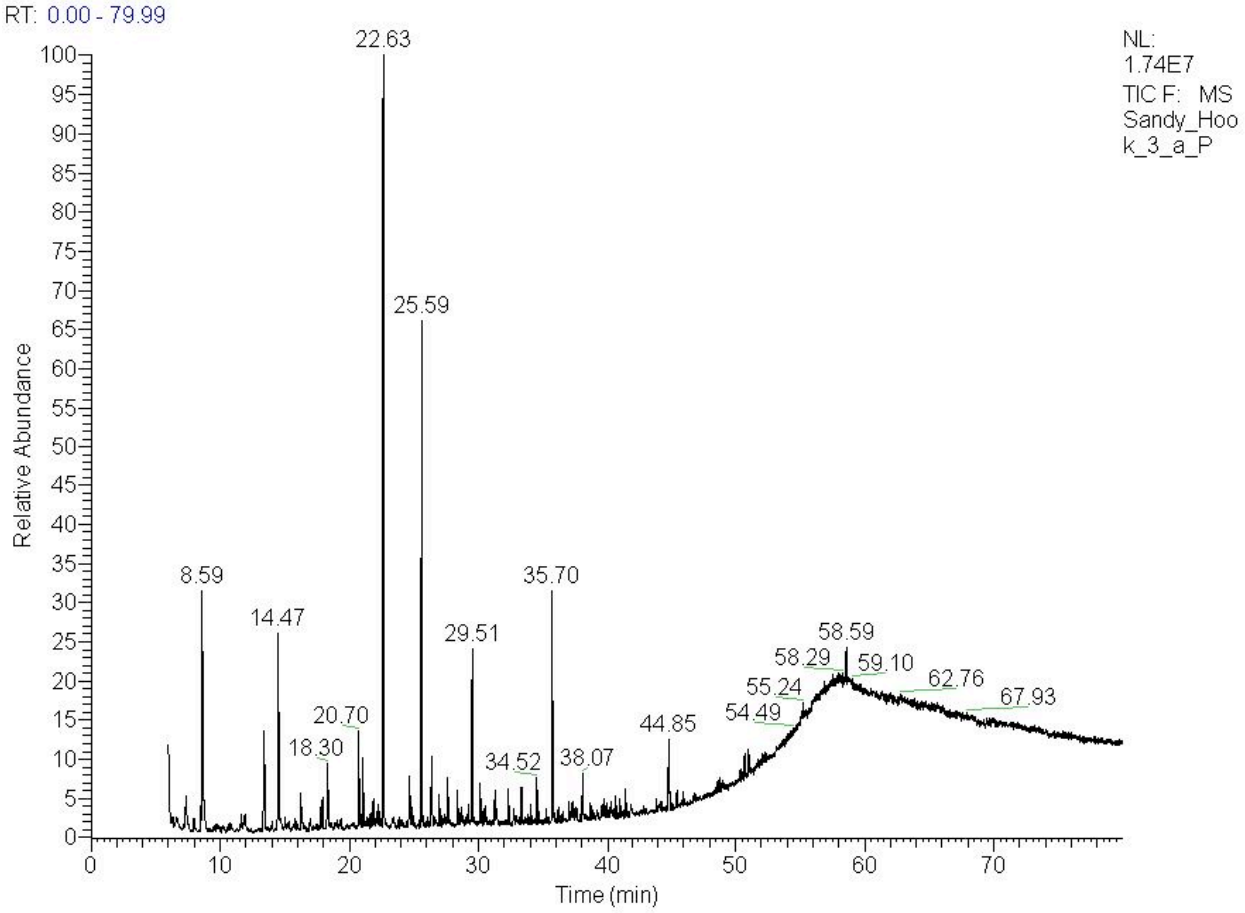
Jamaica Bay
Sample point NB
SIM method



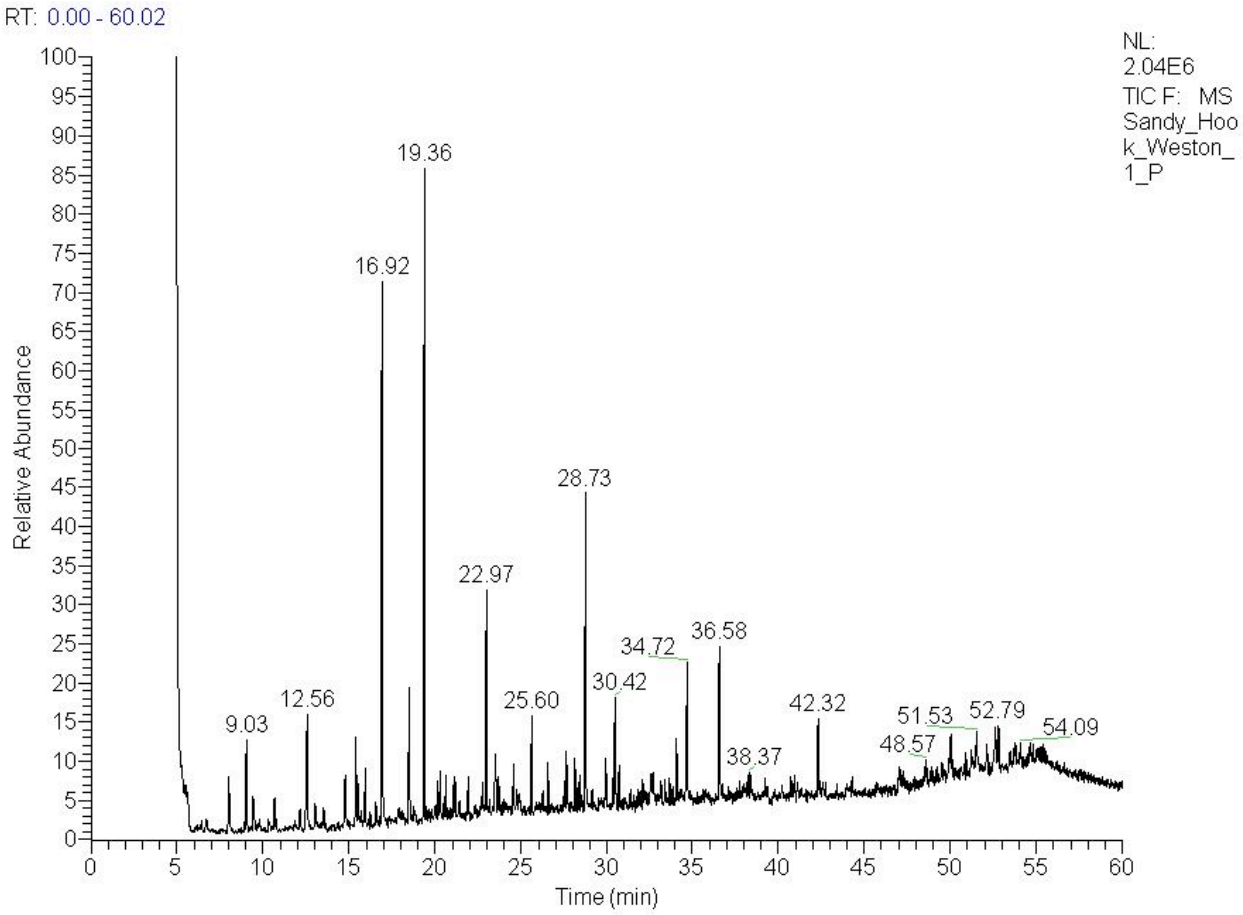
Sandy Hook
Sample Point 1
Full Scan method



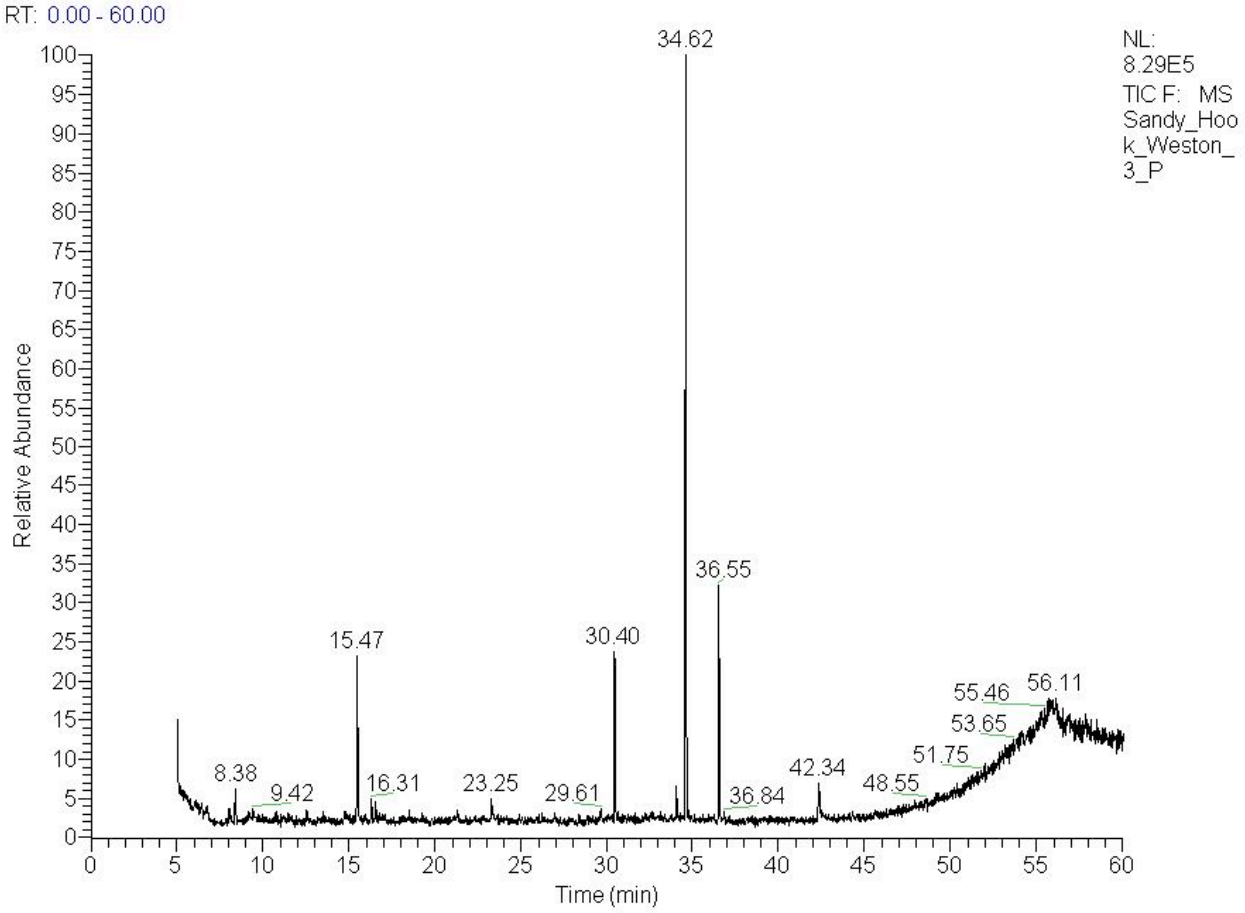
Sandy Hook
Sample Point 2
Full Scan method



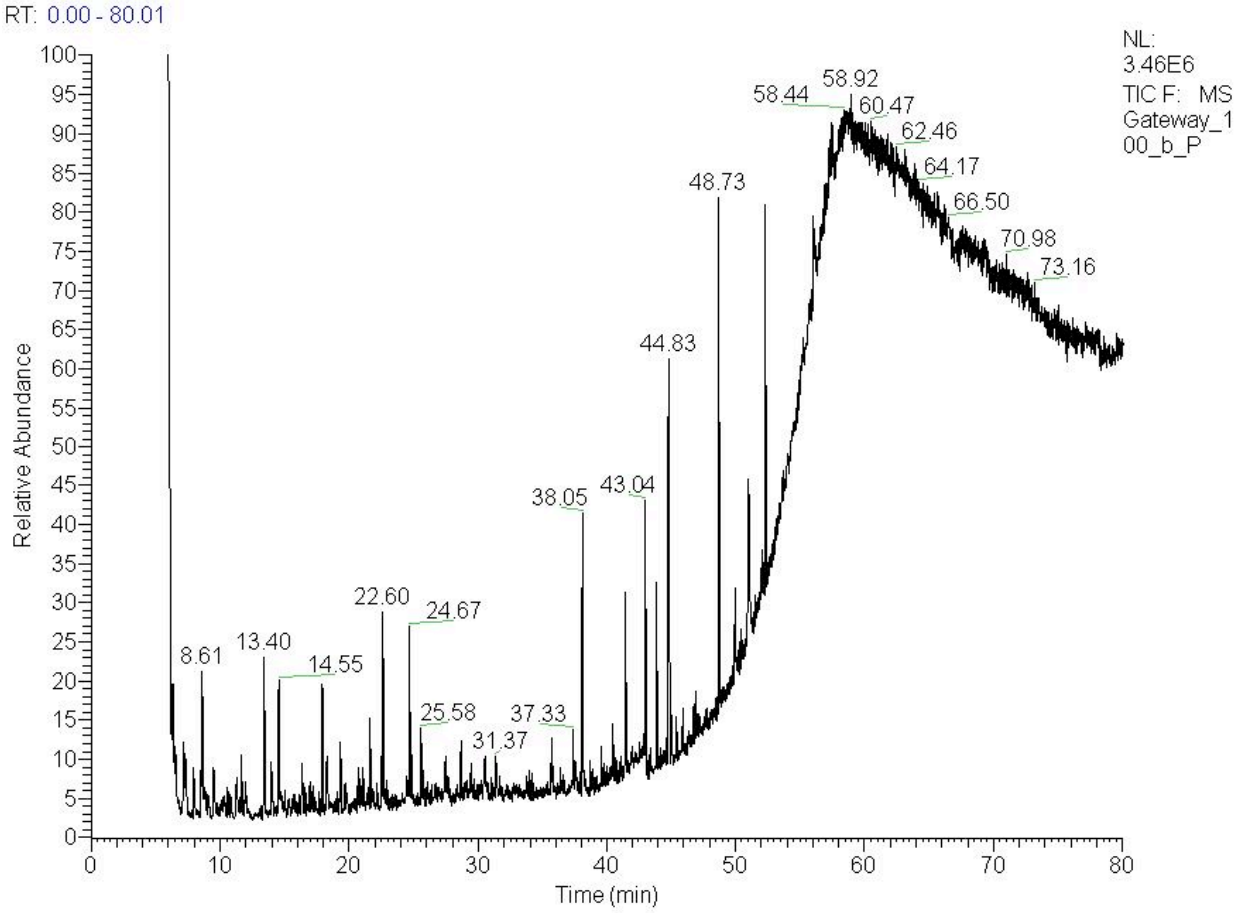
Sandy Hook
Sample Point 3
Full Scan method



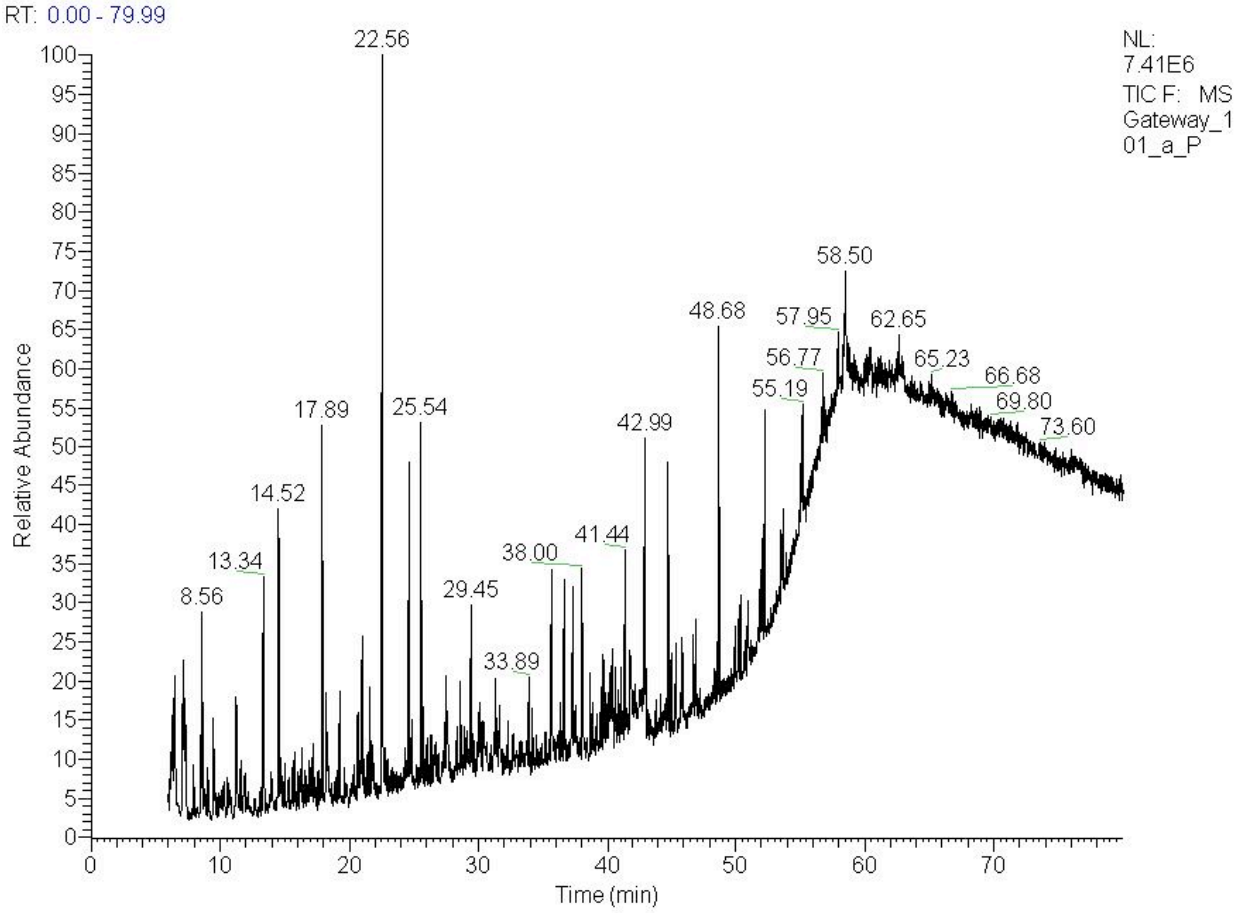
Sandy Hook
Sample Point Montclair State 1
Full Scan method



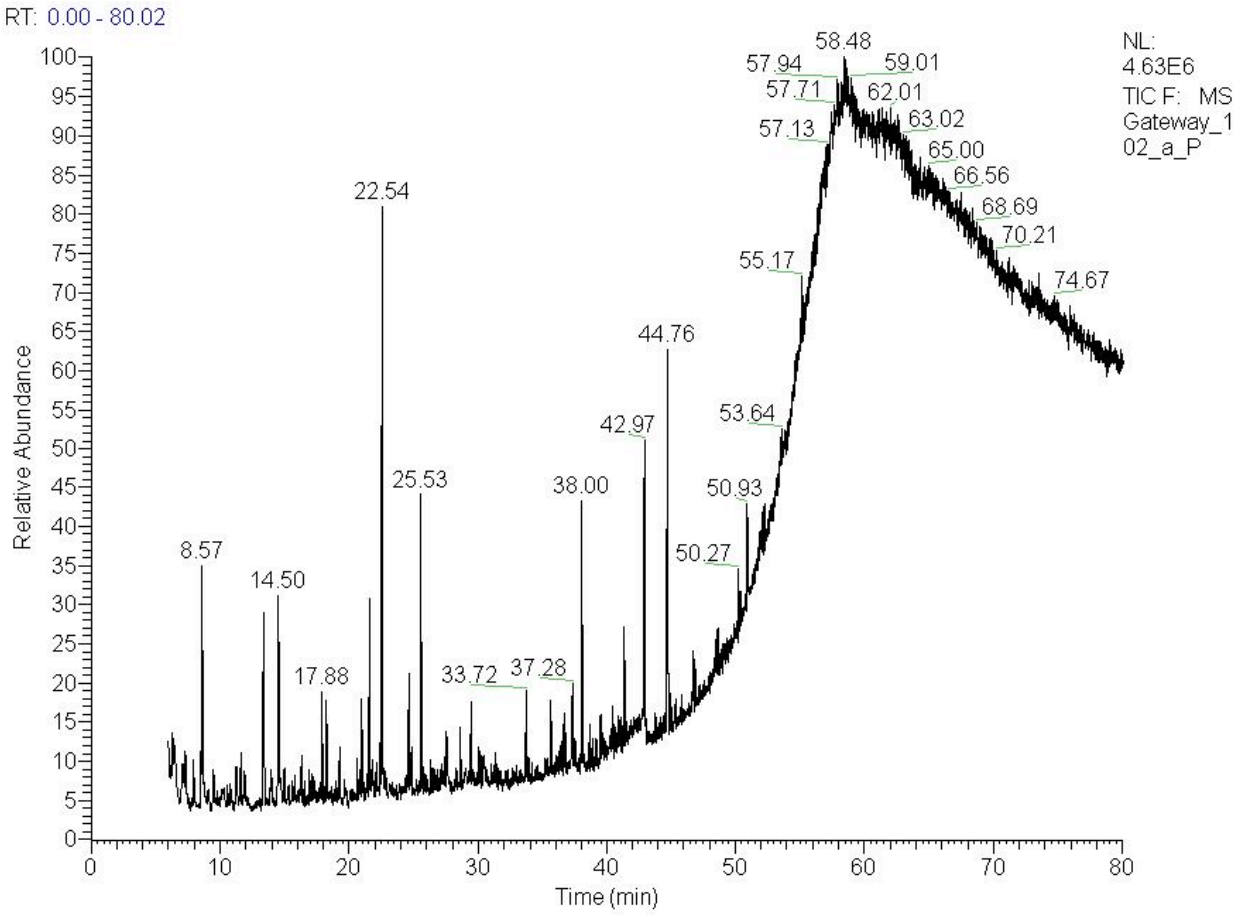
Sandy Hook
Sample Point Montclair State 3
Full Scan method



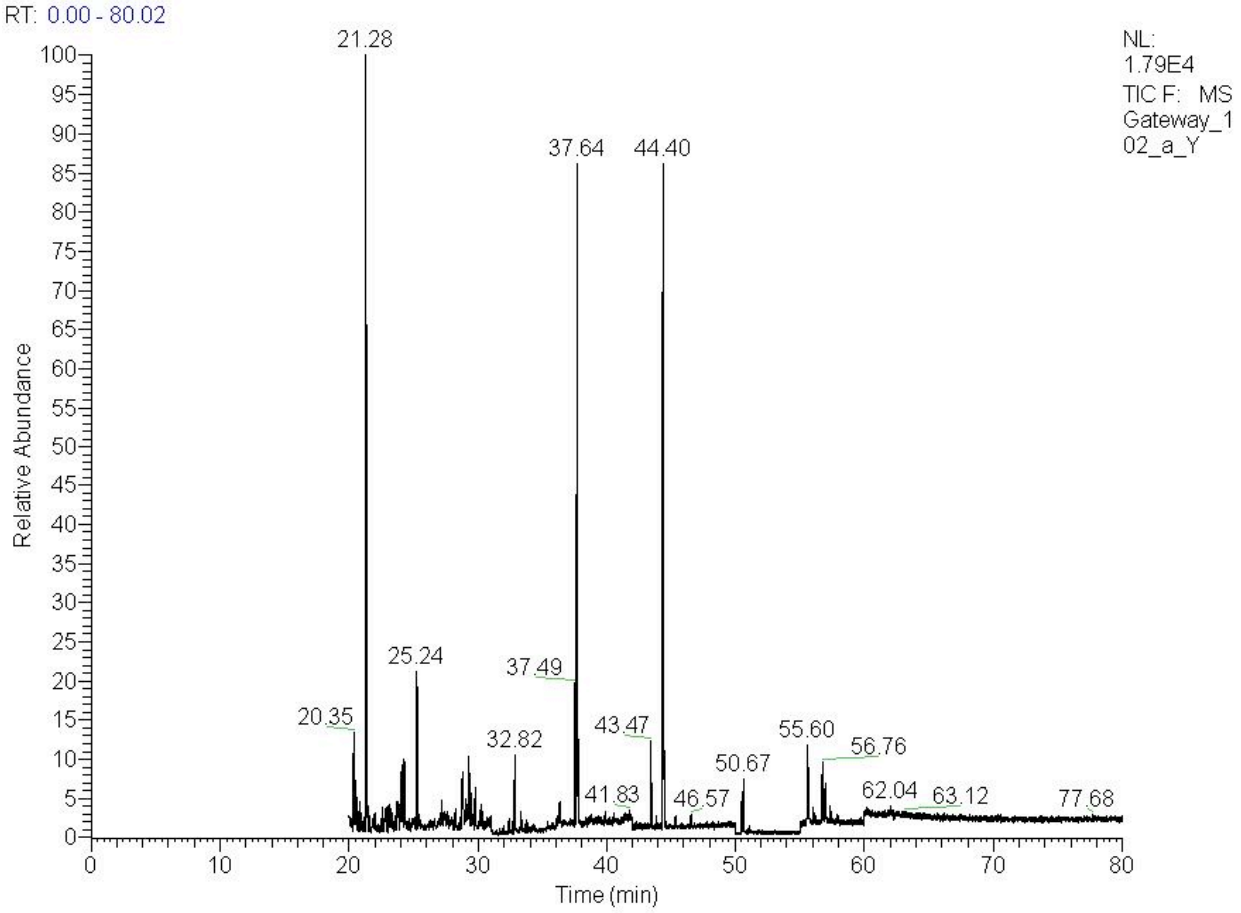
Staten Island
Sample Point 100
Full Scan method



Staten Island
Sample Point 101
Full Scan method



Staten Island
Sample Point 102
Full Scan method



Staten Island
Sample Point 102
Full Scan method