Appendix J. Project Report from Rehoboth Parking Lot Sweeping Study

CHARACTERIZATION AND ANALYSIS OF PARKING LOT RESIDUE USING REGENERATIVE WET VACUUM STREET SWEEPER, REHOBOTH BEACH, DELAWARE

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ABSTRACT

Street sweeping is considered by most stormwater managers to be an acceptable Best Management Practice (BMP) used to remove pollutants from stormwater runoff; however, linking water quality improvements to this practice remains difficult. In addition, very little data exists on the effectiveness of parking lot sweeping, unlike that of highway sweeping.

This study examines chemical and physical make-up of street sweeper contents collected from a wet-vacuum regenerative air street sweeper from two sites in the Inland Bays Watershed, Delaware, from November 2006 through December 2007. The goals of this study are to gain greater insight on the effectiveness of parking lot sweeping using a vacuum-type sweeper and to implement a widely accepted stormwater BMP on two sites in the Inland Bays Watershed.

Two sites were selected among 24 originally considered in the Inland Bays Watershed. Sites were selected by phone screening surveys based on watershed, parking lot size, sweeping history of the lot, and the site's need for water quality management. Parking lots of each of the two selected sites were swept twice a week from November 2006 through December 2007, where sweeper content was collected from the hopper monthly, and physical and chemical parameters were analyzed.

Based on the screening surveys, 45.8% of the 24 sites performed street sweeping on parking lots at least weekly using a vacuum sweeper. For the two sites selected for this study, there was no statistical difference between sites (99% CI); therefore, data for the two sites were pooled. Physical characteristics of samples exhibited seasonal variability, possibly corresponding to the tourist season, winter snow management, and natural organic matter accumulation such as grass clippings and leaves in fall months.

Data show a trend toward decreasing solids accumulation throughout the course of this study for both Site 1 (y= -4.5305x + 179535; R^2=0.3203) and Site 2 (y= -0.7641x + 188325; R^2=0.5004). The median accumulation rate for both sites was 3.3 lbs/ac/d but ranged from 1.7 to 27.4 lbs/ac/d over the study period. We can infer that more particles are picked up through time, resulting in less contribution into waterways.

Petroleum hydrocarbons tended to be higher at the start of this study and steadily declined over the study period for both sites. This trend can be represented by the equation y=-9.6996x + 38216 (R^2=0.5183) for Site 1 and y=-15.661x + 616989 (R^2=0.6801) for Site 2. This observed trend was most likely due to the gradual removal of residual oil from parking lots through time.

The median removal for petroleum hydrocarbons was 0.453 lbs/Ac (0.011 – 4.986 lbs/Ac), total nitrogen 0.277 lbs/Ac (0.277-10.198 lbs/Ac), and total phosphorus 0.123 lbs/Ac (0.016-1.418 lbs/Ac). Such estimates are within the expected range for street sweeping as an implemented BMP.

This study was successful in demonstrating that bi-weekly parking lot sweeping using regenerative air technology results in respectable estimated pollutant removal rates. Due to the expense with water quality sampling, it remains difficult to establish a relationship between water quality improvements and the use of street sweeping as an effective BMP.

KEY WORDS

Street sweeping, parking lot sweeping, regenerative air flow, effectiveness, water quality, total suspended solids, total maximum daily load, parking lots.

INTRODUCTION

Studies suggest that suspended solids from streets make up approximately 70-80% of urban stormwater, contributing about 20-30% of excess nitrogen and phosphorus to waterways (Pitt, 1985; Bannerman et al., 1993; Waschbusch et al., 1999). Today, best management practices (BMPs) exist to remove such pollutants from waterways; however, these technologies are typically implemented in newly constructed projects, leaving numerous sites across the country having no water quality treatment.

For this reason, stormwater management programs have turned to street sweeping as a BMP for stormwater pollutant removal, since retrofitting older sites can be space consumptive and expensive. While some studies have examined the effectiveness of using regenerative air and wet-vacuum street sweepers at effectively removing fine sediments from roadways (Brzozowski, 2006; Selbig and Bannerman, 2007; Southerland and Jelen, 1997), few studies are able to link street sweeping to water quality benefits (Selbig and Bannerman, 2007). Information pertaining to the benefits of parking lot sweeping is even more limited (Center for Watershed Protection, 2006a).

This study examined chemical and physical make-up of street sweeper contents collected from a wet-vacuum regenerative air street sweeper from two sites in the Inland Bays Watershed, Delaware, from December 2006 through December 2007. This watershed was chosen due to the Total Maximum Daily Load (TMDL) analysis indicating a need to reduce nitrogen and phosphorus from runoff by 40% near the Rehoboth Bay (State of Delaware, 1998; DNREC, 1998). Even higher nutrient reductions are required in the western sections of the Inland Bays Watershed. It is hoped that this study will demonstrate the effectiveness of street sweepers in removing nutrient loads to the watershed, while implementing a widely accepted BMP on two sites currently having no water quality treatment.

Study Goals

The goals of this study are as follows:

- To gain greater insight on the effectiveness of parking lot sweeping using a vacuum-type sweeper
- To implement a widely accepted stormwater BMP on two sites having no water quality treatment in the Inland Bays Watershed

METHODOLOGY

Site Selection

The Inland Bays watershed of Delaware was selected in order to reduce both nitrogen and phosphorus entering into the Delaware Bay as runoff, as determined to be necessary by the State of Delaware's TMDL requirement (State of Delaware, 1998; DNREC, 1998). For this study, two sites were selected from the 24 initially considered (Figure 1), with parking lots ranging in size from 0.3-25.6 hectares (ha) (mean, μ =4.0) or 0.7 - 63.3 acres (ac) (μ= 10) as determined using ArcGIS 9.1. The 24 sites were initially screened by conducting phone interviews based on the following questions:

- Who is the property management company?
- Are you currently sweeping the parking lot?
- If sweeping, how often?
- What type of sweeper are you using (vacuum or non-vacuum)?
- What are your reasons for sweeping?
- Would you be interested in participating in a study on street sweeping with the State of Delaware?

Because one of the study goals was to implement a water quality BMP within the Inland Bays Watershed, sites that currently swept their parking lots were eliminated. Figure 2 represents those sites not performing parking lot sweeping. From those sites, additional sites were eliminated: those having stormwater BMPs; sites currently under construction as sediment could negatively affect study results; sites having the potential to contain large amounts of wind blown sand; sites that were used only seasonally; and sites having unwilling property owners. Figure 3 represents the two sites remaining for inclusion in this study. A general site assessment was performed for each remaining location characterizing them by size; general traffic patterns; ease of sweeping; and ease of sampling. Neither site had historically been swept using any type of sweeping device.

Site Characteristics

Selected sites, designated as Sites 1 and 2, were located in the Inland Bays Watershed along the same major highway (Delaware Route 1). Site 1 (1.14 ha, 2.8 ac of asphalt) is a large grocery shopping center having heavy traffic influences, while Site 2 (1.7 ha, 4.1 ac of asphalt) is a less used shopping center containing smaller businesses, including a gym. The two sites selected for this study (Figure 4) are located relatively close to the ocean, within 2.4 kilometers (1.5 miles) of one another. The landscape is characterized as being urban with seasonal traffic influences relating to the tourist season. Poultry and farming is a predominant land use to the west, while with the Atlantic Ocean sits to the east. Through GIS analysis of soils mapping (NRCS 2006), it was determined that the predominant soil type was Evesboro Loamy Sand (5-15% slope) for Site 1 and Greenwich Urban Complex (0-5% slope) for Site 2.

Sample Collection

Schwarze is a company well-known for producing environmentally efficient wet-vacuum trucks specializing in roadway and highway cleaning (Brzozowski, 2006; Martinelli et al., 2002). Thus, for this study, a local sweeping company that utilizes this type of equipment (Schwartz S 347 LITE vacuum model, 3-cubic yard hopper) was chosen for this project. This sweeper type, designed to pick up both small particles and larger debris, features a regenerative air flow system, where a portion of the air is vented off resulting in a larger volume of air being pumped, and a spray bar, injecting high-pressure water onto the concrete before being vacuum swept.

From November 2006 through December 2007, asphalt paved parking lots of Site 1 and Site 2 were swept twice a week using the spray bar, a device that injects high-pressure water onto the concrete prior to sweeping. Sweeping was performed between the hours of 11 PM and 1 AM to minimize parked cars and ensure maximum parking lot coverage. Physical data were collected from each site from November 2006 through December 2007, while chemical data were collected from December 2006 through December 2007. The hopper samples were collected on the following dates: November 3, December 11, January 19; February 13; March 13; April 23; May 31; June 11; July 30; August 27; September 17; October 9; November 28; and December 17.

Physical Analysis

During sample collection, study staff observed the entire sweeping operation. After each parking lot was swept, the sample was emptied from the hopper onto a paved surface. Upon completion, the hopper content was mixed for approximately three minutes. The material was then placed into at 1.2 x 0.9 meter (m) [(4 x 3 foot (ft)] rectangular grid, and an approximate height was recorded (Figure 4). The sample was then divided into 12-0.3

x 0.3 m (1 x 1 ft) sections. The contents of three randomly selected squares from each site were combined to form one representative, composite sample. All contents within the subsample, including large debris and litter, were included in this study. The composite sample was air-dried and fractioned using 25 millimeter (mm), #5 (4 mm), #10 (2 mm), #60 (0.25 mm), and #230 sieves (0.063 mm). Table 1 describes the US Department of Agriculture and ASTM classifications for soils and sediment. Each fraction was weighed, and an approximate volume was calculated.

From the sieve data, rate of daily solids accumulation on the parking lot was estimated over the study period. The amount of debris removed by routine sweeping was calculated by dividing the acreage of each lot and the number of days between sweeping into the weight of material removed by sweeping.

Chemical Analysis

From each composite sample, a grab sample for chemical analysis was placed into a laboratory bottle prior to the sieve analysis, refrigerated, and analyzed within 30 days by Atlantic Coast Laboratories (Newark, DE) for the following parameters: chloride; copper; nitrate; petroleum hydrocarbon; phosphorus; sodium; Kjeldahl nitrogen; total nitrogen; zinc; and pH. Table 2 describes laboratory methods used for each test. At the lab, samples were refrigerated and analyzed within 30 days of the time that the sample was taken. *Escherichia coli* was not analyzed in this study due to the short analysis requirement for the sample, and the fact that the sample was collected as dry.

Interaction Between Physical and Chemical Parameters

Initially, chemical (chloride, copper, nitrate/nitrite, petroleum hydrocarbons, total phosphorus, sodium, total Kjeldahl nitrogen, total nitrogen, total nitrogen , zinc, pH of mineral fraction) and physical data (25 mm, # 5 sieve, #10 sieve, #60 sieve, #230 sieve, bottom pan) had a correlation analysis conducted on it using the statistical package included in Microsoft Excel spreadsheet software.

The parking lot sample data was coded by site and date of collection, and the coded data was entered into Statgraphics Software for one-way Analysis of Variance (ANOVA).

RESULTS

Site Selection Screening Surveys

Based on the screening surveys for the 24 sites considered in this study, 45.8% of businesses performed sweeping at least weekly on parking lots, where 41.6% of businesses were sweeping twice a week. Of those sweeping, 83% were found to be using vacuum-type sweepers. All businesses performing routine sweeping did it for the purpose of aesthetics, not water quality benefits, as Rehoboth Beach, Delaware, represents a large tourist/beach area.

Physical Analysis

The statistical analysis procedure showed no significant difference (99% confidence interval, CI) between the two sample sampling sites for physical data (Site 1 and Site 2); thus the different sample sites could be analyzed as one data set.

In general, samples contained leaves and organic matter in the late summer and fall, changing to predominantly gravel in the winter months. An increase in litter was observed during the summer months, also the noted tourist season in this region. The sieve analysis indicated that coarse sand (#60 sieve) was the predominant particle size within all samples, representing more than 66% of the sample (Figure 5). Results showed that coarse sand was relatively high in the winter months, most likely corresponding to winter events and winter snow management (Figure 6). The only material retained on the 25 mm sieve was litter and organic debris, with seasonal differences noted. A larger percentage of organic matter was present in summer months, and a higher percentage of garbage was present during the tourist season (Figure 7).

In the #5 sieve, the majority of the sample for both sites was made up of organic matter such as leaves and sticks or gravel (65-100%), with only 5-25% of the sample being comprised of litter including cigarette butts ($\mu = 7.8$).

The material finer than the #230 sieve (0.063 mm) was used an estimate for Total Suspended Solids (TSS), since most TSS is made up of silt and clay. This material represented from 0-5.5% of the sample depending on the time of year (Figure 8).

Figures 9 and 10 show a general trend toward decreasing solids accumulation throughout the course of this study for both Site 1 ($y = -4.5305x + 179535$; $R^2=0.3203$) and Site 2 ($y = -0.7641x + 188325$; $R^2=0.5004$). The median accumulation rate for both sites was 3.3 lbs/ac/d but ranged from 1.7 to 27.4 lbs/ac/d over the study period. We can infer that more particles are picked up through time, resulting in less contribution into waterways.

Chemical Analysis

The statistical analysis procedure showed no significant difference (99% CI) between the two sample sites for chemical data (Site 1 and Site 2) with exception of sodium and chloride; thus the different sample sites could be analyzed as one data set. The June 11th sample was excluded from analysis due to sample contamination.

Once the data was pooled and analyzed by sampling date, ANOVA indicated no significance among the samplings except for chloride, petroleum hydrocarbons, total Kjeldhl nitrogen, total nitrogen, zinc and #10 fine gravel (95% CI).

Chloride and sodium tended to be higher in the fall and winter months of this study (Figures 11 and 12), as expected due to winter parking lot salting. An elevated level of both sodium and chloride was noted on the sampling dates of February 3 and November 3, 2007.

Petroleum hydrocarbons tended to be higher at the start of this study and steadily declined over the study period for both Site 1 (Figure 13) and Site 2 (Figure 14). This trend can be represented by the equation $y=-9.6996x + 38216$ ($R^2=0.5183$) for Site 1 and $y=-15.661x + 616989$ ($R^2=0.6801$) for Site 2. This observed trend was most likely due to the gradual removal of residual oil from parking lots through time.

Total Kjeldahl nitrogen appeared to exhibit some cyclical trends with late summer and early fall have the highest concentrations (Figure 15). Total nitrogen show similar tendency because most of the nitrogen was in organic form as indicated by Kjeldahl nitrogen. This could be due to grass clippings in the summer months, and fallen leaves in the late summer and fall; however, there was no correlation between Kjeldahl nitrogen and organic matter. Zinc showed the same trend as total Kjeldahl nitrogen and total nitrogen, which could be attributed to the increase in traffic and tire wear on parking lots during the tourist season.

Interaction Between Physical and Chemical Parameters

Correlation analysis between chemical and physical data indicated that the following were correlated: sodium to chloride, total phosphorus to 25mm sieve material, zinc to #10 sieve material, #230 sieve material to Kjeldahl nitrogen, and total nitrogen to total Kjeldahl nitrogen (Table 3). The significant correlations were examined further using regression analysis procedures. Results indicated no correlation between nitrogen and 25 mm sieve; however, there was a correlation between phosphorous and 25 mm sieve (Table 3), perhaps indicating that phosphorus was attached to the 25 mm particles.

Table 4 shows the median, minimum, and maximum estimates for pollutant removal effeciencies for all chemical parameters tested. The median removal for petroleum hydrocarbons was 0.453 lbs/Ac (0.011 – 4.986 lbs/Ac), total nitrogen 0.277 lbs/Ac (0.277-10.198 lbs/Ac), and total phosphorus 0.123 lbs/Ac (0.016-1.418 lbs/Ac). Such estimates are within the expected range for street sweeping as an implemented BMP (Center for Watershed Protection, 2008; Center for Watershed Protection 2006a; Center for Watershed Protection 2006b).

DISCUSSION

It is widely known that street sweepers vary greatly in capacity to remove small sediment particles from concrete or pavement. For example, mechanical-type sweepers are fairly ineffectiveness at removing fine particles from roadways (Center for Watershed Protection, 2008; Selbig and Bannerman, 2007). On the contrary, numerous studies indicate that using more sophisticated technology such as regenerative-air and wet-vacuum street sweepers (weekly sweeping) result in high pick-up efficiencies (Brzozowski, 2006; Center for Watershed Protection, 2008; Selbig and Bannerman, 2007; Southerland and Jelen, 1997). For example, the Wisconsin Department of Transportation conducted a study of the effectiveness of vacuum sweeping on roadway sites, and found that sweeping once a week resulted in an overall reduction in TSS (Martinelli et al., 2002). Selbig and Bannerman (2007) demonstrated the effectiveness of using both regenerative-air and vacuum-assist sweepers (weekly sweeping) at reducing street-dirt by 76% and 63% (5% significance level), respectively. Based on conceptual model from other studies, the Center for Watershed Protection (2008) determined that using regenerative air/vacuum sweeper (weekly sweeping) resulted in 31% removal efficiency for TSS, 8% total phosphorus, and 7% total nitrogen removal.

This study found that parking lot sweeping is largely performed for aesthetic purposes. The Center for Watershed Protection (2006) revealed the same to be true for street sweeping. However, in this study, we found the majority of sweepers used for parking lot sweeping to be vacuum-type sweepers (83%). On the contrary, 25% of street sweepers in MS4 communities within the Chesapeake Bay Watershed were found to be using mechanical sweepers (Center for Watershed Protection, 2008). This is to be expected, as businesses have the financial means to use better technologies unlike sparce resources of many municipalities.

The median removal for petroleum hydrocarbons was 0.453 lbs/Ac (0.011 – 4.986 lbs/Ac), total nitrogen 0.277 lbs/Ac (0.277-10.198 lbs/Ac), and total phosphorus 0.123 lbs/Ac (0.016-1.418 lbs/Ac), consistent with findings from similar studies (Center for Watershed Protection, 2006b; Center for Watershed Protection, 2008; Selbig and Bannerman, 2007).

This study showed a decrease in polycyclic aromatic hydrocarbons through time. Polycyclic aromatic hydrocarbons are found routinely in highway runoff (Smith et al. 2000) and in soils next to high-traffic roads (Dierkes and Geiger, 1999; Tuhackov et al., 2001). Although asphalt and pavement does not typically leach large amounts of polycyclic aromatic hydrocarbons (Townsend and Brentley, 1998), daily wear and tear of pavement by traffic and weather results in asphalt particles being picked up by the street sweeper (Walch et al., 2005).

Zinc showed the same trend as total Kjeldahl nitrogen and total nitrogen, which could be attributed to the increase in traffic and tire wear on parking lots during the tourist season. The contribution of zinc is most likely from tire–tread material, which has been documented to contain 1.5% zinc by weight (Amari et al., 1990); therefore, zinc would be found in the parking lot of both businesses in higher concentrations amounts during busier summer months due to automobile traffic.

CONCLUSION

This study was successful in demonstrating that bi-weekly parking lot sweeping using regenerative air technology results in respectable estimates on pollutant removal efficiencies. In addition, we noted a decreasing trend in solids accumulation and petroleum hydrocarbons through time. Unfortunately, we are still unable to link street sweeping as a BMP with an improvement in water quality associated with sediment and nutrient pollutant loadings due to the expense in obtaining water quality data on a grand scale. The Delaware Department of Transportation performed similar physical/chemical analyses of sweeper waste in a study conducted between 2003 and 2005 (Walch et al.

2005) in order to examine alternatives to landfill disposal waste material. Although contaminant load removal from roadways could be calculated, there was insufficient information to assess adequately the water quality impacts of street sweeping operations.

ACKNOWLEDGEMENTS

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TABLES AND FIGURES

Figure 15. Relationship between total Kjeldahl nitrogen and sampling date.

Classification	US Department of Agriculture (mm)	ASTM (mm)
Clay	<0.002	<0.005
Sill	0.002-0.05	0.005-0.074
Very Fine Sand	>0.05-0.10	
Fine Sand	<0.10-0.25	>0.074-0.420
Medium Sand	>0.25-0.05	>0.420-2.0
Coarse Sand	>0.5-1.0	>2.0-4.76
Very Coarse Sand	>1.0-2.0	
Gravel	>2.0	>4.75

Table 1. US Department of Agriculture and ASTM particle size classification (mm) for soils and sediment.

Study Parameter	Test Method
Copper (Cu) – ICP/OES	
Wastewater & drinking water	EPA Method 200.7
RCRA TCLP & groundwater	SW 846 Method 6010
Solids	SW 846 Method 6010
Digestion, Metals in Solids	SW-846 Method 3050B
Sodium (Na) – ICP/OES	
Wastewater & drinking water	EPA (1993) Method 200.7
RCRA TCLP & groundwater	SW 846 Method 6010
Solids	SW 846 Method 6010
Zinc (Zn) – ICP/OES	
Wastewater & drinking water	EPA (1993) Method 200.7
RCRA TCLP & groundwater	SW 846 Method 6010
Solids	SW 846 Method 6010
Percent solids	SM2540B
Total Petroleum Hydrocarbons	
Soil SW-846 Method 3550	EPA Method 418.1 (sonication, infared)
Chloride	EPA 300.0 Ion Chromatography
Nitrate/Nitrite (combined)	
Ion Chromatography	EPA Method 300.0
Phosphorus, Total	EPA Method 365.4
Ph, Soil *Reported as "Soil pH as measured in 0.01M CaCl2"	SW 846 Method 9045
Total Kjeldahl Nitrogen	EPA 351.2 automated phenate

Table 2. Parmaters examined in this study and associated test method.

Parameter	Parameter	Correlation Coefficient
Sodium	Chloride	0.62
Total Kjeldahl Nitrogen	Total Nitrogen	0.99
Total Kjeldahl Nitrogen	Zinc	0.74
25 mm Sieve	Total Phosphorus	0.49
#10 Sieve	Zinc	-0.65
#10 Sieve	#5 Sieve	0.59
#230 Sieve	Total Kjeldhl Nitrogen or Total Nitrogen	0.47
Organic Matter	Copper	0.51
Organic Matter	#10 Sieve	0.49

Table 3. Correlation between various parameters tested.

	Median (lbs/Ac)	Minimum (lbs/Ac)	Maximum (lbs/Ac)
Chloride	0.019	0.002	1.918
Copper	0.010	0.003	0.282
Nitrate/nitrite	0.001	0	0.009
Petroleum Hydrocarbons	0.453	0.011	4.986
Total Phosphorus	0.123	0.016	1.418
Sodium	0.055	0	17.445
Total Kjeldahl Nitrogen	0.276	0.002	1.918
Total Nitrogen	0.277	0.277	10.198
Zinc	0.027	0.008	0.397

Table 4. Estimate of the annual median, minimum and maximum values of various chemical parameters (lbs/acre) removed by sweeping the parking lots of two commercial facilities.

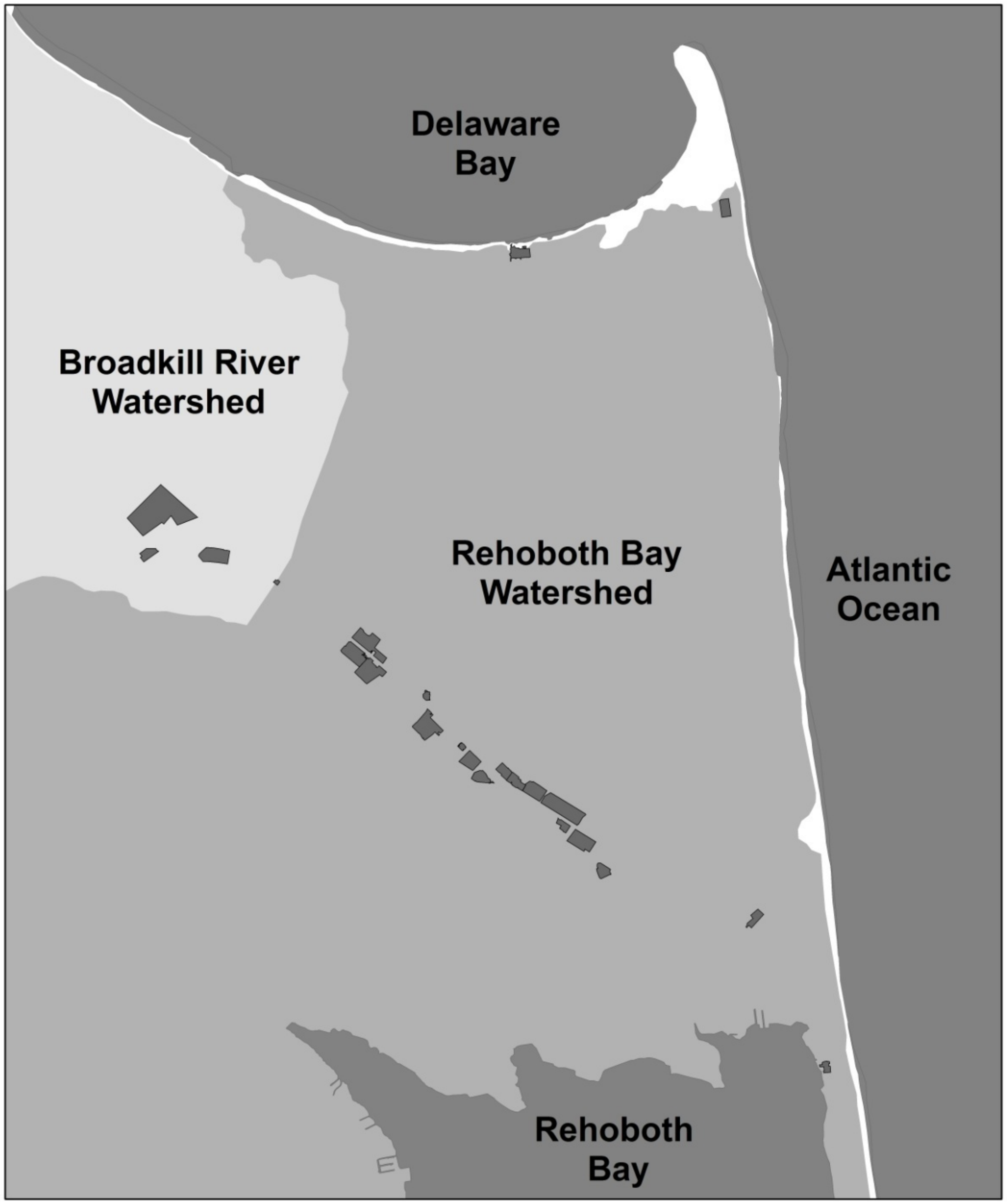

Figure 1. All 24 sites initially considered in Broadkill River and Inland Bays watersheds.

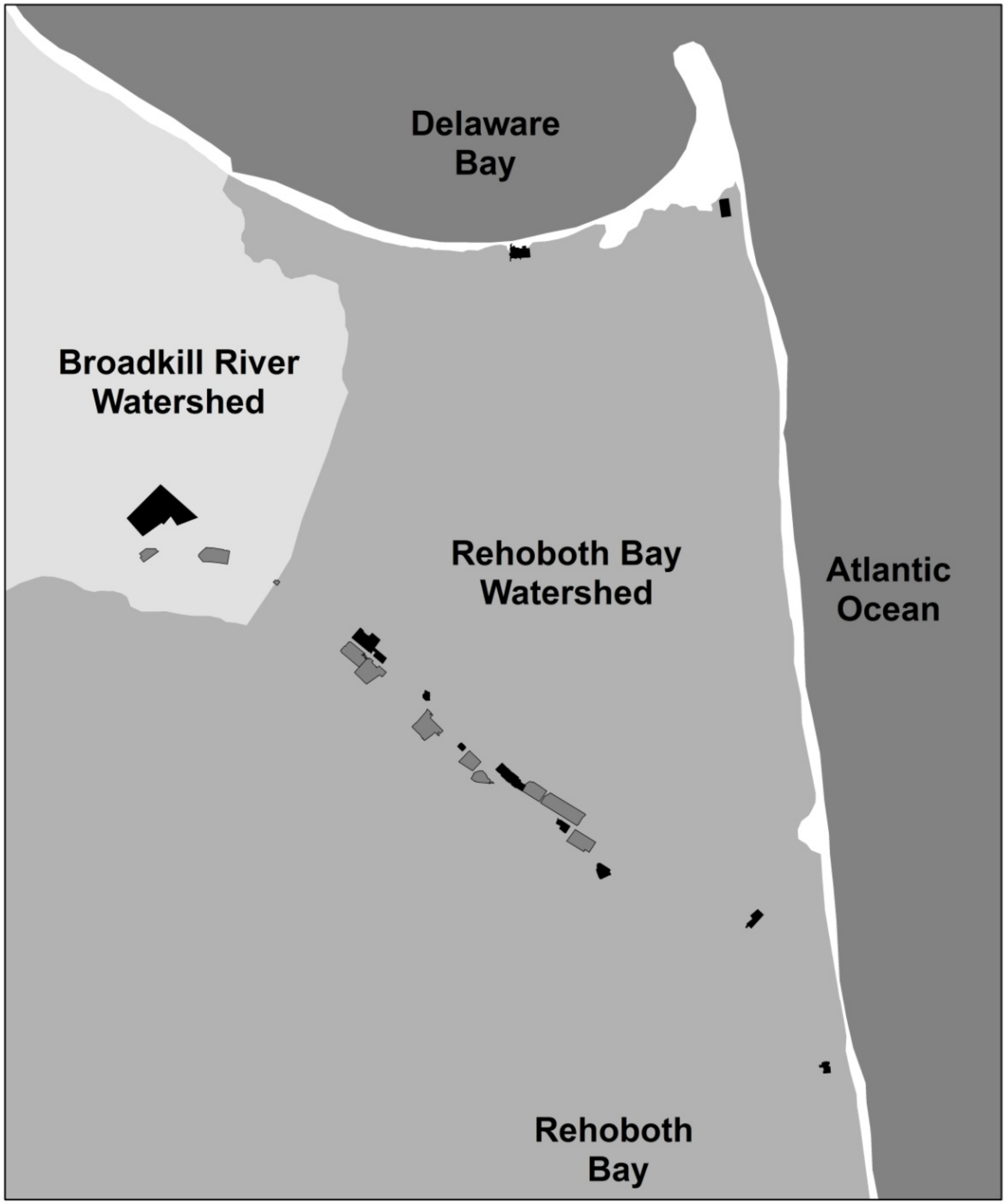

Figure 2. Sites (represented in black) not performing street sweeping.

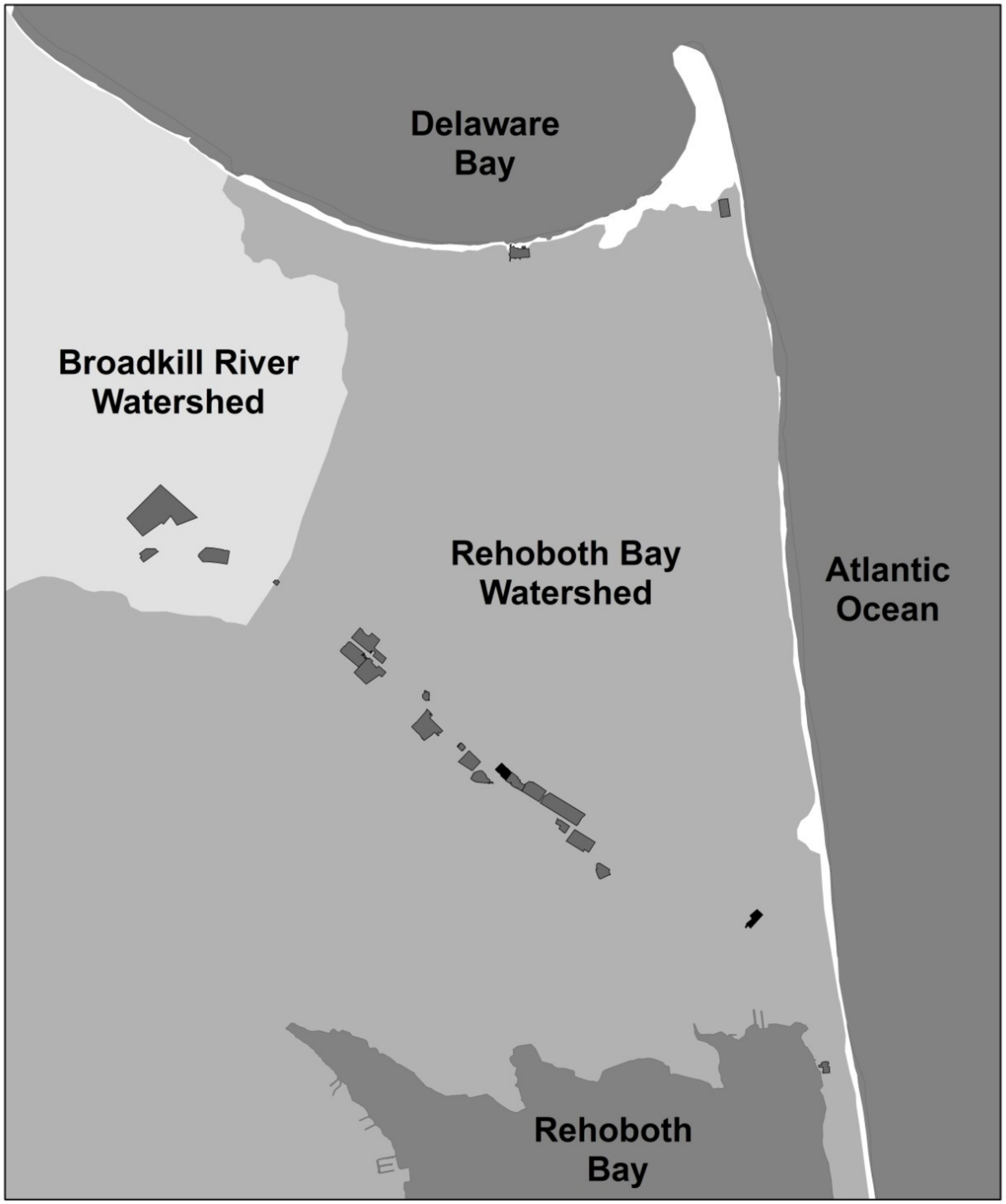

Figure 3. Final sites (represented in black) selected for the study.

Figure 4. Images of the sample being collected in the street sweeper's hopper, emptied onto a paved area, then divided into 12-0.3 x 0.3 m (1 x 1 ft) sections.

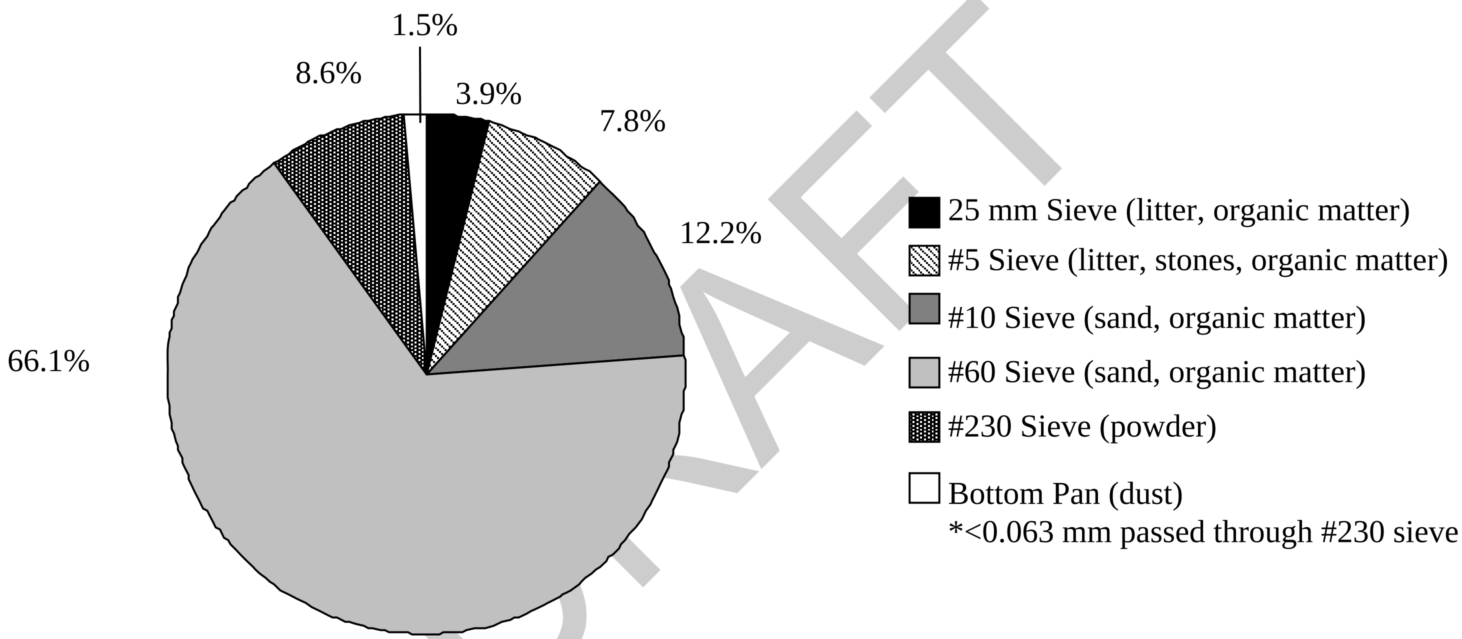

Figure 5. Average percent by volume retained on sieve.

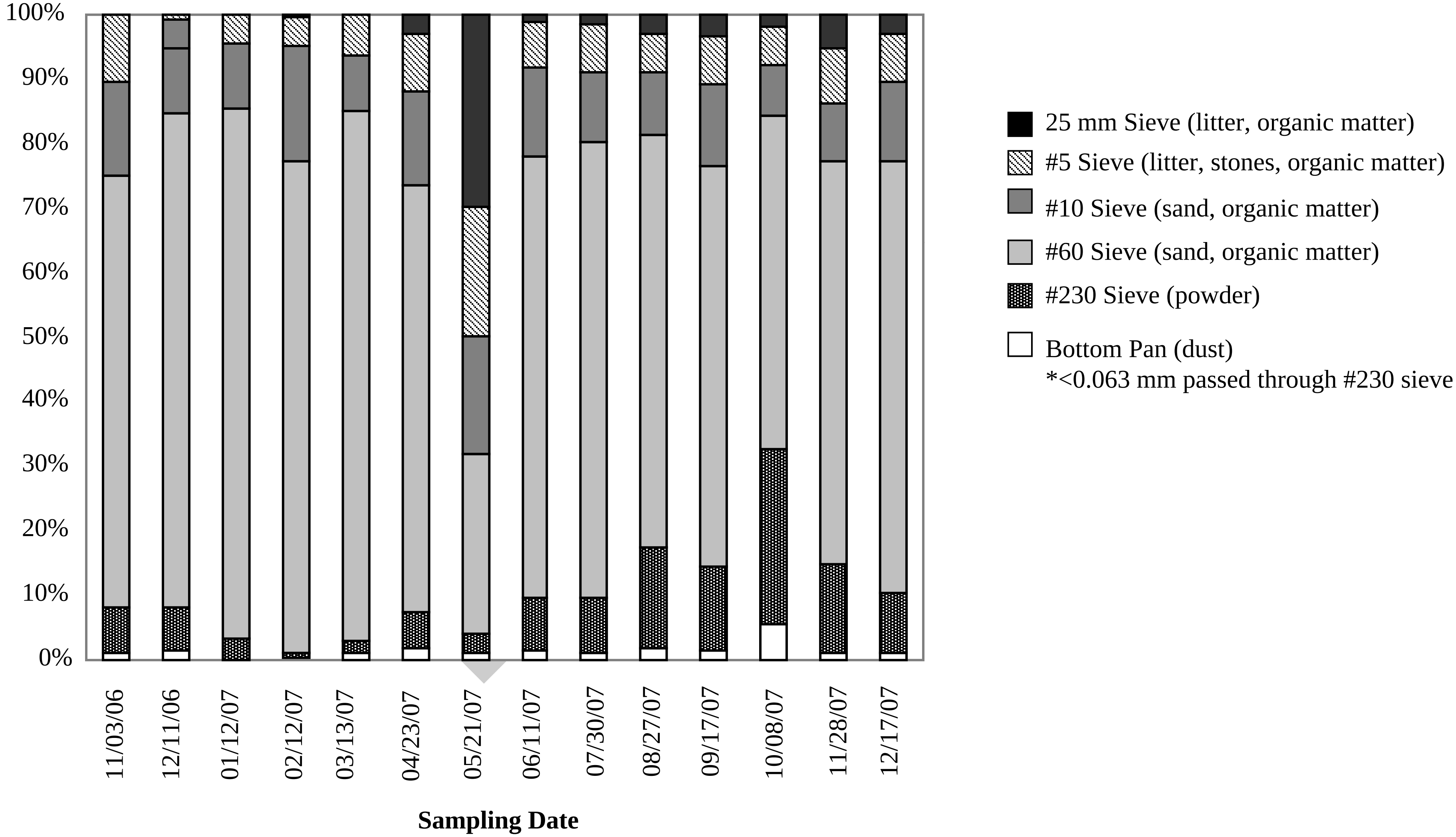

Figure 6. Sieve analysis represented in average percent by volume retained on sieve.

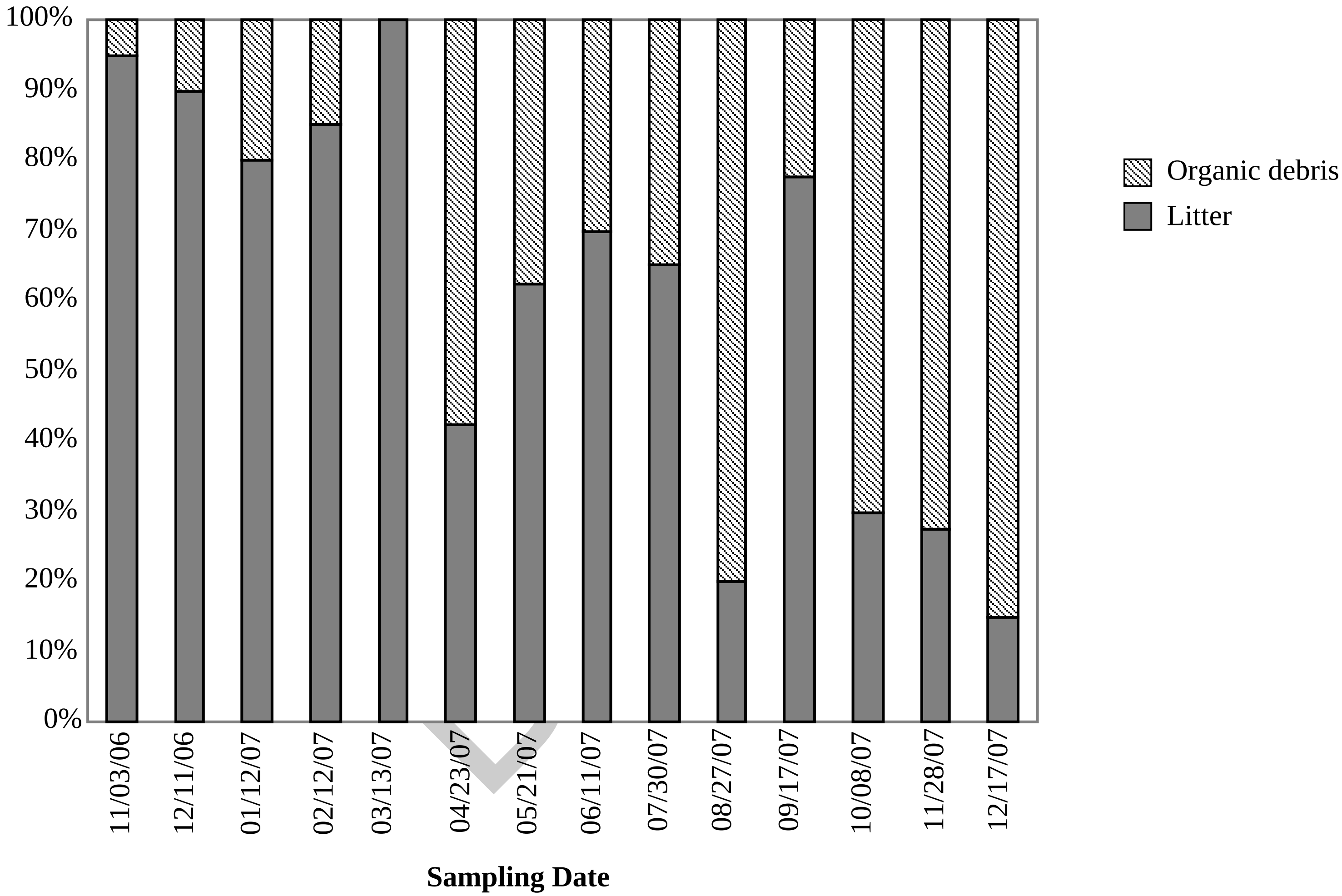

Figure 7. Average content (organic debris and trash) retained on 25 mm sieve.

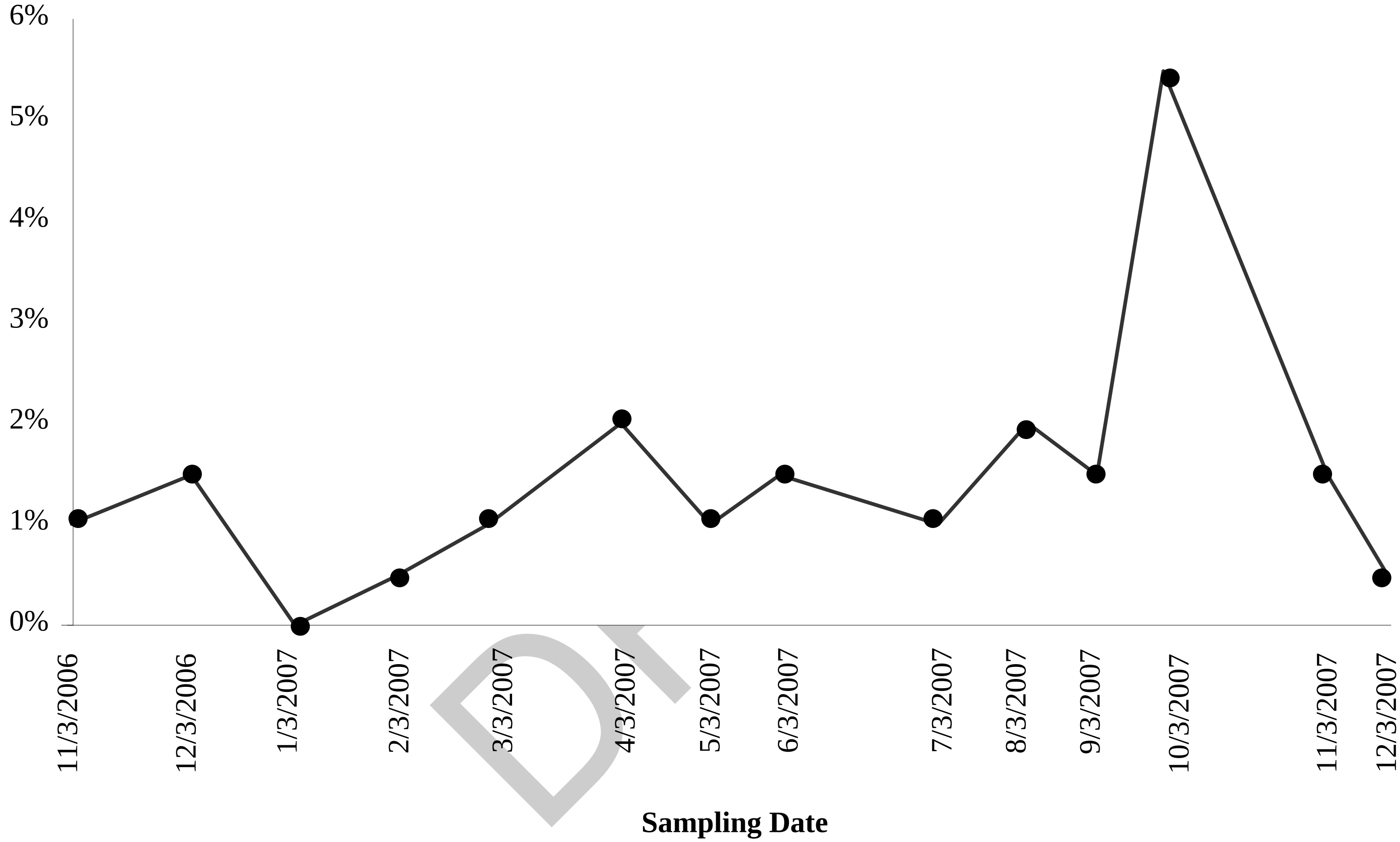

Figure 8. Percent by volume passing through #230 sieve (0.063 mm).

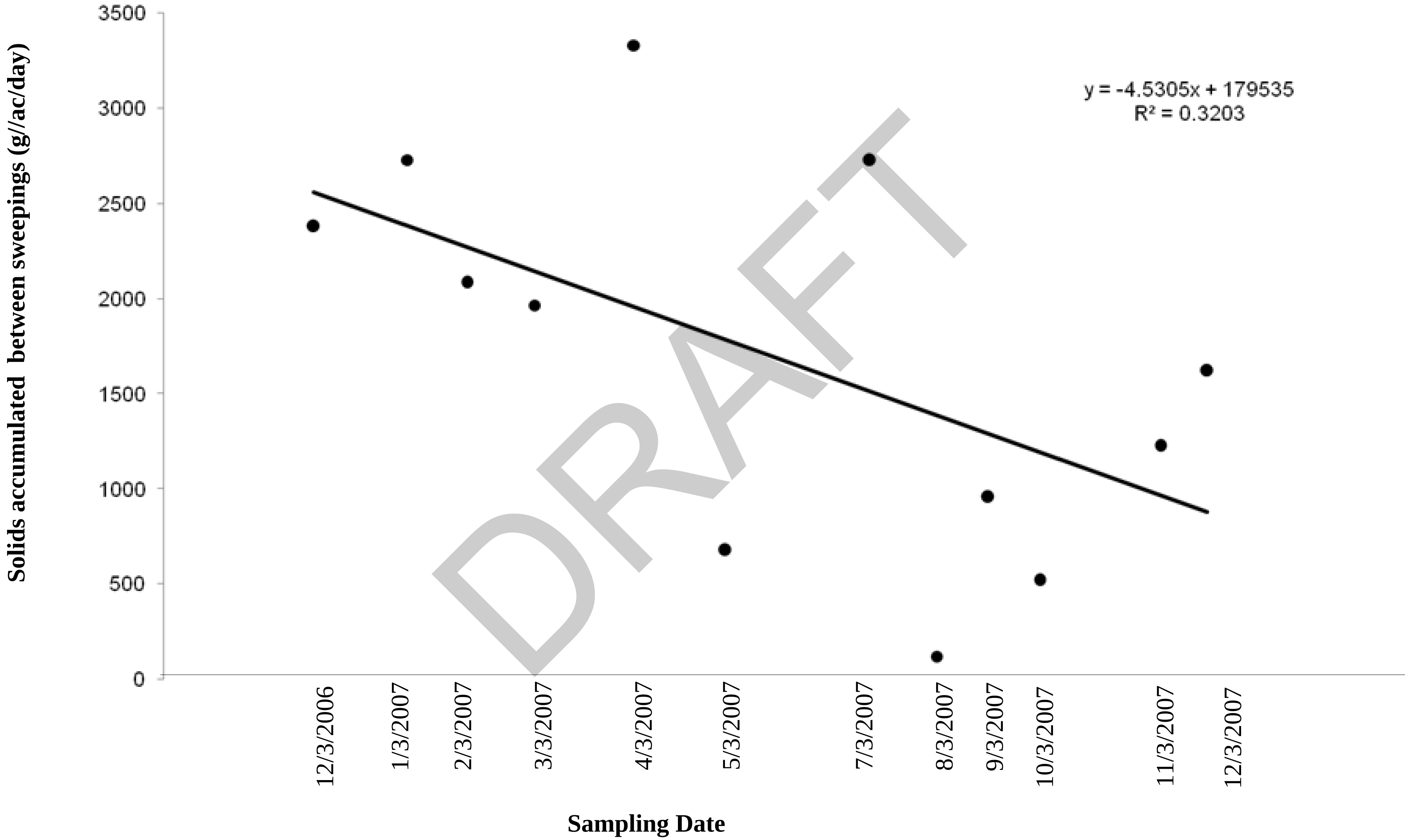

Figure 9. Solids accumulation between sweepings (g/ac/day) for Site 1.

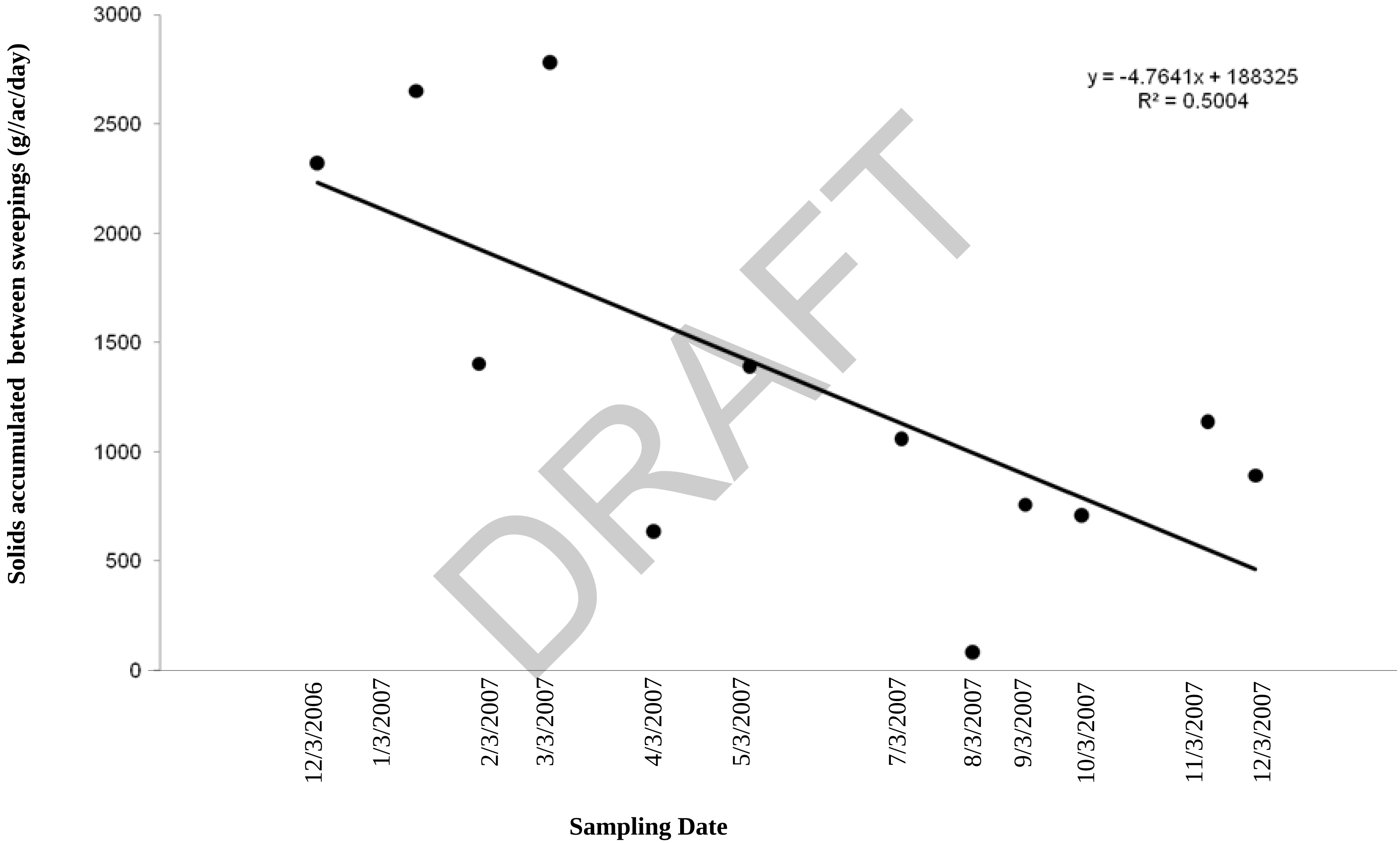

Figure 10. Solids accumulation between sweepings (g/ac/day) for Site 2.

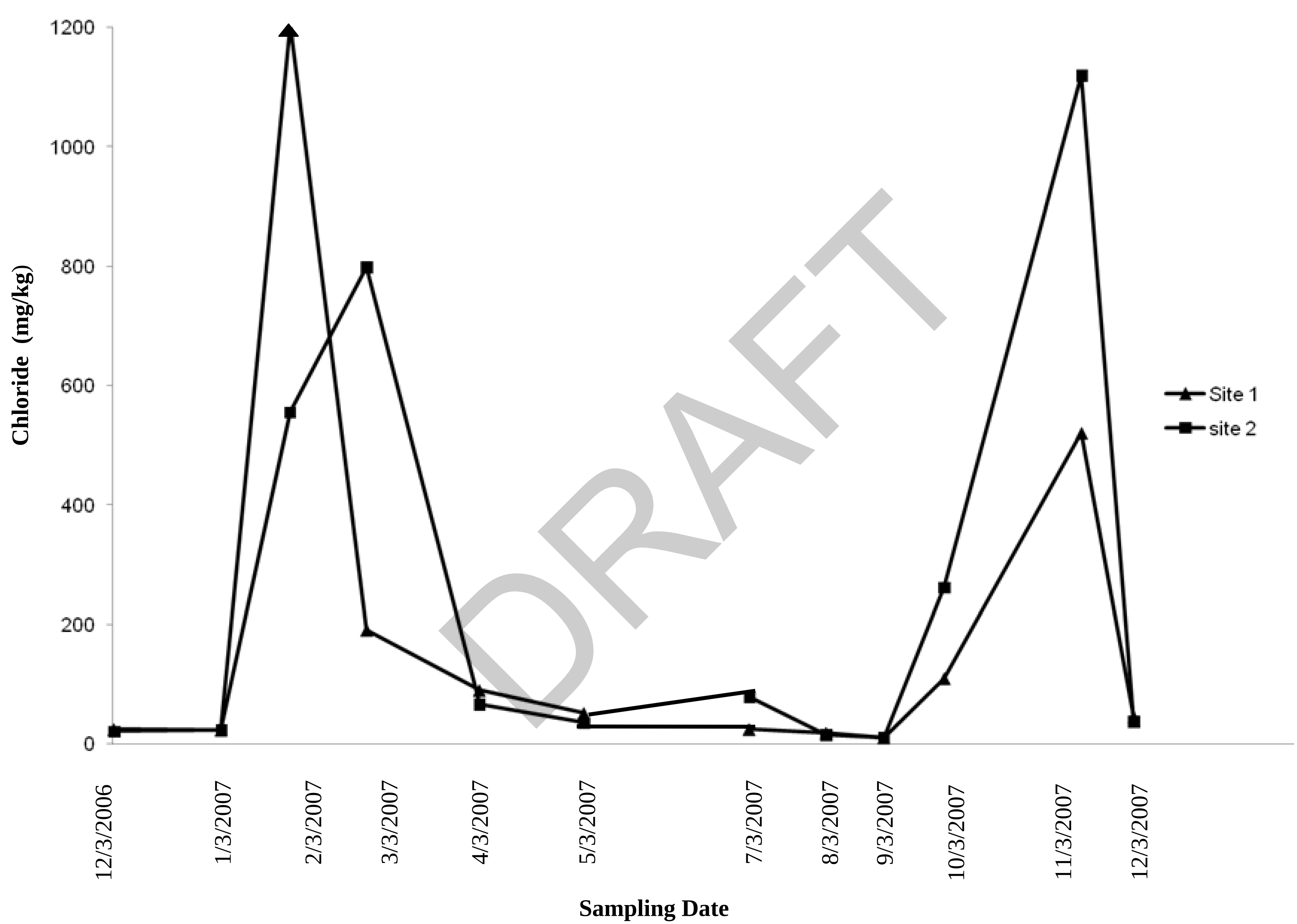

Figure 11. Concentration for chloride (mg/kg) by sampling date.

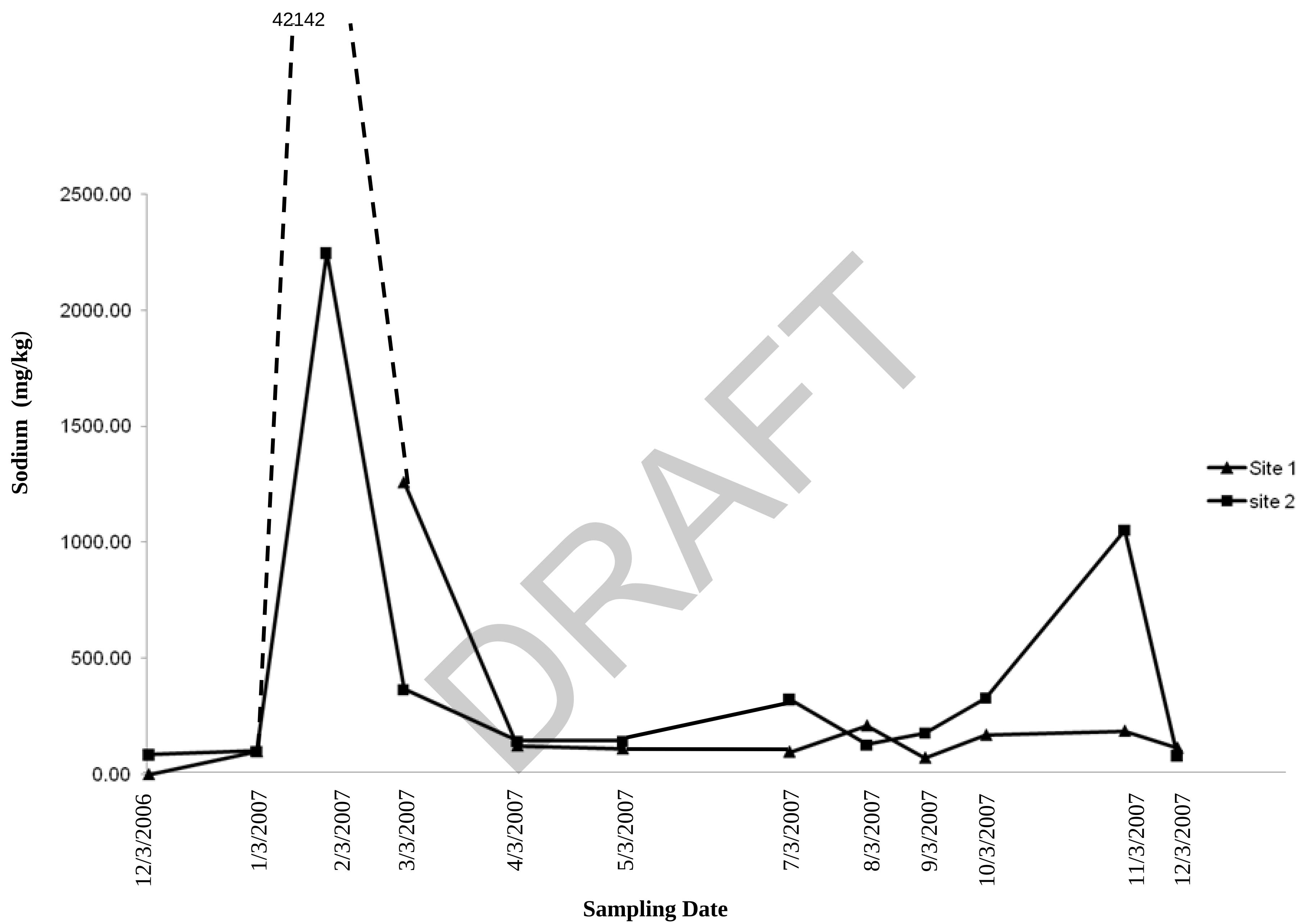

Figure 12. Concentration for sodium (mg/kg) by sampling date.

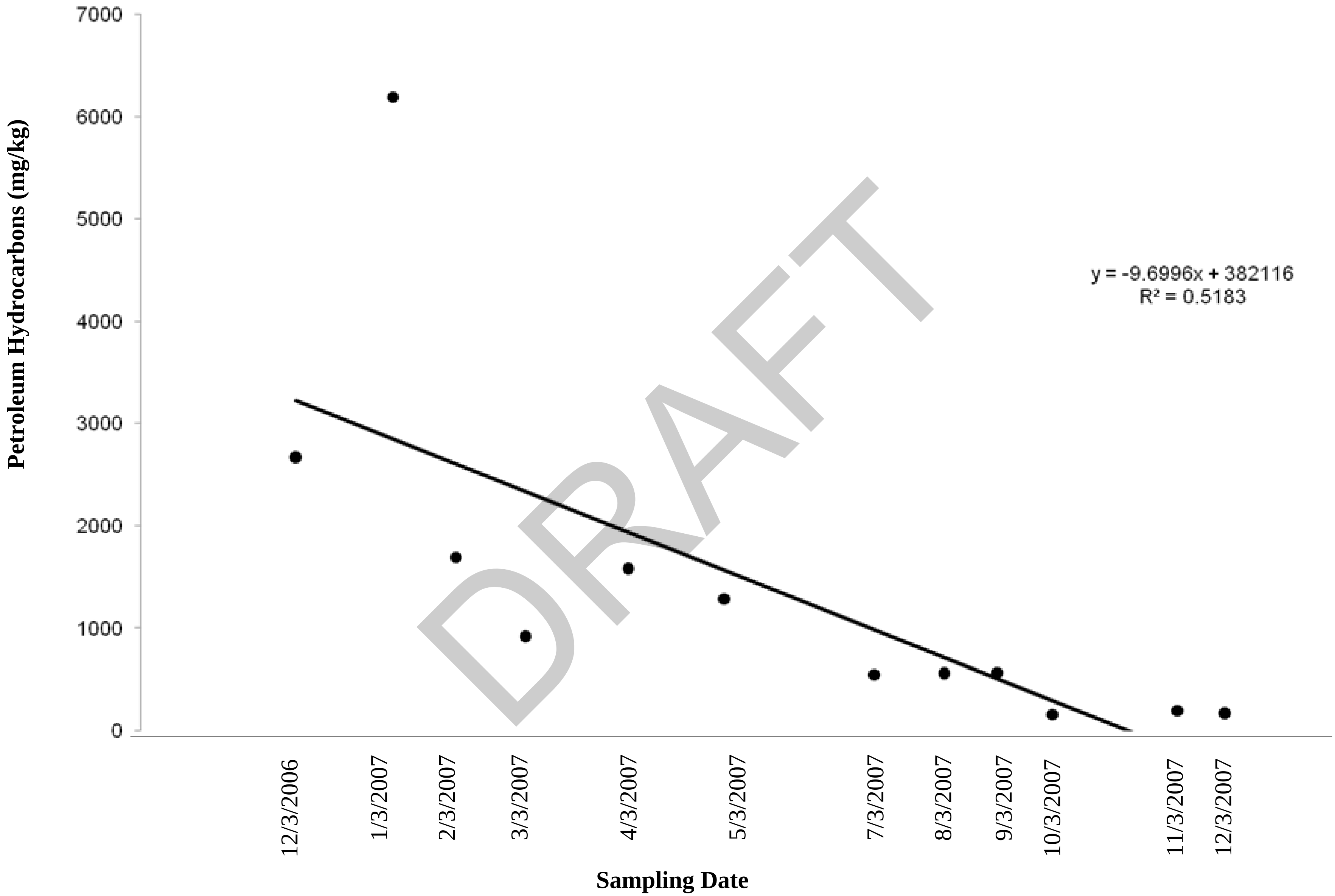

Figure 13. Relationship between petroleum hydrocarbon concentration and sampling date (Site 1).

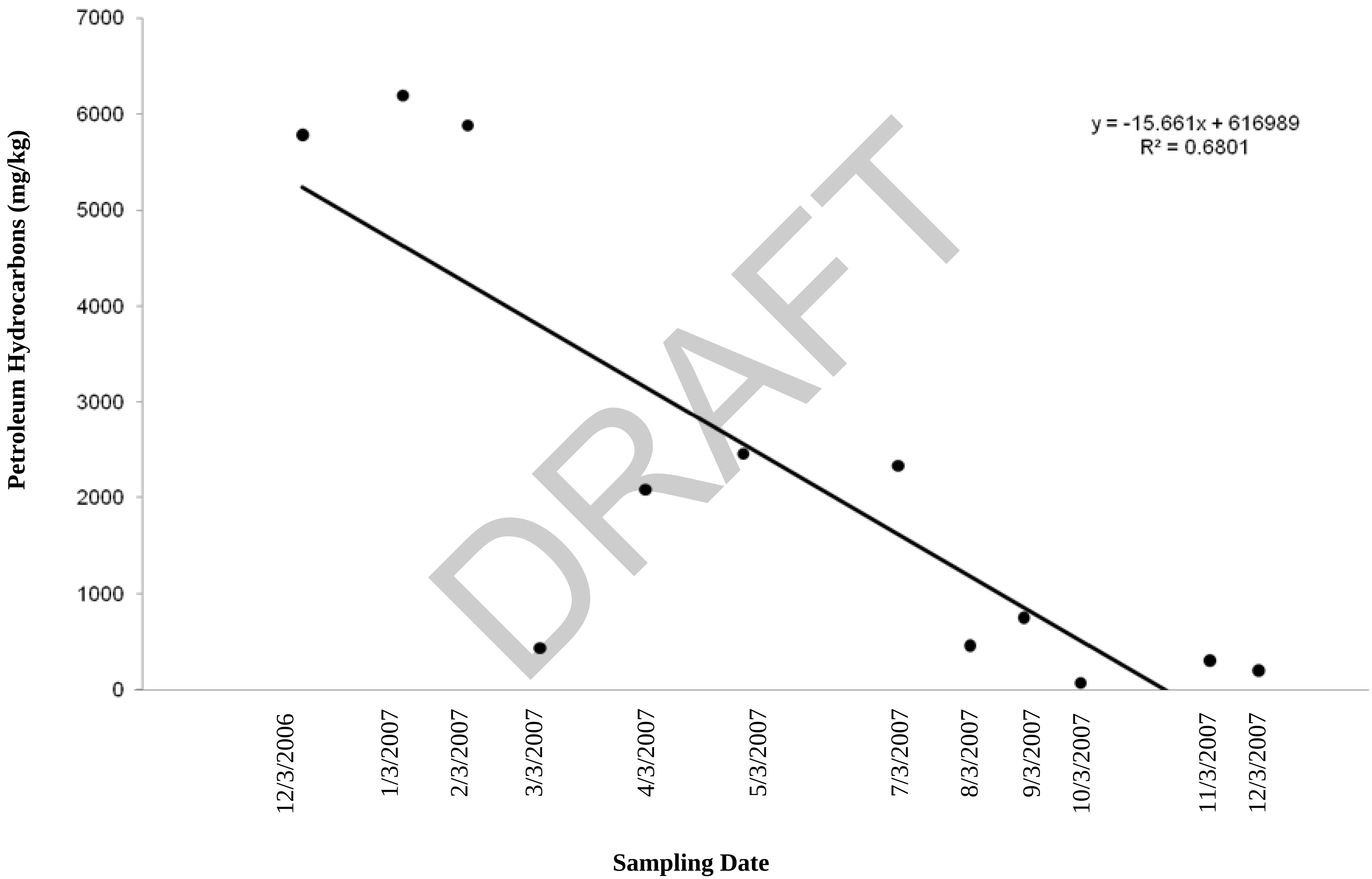

Figure 14. Relationship between petroleum hydrocarbon concentration and sampling date (Site 2).

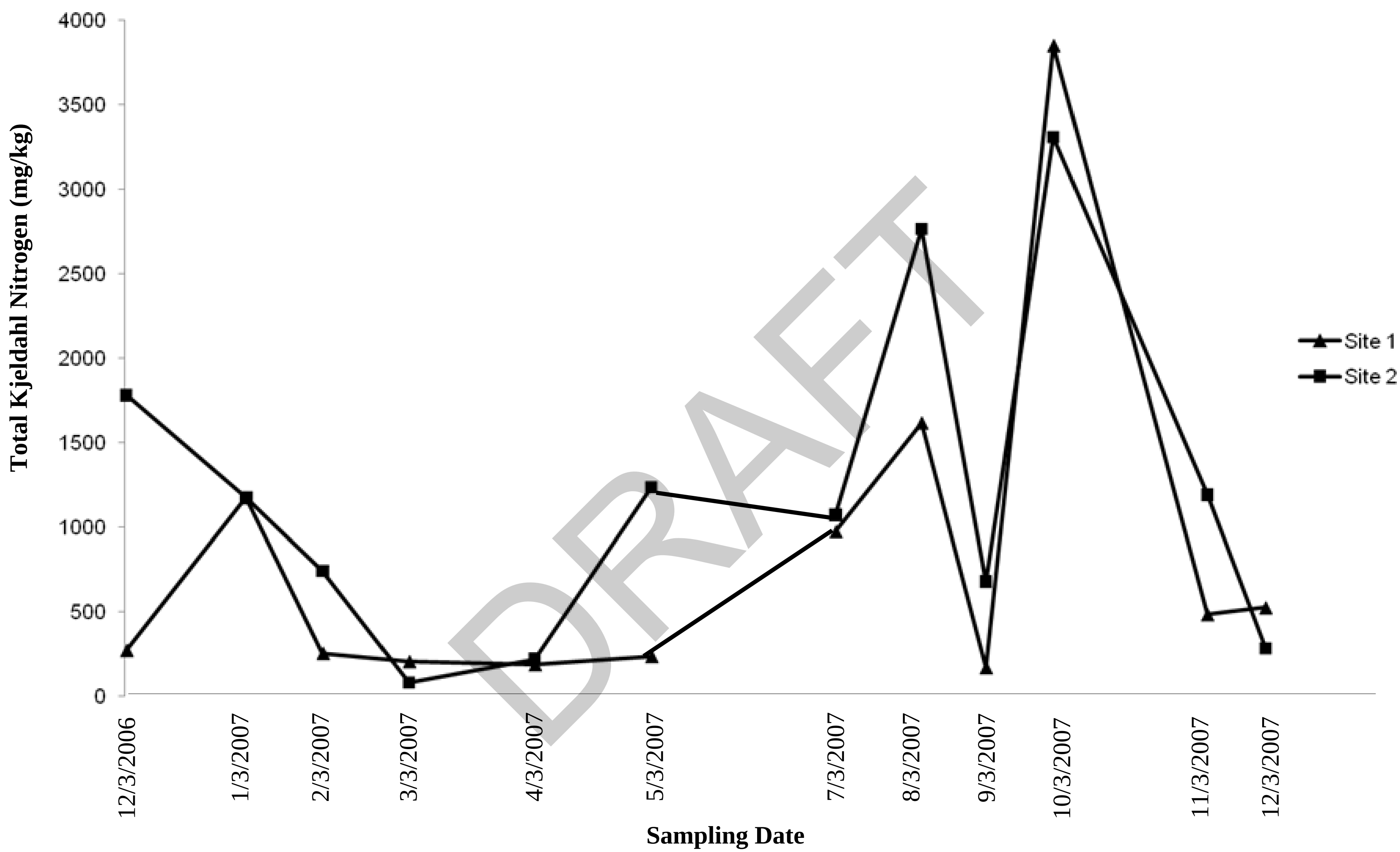

Figure 15. Relationship between total Kjeldahl nitrogen and sampling date.