

# **An Evaluation of the Toxicity of Accumulated Sediments in Stormwater Wetlands and Wetponds**

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## Executive Summary

Various design features are being incorporated in best management practices (BMPs) to improve pollutant removal and mitigate runoff. One such feature is the forebay, a settling basin placed at the inlet of a BMP to encourage sedimentation. Pollutants sorbed to the sediment are intended to remain in the forebay instead of progressing into the remainder of the BMP. Thus, the forebay is designed so that it alone needs excavation, simplifying BMP maintenance. Because there are no formal regulations exclusive to accumulated BMP sediments, questions persist in how to dispose of sediments upon excavation. The ultimate fate of BMP spoils is dependent upon predetermined sediment toxicity.

This study examined sediment from 30 wetlands and wetponds across North Carolina in the following counties: Durham, Guilford, Mecklenberg, and Wake. Twenty-one commercial watersheds and 9 residential watersheds were examined. Each forebay was divided into a 9-section grid so that 3 quadrats were near the stormwater inlet (in the front of the forebay), 3 were in the middle of the forebay, and 3 were in the back of the forebay. A sample was taken from each quadrat using a steel auger or a large plastic serving spoon (if forebay depths were minimal). The samples were composited into one 500 mL nalgene laboratory bottle. For ten of the ponds, three additional samples were taken near the outlet structure and composited for spatial comparison.

Sediments were tested for 7 metals: cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), nickel (Ni), lead (Pb), and zinc (Zn). Analytical testing procedures for total metals were completed by North Carolina State University's Analytical Testing Laboratory in the Department of Soil Science. Of 30 forebays tested, 28 were also tested for plant available metals and nutrients, including: nitrate-nitrite ( $\text{NO}_3\text{-NO}_2$ ), total kjeldahl nitrogen (TKN), total nitrogen (TN) from the sum of TKN and  $\text{NO}_3\text{-NO}_2$ , and total phosphorus (TP). These samples were analyzed by North Carolina State University's Environmental Analysis Laboratory in the Department of Biological and Agricultural Engineering.

All sampled sediment metal concentrations were compared to existing toxicity standards for a relative toxicity measure. Both aquatic health sediment guidelines and EPA land application of biosolid standards (40 CFR503) were used as baselines for comparison. Pollutant limits set for aquatic health are considerably more stringent than land application standards. Twenty-two of 30 sites exceeded sediment guidelines for aquatic health with respect to one or more pollutants, emphasizing the need for routine forebay sediment removal. Importantly, none of the sites violated 40 CFR503 limits with respect to Cd, Cr, Cu, Ni, Pb, and Zn. All samples met 40 CFR 503 limits with factors of safety ranging from 5 to 13. It is very important to note that other pollutants such as PAHs, PCBs, and pathogens were *not included in this study* and may impact aquatic health and/or the viability of land application.

Furthermore, bioavailable sediment nutrient concentrations were compared to the optimal fertilization requirements of four low maintenance grasses. Grass species are relatively low cost, yet may effectively minimize erosion of sediments and spread of contaminants upon land application. All minimum nitrogen recommendations can be met dependent on sediment depth and area of land application. Phosphorus requirements could not be evaluated because plant needs are typically provided in terms of phosphate, which is not comparable to the measured TP concentrations presented in this study. However, given the concentrations of nitrogen and phosphorus in the forebays sampled, the authors believe there are sufficient nutrients to establish

and sustain various species of grasses and other low-maintenance plant species, yet authors do encourage testing the sediment for other nutrients essential to plant growth, such as calcium and potassium

Raw data suggest that residential landuses have higher median concentrations of Cr, Fe, and Ni, while commercial landuses have higher median concentrations of Zn, Pb, and Cu. However, non-parametric statistical analysis using SAS software showed that only Zn was significantly different between landuses, which was shown to be significantly higher in commercial landuses ( $p < 0.05$ ).

In conclusion, land application of accumulated forebay sediments is unlikely to pose a threat to the environment when excavated sediment is held to 40 CFR503 biosolid standards. However, leaving contaminated sediment inside forebays may pose a risk to aquatic health. It is very important to consider pollutants of concern that were not accounted for in this study such as: PAHs, PCBs, and pathogens before selecting a sediment disposal method. Optimal grass growth on excavated sediments is probable based on bioavailable nitrogen and phosphorus concentrations. Lastly, the only significant difference between commercial and residential landuses was for Zn, where concentrations were significantly higher in sites located in commercial landuses when compared to sites in residential landuses. However, the maximum concentrations for each metal sampled were all found in commercial landuses.

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## I. Background

When properly designed and maintained, best management practices (BMPs) efficiently capture sediment from runoff and decrease peak and total flow (Hsieh and Davis, 2005; Hunt et al., 2006; Li and Davis, 2008; OMOE, 2003; Urbonas et al., 1995). Nutrients and metals in runoff sorb to soils, and accumulate in BMPs such as stormwater wetponds and wetlands, instead of flowing directly into waterbodies (Burton, 1992; Councell et al., 2004; Crowe et al., 2007; Davis et al., 2001; Lau and Stenstrom, 2005; Lee et al., 2002; Obarska-Pempkowiak and Klimkowska, 1999). The efficiency of sediment removal is related to the available storage volume of a BMP, particularly in constructed wetponds and stormwater wetlands (Graham and Lei, 2000; Obarska-Pempkowiak and Klimkowska, 1999). While increased sediment accumulation implies that a BMP is performing optimally, as accumulation occurs, the available storage volume decreases, decreasing sediment removal and increasing the risk of flooding/pollutant transfer downstream (Heal et al., 2006; Marsalek and Marsalek, 1997; OMOE, 2003). This relationship necessitates the removal of accumulated sediments on a regular basis, dependent on individual BMP parameters effecting sediment accumulation rate, such as: landuse (including construction activity), watershed area, and the presence/absence of upstream BMPs (Liebens, 2001).

Previous studies have examined metal and nutrient concentrations in conventional stormwater wetponds and wetlands; still, variations in metal and nutrient data make sediment disposal a difficult task. As a majority of the existing studies in Canada and Scotland, results may not be indicative of BMP sediment in the United States (Graham and Lei, 2000; Heal et al., 2006; Marsalek and Marsalek, 1997; Marsalek et al., 2006; Van Loon et al., 2000). More specifically, soils in Canada and Scotland may be impacted by a glacial influence; whereas, soils in North Carolina do not have glacial influence. Regionally specific guidelines are encouraged to account for geographical differences in soil chemical properties that may impact the sorption capacity of pollutants to soil/sediment, such as: pH, CEC, organic matter, and salinity. For instance, a forebay in a cold-climate region may receive runoff from roads that have been salted to remove ice, creating a pollutant (salt) in BMP sediments that is not as prevalent in warmer climates. Plant intolerance to salt may inhibit the use of land spreading and seeding sediments in areas prone to ice. Accumulated BMP sediments should be studied specifically in regions of the United States, and even regions of North Carolina, to create locally specified sediment maintenance guidelines.

Existing studies have not isolated the forebay for analysis. The forebay, in most cases, is the intended portion of a wetland or wetpond to be excavated for captured sediment and solids removal. It is important to differentiate the toxicity of forebay sediments from the remainder of the pond/wetland sediments. No peer-reviewed and published studies are available with regard to *forebay* sediment metal concentrations specifically; rather, entire wetponds or wetlands have been analyzed. Forebay sediment toxicity, exclusively, needs to be examined.

This study's primary objective is to quantify the level of metals in accumulated sediments found in stormwater wetland and wet-pond forebays in North Carolina. Based on existing toxicity standards, disposal recommendations will be made.

Currently U.S. hazardous waste disposal legislation (40 CFR 239<sup>1</sup> to 40 CFR 259) does not include explicit regulations for BMP accumulated sediments; however, several states within the U.S. are beginning to adopt legislation for biosolids and sewage sludge (40 CFR503) for forebay

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<sup>1</sup> 40 CFR 239 = Code of Federal Regulations, Title 40, Part 239.

sediment disposal purposes. 40 CFR503 “*establishes standards, which consist of general requirements, pollutant limits, management practices, and operational standards, for the final use or disposal of sewage sludge generated during the treatment of domestic sewage in a treatment works. Standards are included in this part for sewage sludge applied to the land, placed on a surface disposal site, or fired in a sewage sludge incinerator. Also included in this part are pathogen and alternative vector attraction reduction requirements for sewage sludge applied to the land or placed on a surface disposal site.*” While 40 CFR 530 specifically applies to other wastes, it may be applicable to accumulated forebay sediment.

A survey of 48 continental states and 6 Canadian provinces showed that of the responding 26 states and 4 provinces, 6 claimed to specifically monitor stormwater wetpond sediment disposal and/or use: Florida, Maryland, Minnesota, New Mexico, New York, and Washington (Polta, 2004). Sediment disposal measures varied by state and included the following practices:

- Beneficial use for landfill covering, road construction and maintenance
- Dewatering and landfilling
- Land application

The most desirable and economical disposal measure would be to: (1) spread sediment on adjacent land upon excavation and (2) then seed with a cost-effective grass or ground cover to stabilize the applied soil. The levels of sediment-borne pollutants will determine if any soil toxicity limits are exceeded and whether land application is possible. Nutrient levels can also be determined to verify the feasibility of plant growth on the disposed of sediments. Land-application is not a suitable disposal measure if pollutant levels have potential to cause human or ecological harm. If pollutant levels are too high for land application, excavated spoils may still be used in roadway construction or as a landfill cover. Unfortunately, if sediment toxicity is determined to be too high for both land-application and for beneficial use, sediments may require landfilling which would be an extremely costly disposal option.

#### **A. Assessing Toxicity**

Three measures were selected with which toxicity of sediments could be evaluated: (1) with respect to aquatic organism health (pre-excavation) (2) with respect to land-application and (3) with respect to landfilling (both 2 and 3 are post-excavation). Additionally, accumulated sediments were compared to average pollutant concentrations typically found in native North Carolina soils (Hardy et al, 2008).

- 1. EXISTING REGULATIONS FOR AQUATIC SEDIMENTS.** Of several methods used to establish sediment guidelines for aquatic health, the most commonly accepted is the effects range approach (ANZECC, 2000). This approach uses field data to determine pollutant concentrations in which adverse effects are observed or not observed in aquatic biota. The Australian and New Zealand Environmental and Conservation Council (ANZECC, 2000) and the U.S. National Oceanic and Atmospheric Administration (NOAA, 1999) have both used the effects range approach to establish sediment quality guidelines. Furthermore, the effects range approach was used to set guidelines for the Canadian Sediment Quality Guidelines (CCME, 1995).

NOAA conducted a study on marine biota as an informal metric to compare aquatic health and determine priority pollutants. The study resulted in the “Effects Range-Low” (ERL: the lower 10<sup>th</sup> percentile of pollutant concentration data in which adverse effects rarely occurred), and the “Effects Range Median” (ERM: the 50<sup>th</sup> percentile of pollutant concentration data, above which adverse effects frequently occur) (NOAA, 1999). Furthermore, the Florida Department of Environmental Protection (FDEP) conducted a more comprehensive study, compiling data from across the United States to develop a range of effects including the Threshold Effects Level (TEL) and the Probable Effects Limit (PEL). (MacDonald et al., 2000) also conducted a more comprehensive study; however, it is specific to freshwater ecosystems, unlike the FDEP guidelines. Seventeen studies across the United States were compiled to form a threshold effect concentration (TEC) and a probable effect concentration (PEC). The TEC and PEC were derived by taking the geometric mean of concentrations below which adverse effects were not observed and of concentrations above which adverse effects were noted, respectively. Notably, both the FDEP and MacDonald studies result in fairly similar metal concentration guidelines. ANZECC asserts that the FDEP effects range “is one of the most comprehensive documentations of sediment quality assessment” (ANZECC, 2000), and therefore both the FDEP and MacDonald guidelines are used to assess biotic health in this study.

2. **REGULATIONS FOR BIOSOLIDS.** Title 40, Part 503, Section 13 of the Federal Code of Regulations (40 CFR 503) sets maximum pollutant concentrations for the land-application of sewage sludge and other biosolids (Appendix A). In addition to one-time measurement limits, monthly averages and annual loading rates are also defined. Metal, nutrient, and pathogen standards are included. Several states have adopted code 40 CFR 503 for regulating stormwater sediment disposal, including Georgia and South Dakota (Polta, 2004; Sonon and Gaskin, 2009). The Ontario Ministry of the Environment (OMOE) also sets guidelines for the use of biosolids and other wastes on agricultural land (OMOE, 1996). These regulations provide maximum metal, nutrient and pathogen limits for the land application of wastes onto agricultural crops. More stringent standards are placed on lands where crops are grown specifically for human consumption (grains, vegetables, tobacco, etc) (OMOE, 1996). Both the 40 CFR 503 and the OMOE regulations are practical standards to determine the most appropriate sediment disposal measure.
3. **EXISTING REGULATIONS FOR HAZARDOUS WASTE.** As previously stated, if land application or beneficial use is not an option, landfilling is recommended. However, even landfilling regulations requires compliance to standards (40 CFR 268). To be landfilled, wastes must meet a variety of standards, including those set for the Toxicity Characteristic Leaching Procedure (TCLP). The TCLP simulates landfill conditions to determine potential mobility of pollutants by measuring the pollutants in leachate produced when water or other liquids percolate through the simulated landfill. The EPA requires that all leachate meet concentrations defined specifically for the TCLP, based on groundwater and ecological protection measures (40 CFR Part 261). Likewise, the OMOE stipulates pollutant concentrations that must be met by wastes undergoing a

TCLP under Regulation 347 (OMOE, 1990). If the EPA TCLP concentrations or Reg. 347 concentrations are exceeded, even landfilling is not an option in the United States and Canada, respectively, and alternate measures would be necessary.

## II. Site Selection and Sampling Protocols

Thirty forebays were selected based on cooperating municipalities, and entities ease of access and data collection, as well as property-owner consent. All property owners and specific site locations remain anonymous. Municipalities in which sampling occurred include: Apex, Charlotte, Durham, High Point, and Raleigh. Both commercial and residential landuses were selected (Table 1). All institutional sites, such as those located on the NC State University campus, and industrial sites, such as gas stations, were included in the commercial landuse category. Percent imperviousness of the watershed, approximate drainage area, system age, and forebay surface area were recorded for each forebay (Table 1). Drainage areas ranged from 0.46 acres to 120 acres, while surface areas ranged from 300 ft<sup>2</sup> to 14,375 ft<sup>2</sup>. System age, or years since last maintenance period, ranged from 1 to 10 years and the percent imperviousness of watersheds ranged from 20 percent to 90 percent.

**Table 1. The breakdown of forebays sampled by landuse and location**

Location	Landuse		Totals
	Commercial	Residential	
Durham	9 (5)	8 (4)	17 (9)
Raleigh	8 (1)	0 (0)	8 (1)
Apex	2 (0)	0 (0)	2 (0)
Charlotte	1 (0)	1 (0)	2 (0)
High Point	1 (0)	0 (0)	1 (0)
	<b>21 (6)</b>	<b>9 (4)</b>	<b>30 (10)</b>

( ) values in parenthesis represent sites that had additional samples taken at the outlet structure.

**Table 2. Characteristics of each site sampled, including: location, landuse, age, drainage area (DA), and surface area of the forebay (SA).**

Site	Location	Landuse	Age	DA	SA	% Imp
			yrs.	acres	ft <sup>2</sup>	
A	APEX	COM	4	1.03	2083	73
B	APEX	COM	4	3.13	2077	73
<b>C*</b>	DURHAM	COM	3	0.46	1204	65
<b>D*</b>	DURHAM	COM	3	3.16	861	90
E	DURHAM	COM	5	13	820	25
F	DURHAM	COM	7	10.7	3200	29
G	DURHAM	COM	2	1.8	570	67
H	DURHAM	COM	3	5.8	1638	70
I	HIGH POINT	COM	10	3.7	300	40
J	RALEIGH	COM	4	7.6	2338	52
K	RALEIGH	COM	3	19	4184	50
L	RALEIGH	COM	6	2.6	470	48
M	RALEIGH	COM	6	1.28	552	86
N	RALEIGH	COM	6	4.4	730	58
O	RALEIGH	COM	3	11.8	2088	52
P	RALEIGH	COM	8	19	1740	70
Q	CHARLOTTE	COM	5	120	2550	35
<b>R*</b>	DURHAM	COM	1	2.7	920	73
<b>S*</b>	DURHAM	COM	3	20.3	4400	69
<b>T*</b>	DURHAM	COM	3	54	10400	85
<b>U*</b>	RALEIGH	COM	4	10.4	440	37
<b>V*</b>	DURHAM	RES	5	9.0	4356	52
W	DURHAM	RES	8	16.5	2180	64
X	DURHAM	RES	8	7.1	3480	65
Y	DURHAM	RES	6	35.9	4800	39
Z	CHARLOTTE	RES	6	15.8	2360	60
<b>AB*</b>	DURHAM	RES	8	89	1787	20
<b>CD*</b>	DURHAM	RES	5	56.6	14375	47
<b>EF*</b>	DURHAM	RES	1	4.6	720	27
GH	DURHAM	RES	6	13	3050	32

\* Sites that had additional samples taken near outlet structure for spatial variation analysis.

All forebays were sampled for 7 metals commonly found in stormwater: copper (Cu), zinc (Zn), iron (Fe), nickel (Ni), cadmium (Cd), chromium (Cr), and lead (Pb) (Graham, 2000; Liebens, 2002; USEPA, 1983). Total metal concentrations were analyzed by North Carolina State University’s Analytical Services Laboratory in the Soil Science Department using EPA Method 3050B (EPA 3050B, 1996). Results were reported on a dry weight basis.

Of 30 forebays, 28 were analyzed for bioavailable metals by North Carolina State University’s Environmental Analysis Laboratory in the Department of Biological and Agricultural Engineering (BAE) using extraction with a weak acid (0.05 M + 0.025 M H<sub>2</sub>SO<sub>4</sub>). The BAE lab also analyzed samples for nutrients including: nitrate-nitrite (NO<sub>3</sub>-NO<sub>2</sub>), total kjeldahl nitrogen

(TKN), total nitrogen (TN) from the sum of TKN and NO<sub>3</sub>-NO<sub>2</sub>, and total phosphorus (TP) (EPA 353.2, 1979; EPA 351.2, 1979; EPA 365.4, 1979).

Samples sent to the BAE lab were reported on a wet weight basis, so the moisture content of samples was also analyzed in order to convert results to dry weight. This conversion was necessary to compare results to existing toxicity standards. Analytical testing procedures and instruments of analysis are listed (Table 3).

**Table 3. Analytical Testing Procedures and Instruments of Analysis**

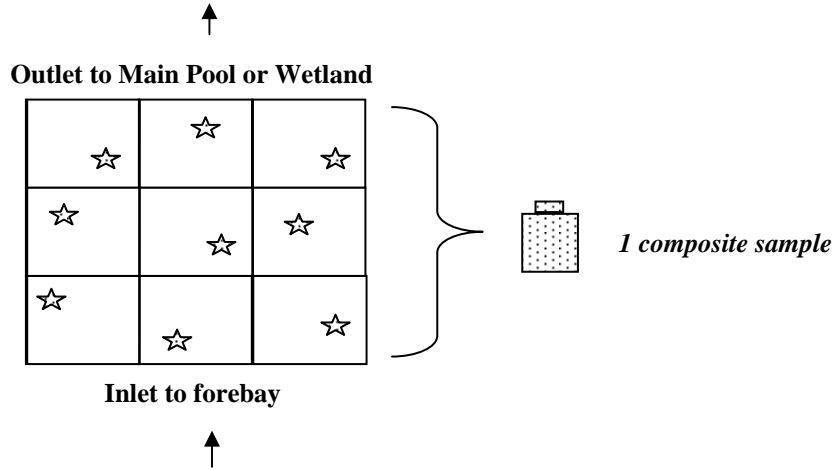
Metal	Form	Analytical Testing Procedure	Analysis Instrumentation
Cr, Cu, Fe, and Zn	Total	EPA Method 3050B, strong acid digestion	ICP-OES
Pb, Cd, and Ni	Total	EPA Method 3050B, strong acid digestion	ICP-MS
Cr, Cu, Fe, and Zn	Plant Available	extraction with weak acid (0.05 N + 0.025 N H <sub>2</sub> SO <sub>4</sub> )	direct aspiration atomic absorption spectroscopy
Pb, Cd, and Ni	Plant Available	extraction with weak acid (0.05 N + 0.025 N H <sub>2</sub> SO <sub>4</sub> )	direct aspiration atomic absorption spectroscopy
TKN	Total	EPA Manual 351.2 (1979)	Automated
NO <sub>3</sub> N + NO <sub>2</sub> -N	Total	EPA Method 353.2 (1979)	Automated
TP	Total	EPA Method 365.4 (1979)	Automated

ICP-OES = Inductively Coupled Plasma Optical Emission Spectroscopy  
 ICP-MS= Inductively Coupled Mass Spectroscopy

### A. Sampling

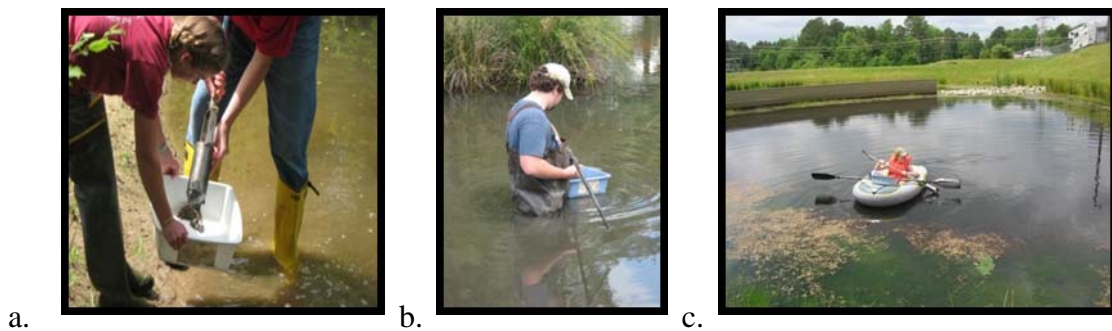
All forebays were divided into a 9-segment grid (Figure 1) and a sample was taken within each quadrat using a steel auger or a plastic spoon, depending upon sediment depth and underlying substrate (Figure 1). For ten of 30 sites three additional samples were taken near the outlet structure of the pond or wetland and composited into one bottle very similarly to the composite in the Basic Sampling Protocol described below. Outlet samples were taken to investigate fluctuations in sediment toxicity with spatial variation.

- BASIC SAMPLING PROTOCOL.** Each composite consisted of 9 samples of equal weight. Samples were weighed and transferred into a 500 mL nalgene laboratory sample bottle (Figure 3). For example: 9 samples, weighed at 50 g (+/- 0.5 g) each were composited into one container, making a total mass of 450 g.



**Figure 1.** A theoretical example of the grid-like pattern used in sampling of accumulated sediment in forebays, where a star indicates sampling location.

In most cases, the forebay samples could be taken on foot; however in some instances, accumulated muck, or considerable forebay water depths prohibited sampling on foot and required a small inflatable raft (Figure 2c). All outlet samples were collected using the raft. However, when forebay depth was minimal, a large plastic serving spoon was used to collect samples. Some forebays contained substantial quantities of rip-rap or dense vegetation, so the exact sampling location varied depending on the specific segment. Regardless of the variations in sampling locations, each quadrat was sampled. Three to four samples were placed at opposite corners in rectangular floating bins during sampling to prevent samples from mixing (Figure 2a).



**Figure 2.** Photos of sediment collection procedure (a) steel augur used in sediment sampling (b) floatable bins used in collection (c) inflatable raft used for sampling when forebay was not wadeable.

Samples were then carried to a portable scale, which held a clean plastic container to retain the sediments while being weighed (Figure 3). The scale was initially zeroed (before sediments were added to the clean plastic container) and again between consecutive measurements (Figure 3). Between composite samples, all equipment was rinsed with deionized water. Samples were immediately sealed, and returned to the appropriate laboratory for analysis. Each sample bottle was assigned a code based on site location.

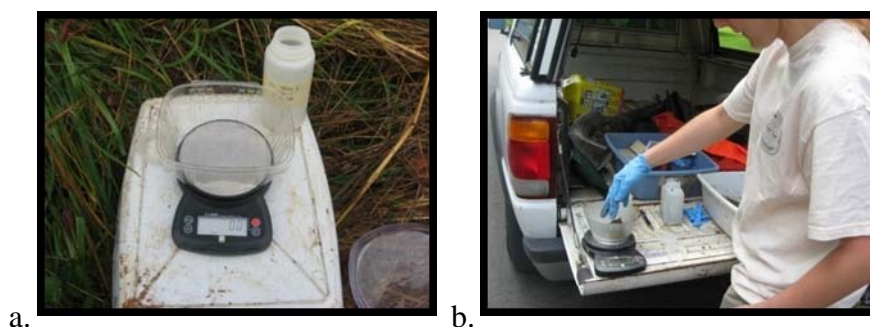


Figure 3. (a) Photo displaying field scale zeroed between samples (b) photo of sediments being weighed

### III. Results and Interpretation

For comparison to aquatic health guidelines and 40 CFR 503 limits, all concentrations were reported in milligrams of pollutant per kilogram of soil in dry weight. Overall mean and median values were calculated, as well as mean and median pollutant concentrations for each landuse (Table 4).

Table 4. Median and Mean Pollutant Concentrations Measured in 30 forebays across North Carolina

Landuse		Pollutant Concentration (mg/kg, dry weight)						
		* Cd	Cr	Cu	Fe	Ni	Pb	Zn
Commercial (n=21)	Mean	ND	20.9	28.0	24695	14.4	13.7	140.0
	Median	ND	20.0	23.0	22127	13.0	13.0	75.0
Residential (n=9)	Mean	ND	23.8	18.6	22380	16.0	12.3	58.4
	Median	ND	28.3	15.1	23300	15.9	11.4	44.0

\* Cd was not detected in 28 of 30 cases. In 2 of 30 cases, Cd was reported as < limit of quantitation (LOQ), or [Cd] < 5.0 mg/kg dry weight.

The median values sampled follow some trends exhibited by the extensive National Urban Runoff Program (NURP) study (USEPA, 1983). For example, commercial landuse areas, as compared to areas of residential landuse, exhibited higher pollutant concentrations of Zn. Unlike the NURP study, commercial areas exhibited higher median concentrations of Pb and Cu when compared to residential areas. This difference may be due to increased vehicular use since 1983 (the year the NURP study was conducted), particularly in commercial areas. Vehicular use, particularly brake and tire wear are associated with Pb, Cu, Cd, and Zn in stormwater runoff (Davis et al., 2001). Median Fe, Ni, Cd, and Cr concentrations were sampled and detected in the NURP study; however, median values were not reported, therefore could not be used as a comparison. In this study, median Fe, Cr and Ni concentrations were higher, sometimes slightly, in residential landuses, when compared to commercial landuses. Median Cd concentrations were below detection limits in nearly all cases.

Sample pollutant concentrations were also compared to other published studies to determine the relative toxicity of forebays. Median metal and nutrient concentrations measured in North Carolina forebays appear similar to respective pollutant medians measured in (1) naturally occurring ponds with an area of concern<sup>2</sup> (2) overall stormwater wetponds and wetlands and (3) roadside swales (Table 5). In all cases, median forebay sediment concentrations were higher than mean soil metal concentrations in native North Carolina soils (Table 5).

**Table 5. Levels of Metal in sediments from various sources (mg/kg dry weight, unless otherwise noted)**

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<sup>2</sup> An area of concern is defined as, “a geographical area whose failure has caused or is likely to cause impairment of beneficial use of the area's ability to support aquatic life” (US-Canada Great Lakes Water Quality Agreement, 1987).

Reference - Location	Cd	Cr	Cu	Fe	Ni	Pb	Zn
All pollutants reported in mg/kg, dry weight.							
Heal et al., 2006 - Scotland							
<i>Halbeath Pond (mixed)</i>	0.21	70.7	18.8	4.41 (%)	63.3	26.3	78.4
<i>Linburn Pond (mixed)</i>	0.22	78.2	20.9	4.74 (%)	68.4	25.4	110
<i>Pond 7 (mixed)</i>	0.32	118	16.3	3.87 (%)	83.9	18.2	77
<i>Wetland (mixed)</i>	0.39	76.7	17.4	7.16 (%)	63.6	22.6	93.1
Liebens, 2001 - United States, FL							
<i>Pond (Commercial), n=3</i>	1.15	22.48	27.41	-	13.42	142.31	253.85
<i>Pond (Commercial), n=4</i>							
<i>Pond (Residential), n=3</i>	0.38	14.27	11.04	-	7.87	15.68	39.73
<i>Pond (Residential), n=9</i>							
<i>Roadside Swale (Commercial)</i>	1.69	24.53	27.1	-	12.46	121.1	268.39
<i>Roadside Swale (Agricultural)</i>	0.64	12.08	9.21	-	10.59	48.46	38.29
Crane, 2005 - United States, MN							
<i>St. Louis River, Area of Concern*</i>	1	34	37.4	-	22.2	62.5	171
<i>St. Louis River, Area of Concern**</i>	1.1	31.8	37.5	-	22.0	93.3	199
Hardy et al., 2008 - United States, NC							
<i>Mean North Carolina Soils</i>	0.1	0.2	9.2	-	0.8	4.2	27.2
Forebay Study, 2009 - United States, NC							
<i>Median Commercial Land-use Sites</i>	ND	20	23	22127	13	13	75
<i>Median Residential Land-use Sites</i>	ND	28.3	15.1	23300	15.85	11.4	44
* concentration of surficial sediments							
** concentrations of sub-surface sediments							

### Statistical Analysis of Spatial Variability

Metal concentrations, by soil type, are shown to be highest among clayey soils (Liebens, 2001). Thus, forebays, closer to the inlet than the remainder of the wetland or wetpond, should theoretically contain proportionally more coarse sand particles than fine clay particles. Consequently, forebay sediment toxicity would be relatively lower than the remainder of the BMP's toxicity due to the low sorption capacity of sand for pollutants. Accordingly, data suggest that metal concentrations measured at the outlet structure in wetponds and wetlands are considerably greater than metal concentrations found in the forebay, or inlet of the pond/wetland (Table 7). This hypothesis was statistically analyzed using t-tests on normalized data and non-parametric statistics for non-normal data. Data for Cu, Zn, and Pb were normal in raw form, and Fe data was normal upon log transformation, using Cramer-von Mises test for normality. Cr and Ni were non-normal in raw and log-transformed states, thus these metals were analyzed using non-parametric statistics. Contrasting initial supposition, t-tests for Cu, Fe, Pb, and Zn showed no significant differences between forebay metal concentrations and outlet metal concentrations (Table 8). Also, the tau-associations for Cr and Ni were relatively low, indicating there was minimal significant difference between forebay metal concentrations and outlet metal concentrations (Table 8). Perhaps the lack of statistical evidence is partially a result of a limited number of samples (10) tested.

**Table 6. Comparison of metal concentrations at the inlet/forebay and outlet structures of ten stormwater wetlands/wetponds in North Carolina, where IN = sediments in the forebay and OUT = sediments near the outlet structure.**

	Metal Concentrations, mg/L						
	Conc. Cr	Conc. Cu	Conc. Fe	Conc. Zn	Conc. Cd	Conc. Ni	Conc. Pb
Average IN	21.4	18.1	19462	93.9	ND	16.9	11.7
Average OUT	27.4	25.2	24950	151	ND	18.5	16.9
<b>Difference (OUT-IN)</b>	<b>6</b>	<b>7.1</b>	<b>5488</b>	<b>57.1</b>	<b>ND</b>	<b>1.6</b>	<b>5.2</b>

**Table 7. P-values and tau-associations for differences in forebay metal concentrations and outlet metal concentrations.**

Parameter	Distribution	Test	P-value or Tau ( $\tau$ )
Cu	normal	Satterthwaite T-test	0.27
Zn	normal	Pooled T-test	0.33
Pb	normal	Satterthwaite T-test	0.14
Fe	log-transformed normal	Pooled T-test	0.07
Cr	non-normal	Kendall Tau	*0.33
Ni	non-normal	Kendall Tau	*0.13

\* indicates tau value for association. Do not mistake for p-value.

#### **A. Statistical Analysis on Landuse**

Raw data suggested that residential landuses would have (1) higher Ni and Cr concentrations, (2) slightly higher Fe concentrations, and (3) lower Cu, Pb and Zn concentrations than commercial landuses. To determine the statistical significance of raw data observations, the effect of landuse on pollutant concentrations was tested using SAS statistical software. Histograms were first constructed to visually inspect the distribution of data about respective means. Data did not exhibit strong normal distributions in the majority of the pollutants assessed, due to one or two outlier sites; therefore, non-parametric methods were used to analyze data for landuse effects. The Kendall tau test of association for non-parametric statistics showed that Zn concentrations were significantly different between residential and commercial landuses ( $p < 0.05$ ). All other pollutants displayed highly insignificant differences in concentrations between residential and commercial landuses (Table 9).

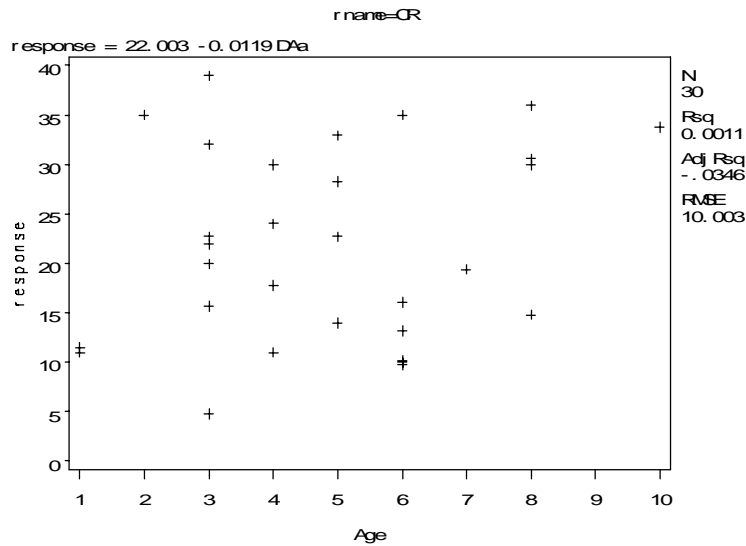
**Table 8. P-values testing for a significant pollutant differences between residential and commercial landuses**

Pollutant	P-Value
*Cd	-
Cr	0.56
Cu	0.20
Fe	0.77
Ni	0.38
Pb	0.56
<b>** Zn</b>	<b>0.01</b>

\* Cd was not detected in almost all cases, thus a landuse comparison was not possible. \*\* Indicates significant difference between commercial and residential land uses.

**B. Analysis of Age on Metal Concentrations**

Raw data indicated that age has no influence over the magnitude of metal concentrations in forebays. A characteristic graph of age versus metal concentration is shown, using Chromium as an example (Figure 4). Additional graphs are included in the Appendix. From a maintenance standpoint, the relationship between age and metal concentrations is important. Many current recommendations for deposited soil removal are based on time increments (others are volume-based). Age-based recommendations do not appear adequate. Perhaps stormwater wetlands and wetponds need to be monitored and sampled more frequently, to ensure excavation of sediments prior to violations of aquatic thresholds. If aquatic health protection becomes a driver for sediment removal, frequent sediment monitoring of stormwater BMPs is strongly encouraged.



**Figure 4. Concentration of Chromium at sites sampled. Age of facility appears to be a non-factor.**

### C. Assessing toxicity

The toxicity of all composite samples was assessed in terms of aquatic health and land-application standards (Table 11). The standard for pollutant concentrations varies in severity depending on the desired use of sediments. For example, maximum metal concentrations for the land application are much higher than metal concentrations predicted to harm aquatic health. If aquatic guidelines are met, then land application standards will also be met; however, the reverse is not true. Sediments may violate all aquatic standards and still be fit for land application.

Twenty-two of the 30 forebays sampled exceeded one or more aquatic limit standards considered for comparison. Fifteen forebays exceeded the FDEP TEL threshold for Cu, indicating that 15 of 30 sites are above the upper, or more conservative, limit in which no adverse effects are observed. Additionally, 12 forebays exceeded the FDEP TEL for Ni, 8 for Pb, and 9 for Zn. One forebay exceeded the PEL threshold for Cu, indicating that the Cu concentration at this particular site is above the lower, or most lenient, limit of the range of values associated with adverse effects. One forebay exceeded the PEL for Pb and 4 forebays exceeded the PEL for Zn. Exceedance of the PEL standards will almost certainly result in adverse effects on aquatic health, providing a strong reason for forebay sediment removal. It is very important to note that other factors, such as PAHs, pathogens, and PCBs may also impact aquatic health. These pollutants were not measured in this study.

With regard to land application, there were clearly no observed concentrations of Cu, Zn, Ni, Cd, Cr, or Pb that exceeded the 40 CFR 503 limits. All pollutants sampled met the 40 CFR 503 limits with factors of safety ranging from 5 to 13 (Table 10), suggesting that the land application of accumulated forebay sediment will not pose an environmental threat.

**Table 9. Sites sampled that exceeded the limits of any of the metrics considered for comparison.**

Toxicity Assesment Metric <i>Reference, metric</i>	Number of Violations per Pollutant Type					
	Cd	Cr	Cu	Ni	Pb	Zn
Aquatic Health						
<i>FDEP, 1994</i>						
TEL	3	0	15	12	8	9
PEL	0	0	1	0	1	4
<i>MacDonald et al., 2000</i>						
TEC	3	0	8	3	8	9
PEC	0	0	0	0	1	1
Land Application						
40 CFR503	0	0	0	0	0	0

**Table 10. Pollutant limits by standard compared to maximum observed concentration with factors of safety.**

Pollutant	Aquatic Health, FDEP		40 CFR 503	Forebay Study, 2009	Landuse of Max Value Reported	Safety Factor		
	TEL (mg/kg) dw	PEL (mg/kg) dw	Monthly Average Ceiling Concentrations (mg/kg) dw	(Max value reported) <sup>1</sup> (mg/kg) dw		TEL	PEL	40 CFR 503
Cd	0.7	4.2	39	< 5.0	COM/RES	Exceeded by factor of 7	Exceeded by factor of 1.2	7.8
Cr	52.3	160	-	39	COM	1.3	4.1	-
Cu	18.7	108	1500	116	COM	Exceeded by factor of 6	Exceeded by factor of 1.1	12.9
Ni	15.9	42.8	420	34	COM	Exceedance by factor of 2	1.3	12.4
Pb	30.2	112	300	29	COM	1.04	4	10.3
Zn	124	271	2800	587	COM	Exceeded by factor of 4.7	Exceeded by factor of 2.2	4.8

dw = dry weight basis  
<sup>1</sup> Of all forebays this is the "worst case" scenario

Arsenic (As), mercury (Hg), molybdenum (Mo), and selenium (Se) concentrations must meet standards under 40CFR 503 as well, if forebay sediments are held to 40CFR 503 standards. These were not included in the study due to budgetary constraints. It is unlikely that such metals will be present in significant quantities given that none of the pollutants that *were* measured in the study were within 25% of the 40 CFR 503 level.

**D. Plant Growth Potential**

While the toxicity of metals in sediment was not problematic by 40 CFR 530 standards, it is important to evaluate the potential nutrient availability for plant uptake and consequent growth. If plants cannot establish on applied sediments, stabilization will not occur and spoils, or excavated sediments, will erode, creating toxicity problems elsewhere. To assess nutrient availability, total mass of phosphorus and nitrogen were calculated for each forebay, assuming the theoretical excavation would occur to a depth of 2 feet. The mass of phosphorus and nitrogen per excavation period ranged from 12.5 lbs to 500 lbs and 16.3 lbs to 1600 lbs, respectively (Table 12).

**Table 11. Theoretical calculated amount of TN and TP removed per excavation period (lbs)**

	pH (pre- excavation)	TP (mg/kg) ww	* lbs of TP per excavation period	TN (mg/kg) ww	*lbs of TN per excavation period
MEAN	6.1	169.3	117	447.8	283.4
MEDIAN	6.3	143.8	66	360.1	158.3
MIN	5.2	39.5	12.5	86.9	16.3
MAX	7.2	571.7	500.2	2602	1596.6

\* excavation period = time at which forebay sediments are excavated. Time of excavation varies depending on sedimentation rates and individual forebay characteristics. ww= wet weight.

Ideal nitrogen fertilization loads for four low-maintenance grasses (Table 13) were obtained from Hardy et al. (2009). Recommended phosphorus loads were not provided. All sediments sampled have potential to meet minimum nitrogen fertilization recommendations for all 4 grasses; however, this is dependent upon the dimensions of application including depth and area to be covered. Reasonably, a minimum sediment application depth of 6 inches would allow for the establishment of plants. Overall, authors believe that the amount of nitrogen in forebay sediments will be adequate for grass growth. Still, it is recommended that a soil analysis be completed prior to land-application to identify types and quantities of essential elements of plant growth. At the very least, sediments should be assessed for bioavailable nitrogen, phosphorus, calcium, and potassium, near the time of excavation.

**Table 12. Ideal nitrogen requirements for 4 grasses (Hardy et al., 2009)**

Example Crop type	Recommended Fertilizer Rate of N (lbs/acre) for optimal plant growth
Bluegrass (pH=6.0)	100-200
Clover, grass establishment (pH=6.5)	10-30
Fescue/Orchard/Timothy establishment (pH=6.5)	50-70
Switchgrass (pH=5/5)	120-160

(Hardy et al., 2009)

#### IV. Conclusions

1. Based on 40 CFR503, land application standards, sampled forebay sediments show no environmental threat subsequent to land application for Cu, Zn, Fe, Ni, Cd, Cr, and Pb. Pathogens, PCBs, and PAHs were *not* assessed in this study and could possibly limit land application.
2. Based on FDEP Effects Range Approach limits, concentrations of Cu, Pb, and Zn are *likely* to pose a threat to aquatic health, which further emphasizes the necessity for forebay sediments to be routinely excavated. Concentrations of Cd and Cr did not violate aquatic standards, and thus neither constituent is likely to be of concern in sediment excavation.

However, the FDEP limits do not account for nutrient levels which may also be detrimental to aquatic health.

3. There was no significant differences in metal concentrations between residential and commercial landuses, with the exception of Zn, which was statistically higher in commercial landuses. Interestingly, the maximum concentration exhibited by each pollutant was found in the commercial landuse category, indicating that commercial landuses may need to undergo more thorough testing than residential sites, before land application of sediments.
4. There was not a statistical difference in metal concentrations between forebay sediments and sediments taken near the outlet structures of 10 ponds and wetlands; however, raw data showed that metal concentrations in outlet sediments were higher for all metals detected.
5. Regardless of facility age, percent imperviousness, and drainage area, all forebays tested may be land applied upon excavation. Other factors may hinder land application of sediments such as community resistance to land spreading sediment, resulting from temporary foul odors.
6. Authors recommend that forebay sediments be tested, near time of excavation and prior to land application, for bioavailable nitrogen, phosphorus, calcium, and potassium, to ensure adequate plant growth, and thus prevent erosion of sediments and associated contaminants. Perhaps a subsequent study could establish that bioavailability of nutrients is not detrimental for plant growth. This would alleviate the need for case-by-case testing.

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**Appendix A.** Study Data Compared to Existing Standards and Average Soils in North Carolina

**Table A 1. Comparison of observed pollutant concentrations to 4 metrics**

		Pollutant Concentrations (mg/kg, dry weight basis)						
Regulation (Source)		Cd	Cr	Cu	Ni	Pb	Zn	
Aquatic Health, FDEP		<i>TEL</i>	0.7	52.3	18.7	15.9	30.2	124
Effects Range Approach Standards (FDEP, 1994)		<i>PEL</i>	4.2	160.0	108	42.8	112	271
Freshwater Sediment Quality Guidelines, Consensus Based (MacDonald et al., 2000)		<i>TEC</i>	0.99	43.4	31.6	22.7	35.8	121
40 CFR 503 Monthly Average Ceiling Concentrations		<i>PEC</i>	4.98	111	149	48.6	128	459
Mean N.C. soils			39.0	-	1500	420.0	300	2800
Site	Landuse	Cd	Cr	Cu	Ni	Pb	Zn	
A	COM	ND	17.8	<b>29.0</b>	12.9	15.8	<b>370.0</b>	
B	COM	ND	24.0	12.5	9.4	14.9	72.8	
C*	COM	ND	22.7	<b>33.0</b>	13.0	12.7	<b>282.0</b>	
D*	COM	ND	32.0	<b>31.8</b>	<b>22.0</b>	18.1	<b>141.0</b>	
E	COM	ND	22.7	<b>23.0</b>	<b>31.0</b>	10.3	75.0	
F	COM	ND	19.4	14.8	<b>16.9</b>	12.0	69.0	
G	COM	ND	35.0	<b>116.0</b>	<b>34.0</b>	18.0	<b>292.0</b>	
H	COM	ND	20.0	10.3	14.0	17.8	34.0	
I	COM	ND	33.8	<b>53.0</b>	<b>18.4</b>	9.4	<b>125.0</b>	
J	COM	ND	30.0	<b>36.6</b>	9.4	15.6	45.0	
K	COM	ND	4.8	6.8	3.0	3.3	37.0	
L	COM	ND	13.2	17.0	6.6	29.0	68.0	
M	COM	ND	10.2	15.6	5.9	10.0	<b>171.0</b>	
N	COM	ND	10.0	<b>28.5</b>	6.8	13.0	<b>587.0</b>	
O	COM	ND	22.0	<b>39.0</b>	14.2	7.9	68.7	
P	COM	ND	30.0	<b>28.7</b>	13.4	19.6	<b>128.0</b>	
Q	COM	ND	14.0	15.4	5.9	19.0	50.0	
R	COM	ND	11.5	15.0	8.8	6.3	45.0	
S*	COM	ND	15.7	<b>18.9</b>	<b>16.7</b>	10.0	113.0	
T*	COM	<b>2.5</b>	39.0	<b>27.0</b>	<b>29.3</b>	13.5	110.0	
U*	COM	ND	11.0	16.0	10.0	11.0	57.0	
V*	RES	ND	28.3	16.2	<b>15.9</b>	<b>42.5</b>	42.5	
W	RES	ND	30.6	<b>34.9</b>	<b>18.3</b>	<b>44.0</b>	44.0	
X	RES	ND	36.0	<b>19.0</b>	<b>18.4</b>	<b>46.9</b>	46.9	
Y	RES	ND	16.1	13.1	10.6	26.4	26.4	
Z	RES	<b>2.5</b>	35.0	<b>43.0</b>	<b>17.2</b>	<b>166.0</b>	<b>166.0</b>	
AB*	RES	ND	14.8	5.1	14.0	<b>40.5</b>	40.5	
CD*	RES	ND	33.0	15.1	<b>22.4</b>	<b>63.0</b>	63.0	
EF*	RES	ND	11.0	10.6	14.8	<b>53.0</b>	53.0	
GH	RES	ND	9.8	10.6	12.7	<b>43.0</b>	43.0	

\*\* Bolded concentrations indicate sediments violate one or more regulatory limit. Shaded concentrations are those that exceed a PEL or PEC limit. Fe is not accounted for in the regulations listed and were hence excluded from the table.

Table A 2. Regulations for the land application of sewage sludge and other biosolids (40 CFR503)

	*Ceiling Concentration Limits (CCL)	**Pollutant Concentration Limits (PCL)	***Cumulative Pollutant Loading Rate Limits for Biosolids (CPLR)	****Annual Pollutant Loading Rate Limits for Biosolids (APLR)
<b>Pollutant</b>	<b>mg/kg (dry wt.)</b>	<b>mg/kg (dry wt.)</b>	<b>kg/ha</b>	<b>kg/ha/year</b>
Cd	85	39	39	2
Cr	-	-	-	-
Cu	4300	1500	1500	75
Fe	-	-	-	-
Ni	420	420	420	21
Pb	840	300	300	15
Zn	7500	2800	2800	140

\* Biosolids that are land applied cannot exceed these concentrations.

\*\* Biosolids that are land applied do not need a permit if pollutants exist at or below the listed concentrations.

\*\*\* Total cumulative loading of pollutants cannot exceed listed values.

\*\*\*\* Annual cumulative loading of pollutants cannot exceed listed values.

## Appendix B. Graphical View of Metal Concentrations

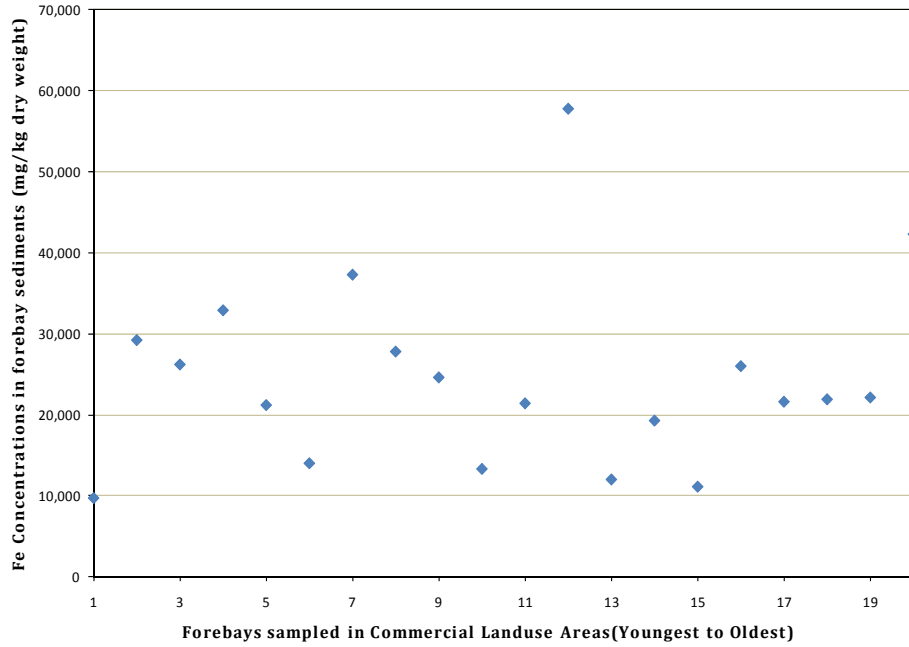


Figure B 1. Fe concentration for each forebay sampled in commercial landuse areas (left to right: youngest to oldest)

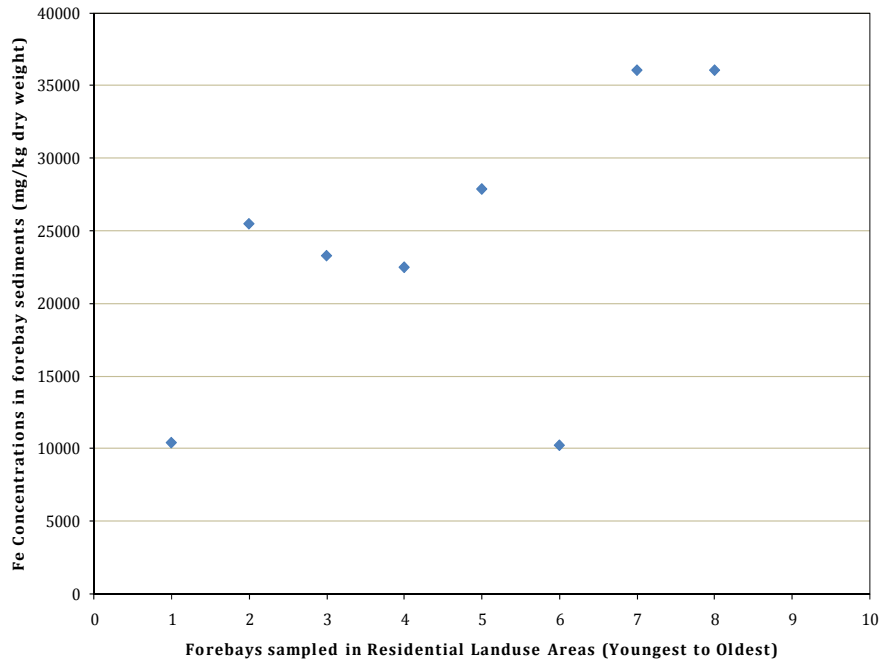


Figure B 2. Fe concentration for each forebay sampled in residential landuse areas (left to right: youngest to oldest)

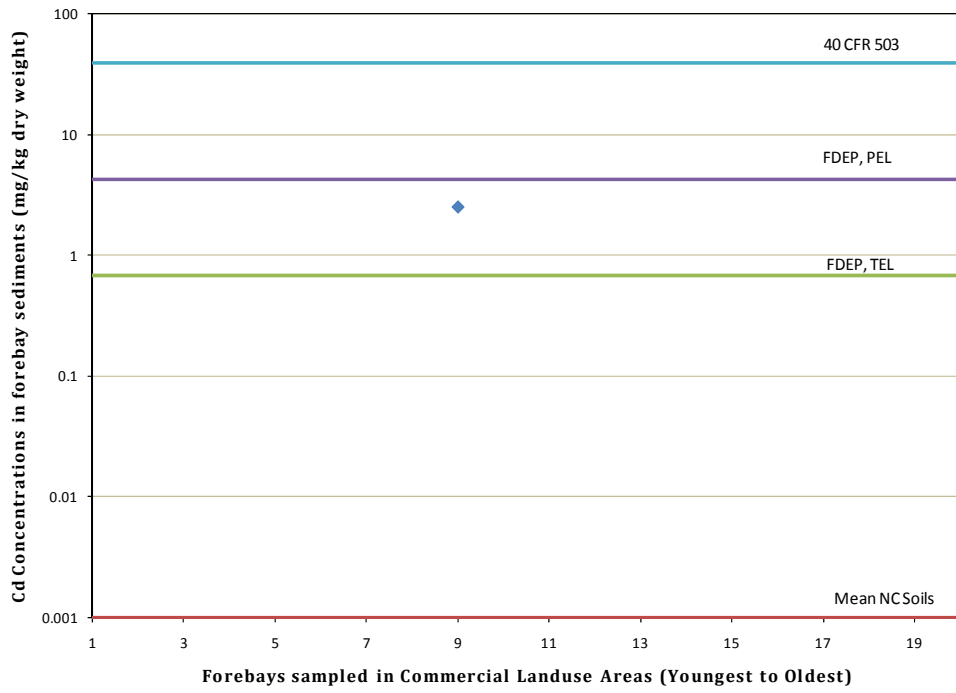
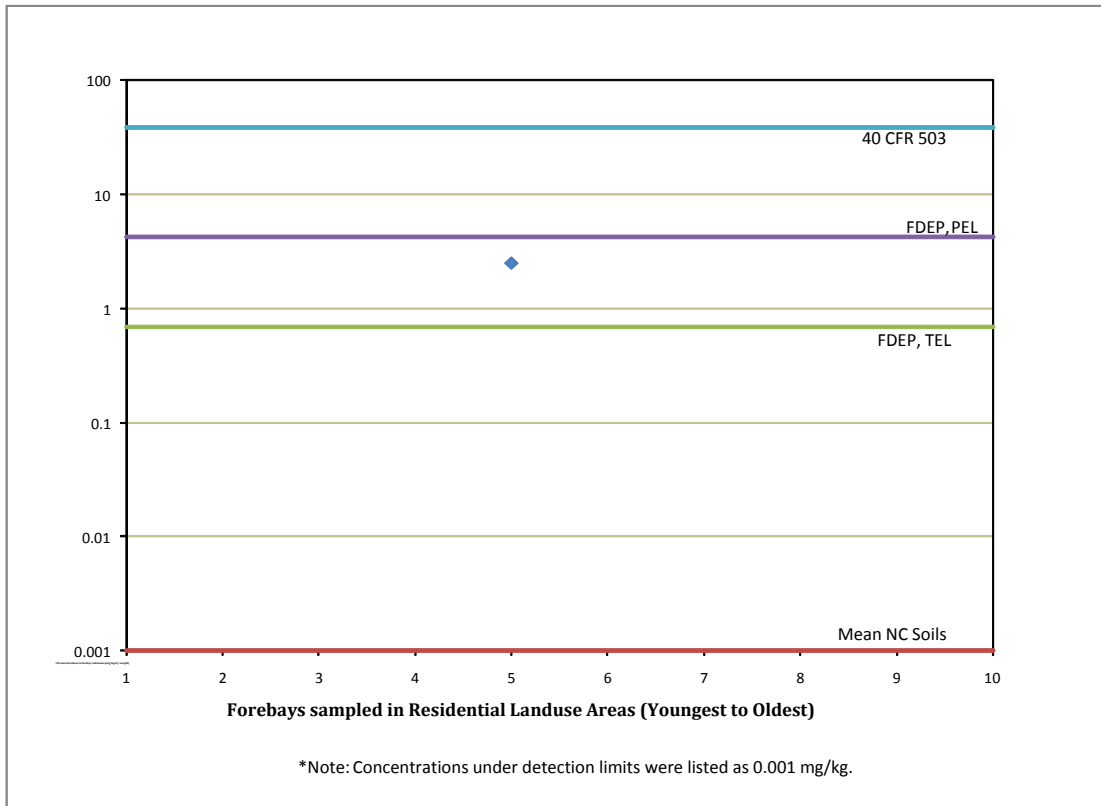


Figure B 3. Cd concentration for each forebay sampled in commercial landuse areas (left to right: youngest to oldest)



**Figure B 4. Cd concentration for each forebay sampled in residential landuse areas (left to right: youngest to oldest)**

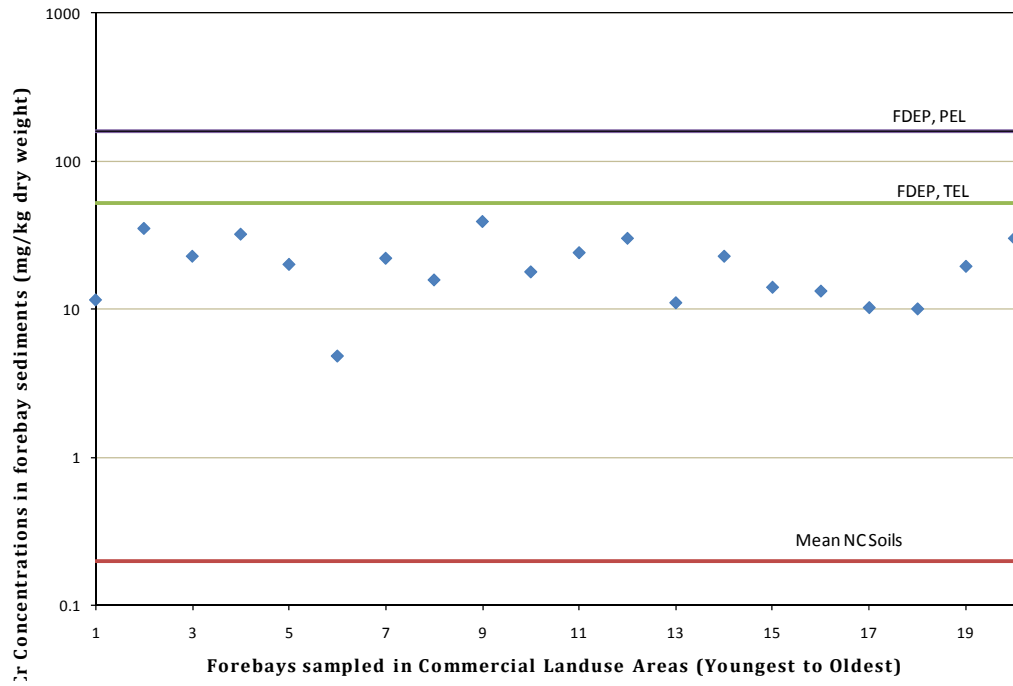


Figure B 5. Cr concentration for each forebay sampled in commercial landuse areas (left to right: youngest to oldest)

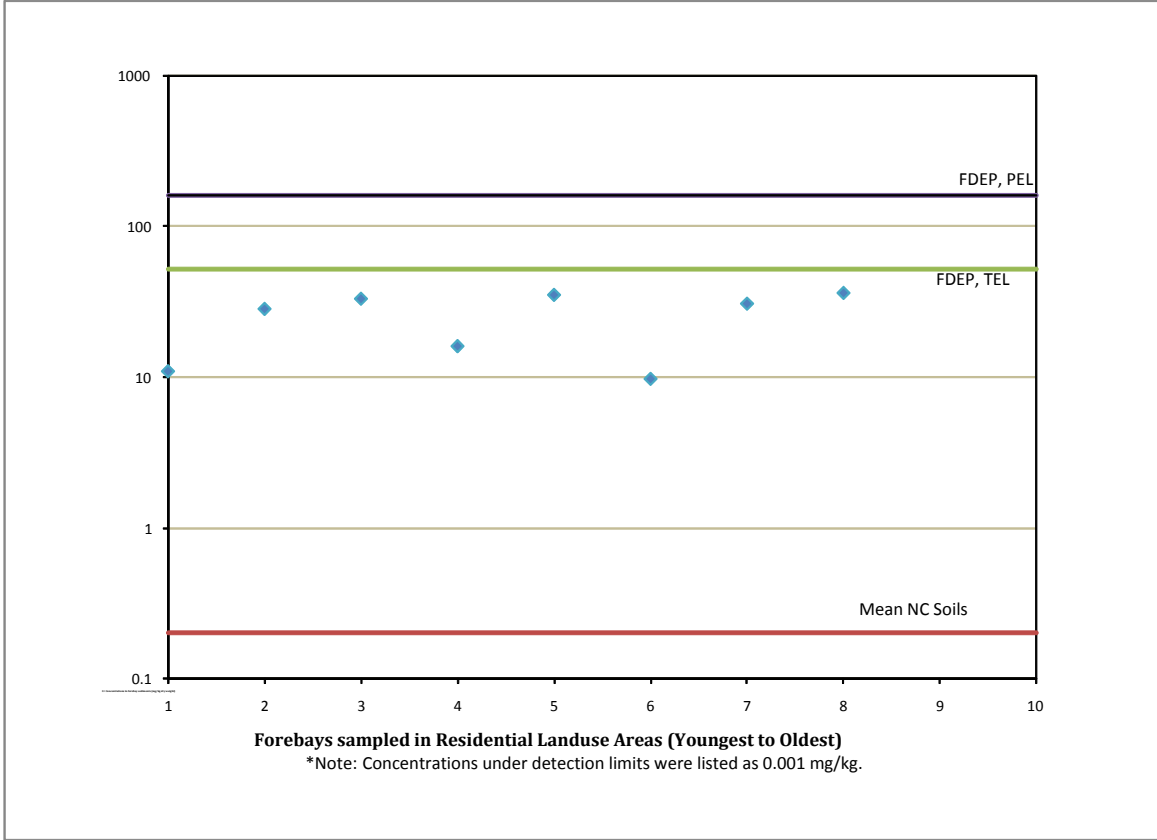


Figure B 6. Cr concentration for each forebay sampled in residential landuse areas (left to right: youngest to oldest)

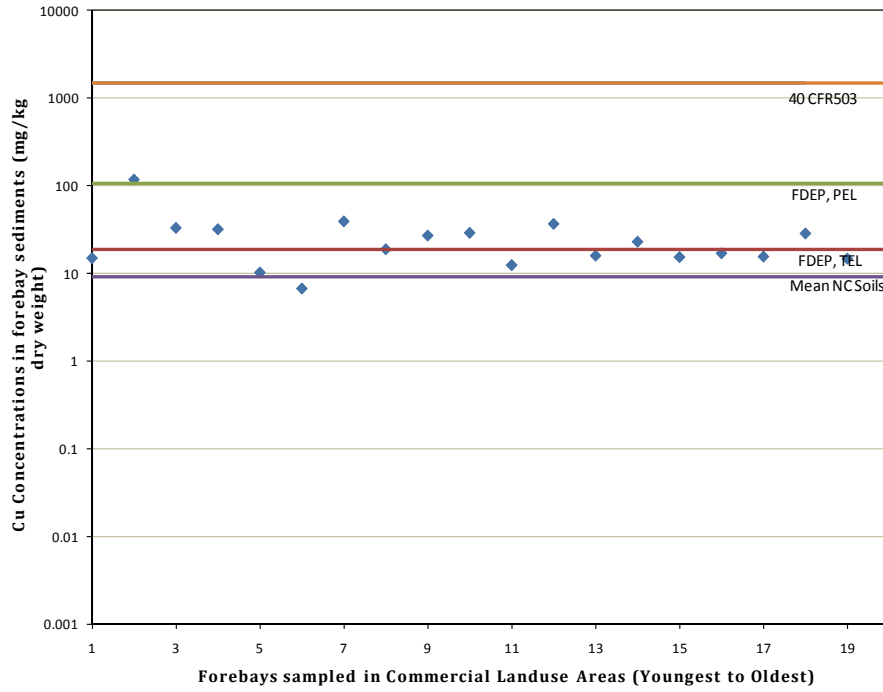


Figure B 7. Cu concentration for each forebay sampled in commercial landuse areas (left to right: youngest to oldest)

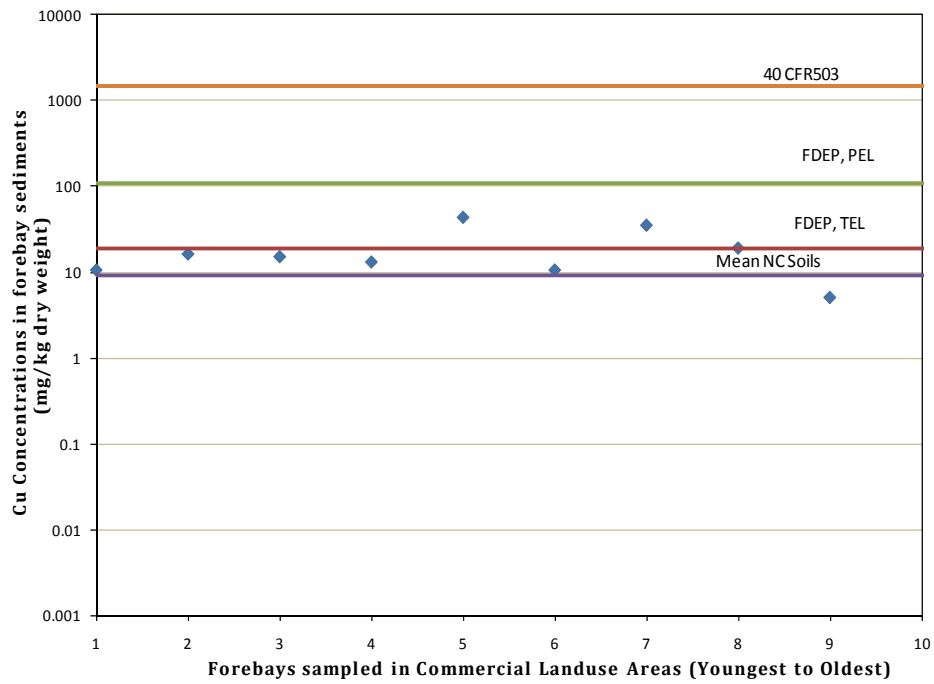


Figure B 8. Cu concentration for each forebay sampled in residential landuse areas (left to right: youngest to oldest)

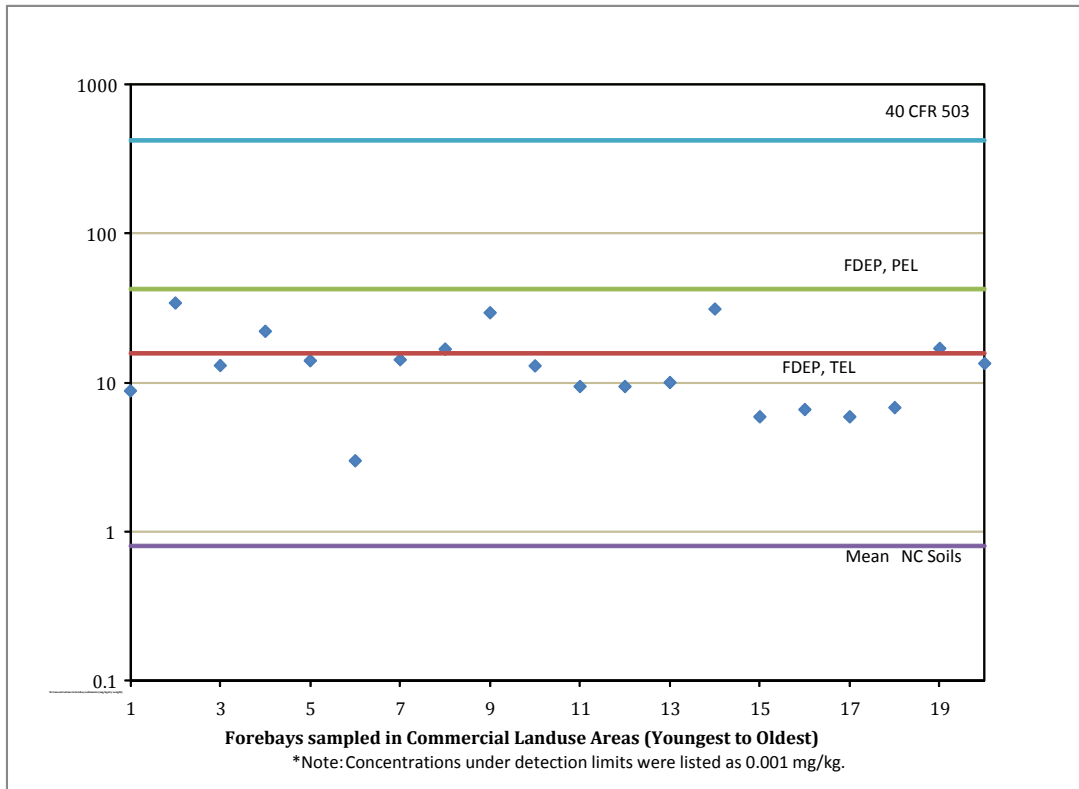


Figure B 9. Ni concentration for each forebay sampled in commercial landuse areas (left to right: youngest to oldest)

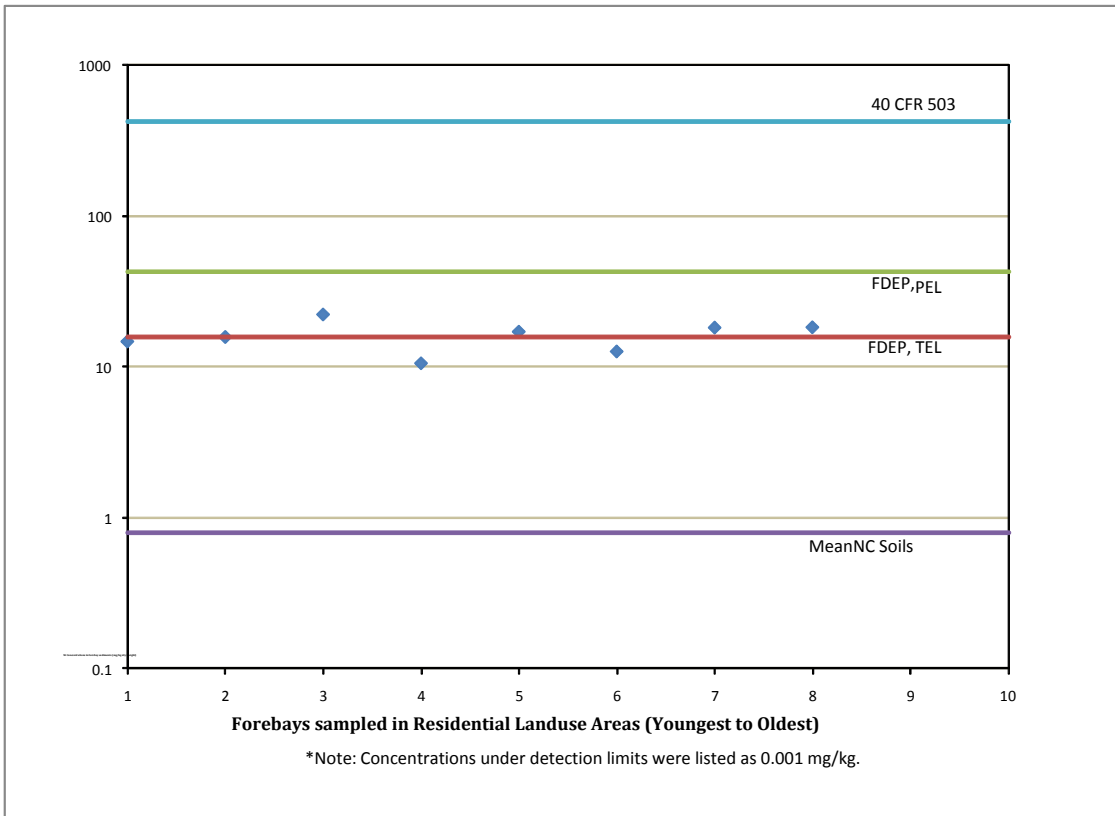


Figure B 10. Ni concentration for each forebay sampled in residential landuse areas (left to right: youngest to oldest)

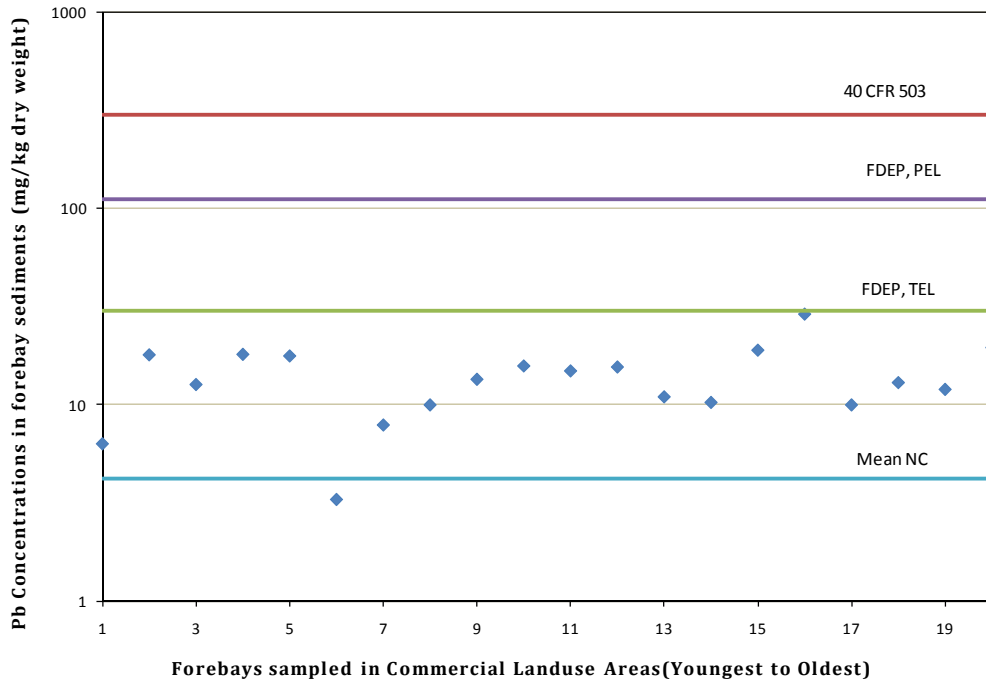


Figure B 11. Pb concentration for each forebay sampled in commercial landuse areas (left to right: youngest to oldest)

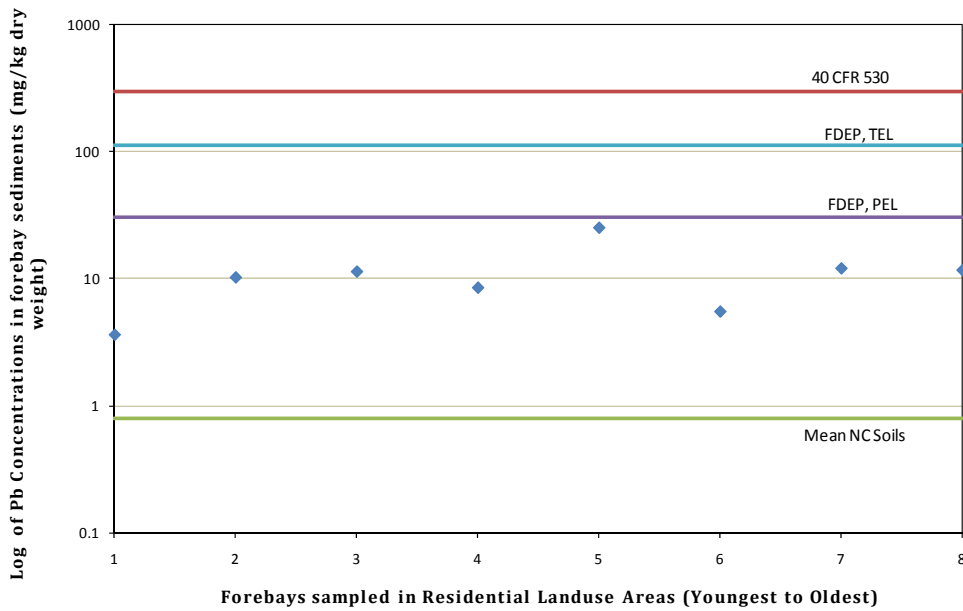


Figure B 12. Pb concentration for each forebay sampled in residential landuse areas (left to right: youngest to oldest)

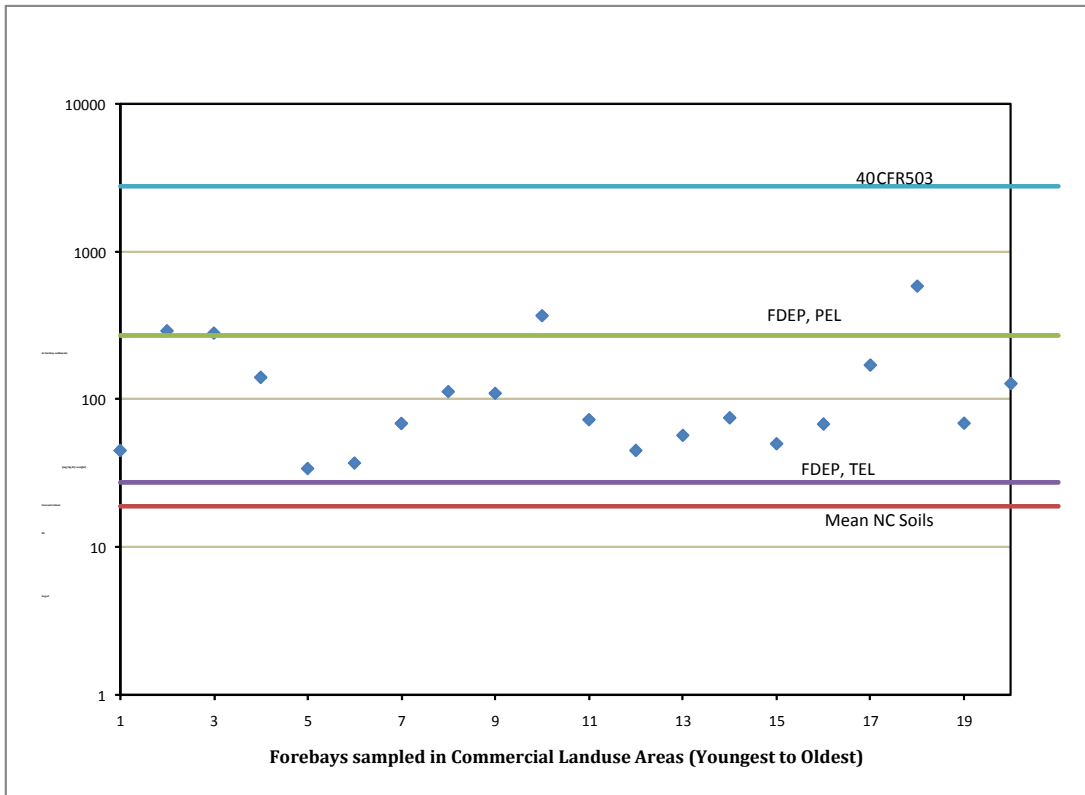


Figure B 13. Zn concentration for each forebay sampled in commercial landuse areas (left to right: youngest to oldest)

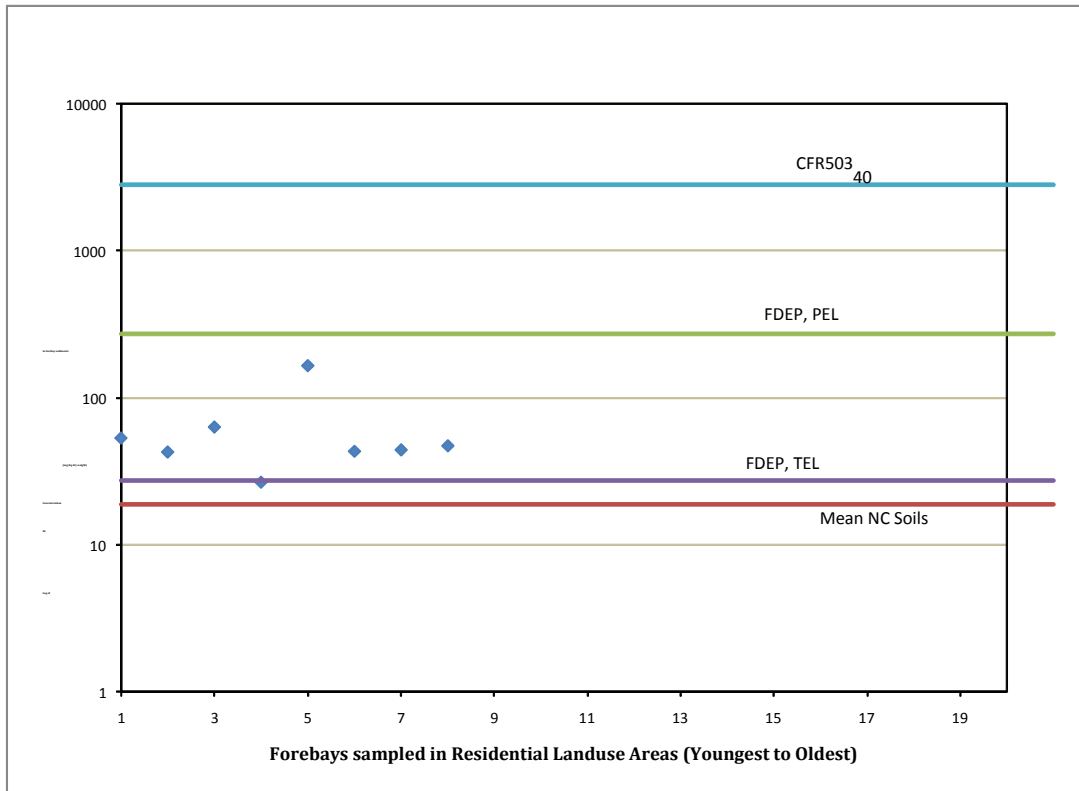


Figure B 14. Zn concentration for each forebay sampled in residential landuse areas (left to right: youngest to oldest)