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ENVIRONMENT BERMUDA

SOIL AND WATER TANK SURVEY 2005

Bermuda Biological Station for Research, Inc.

August 2006

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ENVIRONMENT BERMUDA

SOIL AND WATER TANK SURVEY 2005

Contents i
List of Tables iv
List of Figures v
Executive Summary vi
Acknowledgements x
Glossary of Terms and Abbreviations xi

Chapter 1 - Municipal Solid Waste Incineration in Bermuda 1

1.1 - Introduction 1

1.2 - Types and Impacts of Emissions from Municipal Solid Waste Incinerators 1
  1.2.1 - Introduction 1
  1.2.2 - Environmental and Health Effects of MSWI 2

1.3 - Municipal Solid Waste Disposal in Bermuda 6

1.4 - Bermuda Soil and Water Tank Survey 2005 11
  1.4.1 - Numbers and Types of Samples Acquired 11
  1.4.2 - Chemical Analysis 12

1.5 - Notes on Statistical Analysis of Data 12

Chapter 2 - Environmental Contaminants Surveyed in 2005 13

2.1 - Introduction 13

2.2 - Heavy Metals and Metalloids 13
  2.2.1 - Introduction 13

2.3 - Dioxins 21
  2.3.1 - Introduction 21
  2.3.2 - Dioxin Toxicity 22
  2.3.3 - Patterns of PCDD/F congeners and homologues 24

2.4 - Polycyclic Aromatic Hydrocarbons 25
  2.4.1 - Introduction 25
  2.4.2 - PAH Toxicity and Carcinogenicity 25

(cont. overleaf)

Chapter 3 - Contaminants in Soil 28

3.1 - Bermuda's Soil 28

3.2 - Metals and Metalloids in Soil 28
3.2.1 - Sampling 28
3.2.2 - Analysis 30
3.2.3 - Results: Summary Statistics 30
3.2.4 - Comparison of Soil Concentrations with Background Levels 35
3.2.5 - Comparison of Soil Concentrations with Regulatory Limits 38
3.2.6 - Significance and Sources of Specific Metals in Bermuda Soils 40
3.2.6.1 - Arsenic 40
3.2.6.2 - Mercury 41
3.2.6.3 - Chromium 41
3.2.6.4 - Lead 42
3.2.6.5 - Other elements 42
3.2.7 - Profiles of Metals in Soil and TBWTF Incinerator Emissions 43
3.2.8 - Dependence of Soil Metal Concentrations on Proximity to Incinerator 43
3.2.9 - Spatial Trends in Metal Concentrations in Soil 46
3.2.10 - Temporal Trends 50

3.3 - Organic Contaminants in Soil 54
3.3.1 Sampling 54
3.3.2 Analysis 54
3.3.3 Dioxins 55
3.3.3.1 - Results 55
3.3.3.2 - Comparison with Legislative limits 55
3.3.3.3 - Comparison of Soil PCDD/F Concentrations with Background Levels 58
3.3.3.4 - Dependence of Soil PCDD/F Concentrations on Proximity to Incinerator 58
3.3.3.5 - Potential Sources of PCDD/Fs in Soil 60
3.3.4 PAHs 63
3.3.4.1 - Results 63
3.3.4.2 - Comparison with Legislative limits 63
3.3.4.3 - Comparison of Soil PAH Concentrations with Background Levels 67
3.3.4.4 - Dependence of Soil PAH Concentrations on Proximity to Incinerator .. 68
3.3.4.5 - Potential Sources of PAHs in Soil 68

(cont. overleaf)

Chapter 4 - Contaminants in Water Tanks 70

4.1 - Introduction 70

4.2 - Metals and Major Ions in Tank Water 71
4.2.1 - Sampling 71
4.2.2 - Analysis 71
4.2.3 - Results: Summary Statistics 73
4.2.4 - Comparison with Regulatory Limits 77
4.2.5 - Dependence on Proximity to Incinerator 78

4.3 - Metals in Tank Sediment 79
4.3.1 - Sampling 79
4.3.2 - Analysis 80
4.3.3 - Results: Summary Statistics 80
4.3.4 - Comparison with Regulatory Limits 85
4.3.5 - Distribution of Metals in Tank Sediment and Soil 86
4.3.6 - Distribution of Metals in Tank Sediment and Tank Water 87
4.3.7 - Dependence on Proximity to Incinerator 87

4.4 - Organic Contaminants in Tank Water 88
4.4.1 - Sampling 88
4.4.2 - Analysis 88
4.4.3 - Dioxins 88
4.4.3.1 - Results 88
4.4.3.2 - Comparison with Regulatory Limits 89
4.4.4 - PAHs 90
4.4.4.1 - Results 90

4.5 - Organic Contaminants in Tank Sediment 90
4.5.1 - Sampling 90
4.5.2 - Analysis 90
4.5.3 - Dioxins 91
4.5.3.1 - Results 91
4.5.3.2 - Comparison with Regulatory Limits 91
4.5.3.3 - Dependence of Sediment PCDD/F Concentrations on Proximity to Incinerator 93
4.5.3.4 - Dioxin Profile in Tank Sediment 93
4.5.4 - PAHs 96
4.5.4.1 - Results 96
4.5.4.2 - Comparison with Regulatory Limits 97
4.5.4.3 - Dependence of Sediment PAH Concentrations on Proximity to Incinerator 97

References 99

Data Appendix 105

List of Tables

Table 1.1: Amounts (kg per capita) of municipal solid waste (MSW) collected, incinerated and landfilled in different countries. ... 7
Table 1.2: Results of annual stack emission testing at TBWTF in 2004 ... 9
Table 1.3: Types and numbers of samples collected in 2005. ... 11
Table 1.4: Contaminant analytes and other parameters measured ... 11

Table 2.1: PCDD and PCDF human/mammalian TEFs determined by the WHO ... 24
Table 2.2: Classification of carcinogenic toxicity of PAHs ... 25

Table 3.1: Analytical methods and techniques used for metals in soil ... 30
Table 3.2: Rate of detection, detection limits and distribution type for elements and LOI in Bermuda soil ... 31
Table 3.3: Summary statistics for metals and LOI measured in Bermuda soil ... 34
Table 3.4: Comparison of mean and background Bermuda soil metal concentrations with background concentrations from other regions ... 37
Table 3.5: Exceedences by metals in Bermuda soil of the U.S. generic Soil Screening Limits (SSL) for residential scenarios and Canadian Soil Quality Guidelines (SQG) for residential/parkland scenarios ... 39
Table 3.6: Significant differences in mean concentrations of metals in Bermuda soil with distance from the incinerator ... 45
Table 3.7: Geometric mean values of selected elements in Bermuda soil for groups identified by AHC analysis ... 48
Table 3.8: Summary statistics for dioxin congeners and homolog groups measured in Bermuda soil ... 57
Table 3.9: Geometric mean concentrations of PCDD/F congeners and homolog groups measured in Bermuda soil at distances of < 1 km and > 1 km from the incinerator at TBWTF ... 59
Table 3.10: Summary statistics for PAHs measured in Bermuda soil ... 65
Table 3.11: Exceedences by PAHs of U.S. EPA Soil Screening Levels (SSL) and Canadian Soil Quality Guideline (SQG) levels ... 66
Table 3.12: Comparison of U.S. background concentration of PAHs in soil with values observed in Bermuda ... 67
Table 3.13: Geometric mean concentrations of PAHs measured in Bermuda soil at distances of < 1 km and > 1 km from the incinerator at TBWTF ... 68

Table 4.1: Analytical methods and techniques for water samples ... 73
Table 4.2: Summary statistics for pH, conductivity, major ions and metals in tank water ... 76
Table 4.3: Drinking water standards (DWS) in effect in Bermuda ... 77
Table 4.4: Median and geometric mean values of Mo and Sb in tank water at varying distances from the incinerator ... 78
Table 4.5: Rate of detection, detection limits and distribution type for elements and LOI in tank sediment ... 81
Table 4.6: Summary statistics for LOI and metals measured in tank sediment ... 84
Table 4.7: U.S. generic Soil Screening Limits (SSL) for ingestion of soil in residential scenarios and exceedences in tank sediment and soil samples ... 85
Table 4.8: Median and geometric mean values of As in tank sediment at varying distances from the incinerator ... 87
Table 4.9: Dioxins concentrations in water samples ... 89
Table 4.10: Summary statistics for dioxin congeners and homolog groups measured in tank sediment ... 92
Table 4.11: Geometric mean concentrations of PCDD/F congeners and homolog groups in water tank sediment at distances of < 1 km and > 1 km from the incinerator at TBWTF ... 94
Table 4.12: Summary statistics for PAHs measured in tank sediment ... 96
Table 4.13: Exceedences of U.S. EPA Soil Screening Levels (SSL) and Canadian Soil Quality Guideline (SQG) levels for PAHs in water tank sediment ... 98

List of Figures

Figure 1.1: Location of Tynes Bay Waste Treatment Facility, Bermuda 10

Figure 2.1: Chemical structure of polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans 21
Figure 2.2: Structures, chemical formulae and molecular weights of the EPA 16 PAHs 27

Figure 3.1: Map showing soil sampling locations 29
Figure 3.2: Histograms of element and LOI frequency distributions.. 32
Figure 3.3: Correlations of As with Al and Fe in Bermuda soil 41
Figure 3.4: Correlations of Cr with Al and Fe in Bermuda soil.. 42
Figure 3.5: Profile of metal concentrations in soil < 1 km and > 1 km from the incinerator and in the TBWTF incinerator stack emissions... 43
Figure 3.6: Dendrogram from AHC analysis of soil metal data... 48
Figure 3.7: Factor plot and correlation circle of the first 2 components identified by principal component analysis... 49
Figure 3.8: Concentrations of metals in Bermuda soil, 1994, 2000 and 2005.. 51
Figure 3.9a: Histograms of PCDD congener frequency distributions 56
Figure 3.9b: Histograms of PCDF congener frequency distributions 56
Figure 3.10: Top: Congener profiles for dioxins in soil samples at distances of < 1 km and > 1 km from the incinerator at TBWTF; Middle: correlation of the congener concentrations; Bottom: congener profile from stack emission testing of the incinerator at TBWTF.................................. 61
Figure 3.11: PCDD/F congener profiles for particular sources 62
Figure 3.12: Histograms of PAH frequency distributions... 64

Figure 4.1: Map showing water tank sampling locations 72
Figure 4.2a: Histograms of major anion frequency distributions... 74
Figure 4.2b: Histograms of pH, conductivity and major cation frequency distributions 74
Figure 4.2c: Histograms of frequency distributions for metals.. 75
Figure 4.3: Histograms of LOI and metal frequency distributions in tank sediment 82
Figure 4.4: Correlation of the geometric means for metal concentrations in sediment and soil................ 86
Figure 4.5: Congener profile of dioxins in water tank sediment.. 95

ENVIRONMENT BERMUDA

SOIL AND WATER TANK SURVEY 2005

Executive Summary

Introduction

- This report provides an analysis of data collected from a survey of soil and domestic water tanks in Bermuda, conducted in 2005. The objective of the survey was to investigate the impact on soil and water quality attributable to waste emissions from incineration operations at Tynes Bay Waste Treatment Facility (TBWTF).

- This survey supplements 2 previous surveys conducted by BBSR in 1994 and in 2000 and which were analysed in a previous report submitted to the Department of Environmental Protection: Environment Bermuda - Atmospheric and Terrestrial Studies: Survey Data Report.

- This report includes brief reviews of the types and impacts of emissions from municipal solid waste incinerators and of municipal waste disposal in Bermuda.

- The 2005 survey measured a suite of heavy metals and 2 classes of organic contaminants (dioxins and polycyclic aromatic hydrocarbons (PAHs)) in soil, domestic tank drinking water and domestic tank sediments from a number of sites across Bermuda.

- Where applicable, the data have been compared with statutory levels in effect in Bermuda. Where these are not available, relevant values from the USA and/or Canada have been used.

- The findings suggest that waste incineration at TBWTF has had little measurable impact on soil and water tank quality. However, there still remain some areas of concern and there is, in some cases, a need for further monitoring and/or research.

Municipal Waste Disposal in Bermuda

- In 2004, the incinerator received *c*. 74,000 tonnes of waste. Of this, *c*. 73,000 tonnes (99%) was incinerated at a mean rate of 200 tonnes/day. The remaining *c*. 900 tonnes (1%) was redirected to the Bermuda Airport dump.

- In 2004, the TBWTF incinerator generated *c*. 12,000 tonnes of ash (16% of combusted mass) and *c*. 1,100 tonnes of metal residue (2% of combusted mass). Over the same time period the facility generated *c*. 24,000 MWh of electricity, *c*. 16,000 MWh of which was exported to the island's electricity generation company, BELCO.

- Annual stack emission testing shows that the TBWTF incinerator is in compliance with all parameters regulated in Bermuda, with the exception of dioxin emissions. It also complies with relevant U.S. limits for the same age, type and size of incinerator, with the exception of total dioxins and mercury. Recent EU limits designated in the EU Waste Incineration Directive are more strict, and the TBWTF incinerator exceeds the EU limits for HCl, dioxins, mercury and one group of toxic metals.

- Annual results of ambient air quality monitoring conducted by BBSR on behalf of the Department of Environmental Protection have shown that, to date, there have been no observable impacts from the incinerator on air quality parameters measured at the monitoring location.

Metals in Soil

- The concentrations of Fe and Al in soil are high, reflecting the high clay content of Bermuda soil.

- Levels of Ca, Mg and Sr in soil reflect the influence on soil chemistry of the limestone bedrock.

- At all sites studied, As exceeded the U.S. EPA generic soil screening level for human ingestion and dermal adsorption. This suggests that levels of As in soil in Bermuda require further assessment, particularly at the sites displaying maximum values. However, when compared with other regions, As levels in Bermuda soil are within or close to expected background levels.

- Cr and Pb exceeded the U.S. EPA generic soil screening level for human ingestion and dermal adsorption at 8 (13%) and 1 (2%) sites, respectively.

- The Canadian Soil Quality Guideline limits were exceeded by As (18%), Hg (2%), Se (5%), Cr (52%), Cu (5%), Pb (8%) and Zn (3%) (numbers in brackets indicate percentage of site exceedences).

- Concentrations of As, Cr, Se, Cu and Zn are significantly and positively correlated with Fe and Al content of soil, indicating that these metals may be present in soil in Bermuda at naturally high background levels owing to inclusion in African dust from which the majority of Bermuda's soil is derived. Additionally, historic land use practices may account for localised concentration maxima in particular locations though there is no evidence available to support or refute this hypothesis.

- Pb and Hg are not correlated with Fe and Al content of soil, indicating possible local sources of these metals. In particular, it appears that Gibbs Hill lighthouse has been a significant source of Hg in soil in the immediate vicinity.

- Incidences of high metal concentration in soil are well distributed across Bermuda and there does not appear to be any geographical clustering associated with the Tynes Bay incinerator.

- The concentrations of heavy metals in soil have in general decreased over the period 1994-2005.

- Contamination of soil resulting from incinerator activities was not conclusively detected.

  Recommendations:

  - *A more complete mineralogical and geochemical analysis of Bermuda's soil and bedrock would better enable the determination of background levels of major and trace elements in Bermuda soil.*

  - *At those sites where the U.S. generic soil screening level of metals is exceeded, further risk assessment may be necessary.*

  - *The chemical speciation (i.e. determination of organic v. inorganic As-compounds) and an assessment of the (bio)availability of As in soil is necessary to fully characterise the risk posed by exposure to As present in Bermuda soil.*

Organic Contaminants in Soil

- The mean concentration of dioxins in Bermuda soil is approximately 3 orders of magnitude (i.e. 1000 times) lower than the U.S. EPA clean-up standard and a factor of 4 lower than the Canadian sediment quality guideline value. No single sample exceeded either of these limits.

- Dioxin levels were also less than mean rural and urban background concentrations of dioxins in soil from a range of locations in North America and Europe.

- Dioxin levels from sites closer to (< 1km) the Tynes Bay incinerator were significantly higher by a factor of 2 than from sites located at greater distances (> 1km), but were still well below legislative limits.

- The profile of the individual dioxin compounds present is uniform across all sites and suggests that road vehicle emissions are the predominant source of dioxins in soil and the higher levels close to TBWTF may be the result of vehicular activity related to this facility and to the nearby road and bus depot. PCP, an industrial wood preservative, may also be a local source of dioxins.

- The U.S. EPA generic soil screening level for 5 PAH compounds was exceeded at 8 out of 20 sites sampled and the Canadian soil quality guideline value was exceeded by BaP at one site. This indicates that PAHs should be subjected to further risk assessment.

- The mean levels of PAHs all fell within the expected range for background agricultural soils in the U.S.A. and were lower than expected levels in U.S. urban soils.

- There was no significant difference observed between PAH levels in soil at distances of < 1 km and > 1 km from the incinerator.

- The profile of PAH compounds suggests that combustion sources are responsible for PAH loadings in soil. Likely sources include emissions from road traffic and power generation, as well as the incinerator.

Recommendations:

- *Further investigation of PAH levels in Bermuda soil is recommended to provide a better risk assessment for those PAH compounds which exceeded U.S. EPA generic soil screening levels and to better identify sources of PAHs in soil.*

Metals in Domestic Water Tanks

- Out of the 112 water tanks tested, 3 exhibited exceedences of 1 or more Bermuda Primary Drinking Water Standards. These were for nitrate (3 locations), Pb (1 location) and Se (1 location). In addition, Secondary Drinking Water Standards were exceeded at 24 other locations. The majority of these related to Al (17 locations) and pH (7 locations). Full details of non-compliance with Bermuda Drinking Water Standards were provided to the Department of Environmental Protection as soon as the results were available so that immediate action could be taken, as appropriate.

- There were no significant differences observed between metal concentrations in tank water based on proximity to the incinerator, indicating that the incinerator does not appear to be a source of heavy metals in tank water.

- Sediment was sampled from 36 of the water tanks used for water sampling. Of these, all sites had As concentrations in sediment which exceeded the U.S. EPA generic soil screening level for human ingestion and dermal adsorption. However, the fact that the corresponding water samples did not contain significant levels of As suggests that the As in tank sediment is not readily exchangeable.

- The distribution profile of all metals in tank sediments was highly correlated with that in soils, suggesting that soil is the predominant source of tank sediment and associated metals.

- There was no observable relationship between levels of metals in sediment and in the overlying water, suggesting that tank sediment is not a significant source of dissolved metals in tank water.

- When analysed for spatial trends, As was the only metal which displayed a significant trend with distance from the incinerator: higher mean concentrations of As were observed with increasing distance from the incinerator.

Recommendations

  - *A better understanding of the potential impacts of metals contaminants in water tanks would be gained by systematically studying a small number of water tanks over an extended period of time to assess the behaviour of contaminants during typical use and recharge conditions.*
  - *Domestic water supplies should be equipped with sediment filters to remove suspended sediment from drinking water.*

Organic Contaminants in Domestic Water Tanks

- Dioxins and PAHs were detected at negligible levels in tank water, indicating that consumption of tank water does not pose a significant human health risk from these compounds.
- The mean island-wide concentration of dioxins in water tank sediment in Bermuda is 2 orders of magnitude lower than the U.S. EPA clean-up standard for soil but 10 times higher than the more stringent Canadian soil quality guideline limit.
- Dioxin levels in sediment from water tanks closer to (< 1km) the Tynes Bay incinerator were significantly higher by a factor of 10 than in sediment from sites located at greater distances (> 1km) from the incinerator, but were still a factor of 10 lower than the U.S. EPA cleanup level.
- The profile of dioxins in water tank sediment corresponded with that observed in soil, suggesting a similar source of dioxins, i.e. road traffic emissions.
- PAHs exceeded the U.S. EPA generic soil screening level at 10 out of 20 locations. These results indicate that PAHs in water tank sediment may be of concern owing to the potential for ingestion of PAH-contaminated sediment particles entrained in drinking water.
- No significant difference in PAH concentration with distance from the incinerator was observed, suggesting that PAHs in tank sediment are randomly distributed on a spatial scale

Recommendations

  - *Further investigation of PAH levels in sediment in water tanks is recommended to provide a better risk assessment for those PAH compounds which exceeded U.S. EPA generic soil screening levels.*
  - *A better understanding of the potential impacts of organic contaminants in water tanks would be gained by systematically studying a small number of water tanks over an extended period of time to assess the behaviour of contaminants during typical use and recharge conditions.*
  - *Domestic water supplies should be equipped with sediment filters to remove suspended sediment from drinking water.*

ENVIRONMENT BERMUDA

SOIL AND WATER TANK SURVEY 2005

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- GIS map graphics were prepared by Aja Peters-Mason (Duke University/BAMZ Intern).

ENVIRONMENT BERMUDA

SOIL AND WATER TANK SURVEY 2005

Glossary of Terms and Abbreviations

µg:	microgram (1 millionth g; 10^{-6} g)
µS:	microsiemens (measure of electrical conductivity of water)
AAS:	atomic absorption spectroscopy
Ag:	Silver
AHC:	agglomerative hierarchical clustering
Al:	Aluminum
APHA:	American Public Health Association
As:	Arsenic
ATSDR:	Agency for Toxic Substances and Disease Registry
B:	Boron
Ba:	Barium
Be:	Beryllium
Bi:	Bismuth
c.:	approximately (Latin: *circa*)
Ca:	Calcium
Cd:	Cadmium
CI:	confidence interval
Cl^-:	Chloride
cm:	centimeter (1 hundredth m)
Co:	Cobalt
CoV:	coefficient of variation
Cr:	Chromium
Cu:	Copper
DAF:	dilution attenuation factor
DL:	detection limit
DWS:	drinking water standard
EPA:	Environmental Protection Agency
EU:	European Union
Fe:	Iron
g:	gram
GIS:	geographic information system
GDP:	gross domestic productivity
GM:	geometric mean
Hg:	Mercury
K:	Potassium
kg:	kilogram (1000 g)
km:	kilometer (1000 m)
L:	liter
LOI:	loss-on-ignition
m:	meter
MCL:	Maximum Contaminant Level
MCLG:	Maximum Contaminant Level Goal
Mg:	Magnesium
mg:	milligram (1 thousandth g; 10^{-3} g)
mm:	millimeter (1 thousandth m)
Mn:	Manganese
Mo:	Molybdenum
MSW:	municipal solid waste
MSWI:	municipal solid waste incineration/ incinerator
n.d.:	not detected
n/a:	not available
Na:	Sodium
ng:	nanogram (1 billionth g; 10^{-9} g)
Ni:	Nickel
Nm^3:	normal cubic meters
NO_3^-:	Nitrate
P:	Phosphorus
P:	probability (when referring to statistical analyses)
PAH:	polycyclic aromatic hydrocarbon
Pb:	Lead
PCA:	principal component analysis
PCDD:	polychlorinated dibenzo-*p*-dioxin
PCDF:	polychlorinated dibenzofuran
pg:	picogram (1 trillionth g; 10^{-12} g)
pH:	measure of acidity
RAIS:	Risk Assessment Information System
s.d.:	standard deviation
Sb:	Antimony
Se:	Selenium
Sn:	Tin
SO_4^{2-}:	Sulphate
SQG:	Soil Quality Guideline
Sr:	Strontium
SSL:	Soil Screening Limit
TBWTF:	Tynes Bay Waste Treatment Facility
TCDD:	tetrachlorodibenzo-*p*-dioxin
TEF:	toxic equivalence factor
TEQ:	toxic equivalence
Ti:	Titanium
Tl:	Thallium
U:	Uranium
V:	Vanadium
WHO:	World Health Organization
Zn:	Zinc

Chapter 1 - Municipal Solid Waste Incineration in Bermuda

1.1 - Introduction

To assess the potential environmental impacts of exhaust emissions from the Tynes Bay Waste Treatment Facility (TBWTF) incinerator, the Department of Environmental Protection (part of the Ministry of the Environment) has commissioned the Bermuda Biological Station for Research (BBSR) to undertake two previous environmental surveys: one in early 1994 prior to the commencement of incinerator operations later that year; and one in 2000 after approximately 5 years of operation. These surveys provided measurements of the chemical quality of Bermuda's domestic water tanks, air, soil and locally produced vegetables. The results from these 2 surveys were analysed and compared in a previous report submitted by BBSR to the Department of Environmental Protection (Environment Bermuda - Atmospheric and Terrestrial Studies: Survey Data Report).

A third follow-up survey was commissioned in 2005 and is the subject of this report. Soil, domestic tank water and water tank sediment were sampled throughout Bermuda in 2005 for analysis of a suite of metal and metalloid elements and for the organic contaminants dioxins and polycyclic aromatic hydrocarbons (PAHs). Details of these parameters are presented in Section 1.4, below, and the general environmental and toxicological significance of the contaminants are summarised in Chapter 2.

It is important to note that surveys of this type provide only a "snapshot" of the environmental quality of the media examined and therefore the data only represent the conditions at the time when the samples were taken. In particular, water in domestic water tanks can be expected to exhibit large temporal variations in chemical and physical properties. Conversely, undisturbed soil and tank sediment may provide a representative cumulative record of contaminant accumulation over long periods of time.

1.2 - Types and Impacts of Emissions from Municipal Solid Waste Incinerators

1.2.1 - Introduction

Incineration of municipal solid waste (MSW) involves the controlled burning of wastes at temperatures above 850°C for a sustained period, achieving a significant reduction in the volume and mass of waste (DEFRA, 2004). This process produces two main types of waste product: 1) solid ash, consisting of bottom ash from the incinerator and fly ash from the stack which is usually predominantly retained by air pollution control measures; and 2) stack exhaust emissions, consisting of particulate matter and gases. In municipal waste incinerators, bottom ash is approximately 10% by volume and approximately 20 to 35% by weight of the solid waste input (Irish EPA, 2004). Fly ash quantities are much lower, typically about 4% of the weight of waste incinerated (DEFRA, 2004). The proportions of solid residue vary greatly according to the waste type and process design.

The most common and commercially viable designs of municipal solid waste incinerators (MSWI) are grate and fluidised bed systems (Irish EPA, 2004). Grate systems involve a system of moving grates to facilitate the movement of the waste through the combustion zone, which allows the provision of adequate supplies of air to guarantee complete combustion of the waste. This is the type of incinerator design used at TBWTF. It is the predominant design found in most recent MSW incinerators in the USA (NRC, 2000). Fluidised bed technology requires waste to be within a certain particle size range, which usually requires some degree of pretreatment and/or the selective collection of waste. A bed of sand is placed in the combustion chamber and brought to its operating temperature before waste is added. It is then fluidised by supplying combustion air. Fluidised bed incinerators for MSW are more common in Europe and are rarely used for MSW incineration in the USA (NRC, 2000).

1.2.2 - Environmental and Health Effects of MSWI

The use of incineration as a method of disposal for waste has been and continues to be a contentious subject. Estimates of large increments in ambient concentrations of various pollutants attributable to existing incinerators, particularly heavy metals and dioxins and furans, have led to legitimate concerns about potential health effects (NRC, 2000). This report concerns only those sources of pollution emitted by the combustion process: it does not consider sources of pollution arising from the collection, storage and handling of waste, or from peripheral activities such as use and treatment of cooling water used for power cogeneration.

The main atmospheric emissions of concern arising from waste combustion are CO_2, water vapor and fly ash. However, when combustion is not complete, other substances can also be produced. The types and concentrations of contaminants in the exhaust depends on: i) the process type; ii) the composition of the waste being burned; and iii) combustion conditions. The resulting pollutants are derived from three sources: pollutants (or their precursor chemicals) present in the waste feed; ii) formation during the combustion process because of incomplete oxidation; or iii) reactions during cooling of the exhaust gases and/or in air pollution control devices (NRC, 2000).

The pollutants of primary concern, owing to their potential effects on human health and the environment, include: particulate matter; carbon monoxide (CO); oxides of nitrogen (NO_x); oxides of sulphur (SO_x); hydrogen chloride (HCl); and metals and metalloids (inc. cadmium, lead, mercury, chromium, arsenic); polychlorinated dibenzo-dioxins/furans (“dioxins”, PCCD/Fs); polychlorinated biphenyls (PCBs); and polycyclic aromatic hydrocarbons (PAHs) (NRC, 2000). These pollutants can arise owing to their presence in the MSW (e.g. cadmium) and/or they can be products of incomplete combustion (e.g. dioxins).

Once emitted to the atmosphere, these pollutants are subject to a wide range of processes including: dispersion; dry deposition through gravitational settling; wet deposition through incorporation into precipitation; chemical and physical transformation. Some components may be deposited or impact on environmental and human health on a local scale (~10 km) while others may be transported on a regional or global scale. They can then undergo intermedia transport processes and become incorporated in food and drinking water. Health impacts can be acute (e.g. respiratory damage caused by exposure to NO_x) or chronic (e.g. long-term exposure to dioxins incorporated in the food chain). With specific regard to Bermuda, the potential for atmospheric contaminants to be deposited to rainwater catchment surfaces, including house roofs, may lead to the ingestion of contaminants incorporated in drinking water.

However, studies of health outcomes in populations living close to incinerators have not provided conclusive indications of the presence or absence of effects of incinerator emissions. There have been two recent comprehensive reviews of the environmental and health impacts of waste incineration: one conducted by the US National Research Council's Committee on Health Effects of Waste Incineration (NRC, 2000); and one by the UK Government's Department for Environment, Food and Rural Affairs (DEFRA, 2004) as part of a review of all municipal waste disposal methods.

Key conclusions of the NRC review are:

- Pollutants emitted by incinerators that appear to have the potential to cause the largest health effects are particulate matter, lead, mercury, and dioxins and furans. However, there is wide variation in the contributions that incinerators can make to environmental concentrations of those contaminants. Although emissions from newer, well-run facilities are expected to contribute little to environmental concentrations and to health risks, the same might not be true for some older or poorly run facilities.

- Studies of workers at municipal solid-waste incinerators show that workers are at much higher risk for adverse health effects than individual residents in the surrounding area. In the past, incinerator workers have been exposed to high concentrations of dioxins and toxic metals, particularly lead, cadmium, and mercury.

- On the basis of available data, a well-designed and properly operated incineration facility emits relatively small amounts of pollutants, contributes little to ambient concentrations, and so is not expected to pose a substantial health risk. However, such assessments of risk under normal operating conditions may inadequately characterize the risks or lack of risks because of gaps in and limitations of existing data or techniques used to assess risk, the collective effects of multiple facilities not considered in plant-by-plant risk assessments, potential synergisms in the combined effects of the chemicals to which people are exposed, the possible effect of small increments in exposure on unusually susceptible people, and the potential effects of short-term emission increases due to off-normal operations.

- Epidemiologic studies assessing whether adverse effects actually occurred at individual incinerators have been few and were mostly unable to detect any effects. That result is not surprising, given: the small populations available to study; the presence of effect modifiers and potentially confounding factors (such as other exposures and risks in the same communities); the long periods that might be necessary for health effects to be manifested; and the low concentrations (and small increments in background concentrations) of the pollutants of concern. Although such results could mean that adverse health effects are not present, they could also mean that the effects may not be detectable using feasible methods and available data sources.

- The potential health effects of particulate matter emitted by incinerators may not have received appropriate attention in traditional risk assessments. In particular, in well-characterized situations (with well-measured emissions) where the contribution of particulate matter to the total ambient particle load is small (around 1%), the acute health effect of emitted particulate matter might be as large as or larger than that of other incinerator-related pollutants. Some past studies have shown the overall urban background of particulate matter already appear to be causing excess mortality and morbidity in the U.S. population, and the particulate matter increment from all incinerators adds to the existing burden.

- In addition to possible physical-health effects, a waste-incineration facility may have other effects on individuals, groups, or the entire population in the surrounding area. The effects might be economic (such as job creation or decrease in property values), psychological (such as stress or stigma), or social (such as community factionalization or unity). However, there is little rigorous information on those impacts of waste-incineration facilities.

The UK DEFRA review reached similar conclusions:

- Waste incinerators contribute to local air pollution. This contribution, however, is usually a small proportion of existing background levels which is not detectable through environmental monitoring (for example, by comparing upwind and downwind levels of airborne pollutants or substances deposited to land). In some cases, waste incinerator facilities may make a more detectable contribution to air pollution. Because current MSW incinerators are located predominantly in urban areas, effects on air quality are likely to be so small as to be undetectable in practice.

- Although many studies have produced evidence of association between a health outcome and an environmental pollutant, they cannot, by themselves, demonstrate a cause and effect relationship. The studies examining possible health effects are frequently retrospective and employ routinely collected data such as cancer registrations, birth and death records which do not allow conclusive interpretations.
- The review did not find a link between the current generation of municipal solid waste incinerators and health effects. Adverse health effects have been observed in populations living around older, more polluting incinerators and industrial areas. However, the current generation of waste incinerators result in much lower levels of exposure to pollutants.
- Many studies have investigated how many cancer cases occur close to incinerators. These have mainly considered cancers of the stomach, colorectal, liver, lung, larynx and non-Hodgkins lymphoma. There is no consistent evidence of a link between exposure to emissions from incinerators and an increased rate of cancer. Where apparently significant effects have been observed, these are often in relation to incinerators close to other sources of potentially hazardous emissions, which makes it much harder to determine the source of any effect.
- There is little evidence that emissions from incinerators make respiratory problems worse. In most cases the incinerator contributes only a small proportion to the local level of pollutants.

Importantly, both reviews highlighted the need for MSW incinerators to operate under optimal conditions to ensure efficient combustion and to minimize any emissions of concern.

1.3 - Municipal Solid Waste Disposal in Bermuda

The options for waste disposal in Bermuda are limited. The island is densely populated: the population density calculated using the 2000 census figures is 1,155 people/km^2 (Government of Bermuda, 2005). This is equivalent to the density of large cities in North America, such as Houston, TX, which has a population density of 1,300 people/km^2 (US Census Bureau, 2006). Bermuda is also highly developed, with little available land area to feasibly use for landfill disposal. In addition, the residents of Bermuda enjoy a high standard of living, with a GDP per capita of $53,414 in 2003 (Government of Bermuda, 2005). This enables a high rate of consumption of consumer goods, the vast majority of which require importation, thus leading to the generation of large quantities of shipping and packaging waste.

In recognition of these pressures and the fact that existing landfill sites were close to capacity and/or were potential sources of unacceptable environmental degradation, in the late 1980's the government of Bermuda decided that incineration was the best viable option to deal with municipal waste. Subsequently, a waste treatment facility equipped with a municipal waste incinerator was constructed at Tynes Bay on the north shore of the island. This facility, the Tynes Bay Waste Treatment Facility (TBWTF) is managed and operated by the Ministry of Works and Engineering (MW&E).

The incinerator was first brought into operation in September 1994. The incinerator is a Von Roll Ltd. designed, water-walled mass burn incinerator with two waste streams, each with a maximum capacity of 144 tonnes per day (a third waste stream is planned for installation in the near future). The facility utilizes the heat output to generate electricity (cogeneration or "energy from waste"). The mass of combustible waste is reduced by approximately 80-90% by the combustion process. Waste gases are treated by electrostatic precipitation to remove particulates and then vented to the atmosphere *via* a 90 m stack. There are no chemical scrubbers in the exhaust line. The ash from the incinerator is screened to remove non-combusted metal waste which is then sent to the Bermuda Airport dump in Castle Harbour. The remaining ash is incorporated into 1 m^3 concrete/ash blocks. These are used for near-shore in-filling and stabilization of the Bermuda Airport dump.

Bermuda generates and incinerates significantly more waste compared to many other developed countries (see Table 1.1). In 2004, the incinerator received 73,953 tonnes of waste. Of this, 72,961 tonnes (98.7%) was incinerated at a mean rate of 200 tonnes/day. The remaining 925 tonnes (1.3%), comprised predominantly of solid metallic waste removed from the waste stream prior to combustion, was redirected to the Bermuda Airport dump (MW&E, 2005). The proportion of MSW currently incinerated in Bermuda is matched by that in Switzerland, where, since restrictions were placed on landfill in 2000, 99% of MSW was incinerated in 2004 (FOEN, 2006).

In 2004, the TBWTF incinerator generated 11,527 tonnes of ash (15.7% of combusted mass) and 1,074 tonnes of metal residue (1.5% of combusted mass). Over the same time period, the facility generated 23,742 MWh of electricity, 16,299 MWh (69%) of which was exported to the island's electricity generation company, BELCO (MW&E, 2005).

Country	MSW Collected	MSW Incinerated	MSW Landfilled	% Incinerated
Switzerland [1]	360	320	40	89%
Denmark	665	347	67	52%
Luxembourg	648[a]	310[a]	140[a]	48%
Sweden	429	165	138	39%
Netherlands	615	233	87	38%
Belgium	484	163	134	34%
France	531	176	244	33%
Germany	555	128	182[a]	23%
Japan	407[a]	86[a]	27[a]	21%
Portugal	444	91[a]	334	21%
USA	749	114[a]	441[a]	15%
Norway	615	90	336	15%
Finland	483	52	306	11%
Austria	556[a]	56[a]	192[a]	10%
United Kingdom	558[a]	49[a]	511[a]	9%
Iceland	710	61	555	9%
Spain	520	43	319	8%
Italy	502	37[a]	377[a]	7%
Ireland	626	0	554	0%
Bermuda (2000)	**1075**	**1054**	**21**	**98%**
Bermuda (2004)	**1191**	**1176**	**15**	**99%**

Table 1.1: Amounts (kg per capita) of municipal solid waste (MSW) collected, incinerated and landfilled in different countries.

All data for 2000, except - a: data from 1999;
Bermuda MSW data from MW&E (2001; 2005);
Population data used for per capita calculations from Government of Bermuda (2005);
All other country data from DEFRA (2004) except - 1: FOEN (2006), 2000 data.

The TBWTF incinerator emissions are monitored by both direct stack measurements and ambient air quality monitoring. Stack monitoring is conducted by MW&E using a continuous emissions monitoring system (installed in 2005) and also by an accredited external contractor who conducts annual stack emission testing. The results of the annual testing conducted in 2004 are presented in Table 1.2, along with relevant Bermuda, US and European limit values.

Note that pollutant concentrations specified in U.S. air pollution regulations are expressed on a 7% oxygen basis. In some other jurisdictions, e.g. the European Union (E.U.), an 11% oxygen basis is used. These formats are used to account for dilution air that often enters through fans, cracks in ductwork expansion joints, and air pollution control equipment. The 7% and 11% oxygen formats for the concentration limit ensure that regulations are fair for all sources, regardless of the extent of ambient air dilution of the effluent gas stream prior to the continuous emission monitor or the emission test location. It is also useful for comparing emissions from different facilities having substantially different oxygen concentrations in the gas stream (USEPA, 2006b). The standard equation for the correction of concentration to a specific oxygen level is:

$$[i]_{std.O_2} = [i]_{measd.O_2} \times \left(\frac{20.9\% - std.O_2\%}{20.9\% - measd.O_2\%} \right) \tag{1}$$

where:

$[i]_{std.O_2}$ = concentration of component i at standard O_2 level;

$[i]_{meads.O_2}$ = concentration of component i at measured O_2 level;

std.O_2% = oxygen concentration at standard level;

meads.O2% = oxygen concentration at measured level.

The value, 20.9% in Equation 1, is the oxygen concentration in the atmosphere.

Equation 1 (USEPA, 2006b) was used to convert the U.S. regulations to conditions of 11% O_2 to enable a comparison to be made to the Bermuda and E.U. limit values which are expressed at conditions of 11% O_2. This formula was also used to calculate the standard concentration of metals in the stack emissions using the mean emission rates, flow rates and oxygen level measured during testing, as reported in MW&E (2005).

From Table 1.2 it can be seen that the TBWTF incinerator is in compliance with all parameters regulated in Bermuda except for dioxins (4.3 ng TEQ/Nm^3 measured, *cf*. 1 ng TEQ/Nm^3 limit value). It also complies with relevant U.S. limit values for this age, type and size of incinerator, with the exception of total dioxins (220 ng/Nm^3, cf. 89 ng/Nm^3 limit value) and mercury (70 µg/Nm^3, cf. 57 µg/Nm^3 limit value). Recent EU limits designated in the EU Waste Incineration Directive are more strict, and the TBWTF incinerator exceeds the EU limits for HCl, dioxins (TEQ), mercury and one group of metals (see note g in

Table 1.2), with a value for this latter group of at least 8,000 $\mu g/Nm^3$ (only 5 of the 9 metals were reported) versus a total limit value of 500 $\mu g/Nm^3$.

Test Parameter	Units	Result [a]	Bermuda Limit [b]	US Limit [c]	Corr. US Limit [d]	EU Limit [e]
Particulates	mg/Nm^3	7.9	35	27	19	10
Total hydrocarbons (as CH_4)	mg/Nm^3	0.47				
Carbon monoxide (CO)	mg/Nm^3	14	80	125	89	50
NO_x	mg/Nm^3	180				200
HCl	mg/Nm^3	220	1200	407	290	10
SO_2	mg/Nm^3	16	200	220	157	50
Dioxins (TEQ-NATO)	ng/Nm^3	4.3	1			
Dioxins (TEQ-WHO)	ng/Nm^3	~4.3				0.1
Dioxins (total)	ng/Nm^3	220 [f]		125 [f]	89 [f]	
Metals:						
As	$\mu g/Nm^3$	25				*500* [g]
Be	$\mu g/Nm^3$	0.052				
Cd	$\mu g/Nm^3$	13		100	71	*50* [h]
Cr	$\mu g/Nm^3$	4800				*500* [g]
Cu	$\mu g/Nm^3$	150				*500* [g]
Pb	$\mu g/Nm^3$	170		1600	1140	*500* [g]
Ni	$\mu g/Nm^3$	2900				*500* [g]
Se	$\mu g/Nm^3$	3.6				
Zn	$\mu g/Nm^3$	730				
Hg	$\mu g/Nm^3$	70		80	57	50

Table 1.2: Results of annual stack emission testing at TBWTF in 2004 and comparison with limit values.

a: Results given to 2 sig. fig. and at 11% O_2 content;
b: Permit limit in effect in Bermuda (MW&E, 2005);
c: US Government (2000), at 7% O_2. Data for Class II incinerators (≤ 250 T/day) constructed on or before Aug. 1999;
d: US limit values corrected to 11% O_2 content;
e: EU (2000), at 11% O_2;
f: sum of all tetra- to octa-PCDD/Fs;
g: limit refers to sum of Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V and their compounds;
h: limit refers to sum of Cd+Tl and their compounds.

The ambient air quality monitoring program designed to monitor the impact of the incinerator emissions on ambient air in Bermuda is contracted to BBSR by the Department of Environmental Protection. The prevailing winds in Bermuda are south-westerly and therefore, owing to the location of the incinerator (see Figure 1.1) for the majority of the time emissions from the incinerator exhaust stack are dispersed over the Atlantic Ocean. However, at other times the wind carries emissions over Bermuda. Modelling of emissions under these conditions predicted that the worst case scenario for ground level exposure was Fort Prospect, approximately 1 km south of the incinerator (Simmons and Knap, 1991). An air quality monitoring station was therefore established on a water catchment at this site in 1989 to establish baseline air quality data prior to the initiation of waste incineration and to monitor any impacts on air quality after incineration operations started. Parameters monitored are: toxic gases (NO_x

and SO_2); airborne particulate matter (TSP, PM_{10} and $PM_{2.5}$); and rain and precipitation chemistry. Annual results of this monitoring are submitted to the Department of Environmental Protection. To date, there have been no observable impacts on air or rainwater quality at the monitoring location which are attributable to the TBWTF incinerator.

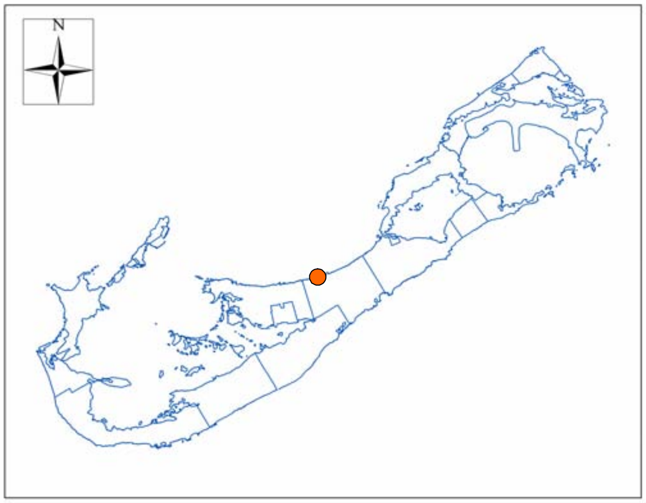


Figure 1.1: Location of Tynes Bay Waste Treatment Facility, Bermuda.

1.4 - Bermuda Soil and Water Tank Survey 2005

1.4.1 - Numbers and Types of Samples Acquired

The number of sites and types of samples collected are shown in Table 1.3 and the specific analytes are detailed in Table 1.4 (note that in addition to contaminants, major ions were also measured in tank water). As far as possible, the same sites used in the two previous island-wide surveys conducted in 1994 and 2000 were used. For soil sampling, the sites have been consistent in all 3 surveys. For water tank sampling in 2005, in cases where replication of site sampling was not possible, alternative sites located as close as possible to the location used in 2000 were used. An additional 10 sites within a 1 km radius of the TBWTF incinerator were selected for all analyses in 2005. These extra sites were included as part of a human health-based risk assessment conducted by MW&E as part of the process of adding a third stream to the incinerator's capacity. Specific details of sampling and analytical methodology are presented in subsequent chapters.

	Soil	**Water Tanks**	
		Water	**Sediment**
Metals and metalloids	61	112	36
Dioxins	20	20	20
PAHs	20	20	20

Table 1.3: Types and numbers of samples collected in 2005.

	Analytes
Metals and metalloids (*: in soil/sediment only) (‡: in water only)	Antimony (Sb), Arsenic (As), Mercury (Hg), Selenium (Se), Silver (Ag), Aluminum (Al), Barium (Ba), Beryllium (Be), Bismuth‡ (Bi), Boron‡ (B), Cadmium (Cd), Cobalt (Co), Chromium (Cr), Copper (Cu), Iron (Fe), Manganese (Mn), Molybdenum (Mo), Nickel (Ni), Lead (Pb), Phosphorus* (P), Tin (Sn), Strontium (Sr), Titanium (Ti), Thallium (Tl), Vanadium (V), Zinc (Zn), Uranium (U)
Dioxins (the seventeen 2,3,7,8-substituted congeners exhibiting significant toxicity)	2378-TeCDD, 12378-PeCDD, 123478-HxCDD, 123678-HxCDD, 123789-HxCDD, 1234678-HpCDD, OCDD 2378-TeCDF, 12378-PeCDF, 23478-PeCDF, 123478-HxCDF, 123678-HxCDF, 123789-HxCDF, 234678-HxCDF, 1234678-HpCDF, 1234789-HpCDF, OCDF
PAHs (EPA 16)	NAP, ACY, ACE, FLR, PHN, ANT, FLT, PYR, BaA, CHR, BbF, BkF, BaP, IP, DBahA, BghiP
Major ions and other parameters (soil/sediment)	Sodium (Na), Potassium (K), Magnesium (Mg), Calcium (Ca), Phosphorus (P), Loss on ignition (LOI)
Major ions and other parameters (water)	Sodium (Na), Potassium (K), Magnesium (Mg), Calcium (Ca), Chloride (Cl^-), Sulphate (SO_4^{2-}), Nitrate (NO_3^-), pH, Conductivity

Table 1.4: Contaminant analytes and other parameters measured.

1.4.2 - Chemical Analyses

The majority of the analyses were conducted by EnviroTest Laboratories (ETL) in Edmonton, Canada (ETL has since become part of the ALS Environmental group of companies). The laboratory is an ISO/IEC 17025 accredited laboratory. Full details of media specific analyses are presented in subsequent sections.

Analysis of major ion concentrations, conductivity and pH of water samples and loss-on-ignition determination of tank sediment samples were conducted by the Environmental Quality Laboratory at BBSR. A QA/QC program is employed to ensure the quality of analytical data. This includes the use of certified reference standards for instrument calibration and certified reference materials for analytical verification.

1.5 - Notes on Statistical Analysis of Data

Statistical analysis of the generated data has been performed using XLStat, a commercial statistical add-in package for Microsoft's Excel spreadsheet program. In general, the statistical procedure used is:

1) Analysis of degree of censoring (i.e. incidence of non-detected values);
2) Values below detection limits are assigned a value of 0.5 × detection limit;
3) Generation of summary statistics;
4) In cases where the resulting mean, geometric mean or median value are below the detection limit, these parameters were designated as "trace";
5) Test for normality of distribution using the Shapiro-Wilk test. Data then transformed to $\log_e$ values and the Shapiro-Wilk test repeated to test for log-normal distribution;

Where appropriate, further data analysis consisted of:

7) Non-parametric analysis (Mann-Whitney or Kruskal-Wallis test) performed to determine if significant differences exist in mean concentration with distance from incinerator;
8) Analysis of spatial trends using hierarchical cluster analysis and principal component analysis;
9) Non-parametric analysis (Mann-Whitney or Kruskal-Wallis test) performed to determine if significant differences exist over time.

Specific statistical analysis is further discussed in the report where appropriate.

Chapter 2 - Environmental Contaminants Surveyed in 2005

2.1 - Introduction

A suite of 29 metal and metalloid elements were measured in all samples collected. Additionally, 17 dioxin compounds and 17 polycyclic aromatic hydrocarbon compounds were measured in a sub-set of selected samples. Descriptions of these groups of contaminants and their toxicological significance are presented below.

2.2 - Heavy Metals and Metalloids

2.2.1 - Introduction

Metals and metalloids (generally referred to collectively as metals) are natural constituents of the Earth's crust. They are stable and cannot be degraded or destroyed, and therefore tend to accumulate in soils and sediments. However, human activities have drastically altered the biochemical and geochemical cycles and balance of some metals. The principal anthropogenic sources of metals are industrial point sources (e.g. mines, foundries and smelters) and diffuse sources (e.g. combustion by-products, traffic, etc.). Relatively volatile metals and those that become attached to airborne particles can be widely dispersed on very large scales. The following profiles of the most significant elements measured in this study are taken from the Agency for Toxic Substances and Disease Registry’s ToxFAQ publications (ATSDR, 2005):

Aluminum (Al) - Aluminum occurs naturally and makes up about 8% of the surface of the earth. It is always found combined with other elements such as oxygen, silicon, and fluorine. Aluminum metal is silver-white and flexible. It is often used in cooking utensils, containers, appliances, and building materials. It is also used in paints and fireworks; to produce glass, rubber, and ceramics; and in consumer products such as antacids, astringents, buffered aspirin, food additives, and antiperspirants. People who are exposed to high levels of aluminum in air may have respiratory problems including coughing and asthma from breathing dust. Some studies show that people with Alzheimer's disease have more aluminum than usual in their brains. We do not know whether aluminum causes the disease or whether the buildup of aluminum happens to people who already have the disease. Infants and adults who received large doses of aluminum as a treatment for another problem developed bone diseases, which suggests that aluminum may cause skeletal problems. Some sensitive people develop skin rashes from using aluminum chlorohydrate deodorants.

Arsenic (As) - Arsenic is a naturally occurring element widely distributed in the earth's crust. In the environment, arsenic can combine with oxygen, chlorine, and sulfur to form inorganic arsenic compounds. Arsenic in animals and plants combines with carbon and hydrogen to form organic arsenic compounds. Inorganic arsenic compounds are mainly used to preserve wood. Copper chromated arsenic (CCA) is used to make "pressure-treated" lumber. CCA is no longer used in the U.S. for residential uses; it is still used in industrial applications. Organic arsenic compounds are used as pesticides, primarily on cotton plants. Exposure to higher than average levels of arsenic occur mostly in the workplace, near hazardous waste sites, or in areas with high natural levels. Breathing high levels of inorganic arsenic can cause sore throat or irritated lungs. Ingesting very high levels of arsenic can result in death. Exposure to lower levels can cause nausea and vomiting, decreased production of red and white blood cells, abnormal heart rhythm, damage to blood vessels, and a sensation of "pins and needles" in hands and feet. Ingesting or breathing low levels of inorganic arsenic for a long time can cause a darkening of the skin and the appearance of small "corns" or "warts" on the palms, soles, and torso. Skin contact with inorganic arsenic may cause redness and swelling. Organic arsenic compounds are less toxic than inorganic arsenic compounds. Exposure to high levels of some organic arsenic compounds may cause similar effects as inorganic arsenic.

Barium (Ba) - Barium is a silvery-white metal which exists in nature only in ores containing mixtures of elements. It combines with other chemicals such as sulfur or carbon and oxygen to form barium compounds. Barium compounds are used by the oil and gas industries to make drilling muds. They are also used to make paint, bricks, ceramics, glass, and rubber. Barium sulfate is sometimes used by doctors to perform medical tests and to take x-rays of the gastrointestinal tract. The health effects of the different barium compounds depend on how well the compound dissolves in water or in the stomach contents. Barium compounds that do not dissolve well, such as barium sulfate, are not generally harmful.

Barium has been found to potentially cause gastrointestinal disturbances and muscular weakness when people are exposed to it at levels above the EPA drinking water standards for relatively short periods of time. Some people who eat or drink amounts of barium above background levels found in food and water for a short period may experience vomiting, abdominal cramps, diarrhea, difficulties in breathing, increased or decreased blood pressure, numbness around the face, and muscle weakness. Eating or drinking very large amounts of barium compounds that easily dissolve can cause changes in heart rhythm or paralysis and possibly death. Animals that drank barium over long periods had damage to the kidneys, decreases in body weight, and some died.

Beryllium (Be) - Beryllium is a hard, grayish metal naturally found in mineral rocks, coal, soil, and volcanic dust. Beryllium compounds are commercially mined, and the beryllium is purified for use in nuclear weapons and reactors, aircraft and space vehicle structures, instruments, x-ray machines, and mirrors. Beryllium ores are used to make speciality ceramics for electrical and high-technology applications. Beryllium alloys are used in automobiles, computers, sports equipment (golf clubs and bicycle frames), and dental bridges. Beryllium can be harmful if you breathe it. The effects depend on how much you are exposed to and for how long. If beryllium air levels are high enough (greater than 1000 µg/m^3), an acute condition can result. This condition resembles pneumonia and is called acute beryllium disease. Some people (1-15%) become sensitive to beryllium. These individuals may develop an inflammatory reaction in the respiratory system. This condition is called chronic beryllium disease (CBD), and can occur many years after exposure to higher than normal levels of beryllium (greater than 0.5 µg/m^3). This disease can make you feel weak and tired, and can cause difficulty in breathing. It can also result in anorexia, weight loss, and may also lead to right side heart enlargement and heart disease in advanced cases. Some people who are sensitized to beryllium may not have any symptoms. The general population is unlikely to develop acute or chronic beryllium disease because ambient air levels of beryllium are normally very low (0.00003-0.0002 µg/m^3). Swallowing beryllium has not been reported to cause effects in humans because very little beryllium is absorbed from the stomach and intestines. Ulcers have been seen in dogs ingesting beryllium in the diet. Beryllium contact with skin that has been scraped or cut may cause rashes or ulcers.

Cadmium (Cd) - Cadmium is a natural element in the earth's crust. It is usually found as a mineral combined with other elements such as oxygen (cadmium oxide), chlorine (cadmium chloride), or sulfur (cadmium sulfate, cadmium sulfide). All soils and rocks, including coal and mineral fertilizers, contain some cadmium. Most cadmium used in the United States is extracted during the production of other metals like zinc, lead, and copper. Cadmium does not corrode easily and has many uses, including batteries, pigments, metal coatings, and plastics. Breathing high levels of cadmium severely damages the lungs and can cause death. Eating food or drinking water with very high levels severely irritates the stomach, leading to vomiting and diarrhea. Long-term exposure to lower levels of cadmium in air, food, or water leads to a buildup of cadmium in the kidneys and possible kidney disease. Other long-term effects are lung damage and fragile bones. Animals given cadmium in food or water had high blood pressure, iron-poor blood, liver disease, and nerve or brain damage. We don't know if humans get any of these diseases from eating or drinking cadmium. Skin contact with cadmium is not known to cause health effects in humans or animals.

Chromium (Cr) - Chromium is a naturally occurring element found in rocks, animals, plants, soil, and in volcanic dust and gases. Chromium is present in the environment in several different forms. The most common forms are chromium(0), chromium(III), and chromium(VI). No taste or odor is associated with chromium compounds. Chromium(III) occurs naturally in the environment and is an essential nutrient. Chromium(VI) and chromium(0) are generally produced by industrial processes. The metal chromium, which is the chromium(0) form, is used for making steel. Chromium(VI) and chromium(III) are used for chrome plating, dyes and pigments, leather tanning, and wood preserving. Chromium(III) is an essential nutrient that helps the body use sugar, protein, and fat. Breathing high levels of chromium(VI) can cause irritation to the nose, such as runny nose, nosebleeds, and ulcers and holes in the nasal septum. Ingesting large amounts of chromium(VI) can cause stomach upsets and ulcers, convulsions, kidney and liver damage, and even death. Skin contact with certain chromium(VI) compounds can cause skin ulcers. Some people are extremely sensitive to chromium(VI) or chromium(III). Allergic reactions consisting of severe redness and swelling of the skin have been noted.

Copper (Cu) - Copper is a metal that occurs naturally throughout the environment, in rocks, soil, water, and air. Copper is an essential element in plants and animals (including humans), which means it is necessary for us to live. Therefore, plants and animals must absorb some copper from eating, drinking, and breathing. Copper is used to make many different kinds of products like wire, plumbing pipes, and sheet metal. Copper is also combined with other metals to make brass and bronze pipes and faucets. Copper compounds are commonly used in agriculture to treat plant diseases like mildew, for water treatment and, as preservatives for wood, leather, and fabrics. Everyone must absorb small amounts of copper every day because copper is essential for good health. High levels of copper can be harmful. Breathing high levels of copper can cause irritation of your nose and throat. Ingesting high levels of copper can cause nausea, vomiting, and diarrhea. Very-high doses of copper can cause damage to your liver and kidneys, and can even cause death.

Lead (Pb) - Lead is a naturally occurring bluish-gray metal found in small amounts in the earth's crust. Lead can be found in all parts of our environment. Much of it comes from human activities including burning fossil fuels, mining, and manufacturing. Lead has many different uses. It is used in the production of batteries, ammunition, metal products (solder and pipes), and devices to shield X-rays. Because of health concerns, lead from gasoline, paints and ceramic products, caulking, and pipe solder has been dramatically reduced in recent years. The effects of lead are the same whether it enters the body through breathing or swallowing. Lead can affect almost every organ and system in your body. The main target for lead toxicity is the nervous system, both in adults and children. Long-term exposure of adults can result in decreased performance in some tests that measure functions of the nervous system. It may also cause weakness in fingers, wrists, or ankles. Lead exposure also causes small increases in blood pressure, particularly in middle-aged and older people and can cause anemia. Exposure to high lead levels can severely damage the brain and kidneys in adults or children and ultimately cause death. In pregnant women, high levels of exposure to lead may cause miscarriage. High-level exposure in men can damage the organs responsible for sperm production.

Manganese (Mn) - Manganese is a naturally occurring metal that is found in many types of rocks. Pure manganese is silver-colored, but does not occur naturally. It combines with other substances such as oxygen, sulfur, or chlorine. Manganese can also be combined with carbon to make organic manganese compounds. Common organic manganese compounds include pesticides, such as maneb or mancozeb, and methylcyclopentadienyl manganese tricarbonyl (MMT), a fuel additive in some gasolines. Manganese is an essential trace element and is necessary for good health. Manganese can be found in several food items, including grains and cereals, and is found in high amounts in other foods, such as tea. Some individuals exposed to very high levels of manganese for long periods of time in their work developed mental and emotional disturbances and slow and clumsy body movements. This combination of symptoms is a disease called "manganism". Workers usually do not develop symptoms of manganism unless they have been exposed to manganese for many months or years. Manganism occurs because too much manganese injures a part of the brain that helps control body movements. Exposure to high levels of airborne manganese, such as in a manganese foundry or battery plant, can affect motor skills such as holding one's hand steady, performing fast hand movements, and maintaining balance. Exposure to high levels of the metal may also cause respiratory problems and sexual dysfunction.

Mercury (Hg) - Mercury is a naturally occurring metal which has several forms. The metallic mercury is a shiny, silver-white, odorless liquid. If heated, it is a colorless, odorless gas. Mercury combines with other elements, such as chlorine, sulfur, or oxygen, to form inorganic mercury compounds or "salts," which are usually white powders or crystals. Mercury also combines with carbon to make organic mercury compounds. The most common one, methylmercury, is produced mainly by microscopic organisms in the water and soil. More mercury in the environment can increase the amounts of methylmercury that these small organisms make. Metallic mercury is used to produce chlorine gas and caustic soda, and is also used in thermometers, dental fillings, and batteries. Mercury salts are sometimes used in skin lightening creams and as antiseptic creams and ointments. The nervous system is very sensitive to all forms of mercury. Methylmercury and metallic mercury vapors are more harmful than other forms, because more mercury in these forms reaches the brain. Exposure to high levels of metallic, inorganic, or organic mercury can permanently damage the brain, kidneys, and developing fetus. Effects on brain functioning may result in irritability, shyness, tremors, changes in vision or hearing, and memory problems. Short-term exposure to high levels of metallic mercury vapors may cause effects including lung damage, nausea, vomiting, diarrhea, increases in blood pressure or heart rate, skin rashes, and eye irritation.

Nickel (Ni) - Nickel is a very abundant natural element. Pure nickel is a hard, silvery-white metal. Nickel can be combined with other metals, such as iron, copper, chromium, and zinc, to form alloys. These alloys are used to make coins, jewelry, and items such as valves and heat exchangers. Most nickel is used to make stainless steel. Nickel can combine with other elements such as chlorine, sulfur, and oxygen to form nickel compounds. Many nickel compounds dissolve fairly easy in water and have a green color. Nickel compounds are used for nickel plating, to color ceramics, to make some batteries, and as substances known as catalysts that increase the rate of chemical reactions. Nickel is found in all soil and is emitted from volcanoes. Nickel is also found in meteorites and on the ocean floor. Nickel and its compounds have no characteristic odor or taste. The most common harmful health effect of nickel in humans is an allergic reaction. Approximately 10-20% of the population is sensitive to nickel. People can become sensitive to nickel when jewelry or other things containing it are in direct contact with the skin for a long time. Once a person is sensitized to nickel, further contact with the metal may produce a reaction. The most common reaction is a skin rash at the site of contact. The skin rash may also occur at a site away from the site of contact. Less frequently, some people who are sensitive to nickel have asthma attacks following exposure to nickel. Some sensitized people react when they consume food or water containing nickel or breathe dust containing it. People working in nickel refineries or nickel-processing plants have experienced chronic bronchitis and reduced lung function. These persons breathed amounts of nickel much higher than levels found normally in the environment. Workers who drank water containing high amounts of nickel had stomach ache and suffered adverse effects to their blood and kidneys. Damage to the lung and nasal cavity has been observed in rats and mice breathing nickel compounds. Eating or drinking large amounts of nickel has caused lung disease in dogs and rats and has affected the stomach, blood, liver, kidneys, and immune system in rats and mice, as well as their reproduction and development.

Selenium (Se) - Selenium is a naturally occurring mineral element that is distributed widely in nature in most rocks and soils. In its pure form, it exists as metallic gray to black hexagonal crystals, but in nature it is usually combined with sulfide or with silver, copper, lead, and nickel minerals. Most processed selenium is used in the electronics industry, but it is also used: as a nutritional supplement; in the glass industry; as a component of pigments in plastics, paints, enamels, inks, and rubber; in the preparation of pharmaceuticals; as a nutritional feed additive for poultry and livestock; in pesticide formulations; in rubber production; as an ingredient in antidandruff shampoos; and as a constituent of fungicides. Radioactive selenium is used in diagnostic medicine. Selenium has both beneficial and harmful effects. Low doses of selenium are needed to maintain good health. However, exposure to high levels can cause adverse health effects. Short-term oral exposure to high concentrations of selenium may cause nausea, vomiting, and diarrhea. Chronic oral exposure to high concentrations of selenium compounds can produce a disease called selenosis. The major signs of selenosis are hair loss, nail brittleness, and neurological abnormalities (such as numbness and other odd sensations in the extremities). Brief exposures to high levels of elemental selenium or selenium dioxide in air can result in respiratory tract irritation, bronchitis, difficulty breathing, and stomach pains. Longer-term exposure to either of these air-borne forms can cause respiratory irritation, bronchial spasms, and coughing. Levels of these forms of selenium that would be necessary to produce such effects are normally not seen outside of the workplace. Animal studies have shown that very high amounts of selenium can affect sperm production and the female reproductive cycle. We do not know if similar effects would occur in humans.

Silver (Ag) - Silver is a naturally occurring element. It is found in the environment combined with other elements such as sulfide, chloride, and nitrate. Pure silver is "silver" colored, but silver nitrate and silver chloride are powdery white and silver sulfide and silver oxide are dark-gray to black. Silver is often found as a by-product during the retrieval of copper, lead, zinc, and gold ores. Silver is used to make jewelry, silverware, electronic equipment, and dental fillings. It is also used to make photographs, in brazing alloys and solders, to disinfect drinking water and water in swimming pools, and as an antibacterial agent. Silver has also been used in lozenges and chewing gum to help people stop smoking. Exposure to high levels of silver for a long period of time may result in a condition called arygria, a blue-gray discoloration of the skin and other body tissues. Lower-level exposures to silver may also cause silver to be deposited in the skin and other parts of the body; however, this is not known to be harmful. Argyria is a permanent effect, but it appears to be a cosmetic problem that may not be otherwise harmful to health. Exposure to high levels of silver in the air has resulted in breathing problems, lung and throat irritation, and stomach pains. Skin contact with silver can cause mild allergic reactions such as rash, swelling, and inflammation in some people. Animal studies have shown that swallowing silver results in the deposit of silver in the skin. One study in mice found that the animals exposed to silver in drinking water were less active than unexposed animals. No studies are available on whether silver affects reproduction or causes developmental problems in people.

Vanadium (V) - Vanadium is an element that occurs in nature as a white-to-gray metal, and is often found as crystals. Pure vanadium has no smell. It usually combines with other elements such as oxygen, sodium, sulfur, or chloride. Vanadium and vanadium compounds can be found in the earth's crust and in rocks, some iron ores, and crude petroleum deposits. Vanadium is mostly combined with other metals to make called alloys. Vanadium in the form of vanadium oxide is a component in special kinds of steel that is used for automobile parts, springs, and ball bearings. Most of the vanadium used in the United States is used to make steel. Vanadium oxide is a yellow-orange powder, dark-gray flakes, or yellow crystals. Vanadium is also mixed with iron to make important parts for aircraft engines. Small amounts of vanadium are used in making rubber, plastics, ceramics, and other chemicals. Exposure to high levels of vanadium can cause harmful health effects. The major effects from breathing high levels of vanadium are on the lungs, throat, and eyes. Workers who breathed it for short and long periods sometimes had lung irritation, coughing, wheezing, chest pain, runny nose, and a sore throat. These effects stopped soon after they stopped breathing the contaminated air. Similar effects have been observed in animal studies. No other significant health effects of vanadium have been found in people. We do not know the health effects in people of ingesting vanadium. Animals that ingested very large doses have died. Lower, but still high levels of vanadium in the water of pregnant animals resulted in minor birth defects. Some animals that breathed or ingested vanadium over a long term had minor kidney and liver changes. The amounts of vanadium given in these animal studies that resulted in harmful effects are much higher than those likely to occur in the environment.

Zinc (Zn) - Zinc is one of the most common elements in the earth's crust. It is found in air, soil, and water, and is present in all foods. Pure zinc is a bluish-white shiny metal. Zinc has many commercial uses as coatings to prevent rust, in dry cell batteries, and mixed with other metals to make alloys like brass, and bronze. A zinc and copper alloy is used to make pennies in the United States. Zinc combines with other elements to form zinc compounds. Common zinc compounds found at hazardous waste sites include zinc chloride, zinc oxide, zinc sulfate, and zinc sulfide. Zinc compounds are widely used in industry to make paint, rubber, dyes, wood preservatives, and ointments. Zinc is an essential element in our diet. Too little zinc can cause problems, but too much zinc is also harmful. Harmful effects generally begin at levels 10-15 times higher than the amount needed for good health. Large doses taken by mouth even for a short time can cause stomach cramps, nausea, and vomiting. Taken longer, it can cause anemia and decrease the levels of your good cholesterol. We do not know if high levels of zinc affect reproduction in humans. Rats that were fed large amounts of zinc became infertile. Inhaling large amounts of zinc (as dusts or fumes) can cause a specific short-term disease called metal fume fever. We do not know the long-term effects of breathing high levels of zinc. Putting low levels of zinc acetate and zinc chloride on the skin of rabbits, guinea pigs, and mice caused skin irritation. Skin irritation will probably occur in people.

2.3 - Dioxins

2.3.1 - Introduction

The term "dioxins" refers to a group of chemical compounds comprised of polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs), two series of tricyclic aromatic compounds with similar chemical and physical properties. PCDDs and PCDFs are waste products and are not created intentionally: there are no known technical uses for PCDDs and PCDFs. Some natural processes also produce PCDDs and PCDFs (WHO, 2000).

PCDDs and PCDFs contain from one to eight chlorine atoms substituted on the 2 aromatic rings of their base structure (see Figure 2.1), resulting in 75 positional isomers of PCDDs and 135 isomers of PCDFs. The pattern of chlorine substitution is an important factor determining the toxic properties of dioxins (see Section 2.3.2).

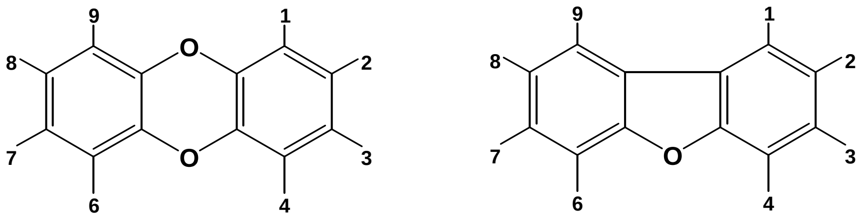


Figure 2.1: Chemical structure of polychlorinated dibenzo-*p*-dioxins (left) and polychlorinated dibenzofurans (right). Up to 8 chlorine atoms can be substituted at positions 1-4 and 6-9.

Dioxins are persistent organic pollutants. Owing to their hydrophobic nature and their resistance to metabolic processes, PCDD/Fs can accumulate in fatty tissue in biota and thus are subject to bioaccumulation in food chains. Dioxins are found in many environmental and biological compartments as complex mixtures of congeners which vary between media and across trophic levels (Van den Berg *et al.*, 1998).

The primary sources of dioxins is inefficient combustion of organic matter in the presence of chlorine and chemical manufacturing processes. The most important historical and current sources of PCDDs and PCDFs in the environment include:

- Incineration of municipal solid waste
- Incineration of medical waste
- Secondary copper smelting
- Forest fires
- Land application of sewage sludge

- Cement kilns
- Coal fired power plants
- Residential wood burning
- Chlorine bleaching of wood pulp
- Chloralkali plants
- Contamination as manufacturing by-products in synthetic chemicals (e.g. PCBs)
- Vehicle emissions

The U.S. EPA is currently in the process of re-evaluating its assessment of dioxin exposure and human health effects. A draft document, Exposure and Human Health Reassessment of 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD) and Related Compounds, has been submitted to the U.S. National Academies' Research Council for expert review. The draft document is openly available from the U.S. EPA but is not intended to be quoted or cited (USEPA, 2006b).

2.3.2 - Dioxin Toxicity

Only 7 of the 75 PCDD congeners are considered to exhibit mammalian toxicity; these are ones with chlorine substitutions in the 2, 3, 7, and 8 positions (see Figure 2.1). Similarly, only 10 of the 135 possible PCDF congeners are thought to have dioxin-like toxicity; these also are ones with substitutions in the 2, 3, 7, and 8 positions.

The toxic effects of dioxins in humans are wide-ranging and include or, from animal studies, are suspected of including: enzyme induction; developmental toxicity; immunotoxicity; hepatic toxicity; hormone disruption; mutagenicity; terratogenicity; and carcinogenicity. Human exposure to 2,3,7,8-TCDD has been associated with noncancer effects in most systems. The majority of effects have been reported among occupationally exposed groups, such as chemical production workers, pesticide users and individuals who handled or were exposed materials treated with 2,3,7,8-TCDD-contaminated pesticides, and among residents of communities contaminated with tainted waste oil (Missouri, USA) and industrial effluent (Seveso, Italy). These effects represent a complex network of responses ranging from changes in hepatic enzyme levels which, based on current evidence, do not appear to be related to clinical disease, to observable alterations in the character and physiology of the sebaceous gland, as in chloracne, a severe skin disease with acne-like lesions that occur mainly on the face and upper body (USEPA, 2006b).

The primary mode of toxicity of dioxin-like compounds involves the molecule binding to a cytosolic protein, the aryl-hydrocarbon (Ah) receptor, then the receptor-chemical complex migrates to the cell's nucleus and binds with the Ah-receptor nuclear translocator protein (Arnt). This complex can then interact with specific DNA sequences and alter the expression of regulated genes, leading to a toxic response.

Since only 17 congeners exhibit significant toxicity, the concept of a toxic equivalence (TEQ) was introduced to estimate total toxicity in a particular sample or system. This method is based on summing the relative toxicity of the 17 active dioxins and furans compared to 2,3,7,8- tetrachloro-dibenzodioxin, the most toxic dioxin. Other classes of chemicals, such as some polychlorinated biphenyls (PCBs), also exhibit dioxin-like toxicity and can also be included in TEQ calculations where appropriate.

A TEQ is derived by multiplying the concentration of each active congener by a toxic equivalence factor (TEF) and has the same units as the concentration units (e.g. pg/g). The TEQ is the sum of each component's concentration multiplied by its TEF:

$$TEQ = \Sigma_{n1}[PCDD_i \times TEF_i] + \Sigma_{n2}[PCDF_i \times TEF_i] + \ldots$$

where: TEQ = toxic equivalence (e.g. in pg/g);
TEF_i = unitless toxic equivalence factor of PCDD/F congener i (see Table 2.1);
$PCDD_i/PCDF_i$ = concentration of PCDD/F congener i (e.g. in pg/g).

TEFs and TEQs are used for risk characterisation and management purposes, for example to help prioritise areas of concern for site clean-up. Owing to the fact that these calculations are based on biological assumptions, caution should be applied when they are applied to abiotic compartments. However they remain useful as a relative measure of risk in abiotic compartments (Van den Berg *et al.*, 1988).

The current TEF system was developed by a panel of experts convened in June 1997 by the World Health Organization (WHO) (van den Berg *et al.*, 1998). TEF-WHO_{98} refers to the 1998 WHO update to the previously established TEFs for dioxins, furans, and dioxin-like PCBs (van den Berg *et al.*, 1998). The nomenclature also uses subscripts to indicate which family of compounds is included in any specific TEQ calculation. Under this convention, the subscript D is used to designate dioxins, the subscript F to designate furans and the subscript P to designate PCBs. As an example, "TEQ_{DF}-WHO_{98}" would be used to describe a mixture for which only PCDD and PCDF congeners were determined and where the TEQ was calculated using the WHO_{98} scheme. Note that separate TEF schemes have been derived based on human/mammalian, fish and avian toxicity. The human/mammalian TEF-WHO_{98} values for PCDDs and PCDFs are presented in Table 2.1.

This WHO_{98} system replaces an older set of TEFs developed in 1988 by an earlier expert panel. The older TEFs are sometimes called I-TEFS, or international TEFs. I-TEFs are still widely used in the United States, but are being replaced by the newer WHO TEFs for recent U.S. and European studies on animal feed and animal feed ingredients. TEQs presented in this report are those calculated using the current TEQ_{DF}-WHO_{98} scheme.

In terms of human exposure to dioxins, it is generally recognised that the principal route of exposure is through consumption of food, particularly food of animal origin (i.e. meat and dairy products). Exposure *via* ambient air is low, and exposure through drinking water is negligible (WHO, 2000). However, occupational exposure from all potential routes may be significant for some subpopulations.

PCDD Congener	**TEF-WHO_{98}**	**PCDF Congener**	**TEF-WHO_{98}**
2,3,7,8-TeCDD	1.0	2,3,7,8-TeCDF	0.1
1,2,3,7,8-PeCDD	1.0	1,2,3,7,8-PeCDF	0.05
1,2,3,4,7,8-HxCDD	0.1	2,3,4,7,8-PeCDF	0.5
1,2,3,6,7,8-HxCDD	0.1	1,2,3,4,7,8-HxCDF	0.1
1,2,3,7,8,9-HxCDD	0.1	1,2,3,6,7,8-HxCDF	0.1
1,2,3,4,6,7,8-HpCDD	0.01	1,2,3,7,8,9-HxCDF	0.1
OCDD	0.0001	2,3,4,6,7,8-HxCDF	0.1
		1,2,3,4,6,7,8-HpCDF	0.01
		1,2,3,4,7,8,9-HpCDF	0.01
		OCDF	0.0001

Table 2.1: PCDD and PCDF human/mammalian TEFs determined by the World Health Organisation (Van den Berg *et al.*, 1998).

2.3.3 - Patterns of PCDD/F congeners and homologues

Dioxins are found in the environment as complex mixtures of congeners. These variations are a result of differences in: source emissions; physicochemical properties between congeners (e.g. aqueous solubility, volatility); susceptibility to biotic and abiotic degradation. As a result, environmental mixtures of PCDDs and PCDFs can exhibit spatial and temporal patterns which may be very different from the mixture released by any particular source (Van den Berg *et al.*, 1998). This makes difficult the unequivocal identification of sources of PCDD/Fs in the environment. However, the profile of congeners present can be used to give some indication of the likely source (Cleverley *et al.*, 1997). This is considered further in subsequent chapters discussing the PCDD/F profiles measured in Bermuda.

2.4 - Polycyclic Aromatic Hydrocarbons

2.4.1 - Introduction

Polycyclic aromatic hydrocarbons (PAHs) are compounds which contain carbon and hydrogen atoms only, and which have in common a molecular structure consisting of two or more fused six-membered or five- and six-membered carbon rings (see Figure 2.2) which can also exhibit varying degrees of alkylation. The group includes a large number of isomeric compounds.

PAHs are ubiquitous environmental contaminants, resulting from combustion processes, biological synthesis and by diagenetic processes. Anthropogenic combustion sources are the primary source of PAHs in the environment (Howsam and Jones, 1998). Significant sources of PAHs in the environment include:

- Fossil fuel use and combustion (coal and petroleum products)
- Wood and other biofuel combustion
- Creosote production and use
- Coal-tar production and use
- Waste incineration
- Tobacco smoke

The environmental presence of PAHs is of particular concern because certain PAH compounds are known or suspected to have carcinogenic, mutagenic and/or toxic properties (see below). Owing to the large number of possible PAH compounds which may be present in the environment, a sub-set is often chosen for analysis. Sixteen PAH compounds were included on the US EPA's Priority Pollutant List generated in the 1970s under the Clean Water Act. These 16 PAH compounds are now listed on the Contract Laboratory Program Target Compound List for the Superfund Program and are frequently the target analytes of studies of PAHs. The so-called "EPA 16 PAHs" are illustrated in Figure 2.2.

2.4.2 - PAH Toxicity and Carcinogenicity

Laboratory experiments on animals and results of occupational exposure in humans have demonstrated that PAHs can exhibit a wide range of carcinogenic, mutagenic and/or toxic effects, for example resulting in the occurrence of tumours and other cancerous developments and reproductive and developmental deficiencies (ATSDR, 1995). In mammals, PAHs are incorporated by being absorbed by the skin or following inhalation and ingestion. They then concentrate in the liver and kidneys from which they are eventually metabolised and excreted. Being lipophilic, they also concentrate in lipid rich tissues, such as mammary and adrenal glands and fat reserves, where they remain for long periods of time.

PAHs require metabolic biotransformation of the parent molecule to enable the carcinogenic effect to occur (Harvey, 1998). In mammals, this process is principally catalyzed by cytochrome P-450 mono-oxygenases, leading to a series of reactions resulting in a PAH-diol-epoxide metabolite species which is the ultimate carcinogen.

As for PCDD/F toxicity described in Section 2.3.2. above, a similar assessment scheme for PAH toxicity has been proposed, termed the Relative Potency Value (USEPA, 1993). This is based on the carcinogenic potency of each compound relative to that of benzo[a]pyrene. However, this approach to risk assessment of PAH exposure has not yet been widely adopted. This scheme, along with the USEPA and IARC carcinogen classifications, is shown in Table 2.2. It is important to take into account that PAHs which are considered unclassified under this scheme may also contribute to carcinogenic risk (Nisbet and LaGoy, 1992) and should not necessarily be assumed to be "noncarcinogens". Furthermore, all PAHs identified as contaminants of concern should be evaluated in terms of potential noncancer risk: carcinogenic PAHs may also be associated with noncancer health effects (Nisbet and LaGoy, 1992).

Compound	**Relative Potency Factor** [1]	**USEPA Carcinogenicity Classification** [2]	**IARC Carcinogenicity Classification** [3]
Acenaphthene	*n.a.*[4]	*n.a.*	*n.a.*
Acenaphthylene	*n.a.*	D	*n.a.*
Anthracene	*n.a.*	D	3
Benz[a]anthracene	0.1	B2	2A
Benzo[a]pyrene	1.0	B2	2A
Benzo[e]pyrene	*n.a.*	*n.a.*	3
Benzo[b]fluoranthene	0.1	B2	2B
Benzo[j]fluoranthene	*n.a.*	*n.a.*	2B
Benzo[k]fluoranthene	0.01	B2	2B
Benzo[ghi]perylene	*n.a.*	*n.a.*	3
Chrysene	0.01	B2	3
Dibenz[ah]anthracene	1.0	B2	*n.a.*
Fluoranthene	*n.a.*	D	3
Fluorene	*n.a.*	*n.a.*	3
Indeno[123-cd]pyrene	0.1	B2	2B
2-methylnaphthalene	*n.a.*	*n.a.*	*n.a.*
Naphthalene	*n.a.*	D	3
Phenanthrene	*n.a.*	D	3
Pyrene	*n.a.*	D	3

Table 2.2: Classification of carcinogenic toxicity of PAHs.

1: Relative potencies of PAH carcinogenicity (USEPA, 1993);
2: USEPA: B2 = probable human carcinogen; D = not classifiable (ATSDR, 1995);
3: International Agency for Research on Cancer: 2A = probable human carcinogen; 2B = possible human carcinogen; 3 = not classifiable (ATSDR, 1995);
4: *n.a.* = not available, or chemical is not currently considered by USEPA to be carcinogenic (USEPA, 1993; ATSDR, 1995).

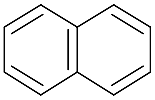
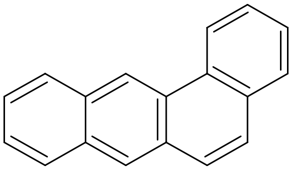
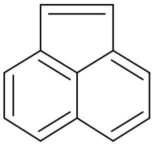
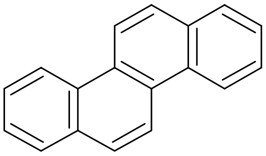
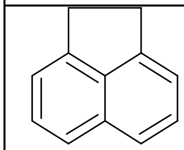
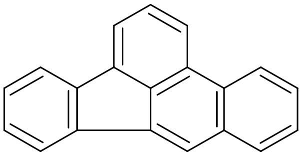
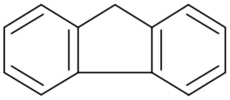
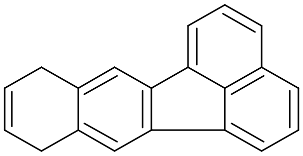
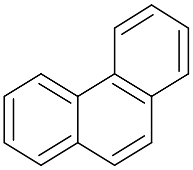
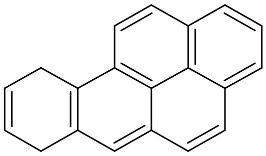
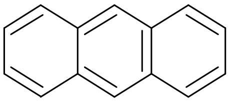
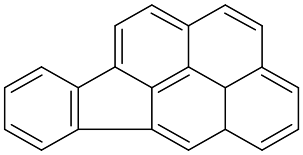
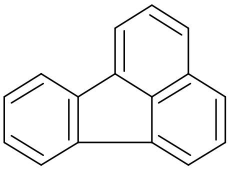
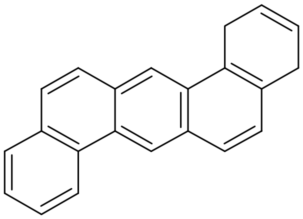
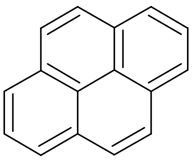
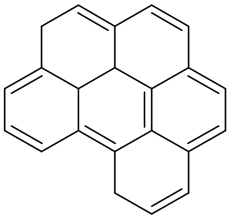
	Naphthalene (NAP) $C_{10}H_8$ mw = 128		Benz[a]anthracene (BaA) $C_{18}H_{12}$ mw = 228
	Acenaphthylene (ACY) $C_{12}H_8$ mw = 152		Chrysene (CHR) $C_{18}H_{12}$ mw = 228
	Acenaphthene (ACN) $C_{12}H_{10}$ mw = 154		Benzo[b]fluoranthene (BbF) $C_{20}H_{12}$ mw = 252
	Fluorene (FLR) $C_{13}H_{10}$ mw = 166		Benzo[k]fluoranthene (BkF) $C_{20}H_{12}$ mw = 252
	Phenanthrene (PHN) $C_{14}H_{10}$ mw = 178		Benzo[a]pyrene (BaP) $C_{20}H_{12}$ mw = 252
	Anthracene (ANT) $C_{14}H_{10}$ mw = 178		Indeno[1,2,3-cd]pyrene (IP) $C_{22}H_{12}$ mw = 276
	Fluoranthene (FLT) $C_{16}H_{10}$ mw = 202		Dibenz[ah]anthracene (DbahA) $C_{22}H_{14}$ mw = 278
	Pyrene (PYR) $C_{16}H_{10}$ mw = 202		Benzo[ghi]perylene (BghiP) $C_{22}H_{12}$ mw = 276

Figure 2.2: Structures, chemical formulae and molecular weights of the EPA 16 PAHs

Chapter 3 - Contaminants in Soil

3.1 - Bermuda's Soil

Bermuda's soil consists of shallow deposits of reddish-brown coloured, clay-rich soils, formed primarily from palaeosols, termed "terra rossa" (trans. "red earth"). They are derived mainly from fallout of atmospheric dust originating in Northwest Africa, with minor contributions from the underlying geology and accumulated organic matter from plants (Muhs, *et al.* 1990; Vacher and Rowe, 1997; Rowe, 1998). The main deposition events occurred during relatively long interruptions in calcarenite accumulations during glacial maxima (Herwitz *et al.*, 1996; Vacher and Rowe, 1997).

3.2 - Metals and Metalloids in Soil

3.2.1 - Sampling

Samples of soil for analysis of metals and metalloids (referred to collectively hereafter as "metals") were collected from 61 locations across Bermuda (see Figure 3.1) at an average sample resolution of 1.2 samples/km^2. This compares to a resolution of 1 sample/2.5km^2 used for a regional geochemical soil survey in the U.K. (Rawlins *et al.*, 2002). However, unlike the U.K. survey, the sites selected for this study are not randomly distributed owing to the spatial distribution of exposed soil and the access to potential sampling locations. Furthermore, of the total number of sites, 23 sites (38%) were specifically selected within a 1 km radius of the Tynes Bay Waste Treatment Facility.

Soil was sampled by first removing any turf present with a clean, stainless steel shovel which was thoroughly washed between sites with purified deionised water (Milli-Q water). The top *c.* 1 cm of the exposed soil was removed and discarded, using an acid washed, high density polyethylene (HDPE) scoop. The underlying *c.* 5 cm of soil was then sampled using an acid washed, HDPE hand scoop, and placed in new self-sealing polyethylene bags (ZipLok brand). A new pair of nitrile gloves were used by personnel conducting the sampling at each site and care was taken to eliminate contamination of the samples by contact with any extraneous material. Soil coring was considered but discarded as a sampling method owing to the relatively shallow soil in Bermuda (average depth = 100 mm; Government of Bermuda, 2006) and the presence in some areas of extensive shallow bed-rock and/or large amounts of loose stones. Areas of soil within the sampling location which were likely to have been exposed to recent disturbance were avoided (e.g. flower beds, sports fields, agricultural land, areas of extensive root growth). In such cases, soil was sampled immediately adjacent to the zone of disturbance.

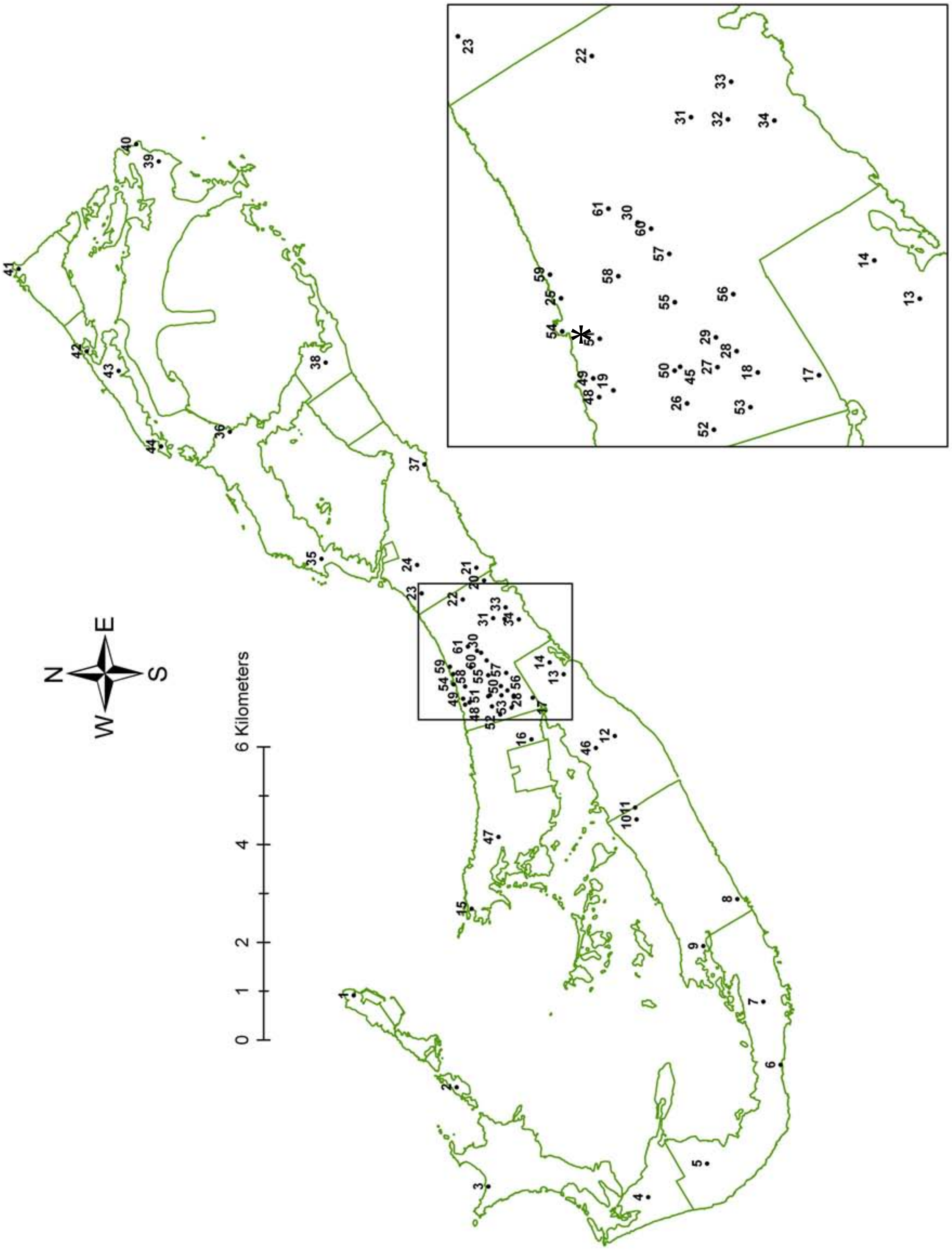


Figure 3.1: Map showing soil sampling locations. Inset map shown in larger scale for clarity. Note symbol * in inset map, showing location of incinerator.

Sub-samples from 5 locations within an area of approximately 2-4 m^2 at each site were combined to provide a total sample of *c.* 500 g. The samples were stored in coolers containing freezer packs until their return to the laboratory at BBSR where they were stored in the dark at 4°C. On average, 4 soil samples were collected each day and samples were then dispatched to the analytical laboratory by express courier in batches of 10 - 15 samples. The samples were shipped in coolers with freezer packs to maintain refrigerated conditions.

3.2.2 - Analysis

Soil samples were extracted in conc. nitric acid by microwave assisted acid digestion, according to EPA Method 3051. A suite of 29 elements were analysed according to Table 3.1. Loss on ignition (LOI) was also measured to provide an estimate of soil organic carbon content. All results are expressed in mg/kg dry weight.

Element	Method	Technique
Sb, As, Se	APHA [a] 3114 C	AAS [c] hydride generation
Hg	APHA 3112 B	AAS cold vapour
Others	EPA SW 846 [b] Method 6010	ICP-OES [d]
LOI	Combustion at 420°C	Gravimetric

Table 3.1: Analytical methods and techniques used for metals in soil.

a: APHA - American Public Health Association;
b: EPA SW 846 - US EPA Test Methods for Evaluating Solid Waste, Physical/Chemical Methods;
c: AAS - atomic absorption spectroscopy;
d: ICP-OES - inductively coupled plasma optical emission spectroscopy.

3.2.3 - Results: Summary Statistics

The summary statistics for metals are presented in Tables 3.2 and 3.3. Four elements (Ag, Sn, Tl and U) were not detected in any samples and have been designated as “not detected (n.d.)”. Two elements (Be and Mo) had low rates of detection (%>DL in Table 3.2). Following designation of values reported to be less than the detection limit (DL) to a value of 0.5×DL, the measures of central tendency (mean, median and geometric mean) for Be and Mo had values less than the analytical DL. They have therefore been designated as “trace”, indicating that they were present at trace levels.

All data were analysed to determine if they were normally distributed using the Shapiro-Wilks test at $P \leq 0.05$. Data that did not pass this test were then $\log_e$ transformed and re-tested in the same way for log-normal distribution. For those elements where neither distribution type could be unequivocally demonstrated, an assumption of a log-normal distribution can be made based on consideration of the histograms in Figure 3.2. In these cases, the distributions exhibit right skewness approximating a log-normal distribution (e.g. see Sb and Se). Thus, most parameters can be considered to follow a log-normal distribution (Table 3.2), with the exception of Na and Sr which are normally distributed. Calcium (Ca) is an exception, demonstrating a non-normal left skewed distribution. Previous studies have found that soil properties do not necessarily follow one common distribution type (Brejda, *et al.*, 2000; Zhang, 2006).

N = 61	**N > DL**	**% > DL**	**DL [a] (mg/kg)**	**Dist. [b]**
LOI	61	100%	0.0	**L-N**
Sb	57	93%	0.10	L-N
As	61	100%	0.10	**L-N**
Hg	47	77%	0.050	**L-N**
Se	60	98%	0.10	L-N
Al	61	100%	200	**L-N**
Ba	61	100%	5.0	**L-N**
Ca	61	100%	100	left skewed
Cd	60	98%	0.50	**L-N**
Co	54	89%	1.0	L-N
Cr	61	100%	0.50	**L-N**
Cu	61	100%	2.0	L-N
Fe	61	100%	200	**L-N**
K	61	100%	20	**L-N**
Mg	61	100%	100	L-N
Mn	61	100%	20	**L-N**
Na	61	100%	100	**N**
Ni	46	75%	2.0	L-N
P	61	100%	10	**L-N**
Pb	61	100%	5.0	**L-N**
Sr	61	100%	1.0	**N**
Ti	61	100%	5.0	**L-N**
V	61	100%	1.0	**L-N**
Zn	61	100%	10	**L-N**
Be	*18*	*30%*	*1.0*	*n.a.*
Mo	*2*	*3%*	*1.0*	*n.a.*
Ag	*0*	*0%*	*1.0*	*n.a.*
Sn	*0*	*0%*	*5.0*	*n.a.*
Tl	*0*	*0%*	*1.0*	*n.a.*
U	*0*	*0%*	*40*	*n.a.*

Table 3.2: Rate of detection, detection limits and distribution type for elements and LOI in Bermuda soil.

a: DL = detection limit;
b: Dist. = probability distribution of data, where:
N = normal, based on Shapiro-Wilks test at P ≤ 0.05;
L-N = log-normal, based on Shapiro-Wilks test at P ≤ 0.05;
L-N = log-normal, assumption based on histogram (Figure 3.2)
n.a. = analysis not applicable owing to low rate of detection (%>DL).

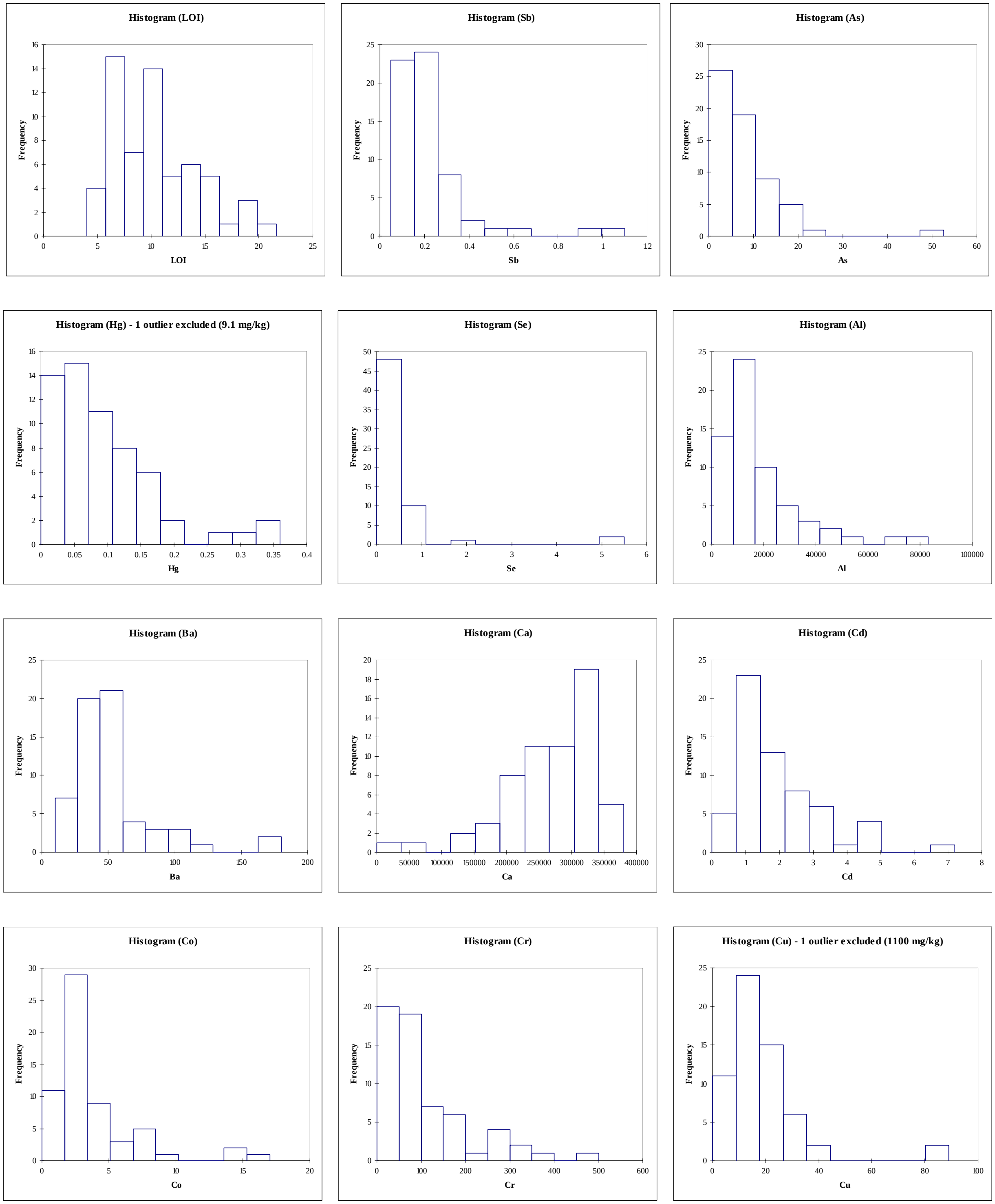


Figure 3.2: Histograms of element (mg/kg) and LOI (%) frequency distributions. Note that one outlying data point has been excluded from each of the histograms for Hg and Cu to better illustrate the underlying distribution. (cont. overleaf)

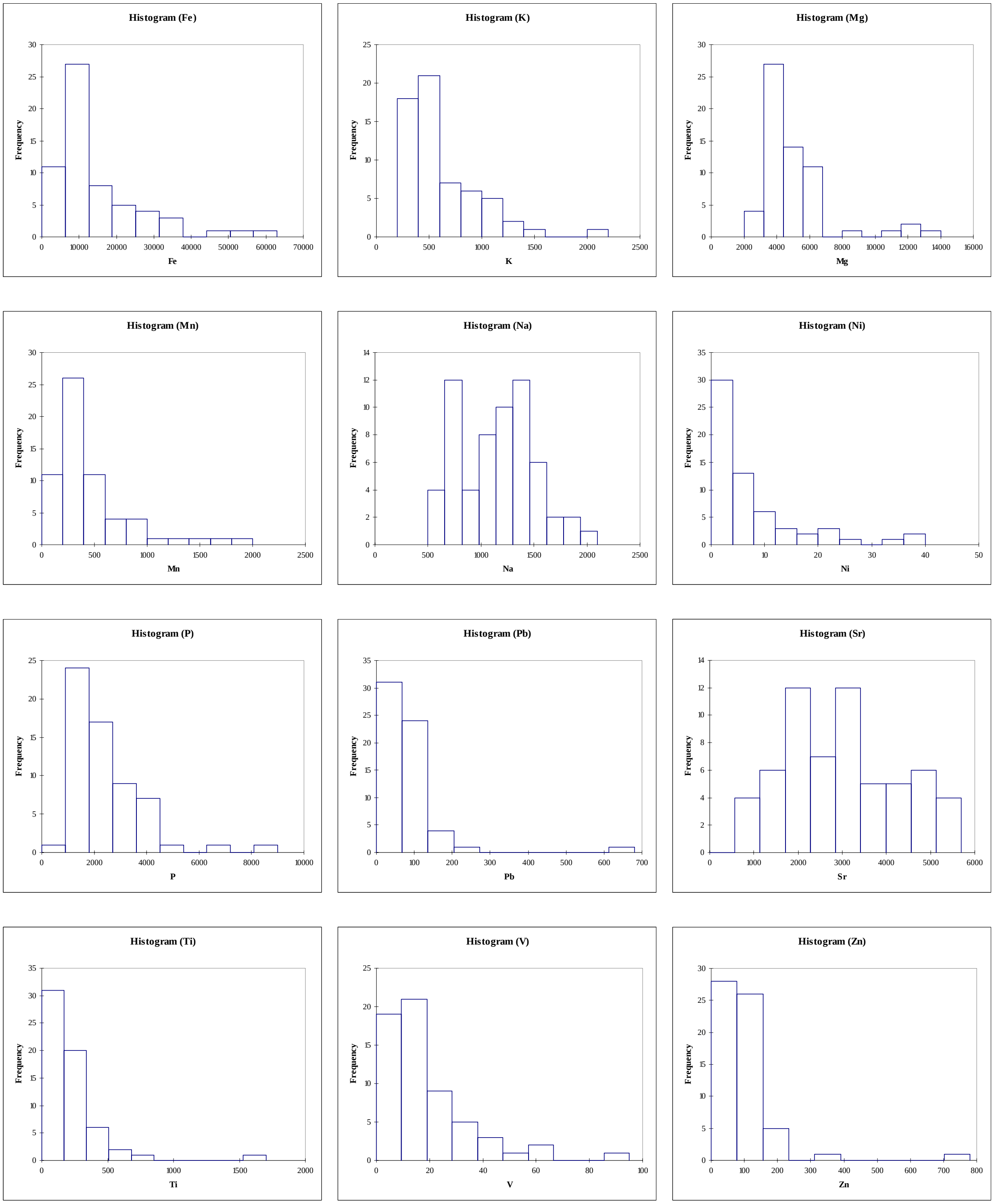


Figure 3.2 (cont.): Histograms of element (mg/kg) frequency distributions.

	Mean	s.d.	CoV [a]	95th %ile [b]	Median	Geo. mean	Geo. lower 95% CI [c]	Geo. upper 95% CI [d]	Min.	Max.
LOI	10	4.0	38%	20	10	**9.7**	4.6	20	4.4	21
Sb	0.21	0.17	80%	0.50	0.20	**0.17**	< 0.1	0.61	< 0.1	1.0
As	8.1	7.7	95%	20	5.6	**5.9**	1.3	28	1.3	52
Hg	0.25	1.2	467%	0.31	0.080	**0.081**	< 0.05	0.54	< 0.05	9.1
Hg[e]	0.10	0.076	76%	0.27	0.080	**0.074**	< 0.05	0.33	< 0.05	0.35
Se	0.55	0.90	162%	0.90	0.30	**0.37**	< 0.1	1.6	< 0.1	5.4
Al	18000	16000	87%	49000	13000	**13000**	2300	74000	1300	82000
Ba	52	32	60%	100	48	**45**	15	130	10	180
Ca	270000	72000	27%	350000	**290000**	250000	97000	650000	17000	370000
Cd	2.0	1.3	67%	4.8	1.6	**1.6**	< 0.5	5.6	< 0.5	7.1
Co	3.7	3.4	92%	9.0	2.0	**2.6**	< 1	14	< 1	16
Cr	110	100	92%	310	65	**76**	15	380	16	500
Cu	37	140	377%	37	16	**17**	3.2	86	2.0	1100
Cu[f]	19	15	79%	37	16	**15**	4.3	55	2.0	88
Fe	15000	12000	81%	38000	10000	**11000**	2700	48000	2500	62000
K	620	360	57%	1200	510	**550**	210	1400	230	2200
Mg	5000	2300	45%	11000	4300	**4600**	2300	9300	2600	14000
Mn	440	390	86%	1300	320	**330**	71	1500	50	1900
Na	**1100**	350	30%	1700	1200	1100	580	2000	500	2000
Ni	7.5	9.1	120%	25	4.0	**4.1**	< 2	36	< 2	39
P	2500	1500	59%	4500	2100	**2100**	770	5900	580	8900
Pb	84	90	106%	200	67	**63**	14	270	9.0	670
Sr	**3000**	1300	44%	5200	2900	2700	970	7300	590	5700
Ti	230	240	103%	550	160	**170**	36	810	26	1700
V	19	16	86%	48	13	**14**	3.2	63	2.0	94
Zn	100	100	102%	180	80	**79**	23	270	20	770
Be	*trace*				*trace*	*trace*			*< 1.0*	*4.0*
Mo	*trace*				*trace*	*trace*			*< 1.0*	*11*
Ag	*n.d.*				*n.d.*	*n.d.*			*< 1.0*	*< 1.0*
Sn	*n.d.*				*n.d.*	*n.d.*			*< 5.0*	*< 5.0*
Tl	*n.d.*				*n.d.*	*n.d.*			*< 1.0*	*< 1.0*
U	*n.d.*				*n.d.*	*n.d.*			*< 40*	*< 40*

Table 3.3: Summary statistics for metals (mg/kg) and LOI (%) measured in Bermuda soil. Concentration data to 2 sig. figs. Shading added to aid with interpretation.

bold: best estimate of central tendency;
a: CoV - coefficient of variation = mean/s.d.;
b: 95th percentile of untransformed data;
c: Lower 95% confidence interval of the geometric mean = $GM/GSD^{1.96}$;
d: Upper 95% confidence interval of the geometric mean = $GM \times GSD^{1.96}$;
e: Hg data with one outlier excluded (9.1 mg/kg);
f: Cu data with one outlier excluded (1100 mg/kg).

For those parameters which do exhibit a normal distribution (Na and Sr), the arithmetic mean is the best estimate of central tendency ("average"), and for log-normal distributions, the geometric mean is the best estimate of central tendency (Ginevan and Splitstone, 2004). The distribution of Ca can not easily be fitted to an appropriate probability distribution and the median is the best estimate of central tendency for this element.

3.2.4 - Comparison of Soil Concentrations with Background Levels

A particular problem in risk assessment of contaminants in soil is establishing a “background” concentration against which comparisons can be made (Chen, *et al.*, 2002; USEPA, 2002b; Hamon *et al.*, 2004).

Table 3.4 shows background ranges of metals in some U.S. soils. They include generic values provided by the U.S. Risk Assessment Information System (RAIS) which can be used to establish a baseline for local background concentrations or to provide appropriate background concentrations when site-specific values are lacking (USDOE, 2006). The RAIS range presented for each element is derived from the minimum and maximum range values for 3 soil types which closely resemble Bermuda’s soil type: i) clay and clay-loamy soils; ii) soils over limestones and calcareous rocks; and iii) various soils.

Also shown in Table 3.4 are:
1) background soil concentrations for some metals in surface soil from Florida (Chen *et al.,* 1999);
2) background soil concentrations for some metals calculated using the observed 95th percentile of Fe in Bermuda soil and based on soil data from SE Asia and Australia (Hamon *et al.*, 2004);
3) background soil concentrations for some metals calculated for risk assessment purposes in the Netherlands (Crommentuijn *et al.*, 2000).

When compared with the U.S. background values, the elements for which these data are available fall into 3 groups:
1) Background - Sb, As, Se (two outliers excluded), Hg (one outlier excluded), Ba, Co, Cr, Cu (one outlier excluded), Mn, Ni, V and Zn (two outliers excluded): elements with mean and all maximum values lying within the background range expected for U.S. soils;
2) Upper background - Pb: elements with mean values lying within the background range expected for U.S. soils but with more than 2 maximum values greater than this range;
3) Above background - Al, Cd, Fe, Sr and Ti: elements with mean and maximum values greater than the background range expected for U.S. soils.

The fact that Al and Fe have higher concentrations than most U.S. soils is a reflection of the high clay content of Bermuda soil: clay minerals are rich in Al and Fe. The high levels of Sr (and Ca and Mg, all 3 of which are members of the alkaline earth group (Group 2) of elements) in Bermuda soil may reflect the influence on soil chemistry of Bermuda’s limestone bedrock. A more complete mineralogical and geochemical analysis of Bermuda’s soil and bedrock would better enable the determination of appropriate background levels of major and trace elements in soil.

When compared with the Florida data of Chen *et al.* (1999), the data fall into the following categories:
1) Background - Sb (two outliers excluded) and Ni: elements with mean and all maximum values lying within the background range of Florida soils;
2) Upper background - As, Se, Ba, Cr and Cu: elements with mean values lying within the background range but with more than 2 maximum values greater than this range;
3) Above background - Hg, Cd, Pb and Zn: elements with mean and maximum values greater than the background range estimated for Florida soils.

The data also further suggest that Cu, Pb, Zn and Cd are present in Bermuda soil at concentrations above background levels soils from SE Asia/Australia and the Netherlands (Hamon *et al.*, 2004; Crommentuijn *et al.*, 2000).

Of the metals identified by these comparisons as being present above background, the levels of As, Hg, Se, Ba, Cr, Cd, Cu, Pb and Zn may be of concern owing to their toxicological properties. However, it is important to note that, with the exception of Cd, metals are present in Bermuda soil at mean concentrations lower than the background concentrations determined for the Netherlands. Furthermore, the fact that any particular metal may be present at a mean concentration higher than in another region/country does not necessarily indicate an increase in risk. This aspect is discussed further in Sections 3.25 and 3.26, below.

Specific background levels for metals in Bermuda soil were calculated using the method of Chen *et al.* (2001) and are shown in Table 3.4. This method defines the background concentration as being the upper 95th percentile of the expected range of background concentrations. The upper 95% confidence interval of the geometric mean was used for data following a log-normal distribution and the 95th percentile was used for data not log-normally distributed (Ca, Na and Sr). This approach assumes that all sample sites represent undisturbed soil with no extensive anthropogenic pollution. The number of sites with sample concentrations above these calculated values are low, ranging from 1 to 4 sites for each element (see Table 3.4).

	Bermuda mean conc. [a]	**Bermuda background conc.** [b]	**N > BBM** [c]	**U.S. background conc. range** [d]	**Florida background conc. range** [e]	**SE Asia and Australia background conc. range** [f]	**Netherlands background conc. range** [g]
Sb	0.17	0.61	2	0.25-6.0	0.06-0.79		3.0
As	5.9	28	1	1.0-93	0.02-7.01	<10	29
Hg	0.081	0.33 [h]	1	0.01-1.5	0.0008-0.04		0.3
Se	0.37	1.6	3	<0.1-4.0	0.01-1.11		0.7
Al	13000	74000	1	4.3-100			
Ba	45	130	2	70-3000	1.67-112		155
Ca	290000	350000 [j]	3				
Cd	1.6	5.6	1	0.41-0.57	0-0.33		0.8
Co	2.6	14	3	3-30			9.0
Cr	76	380	2	5-1500	0.89-80.7	<80	100
Cu	17	55 [i]	2	3-300	0.22-21.9	<15	36
Fe	11000	48000	2	4000-10000			
K	550	1400	2				
Mg	4600	9300	4				
Mn	330	1500	2	20-3000			
Na	1100	1700 [j]	3				
Ni	4.1	36	2	<5-150	1.7-48.5	<25	35
P	2100	5900	2				
Pb	63	270	1	<10-70	0.69-42	<4	85
Sr	3000	5200 [j]	3	7-1000			
Ti	170	810	1	0.05-1.0			
V	14	63	1	0.7-150			42
Zn	79	270	2	10-300	0.89-29.6	<35	140
Be	*trace*			<1-15	0.04-4.15		1.1
Mo	*trace*			0.3-3.3	0.13-6.76		0.5
Ag	*n.d.*			0.03-0.09	0.07-2.5		
Sn	*n.d.*			<0.1-3.1			19
Tl	*n.d.*			0.01-2.8			1.0
U	*n.d.*			0.3-11			

Table 3.4: Comparison of mean and background Bermuda soil metal concentrations with background concentrations from other regions. Shading added to aid interpretation.

a: Mean concentration observed in Bermuda soil - best indicator of central tendency as presented in Table 3.3;
b: Background concentration estimated for Bermuda (see text);
c: Number of samples with concentration above Bermuda background level;
d: U.S. Risk Assessment Information System generic background soil concentration range for 3 soil types - see text for details (USDOE, 2006);
e: Background soil concentration range for Florida surface soils (Chen *et al.*, 1999);
f: Estimate of metal concentration for SE Asian and Australian soils, based on observed 95th percentile value of Fe in Bermuda soil (Hamon *et al.*, 2004);
g: Background soil concentration determined for Netehrlands soil with 10% organic matter and 25% clay (Crommentuijn *et al.*, 2000);
h: Hg data with one outlier excluded (9.1 mg/kg);
i: Cu data with one outlier excluded (1100 mg/kg);
j: 95th percentile used for data which is not log-normally distributed.

3.2.5 - Comparison of Soil Concentrations with Regulatory Limits

Regulatory limits for metals in soil are not well defined and vary greatly among countries, regional jurisdictions and land use type (Chen *et al.*, 2002). Furthermore, single threshold values based on a total metal concentration may have little or no meaning in terms of protection of the soil ecosystem (Chen *et al.*, 2001; Gorusch, *et al.*, 2006) owing to the complex, variable and dynamic conditions which apply. Where comparison to a single regulatory value is made, assessments are often conservative and further refinement of the assessment may be required.

Concentrations of metals in Bermuda soil are compared in Table 3.5 with guideline values used by the U.S. and Canadian governments for assessment of human and environmental health risks. However, this type of data comparison should be considered with caution, as discussed above. There currently are no Bermudian regulatory limits for contaminants in soil.

It is important to note that the U.S. Soil Screening Limits (SSLs) are not statutory or cleanup standards: they are used to identify sites that do not require further Federal attention under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), also known as “Superfund” (USEPA, 1996; 2002a). They are part of a three-tiered framework which includes: a set of conservative, generic SSLs (as shown in Table 3.5); a simple site-specific approach for calculating SSLs; and a detailed site-specific modelling approach for more comprehensive consideration of site conditions in establishing SSLs. When considering these generic SSLs it is essential that it is recognised that they are: 1) screening values, used to identify potential contamination and exposure; and 2) they are more stringent (i.e. conservatively protective) than site-specific levels. Where contaminant concentrations equal or exceed SSLs, further study or investigation is warranted but not necessarily cleanup or other remedial action (USEPA, 1996).

In addition to the generic SSLs for human ingestion/dermal absorption and inhalation, Table 3.5 also includes generic SSLs for protection of groundwater. These concentrations are back-calculated from an acceptable target soil leachate concentration using an appropriate Dilution-Attenuation Factor (DAF) (USEPA, 2002a). SSLs derived with a DAF value of 1.0 (no dilution or attenuation) have been used to provide a conservative estimate as the soil in Bermuda is shallow and may not significantly impede migration to groundwater. The U.S. EPA recommend applying a DAF of 1.0 at sites where: “little or no dilution or attenuation of soil leachate concentrations is expected; this will be the case at sites with characteristics such as shallow water tables, fractured media, karst topography, or source size greater than 30 acres” (USEPA, 2002a). Most of these characteristics apply to Bermuda soil.

The Canadian Soil Quality Guidelines presented in Table 3.5 are “science-based goals for the quality of atmospheric, aquatic, and terrestrial ecosystems. Environmental quality guidelines are defined as numerical concentrations or narrative statements that are recommended as levels that should result in negligible risk to biota, their functions, or any interactions that are integral to sustaining the health of ecosystems and the designated resource uses they support” (CCME, 2004).

	Ingestion/ dermal [a] (mg/kg)	**N> SSL [b]**	**%> SSL [c]**	**Inhalation [d] (mg/kg)**	**N> SSL**	**%> SSL**	**G-water 1 DAF [e] (mg/kg)**	**N>1 DAF**	**%>1 DAF**	**SQG [f] (mg/kg)**	**N> SQG**	**%> SQG**
Sb	31	0	0%				0.3	6	**10%**			
As	0.4	61	**100%**	770	0	0%	1	61	**100%**	12	11	**18%**
Hg	23	0	0%	10 [g]	0	0%	0.1	21	**34%**	6.6	1	**2%**
Se	390	0	0%				0.3	30	**49%**	1	3	**5%**
Ba	5500	0	0%	710000	0	0%	82	9	**15%**	500	0	0%
Be	160	0	0%	1400	0	0%	3	2	**3%**			
Cd	70	0	0%	1800	0	0%	0.4	60	**98%**	10	0	0%
Cr	230	8	**13%**	230	8	**13%**	2	61	**100%**	64	32	**52%**
Cu										63	3	**5%**
Ni	1600	0	0%	14000	0	0%	7	18	**30%**	50	0	0%
Pb	400	1	**2%**							140	5	**8%**
V	550	0	0%				300	0	0%	130	0	0%
Zn	23000	0	0%				620	1	**2%**	200	2	**3%**
Ag	390	0	0%				2	0	0%			
Tl	6	0	0%				0.04 [h]	0	0%	1	0	0%

Table 3.5: Exceedences by metals in Bermuda soil of the U.S. generic Soil Screening Limits (SSL) for residential scenarios and Canadian Soil Quality Guidelines (SQG) for residential/parkland scenarios.

bold: Percentage of sites (N=61) exceeding SSL/DAF/SQG when > 0%;
a: U.S. EPA limit for human ingestion and dermal absorption exposure pathway;
b: N>SSL/DAF/SQG = number of Bermuda soil sample sites exceeding the SSL/DAF/SQG;
c: %>SSL/DAF/SQG = percentage of Bermuda soil sample sites exceeding the SSL/DAF/SQG;
d: U.S. EPA limit for human inhalation exposure pathway (fugitive particles, except for Hg);
e: U.S. EPA SSL for protection of groundwater from leaching of elements when a DAF (Dilution-Attenuation Factor) of 1.0 is applied;
f: Canadian Soil Quality Guideline;
g: Hg inhalation SSL for volatile Hg only, not fugitive particles;
h: Groundwater SSL for Tl is lower than the analytical detection limit;

Sources: USEPA (1994; 2002a) and CCME (2004).

It can be seen that a number of elements exceed one or more SSL and/or SQG. The most significant of these are discussed in Section 3.2.6. Ten out of the 13 U.S. EPA SSLs for groundwater protection are exceeded. However it is difficult to interpret these without a better understanding of the soil structure and physicochemical properties (e.g. soil horizon characteristics, mineralogy and cation exchange capacity) as these factors will determine the extent of attenuation of elements within the soil layer. To the author's best knowledge, there has been no survey of soil in Bermuda which would otherwise provide these data.

Sample locations which exhibit more than 2 exceedences of a SSL or SQG value are:

- Devonshire Marsh West* - As, Cr, Cu
- Watlington Point* - As, Cr, Pb
- American Consul - As, Cr, Pb
- Bermuda College - As, Cr, Cu
- Brighton Hill - As, Cr, Cu, Pb
- Ferry Point Park - As, Se, Cr, Zn
- Gibbs Hill - As, Hg, Pb, Zn
- Hog Bay Park - As, Se, Cr
- Warwick Academy - As, Se, Cr

* = sites located < 1 km from TBWTF.

These sites are well distributed across Bermuda and only 2 of these (Devonshire Marsh West and Watlington Point) are located within 1 km of the incinerator. There does not appear to be any geographical clustering of sites with maximum metal concentrations which may indicate that metals are distributed randomly across the island at naturally elevated levels (see next Section). Alternatively, historic land use practices may account for these maxima. Many marshes and ponds in Bermuda were used as garbage disposal sites until the mid-20th century: this may account for the high levels of Cr and Cu observed at Devonshire Marsh West, and Ferry Point Park is located close to past military sites and the former railway. Both of these activities may have been sources of some metals to soil.

3.2.6 - Significance and Sources of Specific Metals in Bermuda Soils

3.2.6.1 - Arsenic At all sites, arsenic (As) exceeds the U.S. generic SSL for human ingestion and dermal adsorption, as well as the SSL for the protection of groundwater. The Canadian SQG for As is also exceeded at 11 sites, all at a distance of > 1 km from the incinerator. This suggests that levels of As in soil in Bermuda may be of concern, particularly at the sites displaying maximum concentrations of As: Brighton Hill, Bermuda College, Warwick Academy, Hog Bay Park, Ferry Point Park, Fort Hamilton and BBSR. These 7 sites have As soil concentrations > 15 mg/kg. However, it is important to remember that As levels in Bermuda soil are within or close to expected background levels (see Section 3.2.4).

Arsenic can be a significant environmental contaminant, having sources arising from industrial and agricultural processes, but Bermuda has no major industries and limited agricultural activity. The latter was more prevalent in the past and it is conceivable that arsenic-based pesticides were used, but it is difficult to perceive a way in which soil became heavily contaminated with As across the whole of Bermuda. It is therefore important to further consider the hypothesis that the level of As in Bermuda soil is natural and the apparently high levels (i.e. elevated with respect to the generic SSL) are not anthropogenic. As seen above in Section 3.2.4, As concentrations in soil in Bermuda lie within or close to the expected background (or natural) range of As in various soils in the U.S.A., SE Asia, Australia and the Netherlands, suggesting that the levels of As observed in Bermuda are not unusual.

The most likely source of As in Bermuda soil is the African dust from which the soil is chiefly derived. It has been demonstrated that significant amounts of As and other metals (including Hg, Pb, Cr and Fe) are transported in Saharan dust: it has been estimated that *c.* 25% of atmospheric deposition of As in the southeastern U.S. is from this source (Holmes and Miller, 2004). Chen *et al.* (2002) report a range of 0.01 - 50.6 mg/kg of As in a range of soil types from Florida, similar to that observed in this study (1.3 - 52 mg/kg) and Holmes and Miller (2004) report As concentrations in aerosol samples from the SE U.S.A. of 17 and 79 mg/kg from the Virgin Islands and Florida, respectively.

Further evidence of a natural source of As is the relationship between Fe and As, and Al and As. As is absorbed by Fe- and Al-oxides on soil and aerosol particles (Holmes *et al.*, 2004; Beaulieu and Savage, 2005). Figure 3.3 shows that As is highly correlated with both Fe and Al in Bermuda soil.

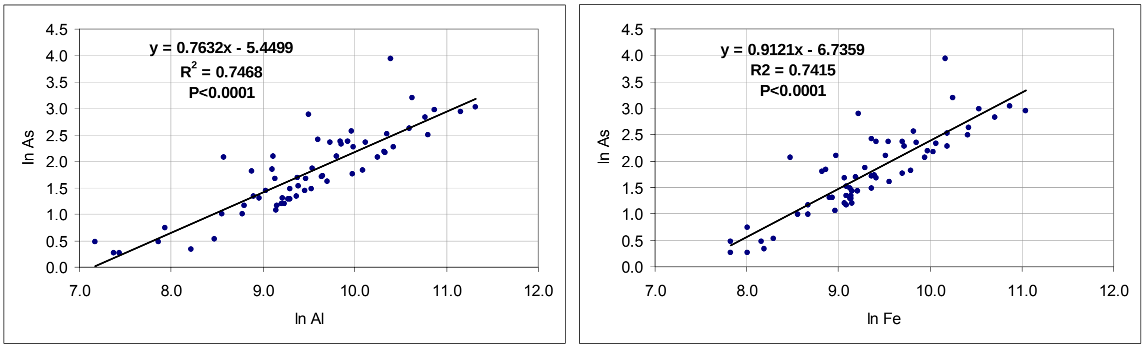


Figure 3.3: Correlations of As with Al and Fe in Bermuda soil.

3.2.6.2 - Mercury - Mercury showed one exceedence of the Canadian SQG, attributable to one extreme outlier value of 9.1 mg/kg (versus a SQG value of 6.6 mg/kg). This occurred at the Gibbs Hill sampling location, next to Gibbs Hill lighthouse which until 2003 employed a mercury bath bearing for the rotating light. This was damaged during hurricane Fabian in September 2003 and a significant amount of mercury was released. However, this site also recorded the highest concentrations of Hg in soil in the 2 previous surveys conducted in 1994 and 2000 and so the Hg burden of soil at this location probably reflects a localised and long-term source of mercury, i.e. the lighthouse. The light has since been equipped with a mechanical bearing and so it can be expected that the Hg level in soil at Gibbs Hill will decrease in subsequent years.

3.2.6.3 - Chromium - Cr exceeded the U.S. EPA human ingestion/dermal absorption and inhalation SSLs at 8 sites, all at a distance of > 1 km from the incinerator. It also exceeded the Canadian SQG at 32 sites.

Of these, 11 are at sites < 1 km from the incinerator and 21 are at sites > 1 km from the incinerator. To better understand the source of Cr in Bermuda soil, more detailed analyses are required to determine the speciation of Cr present: Cr(III) occurs naturally in the environment while Cr(VI) and Cr(0) are generally produced by industrial processes (ATSDR, 2005). As is the case with As, Cr also demonstrates highly significant correlations with Al and Fe (see Figure 3.4), indicating that Cr levels in Bermuda soil may also be naturally derived from inputs of African dust.

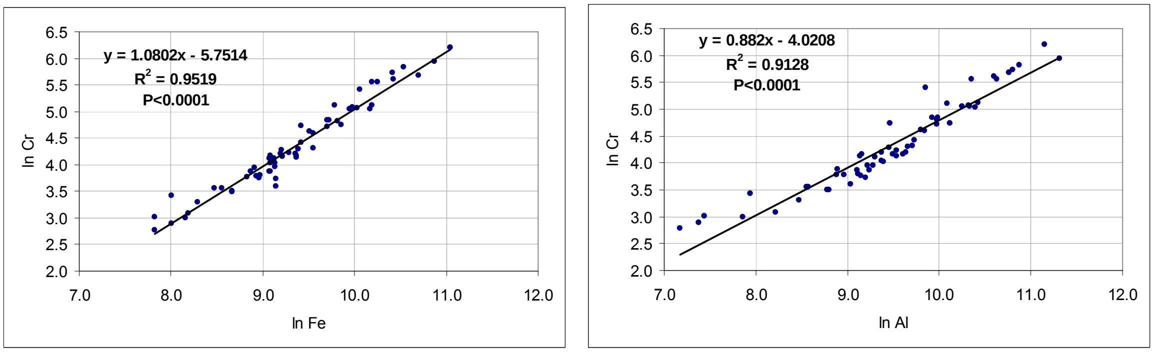


Figure 3.4: Correlations of Cr with Al and Fe in Bermuda soil.

3.2.6.4 - Lead - Pb exceeded the U.S. EPA human ingestion/dermal absorption SSL at 1 location and exceeded the Canadian SQG value at 5 locations. The SSL exceedence occurred at Gibbs Hill, coincident with the maximum value for Hg. Unlike As and Cr, Pb displays no significant ($P \leq 0.05$) correlations with Al or Fe. This may indicate that Pb may have a localised source. The incinerator is one possible source, as is the historic use of Pb in gasoline in Bermuda. This practice was discontinued in 1990 but residual Pb could still be present in soil. Long-range atmospheric transport and deposition of Pb from North America is also a possible source, though evidence suggests that this has dramatically decreased over the last 2 decades (Huang *et al.*, 1996).

3.2.6.5 - Other elements - Se, Cu and Zn exceeded Canadian SQG values at 3, 3 and 2 sites, respectively. The levels of all 3 of these elements were classified as background level when compared with U.S. soil data (Section 3.2.4) and upper background (Se and Cu) and above background (Zn) when compared with Florida soil. These 3 elements exhibit significant ($P \leq 0.05$) correlations with Al and Fe, indicating a possible natural source.

3.2.7 - Profiles of Metals in Soil and TBWTF Incinerator Emissions

Figure 3.5 shows the profiles of metals measured in Bermuda soil and in the stack emissions from the TBWTF exhaust stack (see Section 1.3, Table 1.2). It can be seen that Cr is a major component of both the soil burden and the incinerator emissions, indicating that the incinerator may be source of Cr in Bermuda soil. However, a direct comparison of these data is overly simplistic as it relies on the assumption of conservation of the incinerator signal without modification in the air and soil. This is unlikely owing to differential physicochemical removal processes which will be in effect for different elements.

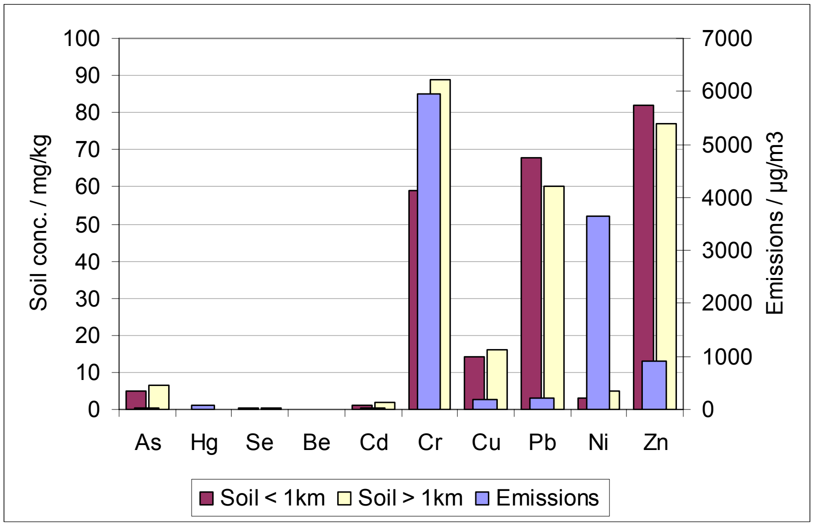


Figure 3.5: Profile of metal concentrations in soil < 1 km and > 1 km from the incinerator and in the TBWTF incinerator stack emissions.

3.2.8 - Dependence of Soil Metal Concentrations on Proximity to Incinerator

Owing to the uncertainty associated with the determination of probability distributions for the data, and because there was not one common distribution for the whole data set, a nonparametric statistical test was used to determine if mean metal concentrations differed significantly between sites located closer to (< 1 km) and further away (> 1 km) from the incinerator. The test used was a two-tailed Mann-Whitney test, a statistically robust test, frequently used in determination of background versus contaminated concentrations of contaminants in soil (USEPA, 2002b). The analysis assumes that the 2 sets of data being compared are independent and does not rely on an assumption of the probability distribution of the data. Results were assessed at the $P \leq 0.05$ and 0.20 levels, the latter being the minimum significance level recommended for use by the U.S. EPA (USEPA, 2002b). The results are shown in Table 3.6.

Significant differences at $P \leq 0.05$ in mean concentrations with distance from the incinerator were identified for Cd, Mg, P and Sr. Of these, Sr was determined to have significantly higher concentrations nearer the incinerator and Cd, Mg and P have significantly higher concentrations further away from the incinerator. At $P = 0.20$, a further 8 elements (Sb, As, Co, Cr, Fe, K, Mn and Ni) had higher concentrations at distances > 1 km from the incinerator and 2 (Ca and Na) had higher concentrations at distances < 1 km from the incinerator. The latter observation may be explained by increased deposition of sea salt at these locations, resulting in higher soil concentrations of Ca and Na. The fact that some elements show increased concentration further away from the incinerator is not necessarily an indication that the incinerator is not a source of these elements. It could be an indication that the majority of atmospheric fallout of the exhaust plume is occurring at distances greater than 1 km from the stack. During the planning process related to construction of the incinerator, atmospheric dispersion modelling performed using the US EPA ISCT3 model suggested that Fort Prospect, located 1 km south of the incinerator, would experience maximum ground level exposure to deposition of exhaust gases from the incinerator (Simmons and Knap, 1991). More recent dispersion modelling using the same model (but with different meteorological parameters) conducted as part of the planning process for the planned third waste stream at the incinerator suggested that maximum deposition would occur at 2 – 3 km East of the incinerator (Roffman report submitted to Department of Environmental Protection, August 2006).

	Arithmetic Mean		Geometric Mean		P [c]
	< 1 km [a] (mg/kg)	> 1 km [b] (mg/kg)	< 1 km (mg/kg)	> 1 km (mg/kg)	
LOI	9.8	11	9.1	10	0.2487
Sb	0.21	0.22	0.20	0.16	0.0546
As	5.7	9.6	4.9	6.6	0.0955
Hg	0.099	0.33	0.083	0.079	0.6365
Hg [d]	0.099	0.10	0.083	0.069	0.5096
Se	0.36	0.67	0.32	0.40	0.3316
Al	13000	21000	12000	14000	0.2549
Ba	50	54	45	45	0.4129
Ca	290000	260000	290000	230000	0.1130
Cd	1.5	**2.2**	1.3	**1.8**	0.0420
Co	2.5	4.4	2.2	2.9	0.1497
Cr	67	130	59	89	0.0986
Cu	63	21	17	16	0.4254
Cu [e]	16	21	14	16	0.2654
Fe	11000	17000	9800	12000	0.1979
K	500	690	480	590	0.1234
Mg	3800	**5700**	3700	**5300**	0.0001
Mn	300	540	270	370	0.0716
Na	*1200*	1100	*1200*	1000	0.1736
Ni	4.0	9.6	3.0	5.0	0.1287
P	2000	**2700**	1800	**2400**	0.0422
Pb	78	88	68	60	0.4842
Sr	**3600**	2600	**3400**	2300	0.0040
Ti	170	270	150	180	0.2112
V	14	22	12	15	0.2543
Zn	90	110	82	77	0.5601

Table 3.6: Significant differences in mean concentrations of metals in Bermuda soil with distance from incinerator.

a: < 1 km - mean concentration at sites located < 1 km of incinerator (N = 23);
b: > 1 km - mean concentration at sites located > 1 km of incinerator (N = 38);
c: P value from two-tailed Mann-Whitney test;
d: Hg data with one outlier excluded (9.1 mg/kg);
e: Cu data with one outlier excluded (1100 mg/kg);
bold: significant at $P \leq 0.05$ (95%);
underline: significant at $P \leq 0.20$ (80%).

3.2.9 - Spatial Trends in Metal Concentrations in Soil

To further analyse the spatial distribution of metals in soil, the data for those metals for which a SSL or SQG exist (excluding Be which had a low level of detection) and the geochemical crustal indicators (Al, Ca, Fe and LOI) were subjected to agglomerative hierarchical clustering (AHC) and principal component analysis (PCA). AHC identifies homogeneous groups of objects (classes) on the basis of their description by a set of variables and PCA analyzes a set of quantitative observations to: i) study and visualize correlations between variables; ii) obtain non-correlated factors which are linear combinations of the initial variables; and iii) visualize observations in a 2- or 3-dimensional space.

AHC analysis was performed using Ward's method and assessing dissimilarity on Euclidean distance. This identified 4 groups within the soil sampling sites (see Figure 3.6 and Table 3.7):
Group 1 - sites with lowest concentrations of legislated metals;
Group 2 - sites with high Cu levels and low to moderate concentrations of other legislated metals;
Group 3 - consists of 4 sites: BBSR, Ferry Point Park, Hog Bay Park and Warwick Academy. These sites are characterised by the highest geometric mean value for As, Se, Cd, Cr, Ni and V and for the crustal tracers Al and Fe.
Group 4 - consists of 1 site, Gibbs Hill, which is characterised by the maximum observed levels of Sb, Hg, Ba, Pb and Zn.

As with the data for the sites with 2 or more exceedences listed in Section 3.2.5, there is no geographical pattern evident in these classifications.

Application of PCA based on Pearson correlation coefficients to the same sub-set of data supported the AHC analysis. The first 3 components accounted for 79.3% of the total variability of the data. The first component accounted for 51.7% of the variance, and had positive loadings for As, Se, Cd, Cr, Ni and V, positive loadings for the crustal/natural indicators LOI, Fe and Al and a negative loading on Ca. The second component accounted for 20.9% of the total variance, including most of the variation in Hg, Ba, Pb and Zn. The third component accounted for 6.7%, attributable to Cu.

These results further suggest that the source of As, Se, Cd, Cr, Ni and V in Bermuda soil is natural and most likely a result of incorporation of these metals in atmospherically transported African dust. This hypothesis is based on the high degree of positive correlation of these metals with Al and Fe (major components of fine clay minerals) and inverse correlation with Ca (in situ source from bedrock). Conversely, there are indications that Hg, Pb and Zn are from a different source(s), in that these elements are not well correlated with Al, Fe or Ca and are in some cases elevated with respect to expected background concentrations in soil.

Owing to the evidence of a significant natural source for some metals and the lack of evidence for point pollution sources in most cases (Hg at Gibbs Hill being an exception), the Bermuda background values calculated in Section 3.2.4 and listed in Table 3.4 can be considered as "natural background concentrations" rather than "background concentrations", as defined by the International Standards Organisation (ISO, 1996) standards for defining soil quality. The former classification represents concentrations derived solely from natural sources and the latter represents concentrations arising from both natural sources and non-natural diffuse sources, such as atmospheric deposition.

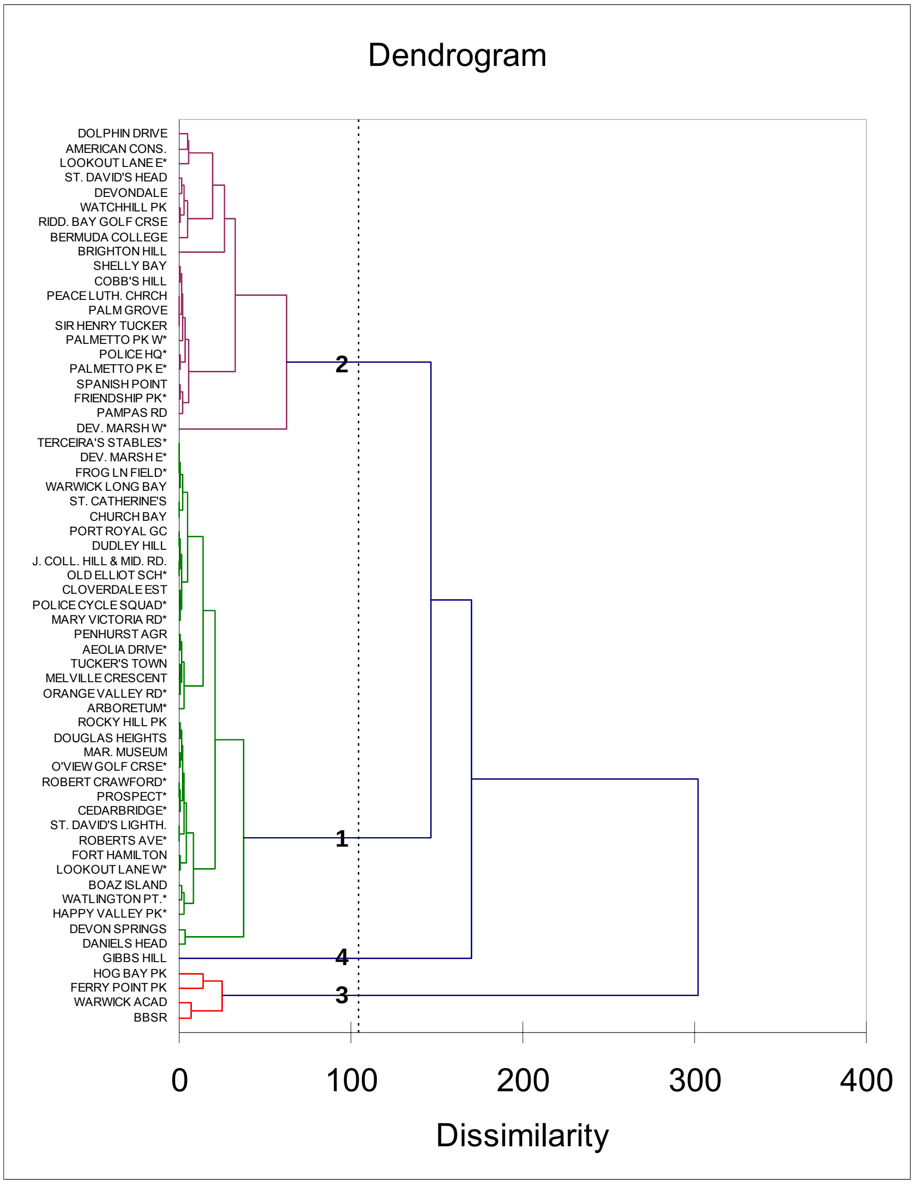


Figure 3.6: Dendrogram from AHC analysis of soil metal data. Site names indicated by * are located < 1 km from the TBWTF incinerator.

	Sb	As	Hg	Se	Ba	Cd	Cr	Cu	Ni	Pb	V	Zn	LOI%	Ca	Fe	Al
Group 1	0.20	3.9	0.057	0.27	35	1.1	46	13	1.9	54	9.0	66	7.9	310000	7200	7900
Group 2	0.15	10	0.10	0.43	58	2.6	140	**24**	10	71	24	87	12	230000	20000	25000
Group 3	0.084	**19**	0.13	**2.3**	73	**5.3**	**370**	19	**34**	62	**64**	130	**19**	58000	**48000**	**62000**
Group 4	**0.60**	1.6	**9.1**	0.20	**160**	0.80	16	15	1.0	**670**	3.0	**770**	7.0	**340000**	2500	1300

Table 3.7: Geometric mean values (mg/kg) of selected elements in Bermuda soil for groups identified by AHC analysis. Bold values indicate maximum value.

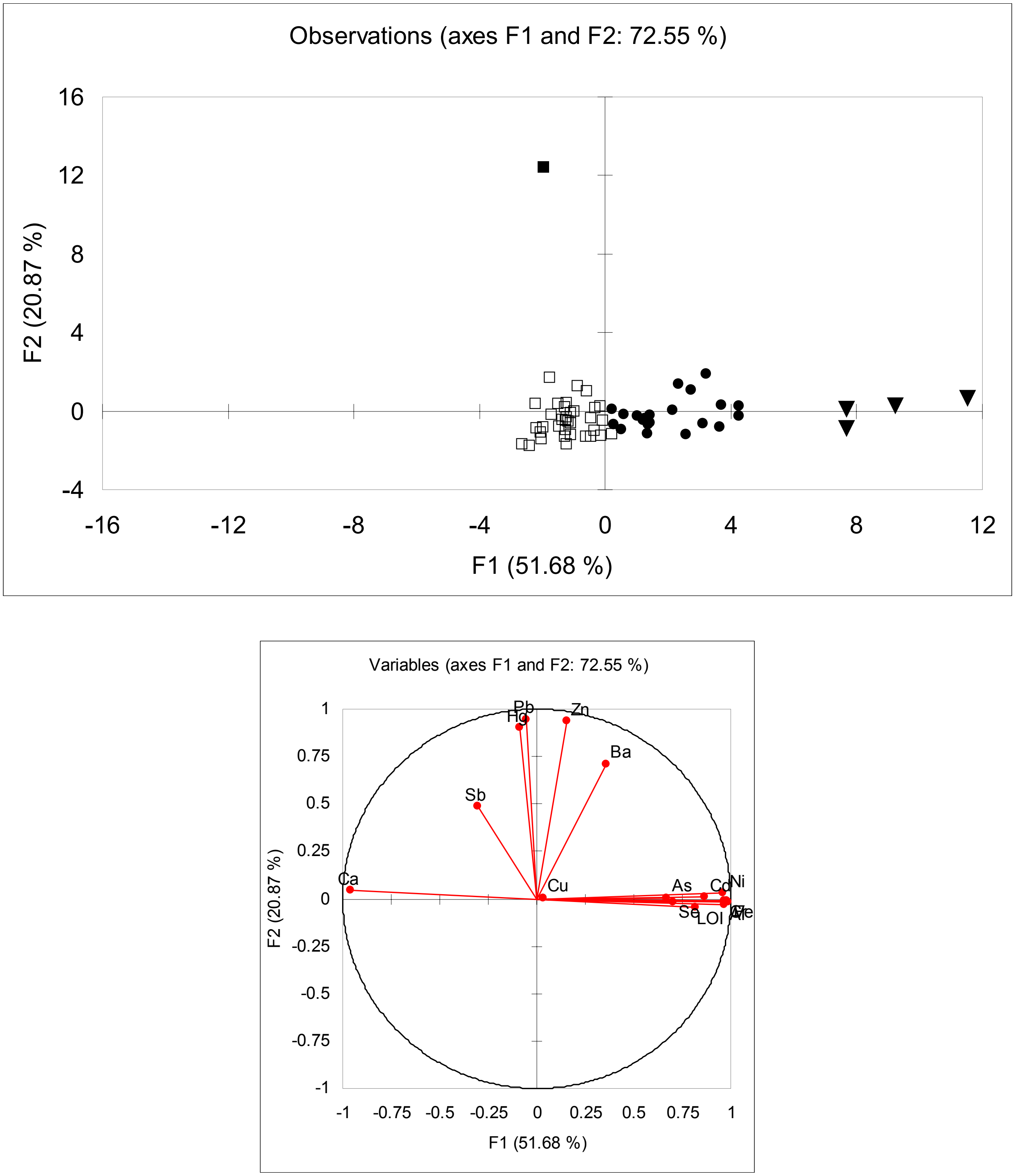


Figure 3.7: Factor plot and correlation circle of the first 2 components identified by principal component analysis. Points identified by grouping from AHC analysis, where: □ = Group 1; ● = Group 2; ▼ = Group 3; ■ = Group 4.

3.2.10 - Temporal Trends

To determine if there are any long term trends in metal concentrations in soil, the results from the current survey and those of the previous two surveys conducted in 1994 and 2000 were compared. Data for a suite of 17 metals common to all 3 surveys were analysed. The data distributions for each metal from each survey are shown in Figure 3.4, along with the U.S. EPA soil screening limits discussed in Section 3.2.5.

For the reasons discussed above in relation to the probability distributions of the data, a non-parametric test was used to determine if the results for each metal showed a significant ($P \leq 0.05$) difference over the time period. The Kruskal-Wallis test is a non-parametric alternative to a one-way ANOVA analysis (Ginevan and Splitstone, 2004). The null and alternative hypothesis tested are: H0: the samples are not significantly different (i.e. they are from the same population of data); and Ha: the samples do not come from the same population (i.e. there is significant difference between sets of data).

Of the 17 metals analysed, only Cd showed no significant difference in the 1994, 2000 and 2005 data. This suggests that the concentration of Cd in soil in Bermuda has not shown any significant increase or decrease over the time period. Assuming that the remaining 16 metals do exhibit significant differences over the time period, examination of Figure 3.4 suggests that all of these metals show a decrease in soil concentrations over the period 1994-2005, as it can be seen that the median value in each case shows a consistent decrease (i.e. the median value follows the trend: 1994>2000>2005).

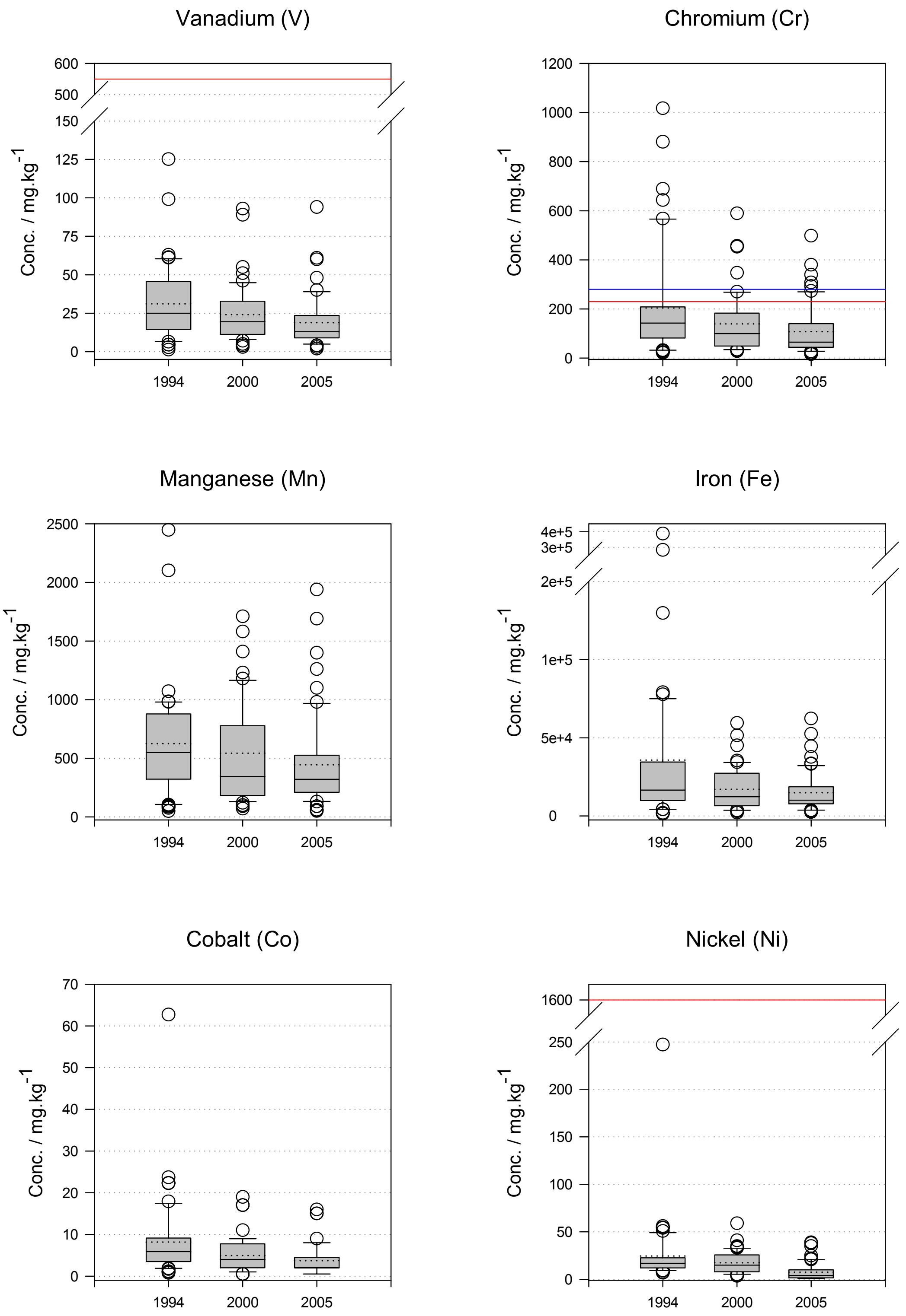


Figure 3.8: Concentrations of metals in Bermuda soil, 1994, 2000 and 2005. Upper and lower edges of box = 75th and 25th percentiles; upper and lower whiskers = 90th and 10th percentiles; open circles = outliers; solid line = median; dotted line = mean; n.d. = not detected. All symbols may not be present, depending on sample size. Where shown: red line = U.S. EPA SSL for human ingestion/dermal absorption; blue line = U.S. EPA SSL for human inhalation.

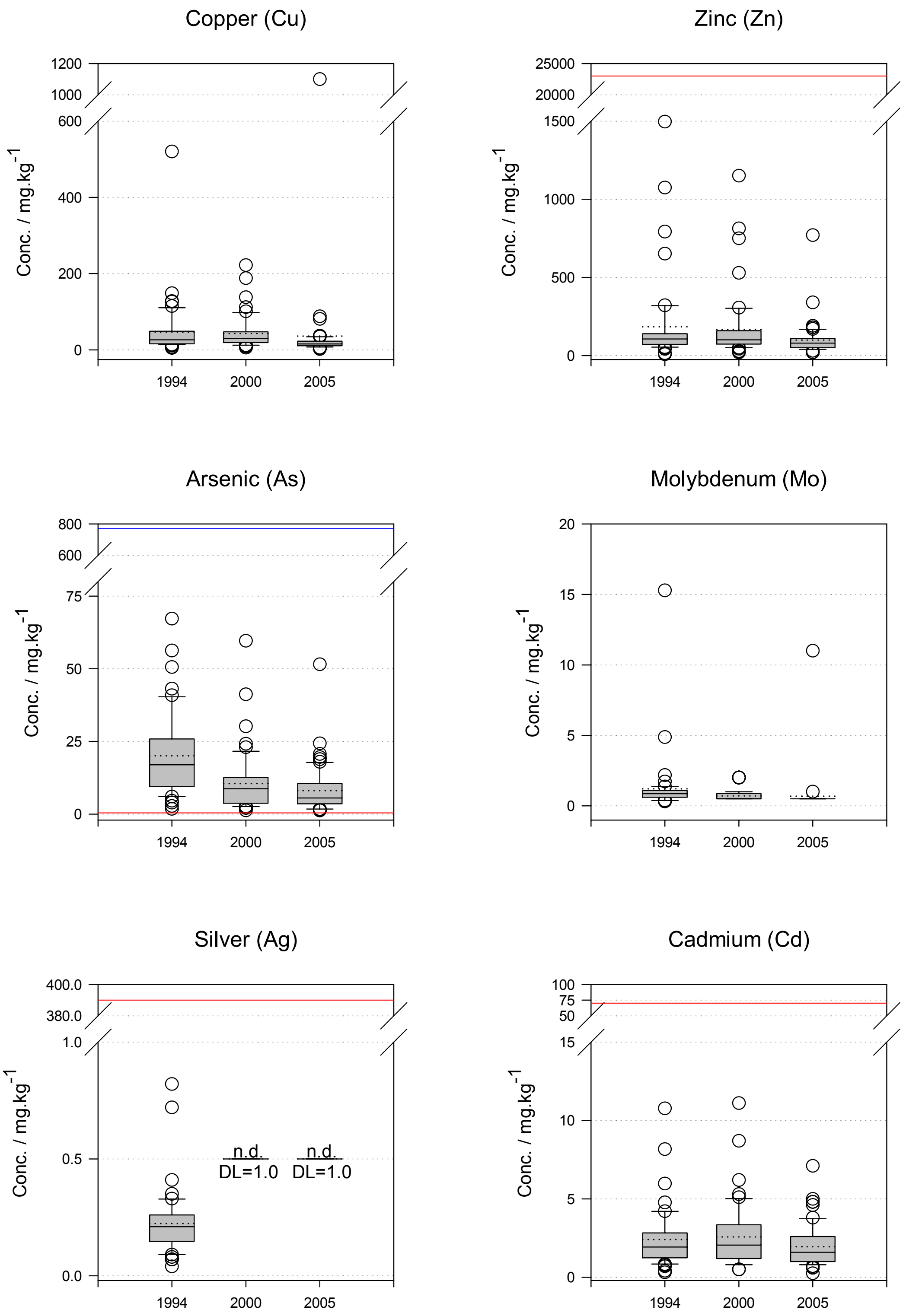


Figure 3.8 (cont.): Concentrations of metals in Bermuda soil, 1994, 2000 and 2005. Upper and lower edges of box = 75th and 25th percentiles; upper and lower whiskers = 90th and 10th percentiles; open circles = outliers; solid line = median; dotted line = mean; n.d. = not detected. All symbols may not be present, depending on sample size. Where shown: red line = U.S. EPA SSL for human ingestion/dermal absorption; blue line = U.S. EPA SSL for human inhalation.

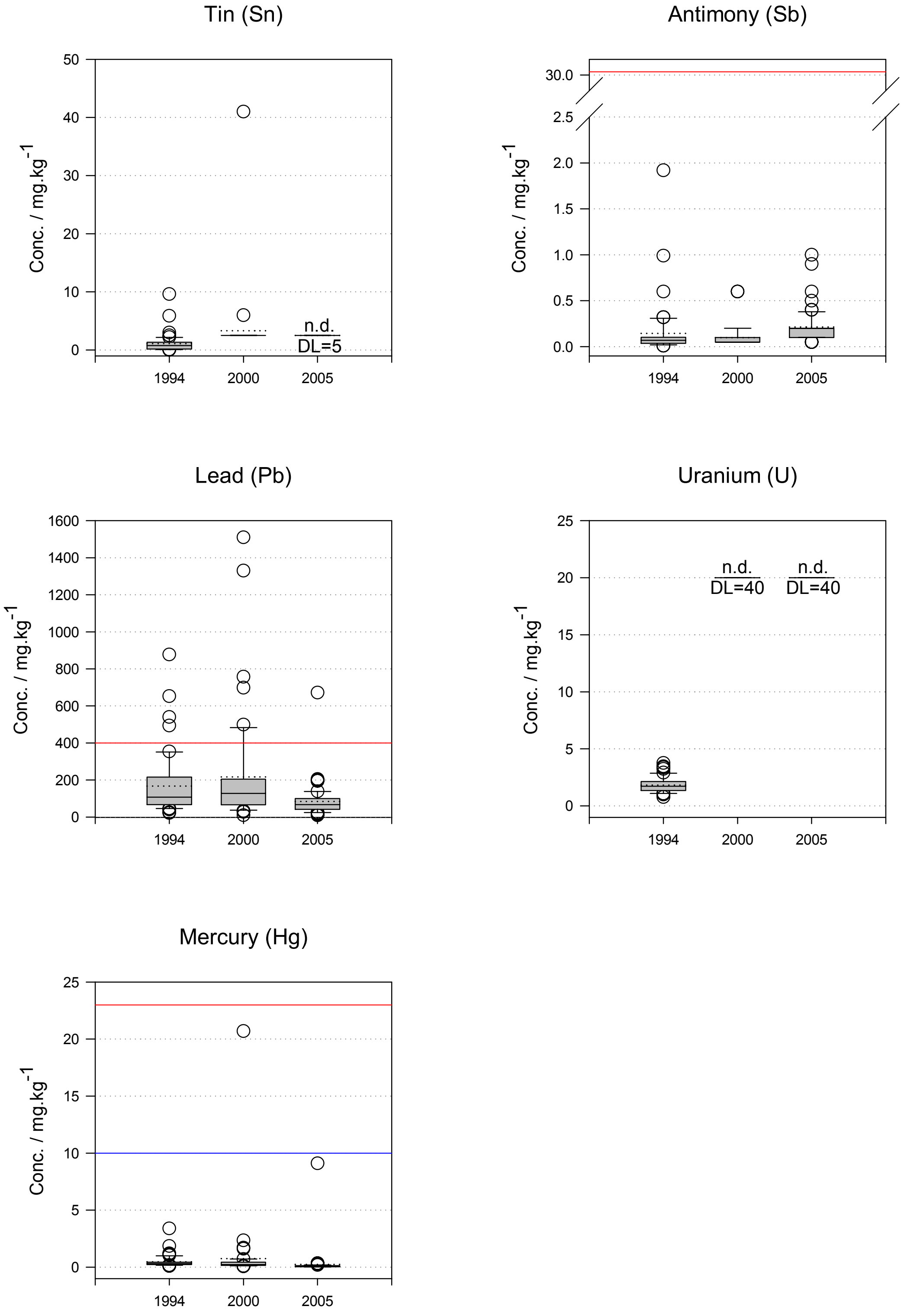


Figure 3.8 (cont.): Concentrations of metals in Bermuda soil, 1994, 2000 and 2005. Upper and lower edges of box = 75th and 25th percentiles; upper and lower whiskers = 90th and 10th percentiles; open circles = outliers; solid line = median; dotted line = mean; n.d. = not detected. All symbols may not be present, depending on sample size. Where shown: red line = U.S. EPA SSL for human ingestion/dermal absorption; blue line = U.S. EPA SSL for human inhalation.

3.3 - Organic Contaminants in Soil

3.3.1 Sampling

Samples for the analysis of organic contaminants (dioxins and PAHs) were colleted from 20 locations across Bermuda (see Figure 3.1). Of these, 13 sites (65%) were within a 1 km radius of the Tynes Bay Waste Treatment Facility. Areas of soil within the sampling location which were likely to have been exposed to recent disturbance were avoided (e.g. flower beds, sports fields, agricultural land, areas of extensive root growth). In such cases, soil was sampled immediately adjacent to the zone of disturbance.

Soil was sampled by first removing any turf present with a clean, stainless steel shovel which was thoroughly washed between sites with purified deionised water (Milli-Q water) and acetone. The top *c.* 1 cm of the exposed soil was removed and discarded, using a clean, acetone rinsed, stainless steel hand scoop. The underlying *c.* 5 cm of soil was then sampled using a clean, acetone rinsed, stainless steel hand scoop, and placed in clean 125 mL glass sampling jars. All sample containers were provided by the analytical laboratory, prepared according to their standard operating procedures. A new pair of nitrile gloves were used by personnel conducting the sampling at each site and care was taken to eliminate contamination of the samples by contact with any extraneous material. As with sampling for metal analysis, soil coring was considered but discarded for the same reasons.

Sub-samples from 5 locations within an area of approximately 2-4 m^2 at each site were combined to provide a total sample of *c.* 100 g. The sample jars were stored in the field in coolers containing freezer packs until their return to the laboratory at BBSR where they were stored in the dark at 4°C. The samples were shipped in coolers with freezer packs to maintain refrigerated conditions.

3.3.2 Analysis

Samples for dioxin analysis were extracted using Soxhlet/Dean-Stark apparatus and analysed by isotope-dilution high-resolution gas chromatography with high-resolution mass spectrometry (HRGC-HRMS), according to U.S. EPA Method 1613, Revision B. This provides isomer-specific determination of the seventeen 2,3,7,8-substituted, tetra- through octa-chlorinated, dibenzo-p-dioxin and dibenzofurans.

Samples for PAH analysis were extracted by Soxhlet extraction, according to U.S. EPA Method 3540C, and analysed by gas chromatography with mass spectrometry (GC-MS) according to U.S. EPA Method 8270. This method provides for the analysis of the 16 PAHs designated as “priority pollutants” by the U.S. EPA.

3.3.3 Dioxins

3.3.3.1 - Results

The summary statistics for the dioxin results are shown in Table 3.8. Of the 17 individual congeners measured, 4 PCDD and 5 PCDF congeners had low rates of detection (< 75% of samples). Application of the Shapiro-Wilks test at $P \leq 0.05$ on the untransformed (raw) data revealed that, with the exception of 1 out of the 17 congeners, the data do not follow a normal distribution. The $\log_e$ transformed data showed a better rate of compliance with a log-normal distribution, but this was not comprehensive: only 9 out of 17 congeners were conclusively log-normally distributed at $P \leq 0.05$. This analysis is constrained by the relatively small sample size (N = 20). Figures 3.9a and 3.9b show the distribution for those congeners which had a > 75% detection rate.

The geometric mean is the best estimate of central tendency for dioxin concentrations in Bermuda soil, with mean concentrations of total PCDDs and total PCDFs of 210 and 22 pg/g, respectively. The mean $\mathrm{TEQ_{DF}}$-$\mathrm{WHO_{98}}$ is 0.87 pg/g with a 95% confidence interval range of 0.22 - 3.4 pg/g (when calculated with the assumption that values reported as below detection limit are assigned a value of 0.5 × DL).

3.3.3.2 - Comparison with Legislative limits

The U.S. EPA has adopted a standard of 1.0 ng/g (1000 pg/g) as a starting point for setting cleanup levels for CERCLA removal sites and as a preliminary remediation goal for surface soil in residential scenarios (USEPA, 1998). The U.S. Agency for Toxic Substances and Disease Registry (ATSDR) has adopted an interim policy guideline screening level value of 50 ng/g (50,000 pg/g) and a guideline action level value of 1.0 ng/g (1000 pg/g) (ATSDR, 1997). In Canada, the national soil quality guideline limit for dioxins in soil of all application types is 4 pg/g (CCME, 2004). All of these values are expressed in TEQ concentrations.

The mean TEQ concentration of dioxins in Bermuda soil is 3 orders of magnitude lower than the U.S. limits discussed above and a factor of 4 lower than the more stringent Canadian guideline limit. The upper 95% confidence interval of dioxin TEQ concentrations in Bermuda (3.4 pg/g) is close to the Canadian guideline limit. However this limit was not exceeded at any of the 20 sample locations (maximum = 3.3 pg/g).

This suggests that dioxins in soil in Bermuda do not present a significant human or environmental health risk. However this study employed a relatively small number of samples (N = 20) and further monitoring is advised to ensure that dioxin levels are remaining within acceptable limits.

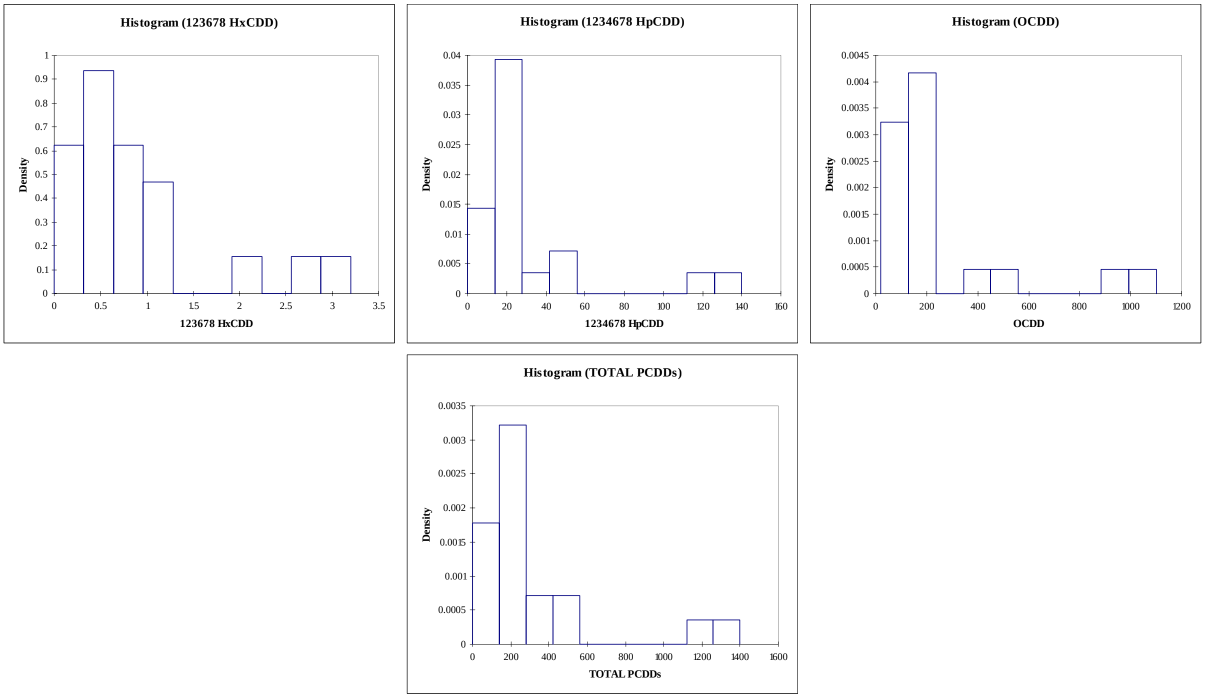


Figure 3.9a: Histograms of PCDD congener frequency distributions for congener groups with > 75% detection rate and for total PCDDs.

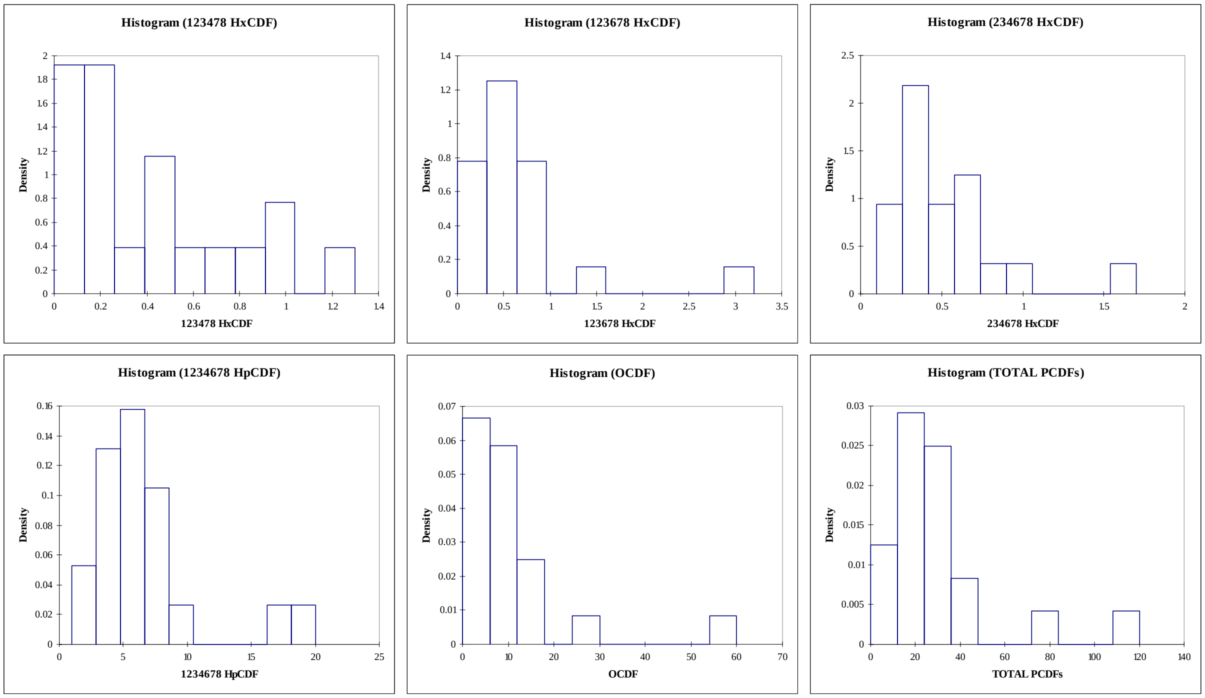


Figure 3.9b: Histograms of PCDF congener frequency distributions for congener groups with > 75% detection rate and for total PCDFs.

Congener/ Homolog [a]	DL [b]	N>DL	%>DL	Arith. mean	s.d.	CoV [c]	95th %ile [d]	Median	Geo. mean	Geo. lower 95% CI [e]	Geo. upper 95% CI [f]	Min.	Max.
2378 TCDD	0.1	0	0%	n.d. [g]				n.d.	n.d.				
12378 PeCDD	0.1	2	10%	0.14	0.31	2.2	0.28	trace [h]	trace	<0.1	0.37	<0.1	1.4
123478 HxCDD	0.1	9	45%	0.42	0.61	1.5	0.70	n.d.	0.15	<0.1	2.5	<0.1	2.3
123678 HxCDD	0.1	17	85%	0.90	0.85	0.94	1.3	0.68	0.54	<0.1	5.8	<0.1	3.1
123789 HxCDD	0.1	13	65%	0.59	0.81	1.4	0.96	0.36	0.27	<0.1	4.0	<0.1	3.5
1234678 HpCDD	0.1	20	100%	31	34	1.1	46	19	20	3.6	120	3.1	130
OCDD	0.1	20	100%	250	270	1.1	370	170	160	27	980	21	1000
Total TCDD	0.1	0	0%	n.d.				n.d.	n.d.				
Total PeCDD	0.1	4	20%	0.72	2.2	3.1	1.7	trace	0.10				
Total HxCDD	0.1	20	100%	9.0	9.1	1.0	13	6.1	6.1	1.0	36	0.95	37
Total HpCDD	0.1	20	100%	54	60	1.1	81	33	36	6.2	210	5.4	230
TOTAL PCDDs	0.1	20	100%	310	340	1.1	470	200	210	36	1200	28	1300
2378 TCDF	0.1	0	0%	n.d.				n.d.	n.d.				
12378 PeCDF	0.1	11	55%	0.39	0.59	1.5	0.67	0.28	0.18	<0.1	2.3	<0.1	2.7
23478 PeCDF	0.1	13	65%	0.26	0.23	0.89	0.37	0.21	0.17	<0.1	1.2	<0.1	0.85
123478 HxCDF	0.1	15	75%	0.40	0.35	0.88	0.56	0.27	0.24	<0.1	2.2	<0.1	1.2
123678 HxCDF	0.1	19	95%	0.62	0.65	1.1	0.91	0.48	0.43	<0.1	2.5	<0.1	3.1
123789 HxCDF	0.1	2	10%	trace				trace	trace			<0.1	0.33
234678 HxCDF	0.1	20	100%	0.52	0.34	0.65	0.67	0.44	0.44	0.14	1.4	0.15	1.6
1234678 HpCDF	0.1	20	100%	6.6	4.6	0.70	8.7	5.7	5.3	1.4	21	1.1	19
1234789 HpCDF	0.1	7	35%	0.23	0.32	1.4	0.37	n.d.	0.11	<0.1	1.0	<0.1	1.1
OCDF	0.1	20	100%	11	13	1.2	17	7.4	7.0	1.1	44	0.84	59
Total TCDF	0.1	1	5%	trace				trace	trace			<0.1	0.99
Total PeCDF	0.1	16	80%	1.4	1.7	1.2	2.2	0.96	0.62	<0.1	13	<0.1	7.4
Total HxCDF	0.1	20	100%	4.5	2.9	0.65	5.8	3.9	3.6	0.86	15	0.78	13
Total HpCDF	0.1	20	100%	13	10	0.79	17	11	10	2.4	42	2.2	46
TOTAL PCDFs	0.1	20	100%	29	25	0.84	41	24	22	5.0	100	4.7	110
Total TEQ (ND=0)				1.0	0.89	0.88	1.4	0.70	0.74	0.15	3.6	0.20	3.2
Total TEQ (ND=0.5DL)				1.1	0.89	0.80	1.5	0.85	0.87	0.22	3.4	0.30	3.3
Total TEQ (ND=DL)				1.2	0.87	0.70	1.6	1.0	1.0	0.31	3.4	0.40	3.3

Table 3.8: Summary statistics for dioxin congeners and homolog groups measured in Bermuda soil. All results in pg/g dry weight. Data to 2 sig. figs. Shading added to aid interpretation. TEQ values are derived using the TEQ_{DF}-WHO_{98} scheme.

a: T = tetra; Pe = penta; Hx = hexa; Hp = hepta; O = octa;
b: DL = detection limit;
c: CoV - coefficient of variation = mean/s.d.;
d: 95th percentile of untransformed data;
e: Lower 95% confidence interval of the geometric mean = $GM/GSD^{1.96}$;
f: Upper 95% confidence interval of the geometric mean = $GM \times GSD^{1.96}$;
g: n.d. = not detected (all values < D.L.); h: trace = calculated value < D.L.

3.3.3.3 - Comparison of Soil PCDD/F Concentrations with Background Levels

Representative estimates of background PCDD/F concentrations for North America have been compiled in the U.S. EPA draft reassessment document (USEPA, 2006b). However, owing to the limited geographic coverage and non-uniformity of studies, there is a degree of uncertainty in these estimates. Mean rural and urban background concentrations of PCCD/Fs reported are 2.6 and 8.8 pg/g as TEQ_{DF}-WHO_{98}. This compares to a corresponding geometric mean value of 0.74 pg/g from the current study. The stated background values were calculated from sample sizes of N = 319 and 305, respectively and assuming non-detect = zero. The U.S. EPA made this assumption owing to the fact that congener-specific detection limits were not available for all of the data from which the values were generated (USEPA, 2006b). European background levels are comparable to those observed in North America (USEPA, 2006b).

In one study, soil samples were collected in the vicinity of a municipal waste incinerator in Ohio, USA, to determine if soil around the incinerator had higher PCDD/F levels than soils from background sites. Samples were collected from: 1) on-site; 2) urban background locations near the incinerator; and 3) rural background sites remote from the facility. The results indicated that soil from the rural background sites had the lowest concentrations and on-site samples had the highest concentrations. For rural background soil samples, the mean TEQ_{DF}-WHO_{98} was 1.3 pg/g, when non-detects were set to one-half the detection limit. For the urban background soils the mean TEQ_{DF}-WHO_{98} was 21 pg/g and for on-site samples the mean was 444 pg/g. (Lorber *et al.*,1998; with recalculated TEQ_{DF}-WHO_{98} values from USEPA, 2006b). The observed mean value in Bermuda is similar to the rural background sites measured by Lorber *et al.* (1998) and significantly lower than the urban background and incinerator site.

3.3.3.4 - Dependence of Soil PCDD/F Concentrations on Proximity to Incinerator

Table 3.9 shows the mean values of PCDD/F levels based on proximity to the incinerator. These data were subjected to a non-parametric Mann-Whitney test (as described in Section 3.2.8) to determine if there is any significant difference between the mean concentrations measured at distances of < 1 km and > 1 km from the TBWTF. This revealed that 4 of the 2,3,7,8-substituted congeners, one homolog group (hexa-CDD's) and total PCDFs had higher mean concentrations closer to the incinerator. Furthermore, the TEQ_{DF}-WHO_{98} was significantly higher by a factor of 2 closer to the incinerator. However, this analysis is based on a small number of samples and a survey employing a larger sample size would better determine any influence that incinerator emissions may have on the spatial distribution of PCDD/Fs in Bermuda soil.

Congener/ Homolog [a]	**Geo. mean < 1 km N=13**	**Geo. mean > 1 km N=7**	**P [b]**
2378 TCDD	n.d. [c]	n.d.	
12378 PeCDD	trace [d]	n.d.	
123478 HxCDD	0.23	trace	
123678 HxCDD	**0.84**	0.24	0.0120
123789 HxCDD	0.33	0.17	0.2556
1234678 HpCDD	28	11	0.0523
OCDD	210	100	0.1635
Total TCDD	n.d.	n.d.	
Total PeCDD	0.12	trace	
Total HxCDD	**8.5**	3.4	0.0456
Total HpCDD	49	20	0.0925
TOTAL PCDDs	280	130	0.1290
2378 TCDF	n.d.	n.d.	
12378 PeCDF	0.24	0.11	0.1399
23478 PeCDF	0.20	0.12	0.2999
123478 HxCDF	0.34	0.13	0.0795
123678 HxCDF	**0.63**	0.21	0.0111
123789 HxCDF	trace	n.d.	
234678 HxCDF	0.51	0.33	0.1343
1234678 HpCDF	**6.9**	3.3	0.0221
1234789 HpCDF	0.15	trace	
OCDF	**9.8**	3.8	0.0456
Total TCDF	trace	n.d.	
Total PeCDF	0.88	0.33	0.1745
Total HxCDF	4.7	2.2	0.0534
Total HpCDF	13	6.3	0.0806
TOTAL PCDFs	**30**	13	0.0354
Total TEQ (ND=0)	**1.0**	0.42	0.0359
Total TEQ (ND=0.5DL)	**1.1**	0.54	0.0239
Total TEQ (ND=DL)	**1.3**	0.66	0.0305

Table 3.9: Geometric mean concentrations of PCDD/F congeners and homolog groups measured in Bermuda soil at distances of < 1 km and > 1 km from the incinerator at TBWTF and results of significance testing. All results in pg/g dry weight. Geometric mean values to 2 sig. figs. Shading added to aid interpretation. TEQ values are derived using the TEQ_{DF}-WHO_{98} scheme.

bold: mean value significantly higher ($P \leq 0.05$)
a: T = tetra; Pe = penta; Hx = hexa; Hp = hepta; O = octa;
b: P = P value from two-tailed Mann-Whitney test;
c: n.d. = not detected (all values < D.L.);
d: trace = calculated value < D.L.

3.3.3.5 - Potential Sources of PCDD/Fs in Soil

Congener profiles are the fractional distribution of PCDD/F congeners in a sample. Different sources can emit different proportions of congeners and if these patterns are preserved in the environment, the resulting profile may give some indication of possible source(s). Figure 3.10 shows the congener profiles derived from the geometric mean values observed in soil at distances of < 1 km and > 1 km from the incinerator. The profiles are identical in terms of the relative contribution from each congener, as shown by regression analysis of the 11 congeners which were detected in both sets of samples. The congener profile in Bermuda soil is dominated by OCDD (~80%) with minor contributions from 1,2,3,4,6,7,8-heptaCDD (~10%), OCDF (~3%) and 1,2,3,4,6,7,8-heptaCDF (~3%). This profile is similar to that observed in various urban and rural background soils (USEPA, 2006b).

Figure 3.10 also shows the congener profile measured in the incinerator stack during the annual emission testing undertaken in 2001 (E_3-Killam, 2001). The profile is derived from the data from duplicate measurements. It can be seen that the profile observed in the stack emissions is significantly different from that observed in soil, suggesting that either the incinerator is not a significant source of PCDD/Fs to soil or that PCDD/Fs emitted by the incinerator undergo major differential degradation/dissipation processes subsequent to emission. However, owing to their relative stability and persistence in the environment, this is unlikely.

Figure 3.11 shows congener profiles for sources which might be significant in Bermuda. These profiles were derived from multiple data sources (Cleverley *et al.*, 1997). It can be seen that the typical congener profile for a mass burn water wall incinerator with electrostatic precipitation (i.e. the same type as at TBWTF) is dominated by significantly higher proportions of hepta- and octa-CDFs than is observed in Bermuda soil. The profile in soil more closely resembles typical congener profiles arising from road vehicle emissions. The TBWTF receives a mean of 220 government garbage trucks per day (MW&E, 2005), plus an unknown number of private trucks. The facility is also located very close to the Bermuda public transport bus depot. Such a large concentration of heavy diesel vehicle traffic could account for the congener pattern and also for the higher TEQ_{DF}-WHO_{98} concentrations observed in soil from sites within 1 km of the incinerator. The soil profile also resembles that arising from PCDD/F contamination of pentachlorophenol (PCP), a heavy-duty wood preservative which is currently authorized for restricted industrial use in the U.S.A. and Canada. The extent of usage of PCP in Bermuda is unknown but it is possible that treated lumber products, such as wooden utility poles, imported from North America may contain PCP which could also have been a local source of PCDD/Fs.

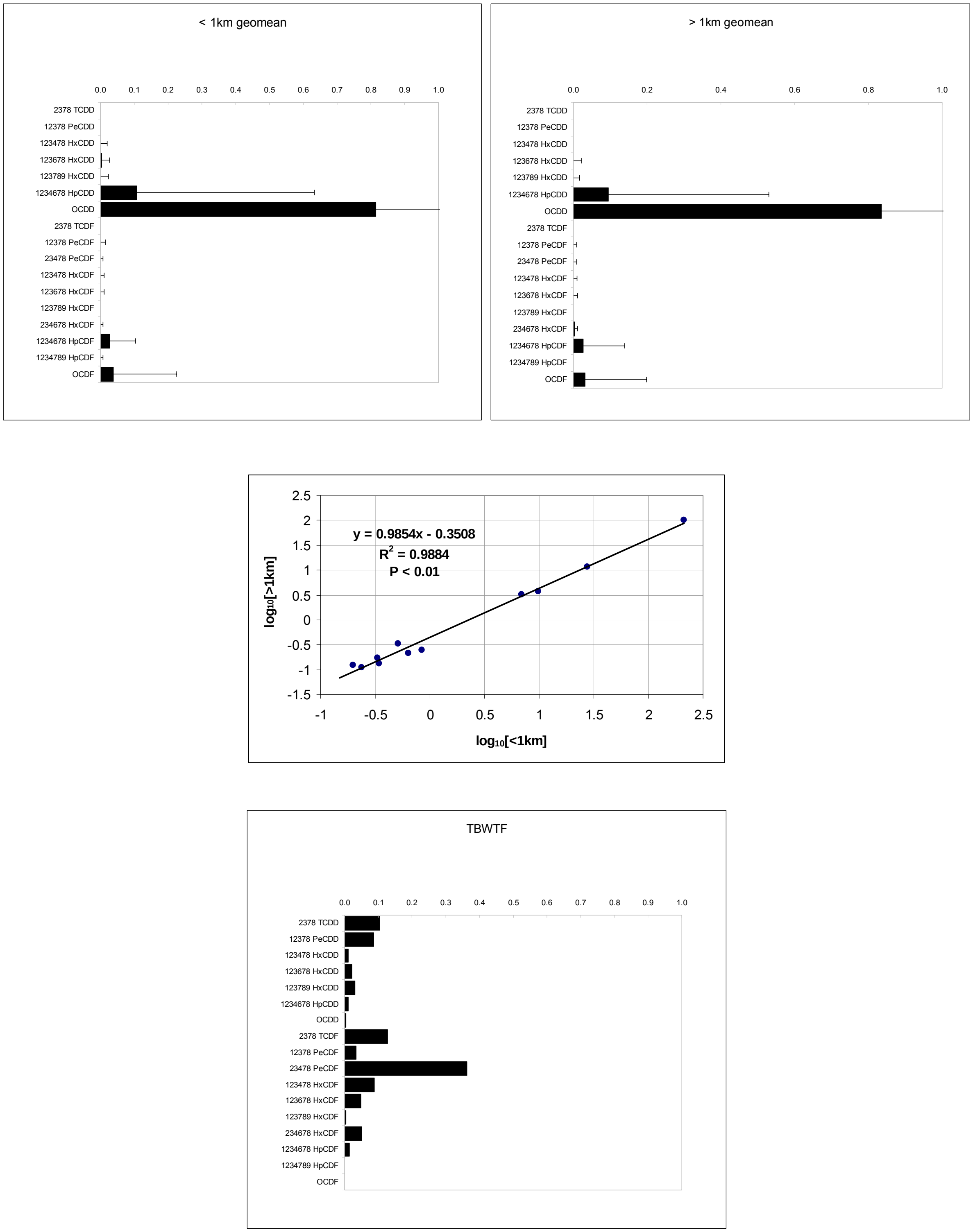


Figure 3.10: Top: Congener profiles for dioxins in soil samples at distances of < 1 km and > 1 km from the incinerator at TBWTF; Middle: correlation of the congener concentrations; Bottom: congener profile from stack emission testing of the incinerator at TBWTF.

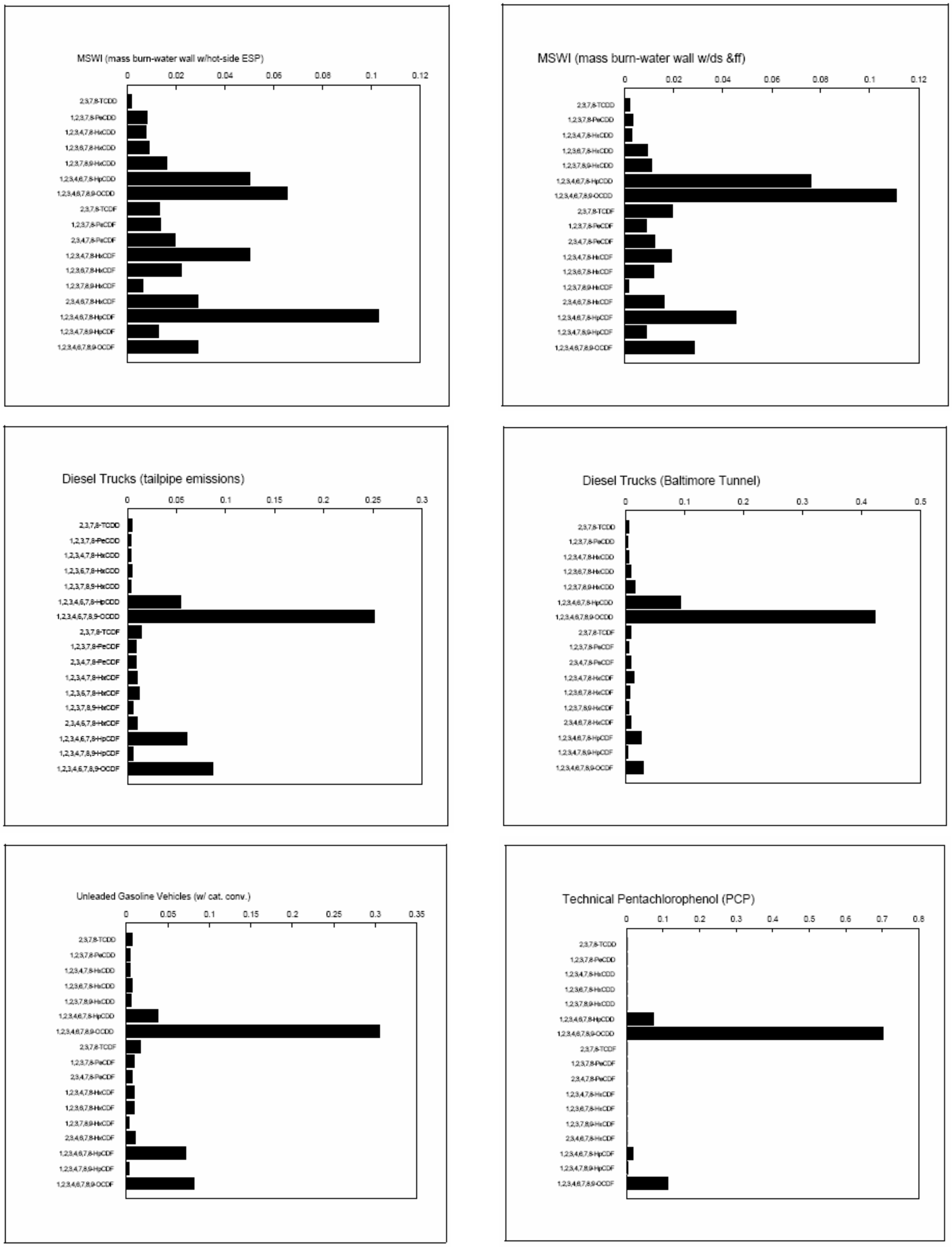


Figure 3.11: PCDD/F congener profiles for particular sources (from Cleverley *et al.*, 1997). ESP = electro-static precipitators; ds = dry scrubbers; ff = fabric filters.

3.3.4 PAHs

3.3.4.1 - Results

For abbreviations of names of PAH compounds see Section 2, Figure 2.2. The summary statistics for the PAH results are shown in Table 3.10. Of the 16 PAHs measured, 10 had low rates of detection (< 75% of samples). Application of the Shapiro-Wilks test at $P \leq 0.05$ on the untransformed (raw) data revealed that none of the PAH data follow a normal distribution. Following $\log_e$ transformation, 6 out of 16 compounds were conclusively log-normally distributed at $P \leq 0.05$ (see Figure 3.12). These were the 6 PAHs which had detection rates of > 75% (FLT, PYR, BaA, CHR, BbF and BaP). As is the case with the dioxin data described above, statistical analysis is constrained by the relatively small sample size (N = 20).

3.3.4.2 - Comparison with Legislative limits

With the exception of ACY and PHN for which no limit applies, the U.S. EPA has established generic Soil Screening Limits (SSLs) for all of the PAHs measured (USEPA, 2002a). These were exceeded by 5 PAHs at one or more sites (see Table 3.11).

There were 14 exceedences at 5 sites located < 1 km from TBWTF:

- Prospect - BaP, DBahA and BghiP;
- Roberts Ave. - BaP;
- Mary Victoria Rd. - BbF, BaP, DBahA, BghiP;
- Oceanview Golf Course - BaA, BbF, BaP, DBahA, BghiP;
- Palmetto Park East - BaP.

There were 8 exceedences at 3 sites located > 1 km from TBWTF:

- Boaz Island - BaP, BghiP;
- American Consulate - BaA, BbF, BaP, DBahA, BghiP;
- Cloverdale Estate - BaP.

The Canadian Government's Soil Quality Guidelines (SQG) Summary Tables contain SQG values for NAP and BaP (see Table 3.11). The SQG for BaP was exceeded at one sample location: Oceanview Golf Course.

These results indicate that PAHs may be of concern at those sites where a SSL is exceeded. Of particular importance is the high incidence of exceedences by BaP, the PAH with the highest human toxicity (see Section 2.4.2). However it is important to consider the caveats discussed in Section 3.2.5 in relation to the application of generic legislative limits: these are not strictly applicable to all situations and should be viewed as the first step of a tiered approach to risk assessment.

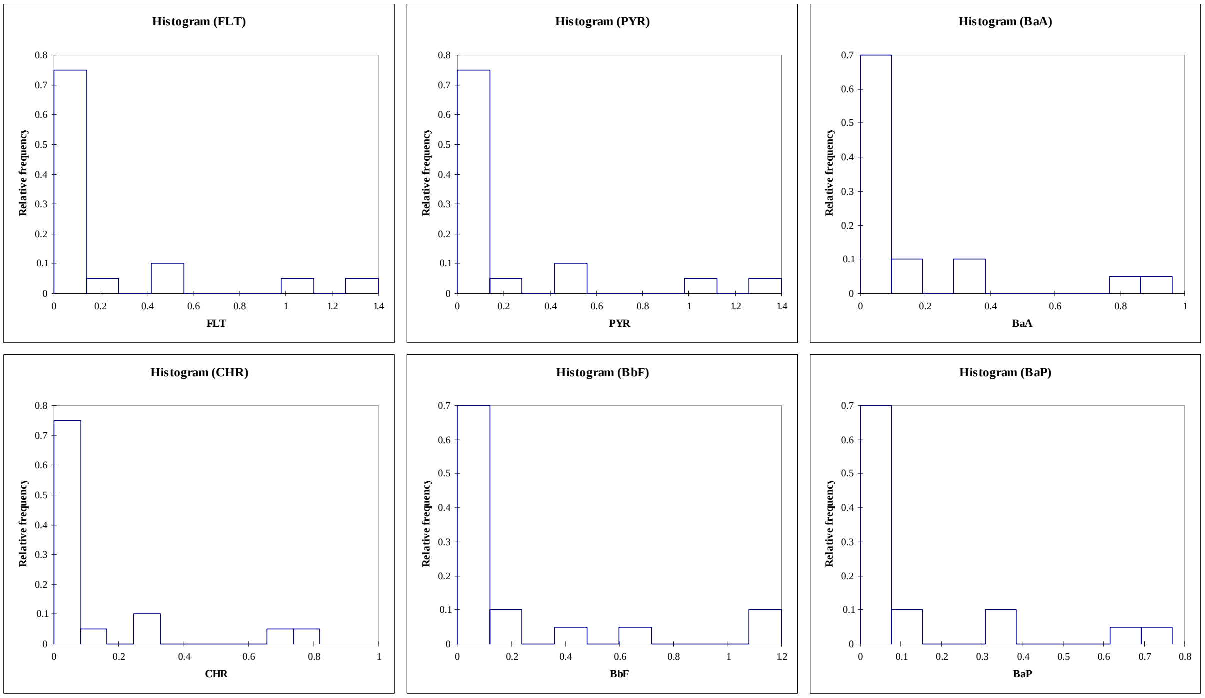


Figure 3.12: Histograms of PAH frequency distributions for compounds with > 75% detection rate. Note that concentration classes are in units of mg/kg.

	DL[a]	N>DL	%>DL	Arith. mean	s.d.	CoV [b]	95th %ile [c]	Median	Geo. mean	Geo. lower 95% CI [d]	Geo. upper 95% CI [e]	Min.	Max.
NAP	10	6	30%	trace [f]					trace			<10	20
ACY	10	5	25%	16	24	143%	27	<10	trace			<10	80
ACE	10	1	5%	trace					trace			<10	10
FLR	10	1	5%	trace					trace			<10	10
PHN	10	12	60%	84	150	171%	150	20	22	<10	540	<10	480
ANT	10	4	20%	18	28	158%	30	<10	trace			<10	110
FLT	10	19	95%	210	370	172%	380	35	63	<10	1300	<10	1300
PYR	10	18	90%	200	360	171%	370	40	58	<10	1400	<10	1300
BaA	10	17	85%	160	270	169%	280	40	50	<10	1100	<10	950
CHR	10	18	90%	130	230	175%	240	30	39	<10	800	<10	810
BbF	10	19	95%	210	340	162%	360	50	68	<10	1300	<10	1100
BkF	10	14	70%	70	120	163%	120	20	23	<10	430	<10	410
BaP	10	17	85%	130	220	162%	240	35	42	<10	920	<10	760
IP	10	13	65%	79	120	154%	140	25	25	<10	550	<10	430
DBahA	10	6	30%	19	26	133%	31	<10	trace			<10	90
BghiP	10	13	65%	62	89	141%	100	20	22	<10	410	<10	290
ΣEPA_{16} [g]	10	20	100%	1400	2300	162%	2500	340	500	32	7700	100	8000

Table 3.10: Summary statistics for PAHs measured in Bermuda soil. All results in µg/kg dry weight. Data to 2 sig. figs. Shading added to aid interpretation. Abbreviations provided in Figure 2.2.

a: DL = detection limit;
b: CoV - coefficient of variation = mean/s.d.;
c: 95th percentile of untransformed data;
d: Lower 95% confidence interval of the geometric mean = $GM/GSD^{1.96}$;
e: Upper 95% confidence interval of the geometric mean = $GM \times GSD^{1.96}$;
f: trace = calculated value < D.L.;
g: ΣEPA_{16} = sum of the 16 EPA priority pollutant PAHs.

	SSL	**N>SSL**		**%>SSL**		**SQG**	**N>SQG**		**%>SQG**	
	µg/kg	**<1km N=13**	**>1km N=7**	**<1km N=13**	**>1km N=7**	**µg/kg**	**<1km N=13**	**>1km N=7**	**<1km N=13**	**>1km N=7**
NAP	**1.1 × 10^6**					**600**				
ACY	n/a					n/a				
ACE	**3.4 × 10^6**					n/a				
FLR	**2.3 × 10^6**					n/a				
PHN	n/a					n/a				
ANT	**17 × 10^6**					n/a				
FLT	**2.3 × 10^6**					n/a				
PYR	**1.7 × 10^6**					n/a				
BaA	**600**	1	1	8%	14%	n/a				
CHR	**62,000**					n/a				
BbF	**600**	2	1	15%	14%	n/a				
BkF	**6000**					n/a				
BaP	**60**	5	3	38%	43%	**700**	1	8%		
IP	**600**					n/a				
DBahA	**60**	3	1	23%	14%	n/a				
BghiP	**60**	3	2	23%	29%	n/a				

Table 3.11: Exceedences by PAHs of U.S. EPA Soil Screening Levels (SSL) and Canadian Soil Quality Guideline (SQG) levels. All values in µg/kg.
n/a = not available

3.3.4.3 - Comparison of Soil PAH Concentrations with Background Levels

Background concentrations of PAHs in soil have been compiled by the ATSDR (1995) and are shown in Table 3.12 along with the observed geometric mean and maximum values from the current study. This shows that PAH levels in Bermuda soil are low. All of the mean values for individual PAHs lie within the range expected for rural or agricultural soils. Some maximum values lie outside these ranges but are still at the lower end of the range for urban soil. This is not surprising given that Bermuda is a highly urbanized society with a population density equivalent to those of some large cities in North America (see Section 1.3).

It can also be seen that the profile of PAHs in Bermuda soil follows the profile observed in the background samples, i.e. the profile is dominated by FLT, PYR, BbF and BaA.

	Rural Soil	Agricultural Soil	Urban Soil	Bermuda Geo. Mean	Bermuda Max.
NAP	n/a	n/a	n/a	trace	20
ACY	n/a	5	n/a	trace	80
ACE	1.7	6	n/a	trace	10
FLR	n/a	9.7	n/a	trace	10
PHN	30	48 - 140	n/a	22	480
ANT	n/a	11 - 13	n/a	trace	110
FLT	0.3 - 40	120 - 210	200 - 166,000	63	1300
PYR	1 - 19.7	99 - 150	145 - 147,000	58	1300
BaA	5 - 20	56 - 110	169 - 59,000	50	950
CHR	38.3	78 - 120	251 - 640	39	810
BbF	20 - 30	58 - 220	15,000 - 62,000	68	1100
BkF	10 - 110	58 - 250	300 - 26,000	23	410
BaP	2 - 1,300	4.6 - 900	165 - 220	42	760
IP	10 - 15	63 - 100	8,000 - 61,000	25	430
DBahA	n/a	n/a	n/a	trace	90
BghiP	10 - 70	66	900 - 47,000	22	290

Table 3.12: Comparison of U.S. background concentration (in µg/kg) of PAHs in soil (ATSDR, 1995) with mean and maximum values observed in Bermuda. n/a = not available

3.3.4.4 - Dependence of Soil PAH Concentrations on Proximity to Incinerator

Table 3.13 shows the mean values of PAH levels based on proximity to the incinerator. These data were subjected to a non-parametric Mann-Whitney test (as described in Section 3.2.8) to determine if there is any significant difference between the mean concentrations measured at distances of < 1 km and > 1 km from the TBWTF. This revealed that there was no significant difference at P ≤ 0.05 in PAH levels between the 2 categories.

	Geo. mean < 1 km N=13	**Geo. mean > 1 km N=7**	**P [a]**
NAP	trace [b]	trace	
ACY	trace	trace	
ACE	n.d. [c]	trace	
FLR	n.d.	trace	
PHN	20	29	0.4098
ANT	trace	n.d.	
FLT	68	53	0.7426
PYR	61	53	0.9534
BaA	53	44	0.7662
CHR	41	35	0.7705
BbF	77	55	0.7673
BkF	25	22	0.8230
BaP	44	37	0.8309
IP	24	26	0.8273
DBahA	10	trace	
BghiP	23	21	0.9485
ΣEPA_{16} [g]	520	460	1.0000

Table 3.13: Geometric mean concentrations of PAHs measured in Bermuda soil at distances of < 1 km and > 1 km from the incinerator at TBWTF and results of significance testing. All results in µg/kg dry weight. Geometric mean values to 2 sig. figs. Shading added to aid interpretation.

a: P = P value from two-tailed Mann-Whitney test;
b: n.d. = not detected (all values < D.L.);
c: trace = calculated value < D.L.

3.3.4.5 - Potential Sources of PAHs in Soil

The PAHs of most concern detected in soil (i.e. those showing exceedence of legislative limits) are high molecular weight PAHs of 4+ rings. This indicates that combustion sources are a probable source. Owing to the fact that these sites are widely dispersed and not clustered close to or predominantly downwind of the incinerator, it is likely that the incinerator is not the primary source of these PAHs. However, this analysis is based on a small number of samples and a survey employing a larger sample size would better determine any influence that incinerator emissions may have on the spatial distribution of PAHs in Bermuda soil.

Other sources of PAH deposition to soil in Bermuda include road traffic emissions, BELCO emissions and atmospheric deposition of PAHs arising from long-range atmospheric transport of pollutants. Most of the PAHs in soil are believed to result from this latter category (ATSDR, 1995).

Chapter 4 - Contaminants in Water Tanks

4.1 - Introduction

The residents of Bermuda have always used rain as the principal source of potable water owing to the absence of rivers and lakes and limited groundwater resources. Rainwater collected from roof runoff is diverted into storage tanks, normally located under each house. Average per capita consumption is about 140 litres per day, with a mean of 11×10^6 litres per day used in homes and hotels (commercial, industrial and agricultural water use is not included in this figure). Household roof runoff can supply 9.6×10^6 litres per day and an estimated 2.6×10^6 litres per day is supplied by other roof and constructed water catchments. Water supplies are supplemented when needed by private wells (which must be registered) and/or deliveries of water acquired from groundwater lenses and water treatment plants (Government of Bermuda, 2006).

The quality of water collected by private households is therefore of concern and particularly so if the quality is compromised by emissions from the municipal waste incinerator at Tynes Bay. The aim of this part of the current study was to: 1) assess the extent or absence of incidences of chemical contamination of private domestic water tanks; and 2) examine any relationship between tank water and sediment chemistry and the location of the tanks with respect to the TBWTF.

In addition to chemical contaminants which may be incorporated in rainwater or washed off roofs after dry deposition, there is also a high potential for fecal matter from cats, rats, birds and lizards to be washed into water tanks. This is of concern in relation to the biological quality of the water as it may lead to exposure to pathogens (bacteria, viruses and parasites). This aspect is not considered in this report but the biological quality of Bermuda tank water was studied by the Atlantis Project's mobile laboratory in 2003. The results from 102 residences showed that 90% of the tanks analysed were contaminated with total coliforms and approximately 66% of samples showed contamination with *E. coli* (Atlantis Project, 2004).

4.2 - Metals and Major Ions in Tank Water

4.2.1 - Sampling

Water samples for the analysis of metals and major ions were collected from 112 private households across the island (see Figure 4.1). Of these, 29 (26%) were located < 1 km from the incinerator, 21 (19%) were located 1 - 2 km from the incinerator and 62 (55%) were located > 2 km from the incinerator.

Water was sampled directly from the water tanks, prior to any point of contact with plumbing, pumps or filters. The results thus reflect the quality of the water entering tanks directly from the surface of roofs and not necessarily the quality of water obtained from faucets inside the residence. This provides a better estimation of island-wide water quality as individual residences may vary significantly in terms of the age and quality of plumbing and in the types of water treatment techniques in place (if applicable). Residences were excluded from the survey in cases where they had received supplemental water deliveries or had the tank cleaned within 6 months prior to sampling.

Samples were collected by immersing the sample containers into the water tanks using a grab pole. This enabled the container to be fully submerged below the surface of the water, taking care not to disturb the underlying sediment. All water samples were collected before any sediment sampling was undertaken. One sample was collected for metal analysis in a 250 mL high-density polycarbonate bottle and one sample was collected in a 250 mL high-density polyethylene bottle for major ion analysis and pH and conductivity determination. The containers for metal analysis were supplied pre-cleaned by the analytical laboratory and the bottle for major ion analysis and pH and conductivity determination were cleaned according the standard operating procedures of the BBSR Air Quality Program.

All samples were stored in coolers containing freezer packs until their return to the laboratory at BBSR where they were stored in the dark at 4°C. On average, samples from 2 locations were collected each day when sediment samples were also collected, or 5 locations each day when water only was sampled. Samples were dispatched to the analytical laboratory by express courier in batches of 8 -10 samples. The samples were shipped in coolers with freezer packs to maintain refrigerated conditions.

4.2.2 - Analysis

Analysis of major cations (Ca, K, Mg and Na) and metal and metalloid elements were performed by EnviroTest Laboratories. Analysis of major anions and determination of pH and conductivity were undertaken in the BBSR Environmental Quality Program laboratory. Table 4.1 details the methods and techniques employed.

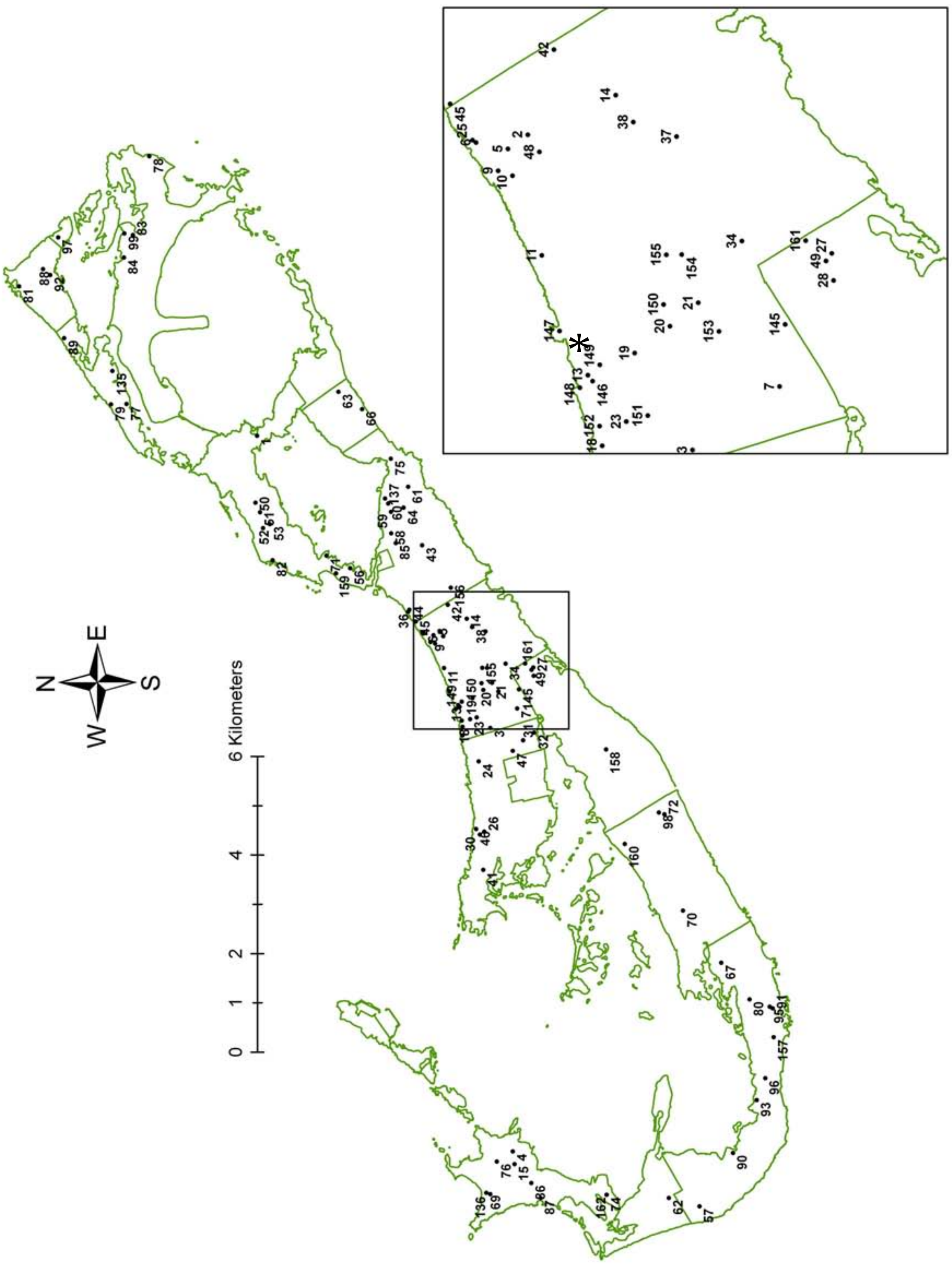


Figure 4.1: Map showing water tank sampling locations. Inset map shown in larger scale for clarity. Note symbol * in inset map, showing location of incinerator.

Element	Method	Technique
Ca, K, Mg, Na, Fe, Mn	APHA [a] 3120 B	ICP-OES [b]
Other elements	APHA 3125 B	ICP-MS [c]
Cl, SO_4, NO_3	BBSR in-house	Ion chromatography
pH	BBSR in-house	Corning model 345 pH meter
Conductivity	BBSR in-house	Orion Model 160 Conductivity Meter

Table 4.1: Analytical methods and techniques for water samples.

a: APHA - American Public Health Association;
b: ICP-OES - inductively coupled plasma optical emission spectroscopy;
c: ICP-MS - inductively coupled plasma mass spectrometry.

4.2.3 - Results: Summary Statistics

All data were analysed to determine if they were normally distributed using the Shapiro-Wilks test at $P \leq 0.05$. Data that did not pass this test were then $\log_e$ transformed and re-tested in the same way for log-normal distribution. Only one parameter, Ba, was found to conclusively follow a log-normal distribution. The distributions of the remaining parameters approximate a log-normal distribution, as shown the histograms in Figure 4.2a-c, and the geometric mean is therefore the best estimate of central tendency.

The summary statistics for metals are presented in Table 4.1. Two elements (Be and Co) were not detected in any samples and have been designated as “not detected (n.d.)”. Of the remaining metals, 20 had low rates of detection (< 75%), and only 6 (Al, Ba, Sb, Sr, V and Zn) had rates of detection > 75%. Following designation of values reported to be less than the detection limit (DL) to a value of 0.5×DL, the measures of central tendency (mean, median and geometric mean) for 15 elements had values less than the analytical DL. They have therefore been designated as “trace”, indicating that they were present at trace levels.

The geometric mean of pH values recorded in tank water was 7.8. This is lower than the pH of rainwater observed in 2003 to 2004, which had a volume weighted average value of 5.2 (Peters, unpublished data). This reflects the dissolution of carbonate in the cement and limestone walls of water tanks which neutralises the slight acidity of rainwater and in some cases causes tank water to become alkaline, as demonstrated by an upper 95% confidence interval of the mean pH of tank water of 8.6.

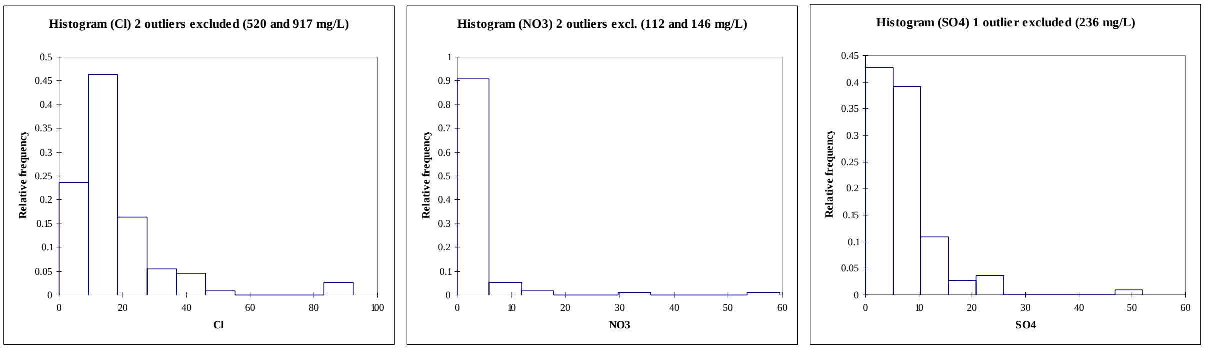
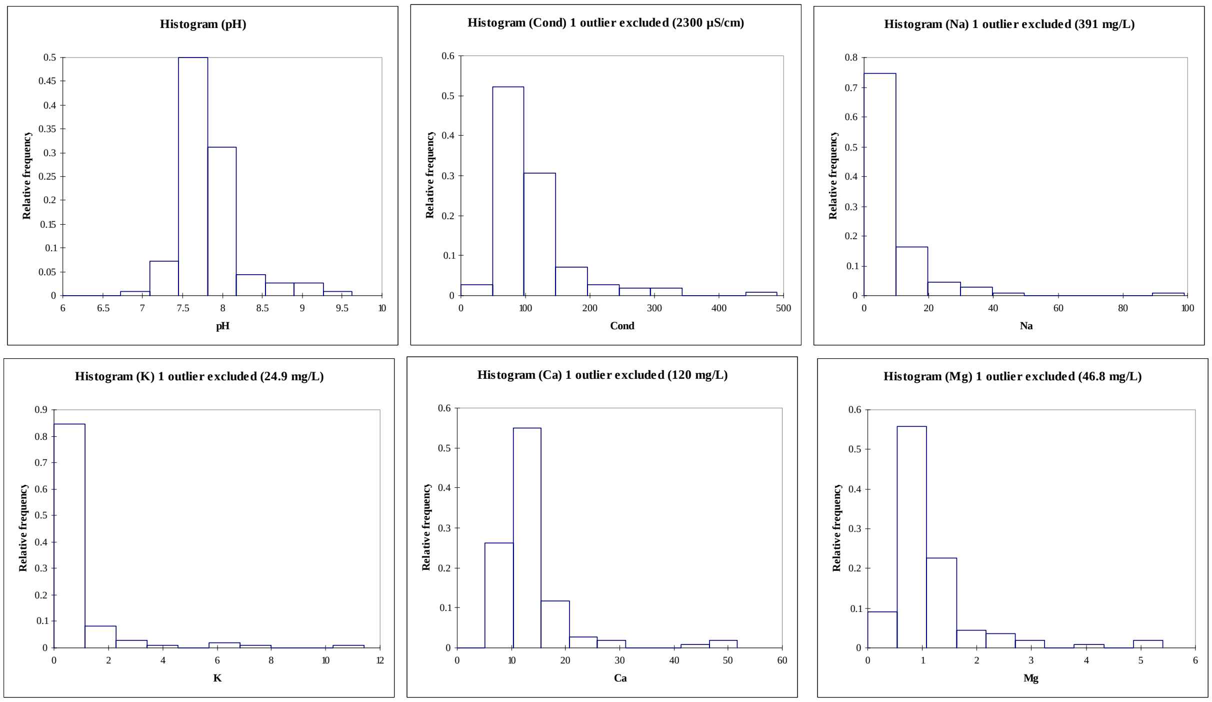


Figure 4.2a: Histograms of major anion frequency distributions. Note that some outlying data points have been excluded to better illustrate the underlying distributions.



4.2b: Histograms of pH, conductivity and major cation frequency distributions. Note that some outlying data points have been excluded to better illustrate the underlying distributions.

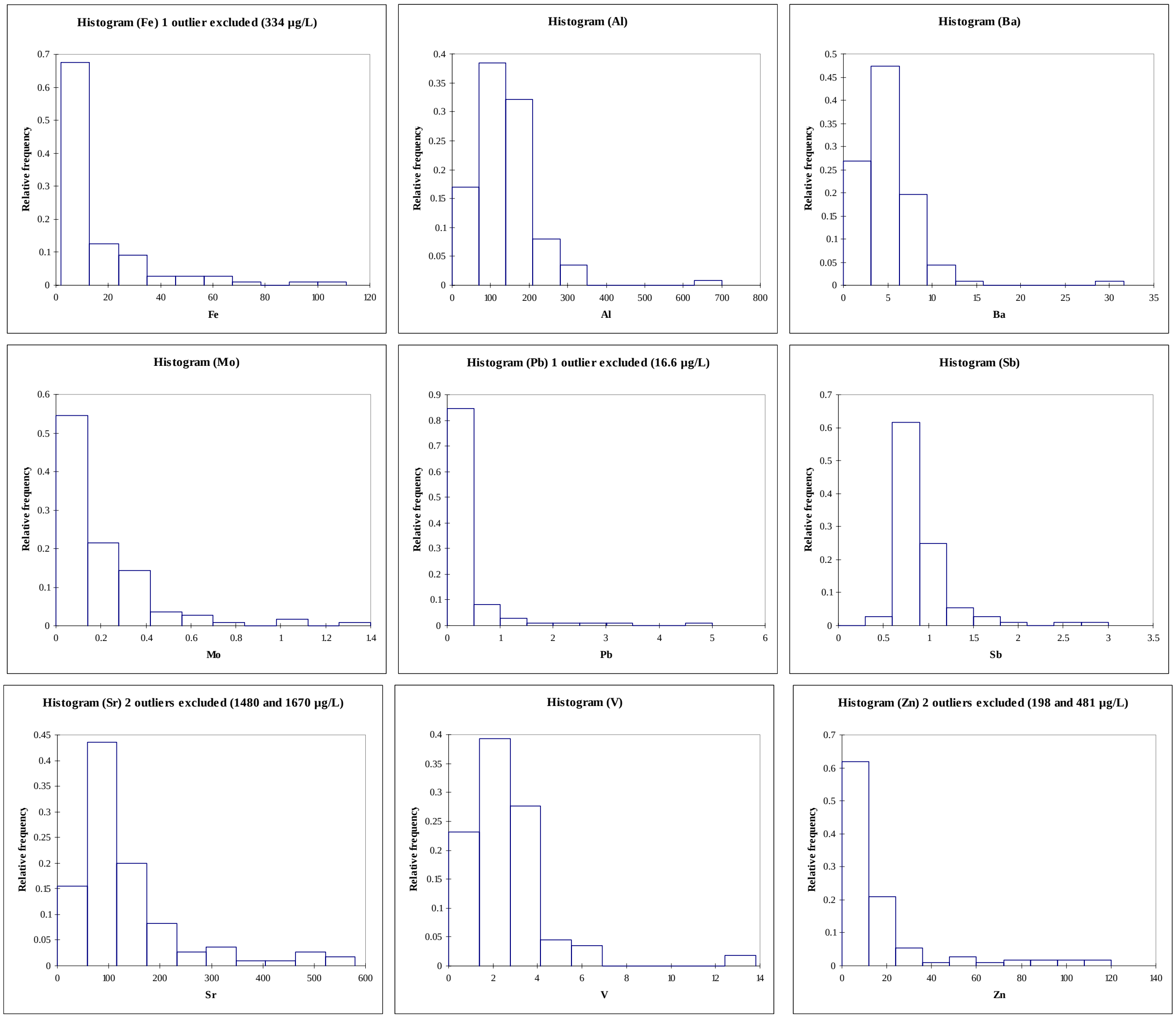


Figure 4.2c: Histograms of frequency distributions for metals with geometric mean values > detection limit. Note that some outlying data points have been excluded to better illustrate the underlying distributions.

N=112	**DL**[a]	**N>DL**	**%>DL**	**Arith. mean**	**s.d.**	**CoV** [b]	**95th %ile** [c]	**Median**	**Geo. mean**	**Geo. lower 95% CI** [d]	**Geo. upper 95% CI** [e]	**Min.**	**Max.**
pH and Conductivity (µS/cm):													
pH	0	112	100%	7.82	0.37	5%	7.89	7.77	**7.81**	7.13	8.55	6.93	9.53
Cond	0	112	100%	130	220	168%	170	96	**100**	37	280	36	2300
Major Ions (mg/L):													
Cl	0.5	112	100%	30	98	323%	48	13	**15**	2.9	77	0.69	920
NO_3	0.5	111	99%	5.0	18	358%	8.4	1.2	**1.6**	<0.5	13	<0.5	150
SO_4	0.5	111	99%	9.7	22	231%	14	5.5	**6.4**	1.5	27	<0.5	240
Ca	0.5	112	100%	15	12	85%	17	12	**13**	5.5	30	5.4	120
K	0.1	109	97%	1.2	2.7	229%	1.7	0.50	**0.61**	<0.1	4.0	<0.1	25
Mg	0.1	112	100%	1.5	4.4	284%	2.4	1.0	**1.0**	0.29	3.5	0.30	47
Na	1	112	100%	13	38	286%	20	7.0	**7.7**	1.8	33	2.0	390
Metals (µg/L):													
Fe	5	70	63%	17	35	207%	24	6.0	**7.8**	<5	73	<5	330
Mn	1	37	33%	trace[f]				trace	**trace**			<1	11
Ag	0.4	4	4%	trace				trace	**trace**			<0.4	0.70
Al	20	109	97%	130	85	63%	150	130	**110**	28	430	<20	690
As	0.4	13	12%	trace				trace	**trace**			<0.4	1.8
B	20	17	15%	trace				trace	**trace**			<20	360
Ba	0.2	112	100%	5.0	3.5	70%	5.6	3.9	**4.2**	1.4	13	1.2	31
Be	1	0	0%	n.d. [g]				n.d.	**n.d.**				
Bi	0.1	8	7%	trace				trace	**trace**			<0.1	1.2
Cd	0.2	1	1%	trace				trace	**trace**			<0.2	0.40
Co	0.2	0	0%	n.d.				n.d.	**n.d.**				
Cr	0.8	43	38%	0.98	1.5	151%	1.3	trace	**trace**			<0.8	15
Cu	1	27	24%	1.9	7.4	382%	3.3	trace	**trace**			<1	74
Mo	0.1	74	66%	0.20	0.22	110%	0.24	0.10	**0.13**	<0.1	0.75	<0.1	1.3
Ni	0.2	16	14%	trace				trace	**trace**			<0.2	2.0
Pb	0.1	64	57%	0.47	1.7	351%	0.79	0.10	**0.15**	<0.1	1.6	<0.1	17
Sb	0.4	112	100%	0.86	0.34	39%	0.93	0.80	**0.82**	0.46	1.5	0.40	2.9
Se	0.4	57	51%	0.62	2.1	332%	1.0	0.40	**trace**			<0.4	22
Sn	0.4	2	2%	trace				trace	**trace**			<0.4	0.80
Sr	0.2	112	100%	160	220	137%	200	96	**110**	27	470	30	1700
Ti	5	6	5%	trace				trace	**trace**			<5	21
Tl	0.1	8	7%	trace				trace	**trace**			<0.1	0.20
U	0.1	17	15%	trace				trace	**trace**			<0.1	0.50
V	0.2	109	97%	2.6	1.9	74%	2.9	2.2	**2.0**	0.40	9.9	<0.2	13
Zn	4	84	75%	23	53	227%	33	8.0	**9.2**	<4	110	<4	480
Hg	0.2	4	4%	trace				trace	**trace**			<0.2	0.50

Table 4.2: Summary statistics for pH, conductivity (µS/cm), major ions (mg/L) and metals (µg/L) measured in tank water. Concentration data to 2 sig. figs. Shading added to aid with interpretation.

bold: best estimate of central tendency;
a: DL = detection limit;
b: CoV - coefficient of variation = mean/s.d.;
c: 95th percentile of untransformed data;
d: Lower 95% confidence interval of the geometric mean = $GM/GSD^{1.96}$;
e: Upper 95% confidence interval of the geometric mean = $GM \times GSD^{1.96}$;
f: trace = calculated value < DL;
g: n.d. = no samples with value > DL.

4.2.4 - Comparison with Regulatory Limits

The Bermuda Department of Health has issued Drinking Water Standards (DWS) for ensuring healthy supplies of drinking water. These consist of primary standards which specify maximum acceptable limits and are designed to protect human health, and secondary standards which specify limits based on aesthetic quality, i.e. unacceptable colour, taste and odour. The data from the water tanks is compared with the Bermuda DWSs in Table 4.2.

	DWS	N>DWS	%>DWS
PRIMARY STANDARDS			
As	50 µg/L	0	0%
Cd	5 µg/L	0	0%
Cr	50 µg/L	0	0%
Pb	15 µg/L	1	0.9%
Hg	1 µg/L	0	0%
NO_3	44.3 mg/L	3	2.7%
Se	10 µg/L	1	0.9%
Ag	50 µg/L	0	0%
SECONDARY STANDARDS			
Al	200 µg/L	17	15.2%
Cl	300 mg/L	2	1.8%
Cu	1000 µg/L	0	0%
Fe	300 µg/L	1	0.9%
Mn	100µg/L	0	0%
Na	200 mg/L	1	0.9%
pH	6.5 - 8.5	7	6.3%
SO_4	250 mg/L	0	0%
Zn	5000 µg/L	0	0%

Table 4.3: Drinking water standards (DWS) in effect in Bermuda for parameters measured in this study. Note different units of measure.

There were a total of 33 exceedences of a DWS at 27 individual residences. The majority (28 or 85%) of cases were related to secondary standards and only 5 (occurring at a total of 3 residences) were related to primary standards. One residence exceeded 4 DWSs, consisting of 2 secondary (Cl and Na) and 2 primary DWS (NO_3 and Se). Three other residences recorded incidences of exceeding 2 DWSs: two of these residences exceeded secondary DWSs only and one exceeded 2 primary DWSs (NO_3 and Pb). Full details of DWS non-compliance were provided to the Department of Environmental Protection as soon as the results were available (2 March 2006) so that immediate action could be taken, as appropriate.

Exceedence of the DWS for NO_3 could arise from the use of unregistered wells to supplement tank water (Rowe, pers. comm.). Groundwater in Bermuda is prone to contamination with NO_3, arising from cess pit leakage. Exceedence of the DWS for Na and Cl could also arise from the use of well water taken from within the freshwater-saltwater transition zone of a groundwater lens, or it could indicate a significant sea salt component arising from deposition of sea spray onto the roof surface.

4.2.5 - Dependence on Proximity to Incinerator

To determine if there is any significant difference in the observed concentrations with distance from the incinerator, the data were subjected to the non-parametric Kruskal-Wallis test (described in Section 3.2.10). The data were classified into 3 groups based on distance of the sampling location from the incinerator: < 1 km; 1 - 2 km; and > 2 km. The analysis was applied to pH, Na, NO_3 and SO_4 (for which a DWS is in effect) and to those metals which had a rate of detection of > 50% (Fe, Al, Ba, Mo, Pb, Sb, Se, Sr, V and Zn). The results indicate that for all parameters, with the exception of Mo and Sb, the 3 groups of samples are not significantly different at $P \leq 0.05$: i.e. they can be considered to be from the same population of data and can thus be assumed to have a constant distribution in tank water across the island. Conversely, the distribution of Mo and Sb varies between the groups analysed. However, from Table 4.3 it can be seen that no clear trend is evident. In both cases higher geometric means are observed at locations located at a distance between 1 and 2 km, with lower concentrations observed closer to and further away from the incinerator. The significance of this is low: neither Mo or Sb are subject to legislative limits in drinking water.

	Mo / µg/L			**Sb / µg/L**		
	<1km	**1-2km**	**>2km**	**<1km**	**1-2km**	**>2km**
Median	0.10	0.20	0.10	0.70	0.80	0.80
Geo. mean	0.13	0.21	0.12	0.75	0.93	0.82

Table 4.4: Median and geometric mean values of Mo and Sb in tank water at varying distances from the incinerator.

Further analysis of spatial trends was undertaken using AHC and PCA, as described in Section 3.2.9, but the results were inconclusive in that they did not identify any significant clusters or components of the data. This supports the hypothesis that the concentrations of metals in tank water in Bermuda are randomly distributed across the island with no discernible spatial pattern.

4.3 - Metals in Tank Sediment

In addition to water, particulate matter enters drinking water tanks via incorporation in rainwater and/or entrainment of dry deposition by rainwater. Large particles will immediately settle out and finer particles will remain as suspended sediment for some period of time. Over time, a layer of sediment accumulates on the bottom of the tank. Potential sources of sediment in Bermuda water tanks include: soil; soot; dust; pollen; plant material (seeds, leaves and branches); faecal matter from wildlife; and roofing material (eroded cement and paint). Tank sediment may be either a sink or a source of contaminants as they accumulate in the sediment by adsorption from the overlying water or are released to the water by desorption/dissolution. Once in the tank, particles and any associated contaminants may then enter directly into the household water supply system in suspension, and particularly after agitation by inflowing rainwater or truck delivered water, both activities which will cause sediment resuspension to varying degrees.

Tank sediment was sampled at 36 locations, 16 of which were located < 1 km from the incinerator, 5 were located 1 - 2 km and 15 were located > 2 km from the incinerator.

4.3.1 - Sampling

The method of sampling was an adaptation of the plate-filter procedure used by the U.S. Geological Survey for water quality analysis (Wilde *et al.*, 2004). This method uses 142mm diameter filters to remove suspended sediment prior to water analysis. In this study the method was used to collect filter samples for sediment analysis.

Water was pumped directly from water tanks through a 6.35mm diameter PTFE tube, using an in-line ceramic-piston metering pump (Fluid Metering, Inc., Model Q) powered by a 12V automotive battery. The flow then continued through PTFE tubing and into a 142mm diameter polycarbonate in-line filter holder (Geotech Environmental Equipment, Inc.) housing a pre-weighed 142mm diameter glass fibre filter (Whatman GFF), as supplied by the analytical laboratory.

The sample inlet line was attached to a sample grab pole and immersed in the water. Water was pumped through the tubing and pump for *c.* 2 minutes to flush the tubing and wet the filter and then the end of the inlet tube was dragged across the bottom of the water tank to entrain bottom sediment in the inflowing water. The flow rate was in the range of 25-50 mL/min. Sampling was undertaken over a period time judged to be sufficient based on visual inspection of the tank bottom, the loading in the inflowing water observed through the sample inlet line and by direct observation of the filter in the transparent filter holder. In general, sampling for *c.* 5 minutes provided sufficient loading of the filter (0.5 g dry weight minimum).

After sampling, the filter holder and filter were stored in coolers containing freezer packs until their return to the laboratory at BBSR. The filters were then removed from the filter holder using pre-cleaned HDPE forceps, placed in a labeled self-sealing polyethylene bag and stored in the dark at 4°C. The samples were shipped to the analytical laboratory by express courier in coolers with freezer packs to maintain refrigerated conditions. After sampling, all tubing, forceps and the filter holder were washed with purified deionised water (Milli-Q water) and cleaned by soaking in 5% HCl overnight.

4.3.2 - Analysis

Following determination of sample dry weight, the analysis of metals in tank sediment was identical to the analysis of metals in soil samples (see Section 3.2.2).

4.3.3 - Results: Summary Statistics

Two elements (U and Tl) were not detected in any samples and 4 elements (Ag, Be, Mo and Sn) had low rates of detection, defined as < 75% (see Table 4.4). All data were analysed to determine if they were normally distributed using the Shapiro-Wilks test at $P \leq 0.05$. Data that did not pass this test were then $\log_e$ transformed and re-tested in the same way for log-normal distribution. Of the data with detection rates > 75%, 5 parameters were found to conclusively follow a normal distribution and 16 were found to conclusively follow a log-normal distribution (see Table 4.4). The distributions of the remaining 3 parameters approximate a log-normal distribution, as shown the histograms in Figure 4.3, and the geometric mean is therefore the best estimate of central tendency for these elements.

The summary statistics for LOI and metals are presented in Table 4.5. Following designation of values reported to be less than the detection limit (DL) to a value of 0.5×DL, the measures of central tendency (mean, median and geometric mean) for 4 of the elements with low detection rates (< 75%) had values less than the analytical DL. They have therefore been designated as “trace”, indicating that they were present at trace levels. U and Ti have been designated as “not detected (n.d.)” as they were not recorded in any of the samples.

N = 36	N > DL	% > DL	DL [a] (mg/kg)	Dist. [b]
LOI	35	97%	0	L-N
Sb	36	100%	0.1	L-N
As	36	100%	0.1	**L-N**
Hg	36	100%	0.05	**L-N**
Se	36	100%	0.1	**L-N**
Al	36	100%	200	**N**
Ba	36	100%	5	**L-N**
Ca	36	100%	100	**N**
Cd	36	100%	0.5	**L-N**
Co	36	100%	1	**L-N**
Cr	36	100%	0.5	**L-N**
Cu	36	100%	2	**L-N**
Fe	36	100%	200	L-N
K	36	100%	100	**N**
Mg	36	100%	100	**L-N**
Mn	36	100%	20	**L-N**
Na	36	100%	100	**L-N**
Ni	36	100%	2	**N**
P	36	100%	10	**L-N**
Pb	36	100%	5	**L-N**
Sr	36	100%	1	**L-N**
Ti	36	100%	5	**N**
V	36	100%	1	**L-N**
Zn	36	100%	10	**L-N**
Ag	8	22%	1	n.a.
Be	2	6%	1	n.a.
Mo	10	28%	1	n.a.
Sn	4	11%	5	n.a.
U	*0*	*0%*	*40*	n.a.
Tl	*0*	*0%*	*1*	n.a.

Table 4.5: Rate of detection, detection limits and distribution type for elements and LOI in tank sediment.

a: DL = detection limit;
b: Dist. = probability distribution of data, where:
N = normal, based on Shapiro-Wilks test at $P \leq 0.05$;
L-N = log-normal, based on Shapiro-Wilks test at $P \leq 0.05$;
L-N = log-normal, assumption based on histogram (Figure 3.2)
n.a. = analysis not applicable owing to low rate of detection (%>DL).

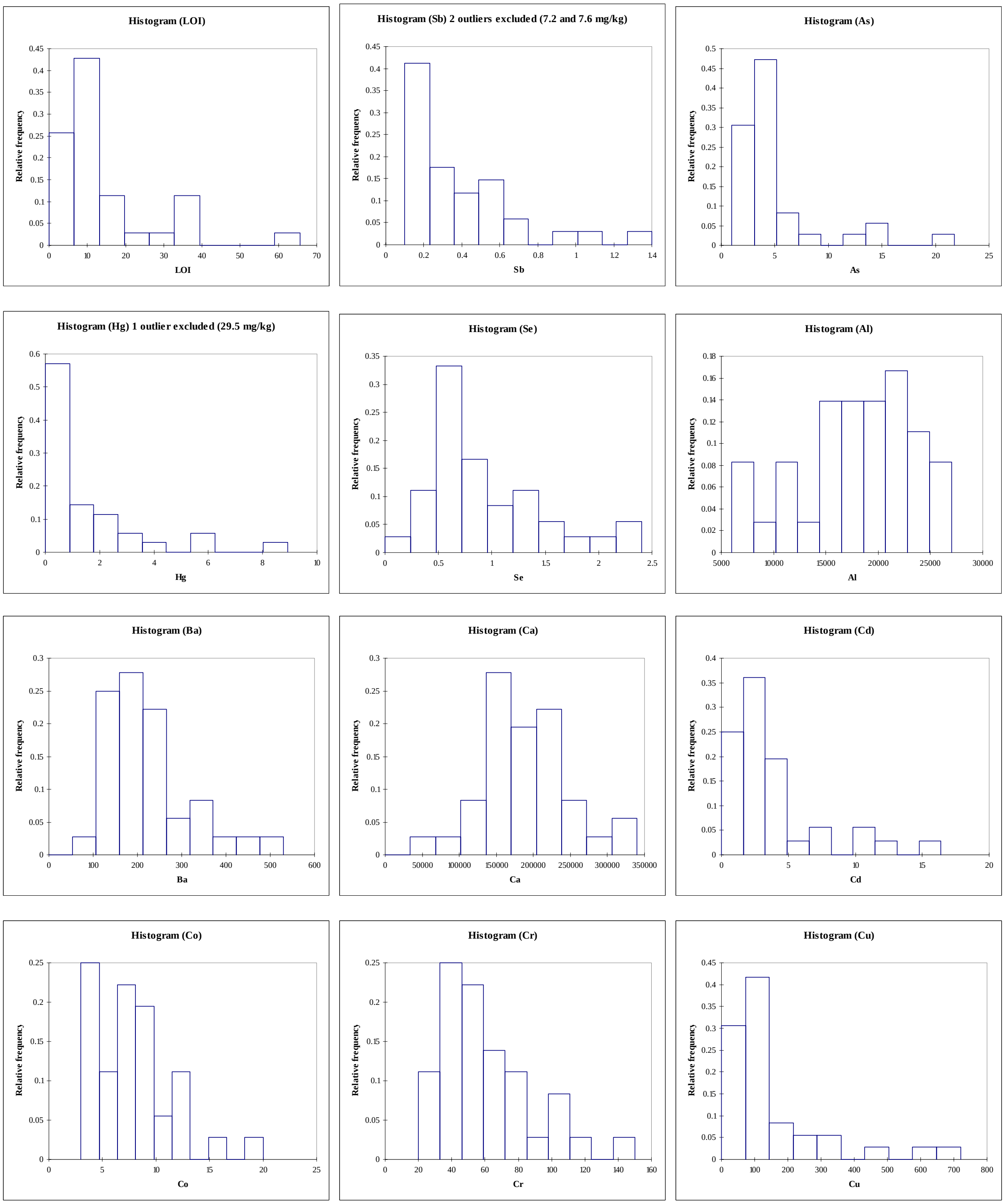


Figure 4.3: Histograms of LOI and metal frequency distributions (metals with detection rate > 75%) for tank sediment. Note that some outlying data points have been excluded to better illustrate the underlying distributions (cont. overleaf).

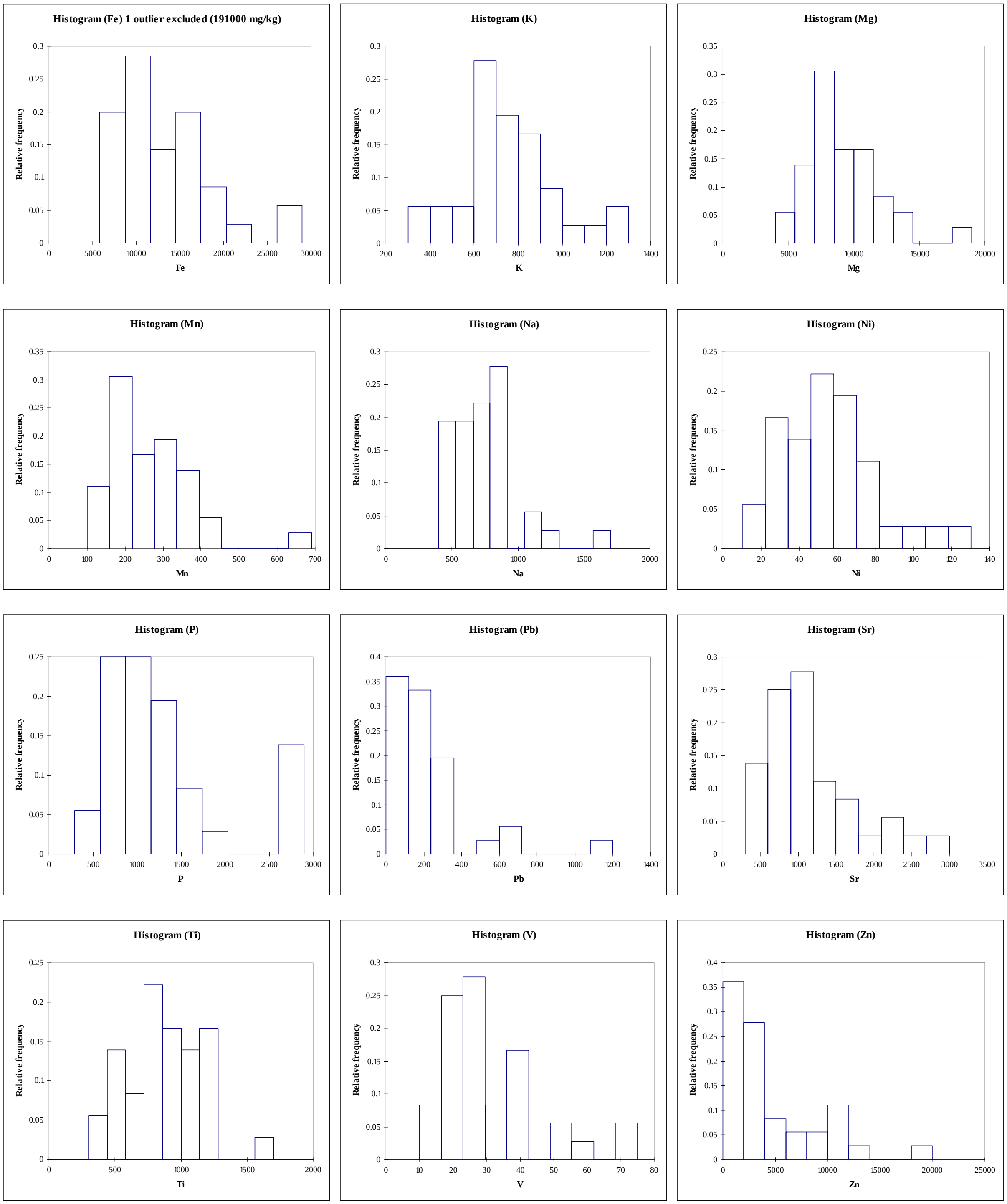


Figure 4.3 (cont.): Histograms of LOI and metal frequency distributions (metals with detection rate > 75%) for tank sediment. Note that some outlying data points have been excluded to better illustrate the underlying distributions.

N=36	**Mean**	**s.d.**	**CoV** [a]	**95th %ile** [b]	**Median**	**Geo. mean**	**Geo. lower 95% CI** [c]	**Geo. upper 95% CI** [d]	**Min.**	**Max.**
LOI	15	13	87%	19	9.7	**11**	3.0	42	4.4	65
Sb	0.78	1.7	209%	1.3	0.30	**0.38**	<0.1	2.5	<0.1	7.6
As	5.0	4.2	84%	6.4	3.8	**3.9**	1.1	14	1.3	21
Hg	2.4	5.0	210%	4.0	0.81	**0.98**	0.088	11	0.090	30
Se	0.93	0.53	57%	1.1	0.80	**0.78**	0.23	2.6	0.10	2.3
Al	**18000**	5500	30%	20000	18000	17000	8100	35000	6800	26000
Ba	220	97	43%	250	190	**200**	90	460	86	530
Ca	**190000**	62000	32%	210000	190000	180000	80000	380000	37000	340000
Cd	3.9	3.5	89%	5.0	2.9	**2.8**	0.58	14	0.70	15
Co	7.8	3.6	46%	9.0	8.0	**7.0**	2.7	18	3.0	19
Cr	61	27	44%	70	54	**56**	24	130	20	140
Cu	150	150	99%	210	110	**110**	26	490	34	720
Fe	18000	30000	162%	28000	12000	**14000**	4400	42000	6800	190000
K	**700**	210	30%	780	700	670	360	1300	300	1200
Mg	9100	2800	30%	10000	8500	**8700**	4900	15000	4800	19000
Mn	260	110	42%	300	230	**240**	110	520	120	680
Na	730	240	32%	810	700	**690**	380	1300	400	1600
Ni	**55**	26	46%	64	55	49	18	130	13	130
P	1300	680	52%	1500	1000	**1100**	440	2900	490	2800
Pb	230	220	94%	300	180	**160**	33	810	33	1100
Sr	1200	600	51%	1400	1000	**1000**	400	2700	460	3000
Ti	**860**	280	32%	960	860	820	410	1600	310	1600
V	32	15	47%	37	27	**29**	12	67	12	74
Zn	4600	4500	97%	6100	2600	**2800**	380	21000	390	20000
Ag	trace [e]				trace	trace			<1	2.0
Be	trace				trace	trace			<1	1.0
Mo	trace				trace	trace			<1	3.0
Sn	trace				trace	trace			<5	20
U	n.d. [f]				n.d.	n.d.				
Tl	n.d.				n.d.	n.d.				

Table 4.6: Summary statistics for LOI (%) and metals (mg/kg) measured in tank sediment. Concentration data to 2 sig. figs. Shading added to aid with interpretation.

bold: best estimate of central tendency;
a: CoV - coefficient of variation = mean/s.d.;
b: 95th percentile of untransformed data;
c: Lower 95% confidence interval of the geometric mean = $GM/GSD^{1.96}$;
d: Upper 95% confidence interval of the geometric mean = $GM \times GSD^{1.96}$;
e: trace = calculated value < DL;
f: n.d. = no samples with value > DL.

4.3.4 - Comparison with Regulatory Limits

There are no legislative limits in effect for sediment in drinking water tanks in Bermuda. However it is of use to compare the concentrations of metals in tank sediment with the U.S. EPA generic soil screening limits (SSLs) calculated to minimise risk from human ingestion of metals in soil, as discussed in Section 3.2.5. The results are shown in Table 4.6, along with the percentage of soil samples exceeding the SSL.

	Sediment			**Soil**
	Ingestion SSL (mg/kg)	**N > SSL**	**% > SSL**	**% > SSL**
Sb	31	0	0%	0%
As	0.4	36	100%	100%
Hg	23	1	3%	0%
Se	390	0	0%	0%
Ba	5500	0	0%	0%
Be	160	0	0%	0%
Cd	70	0	0%	0%
Cr	230	0	0%	13%
Ni	1600	0	0%	0%
Pb	400	4	11%	2%
V	550	0	0%	0%
Zn	23000	0	0%	0%
Ag	390	0	0%	0%
Tl	6	0	0%	0%

Table 4.7: U.S. generic Soil Screening Limits (SSL) for ingestion of soil in residential scenarios and exceedences in tank sediment and soil samples.

In common with the soil data, it can be seen that 100% of water tanks sampled contained sediment with levels of As exceeding the generic SSL. Tank sediment samples also exceeded the SSL for Hg at one location and for Pb at 4 locations. This suggests that ingestion of sediment from Bermuda water tanks may pose a human health risk. However, further information on suspended sediment levels in water tanks is required to fully assess any associated risk.

In addition, the same caveats apply to the interpretation of SSLs with respect to tank sediment as apply with respect to soil data (see Section 3.2.5). Further analysis of the chemical speciation and (bio)availability of As and other metals in tank sediment is required to compile a location specific risk assessment. The fact that none (0%) of the water samples showed As levels above the drinking water standard reflects the low aqueous solubility of As. Thus the sediment is not a significant source of dissolved As in water and the As is most likely strongly bound to sediment particles in Fe-O-As and Al-O-As complexes.

4.3.5 - Distribution of Metals in Tank Sediment and Soil

Comparison of the metal content of tank sediment with that of soil (see Section 3.2) indicates that the two components have a similar composition (see Figure 4.4), suggesting that they may be derived from similar sources and local soil may be a significant source of tank sediment. It is not possible with these data alone to determine if the tank sediment is composed of redistributed (wind-blown) existing soil or is the result of contemporary direct wet and/or dry deposition of African dust. However, the presence of local soil in water tank sediment may explain the high coliform bacteria levels observed in Bermuda water tanks (Atlantis Project, 2004).

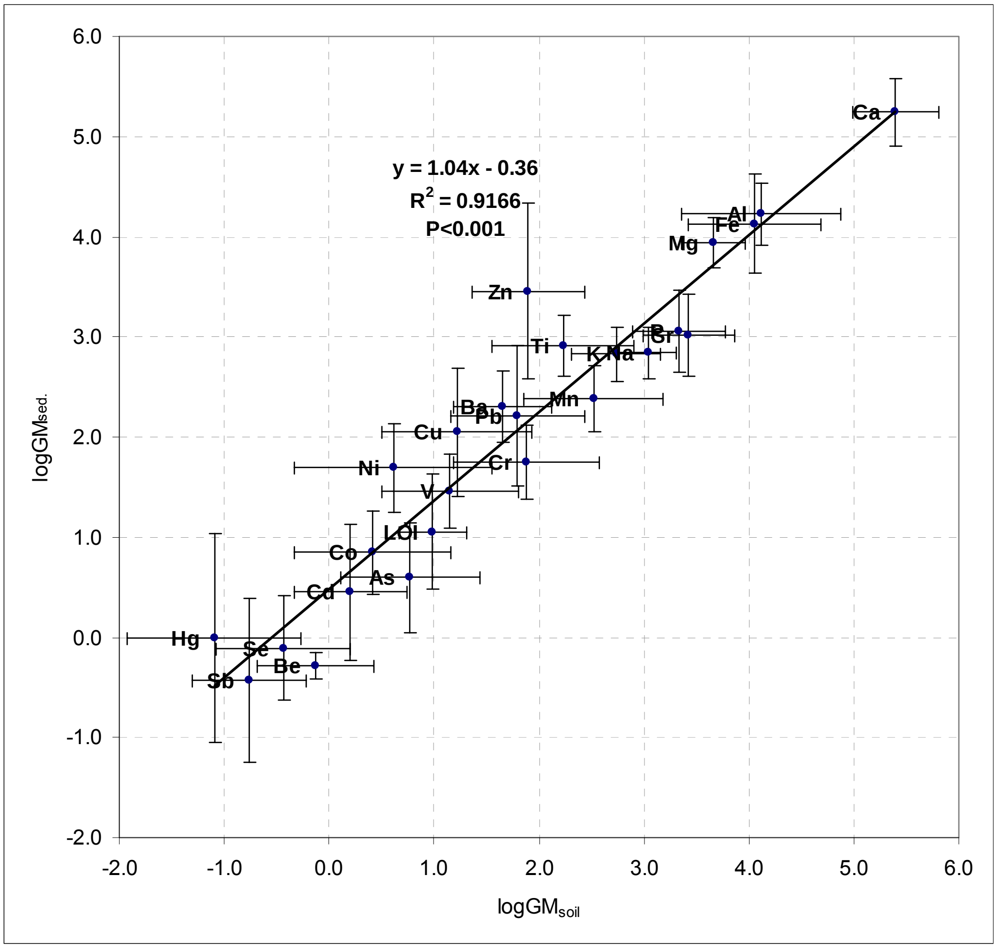


Figure 4.4: Correlation of the geometric means for metal concentrations in sediment ($GM_{sed.}$) and soil (GM_{soil}). Error bars indicate the geometric 95% confidence interval for each value. Note $\log_{10}$ axes scale.

4.3.6 - Distribution of Metals in Tank Sediment and Tank Water

To test for any relationship between tank sediment and the overlying water, pair-wise correlation was performed on data for those metals in sediment and water which recorded mean values above trace level in both Tables 4.1 and 4.5 (Ca, K, Mg, Na, Al, Ba, Fe, Mo, Pb, Sb, Sr, V and Zn). No significant relationships were found at $P \leq 0.05$. This indicates that although metals may accumulate in sediment, the sediment is not a source of metals to water. This could be a result of the relatively short residence time of water in tanks compared to that of the sediment. A detailed study of the kinetics of metal adsorption-desorption in the sediment-water system would help to better determine the significance of sediment accumulation in drinking water tanks.

4.3.7 - Dependence of Tank Sediment Metal Concentrations on Proximity to Incinerator

Owing to the variation in the probability distributions observed (see Table 4.4), the data were subjected to the non-parametric Kruskal-Wallis test (described in Section 3.2.10) to determine if there are any significant differences in the distribution of the data when categorized by distance for the incinerator. The data were classified into 3 groups based on distance of the sampling location from the incinerator: < 1 km; 1 - 2 km; and > 2 km.

The analysis was applied to those metals which had a rate of detection of > 75% (i.e. excluding Ag, Be, Mo, Sn, U and Tl). The results indicate that the distribution of As only is significantly different at $P \leq 0.05$ and can thus be assumed to vary between the groups analysed. From Table 4.3 it can be seen that higher concentrations of As are observed at distances of < 1km from the incinerator.

	As / mg/kg		
	<1km	**1-2km**	**>2km**
Median	4.9	3.6	3.3
Geo. mean	5.5	3.2	3.0

Table 4.8: Median and geometric mean values of As in tank sediment at varying distances from the incinerator.

4.4 - Organic Contaminants in Tank Water

4.4.1 - Sampling

Water samples for the analysis of organic contaminants were collected from 20 private households across the island. Of these, 12 (60%) were located < 1 km from the incinerator and 8 (40%) were located > 1 km from the incinerator.

Water was sampled in the same manner as for samples for metals analysis, described above. Samples for dioxin analysis were collected in 2 × 2 L glass jars and samples for PAHs were collected in 2 × 1 L glass bottles. The containers were supplied pre-cleaned by the analytical laboratory.

All samples were stored in coolers containing freezer packs until their return to the laboratory at BBSR where they were stored in the dark at 4°C. The samples were shipped in coolers with freezer packs to maintain refrigerated conditions.

4.4.2 - Analysis

Samples for dioxin analysis were extracted using liquid-liquid extraction and analysed by isotope-dilution high-resolution gas chromatography with high-resolution mass spectrometry (HRGC-HRMS), according to U.S. EPA Method 1613, Revision B. This provides isomer-specific determination of the seventeen 2,3,7,8-substituted, tetra- through octa-chlorinated, dibenzo-p-dioxin and dibenzofurans.

Samples for PAH analysis were extracted using liquid-liquid extraction, according to U.S. EPA Method 3510C, and analysed by gas chromatography with mass spectrometry (GC-MS) according to U.S. EPA Method 8270. This method provides for the analysis of the 16 PAHs designated as “priority pollutants” by the U.S. EPA.

4.4.3 - Dioxins

4.4.3.1 - Results

Dioxins had a low rate of detection in water samples. None of the 17 congeners analysed had a detection rate > 75%. This is not surprising given the fact that PCDD/Fs are hydrophobic chemicals with low aqueous solubilities. The low detection rate makes difficult the statistical analysis and interpretation of these data. This is further complicated by the fact that individual congeners are subject to both congener specific and sample specific detection limits. For these reasons, spatial analysis of dioxin concentrations in water has not been undertaken. Reported values for 2,3,7,8-TeCDD (the congener for which the U.S. EPA has derived a National Primary Drinking Water Standard, see below), total PCDDs, total PCDFs and TEQs for all samples are presented in Table 4.8, along with limited summary statistics.

Site GIS id	2,3,7,8-TeCDD	Tot PCDDs	Tot PCDFs	TEQ (ND=0)	TEQ (ND=0.5DL)	TEQ (ND=DL)
11	<0.34	<0.77	<0.82	0.0	0.43	0.87
146	<0.24	30	6.4	0.19	0.43	0.67
147	<1.70	<3.3	<1.6	0.0	1.6	3.2
148	<0.66	17	4.6	0.097	0.68	1.3
149	<0.88	<1.6	<0.94	0.0	0.81	1.7
150	<0.41	12	6.0	0.52	0.83	1.2
151	<1.90	<2.9	<1.4	0.0	1.6	3.0
152	<0.21	6.9	1.7	0.061	0.27	0.48
153	<0.41	14	1.9	4.7	4.9	5.2
154	<0.38	8.0	1.2	0.013	0.33	0.65
155	<0.24	12	2.4	0.0035	0.27	0.53
160	<0.10	<2.3	<0.65	0.0	0.20	0.39
43	<0.10	2.6	8.8	0.69	0.81	0.94
44	<0.26	4.4	<0.37	0.013	0.26	0.49
57	<0.10	<2.3	1.4	0.13	0.29	0.45
58	<0.10	<2.3	0.85	0.033	0.20	0.36
75	<0.11	74	18	0.15	0.32	0.48
97	<0.10	<2.3	1.7	0.085	0.25	0.41
135	<0.46	0.97	0.48	0.0	0.45	0.80
145	<1.40	<5.0	<1.9	0.0	1.6	3.2
D.L. range	0.10 - 1.7	0.77 - 5.0	0.37 - 1.9			
min.	n.d.	0.97	0.48	0.0	0.2	0.4
max.	n.d.	74	18	4.7	4.9	5.2

Table 4.9: Dioxins concentrations in water samples (pg/L). All values to 2 sig. figs.

4.4.3.2 - Comparison with Regulatory Limits

As part of the U.S. National Primary Drinking Water Standards, the U.S. EPA has set a Maximum Contaminant Level Goal (MCLG - the level for which there is no known or expected human health risk) and a Maximum Contaminant Level (MCL - the level most technologically and economically feasibly close to the MCLG) for 2,3,7,8-TeCDD of zero and 300 pg/L, respectively (USEPA, 2002c). The MCL is the legally enforceable standard. From Table 4.8 it can be seen that no samples exceeded the U.S. MCL for 2,3,7,8-TeCDD in drinking water.

4.4.4 - PAHS

4.4.4.1 - Results

PAHs also had a very low rate of detection in tank water. Only one location (GIS i.d. 11) had positive results for 4 PAHs: NAP (450 ng/L), FLR (100 ng/L), PHN (160 ng/L) and PYR (20 ng/L). All other observations were below the detection limit of 10 ng/L for each PAH compound. It is difficult to interpret these results with any degree of confidence. However, these values are higher than those observed in drinking water supplies but within the range of values observed in rainwater (IPCS, 1998).

The U.S. EPA has set a MCL of 200 ng/L for BaP in the U.S. National Primary Drinking Water Standards. No samples contained BaP above the detection limit of 10 ng/L.

4.5 - Organic Contaminants in Tank Sediment

4.5.1 - Sampling

Sediment samples for the analysis of organic contaminants were collected from 20 private households across the island. Of these, 12 (60%) were located < 1 km from the incinerator and 8 (40%) were located > 1 km from the incinerator.

Sediment was sampled and handled in the same manner as sediment samples for metals analysis, described above, but with the following key exceptions: The pump (Fluid Metering, Inc., Model Q) was equipped with stainless steel pistons and the in-line filter holder (Geotech Environmental Equipment, Inc.) was a 142mm diameter aluminium assembly. This was cleaned between samples by washing thoroughly with purified deionised water (Milli-Q water) and then rinsing with pesticide residue grade acetone and dichloromethane. Stainless steel forceps were used to handle the filters which were stored in aluminium foil pouches.

4.5.2 - Analysis

Following determination of sample dry weight, the analysis of organic contaminants in tank sediment was identical to the analysis of organic contaminants in soil samples (see Section 3.3.2).

4.5.3 - Dioxins

4.5.3.1 - Results

The summary statistics for dioxins in tank sediment are shown in Table 4.9. Three congeners (2,3,7,8-TeCDD, 1,2,3,7,8-PeCDD and 2,3,7,8-TeCDF) and 3 homolog groups (Tetra- and Penta-CDDs and Tetra-CDFs) had rates of detection < 75%. Estimation of a mean value for these compounds is difficult owing to the fact that individual congeners are subject to sample specific detection limits. The reported mean values should therefore be interpreted with caution. Application of the Shapiro-Wilks test at $P \leq 0.05$ shows that, with the exception of one congener (2,3,4,6,7,8-HxCDF) and 2 homolog groups (Tetra- and Penta-CDFs), the data followed a log-normal distribution. The geometric mean is thus the best estimate of central tendency for dioxins in tank sediment.

4.5.3.2 - Comparison with Regulatory Limits

There are no legislative limits in effect for sediment in drinking water tanks in Bermuda. However it is of use to compare the observed concentrations with the U.S. EPA generic soil screening limits (SSLs) calculated to minimise risk from human ingestion of metals in soil, as discussed in Section 3.2.5. The U.S. EPA has adopted a standard of 1.0 ng/g TEQ (1000 pg/g TEQ) as a starting point for setting cleanup levels for CERCLA removal sites and as a preliminary remediation goal for surface soil in residential scenarios (USEPA, 1998). The U.S. Agency for Toxic Substances and Disease Registry (ATSDR) has adopted an interim policy guideline screening level value of 50 ng/g TEQ (50,000 pg/g TEQ) and a guideline action level value of 1.0 ng/g TEQ (1000 pg/g TEQ) (ATSDR, 1997). In Canada, the national soil quality guideline limit for dioxins in soil of all application types is 4 pg/g TEQ (CCME, 2004).

The mean TEQ (assuming $ND = 0.5 \times DL$) concentration of dioxins in water tank sediment in Bermuda is 40 pg/g. This is 2 orders of magnitude lower than the U.S. limits discussed above but 10 times higher than the more stringent Canadian guideline limit. Of potential concern is the fact that at one residence, a maximum value of 1300 pg/g TEQ was recorded. This one value exceeds the U.S. EPA cleanup level and the ATSDR guideline action level cited above. It is difficult to determine the cause of this single incident. PAHs in this tank’s sediment did not exceed the U.S. EPA SSL but As, Be and Pb in the sediment did exceed their respective SSLs. However, with the exception of the secondary standard for pH (value = 8.6, *cf.* limit of 6.5-8.5), no drinking water quality standards were exceeded at this location.

Congener/ Homolog [a]	N>DL	%>DL	Arith. mean	s.d.	CoV [b]	95th %ile [c]	Median	Geo. mean	Geo. lower 95% CI [d]	Geo. upper 95% CI [e]	Min.	Max.
2378 TeCDD	*9*	*47%*	*4.2*	*9.3*	*223%*	*8.5*	*0.60*	*0.62*	*0.0093*	*41*	*0.050*	*39*
12378 PeCDD	*14*	*74%*	*22*	*50*	*224%*	*45*	*3.7*	*2.6*	*0.019*	*360*	*0.050*	*210*
123478 HxCDD	19	100%	48	88	182%	89	8.6	**14**	0.57	320	1.7	360
123678 HxCDD	19	100%	110	210	185%	210	24	**30**	1.1	800	3.8	850
123789 HxCDD	18	95%	120	230	203%	230	19	**20**	0.29	1400	0.13	980
1234678 HpCDD	19	100%	2200	3100	142%	3600	540	**670**	23	20000	42	11000
OCDD	19	100%	13000	19000	137%	22000	5500	**4500**	160	130000	240	64000
Total TCDD	*11*	*58%*	*67*	*180*	*264%*	*150*	*4.8*	*2.7*	*0.0048*	*1500*	*0.050*	*760*
Total PeCDD	*14*	*74%*	*280*	*680*	*246%*	*590*	*37*	*13*	*0.014*	*13000*	*0.050*	*2900*
Total HxCDD	19	100%	1100	2000	187%	2000	230	**310**	13	7500	25	8300
Total HpCDD	19	100%	4200	6000	142%	7000	1100	**1300**	47	38000	82	21000
TOTAL PCDDs	19	100%	19000	26000	138%	32000	6800	**6400**	230	180000	350	82000
2378 TeCDF	*13*	*68%*	*19*	*41*	*214%*	*38*	*3.7*	*2.4*	*0.018*	*320*	*0.050*	*170*
12378 PeCDF	18	95%	40	78	194%	77	7.7	**8.0**	0.16	410	0.15	320
23478 PeCDF	18	95%	57	130	223%	120	13	**11**	0.21	560	0.13	540
123478 HxCDF	19	100%	200	420	213%	390	35	**31**	0.56	1700	2.5	1700
123678 HxCDF	19	100%	82	170	204%	160	15	**19**	0.68	540	2.4	690
123789 HxCDF	15	79%	6.9	12	172%	12	2.2	**2.1**	0.069	63	0.12	50
234678 HxCDF	19	100%	130	270	211%	250	23	**27**	0.92	790	4.2	1100
1234678 HpCDF	19	100%	780	1400	176%	1400	140	**220**	9.6	5200	34	5200
1234789 HpCDF	17	89%	58	100	175%	110	19	**13**	0.23	740	0.17	410
OCDF	19	100%	660	910	138%	1100	160	**240**	11	5200	21	3100
Total TCDF	*13*	*68%*	*220*	*510*	*237%*	*460*	*39*	*9.4*	*0.0077*	*12000*	*0.050*	*2200*
Total PeCDF	15	79%	370	850	227%	770	71	**22**	0.021	22000	0.050	3600
Total HxCDF	19	100%	720	1400	189%	1400	170	**210**	9.4	4700	29	5700
Total HpCDF	19	100%	1200	1700	148%	2000	180	**400**	19	8500	50	6500
TOTAL PCDFs	19	100%	3100	5200	165%	5600	610	**990**	42	23000	120	21000
Total TEQ (ND=0)	19	100%	160	310	195%	310	39	**39**	1.3	1200	4.2	1300
Total TEQ (ND=0.5DL)	19	100%	160	310	195%	310	39	**40**	1.4	1200	5.1	1300
Total TEQ (ND=DL)	19	100%	160	310	195%	310	39	**41**	1.4	1200	5.4	1300

Table 4.10: Summary statistics for dioxin congeners and homolog groups measured in tank sediment. All results in pg/g dry weight. Data to 2 sig. figs. Shading added to aid interpretation. TEQ values are derived using the TEQ_{DF}-WHO_{98} scheme.

bold: best estimate of central tendency;
italic: congeners/homologs with detection rate < 75%;
a: T = tetra; Pe = penta; Hx = hexa; Hp = hepta; O = octa;
b: CoV - coefficient of variation = mean/s.d.;
c: 95th percentile of untransformed data;
d: Lower 95% confidence interval of the geometric mean = $\mathrm{GM}/\mathrm{GSD}^{1.96}$;
e: Upper 95% confidence interval of the geometric mean = $\mathrm{GM}\times\mathrm{GSD}^{1.96}$.

These results suggest that dioxins in water tank sediment in Bermuda may present a low human or environmental health risk if it is ingested. Further research is required to fully characterise the extent of this risk. Of particular importance is a better understanding of the behaviour of sediment in water tanks. The risk from contaminants in water tank sediment may be minimal only if tank sediment is retained at the bottom of the tanks and does not become remobilised into the water column. However, Bermuda water tank sediment is subject to resuspension when water levels are low and rainwater enters and also when water is discharged into tanks by commercial water truck delivery. This can lead to the direct ingestion of particulate matter if tank water is consumed without filtration.

4.5.3.3 - Dependence of Sediment PCDD/F Concentrations on Proximity to Incinerator

Table 4.11 shows the mean values of PCDD/F levels in tank sediment based on proximity to the incinerator. These data were subjected to a non-parametric Mann-Whitney test (as described in Section 3.2.8) to determine if there is any significant difference between the mean concentrations measured at distances of < 1 km and > 1 km from the TBWTF. This revealed that 15 of the 2,3,7,8-substituted congeners, all of the homolog groups and total PCDDs and PCDFs had higher mean concentrations closer to the incinerator (see Table 4.11). Furthermore, the TEQ_{DF}-WHO_{98} was significantly higher by a factor of 10 closer to the incinerator. While this analysis is based on a small number of samples, and a survey employing a larger sample size would better determine any influence that incinerator emissions may have on the spatial distribution of PCDD/Fs in Bermuda tank sediment, it further supports the hypothesis that PCDD/Fs in tank sediment may represent a significant human health risk if suspended sediment is consumed in drinking water.

4.5.3.4 - Dioxin Profile in Tank Sediment

The profile of PCDD/F congeners is shown in Figure 4.5. It can be seen that this profile is significantly different from the profile observed in the incinerator emissions and is very similar to the profile observed in soil samples (see Figure 3.10). The profile is dominated by OCDD, with minor contributions from 1,2,3,4,6,7,8-HpCDD, 1,2,3,4,6,7,8-HpCDF and OCDF. This is similar to the dioxin profiles observed for vehicular traffic, suggesting that this is a dominant source of dioxins in tank sediment in Bermuda.

Congener/ Homolog [a]	**Geo. mean < 1 km N=13**	**Geo. mean > 1 km N=7**
2378 TCDD	***1.8***	*0.14*
12378 PeCDD	***11***	*0.35*
123478 HxCDD	**27**	5.3
123678 HxCDD	**70**	9.0
123789 HxCDD	**65**	4.1
1234678 HpCDD	**1500**	230
OCDD	9000	1800
Total TCDD	***18***	*0.20*
Total PeCDD	***56***	*1.9*
Total HxCDD	**780**	84
Total HpCDD	**2900**	450
TOTAL PCDDs	**13000**	2400
2378 TCDF	***10***	*0.31*
12378 PeCDF	**23**	1.9
23478 PeCDF	**38**	1.9
123478 HxCDF	**110**	5.2
123678 HxCDF	**55**	4.5
123789 HxCDF	3.3	1.1
234678 HxCDF	**78**	6.3
1234678 HpCDF	**510**	73
1234789 HpCDF	**38**	3.1
OCDF	**450**	97
Total TCDF	***49***	*0.99*
Total PeCDF	**110**	2.4
Total HxCDF	**520**	61
Total HpCDF	**810**	150
TOTAL PCDFs	**2200**	340
Total TEQ (ND=0)	**110**	10
Total TEQ (ND=0.5DL)	**110**	11
Total TEQ (ND=DL)	**110**	11

Table 4.11: Geometric mean concentrations of PCDD/F congeners and homolog groups measured in water tank sediment at distances of < 1 km and > 1 km from the incinerator at TBWTF. All results in pg/g dry weight. Geometric mean values to 2 sig. figs. Shading added to aid interpretation. TEQ values are derived using the TEQ_{DF}-WHO_{98} scheme.

bold: mean value significantly higher (P ≤ 0.05);
italic: congeners/homologs with detection rate < 75% (see Table 4.10);
a: T = tetra; Pe = penta; Hx = hexa; Hp = hepta; O = octa.

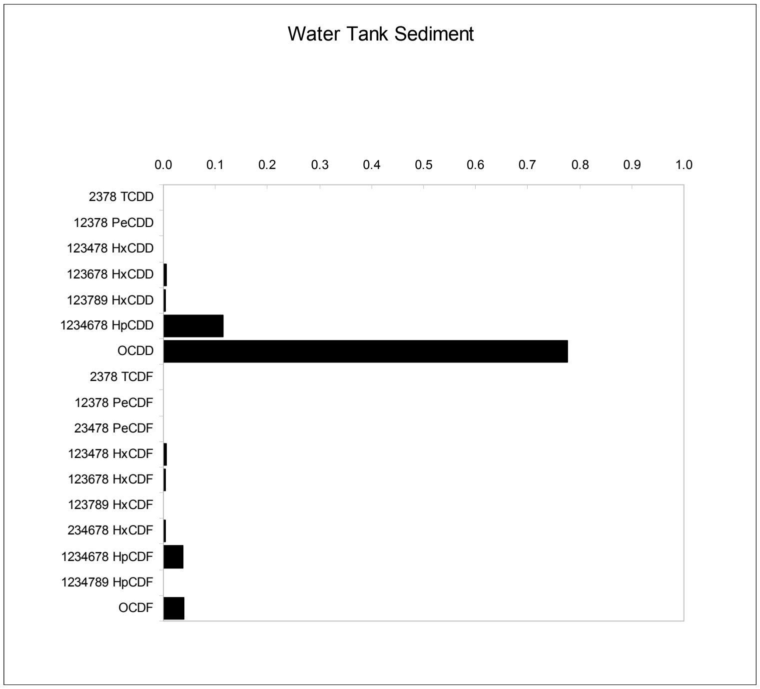


Figure 4.5: Congener profile of dioxins in water tank sediment.

4.5.4 - PAHs

4.5.4.1 - Results

For abbreviations of names of PAH compounds see Section 2, Figure 2.2. The summary statistics for the PAH results are shown in Table 4.10. Of the 16 PAHs measured, 6 had low rates of detection (< 75% of samples) and the calculated means for these compounds were all less than the limit of detection (10 µg/kg). Application of the Shapiro-Wilks test at $P \leq 0.05$ revealed that for those PAHs with a rate of detection > 75 %, the data followed a log-normal distribution. The geometric mean can thus be considered the best estimate of central tendency for PAHs in tank sediment.

	DL[a]	N>DL	%>DL	Arith. mean	s.d.	CoV[b]	95th %ile[c]	Median	Geo. mean	Geo. lower 95% CI[d]	Geo. upper 95% CI[e]	Min.	Max.
NAP	10	8	40%	15	16	107%	22	trace[f]	**trace**			<10	70
ACY	10	2	10%	18	55	296%	43	trace	**trace**			<10	250
ACE	10	0	0%	n.d.[g]				n.d.	**n.d.**				
FLR	10	1	5%	trace				trace	**trace**			<10	20
PHN	10	16	80%	79	180	216%	160	33	**31**	<10	390	<10	810
ANT	10	6	30%	31	95	302%	74	trace	**trace**			<10	430
FLT	10	20	100%	230	440	187%	430	83	**94**	<10	1200	10	2000
PYR	10	20	100%	200	390	196%	380	73	**75**	<10	1100	10	1800
BaA	10	17	85%	120	260	216%	240	37	**39**	<10	660	<10	1200
CHR	10	18	90%	120	200	159%	210	45	**51**	<10	720	<10	870
BbF	10	16	80%	170	280	160%	300	60	**60**	<10	1400	<10	1200
BkF	10	16	80%	110	200	180%	200	38	**41**	<10	700	<10	910
BaP	10	16	80%	120	220	177%	230	48	**44**	<10	840	<10	1000
IP	10	16	80%	110	170	152%	180	35	**41**	<10	740	<10	690
DBahA	10	3	15%	11	17	145%	19	trace	**trace**	<10	34	<10	70
BghiP	10	15	75%	75	94	122%	120	35	**34**	<10	540	<10	360
ΣEPA_{16}[h]	10	20	100%	1400	2600	180%	2600	500	**490**	23	11000	20	12000

Table 4.12: Summary statistics for PAHs measured in tank sediment. All results in µg/kg dry weight. Data to 2 sig. figs. Shading added to aid interpretation. Abbreviations provided in Figure 2.2.

bold: best estimate of central tendency;
a: DL = detection limit;
b: CoV - coefficient of variation = mean/s.d.;
c: 95th percentile of untransformed data;
d: Lower 95% confidence interval of the geometric mean = $GM/GSD^{1.96}$;
e: Upper 95% confidence interval of the geometric mean = $GM \times GSD^{1.96}$;
f: trace = calculated value < D.L.;
g: n.d. = not detected in any sample > DL;
h: ΣEPA_{16} = sum of the 16 EPA priority pollutant PAHs.

The profile and levels of PAHs in tank sediments is very similar to those observed in soil. Both or dominated by FLT, PYR and BbF, and the geometric mean ΣEPA_{16} values for soil and sediment are 500 and 490 µg/kg, respectively.

4.5.4.2 - Comparison with Regulatory Limits

There are no legislative limits in effect for sediment in drinking water tanks in Bermuda. However it is of use to compare the concentrations of metals in tank sediment with the U.S. EPA generic soil screening limits (SSLs) calculated to minimise risk from human ingestion of metals in soil, as discussed in Section 3.2.5.

With the exception of ACY and PHN for which no limit applies, the U.S. EPA has established generic Soil Screening Limits (SSLs) for all of the PAHs measured (USEPA, 2002a) (see Table 4.11). These were exceeded by 5 PAHs at a total of 10 locations (i.e. 50% of residences sampled). Of potential concern is that the SSL for BaP, the most toxic PAH, was exceeded at 8 residences.

The Canadian Government's Soil Quality Guidelines (SQG) Summary Tables contain SQG values for NAP and BaP (see Table 4.11). The SQG for BaP was exceeded at one sample location.

These results indicate that PAHs in water tank sediment may be of concern owing to the potential for ingestion of PAH-contaminated sediment particles. However it is important to consider the caveats discussed in Section 3.2.5 in relation to the application of generic legislative limits: these are not strictly applicable to all situations and should be viewed as the first step of a tiered approach to risk assessment.

4.5.4.3 - Dependence of Sediment PAH Concentrations on Proximity to Incinerator

The PAH sediment data were subjected to a non-parametric Mann-Whitney test (as described in Section 3.2.8) to determine if there is any significant difference between the mean concentrations measured at distances of < 1 km and > 1 km from the TBWTF. No significant differences were found, suggesting that PAHs in tank sediment are randomly distributed on a spatial scale.

	SSL	**N>SSL**	**%>SSL**	**SQG**	**N>SQG**	**%>SQG**
	µg/kg			**µg/kg**		
NAP	**1.1×10^6**	0	0%	**600**	0	0%
ACY	n/a			n/a		
ACE	**3.4×10^6**	0	0%	n/a		
FLR	**2.3×10^6**	0	0%	n/a		
PHN	n/a			n/a		
ANT	**17×10^6**	0	0%	n/a		
FLT	**2.3×10^6**	0	0%	n/a		
PYR	**1.7×10^6**	0	0%	n/a		
BaA	**600**	1	6%	n/a		
CHR	**62,000**	0	0%	n/a		
BbF	**600**	1	6%	n/a		
BkF	**6000**	0	0%	n/a		
BaP	**60**	8	50%	**700**	1	6%
IP	**600**	1	6%	n/a		
DBahA	**60**	1	6%	n/a		
BghiP	**60**	8	50%	n/a		

Table 4.13: Exceedences of U.S. EPA Soil Screening Levels (SSL) and Canadian Soil Quality Guideline (SQG) levels for PAHs in water tank sediment. All values in µg/kg. n/a = not available.

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DATA APPENDIX

Contents:

Table A1: Soil sampling sites – GIS codes, locations and grid coordinates.

Table A2: LOI (%) and metal concentrations (mg/kg) in soil.

Table A3: PCCD/Fs concentrations in soil.

Table A4: PAH concentrations in soil.

Table A5: Water tank sampling sites – GIS codes, locations and grid coordinates.

Table A6: pH, conductivity (µS) and major ion concentrations (mg/L) in water samples located < 1 km and < 2 km from TBWTF.

Table A7: pH, conductivity (µS) and major ion concentrations (mg/L) in water samples located >2 km from TBWTF.

Table A8: Metal concentrations (mg/L) in water samples located < 1 km and < 2 km from TBWTF.

Table A9: Metal concentrations (mg/L) in water samples located > 2 km from TBWTF.

Table A10: PCDD/F concentration in water (pg/L).

Table A11: PAH concentration in water (mg/L).

Table A12: LOI (%) and metal concentrations (mg/kg) in water tank sediment.

Table A13: PCDD/F concentrations (pg/g) in water tank sediment.

Table A14: PAH concentrations (µg/kg) in water tank sediment.

Note: All site locations can be determined from the GIS Codes given in the relevant tables. These codes are in the form X-YYY-ZZ, where X represents the sample type (W = water tank, S = soil), YYY is the location number and ZZ is the year identifier (05 = 2005).

GIS ID	GIS Code	Location	Easting	Northing
1	S-1-05	Maritime Museum	542172.76	136383.80
2	S-2-05	Boaz Island	540294.48	134279.16
3	S-3-05	Daniels Head	538261.88	133628.62
4	S-4-05	Hog Bay Park	538044.25	130360.40
5	S-5-05	Port Royal Golf Course	538728.42	129163.40
6	S-6-05	Church Bay	540755.12	127661.77
7	S-7-05	Gibbs Hill	542045.28	128010.34
8	S-8-05	Warwick Long Bay	544143.75	128543.39
9	S-9-05	Riddells Bay Golf Course	543184.22	129239.36
10	S-10-05	Warwick Academy	545776.45	130601.31
11	S-11-05	Cobbs Hill	546018.64	130629.69
12	S-12-05	Bermuda College	547484.90	131044.06
13	S-13-05	Peace Lutheran Church	548749.80	132089.32
14	S-14-05	Sir Henry Tucker	548990.42	132376.17
15	S-15-05	Spanish Point	543948.21	133973.15
16	S-16-05	Fort Hamilton	547415.73	132748.82
17	S-17-05	American Counsel	548267.22	132724.43
18	S-18-05	Aboretum	548284.29	133109.17
19	S-19-05	Friendship Park	548171.11	134016.80
20	S-20-05	Cloverdale Estates	550665.51	133716.27
21	S-21-05	Pampas Road	550931.14	133876.22
22	S-22-05	Devon Springs	550278.55	134153.02
23	S-23-05	Penhurst Agriculture	550403.69	134995.53
24	S-24-05	Junc. Collectors Hill & Middle Rd.	550984.83	135088.43
25	S-25-05	Palmetto Park	548752.02	134347.09
26	S-26-05	Frog Lane Field	548089.18	133554.24
27	S-27-05	Police Cycle Squad	548317.63	133363.34
28	S-28-05	Police Headquarters	548418.72	133242.67
29	S-29-05	Prospect Site	548506.19	133372.79
30	S-30-05	Old Elliott School	549229.18	133864.44
31	S-31-05	Brighton Hill	549893.85	133530.08
32	S-32-05	Melville Cresent	549880.03	133297.27
33	S-33-05	Palm Grove	550116.91	133277.32
34	S-34-05	Devondale	549872.27	133005.06
35	S-35-05	Shelly Bay	551110.96	137042.64
36	S-36-05	Dolphin Drive	553717.05	138916.24
37	S-37-05	Watch Hill Park	553048.86	134938.48
38	S-38-05	Tucker's Town	555132.35	136955.89
39	S-39-05	St. David's Lighthouse	559251.66	140370.06
40	S-40-05	St. David's Head	559604.82	140828.84
41	S-41-05	St. Catherines	557053.09	143233.28
42	S-42-05	Rocky Hill Park	555361.83	141842.35
43	S-43-05	BBSR	554965.15	141188.97
44	S-44-05	Ferry Point Park	553417.44	140318.60
45	S-45-05	Robert Crawford	548320.26	133598.22
46	S-46-05	Dudley Hill	547238.63	131430.92
47	S-47-05	Douglas Heights	545416.70	133423.75
48	S-48-05	Lookout Lane West	548128.68	134106.30
49	S-49-05	Lookout Lane East	548247.72	134143.64
50	S-50-05	Cedarbridge Academy	548296.02	133633.39
51	S-51-05	Aeolia Drive	548497.70	134103.25
52	S-52-05	Roberts Avenue	547923.51	133386.03
53	S-53-05	Happy Valley Park	548065.36	133155.52
54	S-54-05	Watlington Point	548543.55	134338.77
55	S-55-05	Orange Valley Road	548727.01	133631.33
56	S-56-05	Mary Victoria Road	548777.52	133264.14
57	S-57-05	Terceira's Stables	549031.29	133666.93
58	S-58-05	Ocean View Golf Course	548891.85	133986.35
59	S-59-05	Palmetto Park East	548901.06	134415.93
60	S-60-05	Devonshire Marsh West	549190.97	133779.50
61	S-61-05	Devonshire Marsh East	549316.04	134047.70

Table A1: Soil sampling sites – GIS codes, locations and grid coordinates.

< 1km	GIS Code	LOI	Sb	As	Hg	Se	Ag	Al	Ba	Be	Ca	Cd	Co	Cr	Cu	Fe
	S-01-05	8.4	0.2	6.1	<0.05	0.2	<1	7200	36	<1	303000	1.6	2	43.5	37	6800
	S-02-05	8	0.1	4.4	0.06	0.2	<1	10900	119	<1	319000	1.1	2	60.5	15	9200
	S-03-05	7	1	7.9	<0.05	0.3	<1	5300	54	<1	344000	2.5	1	35.1	18	4800
	S-04-05	18.9	<0.1	19.6	0.12	5	<1	52800	50	3	124000	4.8	9	339	21	37700
	S-05-05	6.9	0.1	4.6	<0.05	0.3	<1	12000	28	<1	315000	1.5	2	56.1	21	8800
	S-06-05	5.3	<0.1	1.3	<0.05	0.2	<1	1700	12	<1	353000	0.8	<1	20.4	4	2500
	S-07-05	7	0.6	1.6	9.11	0.2	<1	1300	163	<1	337000	0.8	<1	16.1	15	2500
	S-08-05	7	0.2	2.1	<0.05	0.3	<1	2800	15	<1	338000	1.2	<1	30.7	6	3000
	S-09-05	13.8	0.1	12.1	0.35	0.6	<1	49000	62	3	180000	2.3	8	308	23	33200
	S-10-05	20.6	0.1	20.7	0.27	1.7	<1	82000	93	4	44400	4.6	15	380	25	52500
	S-11-05	11.5	0.1	6.2	0.16	0.7	<1	24000	51	2	225000	2.1	4	166	11	17800
	S-12-05	11.4	0.2	24.3	0.16	0.5	<1	41300	71	2	207000	3.8	8	259	81	28300
	S-13-05	10.9	0.2	9.7	0.13	0.6	<1	21700	50	1	256000	2.6	4	126	27	16700
	S-14-05	10.9	0.2	10.7	0.15	0.5	<1	20500	59	1	245000	1.9	4	126	35	16300
	S-15-05	9.5	0.1	5.6	0.08	0.3	<1	15600	53	<1	265000	3.2	3	73.7	19	12000
	S-16-05	6.6	0.2	18	0.19	0.3	<1	13300	53	<1	300000	1.2	2	63.8	18	10100
	S-17-05	10.8	0.2	7.9	0.31	0.6	<1	28300	97	2	220000	3.1	6	156	27	20900
*	S-18-05	18.4	0.2	4.2	0.06	0.4	<1	12800	27	<1	262000	1.4	2	72.4	8	10000
*	S-19-05	7.9	0.2	5	0.08	0.5	<1	16400	62	<1	273000	2.7	4	74.9	13	14100
	S-20-05	7.8	0.3	3.8	<0.05	0.1	<1	11700	29	<1	315000	1.2	2	56.8	15	9300
	S-21-05	10.2	0.1	5.8	<0.05	0.4	<1	21500	59	<1	255000	4.8	5	112	18	16300
	S-22-05	10.6	0.9	1.4	0.06	0.3	<1	3700	37	<1	328000	0.6	<1	21.9	10	3600
	S-23-05	13	0.1	1.7	<0.05	0.4	<1	4800	17	<1	278000	0.9	<1	27.1	5	4000
	S-24-05	6.9	0.2	6.3	0.2	0.5	<1	9000	38	<1	308000	1.2	2	47.9	16	7100
*	S-25-05	12.9	<0.1	10.7	0.05	0.3	<1	18800	39	<1	184000	3	3	99.5	32	14000
*	S-26-05	5.6	0.3	2.7	0.06	0.2	<1	6500	26	<1	333000	0.9	1	33.1	13	5800
*	S-27-05	9.8	0.3	3.3	0.06	0.2	<1	10300	33	<1	287000	0.9	2	48	13	8700
*	S-28-05	15.5	0.2	10.5	0.11	0.2	<1	24800	48	1	239000	2	4	115	12	19000
*	S-29-05	5.9	0.2	3.6	0.07	0.2	<1	10700	44	<1	320000	0.9	2	52.3	15	9300
*	S-30-05	7.1	0.2	3.7	0.08	0.3	<1	7800	26	<1	312000	1	2	44.1	26	7600
	S-31-05	12.7	0.2	51.5	0.14	0.3	<1	32600	48	2	192000	2.9	7	155	88	26100
	S-32-05	9.4	0.1	5.3	<0.05	0.5	<1	9300	24	<1	294000	1.7	2	62	37	8700
	S-33-05	10.6	0.2	13	0.08	0.4	<1	21400	50	1	248000	2.6	4	123	20	18400
	S-34-05	13.5	0.1	9.7	0.09	0.3	<1	33700	38	2	195000	2.5	6	168	8	26700
	S-35-05	11.4	0.1	8.1	0.12	0.5	<1	18100	41	<1	262000	1.9	3	102	14	13500
	S-36-05	16.1	0.5	10.2	0.07	0.2	<1	19000	104	<1	233000	2.9	8	223	23	23400
	S-37-05	13.6	0.1	13.8	0.07	0.2	<1	40200	39	2	194000	2	8	273	8	33600
	S-38-05	10.9	0.1	3.2	0.06	0.7	<1	9500	34	<1	263000	1.6	2	64.5	8	8800
	S-39-05	11	0.3	5.3	0.06	0.4	<1	12900	48	<1	285000	1.3	3	114	14	12300
	S-40-05	11	<0.1	12.4	0.07	0.8	<1	31500	73	1	209000	2.8	6	258	9	26600
	S-41-05	4.4	0.1	1.3	<0.05	<0.1	<1	1600	10	<1	359000	<0.5	<1	18	2	3000
	S-42-05	8.9	0.4	3.8	<0.05	0.2	<1	7300	37	<1	310000	1.2	2	48.4	27	8800
	S-43-05	17	0.1	16.9	0.1	0.6	<1	47400	100	3	121000	7.1	15	293	17	44500
	S-44-05	19.6	0.1	18.9	0.09	5.4	<1	70000	60	4	16700	5	16	498	16	62300
*	S-45-05	5.2	0.2	3.3	0.07	0.2	<1	9900	48	<1	287000	0.8	2	41.9	11	9400
	S-46-05	6.7	0.1	3.6	<0.05	0.4	<1	10900	27	<1	332000	0.8	2	61.5	8	9200
	S-47-05	6.8	0.4	4.2	0.09	0.2	<1	8400	56	<1	326000	0.7	2	36.6	28	9400
*	S-48-05	8	0.2	10.6	0.16	0.4	<1	16900	47	<1	300000	1.6	3	83.1	17	12300
*	S-49-05	15.7	0.3	8.9	0.12	0.7	<1	30400	177	1	189000	3.5	5	160	16	21500
*	S-50-05	6.4	0.3	4.4	0.09	0.1	<1	13800	54	<1	312000	1.1	2	62.4	15	11700
*	S-51-05	12.9	0.1	3.7	<0.05	0.6	<1	10100	31	<1	221000	1.5	2	52	5	7400
*	S-52-05	10.6	0.3	5.5	0.34	0.4	<1	15400	54	<1	288000	1.2	3	66.8	19	11600
*	S-53-05	6.6	0.2	3.2	<0.05	0.4	<1	6600	90	<1	374000	0.9	1	32.9	8	5800
*	S-54-05	5.8	0.2	5.4	0.13	0.3	<1	11800	85	<1	330000	1.3	2	66.9	20	9800
*	S-55-05	11.2	0.1	6.5	0.09	0.3	<1	13900	31	<1	313000	1.7	3	68.4	13	10800
*	S-56-05	10.4	0.2	2.9	0.17	0.3	<1	9400	37	<1	327000	1	2	42.7	16	7800
*	S-57-05	6.1	0.2	1.6	0.06	0.3	<1	2600	31	<1	339000	0.7	<1	19.9	14	3500
*	S-58-05	7.6	0.3	8.1	0.14	0.4	<1	9100	45	<1	327000	1	2	44.9	22	7900
*	S-59-05	15.5	0.2	8.7	0.16	0.4	<1	30800	56	2	249000	2.5	5	157	24	22700
*	S-60-05	15.2	0.2	11.2	0.05	0.9	<1	14800	40	<1	279000	1.7	3	64.7	1100	11700
*	S-61-05	5.8	0.2	2.7	0.08	0.2	<1	5200	27	<1	348000	0.6	1	35.1	10	5200

Table A2: LOI (%) and metal concentrations (mg/kg) in soil. See Table A1 for site locations. (cont. overleaf).

< 1km	GIS Code	K	Mg	Mn	Mo	Na	Ni	P	Pb	Sn	Sr	Ti	Tl	V	Zn	U
	S-01-05	330	5900	210	<1	1300	2	2000	135	<5	3170	105	<1	9	110	<40
	S-02-05	510	8200	270	<1	1300	3	1620	108	<5	2700	156	<1	14	190	<40
	S-03-05	360	6600	170	<1	1700	<2	3670	196	<5	3820	81	<1	6	100	<40
	S-04-05	810	4700	1100	<1	600	25	3320	54	<5	1250	477	<1	48	60	<40
	S-05-05	490	6300	350	<1	1400	<2	2390	36	<5	2860	162	<1	10	50	<40
	S-06-05	230	13900	60	<1	2000	<2	1230	9	<5	4170	26	<1	2	20	<40
	S-07-05	230	11600	60	<1	1700	<2	1120	672	<5	3260	26	<1	3	770	<40
	S-08-05	310	12600	90	<1	1900	<2	1170	19	<5	3300	40	<1	4	30	<40
	S-09-05	910	4300	980	<1	600	20	1990	99	<5	866	447	<1	39	70	<40
	S-10-05	1180	4100	1690	1	500	35	3290	82	<5	719	548	<1	61	130	<40
	S-11-05	590	3700	620	<1	600	10	2800	86	<5	1060	248	<1	20	50	<40
	S-12-05	1050	4800	920	11	800	22	4420	91	<5	1740	419	<1	39	140	<40
	S-13-05	840	5900	520	<1	900	10	2970	60	<5	1750	217	<1	22	80	<40
	S-14-05	630	5200	420	<1	900	9	2360	81	<5	2080	216	<1	20	70	<40
	S-15-05	710	4200	450	<1	1300	4	3340	42	<5	3400	184	<1	15	80	<40
	S-16-05	410	3100	240	<1	1400	3	2140	78	<5	4750	188	<1	13	70	<40
	S-17-05	710	3700	800	<1	700	16	2550	205	<5	1700	276	<1	28	150	<40
*	S-18-05	590	4000	330	<1	800	3	1760	41	<5	2270	158	<1	17	40	<40
*	S-19-05	560	3800	340	<1	800	7	4290	103	<5	2540	189	<1	15	110	<40
	S-20-05	470	5700	420	<1	1300	<2	1780	34	<5	3480	177	<1	12	40	<40
	S-21-05	1200	5700	750	<1	1200	6	5380	25	<5	3930	285	<1	20	90	<40
	S-22-05	350	4100	180	<1	800	<2	1560	76	<5	1910	50	<1	5	50	<40
	S-23-05	370	3800	200	<1	1100	<2	1420	13	<5	3010	60	<1	5	20	<40
	S-24-05	380	3900	240	<1	700	2	1630	67	<5	1940	105	<1	9	80	<40
*	S-25-05	630	3200	480	<1	800	6	2960	41	<5	2090	164	<1	19	50	<40
*	S-26-05	320	3300	170	<1	1600	<2	1420	51	<5	5680	97	<1	7	50	<40
*	S-27-05	430	3700	240	<1	1200	2	1400	72	<5	4050	157	<1	11	60	<40
*	S-28-05	780	3400	540	<1	1300	7	2180	112	<5	4310	315	<1	24	80	<40
*	S-29-05	380	3500	230	<1	1500	2	1130	81	<5	5160	177	<1	11	80	<40
*	S-30-05	390	3900	210	<1	800	<2	1390	71	<5	2270	110	<1	9	70	<40
	S-31-05	990	4200	1260	<1	700	13	3330	195	<5	1150	300	<1	29	80	<40
	S-32-05	510	4400	380	<1	1000	3	2690	37	<5	2110	122	<1	13	50	<40
	S-33-05	910	4700	820	<1	1100	8	3740	68	<5	2610	296	<1	23	90	<40
	S-34-05	1050	4500	690	<1	800	12	2330	32	<5	1400	368	<1	34	40	<40
	S-35-05	500	5500	430	<1	1200	6	2010	46	<5	2920	211	<1	17	50	<40
	S-36-05	570	4300	280	<1	700	21	8920	58	<5	4410	660	<1	28	170	<40
	S-37-05	2170	6400	690	<1	1200	18	1990	57	<5	1520	398	<1	40	90	<40
	S-38-05	670	5500	410	<1	900	3	3040	23	<5	1610	137	<1	9	40	<40
	S-39-05	650	5000	330	<1	1100	4	2140	135	<5	2020	199	<1	15	120	<40
	S-40-05	1120	4200	320	<1	1300	14	4220	47	<5	3700	336	<1	33	60	<40
	S-41-05	240	11400	50	<1	1800	<2	580	14	<5	4400	31	<1	5	20	<40
	S-42-05	330	5700	250	<1	1200	3	1190	128	<5	2590	117	<1	8	110	<40
	S-43-05	1300	4400	1940	<1	700	39	6900	56	<5	2800	788	<1	60	100	<40
	S-44-05	1550	4400	1400	<1	1100	38	4120	59	<5	586	1690	<1	94	340	<40
*	S-45-05	480	3400	210	<1	1400	4	970	70	<5	4570	146	<1	11	110	<40
	S-46-05	360	6200	220	<1	1200	3	1540	25	<5	2880	144	<1	10	50	<40
	S-47-05	400	3400	140	<1	1500	3	1370	87	<5	4970	104	<1	9	140	<40
*	S-48-05	510	6500	310	<1	1100	6	2540	46	<5	2650	217	<1	17	100	<40
*	S-49-05	1010	4800	530	<1	900	11	2990	93	<5	1930	272	<1	31	180	<40
*	S-50-05	410	3400	280	<1	1500	4	1450	98	<5	5020	217	<1	13	90	<40
*	S-51-05	550	2600	280	<1	1000	3	1780	25	<5	2520	82	<1	12	60	<40
*	S-52-05	510	2700	280	<1	1400	4	2140	115	<5	4790	188	<1	16	90	<40
*	S-53-05	350	3300	160	<1	1600	<2	1310	45	<5	5380	93	<1	7	60	<40
*	S-54-05	440	5600	250	<1	1200	4	1550	200	<5	3040	162	<1	12	180	<40
*	S-55-05	490	3600	490	<1	1000	3	2470	35	<5	3270	153	<1	15	90	<40
*	S-56-05	320	2900	200	<1	1500	<2	1390	100	<5	5490	145	<1	9	60	<40
*	S-57-05	280	3200	90	<1	1200	<2	960	46	<5	3470	49	<1	4	60	<40
*	S-58-05	450	3700	210	<1	1400	2	1810	139	<5	5050	138	<1	9	140	<40
*	S-59-05	910	4400	490	<1	1200	11	2400	119	<5	3120	362	<1	29	100	<40
*	S-60-05	530	3600	340	<1	1300	6	4450	63	<5	1860	153	<1	13	160	<40
*	S-61-05	280	5400	130	<1	1200	<2	1070	24	<5	3410	93	<1	7	50	<40

Table A2 (cont.): LOI (%) and metal concentrations (mg/kg) in soil. See Table A1 for site locations.

Parameter	Units	D.L.	S-29-05	S-49-05	S-51-05	S-52-05	S-53-05	S-54-05	S-55-05	S-56-05	S-57-05	S-58-05	S-59-05	S-60-05	S-61-05
LOI	%	0	5.9	15.7	12.9	10.6	6.6	5.8	11.2	10.4	6.1	7.6	15.5	15.2	5.8
2378 TeCDD	pg/g	0.1	<0.10	<0.15	<0.50	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
12378 PeCDD	pg/g	0.1	<0.10	1.4	0.5	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
123478 HxCDD	pg/g	0.1	0.28	0.92	0.51	<0.10	1.5	0.96	<0.10	<0.10	<0.10	2.3	<0.10	0.94	<0.10
123678 HxCDD	pg/g	0.1	0.49	2.8	1.1	<0.10	1.2	3.1	0.56	1	0.87	2.1	0.78	0.83	0.57
123789 HxCDD	pg/g	0.1	0.33	3.5	0.87	<0.10	<0.10	1.6	<0.10	0.69	0.4	1.2	<0.10	0.61	0.32
1234678 HpCDD	pg/g	0.1	18	51	15	8.2	20	130	18	32	43	120	20	17	20
OCDD	pg/g	0.1	160	220	70	64	150	960	120	370	460	1000	180	110	190
Total TCDD	pg/g	0.1	<0.10	<0.50	<0.50	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Total PeCDD	pg/g	0.1	<0.10	10	0.5	<0.10	<0.10	1.6	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Total HxCDD	pg/g	0.1	4.8	37	11	4	5.6	29	3	8.4	7.5	16	6.9	7.9	5.4
Total HpCDD	pg/g	0.1	32	88	26	15	34	230	29	54	80	210	37	29	37
TOTAL PCDDs	pg/g	0.1	190	350	110	83	190	1200	150	430	550	1300	230	150	240
2378 TeCDF	pg/g	0.1	<0.10	<0.50	<0.50	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
12378 PeCDF	pg/g	0.1	<0.10	<0.50	<0.50	0.4	0.57	0.54	0.33	2.7	<0.10	0.47	<0.10	0.58	0.84
23478 PeCDF	pg/g	0.1	0.38	<0.50	0.56	0.34	0.16	0.85	<0.10	0.49	<0.10	0.29	<0.10	0.28	0.31
123478 HxCDF	pg/g	0.1	0.91	0.63	0.95	0.2	0.25	1.2	<0.10	0.79	<0.10	0.45	0.42	0.44	0.17
123678 HxCDF	pg/g	0.1	0.33	0.58	0.76	0.52	0.45	1.3	0.36	3.1	0.41	0.66	0.43	0.73	0.65
123789 HxCDF	pg/g	0.1	0.14	<0.50	<0.50	<0.10	<0.10	0.33	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
234678 HxCDF	pg/g	0.1	0.46	0.8	0.93	0.36	0.3	1.6	0.22	0.6	0.3	0.68	0.5	0.51	0.42
1234678 HpCDF	pg/g	0.1	5.5	7.5	7.3	3.5	5.1	18	3.1	9.6	7.4	19	6.6	4.4	7
1234789 HpCDF	pg/g	0.1	0.24	<0.50	<0.50	<0.10	<0.10	1.1	<0.10	0.52	0.43	1	<0.10	0.41	<0.10
OCDF	pg/g	0.1	7.6	7.2	2.9	4.4	9.7	27	4.2	14	17	59	11	5.6	12
Total TCDF	pg/g	0.1	0.99	<0.50	<0.50	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Total PeCDF	pg/g	0.1	1	3.1	1.7	1	0.73	4	0.32	7.4	<0.10	1.6	<0.10	0.91	1.4
Total HxCDF	pg/g	0.1	4	6.3	6.1	3.3	3.3	13	1.8	8.2	3	7	4.8	3.7	4.5
Total HpCDF	pg/g	0.1	12	13	8.4	6	12	31	5.5	17	18	46	12	7.6	14
TOTAL PCDFs	pg/g	0.1	26	30	19	15	25	75	12	46	38	110	28	18	31
Total TEQ (ND=0)	pg/g	0.1	0.7	3.2	1.6	0.4	0.7	3	0.4	1.5	0.8	2.4	0.5	0.8	0.7
Total TEQ (ND=0.5DL)	pg/g	0.1	0.8	3.3	1.6	0.5	0.9	3.1	0.5	1.6	0.9	2.6	0.6	0.9	0.8
Total TEQ (ND=DL)	pg/g	0.1	1	3.3	1.7	0.7	1	3.2	0.7	1.7	1	2.7	0.8	1	0.9

Table A3: PCCD/Fs concentrations in soil. D.L. = detection limit. See Table A1 for site locations.

Parameter	Units	D.L.	S-29-05	S-49-05	S-51-05	S-52-05	S-53-05	S-54-05	S-55-05	S-56-05	S-57-05	S-58-05	S-59-05	S-60-05	S-61-05
Naphthalene	mg/kg	0.01	0.02	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	0.02	<0.01	0.02	<0.01	<0.01	<0.01
Methyl naphthalenes	mg/kg	0.01	0.04	<0.01	<0.01	0.04	<0.01	<0.01	<0.01	0.04	<0.01	0.02	<0.01	<0.01	<0.01
Acenaphthylene	mg/kg	0.01	0.07	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.08	<0.01	0.06	<0.01	<0.01	<0.01
Acenaphthene	mg/kg	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fluorene	mg/kg	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Phenanthrene	mg/kg	0.01	0.2	<0.01	<0.01	0.05	<0.01	0.02	<0.01	0.28	<0.01	0.48	0.03	<0.01	<0.01
Anthracene	mg/kg	0.01	0.05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.07	<0.01	0.11	<0.01	<0.01	<0.01
Fluoranthene	mg/kg	0.01	0.48	0.01	0.02	0.11	0.04	0.09	0.03	0.53	0.03	1.3	0.1	0.01	0.03
Pyrene	mg/kg	0.01	0.49	0.01	0.02	0.12	0.05	0.08	0.02	0.5	0.03	1.3	0.09	<0.01	0.02
Benzo(a)anthracene	mg/kg	0.01	0.36	<0.01	0.02	0.13	0.07	0.07	0.02	0.31	0.03	0.86	0.07	<0.01	0.02
Chrysene	mg/kg	0.01	0.28	0.01	0.01	0.06	0.04	0.05	0.01	0.31	0.02	0.81	0.06	<0.01	0.02
Benzo(b)fluoranthene	mg/kg	0.01	0.45	0.02	0.02	0.14	0.06	0.06	0.02	0.63	0.03	1.1	0.11	0.02	0.04
Benzo(k)fluoranthene	mg/kg	0.01	0.14	<0.01	0.01	0.04	0.03	0.02	<0.01	0.17	<0.01	0.41	0.04	<0.01	0.02
Benzo(a)pyrene	mg/kg	0.01	0.31	<0.01	0.01	0.08	0.05	0.05	0.02	0.38	0.02	0.76	0.07	<0.01	0.02
Indeno(1,2,3-cd)pyrene	mg/kg	0.01	0.21	<0.01	<0.01	0.04	0.04	0.03	<0.01	0.26	0.01	0.43	0.03	<0.01	<0.01
Dibenzo(a,h)anthracene	mg/kg	0.01	0.06	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	0.06	<0.01	0.09	<0.01	<0.01	<0.01
Benzo(g,h,i)perylene	mg/kg	0.01	0.19	<0.01	<0.01	0.04	0.03	0.05	<0.01	0.18	<0.01	0.29	0.03	<0.01	0.01

Table A4: PAH concentrations in soil. D.L. = detection limit. See Table A1 for site locations.

GIS ID	GIS code	Location	Easting	Northing
1	W-1-05	5 Hidden Cove Lane, Hamilton Parish	553772.0	138233.8
2	W-2-05	18 Vesey Street, DV 05	549809.0	134532.0
3	W-3-05	Muriette Rear Apt., 52 Roberts Ave., Devonshire Parish, Hm 15	547839.5	133506.1
4	W-4-05	1 Cavello Heights, Somerset, Sandy's Parish	539246.0	133053.0
5	W-5-05	"Doll Clair", 14 Foothills Road, Devonshire, DV 05	549720.6	134656.6
6	W-6-05	"NorthLyn Cottage", 96 North Shore Road, Devonshire, FL 03	549760.0	134854.9
7	W-7-05	Philobie, 3 Park View Lane, Devonshire, DV 03	548236.0	132963.0
9	W-9-05	6 Loyal Hill Road, Devonshire, DV 05	549583.4	134717.3
10	W-10-05	24 Railway Trail, Devonshire, DV 05	549552.7	134627.8
11	W-11-05	"Palmetto House", 74 North Shore Rd, Devonshire	549055.0	134445.0
13	W-13-05	44 North Shore Road, DV 05	548306.6	134158.2
14	W-14-05	2 Morning Glory, Devonshire Parish, DV06	550057.0	133984.0
15	W-15-05	40 Scott's Hill Road, Somerset Village, Sandy's Parish	538989.0	133015.0
17	W-17-05	8 North Shore Road, Devonshire, DV 01	547691.0	134067.0
18	W-18-05	4 Dock Hill, Devonshire, DV 01	547865.1	134067.6
19	W-19-05	"The Tamarind", 10 Parson's Lane, DV 02	548444.9	133865.5
20	W-20-05	"Burford", 39 Orange Valley Road, Devonshire, DV 02	548613.0	133647.0
21	W-21-05	27 Orange Valley, Devonshire, DV 02	548759.0	133469.9
23	W-23-05	Glen Nook, 1 Junction Lane, Devonshire, DV 01	548017.4	133917.2
24	W-24-05	33 St. Monica's Road, Pembroke Parish, HM 14	547160.0	133742.0
25	W-25-05	100 North Shore Rd, Devonshire, DV01	549776.0	134878.0
26	W-26-05	7 Middle Pk Lane, Pembroke	545735.9	133628.0
27	W-27-05	"Tarry Here", 26 Berry Hill Road, Paget, DV 04	549067.3	132636.8
28	W-28-05	"In-a-bush", 45 Berry Hill Road, Paget, DV 03	548899.0	132626.1
30	W-30-05	9 West Park Lane, Hamilton Parish, HM 07	545676.5	133717.4
31	W-31-05	"Dunroven", 14 Happy Valley Road, Pembroke, HM 19	547590.9	132841.7
32	W-32-05	12 Happy Valley Road, Pembroke Parish, HM 19	547749.3	132617.5
34	W-34-05	"Sunnyvale", 35 Middle Road, Devonshire, DV 06	549145.1	133197.7
36	W-36-05	2 Store Hill, Smith's Parish	550199.6	135172.8
37	W-37-05	"Gondora", 30 Brighton Hill Road, DV 07	549798.3	133605.5
38	W-38-05	"Hibiscus Cottage", 15 Watlington Road East, DV 06	549888.1	133874.8
41	W-41-05	11 St. John's Road, Pembroke	544963.0	133650.0
42	W-42-05	7 Border Dell, Devonshire, FL 02	550341.3	134368.8
43	W-43-05	1 Steeple Road, Smith's, FL 06	551552.3	134887.8
44	W-44-05	"Carmel", 6 Store Hill, Smith's Parish, FL 03	550239.0	135148.0
45	W-45-05	"Hy-Lyn View", 2 Cameron Close, Smith's, FL 03	550001.1	135017.0
46	W-46-05	Boden House, 2 Ridgeway Road, Pembroke	545790.6	133794.5
47	W-47-05	13 Middle Town Road, Pembroke Parish, HM 17	547374.5	133053.2
48	W-48-05	2nd Fl. Apt. West, 26 Vesey Street, DV 05	549702.0	134460.0
49	W-49-05	"Bocage", 1 Berry Hill Close, Paget Parish, DV 03	549021.0	132673.6
50	W-50-05	2 Clay Court, Hamilton Parish, CR 03	552414.9	138265.0
51	W-51-05	"Turnview", 3 Valley View Crescent, Hamilton Parish, CR 03	552223.7	138169.7
52	W-52-05	19 Cottage Hill Road West, Hamilton Parish	551899.4	138110.5
53	W-53-05	1 Cottage Hill Lane, Hamilton Parish, CR 03	551980.9	137973.9
56	W-56-05	"Somers Cottage", 21 Somers Hill Road, Hamilton Parish, FL 04	551082.0	136345.0
57	W-57-05	"Sanderling", 28 Pompano Beach Road, Southhampton Parish, SB 03	538133.5	129271.5
58	W-58-05	"Hillaire", 12 Lolly's Well Road, Smith's Parish, FL 08	551795.7	135515.5
59	W-59-05	4 Queen's Lane, Smith's, FL 07	552230.8	135518.9
60	W-60-05	11 Oleander Hill, Smith's, FL 08	552399.6	135576.3
61	W-61-05	4 Cherry Dale, Smith's	552739.0	135171.0
62	W-62-05	"The Loquats", 2 Tribe Road No.6, Sandy's, SB 03	538300.4	129891.8
63	W-63-05	"Pentana", 3 Long Lane, Hamilton Parish, HS 02	554664.0	136583.0
64	W-64-05	18 Salthouse Lane, Smith's Parish	552313.0	135264.0
66	W-66-05	"Looking Stead", 16 South Road, Hamilton Parish	554314.2	136105.6
67	W-67-05	7 Colony Valley, Southampton, SN 04	543074.1	128830.8
69	W-69-05	"Bay Villa Cottage", 15 Daniels Head Road, Sandy's. MA 03	538405.0	133588.0
70	W-70-05	"Tamarlane", 8 Tamarind Vale, Warwick, WK 05	544132.7	129608.4
71	W-71-05	"Harrinstead", 18 Lemon Grove Road, Hamilton Parish, CR 01	551342.8	136828.4
72	W-72-05	22 Tribe Road No.1, Warwick Parish, WK 10	546085.8	129983.5
74	W-74-05	"Winkit Villa" 68 Railway Trail, Somerset, Sandy's Parish	538366.0	131148.0
75	W-75-05	4 Ashwood Lane, Smith's Parish, HS 01	553307.2	135521.5
76	W-76-05	6 Collector's Hill, Smiths Parish, MA 02	539041.9	133372.4
77	W-77-05	"Ackbar 11", 4 Ferry Close, St. George's Parish, GE 01	554419.6	140875.7
78	W-78-05	"Far East", 38 Cove Valley Road, St. David's, St. George's Parish, D	559447.5	140416.9
79	W-79-05	5 Anchorage View Lane, Ferry Reach, St. George	554409.3	141191.3
80	W-80-05	"Dimensions", 8 Lighthouse Road, Southampton, SN 02	542330.8	128258.5
81	W-81-05	12 Coot Pond Road, St. George, St. George's Parish, GE 03	556804.9	143053.0
82	W-82-05	"Little Harbour", 10 Channel View Lane, Hamilton Parish, CR 02	551249.7	137917.3
83	W-83-05	8 Chapel of Ease Road, St. David's, St. George's Parish	557846.8	140749.6
84	W-84-05	18 Emily's Bay Lane, St. David's, St. George's Parish	557390.4	140931.8
85	W-85-05	18 Town Hill Road, Flatts, Smith's Parish	551596.4	135422.7
86	W-86-05	3 Sandtrap Hill, Sandys, MA 04	538606.1	132677.6
87	W-87-05	81 Somerset Road, Somerset, Sandy's Parish	538300.8	132486.8
88	W-88-05	"Battery Mews", 2 Slippery Hill, St. George's Parish, GE 03	557156.7	142570.8
89	W-89-05	23 Wellington Back Road, St. George's Parish, GE 03	555756.5	142139.6
90	W-90-05	10 Jennings Bay Road, Southampton, SB 04	539215.3	128593.8
91	W-91-05	"Whale View", 23 Lighthouse Road, Southampton, SN 02	542150.5	127790.2
92	W-92-05	11 Shinbone Alley, St. George's Parish	557036.0	142422.1
93	W-93-05	"Portasee", 99 Middle Road, Southampton, SN 01	540290.0	128113.0
95	W-95-05	6 Beaming Hill, Southampton, SN 02	542183.4	127848.9
96	W-96-05	17 Seymour Farm Road, Southampton	540734.7	127939.2
97	W-97-05	"On the Rocks", 6 Sunny Lane, St. George's Parish, GE 04	557799.0	142262.9
98	W-98-05	6 Easedale Lane, Warwick Parish, WK 10	546125.1	130094.6
99	W-99-05	24 Narrows Lane, St. David's, St. George's Parish	557880.1	140920.7
113	W-113-05	22 Vesey Street, Devonshire Parish	549752.7	549752.7
122	W-122-05	#4 Tranquility Lane, St. David's, St. George's Parish	557776.9	557776.9
125	W-125-05	71 Spice Hill Rd., Warwick Parish	544603.4	544603.4
126	W-126-05	5 Sound View Rd., Somerset, Sandy's Parish	539482.6	539482.6
127	W-127-05	9 Shore Hills Lane, St. George's Parish	555041.1	555041.1
131	W-131-05	16 Chapel of Ease Lane, St. George's Parish	557963.8	557963.8
134	W-134-05	7 Aubrey Rd, Hamilton Parish	551819.2	551819.2
135	W-135-05	Big Wind 1, BBSR, St. George's Parish	555087.9	141163.6
136	W-136-05	7 Long Bay Lane, Somerset, Sandy's Parish	538378.0	133506.0
137	W-137-05	21 Oleander Hill, Smith's Parish	552499.2	135641.6
145	W-145-05	56 Middle Rd. Devonshire DV	548624.0	132928.0
146	W-146-05	20 Lookout Lane	548269.0	134128.0
147	W-147-05	49 North Shore Rd	548583.0	134334.0
148	W-148-05	37 Palmetto Rd. - Child Centre	548229.0	134208.0
149	W-149-05	6 Aeolia Dr - Old Family center	548372.0	134083.0
150	W-150-05	24 Orange Valle Lane "The Grove"	548748.0	133686.0
151	W-151-05	10 Frog Lane	548054.0	133783.0
152	W-152-05	26 North Shore Rd	547989.0	134084.0
153	W-153-05	22 Alexandra Road	548581.0	133341.0
154	W-154-05	24 Jubilee Road	549061.0	133573.0
155	W-155-05	1 Watlington Lane N (Side Closest to Jubilee Road)	549059.0	133669.0
156	W-156-05	14 Lightbourne Lane, Smith's Parish, FL02	550687.0	134309.0
157	W-157-05	49 Orchard Drive, Southampton Parish, SN02	541564.0	127769.0
158	W-158-05	6 Southlyn Lane, Paget Parish	547403.0	131162.0
159	W-159-05	2 Stonehaven Road, FL04, Hamilton Parish	550978.0	136635.0
160	W-160-05	15 Keith Hall Road	545487.0	130781.0
161	W-161-05	1 Leafy Way, Paget Parish, DV03	549148.0	132800.0
162	W-162-05	70 Railway Trail, Somerset, Sandy's Parish	538366.0	131148.0

Table A5: Water tank sampling sites – GIS codes, locations and grid coordinates.

Dist	GIS Code	pH	Cond	Cl-	NO3-	SO4 2-	Ca	K	Mg	Na
< 1 km	W-1-05	7.88	76	8.7	1.1	3.8	11.5	0.4	0.8	4.0
< 1 km	W-2-05	9.53	240	48.7	33.1	22.5	17.4	7.2	2.3	30.0
< 1 km	W-3-05	7.82	104	20.2	1.3	9.4	14.7	0.4	0.7	8.0
< 1 km	W-5-05	7.87	68	8.5	0.7	4.2	9.9	0.2	0.6	4.0
< 1 km	W-6-05	7.78	95	18.8	1.1	5.6	11.7	0.6	1.4	8.0
< 1 km	W-7-05	7.86	292	89.0	13.4	23.8	26.4	1.6	3.8	28.0
< 1 km	W-9-05	8.42	80	11.6	1.0	5.1	10.9	0.4	1.0	5.0
< 1 km	W-10-05	7.58	92	18.8	0.6	10.7	12.8	0.7	0.6	8.0
< 1 km	W-11-05	7.79	148	13.8	0.6	5.2	23.3	0.3	0.9	6.0
< 1 km	W-13-05	8.20	59	10.5	1.2	4.7	7.8	0.2	0.6	5.0
< 1 km	W-14-05	7.84	82	12.9	0.9	4.6	12.9	0.5	1.0	6.0
< 1 km	W-17-05	7.84	192	28.8	10.5	12.2	22.4	1.1	2.4	14.0
< 1 km	W-18-05	7.89	93	17.3	1.1	11.3	10.7	0.6	1.3	8.0
< 1 km	W-19-05	7.66	86	9.1	0.4	4.6	11.7	0.2	0.9	4.0
< 1 km	W-20-05	7.75	60	4.9	0.3	2.9	12.0	<0.1	0.5	2.0
< 1 km	W-21-05	7.67	100	5.7	0.6	3.7	19.5	0.3	0.8	3.0
< 1 km	W-23-05	8.36	106	11.4	1.7	6.4	12.9	2.0	0.9	7.0
< 1 km	W-24-05	7.81	111	18.6	2.0	9.8	16.7	0.6	1.0	7.0
< 1 km	W-113-05	7.93	103	22.4	1.4	11.2	11.6	0.3	0.7	11.0
< 1 km	W-146-05	7.76	67	0.7	<0.3	<2.2	10.0	0.7	0.5	7.0
< 1 km	W-147-05	7.84	73	17.1	2.8	5.3	9.0	0.6	1.0	8.0
< 1 km	W-148-05	8.62	71	5.3	1.1	2.6	5.7	0.2	0.3	3.0
< 1 km	W-149-05	7.78	64	7.9	1.3	3.4	10.2	0.7	0.6	4.0
< 1 km	W-150-05	7.24	81	520.2	8.1	19.0	12.0	0.8	1.0	5.0
< 1 km	W-151-05	7.32	78	11.8	1.0	5.2	11.6	0.2	1.0	6.0
< 1 km	W-152-05	7.32	44	7.8	1.4	2.2	5.4	0.5	0.5	4.0
< 1 km	W-153-05	8.93	62	12.5	1.3	3.7	8.2	0.6	0.4	5.0
< 1 km	W-154-05	8.61	n.a.	9.6	0.6	4.2	49.7	1.9	0.8	98.0
< 1 km	W-155-05	6.93	36	5.7	2.3	2.2	5.6	0.4	0.5	3.0
< 2 km	W-25-05	7.70	170	34.3	1.2	11.8	14.3	1.0	2.6	15.0
< 2 km	W-26-05	7.77	117	19.2	2.6	11.1	12.9	0.8	1.6	9.0
< 2 km	W-27-05	7.73	92	9.1	0.5	4.1	14.5	0.2	0.8	4.0
< 2 km	W-28-05	7.58	110	16.3	1.9	7.9	15.9	0.7	1.4	8.0
< 2 km	W-31-05	7.52	107	20.3	3.2	15.7	15.3	0.5	0.5	10.0
< 2 km	W-32-05	7.64	116	18.7	2.9	9.7	15.0	0.6	0.9	10.0
< 2 km	W-34-05	7.60	56	6.9	0.5	5.4	8.0	0.3	1.1	3.0
< 2 km	W-36-05	7.69	98	12.6	1.0	5.4	12.6	0.6	1.2	6.0
< 2 km	W-37-05	7.73	72	10.2	1.4	5.8	10.6	0.5	1.1	5.0
< 2 km	W-38-05	8.18	323	42.6	58.5	24.9	43.8	3.7	2.5	25.0
< 2 km	W-41-05	7.44	480	91.3	111.7	51.0	50.7	5.9	5.3	36.0
< 2 km	W-42-05	7.79	82	10.1	1.5	7.7	10.7	0.6	0.7	5.0
< 2 km	W-43-05	7.97	114	19.3	2.1	10.0	10.5	2.8	1.3	10.0
< 2 km	W-44-05	7.61	99	15.9	2.0	5.2	14.0	0.6	1.3	7.0
< 2 km	W-45-05	8.95	104	18.8	1.9	13.6	12.0	0.5	0.5	8.0
< 2 km	W-46-05	7.56	106	17.1	1.4	7.3	14.1	0.5	1.3	7.0
< 2 km	W-47-05	7.69	216	38.4	8.7	15.5	20.9	1.3	2.8	18.0
< 2 km	W-48-05	8.09	127	12.0	1.4	6.8	17.2	1.1	1.2	8.0
< 2 km	W-49-05	7.59	106	9.8	0.4	4.6	16.9	<0.1	0.8	4.0
< 2 km	W-158-05	7.72	101	18.0	1.2	8.0	14.3	0.8	1.1	9.0
< 2 km	W-161-05	7.70	90	16.7	1.6	6.0	13.2	0.3	1.0	6.0

Table A6: pH, conductivity (µS) and major ion concentrations (mg/L) in water samples located < 1 km and < 2 km from TBWTF. See Table A5 for site locations.

Dist	GIS Code	pH	Cond	Cl-	NO3-	SO4 2-	Ca	K	Mg	Na
> 2 km	W-30-05	7.90	104	7.8	1.0	4.7	15.1	0.1	1.0	5.0
> 2 km	W-4-05	7.81	98	10.5	1.2	4.9	13.1	0.9	1.0	6.0
> 2 km	W-15-05	8.08	202	31.9	6.7	4.0	9.4	1.1	0.7	35.0
> 2 km	W-50-05	7.58	125	25.9	1.4	9.4	13.9	0.4	0.6	15.0
> 2 km	W-51-05	7.65	70	7.9	1.2	2.7	9.6	0.2	0.4	4.0
> 2 km	W-52-05	7.53	81	6.8	0.3	3.0	10.2	0.3	0.8	5.0
> 2 km	W-53-05	7.87	266	39.4	16.8	17.8	30.4	1.9	3.1	21.0
> 2 km	W-56-05	7.61	98	15.9	0.8	12.7	13.6	0.5	0.6	8.0
> 2 km	W-57-05	7.83	92	8.6	0.8	2.9	12.9	0.4	0.8	5.0
> 2 km	W-58-05	7.85	116	10.9	1.1	8.0	13.7	0.2	2.0	7.0
> 2 km	W-59-05	7.97	147	23.4	6.7	9.7	11.0	10.4	1.3	15.0
> 2 km	W-60-05	8.15	60	6.8	1.1	2.9	8.4	0.4	0.3	3.0
> 2 km	W-61-05	7.79	98	10.6	0.8	3.8	12.8	0.4	0.8	7.0
> 2 km	W-62-05	8.01	129	13.2	0.4	4.1	19.8	0.9	1.0	8.0
> 2 km	W-63-05	7.64	63	7.3	0.9	2.5	7.3	<0.1	0.6	4.0
> 2 km	W-64-05	7.62	73	7.4	0.9	5.4	10.6	0.3	1.3	4.0
> 2 km	W-66-05	7.20	153	36.8	0.8	9.6	7.8	1.0	1.9	18.0
> 2 km	W-67-05	7.53	67	8.4	0.9	5.1	10.5	0.3	0.6	4.0
> 2 km	W-69-05	7.45	81	11.7	1.5	4.5	14.5	0.8	1.0	7.0
> 2 km	W-70-05	7.90	79	15.9	0.9	4.4	11.1	0.5	0.7	7.0
> 2 km	W-71-05	7.83	67	11.8	1.3	4.3	7.6	0.2	0.6	5.0
> 2 km	W-72-05	7.54	74	12.1	2.2	5.3	10.9	0.4	1.0	6.0
> 2 km	W-74-05	7.82	104	9.6	1.2	3.6	16.4	0.5	0.9	5.0
> 2 km	W-75-05	7.55	95	12.3	2.1	11.1	12.6	1.1	1.1	7.0
> 2 km	W-76-05	8.16	2320	916.8	146.0	236.3	121.0	24.9	46.8	391.0
> 2 km	W-77-05	7.68	79	11.5	0.9	5.2	11.0	0.4	0.8	5.0
> 2 km	W-78-05	8.99	143	41.1	1.8	10.2	7.6	2.8	1.7	20.0
> 2 km	W-79-05	7.49	155	37.8	1.1	9.8	12.1	1.3	2.0	18.0
> 2 km	W-80-05	7.85	67	9.5	1.0	3.1	8.9	0.3	0.8	5.0
> 2 km	W-81-05	7.54	101	25.6	1.0	5.2	9.3	0.7	1.0	13.0
> 2 km	W-82-05	8.10	93	20.1	2.4	6.6	9.0	2.6	0.7	10.0
> 2 km	W-83-05	7.70	80	13.4	1.1	6.3	12.4	0.4	0.6	6.0
> 2 km	W-84-05	7.94	153	23.6	3.5	6.7	17.2	5.8	1.3	13.0
> 2 km	W-85-05	7.37	85	10.4	1.5	7.9	11.7	0.5	0.6	7.0
> 2 km	W-86-05	7.63	116	15.7	3.9	5.0	11.7	0.8	1.4	9.0
> 2 km	W-87-05	7.66	104	16.1	1.9	7.1	12.8	0.6	1.0	7.0
> 2 km	W-88-05	8.05	303	91.3	1.4	23.4	14.1	2.1	5.0	47.0
> 2 km	W-89-05	7.53	91	18.0	0.8	6.4	10.8	0.4	1.0	7.0
> 2 km	W-90-05	8.01	65	8.4	1.1	2.8	7.8	0.4	0.6	5.0
> 2 km	W-91-05	7.58	96	17.4	1.4	7.0	9.7	0.6	1.2	7.0
> 2 km	W-93-05	7.65	92	9.1	1.0	4.2	10.9	0.5	1.4	8.0
> 2 km	W-92-05	7.75	116	11.4	3.8	7.4	20.3	0.5	0.9	6.0
> 2 km	W-95-05	8.31	141	22.1	1.3	12.9	17.1	0.7	1.1	11.0
> 2 km	W-96-05	7.95	100	17.6	0.9	10.1	13.1	0.5	1.3	7.0
> 2 km	W-97-05	7.94	104	11.8	0.6	4.9	13.4	0.3	1.1	7.0
> 2 km	W-98-05	7.70	95	11.9	1.1	6.1	12.4	0.5	1.0	5.0
> 2 km	W-99-05	7.75	73	14.2	1.3	4.2	9.4	0.5	0.7	6.0
> 2 km	W-122-05	7.93	79	10.0	0.9	5.2	11.8	0.5	0.7	5.0
> 2 km	W-125-05	7.68	69	13.7	2.0	4.6	8.5	0.3	0.6	6.0
> 2 km	W-126-05	7.37	103	22.7	3.2	7.8	8.9	1.5	1.4	11.0
> 2 km	W-127-05	8.54	99	15.2	1.8	10.8	16.0	0.8	1.3	7.0
> 2 km	W-131-05	8.05	80	10.8	0.8	4.9	12.2	0.4	0.8	5.0
> 2 km	W-134-05	7.98	142	32.8	3.6	7.6	10.9	1.7	1.0	19.0
> 2 km	W-135-05	7.64	67	7.9	0.5	3.1	9.0	0.3	0.9	4.0
> 2 km	W-136-05	7.54	97	12.8	4.6	7.3	14.5	1.1	1.7	5.0
> 2 km	W-137-05	7.43	84	6.0	0.4	4.5	11.1	0.5	0.8	4.0
> 2 km	W-145-05	7.52	67	6.4	1.3	6.8	9.1	0.6	0.6	4.0
> 2 km	W-157-05	7.49	77	12.6	1.1	4.5	9.4	0.6	0.7	6.0
> 2 km	W-156-05	7.50	120	20.6	6.1	9.1	15.2	1.1	1.3	10.0
> 2 km	W-159-05	7.81	165	29.8	2.6	8.5	16.0	0.5	0.9	20.0
> 2 km	W-160-05	7.87	74	9.2	1.1	4.5	12.2	0.4	0.7	4.0
> 2 km	W-162-05	7.97	96	9.8	1.2	4.2	12.7	0.9	0.8	6.0

Table A7: pH, conductivity (µS) and major ion concentrations (mg/L) in water samples located >2 km from TBWTF. See Table A5 for site locations.

Dist	GIS Code	Fe	Mn	Ag	Al	As	B	Ba	Be	Bi	Cd	Co	Cr	Cu
< 1 km	W-1-05	0.005	<0.001	<0.0004	0.220	<0.0004	<0.02	0.003	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
< 1 km	W-2-05	0.023	<0.001	<0.0004	0.100	<0.0004	0.02	0.008	<0.001	<0.0001	<0.0002	<0.0002	0.0027	<0.001
< 1 km	W-3-05	<0.005	0.001	<0.0004	0.080	<0.0004	<0.02	0.004	<0.001	0.0001	<0.0002	<0.0002	0.0011	<0.001
< 1 km	W-5-05	0.008	<0.001	<0.0004	0.100	<0.0004	<0.02	0.004	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
< 1 km	W-6-05	0.024	0.001	<0.0004	0.180	0.0005	<0.02	0.006	<0.001	<0.0001	<0.0002	<0.0002	0.0022	<0.001
< 1 km	W-7-05	0.009	<0.001	<0.0004	0.050	<0.0004	0.03	0.003	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
< 1 km	W-9-05	0.067	0.002	<0.0004	0.220	<0.0004	<0.02	0.003	<0.001	<0.0001	<0.0002	<0.0002	0.0009	<0.001
< 1 km	W-10-05	<0.005	<0.001	<0.0004	0.100	<0.0004	<0.02	0.001	<0.001	<0.0001	<0.0002	<0.0002	0.0020	<0.001
< 1 km	W-11-05	0.061	0.001	<0.0004	0.040	0.0005	<0.02	0.004	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	0.004
< 1 km	W-13-05	0.005	<0.001	<0.0004	0.250	<0.0004	<0.02	0.008	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
< 1 km	W-14-05	0.022	0.001	0.0005	0.100	<0.0004	<0.02	0.005	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	0.008
< 1 km	W-17-05	0.024	<0.001	<0.0004	0.130	<0.0004	<0.02	0.004	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
< 1 km	W-18-05	<0.005	<0.001	<0.0004	0.140	<0.0004	<0.02	0.003	<0.001	<0.0001	<0.0002	<0.0002	0.0024	<0.001
< 1 km	W-19-05	0.008	0.001	<0.0004	0.080	<0.0004	<0.02	0.003	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
< 1 km	W-20-05	0.007	0.001	<0.0004	0.130	<0.0004	<0.02	0.004	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
< 1 km	W-21-05	0.013	0.001	<0.0004	0.130	<0.0004	<0.02	0.007	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
< 1 km	W-23-05	0.019	<0.001	<0.0004	0.180	<0.0004	<0.02	0.004	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
< 1 km	W-24-05	0.069	0.001	<0.0004	0.060	<0.0004	<0.02	0.007	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	0.074
< 1 km	W-113-05	0.005	<0.001	<0.0004	0.160	<0.0004	<0.02	0.002	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
< 1 km	W-146-05	0.008	<0.001	<0.0004	0.030	<0.0004	0.03	0.003	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	0.002
< 1 km	W-147-05	0.012	<0.001	<0.0004	0.060	<0.0004	<0.02	0.003	<0.001	<0.0001	<0.0002	<0.0002	0.0009	<0.001
< 1 km	W-148-05	<0.005	<0.001	<0.0004	0.050	<0.0004	<0.02	0.003	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
< 1 km	W-149-05	<0.005	<0.001	<0.0004	0.180	<0.0004	<0.02	0.002	<0.001	<0.0001	<0.0002	<0.0002	0.0014	<0.001
< 1 km	W-150-05	0.010	<0.001	<0.0004	0.100	<0.0004	0.02	0.005	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	0.004
< 1 km	W-151-05	<0.005	<0.001	<0.0004	0.120	<0.0004	<0.02	0.002	<0.001	<0.0001	<0.0002	<0.0002	0.0013	<0.001
< 1 km	W-152-05	0.011	0.001	<0.0004	<0.02	<0.0004	<0.02	0.002	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	0.001
< 1 km	W-153-05	0.035	0.001	0.0005	0.030	<0.0004	<0.02	0.005	<0.001	<0.0001	<0.0002	<0.0002	0.0012	0.003
< 1 km	W-154-05	0.049	0.002	<0.0004	0.160	0.0010	<0.02	0.008	<0.001	<0.0001	<0.0002	<0.0002	0.0033	0.004
< 1 km	W-155-05	0.005	<0.001	<0.0004	0.030	<0.0004	<0.02	0.004	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	0.001
< 2 km	W-25-05	0.006	<0.001	<0.0004	0.190	<0.0004	<0.02	0.003	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	0.001
< 2 km	W-26-05	<0.005	<0.001	<0.0004	0.070	<0.0004	<0.02	0.011	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
< 2 km	W-27-05	0.009	0.001	<0.0004	0.130	<0.0004	<0.02	0.003	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
< 2 km	W-28-05	0.023	<0.001	<0.0004	0.210	<0.0004	<0.02	0.005	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
< 2 km	W-31-05	0.024	0.001	<0.0004	0.180	<0.0004	<0.02	0.004	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	0.001
< 2 km	W-32-05	0.009	0.001	<0.0004	0.060	<0.0004	<0.02	0.005	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	0.002
< 2 km	W-34-05	0.009	0.001	<0.0004	0.060	<0.0004	<0.02	0.004	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
< 2 km	W-36-05	<0.005	<0.001	<0.0004	0.150	<0.0004	<0.02	0.002	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
< 2 km	W-37-05	<0.005	<0.001	<0.0004	0.150	<0.0004	<0.02	0.002	<0.001	<0.0001	<0.0002	<0.0002	0.0028	<0.001
< 2 km	W-38-05	0.046	0.002	<0.0004	0.160	<0.0004	0.06	0.004	<0.001	<0.0001	<0.0002	<0.0002	0.0011	0.002
< 2 km	W-41-05	0.061	0.004	0.0007	0.040	0.0004	0.36	0.007	<0.001	<0.0001	0.0004	<0.0002	<0.0008	0.019
< 2 km	W-42-05	<0.005	<0.001	<0.0004	0.070	<0.0004	<0.02	0.005	<0.001	<0.0001	<0.0002	<0.0002	0.0025	<0.001
< 2 km	W-43-05	<0.005	<0.001	<0.0004	0.160	<0.0004	<0.02	0.004	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
< 2 km	W-44-05	0.024	0.001	<0.0004	0.020	<0.0004	<0.02	0.002	<0.001	0.0001	<0.0002	<0.0002	0.0014	<0.001
< 2 km	W-45-05	0.016	<0.001	<0.0004	0.120	<0.0004	<0.02	0.002	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
< 2 km	W-46-05	0.007	<0.001	<0.0004	0.220	<0.0004	<0.02	0.006	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
< 2 km	W-47-05	0.006	<0.001	<0.0004	0.110	<0.0004	0.03	0.007	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	0.001
< 2 km	W-48-05	<0.005	0.001	<0.0004	0.150	<0.0004	<0.02	0.013	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
< 2 km	W-49-05	<0.005	<0.001	<0.0004	0.150	<0.0004	<0.02	0.004	<0.001	<0.0001	<0.0002	<0.0002	0.0009	<0.001
< 2 km	W-158-05	<0.005	<0.001	<0.0004	0.120	<0.0004	<0.02	0.004	<0.001	<0.0001	<0.0002	<0.0002	0.0010	<0.001
< 2 km	W-161-05	<0.005	<0.001	<0.0004	0.180	<0.0004	<0.02	0.003	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001

Table A8: Metal concentrations (mg/L) in water samples located < 1 km and < 2 km from TBWTF. See Table A5 for site locations (cont. overleaf).

Dist	GIS Code	Mo	Ni	Pb	Sb	Se	Sn	Sr	Ti	Tl	U	V	Zn	Hg
< 1 km	W-1-05	0.0001	<0.0002	<0.0001	0.001	<0.0004	<0.0004	0.110	<0.005	<0.0001	<0.0001	0.0010	0.005	<0.0002
< 1 km	W-2-05	0.0004	0.0003	0.0001	0.001	0.0011	<0.0004	0.481	<0.005	<0.0001	0.0002	0.0034	0.005	<0.0002
< 1 km	W-3-05	0.0003	<0.0002	<0.0001	0.001	<0.0004	<0.0004	0.135	<0.005	<0.0001	<0.0001	0.0031	0.005	<0.0002
< 1 km	W-5-05	<0.0001	<0.0002	<0.0001	0.001	0.0005	<0.0004	0.045	<0.005	<0.0001	<0.0001	0.0021	<0.004	<0.0002
< 1 km	W-6-05	0.0002	<0.0002	<0.0001	0.001	0.0023	<0.0004	0.073	<0.005	<0.0001	<0.0001	0.0037	0.019	<0.0002
< 1 km	W-7-05	0.0001	<0.0002	<0.0001	0.001	0.0013	<0.0004	0.570	<0.005	<0.0001	0.0003	0.0012	0.009	<0.0002
< 1 km	W-9-05	0.0011	<0.0002	0.0011	0.001	<0.0004	<0.0004	0.080	0.005	<0.0001	0.0004	0.0018	0.022	<0.0002
< 1 km	W-10-05	0.0004	<0.0002	<0.0001	0.002	0.0004	<0.0004	0.043	<0.005	<0.0001	<0.0001	0.0045	<0.004	<0.0002
< 1 km	W-11-05	0.0002	<0.0002	0.0003	0.001	<0.0004	<0.0004	0.111	<0.005	<0.0001	<0.0001	0.0037	0.014	<0.0002
< 1 km	W-13-05	<0.0001	<0.0002	0.0002	0.001	0.0004	<0.0004	0.073	<0.005	<0.0001	<0.0001	0.0040	0.005	<0.0002
< 1 km	W-14-05	<0.0001	<0.0002	0.0007	0.001	<0.0004	<0.0004	0.115	<0.005	<0.0001	<0.0001	0.0009	0.113	<0.0002
< 1 km	W-17-05	0.0002	<0.0002	0.0002	0.001	<0.0004	<0.0004	0.251	<0.005	<0.0001	0.0001	0.0020	0.014	<0.0002
< 1 km	W-18-05	0.0007	<0.0002	<0.0001	0.002	<0.0004	<0.0004	0.073	<0.005	<0.0001	<0.0001	0.0064	0.005	<0.0002
< 1 km	W-19-05	<0.0001	<0.0002	0.0002	0.001	<0.0004	<0.0004	0.080	<0.005	<0.0001	<0.0001	0.0016	<0.004	<0.0002
< 1 km	W-20-05	0.0001	<0.0002	0.0003	0.001	0.0004	<0.0004	0.048	<0.005	<0.0001	<0.0001	0.0019	0.034	<0.0002
< 1 km	W-21-05	<0.0001	<0.0002	0.0001	0.001	<0.0004	<0.0004	0.113	<0.005	<0.0001	<0.0001	0.0021	<0.004	<0.0002
< 1 km	W-23-05	0.0002	<0.0002	0.0009	0.001	<0.0004	<0.0004	0.124	<0.005	<0.0001	<0.0001	0.0036	0.016	<0.0002
< 1 km	W-24-05	0.0002	0.0004	0.0029	0.001	0.0005	0.0008	0.138	<0.005	<0.0001	<0.0001	0.0032	0.072	<0.0002
< 1 km	W-113-05	0.0002	<0.0002	<0.0001	0.001	<0.0004	<0.0004	0.064	<0.005	<0.0001	<0.0001	0.0032	<0.004	<0.0002
< 1 km	W-146-05	0.0002	0.0002	<0.0001	0.001	0.0006	<0.0004	0.063	<0.005	<0.0001	<0.0001	0.0021	0.009	0.0002
< 1 km	W-147-05	<0.0001	<0.0002	0.0003	0.001	<0.0004	<0.0004	0.088	<0.005	<0.0001	0.0002	0.0009	0.090	<0.0002
< 1 km	W-148-05	<0.0001	0.0002	0.0003	0.001	<0.0004	<0.0004	0.037	<0.005	<0.0001	<0.0001	0.0013	<0.004	<0.0002
< 1 km	W-149-05	<0.0001	<0.0002	0.0002	0.001	<0.0004	<0.0004	0.073	<0.005	<0.0001	<0.0001	0.0027	<0.004	<0.0002
< 1 km	W-150-05	0.0001	0.0006	0.0002	0.000	<0.0004	<0.0004	0.042	<0.005	<0.0001	<0.0001	0.0014	0.009	0.0005
< 1 km	W-151-05	<0.0001	<0.0002	0.0001	0.001	<0.0004	<0.0004	0.066	<0.005	<0.0001	<0.0001	0.0026	<0.004	<0.0002
< 1 km	W-152-05	<0.0001	0.0003	0.0003	0.001	0.0005	<0.0004	0.030	0.007	<0.0001	<0.0001	<0.0002	0.198	<0.0002
< 1 km	W-153-05	<0.0001	<0.0002	0.0005	0.001	<0.0004	<0.0004	0.134	<0.005	0.000	<0.0001	0.0007	0.053	0.0003
< 1 km	W-154-05	0.0008	<0.0002	0.0049	0.001	<0.0004	<0.0004	0.230	<0.005	0.000	<0.0001	0.0032	0.022	0.0003
< 1 km	W-155-05	<0.0001	<0.0002	<0.0001	0.001	<0.0004	<0.0004	0.067	<0.005	<0.0001	<0.0001	<0.0002	0.025	<0.0002
< 2 km	W-25-05	0.0005	<0.0002	0.0002	0.001	0.0005	<0.0004	0.127	<0.005	<0.0001	0.0001	0.0015	0.013	<0.0002
< 2 km	W-26-05	0.0002	<0.0002	<0.0001	0.001	0.0005	<0.0004	0.125	<0.005	<0.0001	<0.0001	0.0033	0.016	<0.0002
< 2 km	W-27-05	<0.0001	<0.0002	0.0001	0.001	<0.0004	<0.0004	0.063	<0.005	<0.0001	<0.0001	0.0012	0.011	<0.0002
< 2 km	W-28-05	0.0001	<0.0002	0.0002	0.001	<0.0004	<0.0004	0.146	<0.005	<0.0001	<0.0001	0.0020	0.012	<0.0002
< 2 km	W-31-05	0.0004	<0.0002	0.0004	0.001	<0.0004	<0.0004	0.050	<0.005	0.000	0.0002	0.0128	<0.004	<0.0002
< 2 km	W-32-05	0.0003	0.0004	0.0007	0.001	<0.0004	<0.0004	0.087	<0.005	0.000	0.0002	0.0035	0.023	<0.0002
< 2 km	W-34-05	0.0001	<0.0002	0.0010	0.001	0.0005	<0.0004	0.042	<0.005	<0.0001	<0.0001	0.0025	0.007	<0.0002
< 2 km	W-36-05	0.0002	<0.0002	0.0001	0.001	<0.0004	<0.0004	0.059	<0.005	<0.0001	<0.0001	0.0013	<0.004	<0.0002
< 2 km	W-37-05	0.0005	<0.0002	<0.0001	0.003	0.0005	<0.0004	0.122	<0.005	<0.0001	<0.0001	0.0040	<0.004	<0.0002
< 2 km	W-38-05	0.0004	0.0007	0.0005	0.001	0.0007	<0.0004	0.425	<0.005	<0.0001	0.0002	0.0024	<0.004	<0.0002
< 2 km	W-41-05	0.0006	0.0017	0.0166	0.001	<0.0004	<0.0004	1.670	<0.005	<0.0001	0.0002	0.0005	0.481	<0.0002
< 2 km	W-42-05	0.0005	<0.0002	<0.0001	0.002	<0.0004	<0.0004	0.058	<0.005	<0.0001	<0.0001	0.0042	<0.004	<0.0002
< 2 km	W-43-05	0.0002	<0.0002	<0.0001	0.001	0.0005	<0.0004	0.075	<0.005	<0.0001	<0.0001	0.0039	<0.004	<0.0002
< 2 km	W-44-05	0.0003	0.0004	0.0003	0.001	0.0004	<0.0004	0.076	<0.005	<0.0001	<0.0001	0.0016	0.035	<0.0002
< 2 km	W-45-05	0.0003	<0.0002	0.0001	0.001	0.0005	<0.0004	0.142	<0.005	<0.0001	<0.0001	0.0036	0.007	<0.0002
< 2 km	W-46-05	<0.0001	<0.0002	0.0004	0.001	<0.0004	<0.0004	0.362	<0.005	0.000	0.0002	0.0035	0.015	<0.0002
< 2 km	W-47-05	0.0002	<0.0002	0.0002	0.001	0.0009	<0.0004	0.492	<0.005	<0.0001	0.0002	0.0020	0.010	<0.0002
< 2 km	W-48-05	0.0003	<0.0002	0.0001	0.001	0.0006	<0.0004	0.541	<0.005	<0.0001	<0.0001	0.0061	0.022	<0.0002
< 2 km	W-49-05	0.0001	<0.0002	<0.0001	0.002	0.0007	<0.0004	0.098	<0.005	<0.0001	<0.0001	0.0016	<0.004	<0.0002
< 2 km	W-158-05	0.0002	<0.0002	<0.0001	0.001	0.0007	<0.0004	0.093	<0.005	<0.0001	<0.0001	0.0029	0.005	<0.0002
< 2 km	W-161-05	<0.0001	<0.0002	<0.0001	0.001	<0.0004	<0.0004	0.079	<0.005	<0.0001	<0.0001	0.0016	<0.004	<0.0002

Table A8 (cont.): Metal concentrations (mg/L) in water samples located < 1 km and < 2 km from TBWTF. See Table A5 for site locations.

Dist	GIS Code	Fe	Mn	Ag	Al	As	B	Ba	Be	Bi	Cd	Co	Cr	Cu
> 2 km	W-30-05	0.007	<0.001	<0.0004	0.170	<0.0004	<0.02	0.007	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-4-05	0.015	<0.001	<0.0004	0.170	<0.0004	<0.02	0.003	<0.001	<0.0001	<0.0002	<0.0002	0.0016	<0.001
> 2 km	W-15-05	0.012	<0.001	<0.0004	0.170	<0.0004	0.09	0.006	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	0.001
> 2 km	W-50-05	<0.005	<0.001	<0.0004	0.220	<0.0004	<0.02	0.008	<0.001	<0.0001	<0.0002	<0.0002	0.0019	<0.001
> 2 km	W-51-05	0.005	<0.001	<0.0004	0.130	<0.0004	<0.02	0.005	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-52-05	<0.005	<0.001	<0.0004	0.180	<0.0004	<0.02	0.005	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-53-05	0.026	0.001	<0.0004	0.160	<0.0004	0.05	0.009	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	0.002
> 2 km	W-56-05	0.005	<0.001	<0.0004	0.100	<0.0004	<0.02	0.003	<0.001	<0.0001	<0.0002	<0.0002	0.0009	<0.001
> 2 km	W-57-05	<0.005	<0.001	<0.0004	0.200	<0.0004	<0.02	0.002	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-58-05	0.006	<0.001	<0.0004	0.080	<0.0004	<0.02	0.002	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	0.009
> 2 km	W-59-05	<0.005	<0.001	<0.0004	0.170	0.0010	<0.02	0.004	<0.001	<0.0001	<0.0002	<0.0002	0.0027	<0.001
> 2 km	W-60-05	<0.005	<0.001	<0.0004	0.160	<0.0004	<0.02	0.008	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-61-05	0.006	<0.001	<0.0004	0.170	<0.0004	<0.02	0.005	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-62-05	0.334	0.011	<0.0004	0.690	<0.0004	<0.02	0.007	<0.001	<0.0001	<0.0002	<0.0002	0.0027	0.001
> 2 km	W-63-05	<0.005	<0.001	<0.0004	0.040	<0.0004	<0.02	0.004	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-64-05	<0.005	<0.001	<0.0004	0.060	<0.0004	<0.02	0.004	<0.001	<0.0001	<0.0002	<0.0002	0.0016	<0.001
> 2 km	W-66-05	0.047	0.001	<0.0004	0.080	0.0008	<0.02	0.005	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-67-05	<0.005	<0.001	<0.0004	0.080	<0.0004	<0.02	0.002	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-69-05	0.012	<0.001	<0.0004	0.240	<0.0004	<0.02	0.003	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-70-05	0.014	0.001	<0.0004	0.150	<0.0004	0.03	0.004	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-71-05	0.043	0.001	<0.0004	0.080	<0.0004	<0.02	0.006	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	0.009
> 2 km	W-72-05	<0.005	<0.001	<0.0004	0.150	<0.0004	<0.02	0.004	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-74-05	0.101	0.003	<0.0004	0.340	<0.0004	<0.02	0.004	<0.001	<0.0001	<0.0002	<0.0002	0.0012	0.001
> 2 km	W-75-05	0.033	0.001	<0.0004	0.130	<0.0004	<0.02	0.004	<0.001	<0.0001	<0.0002	<0.0002	0.0013	0.001
> 2 km	W-76-05	<0.005	<0.001	<0.0004	<0.02	0.0018	0.28	0.006	<0.001	<0.0001	<0.0002	<0.0002	0.0147	0.020
> 2 km	W-77-05	<0.005	<0.001	<0.0004	0.080	<0.0004	<0.02	0.003	<0.001	<0.0001	<0.0002	<0.0002	0.0015	<0.001
> 2 km	W-78-05	0.019	0.001	<0.0004	0.200	0.0008	<0.02	0.003	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-79-05	0.034	0.001	<0.0004	0.300	0.0005	0.02	0.002	<0.001	0.0012	<0.0002	<0.0002	0.0017	<0.001
> 2 km	W-80-05	0.013	<0.001	<0.0004	0.130	<0.0004	<0.02	0.001	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-81-05	<0.005	<0.001	<0.0004	0.090	<0.0004	0.08	0.003	<0.001	0.0003	<0.0002	<0.0002	0.0013	0.001
> 2 km	W-82-05	0.026	0.001	<0.0004	0.320	<0.0004	<0.02	0.003	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	0.001
> 2 km	W-83-05	<0.005	<0.001	<0.0004	0.120	<0.0004	<0.02	0.006	<0.001	0.0001	<0.0002	<0.0002	0.0013	<0.001
> 2 km	W-84-05	<0.005	<0.001	<0.0004	0.300	<0.0004	<0.02	0.008	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-85-05	<0.005	<0.001	<0.0004	0.050	0.0005	<0.02	0.003	<0.001	<0.0001	<0.0002	<0.0002	0.0010	<0.001
> 2 km	W-86-05	<0.005	<0.001	<0.0004	0.110	<0.0004	<0.02	0.004	<0.001	<0.0001	<0.0002	<0.0002	0.0016	<0.001
> 2 km	W-87-05	<0.005	<0.001	<0.0004	0.130	<0.0004	<0.02	0.005	<0.001	<0.0001	<0.0002	<0.0002	0.0014	<0.001
> 2 km	W-88-05	0.022	0.001	<0.0004	0.100	0.0006	0.03	0.009	<0.001	0.0004	<0.0002	<0.0002	0.0008	<0.001
> 2 km	W-89-05	<0.005	<0.001	<0.0004	0.170	<0.0004	<0.02	0.002	<0.001	<0.0001	<0.0002	<0.0002	0.0015	<0.001
> 2 km	W-90-05	0.036	0.001	<0.0004	0.120	<0.0004	<0.02	0.004	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-91-05	0.005	<0.001	<0.0004	0.130	<0.0004	<0.02	0.004	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-93-05	<0.005	<0.001	<0.0004	0.120	<0.0004	<0.02	0.005	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-92-05	<0.005	<0.001	<0.0004	0.070	<0.0004	<0.02	0.012	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-95-05	0.005	<0.001	<0.0004	0.120	<0.0004	<0.02	0.011	<0.001	<0.0001	<0.0002	<0.0002	0.0016	<0.001
> 2 km	W-96-05	0.005	<0.001	<0.0004	0.110	<0.0004	<0.02	0.003	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-97-05	<0.005	<0.001	<0.0004	0.200	<0.0004	<0.02	0.012	<0.001	<0.0001	<0.0002	<0.0002	0.0026	<0.001
> 2 km	W-98-05	0.025	0.001	<0.0004	0.140	<0.0004	<0.02	0.031	<0.001	<0.0001	<0.0002	<0.0002	0.0010	<0.001
> 2 km	W-99-05	<0.005	<0.001	<0.0004	0.040	<0.0004	<0.02	0.009	<0.001	0.0003	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-122-05	0.012	<0.001	<0.0004	0.140	<0.0004	<0.02	0.006	<0.001	0.0001	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-125-05	<0.005	<0.001	<0.0004	0.130	<0.0004	<0.02	0.010	<0.001	<0.0001	<0.0002	<0.0002	0.0013	<0.001
> 2 km	W-126-05	0.013	0.001	<0.0004	<0.02	<0.0004	0.03	0.008	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-127-05	<0.005	<0.001	<0.0004	0.150	0.0004	<0.02	0.008	<0.001	<0.0001	<0.0002	<0.0002	0.0019	<0.001
> 2 km	W-131-05	0.021	0.001	<0.0004	0.160	0.0008	<0.02	0.003	<0.001	<0.0001	<0.0002	<0.0002	0.0013	<0.001
> 2 km	W-134-05	0.031	0.001	<0.0004	0.150	<0.0004	0.08	0.008	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	0.001
> 2 km	W-135-05	0.018	<0.001	<0.0004	0.080	<0.0004	<0.02	0.004	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-136-05	0.005	<0.001	<0.0004	0.070	<0.0004	<0.02	0.001	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-137-05	0.008	<0.001	<0.0004	0.080	<0.0004	<0.02	0.005	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-145-05	0.005	<0.001	<0.0004	0.110	<0.0004	<0.02	0.003	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-157-05	<0.005	<0.001	<0.0004	0.140	<0.0004	<0.02	0.001	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-156-05	<0.005	<0.001	0.0005	0.070	<0.0004	0.02	0.004	<0.001	<0.0001	<0.0002	<0.0002	0.0016	<0.001
> 2 km	W-159-05	0.090	0.002	<0.0004	0.240	<0.0004	<0.02	0.007	<0.001	<0.0001	<0.0002	<0.0002	0.0010	0.001
> 2 km	W-160-05	0.007	<0.001	<0.0004	0.220	<0.0004	<0.02	0.007	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001
> 2 km	W-162-05	<0.005	<0.001	<0.0004	0.140	<0.0004	<0.02	0.007	<0.001	<0.0001	<0.0002	<0.0002	<0.0008	<0.001

Table A9: Metal concentrations (mg/L) in water samples located > 2 km from TBWTF. See Table A5 for site locations (cont. overleaf).

Dist	GIS Code	Mo	Ni	Pb	Sb	Se	Sn	Sr	Ti	Tl	U	V	Zn	Hg
> 2 km	W-30-05	<0.0001	<0.0002	0.0002	0.001	<0.0004	<0.0004	0.191	<0.005	<0.0001	<0.0001	0.0039	0.006	<0.0002
> 2 km	W-4-05	0.0013	<0.0002	0.0002	0.001	0.0004	<0.0004	0.083	<0.005	<0.0001	<0.0001	0.0034	0.029	<0.0002
> 2 km	W-15-05	0.0003	0.0005	0.0002	0.001	0.0006	<0.0004	0.097	<0.005	<0.0001	<0.0001	0.0007	0.028	<0.0002
> 2 km	W-50-05	0.0002	<0.0002	<0.0001	0.001	0.0008	<0.0004	0.148	<0.005	<0.0001	<0.0001	0.0021	<0.004	<0.0002
> 2 km	W-51-05	<0.0001	<0.0002	<0.0001	0.001	<0.0004	<0.0004	0.128	<0.005	<0.0001	<0.0001	0.0005	0.007	<0.0002
> 2 km	W-52-05	<0.0001	<0.0002	0.0002	0.001	0.0004	<0.0004	0.043	<0.005	<0.0001	<0.0001	0.0022	<0.004	<0.0002
> 2 km	W-53-05	0.0003	0.0003	0.0008	0.002	0.0009	<0.0004	0.296	<0.005	<0.0001	0.0001	0.0016	0.015	<0.0002
> 2 km	W-56-05	0.0003	<0.0002	<0.0001	0.001	<0.0004	<0.0004	0.069	<0.005	<0.0001	<0.0001	0.0043	0.005	<0.0002
> 2 km	W-57-05	<0.0001	<0.0002	<0.0001	0.001	0.0004	<0.0004	0.090	<0.005	<0.0001	<0.0001	0.0014	0.005	<0.0002
> 2 km	W-58-05	0.0002	<0.0002	0.0003	0.001	0.0004	<0.0004	0.074	<0.005	<0.0001	<0.0001	0.0035	0.006	<0.0002
> 2 km	W-59-05	0.0005	<0.0002	<0.0001	0.001	0.0007	<0.0004	0.096	<0.005	<0.0001	<0.0001	0.0126	<0.004	<0.0002
> 2 km	W-60-05	<0.0001	<0.0002	<0.0001	0.001	<0.0004	<0.0004	0.078	<0.005	<0.0001	<0.0001	0.0004	0.026	<0.0002
> 2 km	W-61-05	<0.0001	<0.0002	0.0003	0.001	0.0005	<0.0004	0.131	<0.005	<0.0001	<0.0001	0.0020	0.008	<0.0002
> 2 km	W-62-05	0.0002	<0.0002	0.0031	0.001	0.0006	0.0004	0.470	0.014	<0.0001	<0.0001	0.0016	0.018	<0.0002
> 2 km	W-63-05	0.0001	0.0005	0.0003	0.001	<0.0004	<0.0004	0.174	<0.005	<0.0001	<0.0001	0.0004	0.117	<0.0002
> 2 km	W-64-05	<0.0001	<0.0002	<0.0001	0.001	<0.0004	<0.0004	0.120	<0.005	<0.0001	<0.0001	0.0024	<0.004	<0.0002
> 2 km	W-66-05	0.0002	<0.0002	0.0001	0.001	0.0007	<0.0004	0.215	<0.005	<0.0001	<0.0001	0.0005	0.091	<0.0002
> 2 km	W-67-05	0.0001	<0.0002	0.0002	0.001	<0.0004	<0.0004	0.050	<0.005	0.000	0.0002	0.0020	<0.004	<0.0002
> 2 km	W-69-05	0.0001	<0.0002	<0.0001	0.001	<0.0004	<0.0004	0.135	<0.005	<0.0001	<0.0001	0.0012	0.015	<0.0002
> 2 km	W-70-05	<0.0001	<0.0002	<0.0001	0.001	0.0007	<0.0004	0.049	<0.005	<0.0001	<0.0001	0.0024	<0.004	<0.0002
> 2 km	W-71-05	<0.0001	<0.0002	0.0015	0.001	<0.0004	<0.0004	0.142	<0.005	<0.0001	<0.0001	0.0009	0.013	<0.0002
> 2 km	W-72-05	0.0001	<0.0002	<0.0001	0.001	<0.0004	<0.0004	0.087	<0.005	<0.0001	<0.0001	0.0030	0.010	<0.0002
> 2 km	W-74-05	<0.0001	<0.0002	0.0013	0.001	<0.0004	<0.0004	0.120	0.006	<0.0001	<0.0001	0.0031	0.019	<0.0002
> 2 km	W-75-05	0.0004	<0.0002	0.0006	0.001	<0.0004	<0.0004	0.187	<0.005	0.000	0.0002	0.0055	0.061	<0.0002
> 2 km	W-76-05	0.0011	0.0020	0.0006	0.001	0.0221	<0.0004	1.480	<0.005	<0.0001	0.0005	0.0030	0.052	<0.0002
> 2 km	W-77-05	<0.0001	<0.0002	<0.0001	0.001	<0.0004	<0.0004	0.065	<0.005	<0.0001	<0.0001	0.0026	<0.004	<0.0002
> 2 km	W-78-05	<0.0001	<0.0002	<0.0001	0.001	0.0006	<0.0004	0.090	0.021	<0.0001	<0.0001	0.0014	0.050	<0.0002
> 2 km	W-79-05	0.0002	<0.0002	<0.0001	0.001	0.0007	<0.0004	0.121	0.006	<0.0001	<0.0001	0.0024	0.010	<0.0002
> 2 km	W-80-05	<0.0001	<0.0002	<0.0001	0.001	0.0005	<0.0004	0.048	<0.005	<0.0001	<0.0001	0.0011	0.007	<0.0002
> 2 km	W-81-05	0.0002	0.0003	<0.0001	0.001	0.0008	<0.0004	0.064	<0.005	<0.0001	<0.0001	0.0026	0.010	<0.0002
> 2 km	W-82-05	<0.0001	<0.0002	0.0004	0.001	<0.0004	<0.0004	0.094	<0.005	<0.0001	<0.0001	0.0018	0.097	<0.0002
> 2 km	W-83-05	0.0002	<0.0002	<0.0001	0.001	0.0005	<0.0004	0.184	<0.005	<0.0001	<0.0001	0.0020	0.007	<0.0002
> 2 km	W-84-05	0.0006	<0.0002	<0.0001	0.001	0.0005	<0.0004	0.223	<0.005	<0.0001	<0.0001	0.0012	0.008	<0.0002
> 2 km	W-85-05	0.0002	<0.0002	<0.0001	0.001	0.0007	<0.0004	0.158	<0.005	<0.0001	<0.0001	0.0035	0.005	<0.0002
> 2 km	W-86-05	0.0001	<0.0002	<0.0001	0.001	0.0007	<0.0004	0.106	<0.005	<0.0001	<0.0001	0.0028	0.004	<0.0002
> 2 km	W-87-05	0.0001	<0.0002	<0.0001	0.001	0.0004	<0.0004	0.110	<0.005	<0.0001	<0.0001	0.0029	0.011	<0.0002
> 2 km	W-88-05	0.0004	<0.0002	0.0003	0.001	0.0019	<0.0004	0.250	<0.005	<0.0001	<0.0001	0.0022	0.021	<0.0002
> 2 km	W-89-05	<0.0001	<0.0002	<0.0001	0.001	0.0007	<0.0004	0.054	<0.005	<0.0001	<0.0001	0.0022	0.005	<0.0002
> 2 km	W-90-05	<0.0001	<0.0002	0.0003	0.001	<0.0004	<0.0004	0.073	<0.005	<0.0001	<0.0001	0.0004	0.103	<0.0002
> 2 km	W-91-05	<0.0001	<0.0002	<0.0001	0.001	<0.0004	<0.0004	0.090	<0.005	<0.0001	<0.0001	0.0025	0.007	<0.0002
> 2 km	W-93-05	0.0001	<0.0002	0.0002	0.001	<0.0004	<0.0004	0.094	<0.005	0.000	0.0002	0.0035	<0.004	<0.0002
> 2 km	W-92-05	0.0001	<0.0002	0.0002	0.001	<0.0004	<0.0004	0.152	<0.005	<0.0001	<0.0001	0.0060	0.009	<0.0002
> 2 km	W-95-05	0.0003	<0.0002	0.0001	0.001	0.0006	<0.0004	0.205	<0.005	<0.0001	<0.0001	0.0053	0.007	<0.0002
> 2 km	W-96-05	0.0002	<0.0002	0.0002	0.001	0.0005	<0.0004	0.080	<0.005	<0.0001	<0.0001	0.0024	0.014	<0.0002
> 2 km	W-97-05	<0.0001	<0.0002	<0.0001	0.001	0.0007	<0.0004	0.058	<0.005	<0.0001	<0.0001	0.0032	<0.004	<0.0002
> 2 km	W-98-05	0.0003	<0.0002	0.0003	0.001	0.0007	<0.0004	0.092	<0.005	<0.0001	<0.0001	0.0035	0.009	<0.0002
> 2 km	W-99-05	0.0001	<0.0002	0.0002	0.001	0.0007	<0.0004	0.224	<0.005	<0.0001	<0.0001	0.0010	0.015	<0.0002
> 2 km	W-122-05	0.0001	<0.0002	0.0002	0.001	0.0005	<0.0004	0.293	<0.005	<0.0001	<0.0001	0.0023	0.008	<0.0002
> 2 km	W-125-05	<0.0001	<0.0002	<0.0001	0.001	0.0005	<0.0004	0.288	<0.005	<0.0001	<0.0001	0.0020	0.047	<0.0002
> 2 km	W-126-05	<0.0001	<0.0002	<0.0001	0.001	<0.0004	<0.0004	0.068	<0.005	<0.0001	<0.0001	<0.0002	0.074	<0.0002
> 2 km	W-127-05	0.0002	<0.0002	<0.0001	0.001	<0.0004	<0.0004	0.096	<0.005	<0.0001	<0.0001	0.0061	0.005	<0.0002
> 2 km	W-131-05	<0.0001	0.0002	0.0001	0.001	<0.0004	<0.0004	0.057	<0.005	<0.0001	<0.0001	0.0019	0.006	<0.0002
> 2 km	W-134-05	0.0001	<0.0002	0.0002	0.001	0.0007	<0.0004	0.120	<0.005	<0.0001	<0.0001	0.0015	0.006	<0.0002
> 2 km	W-135-05	<0.0001	<0.0002	<0.0001	0.001	<0.0004	<0.0004	0.057	<0.005	<0.0001	<0.0001	0.0013	<0.004	<0.0002
> 2 km	W-136-05	0.0001	<0.0002	<0.0001	0.001	<0.0004	<0.0004	0.123	<0.005	<0.0001	<0.0001	0.0013	0.005	<0.0002
> 2 km	W-137-05	0.0001	<0.0002	0.0001	0.001	<0.0004	<0.0004	0.064	<0.005	<0.0001	<0.0001	0.0037	0.021	<0.0002
> 2 km	W-145-05	0.0001	<0.0002	0.0003	0.001	<0.0004	<0.0004	0.058	<0.005	<0.0001	<0.0001	0.0018	0.014	<0.0002
> 2 km	W-157-05	<0.0001	<0.0002	<0.0001	0.001	<0.0004	<0.0004	0.046	<0.005	<0.0001	<0.0001	0.0007	<0.004	<0.0002
> 2 km	W-156-05	0.0001	<0.0002	<0.0001	0.001	0.0005	<0.0004	0.321	<0.005	<0.0001	<0.0001	0.0015	<0.004	<0.0002
> 2 km	W-159-05	0.0002	<0.0002	0.0023	0.001	0.0005	<0.0004	0.133	<0.005	<0.0001	<0.0001	0.0033	0.015	<0.0002
> 2 km	W-160-05	0.0001	<0.0002	0.0007	0.001	<0.0004	<0.0004	0.067	<0.005	<0.0001	<0.0001	0.0034	0.006	<0.0002
> 2 km	W-162-05	0.0002	<0.0002	<0.0001	0.001	0.0005	<0.0004	0.299	<0.005	<0.0001	<0.0001	0.0020	0.006	<0.0002

Table A9 (cont.): Metal concentrations (mg/L) in water samples located > 2 km from TBWTF. See Table A5 for site locations.

GIS Code:	W-11-05	W-146-05	W-147-05	W-148-05	W-149-05	W-150-05	W-151-05	W-152-05	W-153-05	W-154-05	W-155-05	W-160-05	W-43-05	W-44-05	W-57-05	W-58-05	W-75-05	W-97-05	W-135-05	W-145-05
2378 TeCDD	<0.34	<0.24	<1.70	<0.66	<0.88	<0.41	<1.90	<0.21	<0.41	<0.38	<0.24	<0.10	<0.10	<0.26	<0.10	<0.10	<0.11	<0.10	<0.46	<1.40
12378 PeCDD	<0.24	<0.17	<0.77	<0.25	<0.39	<0.20	<0.81	<0.12	8.80	<0.24	<0.15	<0.10	<0.10	<0.16	<0.10	<0.10	<0.10	<0.10	<0.20	<0.93
123478 HxCDD	<0.28	<0.21	<0.63	<0.24	<0.43	<0.25	<0.59	<0.14	<0.28	<0.25	<0.20	<0.10	<0.10	<0.17	<0.10	<0.10	<0.10	<0.10	<0.19	<0.83
123678 HxCDD	<0.26	0.54	<0.60	<0.24	<0.42	<0.22	<0.54	<0.12	<0.25	<0.22	<0.19	<0.10	<0.10	<0.16	<0.10	<0.10	<0.10	<0.10	<0.19	<0.79
123789 HxCDD	<0.24	<0.18	<0.59	<0.23	<0.41	<0.21	<0.52	<0.11	5.00	<0.21	<0.18	<0.10	<0.10	<0.16	<0.10	<0.10	<0.10	<0.10	<0.19	<0.74
1234678 HpCDD	<0.77	3.95	<0.92	2.90	<0.54	<0.33	<0.85	<0.25	3.20	1.50	<0.28	<0.10	<0.10	<0.25	<0.10	<0.10	7.05	<0.10	<0.40	<1.20
OCDD	<0.64	23.00	<3.30	14.00	<1.60	11.50	<2.90	6.90	8.00	7.20	11.50	<2.30	2.60	4.40	<2.30	<2.30	63.85	<2.30	<1.00	<5.00
Tot TCDD	<0.34	<0.24	<1.70	<0.66	<0.88	<0.41	<1.90	<0.21	<0.41	<0.38	<0.24	<0.10	<0.10	<0.26	<0.10	<0.10	<0.11	<0.10	<0.46	<1.40
Tot PeCDD	<0.24	<0.17	<0.77	<0.25	<0.39	0.36	<0.81	<0.12	9.40	<0.24	<0.15	<0.10	<0.10	<0.16	<0.10	<0.10	<0.10	<0.10	<0.20	<0.93
Tot HxCDD	<0.28	<0.21	<0.63	<0.24	<0.43	<0.25	<0.59	<0.14	6.10	<0.25	<0.20	<0.10	<0.10	<0.17	<0.10	<0.10	<0.10	<0.10	0.97	<0.83
Tot HpCDD	<0.77	7.25	<0.92	2.80	<0.52	<0.33	<0.85	<0.25	3.10	1.60	<0.28	<0.10	<0.10	<0.25	<0.10	<0.10	10.98	<0.10	<0.40	<1.20
Tot PCDDs	<0.77	30.00	<3.30	17.00	<1.60	12.00	<2.90	6.90	13.50	8.00	11.50	<2.30	2.60	4.40	<2.30	<2.30	74.35	<2.30	0.97	<5.00
2378 TeCDF	<0.23	<0.14	<0.67	<0.31	<0.53	<0.18	<0.71	<0.11	<0.23	<0.24	<0.16	<0.10	<0.10	<0.17	<0.10	<0.10	<0.10	<0.10	<0.28	<1.10
12378 PeCDF	<0.21	0.37	<0.42	<0.18	<0.30	1.06	<0.44	0.83	<0.20	<0.18	<0.13	<0.10	<0.10	<0.12	<0.10	<0.10	<0.10	<0.10	<0.17	<0.84
23478 PeCDF	<0.16	<0.11	<0.44	<0.15	<0.26	0.90	<0.35	<0.10	<0.15	<0.15	<0.11	<0.10	0.67	<0.10	<0.10	<0.10	<0.10	<0.10	<0.13	<0.63
123478 HxCDF	<0.15	0.75	<0.44	0.47	<0.33	1.10	<0.45	0.45	<0.17	<0.18	<0.14	<0.65	2.00	0.26	0.82	<0.10	0.34	0.85	0.24	<0.78
123678 HxCDF	<0.16	<0.11	<0.43	<0.22	<0.33	1.00	<0.42	0.35	<0.16	<0.17	<0.14	<0.10	0.80	<0.10	0.50	0.33	0.17	<0.10	<0.14	<0.74
123789 HxCDF	<0.25	<0.12	<0.55	<0.26	<0.39	1.30	<0.54	<0.10	<0.19	<0.19	<0.15	<0.10	<0.10	<0.11	<0.10	<0.10	<0.10	<0.10	<0.14	<1.10
234678 HxCDF	<0.20	0.85	<0.47	<0.22	<0.36	1.00	<0.45	<0.10	<0.18	<0.18	<0.13	<0.10	0.68	<0.10	<0.10	<0.10	0.30	<0.10	<0.18	<0.79
1234678 HpCDF	<0.44	2.75	<0.56	1.70	<0.35	1.20	<0.49	<0.12	<0.23	0.91	<0.18	<0.10	<0.10	<0.15	<0.10	<0.10	3.50	<0.10	0.48	<0.86
1234789 HpCDF	<0.65	<0.25	<0.75	<0.30	<0.45	1.70	<0.67	<0.17	<0.29	<0.28	<0.25	<0.10	<0.10	<0.22	<0.10	<0.10	<0.11	<0.10	<0.34	<1.20
OCDF	<0.82	2.40	<1.60	2.30	<0.94	2.55	<1.40	1.10	1.90	<0.40	2.35	<0.10	1.50	<0.37	<0.17	<0.10	9.05	<0.12	<0.64	<1.90
Tot TCDF	<0.23	<0.14	<0.67	<0.31	<0.53	<0.18	<0.71	<0.11	<0.23	<0.24	<0.16	<0.10	<0.10	<0.17	<0.10	<0.10	<0.10	<0.10	<0.28	<1.10
Tot PeCDF	<0.21	0.36	<0.44	<0.18	<0.30	1.00	<0.44	1.40	<0.20	<0.18	<0.13	<0.10	2.40	<0.12	<0.10	<0.10	<0.10	<0.10	<0.17	<0.84
Tot HxCDF	<0.25	1.20	<0.55	0.46	<0.39	3.30	<0.54	0.84	<0.19	<0.19	<0.15	<0.65	4.90	0.21	1.40	0.85	1.19	1.70	0.25	<1.10
Tot HpCDF	<0.65	3.20	<0.75	1.80	<0.45	1.30	<0.67	<0.17	<0.29	1.10	<0.25	<0.10	<0.10	<0.22	<0.10	<0.10	16.00	<0.10	0.48	<1.20
Tot PCDFs	<0.82	6.40	<1.60	4.60	<0.94	5.95	<1.40	1.70	1.90	1.20	2.35	<0.65	8.80	<0.37	1.40	0.85	18.15	1.70	0.48	<1.90
TEQ (ND=0)	0.00	0.19	0.00	0.10	0.00	0.52	0.00	0.06	4.65	0.01	0.00	0.00	0.69	0.01	0.13	0.03	0.15	0.09	0.00	0.00
TEQ (ND=0.5DL)	0.43	0.43	1.60	0.68	0.81	0.83	1.55	0.27	4.92	0.33	0.27	0.20	0.81	0.26	0.29	0.20	0.32	0.25	0.45	1.60
TEQ (ND=DL)	0.87	0.67	3.20	1.30	1.65	1.19	3.00	0.48	5.19	0.65	0.53	0.39	0.94	0.49	0.45	0.36	0.48	0.41	0.80	3.20

Table A10: PCDD/F concentration in water (pg/L). See Table A5 for site locations.

GIS Code:	NAP	mNAP	ACY	ACE	FLR	PHN	ANT	FLT	PYR	BaA	CHR	BbF	BkF	BaP	IP	DahA	BghiP
W-11-05	<0.00001	0.00045	<0.00001	<0.00001	0.00010	0.00016	<0.00001	<0.00001	0.00002	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
W-146-05	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
W-147-05	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
W-148-05	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
W-149-05	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
W-150-05	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
W-151-05	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
W-152-05	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
W-153-05	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
W-154-05	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
W-155-05	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
W-160-05	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
W-43-05	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
W-44-05	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
W-57-05	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
W-58-05	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
W-75-05	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
W-97-05	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
W-135-05	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
W-145-05	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001

Table A11: PAH concentration in water (mg/L). See Table A5 for site locations.

Dist	GIS Code	LOI	Sb	As	Hg	Se	Ag	Al	Ba	Be	Ca	Cd	Co	Cr	Cu	Fe
< 1 km	W-6-05	7.8	0.3	4.5	2.3	0.6	1	23100	226	<1	207000	4.0	10.0	54.2	115	16100
< 1 km	W-7-05	9.9	0.2	1.9	1.4	0.7	1	23200	174	<1	164000	1.6	10.0	42.3	91	8600
< 1 km	W-11-05	35.7	0.3	6.8	1.8	1.7	<1	21200	113	<1	142000	10.2	8.0	140.0	155	18700
< 1 km	W-17-05	13.8	0.3	3.4	0.9	1.0	<1	21800	166	<1	197000	4.6	9.0	73.9	97	10500
< 1 km	W-23-05	5.7	0.6	3.7	0.1	0.4	<1	6800	113	<1	337000	0.9	3.0	20.2	45	8300
< 1 km	W-146-05	21.8	0.9	5.3	0.5	1.0	<1	18100	198	<1	196000	3.5	9.0	57.7	128	19300
< 1 km	W-147-05	17.9	7.2	13.2	1.3	2.1	2	17300	244	<1	125000	10.7	8.0	98.6	237	27300
< 1 km	W-148-05	15.0	7.6	14.1	2.5	2.3	2	19700	242	1	88300	12.9	9.0	110.0	303	28100
< 1 km	W-149-05	9.7	0.5	5.0	0.4	2.2	1	26100	325	<1	102000	2.7	12.0	52.4	102	10700
< 1 km	W-150-05	14.6	0.2	2.4	0.5	0.9	<1	16100	261	<1	215000	2.5	4.0	42.7	51	7600
< 1 km	W-151-05	12.4	0.2	8.2	0.7	0.4	<1	25600	86	<1	209000	2.0	9.0	94.2	86	11800
< 1 km	W-152-05	35.6	0.7	4.8	3.0	1.5	1	17200	191	<1	151000	6.6	19.0	115.0	484	14900
< 1 km	W-153-05	64.6	0.5	14.4	1.3	1.5	<1	10300	281	<1	36900	15.4	13.0	74.1	290	191000
< 1 km	W-154-05	12.3	0.1	3.9	0.1	0.1	<1	21800	154	<1	145000	2.9	3.0	31.0	43	11400
< 1 km	W-155-05	13.0	1.1	1.7	29.5	0.6	<1	12700	188	<1	176000	7.2	9.0	52.4	123	14300
< 1 km	W-160-05	33.2	0.2	20.8	0.2	0.4	<1	11500	247	<1	263000	1.2	4.0	62.3	49	9800
< 2 km	W-25-05	7.5	0.4	4.7	5.7	0.8	<1	18000	119	<1	190000	2.1	7.0	58.4	603	15000
< 2 km	W-28-05	8.0	0.2	3.6	6.0	1.4	<1	19500	112	<1	226000	3.2	7.0	98.9	49	18200
< 2 km	W-43-05	6.6	0.2	2.4	8.8	0.5	<1	18700	274	<1	218000	1.0	8.0	53.3	34	12500
< 2 km	W-44-05	8.0	0.3	3.7	0.3	0.6	<1	19800	175	<1	136000	1.8	6.0	46.3	102	8300
< 2 km	W-161-05	5.7	0.2	2.1	4.2	1.2	<1	16100	146	<1	154000	2.7	9.0	46.2	67	15600
> 2 km	W-30-05	12.5	0.4	4.2	1.3	1.1	1	21400	253	<1	151000	2.9	12.0	81.9	152	16200
> 2 km	W-53-05	8.8	0.3	3.3	3.0	0.9	<1	19700	424	<1	215000	3.2	8.0	71.8	130	16900
> 2 km	W-57-05	6.4	0.2	1.3	0.7	0.6	2	15000	175	<1	189000	4.3	12.0	31.0	53	9100
> 2 km	W-58-05	6.4	0.7	2.2	1.0	0.5	<1	15000	136	<1	175000	0.8	4.0	41.5	54	9300
> 2 km	W-69-05	8.7	0.2	3.9	0.6	1.2	<1	21600	176	<1	183000	3.4	7.0	67.2	111	13500
> 2 km	W-75-05	28.0	0.5	5.8	0.4	0.6	<1	22400	332	<1	144000	2.4	15.0	83.5	226	14100
> 2 km	W-82-05	4.4	0.2	4.2	0.8	0.8	<1	7200	136	<1	242000	0.7	3.0	39.0	162	10400
> 2 km	W-87-05	5.2	0.3	4.2	0.2	0.6	<1	15700	227	<1	251000	3.6	3.0	35.3	75	8100
> 2 km	W-90-05	7.0	0.1	3.1	0.6	0.8	<1	24200	404	1	167000	4.6	5.0	65.2	136	22500
> 2 km	W-95-05		0.2	3.8	0.6	0.7	<1	9000	525	<1	307000	2.9	4.0	30.7	60	9600
> 2 km	W-97-05	6.3	0.4	1.9	0.9	0.5	<1	7800	194	<1	300000	0.8	6.0	38.9	138	6800
> 2 km	W-134-05	6.2	0.4	3.8	0.3	1.2	<1	24000	258	<1	133000	1.1	7.0	63.5	117	15500
> 2 km	W-135-05	36.0	0.1	1.5	0.5	0.3	<1	25900	134	<1	140000	1.2	6.0	43.7	49	7800
> 2 km	W-145-05	10.3	0.5	2.2	2.0	0.9	<1	17800	178	<1	231000	1.8	9.0	42.1	118	10700
> 2 km	W-162-05	5.5	1.3	2.7	0.7	0.7	<1	10300	338	<1	226000	6.3	4.0	35.5	717	11200

Table A12: LOI (%) and metal concentrations (mg/kg) in water tank sediment. See Table A5 for site locations (cont. overleaf).

Dist	GIS Code	K	Mg	Mn	Mo	Na	Ni	P	Pb	Sn	Sr	Ti	Tl	V	Zn	U
< 1 km	W-6-05	700	18700	290	<1	600	60	1040	271	<5	1050	1220	<1	29	3720	<40
< 1 km	W-7-05	700	8200	200	<1	600	64	690	246	<5	777	1070	<1	32	2330	<40
< 1 km	W-11-05	600	8400	180	<1	600	38	2710	236	<5	1310	687	<1	74	4830	<40
< 1 km	W-17-05	700	10300	220	1	700	63	1780	298	<5	1140	885	<1	24	2640	<40
< 1 km	W-23-05	300	9400	140	<1	700	13	490	69	<5	2430	449	<1	12	390	<40
< 1 km	W-146-05	800	9400	290	1	900	95	1230	235	6	1220	881	<1	37	2380	<40
< 1 km	W-147-05	1000	5700	450	3	800	65	2700	510	10	949	534	<1	53	12900	<40
< 1 km	W-148-05	1100	5900	430	3	700	80	2670	664	11	680	688	<1	71	10700	<40
< 1 km	W-149-05	900	8000	220	<1	800	128	820	172	<5	629	1210	<1	42	1310	<40
< 1 km	W-150-05	500	8600	170	<1	600	43	1210	115	<5	687	764	<1	27	1690	<40
< 1 km	W-151-05	700	11000	320	1	800	93	1200	106	<5	2200	1010	<1	41	710	<40
< 1 km	W-152-05	600	12200	290	<1	600	54	2730	676	<5	930	791	<1	42	9880	<40
< 1 km	W-153-05	700	5900	680	2	500	62	2830	1120	20	559	313	<1	60	19500	<40
< 1 km	W-154-05	600	4800	140	<1	1200	29	920	53	<5	462	791	<1	55	1210	<40
< 1 km	W-155-05	800	7600	390	<1	700	57	1670	181	<5	1150	677	<1	23	8920	<40
< 1 km	W-160-05	300	7500	170	<1	400	31	590	223	<5	676	721	<1	35	470	<40
< 2 km	W-25-05	700	12800	220	1	700	49	890	248	<5	1020	884	<1	24	11600	<40
< 2 km	W-28-05	600	6800	330	<1	800	39	1370	113	<5	1530	551	<1	26	10800	<40
< 2 km	W-43-05	1200	10000	230	<1	800	60	1020	33	<5	1170	982	<1	22	1190	<40
< 2 km	W-44-05	600	7100	180	<1	500	55	940	154	<5	473	836	<1	22	1550	<40
< 2 km	W-161-05	900	13000	340	<1	500	76	950	132	<5	567	1060	<1	32	6770	<40
> 2 km	W-30-05	800	9900	340	<1	700	111	1720	272	<5	1480	1180	<1	41	2570	<40
> 2 km	W-53-05	800	8800	350	<1	900	48	1430	217	<5	980	1230	<1	27	2390	<40
> 2 km	W-57-05	600	7100	210	<1	600	80	570	70	<5	839	1070	<1	20	4080	<40
> 2 km	W-58-05	600	5400	160	<1	700	38	860	47	<5	1020	748	<1	21	850	<40
> 2 km	W-69-05	800	10800	260	2	600	48	1640	234	<5	881	863	<1	21	7670	<40
> 2 km	W-75-05	800	13000	320	1	800	63	1250	159	<5	1030	1150	<1	25	3080	<40
> 2 km	W-82-05	400	7400	200	<1	700	14	670	68	<5	1560	437	<1	16	4970	<40
> 2 km	W-87-05	600	7300	200	<1	800	23	1110	82	<5	1410	841	<1	18	2180	<40
> 2 km	W-90-05	700	10000	320	<1	500	29	1280	273	<5	686	1180	<1	20	10700	<40
> 2 km	W-95-05	600	8200	120	<1	1100	34	830	41	<5	2230	509	<1	40	3330	<40
> 2 km	W-97-05	400	11500	130	<1	1600	29	880	85	<5	2960	462	<1	21	520	<40
> 2 km	W-134-05	1200	7900	350	1	800	71	990	185	<5	696	1620	<1	22	940	<40
> 2 km	W-135-05	560	11400	190	<1	400	54	770	55	<5	505	1010	<1	29	1160	<40
> 2 km	W-145-05	600	9700	240	<1	400	55	800	254	<5	2090	908	<1	26	1980	<40
> 2 km	W-162-05	900	6200	190	<1	1100	29	580	216	<5	1690	858	<1	15	2920	<40

Table A12 (cont.): LOI (%) and metal concentrations (mg/kg) in water tank sediment. See Table A5 for site locations.

GIS Code:	W-11-05	W-147-05	W-148-05	W-149-05	W-150-05	W-151-05	W-152-05	W-153-05	W-154-05	W-155-05	W-160-05	W-43-05	W-44-05	W-57-05	W-58-05	W-75-05	W-97-05	W-135-05	W-145-05
2378 TeCDD	<0.59	16	39	5.3	1.5	2.6	2.1	2.7	<0.13	7.8	<0.10	<0.12	<0.18	<0.11	<0.32	<0.32	<0.10	<1.20	0.79
12378 PeCDD	<0.48	80	210	30	6	14	18	7.3	3.7	41	2	<0.10	0.975	<0.10	<0.10	1.5	1.3	<0.44	4.5
123478 HxCDD	3.65	130	360	46	9	23	46	13	6.6	94	8	2	1.7	8.6	3.3	2.85	3.8	4.3	148.7
123678 HxCDD	7.05	380	850	130	24	52	210	25	16	210	32	4.4	3.75	8.3	7.5	7.45	11	4.1	130
123789 HxCDD	5.3	400	980	140	25	57	110	24	16	270	19	3.7	2.6	2.9	5.3	5.55	6.1	<0.25	122
1234678 HpCDD	145	6200	11000	1600	350	990	7400	540	260	4400	2800	80	66	150	170	420	830	42	3885
OCDD	1080	39000	49000	7000	1600	5500	64000	5200	2200	25000	14000	460	415	1100	1400	5750	10000	240	23350
Total TCDD	<0.59	240	760	63	16	35	39	25	7.1	83	<0.10	<0.12	<0.18	<0.11	<0.32	0.42	<0.10	<1.20	4.8
Total PeCDD	<0.48	970	2900	290	55	140	240	63	37	420	<0.10	<0.10	5.95	3.4	<0.10	15	12	<0.44	77
Total HxCDD	108	3900	8300	1200	230	620	2000	310	190	2100	460	49	41.5	78	71	109	160	25	525
Total HpCDD	320	12000	21000	3100	680	1900	15000	1100	560	8700	5100	160	125	310	340	870	1800	82	6370
Total PCDDs	1500	56000	82000	12000	2500	8200	81000	6700	2900	37000	20000	670	585	1500	1900	6750	12000	350	30350
2378 TeCDF	<0.37	71	170	17	5.8	3.7	12	8.8	2.4	37	20	1.3	<0.14	<0.10	<0.19	<0.27	0.72	<0.47	8.8
12378 PeCDF	5.1	120	320	40	9	19	25	11	5.4	64	7.7	1.7	1.4	0.76	2.1	1.5	1.3	<0.30	130
23478 PeCDF	5.25	200	540	62	16	31	33	22	9.3	120	19	3.1	2.3	1.1	3.4	2.55	1.5	<0.25	13
123478 HxCDF	5.7	730	1700	280	51	86	110	57	35	570	38	4.1	2.45	3.5	5	3.65	3.1	9.3	29
123678 HxCDF	4.5	290	690	110	24	43	63	30	15	220	22	4.3	2.95	2.4	4.8	3.5	3.8	7.5	11.7
123789 HxCDF	<0.77	19	50	13	2.2	3.3	5	<0.37	<0.26	15	9.4	2	0.92	0.48	2.9	1.05	1.5	<0.23	4.25
234678 HxCDF	8.9	460	1100	170	34	49	63	33	23	410	26	6.5	4.15	4.4	7.9	4.95	5.2	6.2	16
1234678 HpCDF	47	3300	5200	1100	140	380	600	220	110	2400	360	34	34	79	49	58.5	77	58	655
1234789 HpCDF	<1.40	170	410	62	19	36	51	31	12	200	29	3.5	2	2.3	4.4	2.95	3.6	<0.34	64.75
OCDF	46.5	1500	2600	450	110	600	960	360	86	1500	670	33	40.5	86	50	155	130	21	3125
Total TCDF	<0.37	770	2200	210	62	120	120	85	39	360	<0.10	<0.10	4.35	<0.10	<0.19	5.5	4.7	<0.47	150
Total PeCDF	6.5	1300	3600	420	94	200	260	130	71	790	<0.10	<0.10	10.9	9.4	<0.10	15	11	<0.30	180
Total HxCDF	60	2300	5700	890	170	450	800	280	120	1900	250	36	28.5	52	59	42	50	66	450
Total HpCDF	82.5	4100	6500	1400	180	760	1400	410	170	3000	800	50	61.5	180	87	140	180	84	2800
Total PCDFs	195	9900	21000	3300	610	2100	3500	1300	480	7600	1700	120	145	330	200	355	370	170	6420
Total TEQ (ND=0)	8.35	550	1300	190	39	80	190	49	24	370	63	5.7	5.15	6.1	7.9	11	16	4.2	108
Total TEQ (ND=0.5DL	8.75	550	1300	190	39	80	190	49	24	370	63	5.8	5.25	6.2	8.2	11	16	5.1	108
Total TEQ (ND=DL)	9.5	550	1300	190	39	80	190	49	24	370	63	5.9	5.35	6.3	8.4	11.5	16	6	108

Table A13: PCDD/F concentrations (pg/g) in water tank sediment. See Table A5 for site locations.

GIS Code:	W-11-05	W-146-05	W-147-05	W-148-05	W-149-05	W-150-05	W-151-05	W-152-05	W-153-05	W-154-05	W-155-05	W-160-05	W-43-05	W-44-05	W-57-05	W-58-05	W-75-05	W-97-05	W-135-05	W-145-05
NAP	<0.01	0.02	0.02	0.02	<0.01	<0.01	<0.01	0.03	0.07	<0.01	0.03	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01
ACY	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.25	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
ACE	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
FLR	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
PHN	<0.01	0.05	0.04	0.03	0.02	<0.01	<0.01	0.08	0.81	0.01	0.04	0.09	0.07	0.06	0.14	0.04	0.03	0.03	<0.01	0.03
ANT	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.04	0.43	<0.01	<0.01	0.01	0.01	0.02	0.03	<0.01	<0.01	<0.01	<0.01	<0.01
FLT	0.02	0.08	0.09	0.06	0.02	0.16	0.02	0.30	2.00	0.04	0.09	0.25	0.37	0.23	0.51	0.08	0.11	0.07	0.01	0.06
PYR	0.01	0.07	0.09	0.05	0.01	0.04	0.02	0.27	1.80	0.03	0.08	0.21	0.30	0.24	0.43	0.08	0.10	0.05	0.01	0.05
BaA	<0.01	0.04	0.04	0.03	<0.01	0.01	0.01	0.15	1.20	0.02	0.03	0.11	0.17	0.14	0.28	0.04	0.04	0.03	<0.01	0.03
CHR	<0.01	0.03	0.07	0.03	0.01	0.02	0.02	0.16	0.87	0.03	0.05	0.18	0.31	0.16	0.25	0.05	0.08	0.03	<0.01	0.04
BbF	<0.01	0.05	0.08	0.07	<0.01	<0.01	0.02	0.23	1.20	0.04	0.04	0.25	0.59	0.21	0.39	0.08	0.10	0.05	<0.01	0.05
BkF	<0.01	0.02	0.07	0.04	<0.01	<0.01	0.02	0.20	0.91	0.03	0.03	0.08	0.27	0.18	0.16	0.04	0.07	0.02	<0.01	0.04
BaP	<0.01	0.03	0.06	0.05	<0.01	<0.01	0.02	0.18	1.00	0.02	0.05	0.14	0.30	0.17	0.26	0.05	0.07	0.03	<0.01	0.03
IP	<0.01	0.03	0.05	0.02	<0.01	<0.01	0.03	0.15	0.69	0.02	0.08	0.13	0.38	0.19	0.19	0.04	0.07	0.02	<0.01	0.03
DahA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	0.07	<0.01	0.04	<0.01	<0.01	<0.01	<0.01	<0.01
BghiP	<0.01	0.03	0.04	0.03	<0.01	<0.01	0.03	0.10	0.26	0.01	0.07	0.14	0.36	0.13	0.15	0.07	0.05	0.02	<0.01	<0.01

Table A14: PAH concentrations (µg/kg) in water tank sediment. See Table A5 for site locations.