

POLYBROMINATED DIPHENYL ETHERS IN LANDFILLS FROM ELECTRONIC WASTE

by

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ABSTRACT

Previous research on Brominated Flame Retardants (BFRs), including Polybrominated Diphenyl Ethers (PBDEs), has largely focused on their concentrations in the environment and their adverse effects on human health. This thesis explores how these compounds reach the environment, how they are transferred from waste streams to water and soil, and how they are transported to distant locations like Northern Canada. Landfills, which receive a large proportion of society's discarded consumer waste products, including electronic wastes (e-waste), are the major focus of attention.

Leachate was collected and analysed from 27 landfills across southern Canada and 11 dump sites in the Canadian North. There was wide variability in the results, both in terms of the total concentrations of PBDEs and in the distribution of congeners. Northern sites tended to have lower PBDE concentrations than southern ones, but some levels were significant despite the low population density and lack of industry in the north. The North provides a sink for PBDE contaminants. Significant differences in PBDE levels in leachate in contact with wastes originating in different 5-year time intervals suggest that the time-of-manufacture of electronic goods plays an important role in determining the rate of PBDE release into the environment. Electronic components manufactured in the 1985-89 period were found to have especially high PBDE concentrations.

Experiments were carried out in which e-waste was contacted with distilled water and leachate from a major urban landfill in a custom-built contactor. There was transfer of PBDEs to the aqueous phase which increased with greater contact time and increasing temperature. Exposing e-waste to distilled water led to lower PBDE concentrations, probably due to dislodgement of fine dust from the surface of e-waste particles.

A comprehensive mole balance model was prepared to assist in predicting the concentration of PBDEs in and near landfills. The balances were applied to different homologue groups and different subsystems - field e-waste, non-e-waste solids, and aqueous phase. Mass transfer parameters were obtained from solid-liquid contacting experiments with crushed e-waste. Simulations indicate that PBDEs will persist for decades in the environment even if they are no longer manufactured and incorporated in plastics.

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LIST OF SYMBOLS

$a_{I(n \rightarrow \varphi)}$	Interphase transfer area per unit volume between subsystems φ and n , (m^{-1})
C_{Ae}	Concentration at equilibrium (mol/m^3)
C_{As}	Concentration of the solid e-waste particle (mol/m^3)
$C_{i\varphi}$	Concentration of homologous group i in subsystem φ (mol/m^3)
$C_{in,n}(t)$	Concentration of n-BDE (mol/m^3)
$DF_{i(n \rightarrow \varphi)}$	Deposition flux of species i from subsystem n to subsystem φ ($\text{mol}/\text{m}^2\text{s}$)
$d_{sv} = 1/\Sigma(x_i d_i)$	Sauter mean particle diameter (mm)
$EF_{i(n \rightarrow \varphi)}$	Entrainment flux of species i from subsystem n to subsystem φ ($\text{mol}/\text{m}^2\text{s}$)
E_a	Activation energy (kJ/mol)
$E(\tau)$	Residence time distribution (s^{-1})
k_{eff}	Effective mass transfer coefficient (m/s)
k_c	Interphase mass transfer coefficient (m/s)
k_i	First order rate constant (s^{-1})
k_j	Kinetic constant for reaction j (s^{-1})
κ_c	Mass transfer coefficient (m/s)
m/zs	Mass-to-charge ratio (quantification ions) (-)
M^+	Isotope ions
NDF	Net deposition flux (atmospheric deposition flux – entrainment flux) ($\text{mol}/\text{m}^2\text{s}$)
N_C	Number of species in subsystem φ , (-)
N_φ	Number of subsystems (-)
$P(\tau)$	Age distribution of electronics (s^{-1})
$P_{NeWS}(\tau)$	Age distribution of non e-waste solids (NeWS) (s^{-1})
$r_{j\varphi}$	Rate of reaction j in subsystem, φ ($\text{mol}/\text{kg.s}$)
r_1	Decomposition rate ($\text{mol}/\text{m}^3\text{s}$)
τ	Tau, dummy time variable (s^{-1})
t	Time (s)
T	Temperature ($^{\circ}\text{C}$)
U	fluid velocity (m/s)
μA	MicroAngstroms
μL	Microlitre
μm	Micron
v_φ	Volumetric flow rate of subsystem, φ (m^3/s)
V_φ	Total volume of subsystem, φ (m^3)
x_i	mass fraction of particles with a representative size of d_i (-)

Greek Letters

ν_{ij}	Stoichiometric coefficient of species i in reaction j , (-)
Φ	Subsystem φ ()

Subscripts

(1)	E-waste
(2)	Air
(3)	Aqueous (water)
(4)	NeWS (non e-waste solids)
F	Feed
I	Compound i
J	Reaction j
n	Subsystem in contact with subsystem φ

Abbreviations

<i>ABS</i>	Acrylonitrile butadiene styrene
<i>ADF</i>	Atmospheric deposition flux
<i>AMAP</i>	Arctic Monitoring Assessment Program
<i>amu</i>	Atomic mass unit
<i>APC</i>	Air Pollution Control
<i>ASA</i>	Copolymer of acrylonitrile, styrene + acrylate rubber
<i>ASE</i>	Accelerated solvent extraction
<i>BDE</i>	Brominated diphenyl ether
<i>BDL</i>	Below detection limit
<i>BFRs</i>	Brominated flame retardants
<i>BMDL</i>	Below method detection limit
<i>BSEF</i>	Bromine Science and Environmental Forum (Europe)
$^{13}\text{C}_{12}$	Isotopically labelled internal standard
<i>CLLE</i>	Continuous liquid/liquid extraction
<i>CEPA</i>	Canadian Environmental Protection Act
<i>C.I.</i>	Confidence interval
<i>CS1</i>	Calibration Series 1
<i>CS4</i>	Calibration Series 4
<i>DCM</i>	Dichloromethane
<i>di-BDE</i>	Dibromodiphenyl ether
<i>Deca-BDE</i>	Decabromodiphenyl ether (technical product)
<i>Deca-BDE</i>	decabromodiphenyl ether (congener)
<i>DFO-IOS</i>	Department of Fisheries and Oceans Canada – Institute of Ocean Sciences
<i>DOC</i>	Dissolved organic carbon
<i>d.w.</i>	Dry weight
<i>ECD</i>	Electron capture detector
<i>ECNI</i>	Electron capture negative ionisation
<i>EEE</i>	electric and electronic equipment
<i>EHC</i>	Environmental Health Criteria, World Health Organization
<i>EI</i>	Electron ionisation

<i>EU</i>	European Union
<i>eV</i>	ElectroVolt
<i>g</i>	Effective gravitational field
<i>GC</i>	Gas chromatography
<i>GC/HRMS</i>	Gas chromatography/High resolution mass spectrometry
<i>Hexa-BDE</i>	Hexabromodiphenyl ether
<i>HEPA</i>	High efficiency particulate air filter
<i>hepta-BDE</i>	heptabromodiphenyl ether
<i>HIPS</i>	High impact polystyrene
<i>HPLC</i>	High pressure liquid chromatography
<i>HRGC/HRMS</i>	High resolution gas chromatography/high resolution mass spectrometry
<i>HRMS</i>	High resolution mass spectrometry
<i>i.d.</i>	Internal diameter
<i>kV</i>	KiloVolt
<i>kHz</i>	Kilohertz
<i>Low-BDEs</i>	Lower brominated congeners: monobromodiphenylether (mono-BDE), dibromodiphenylether (di-BDE), and tribromodiphenylether (tri-BDE)
<i>LL</i>	Liquid-liquid extraction
<i>m</i>	Metre
<i>MDL</i>	Method detection limit
<i>MOE</i>	Ministry of Environment Ontario
<i>MSW</i>	Municipal solid waste
<i>MS</i>	Mass spectrometry
<i>MT</i>	Mass transfer
<i>m/e</i>	Electron Ionization
<i>mm</i>	Millimetre
<i>m/L</i>	Millilitre
<i>m/z</i>	Mass-to-charge ratio
<i>NaCl</i>	Sodium chloride
<i>Na₂SO₄</i>	Sodium sulphate
<i>NCI</i>	Negative chemical ionisation
<i>NDF</i>	Net deposition flux
<i>ND</i>	Non-detect
<i>NeWS</i>	Non e-waste solids
<i>hg</i>	Nanogram
<i>ng/g</i>	Nanogram per gram
<i>NOEL</i>	No-observed-effect-level
<i>nona-BDE</i>	nonabromodiphenyl ether (congener)
<i>OC</i>	Organic carbon
<i>Octa-BDE</i>	Octabromodiphenyl ether (technical product)
<i>octa-BDE</i>	Octabromodiphenyl ether (congener)
<i>OPR</i>	Ongoing Precision and Recovery
<i>PA</i>	Polyamide
<i>PBDEs</i>	Polybrominated diphenyl ethers
<i>PBT</i>	Polybutylene terephthalate
<i>PC</i>	Personal Computer

<i>PC/ABS</i>	Polycarbonate/acrylonitrile butadiene styrene blend
<i>PCBs</i>	Polychlorinated biphenyls
<i>PE</i>	Polyethylene
<i>Penta-BDE</i>	Pentabromodiphenyl ether (technical product)
<i>penta-BDE</i>	Pentabromodiphenyl ether (congener)
<i>PFOS</i>	Perfluorooctane sulphonate (fluorinated surfactant)
<i>PFOAs</i>	Perfluorooctanoic Acid
<i>PMMA</i>	Polymethyl methacrylate
<i>pg</i>	Picogram
<i>pg/g</i>	Picogram per gram
<i>pg/L</i>	Picogram per litre
<i>POC</i>	Particulate organic carbon
<i>POM</i>	Polyacetal
<i>POPs</i>	Persistent Organic Pollutants
<i>PP</i>	Polypropylene
<i>PPO</i>	Polyphenylene oxide
<i>PS</i>	Polystyrene
<i>PU</i>	Polyurethane
<i>PUR</i>	Polyurethane foam
<i>PVC</i>	Polyvinyl chloride
<i>QA/QC</i>	Quality Assurance/Quality Control
<i>QC</i>	Quality control
<i>RoHS</i>	Restrictions on Hazardous Substances Directive
<i>RP</i>	Resolution power
<i>SAN</i>	Styrene acrylonitrile
<i>SD</i>	Standard deviation
<i>SE</i>	Standard error
<i>SIR</i>	Single ion resolving mode
<i>STP</i>	Sewage Treatment Plant
<i>TCLP</i>	Toxicity characteristic leaching procedure
<i>Tetra-BDE</i>	Tetrabromodiphenyl ether
<i>TOC</i>	Total organic carbon
<i>tri-BDE</i>	Tribromodiphenyl ether
<i>UNEP</i>	United Nations Environment Programme
<i>UV</i>	Ultraviolet
<i>v/v</i>	Liquid to liquid ratio
<i>WEEE</i>	Waste Electric and Electronic Equipment Directive
<i>WHO</i>	World Health Organization
<i>w.w.</i>	Wet weight
<i>WWTP</i>	Wastewater treatment plant

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DEDICATION

*To Borís, Nicole and Karina
For Always being There*

CHAPTER I – INTRODUCTION TO POLYBROMINATED DIPHENYL ETHERS (PBDEs), ELECTRONIC WASTE AND LANDFILLS

1.1 Introduction

Polybrominated Diphenyl Ethers (PBDEs) are used globally as flame retardants. They are highly toxic, persistent; endocrine-disrupting chemicals, with potential for long-range transport. In addition, they are regarded as probable persistent organic pollutants (POPs). Two of the three commercial products have been added to the Stockholm Convention in 2009, developed in response to an urgent need for global action to protect human health and the environment from POPs. There is increasing evidence that PBDEs are spreading globally. This includes expansion in to Polar regions (Liberda *et al.* 2005) at rates (12-fold with a doubling period of 1.6 years) that surpass by far those of “classical” POPs such as dioxins, furans, PCBs and organochlorine pesticides (Rayne *et al.* 2003a). Rising concentrations of PBDEs in the environment and possible ecological and human health risks require early implementation of best-management practices to contain them.

Research on brominated flame retardants (BFRs), including PBDEs, has focused primarily on their concentrations in the environment and their adverse effects on human health. There has been almost no quantification or characterization of the upstream sources from which PBDEs are originating. Such factors as the nature and extent of PBDE contamination, their mobility, bio-availability and accumulation in vegetation, soil, and drainage water need to be estimated. The spatial distribution of PBDE contamination should be calculated around landfill areas.

The study of PBDE leachability from e-wastes and examination of landfill sites to determine the spatial distribution of PBDE contamination, fate and transport are logical and important starting points. However, given the threats of these flame retardants and their widespread appearance, including alarming levels reported in marine mammals (Ikonomou *et al.* 2002a), it is essential that research also focus on how these compounds reach the environment, how they transfer from waste streams to air, water and soil, and how they are transported to distant locations, such as Canada’s far north. One important tool to indicate sources, transfers and accumulation of various between environmental compartments (e.g. water, air, and soil) is mass balance modeling (Mackay and Wania 1995; Wania 1997; Wania and Dugani 2003; Mackay 2005).

A major source of PBDEs in the environment is the plastics industry, in particular plastics used in electronic equipment. Over the past three decades, brominated flame retardants (BFRs), including PBDEs have been incorporated in these plastics. Electronic equipment – computers, printers, facsimile machines, mobile telephones, etc. – have relatively brief life spans. Most are eventually discarded, mainly ending up in landfills as electronic waste (e-waste). The use of computer equipment has expanded by several orders of magnitude since the 1980s, making e-waste a major likely source of PBDEs in the environment. Although many manufacturers have already replaced¹, or will soon phase out, some of the BFRs contained in earlier electronic equipment, older models known to contain substantial quantities of BFRs, up to 30% by weight, are still entering the disposal or end-of-useful life phase (Danish-EPA 1999). There is concern with respect to release of PBDEs into the environment, for example, by leaching from landfills, when incinerated, being transported in sewage treatment effluent, or being applied to land as biosolids. Few studies have been performed which could allow these transfer terms to be estimated.

1.2 Landfills and Electronic Waste (E-waste)

An important element of this thesis is the development of a mass balance model to study the spread of PBDEs in the environment. While such models have had considerable success in accounting for the spread of air pollutants, we are not aware at this time of attempts to determine the decay of PBDE concentrations from plastics in electronic waste via mass balance models (e.g. from landfills.) Mass balance models could contribute to the protection of the environment by helping to understand and predict the impact of discarding e-waste. The research is directly relevant to legislation regarding e-waste recycling.

BFRs may be present in leachate from landfills, but no previous studies on the fate of these compounds in waste disposal streams (landfills, sewage treatment plants, incinerators) have come to light. Discarded plastics are subject to ultra-violet radiation, thermal stress, grinding and other degradation processes at the end of their useful lives (Lymberidi 2001). BFR

¹Alternatives to PBDEs are tetrabromobisphenol A (TBBPA), triaryl phosphate, triaryl phosphates butylated, bisphosphates, bis (tribromophenoxy) ethane, phenoxy-terminated carbonate oligomer of tetrabromobisphenol A Peele, C. (2006). Washington State Polybrominated Diphenyl Ether (PBDE) Chemical Action Plan: Final Plan. Washington State Department of Health, Dept of Ecology Publication No. 05-07-048; Dept of Health Publication No. 334-079: pp 328..

compounds from plastics leach from the plastic, particularly when (as for PBDEs) they are added to the polymer at the moulding stage, allowing these compounds to break down at faster rates. It is not known whether the compounds degrade before they end up in the leachate. Therefore, long-term diffuse emissions and leaching from landfills are possibilities (Danish-EPA 1999; Kim *et al.* 2006). Several studies have measured concentrations of plasticizers, phthalates, and other organic chemicals in plastic waste over time (Sakai *et al.* 1998). However, there is little information on whether PBDEs behave in a manner similar to other plastic additives in landfilled electronic waste. For instance, neither the rate at which PBDEs are released from plastic nor their potential for degradation in leachate is known.

The electric and electronic equipment (EEE) waste stream is of direct concern in this thesis because it has historically included a high percentage of PBDEs. While there has been a recent reduction in BFRs incorporated into new computers, they have not been completely eliminated, and the legacy of historical waste remains.

1.3 Flame Retardants

Flame retardants, such as PBDEs, have been used for many years to inhibit chemical reactions between oxygen and fuel, i.e. by suppressing combustion. They have high resistance to ignition and flame propagation, coupled with low rates of combustion, smoke generation, no change in flammability during use (Pearce 1986), and low rates of carbon-bromine bond decomposition at temperatures from 200 to 300°C (Huber and Ballschmiter 2001). Depending on their nature, retardants can act chemically (e.g. interfere with the free radical chain mechanism which takes place in the gas phase during combustion (Troitzsch 1998)) and/or physically (e.g. via desorption of brominated compounds from a polymer (Choi *et al.* 2009)) in either solid, liquid or gas phases (Danish EPA, 1999). Halogen-containing flame retardants act by chemically interfering with the free radical chain reaction mechanism in the gas phase during combustion (Troitzsch, 1998).

1.4 Brominated Flame Retardants (BFRs)

Bromine-based flame retardant formulations are added to approximately 2.5 million tonnes of polymers per year globally (Law *et al.*, 2003). Approximately 70 different BFR compounds account for a global consumption of more than 300,000 tonnes of BFRs per year (Arias, 2001), which include 56,000 tonnes in North America alone (BSEF, 2003). BFRs are typically used in

thermoplastics (e.g. acrylonitrile butadiene styrene (ABS), high impact polystyrene (HIPS), polystyrene (PS) and polycarbonate (PC)) and are blended with polymer constituents, together with other additives such as plasticizers. They are also found in the effluents from the industrial facilities that manufacture and use them (Alaee *et al.* 2003).

BFRs are formed by substituting bromine for hydrogen in biphenyl molecules. They are divided into 3 subgroups depending on how they are incorporated into the polymer: brominated monomers, **reactive** (chemically bonded to the polymer) and **additive** (blended with the polymer). Additive flame retardants are more likely to leach out of the product (Alaee, 2003).

BFRs are bioaccumulative, persistent, undergo long-range transport (Beyer *et al.* 2000; BSEF 2005; de Wit *et al.* 2006; Gouin *et al.* 2006; Muir and Howard 2006; Raff and Hites 2007; Scheringer 2009), are lipophilic and have the potential to act as endocrine disruptors (Fernlof *et al.* 1997; Darnerud 2001; Birnbaum and Staskal 2004; Staskal *et al.* 2006; Odusanya *et al.* 2008; Toms *et al.* 2009). Their concentrations in the environment have been increasing since the 1970s (Birnbaum and Staskal 2004). They may leach out of products, and go through wastewater treatment facilities to end up in sewage biosolids. BFRs may be present in leachate from landfills, but no previous studies have been carried out on their fate in waste disposal streams (landfills, sewage treatment plants, incinerators). There is also limited knowledge regarding their environmental fate and toxicity.

Trends in concentration depend on the location and type of BFR. For example, sediment in Norway showed a linear increase in concentrations from the 1960s to the end of the 1990s (Watanabe and Sakai 2003). Sediment samples in Germany were found to have lower concentrations of brominated congeners in the 1960s than in the late 1990s. North American PBDE levels are generally much higher than in Europe or Japan, as observed in ringed seals from Holman Island, in northern Canada (Ikonomou *et al.* 2002a; Ikonomou *et al.* 2005).

1.5 Polybrominated Diphenyl Ethers (PBDEs)

PBDEs are the most stable BFRs. They are highly lipophilic, enabling bioaccumulation in animals and humans (Hale *et al.*, 2003). Industry uses these compounds because of their low cost, thermal stability and the efficiency with which their halogen atoms chemically reduce and retard free radical reactions (Darnerud *et al.*, 2001). PBDEs were the first group of brominated

flame retardants to be detected in the environment. They are commonly employed as flame retardants in a wide variety of products such as plastic components of computers and televisions, circuit boards, seats of cars and buses, and textiles (De Boer *et al.*, 1999). PBDEs are believed to be released slowly over the life of the plastics in which they reside, as well as other products such as foam. They are known to find their way into the food chain and the human population (McDonald, 2002).

PBDEs were the first BFRs to be detected in the environment, even though polybrominated biphenyls (PBBs) were manufactured years before PBDEs became popular. Due to their physicochemical properties including hydrophobia, lipophilicity, long-range transport and bioaccumulative tendency, PBDEs are expected to pass through wastewater treatment plants and adsorb on sediment and soil. They partition to organic carbon in soil and sediment. They have been found in biosolids, causing increasing concern due to the widespread application of biosolids on agricultural fields. Ikonomou *et al.* (2002a) provide evidence of long-range transport to remote areas.

PBDEs are potential endocrine disruptors and have the potential to surpass PCB concentrations in the environment (Rayne *et al.*, 2003). They are considered highly toxic (e.g. critical effects of: Penta-BDEs, Octa-BDEs and Deca-BDEs start at 0.6, 2 and 80 mg/kg body weight, respectively (Darnerud 2003)). They are also persistent; and bioaccumulative, with potential for long-range transport (Wania and Dugani 2003; AMAP 2005; de Wit *et al.* 2006; Muir and Howard 2006; Shen *et al.* 2006; Su *et al.* 2007; Jorundsdottir *et al.* 2009; Scheringer 2009). PBDEs were first detected in fish (muscle and liver) from Sweden in the early 1980s. Temporal trends in a study by Kierkegaard *et al.* (2004) showed increased concentrations from the 1970s to the mid-1980s. The concentration of BDE-47 was 24 pg/g (wet weight) in 1968 and increased to 760 pg/g (wet weight) in 1983, a 30-fold increase. The yearly rate of increase corresponded to a doubling time of 5 years, as compared with a Σ PCBs decrease of 5% for the period 1967-1995 (Bignert *et al.* 1998). PBDEs were considered global contaminants in the mid-1980s (Alaee and Wenning 2002) when their presence was found in tissue samples of fish-eating birds and marine mammals collected from the Baltic Sea, North Sea and Arctic Ocean. There was little concern about their environmental occurrence until Norén and Meironyté (2000) indicated exponentially increasing levels in human breast milk in Sweden. Today, PBDEs are considered global contaminants due to samples collected and analysed throughout the world (Law *et al.* 2003;

Kazda *et al.* 2004; Zheng *et al.* 2004). For example, these compounds can accumulate in the aquatic food chain, as well as in human and animal fatty tissue. PBDE concentration in Arctic animals continued to increase until at least 2003 (Ikonomou *et al.* 2002a; Ikonomou *et al.* 2005).

PBDEs are found globally (Tanabe 2004). For instance, they have been detected in Antarctica (Yogui and Sericano 2008), Belgium (Covaci *et al.* 2003), Canada (Ikonomou *et al.* 2000; de Wit 2002; Ikonomou *et al.* 2002a), Finland (Smeds and Saukko 2003), Israel (de Boer *et al.* 1997), Japan (Choi *et al.* 2003), Kuwait (Gevao *et al.* 2005), Netherlands (de Boer *et al.* 2000b), Norway (Herzke *et al.* 2005), Portugal (Lacorte *et al.* 2003; Gama *et al.* 2006), Spain (Meneses *et al.* 1999), Sweden (ter Schure and Larsson 2002a), United Kingdom (Allchin *et al.* 1999), and the United States (Hale *et al.* 2001a). They contaminate oceans (de Boer *et al.* 1998), as well as Arctic regions (Betts 2002a; Ikonomou *et al.* 2002a; Sinkkonen *et al.* 2004; Vorkamp *et al.* 2004; Ikonomou *et al.* 2005; Danon-Schaffer *et al.* 2005b; Danon-Schaffer *et al.* 2007) and northern people (Liberda *et al.* 2005).

PBDEs have contaminated biota including vegetables, cows, pigs and chickens (Öhta *et al.* 2000), fish (Loganathan *et al.* 1995; Sellström *et al.* 1998; Kierkkegaard *et al.* 1999; Renner 2000b; Akutsu *et al.* 2001; Alaee *et al.* 2001; Christensen and Platz 2001; Manchester-Neesvig *et al.* 2001; Hale *et al.* 2001a; Law *et al.* 2003; Zhu and Hites 2004; Kierkkegaard *et al.* 2004a; Hites *et al.* 2004b), whales (de Boer *et al.* 1998; Lebeuf *et al.* 2004; Rayne *et al.* 2004; Tanabe 2004), dolphins (Tanabe 2004), seals (Haglund *et al.* 1997; She *et al.* 2002; Kajiwara *et al.* 2004; Tanabe 2004), and birds (Law *et al.* 2003). They have been detected in human adipose tissue (de Boer *et al.* 1997; Meneses *et al.* 1999; She *et al.* 2002; Choi *et al.* 2003; Madsen *et al.* 2003; Smeds and Saukko 2003; Gill *et al.* 2004), human blood (Hagmar *et al.* 2001; Sjödin *et al.* 2001a; Madsen *et al.* 2003; Mazdai *et al.* 2003; Weiss *et al.* 2004; Sjödin *et al.* 2004a; Faldt *et al.* 2005; Kim *et al.* 2005) and breast milk (Öhta *et al.* 2000; de Wit 2002; Betts 2002a; Madsen *et al.* 2003; Ingelido *et al.* 2004; Kalantzi *et al.* 2004; She *et al.* 2004; Sightline Institute 2004). Occupational exposures (Sjödin *et al.* 1999; Gill *et al.* 2004) and human dietary exposures (Akutsu *et al.* 2001; Choi *et al.* 2003; Sjödin *et al.* 2003) have been investigated. A recent study in the U.S. on a food basket of 30 food types (Schechter *et al.* 2004) found PBDEs in all of them. On the product side, they have been measured in autoshredder residue (Petreas and Oros 2009).

Although PBDE levels have increased exponentially in the last three decades and have recently decreased in Sweden due to phase-out of some commercial formulations, levels continue to rise

in North America (Hites, 2004; Ikonomidou *et al.*, 2002; Rayne *et al.*, 2003). Analytical studies indicate that PBDEs are released during recycling of flame retarded goods, as well as during manufacture and use (Watanabe and Sakai 2003).

Until recently, data were limited because PBDEs were not previously considered to be chemicals of concern (Hooper and McDonald 2000; Hooper and She 2003; Schecter *et al.* 2003; Birnbaum and Staskal 2004), nor did they attract international attention (Renner 2000a). Until the mid-1990s, there were few certified standards for individual PBDE congener analysis. Comparative data analysis was difficult, but analysis is now much more reliable (Gill *et al.* 2004).

1.5.1 PBDE Congeners and Commercial Formulations

The structure of polybrominated diphenyl ethers is shown in Figure 1.1. PBDEs are identified according to IUPAC nomenclature and the systematic numbering systems devised for PCBs (D'Silva *et al.* 2004). There are 209 PBDE congeners, divided into 10 homologue groups, based on the degree of bromination as seen in Table 1.1. The estimated annual global consumption of PBDEs in 2003 was 67,390 tonnes, including 56,100 tonnes of Deca-BDE, 3,790 tonnes of Octa-BDE, and 7,500 tonnes of Penta-BDE (www.BSEF.com). It is important to consider the properties of PBDE congeners individually because toxicity, bioaccumulation, degradation, and persistence of each congener are determined by its structure (D'Silva *et al.* 2004). Commercial PBDE mixtures have congener patterns that depend on production conditions and environmental weathering (Rayne and Ikonomidou 2002). Of the 209 congeners, ~60 can be identified by chemical analysis. There are three commercial PBDE products, each composed of congener mixtures (WHO-EHC-162 1994). The commercial Penta-BDE product is predominantly a combination of congeners BDE-47, BDE-99 and BDE-100; the commercial Octa-BDE product is predominantly composed of BDE-153 and BDE-183. The Deca-BDE is almost exclusively BDE-209 congener with minor nona-BDE impurities (Alaee *et al.* 2003; North 2004). Congeners found at appreciable levels in the commercial formulations are shown in Table 1.2.



Figure 1.1 Polybrominated diphenyl ether (PBDE) molecular structure.

Most commercial PBDE preparations involve bromination of diphenyl ether in the presence of a catalyst. The Penta-BDE formulation is thought to be most persistent and toxic (Hale *et al.* 2003; de Wit *et al.* 2006; Law *et al.* 2006; UNEP 2006; Wang *et al.* 2007).

Table 1.1 PBDE congeners organized by homologue groups. The BDE congeners listed here are those routinely identified and quantified by the Regional Dioxin Lab (now Laboratory of Expertise in Aquatic Chemical Analysis), DFO-IOOS, Sidney, BC, Canada in environmental samples using HRGC/MS analysis per the methods described in Section 2.5. They are presented in more detail in Table A.1 (Appendix A).

Homologue Group	Congener
mono-BDEs	BDE-1, BDE-2, BDE-3
di-BDEs	BDE-7, BDE-8, BDE-10, BDE-11, BDE-12, BDE-13, DE-15
tri-BDEs	BDE-17, BDE-25, BDE-28, BDE-30, BDE-32, BDE-33, BDE-35, BDE-37
tetra-BDEs	BDE-47, BDE-49, BDE-54, BDE-60, BDE-66, BDE-71, BDE-75, BDE-77
penta-BDEs	BDE-82, BDE-85, BDE-97, BDE-99, BDE-100, BDE-101, BDE-102, BDE-104, BDE-105, BDE-116, BDE-118, BDE-119, BDE-120, BDE-126 and some unknowns
hexa-BDEs	BDE-128, BDE-138, BDE-139, BDE-140, BDE-144, BDE-149, BDE-153, BDE-154, BDE-155, BDE-156, BDE-166, BDE-169
hepta-BDEs	BDE-170, BDE-171, BDE-173, BDE-176, BDE-177, BDE-179, BDE-180, BDE-181, BDE-182, BDE-183, BDE-184, BDE-185, BDE-188, BDE-189, BDE-190, BDE-191, BDE-192
octa-BDEs	BDE-194, BDE-BDE-195, BDE-196, BDE-197, BDE-200, BDE-201, BDE-202, BDE-203, BDE-204, BDE-205
nona-BDEs	BDE-206, BDE-207, BDE-208
deca-BDE	BDE-209

Table 1.2 PBDE commercial formulations (Dodder et al. 2002; La Guardia et al. 2006). See Table A.2 (Appendix A) for approximate percentages used in each formula.

Commercial formulation	Congener
Penta-BDEs	BDE-47, BDE-85, BDE-99, BDE-100, BDE-153, BDE-154
Octa-BDEs	BDE-138, BDE-144, BDE-153, BDE-154, BDE-171, BDE-183, BDE-196, BDE-197, BDE-201, BDE-203, BDE-206, BDE-207, BDE-208, BDE-209
Deca-BDE	BDE-206, BDE-207, BDE-208, BDE-209

Deca-BDE is one of the most widely used PBDE flame retardants in high impact polystyrene (HIPS), flexible polyurethane foam (PUF), textile coatings, wire and cable insulation, electrical and electronic connectors and other interior parts. Eighty to ninety percent of PBDEs are used for these products in the United States (Rahman, 2001). PBDE production has increased to comply with strict fire regulations, particularly in the U.S. A secondary application is in upholstery textiles where Deca-BDE is encapsulated in a polymer back coat on the fabric. The potential for environmental release associated with these textiles is higher than for thermoplastics because water is used in the back coating (Hardy, 2002).

Commercial formulations of PBDEs began in the late 1970s (World Health Organization and Environmental Health Criteria 162 1994). Penta-BDE was used in flexible and rigid polyurethane foam, epoxies, flexible polyvinyl chloride (PVC) compounds (Great Lakes Polymer Additives 2004), upholstery, bed mattresses and carpet padding (ENVIRON 2003a). Historically, commercial Penta-BDE has been used to provide coatings for specialty textiles, printed circuit board components, hydraulic and oil field completion fluids, and rubber products. Commercial Octa-BDE was used as an additive flame retardant in acrylonitrile-butadiene-styrene (ABS) terpolymers in computer casings and monitors (ENVIRON 2003b; Oliaei 2005). Commercial Deca-BDE is also an additive flame retardant used in many polymer applications. Approximately 10 to 15% total mass weight of plastic equipment may contain Deca-BDE, used in combination with antimony trioxide (EU 2002). Another application for Deca-BDE is in high-impact polystyrene (HIPS) used in electric and electronic equipment. Even though both Penta-BDE and Octa-BDE commercial products were phased out at the end of 2004 in the United States, they have continued to be used as inventories are being exhausted (UNEP 2006).

1.5.2 PBDE Chemistry and Characteristics

The general chemical formula of a PBDE is $C_{12}H_{(9-0)}Br_{(1-10)}O$, with the sum of H and Br atoms equal to 10 (Figure 1.1). PBDEs have a similar molecular structure to polychlorinated dibenzo-p-dioxins (PCDDs), furans (PCDFs), and polychlorinated biphenyls (PCBs). Not surprisingly, their chemical properties, persistence and distribution in the environment follow similar patterns. Methods of analysis for PCBs are also similar to those for PBDEs and PBBs (Rahman *et al.* 2001). As well, like PCBs, PBDE mixtures have low vapour pressure (3.85 to 13.3 Pa at 20 to 25°C), low water solubility and *n*-octanol/water partition coefficients ($\log P_{ow}$) between 4.3 and 9.9, an indicator of chemical bioaccumulation and highly lipophilic compounds. Key physical properties appear in Tables 1.3 and 1.4. Commercial PBDE mixtures have boiling points between 310 and 425°C.

PBDEs bind to the organic fraction of particulate matter, soils and sediments when they enter the environment (Environment Canada 2006; Canada Gazette Part I. December 2006). Nonetheless, in a study of PBDE loadings and degradation due to UV, this was not the case for solids from a tertiary wastewater treatment plant (Rayne and Ikonou 2005a). The authors suggested that PBDEs can fractionate into bottom sediments, biota, and the atmosphere.

The toxicological effects of PBDEs vary with the degree of bromination. They have a higher affinity to partition to aerosol particulates than PCBs, and their burdens now exceed those of PCBs measured in the Baltic Sea (ter Schure *et al.* 2004a). Lower brominated congeners such as BDE-47 and -99 dominate in the vapour state (Hale *et al.* 2006).

Table 1.3 Vapour pressure (Pa at 20°C), water solubility (pg/L), n-octanol/water partition coefficient (log K_{ow}), and other chemical and physical properties of some PBDE congener groups (World Health Organization and Environmental Health Criteria 162 1994; Darnerud 2001).

Property	tetra-BDE	penta-BDE	hexa-BDE	hepta-BDE	octa-BDE	nona-BDE	deca-BDE
Chemical Formula	C ₁₂ H ₆ OBr ₄	C ₁₂ H ₅ OBr ₅	C ₁₂ H ₄ OBr ₆	C ₁₂ H ₃ OBr ₇	C ₁₂ H ₂ OBr ₈	C ₁₂ HOBr ₉	C ₁₂ OBr ₁₀
Molecular mass	485.8	564.8	643.6	722.3	801.5	880.4	959.2
Vapour pressure (Pa) @ 20°C	no data	4.69x10 ⁻⁵	5.8x10 ^{-6*}	5.7x10 ^{-7*}	<1.33x10 ⁻⁵	no data	1.33 x 10 ⁻⁴
Water solubility (pg/L)[§]	1.09x10 ⁷	2.4x10 ⁶	8.7x10 ⁵	1.5x10 ⁶	5.0x10 ⁵	no data	2.0x10 ⁷ - 3.0x10 ⁷
n-octanol/water partition coefficient (log K_{ow})	5.87-6.16	6.5-7.0	6.9-8.0	no data	5.5-8.9	no data	5.24-10
Boiling Point (°C)	no data	>300	no data	no data	no data	no data	no data
Melting point (°C)	78-79*	97-98*	142-143*	171-173*	75-257	no data	290-306

[§]Original values reported in mg/L. They are converted to pg/L here for consistency with later chapters

*Single congeners

Table 1.4 Mean PBDE congener aqueous solubilities \pm standard deviation at 25°C (S_w ,25), melting point (T_m , °C), Henry's law constants at 25°C (H_{25}) (Tittlemier et al. 2002), and n-octanol/water partition coefficient (log K_{ow}) (Braakevelt et al. 2003)

PBDE Congener	S_w (25°C) [§]	H_{25}	T_m	log K_{ow}
	(pg/L)	(Pa m ³ /mol)	melting point (°C)	
BDE-15	$1.3 \times 10^8 \pm 2.0 \times 10^7$	21	57-58	no data
BDE-28	$7.0 \times 10^7 \pm 1.0 \times 10^7$	5.1	64-64.5	5.94 ± 0.15
BDE-47	$1.5 \times 10^7 \pm 2.0 \times 10^6$	1.5	83.5-84.5	6.81 ± 0.08
BDE-66	$1.8 \times 10^7 \pm 3.0 \times 10^6$	0.5	104-108	no data
BDE-77	$6.0 \times 10^6 \pm 1.0 \times 10^5$	1.2	96.5-98	no data
BDE-85	$6.0 \times 10^6 \pm 1.0 \times 10^5$	0.11	119-121	7.37 ± 0.12
BDE-99	$9.4 \times 10^6 \pm 8.0 \times 10^5$	0.23	90.5-94.5	7.32 ± 0.14
BDE-100	$4.0 \times 10^7 \pm 1.0 \times 10^7$	0.069	100-101	7.24 ± 0.16
BDE-153	$8.7 \times 10^5 \pm 6.0 \times 10^4$	0.067	160-163	7.90 ± 0.14
BDE-154	$8.7 \times 10^5 \pm 9.0 \times 10^4$	0.24	131-132.5	7.82 ± 0.16
BDE-183	$1.5 \times 10^6 \pm 3.0 \times 10^5$	0.0074	171-173	8.27 ± 0.26

[§]Original values reported in mg/L. They are converted to pg/L here for consistency with later chapters

1.5.3 Health Effects and PBDE Toxicity

PBDEs are known to be persistent and to bioaccumulate up the food chain. They are ubiquitous compounds found in most indoor environments through building materials, carpets, textiles, electronics, flooring, mattresses, foam, and plastics. The Cal/EPA PBDE Workgroup (Cal/EPA PBDE Workgroup 2006) found that although Deca-BDE does not bioaccumulate in the human body, people are exposed to Deca-BDE continuously and measurable concentrations are found in the blood.

The toxicity of PBDEs is not as well known as that of PCBs. However, toxicological data show that PBDEs pose serious health effects such as thyrogenic, estrogenic, and dioxin-like activities (Birnbaum and Staskal 2004) affecting the nervous, endocrine (Zhou *et al.* 2001; Stoker *et al.* 2004; Legler 2008) and immune systems (Darnerud 2001; James 2005). They can mimic the biological action of thyroid hormones (Darnerud 2001; de Wit 2002) because of structural similarities. PBDEs are neurotoxin and endocrine disruptors, causing thyroid and neurodevelopmental dysfunctions (Darnerud 2001; Siddiqi *et al.* 2003; Rice *et al.* 2007).

Information on humans is due to accidental exposures (Birnbaum 2008) or from minimal experimental evidence (Staskal *et al.* 2008). For the few PBDE congeners studied, hepatotoxicity, embryotoxicity, thyroid effects, and behavioural effects have been demonstrated at doses ranging from 0.6 to 80 mg/kg wet weight (Darnerud 2001; Darnerud *et al.* 2007). Thyroid effects include reduced serum levels of the thyroid hormone T₄ (thyroxine) when exposed to commercial Penta-BDE at doses of 3 mg/kg/day (Stoker *et al.* 2004), or 10 mg/kg/day (Zhou *et al.* 2001; Zhou *et al.* 2002).

Relatively recent reports (Darnerud 2001; Birnbaum and Cohen Hubal 2006; Tseng *et al.* 2006; Darnerud *et al.* 2007) have indicated that exposure to low concentrations of these chemicals may result in irreparable damage to the nervous and reproductive systems. They are also known to have similar properties and to demonstrate similar dangerous levels of toxicity as PCBs (Alcock *et al.*, 2003). PBDE concentrations have been found in humans to be 10 to 20 times higher in North Americans than in Europeans, whereas the latter are about twice those in Japan. Calculations by Hites (2004) show that body concentrations have been "exponentially increasing, with a doubling time of 4 to 5 years." According to Alaee (2003), of Canada's National Water Research Institute, "Everywhere we look we find measurable amounts of PBDEs."

Animal studies indicate that the biggest concern is the potential for Penta-BDE to promote developmental neurotoxicity (Darnerud 2001; Birnbaum and Cohen Hubal 2006; Rice *et al.* 2007). For instance, studies in Sweden (Eriksson *et al.* 2001; Viberg *et al.* 2003; Viberg *et al.* 2006) show that BDE-47, -99, -153 and -209 impair spontaneous motor activity and cholinergic transmitters and disrupt habituation. The results suggest negative effects on learning and memory, worsening with age. In a recent study of the effects of deca-BDE, a dose of 20 mg/kg/day produced developmental delays in neonatal mice (Rice *et al.* 2007). As adults, these mice exhibited altered spontaneous locomotor activity, suggesting long-term behavioural changes. Rodents exposed to commercial Penta-BDE *in utero* or post-natally showed impacts on brain function including changes in behaviour, learning and memory with a dose of 0.8 mg/kg (Eriksson *et al.* 2001; Eriksson *et al.* 2002; Birnbaum and Staskal 2004). A recent study in cats and dogs revealed pets to be sentinels of PBDEs (Environmental Working Group. 2008b).

Some studies have reported the health effects of recycling and disassembly operations on worker health. For instance, the impacts of specific operations on worker exposure are not well understood. Sjödin *et al.* (1999) studied computer technicians at electronic dismantling plants.

Three occupational groups in Sweden were studied to determine potential levels of PBDEs in human blood. One group consisted of workers at an electronics dismantling plant who dismantled electronic goods such as personal computers, television sets and radios. These workers wore dust masks while shredding the plastic. The second group consisted of workers who sat in front of computer screens 8 hours a day. The third group was composed of hospital cleaners. Congeners BDE-47, BDE-153, BDE-154 and BDE-183 as well as Deca-BDE (BDE-209) were found in the blood plasma of all three groups. The sum of the 5 congeners was highest in the electronic dismantler group (26×10^{-6} pg/g lipid weight). The PBDE congener concentration in the office worker group was 4.1×10^{-6} pg/g lipid weight. The study indicates that PBDEs in computers and electronics contaminate the working environment and accumulate in workers' tissues.

Another study (Thuresson *et al.* 2005) assessed the exposure of workers in manufacturing and handling flamed retarded rubber-coated cables. The results concluded significant (270×10^{-6} pg/g lipid weight) uptake of BDE-209 in workers exposed to the Deca-BDE commercial formulation and potential *in vivo* formation of lower BDEs in these workers. BDE-183 and BDE-47 were also detected. The study suggests that the most probable pathway of exposure was through inhalation of rubber dust generated during winding operations, extrusion and vulcanization. A follow-up study Thuresson *et al.* (2006) assessed the industrial hygiene and occupational exposure changes implemented since the first study took place. Although the amount of electronic goods doubled between the first and second study, the levels of BDE-183 and BDE-209 decreased due to improved industrial hygiene standards. However, the concentrations of BDE-47 did not change significantly.

A study of personal air sampling at an electronic recycling facility in Sweden (Pettersson-Julander *et al.* 2004) showed that exposure to PBDEs varied within the facility and depended on the worker exposure category. The first report on PBDE concentrations arising from uncontrolled e-waste recycling in China, (Wong *et al.* 2007) demonstrated high levels compared to other regions and countries. For example, concentrations of BDE-47, -99, and -100 were 5.2, 5.8 and 4.1 pg/L, respectively, 48, 25 and 3 times higher than corresponding levels in the US. The study concluded that incomplete combustion of e-waste in the open air and dumping of e-waste materials were the primary sources of PBDE emissions.

1.5.4 Occurrence of PBDEs in E-waste

Electronics have become so prevalent in every facet of society that they represent the single largest solid waste management problem facing the planet today, growing three times faster than the average growth of any other waste (Veleva and Sethi 2004) and representing a global disposal problem (Babu *et al.* 2007). In addition, in many parts of Asia, landfills contain mostly e-waste, creating potential PBDE contamination (Choi *et al.* 2009). Electronic equipment – computers, printers, scanners, photocopiers, facsimiles, telephones, mobile phones, etc. – have relatively brief life spans. For example, approximately 500 million computers were projected to become obsolete in the US during 1997 to 2007 (SVTC, 2004) and approximately 1.36 million metric tonnes of e-waste were discarded in landfills (Puckett *et al.* 2002; Greenpeace International 2005; Puckett *et al.* 2005; Hileman 2006; Kahhat *et al.* 2008). E-waste contains many hazardous materials such as heavy metals (e.g. lead, mercury, cadmium, and beryllium), plastics, and BFRs, which, if not properly handled, pose severe human and environmental risks. Each personal computer (PC) contains approximately 1.7 kg of flame retardant, of which ~ 70% (1.2 kg) is in the plastic cabinet, with the remainder coating the printed circuit board (Danish EPA, 1997; Menad *et al.*, 1998). The estimated proportion by weight of plastic contained in PCs and monitors is ~ 23% of the overall computer materials (Pedersen, *et al.*, 1996; RCBC, 2001; SVTC, 2004).

The life span of electronic computers has decreased from decades to a very few years, or even less. Millions of computers, monitors, and peripherals are considered obsolete after barely a year of active use. Many are stored in attics, garages and warehouses for extended periods before being discarded. The useful lifespan of a personal computer to its original owner has decreased to 2 to 4 years. The total lifespan (from manufacture to disposal) of a personal computer is estimated to be 3 to 6 years, considering re-use and storage options (US National Safety Council, 1999; EnvirosRIS 2001). Increasing amounts of e-waste are entering the final disposal stream in Canada as faster equipment replaces older devices. Recycling helps to divert some e-waste. However, much of it enters landfills and/or incineration for final disposal (Nordic Council of Ministers, 2001).

Waste electric and electronic equipment (WEEE) is composed of approximately 60% metals, 20% polymers, and 20% residual materials such as wood or glass (Schlummer *et al.* 2004). Of the polymers, ABS plastics contain ~18 to 22% by weight of OctaBDE while polystyrene

plastics contain ~10 to 12% by weight of DecaBDE. Both of these plastics are used for electronic equipment (Nielsen and Christensen 2001). Electrical and electronic equipment typically contain polymers such as thermoplastics, thermosets and elastomers (Menad *et al.* 1998) as well as BFRs.

Both Penta-BDE and Octa-BDE commercial formulations have been phased out of electronic items (Morf *et al.* 2005) in North America and the EU. However, Deca-BDE is still widely used, though restrictions continue to be debated in North America, with both Maine and Washington enacting bans on its use in some consumer products (La Flamme *et al.* 2008). The EU restricted the use of Deca-BDE as of July 2008 (Betts 2008a; Environment Canada 2009a; Schechter *et al.* 2009a). Prevedouros *et al.* (2004) estimated that the flow of Penta-BDE in disposed WEEE in the EU was between 17 and 60 metric tonnes per year during 2000 to 2005. Morf *et al.* (2005) determined that WEEE accounts for the largest volume of BFRs (in particular, PBDEs) compared to other wastes such as auto-shredder waste with approximately 75% of all Octa-BDE and 44% of Deca-BDE imported to the EU disposed via WEEE in the late 1990s.

Tasaki *et al.* (2004) analysed PBDEs in waste TV sets in Japan. Their results indicated that Deca-BDE was added to e-plastics between 1987 to 1990 and 1993 to 1996. They predict that the amount of PBDEs will rise in TV sets until at least 2020 because of the increasing size of the TV units. In one study of TV casings (Kajiwara *et al.* 2008), photodebromination of Deca-BDE to nona- and octa-BDE was observed. In a related study of TV plastic monitors, Choi *et al.* (2009) found that higher brominated compounds leached out more readily in the presence of dissolved humic matter.

1.5.4.1 End-of-life Issues for E-waste

There is little available information on how PBDEs behave in landfilled electronic waste. Indeed, neither the rate at which PBDEs are released from plastic nor their potential for degradation in leachate is known. Therefore, it is important to consider the impact of possible long-term diffuse emissions from landfills (Danish-EPA 1999; Kim *et al.* 2006). Releases of PBDEs into different environmental compartments could also occur during their synthesis, during their incorporation in products, during the active life of a product or during disposal or recycling. However, in a recent study by Petreas and Oros (2009) of California waste streams, PBDEs in e-waste were found in amounts of up to 1,200 tonnes/year.

According to a report commissioned by Environment Canada (EnvirosRIS. 2002) the total mass of end-of-life IT and telecom equipment recycled and disposed is estimated to be about 81,000 metric tonnes in 2002 and projected to be ~ 91,000 tonnes in 2010, a 12% increase over the 8-year period. The 2002 amount is equivalent to 2.7 kg per capita for a Canadian population of 30 million people, ~1.1% of the total disposed residential waste stream in Canada. If all other electric and electronic equipment products are added, the total electronic equipment reaching its end-of-life is estimated to be approximately 167,500 metric tonnes in 2002 and about 224,500 metric tonnes in 2010, a 34% increase over the 8 year period discussed. The 2002 disposal represents 5.6 kg per capita, or 2.4% of the residential waste stream.

An Environment Canada study predicted the amount of e-waste in Canada recycled or disposed in 1999. They expected the e-waste to be recycled or disposed of in 2005 with a Waste Flow Tool (Figure 1.2, Tables 1.5 and 1.6) (EnvirosRIS 2000, 2001; VanderPol 2003), designed to estimate the number of units and tonnage reaching the end of their life or becoming obsolete each year. The 1999 and 2005 e-waste groups are divided into disposal, recycle, reuse and storage, where disposal could be either to a landfill or by incineration. Reuse includes donated, resold, and refurbished units. Storage includes warehouses, basements, closets, and storerooms. This study predicted that IT disposal would double from 1999 to 2005. Provincial breakdowns are not available except for 2004 data from Ontario. In that province, WEEE (Waste Electric and Electronic equipment, EU directive, 2003) material disposed was estimated to be ~20,000 metric tonnes per year (CSR *et al.* 2005).

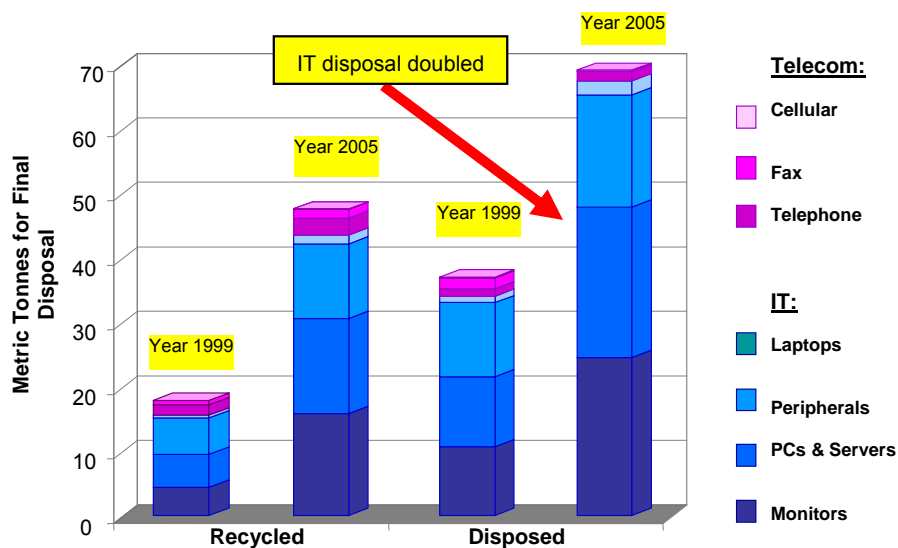


Figure 1.2 E-waste equipment disposed of and recycled in Canada (1999 to 2005) (EnvirosRIS, 2001; VanderPol, 2003)

An increasing number of waste computers and telecommunications equipment are making their way into landfills and other disposal facilities across Canada. According to an Environment Canada study (EnvirosRIS 2001; Mesquita and Grower 2004) on the growing problems associated with the generation and disposal of IT and telecom waste, Canadians discarded enough electronic products to fill 953 Olympic size swimming pools between 1992 and 2000.

End-of-life management of WEEE may be carried out via polymer recycling after removing BFRs from the plastics. Schlummer *et al.* (2007) studied methods to characterise polymer fractions from WEEE and the waste management strategies for efficient implementation under the WEEE Directive. One of the challenges is separating the different polymers found in WEEE, and another is separating the WEEE plastics from hazardous compounds. Other e-waste end-of-life electronics options include (Fisher *et al.* 2004): mechanical recycling, chemical feedstock recycling, biological recycling, process engineered fuel, energy recovery, and landfilling.

Table 1.5 E-Waste in Canada, metric tonnes (1999 to 2005) (EnvirosRIS 2000, 2001; RCBC 2001)

Equipment	1999 (metric tonnes)	%	2005 (metric tonnes)	%
PCs/servers	10,833	31.88	23,349	34.68
Monitors	10,688	31.46	24,472	36.34
Peripherals	11,474	33.77	17,396	25.83
Laptops	977	2.87	2,107	3.12
TOTAL	33,972	100.00	67,324	100.00

Table 1.6 E-Waste disposal management methods in Canada, metric tonnes (1999 to 2005) (EnvirosRIS 2000)

Waste Management Method	E-waste Equipment totals				
	1999 (metric tonnes)	%	2005 (metric tonnes)	%	% increase 1999-2005
Disposed	33,972	42.35	67,324	39.48	98.17
Recycled	15,592	19.44	43,428	25.47	178.52
Reuse	24,507	30.55	47,791	28.03	95.00
Storage	6,128	7.64	11,948	7.00	94.97
TOTAL	80,199	100.00	170,491	100.00	

1.5.5 PBDEs in Northern Canada

Key pathways of contaminant transport to the North include wind, ocean currents, river outflow, precipitation and runoff. Contaminants can spend different amounts of time in air, soil, water, ice, and in food webs, or may degrade (Macdonald *et al.* 2005). Wind can transport volatile and

semi-volatile chemicals from southern regions to the north within a few days (Stern *et al.* 1997; Halsall *et al.* 1998; Hung *et al.* 2001). Microbial degradation of contaminants may occur due to warming of surface waters (Kraemer *et al.* 2005). PBDEs are more likely to persist in Polar regions due to their cold climate (de Wit *et al.* 2006; Hung *et al.* 2008). The discovery of PBDE in the food chain of the Inuit population in the Canadian Arctic indicates wide dispersion of these compounds. As well, climate change is reducing ice coverage, increasing the possibility of PBDEs (and other contaminants) loading directly into the Arctic Ocean (Kraemer *et al.* 2005). Climate change is influenced by such factors as precipitation, UV radiation, cryosphere² degradation and human industrial activities (Kraemer *et al.* 2005). The temperature rise in the North may not be the most important parameter to study, but rather the change in the timing of seasons and whether or not temperature crosses 0 °C, enabling ice, snow, or permafrost to disappear (Macdonald *et al.* 2005). Another factor to consider is a phenomenon known as Arctic Oscillation which contributes to variations in atmospheric pressure over short periods of time, promoting delivery of contaminants to the Arctic (Kraemer *et al.* 2005; Macdonald *et al.* 2005).

Detection of lower brominated BDEs and PBBs in muscle tissue from guillemots (130 ng/g lipid weight) and ringed seal blubber (40 ng/g lipid weight) collected in 1981 (Jansson *et al.* 1987) was the first indication that PBDEs had reached the Arctic (de Wit *et al.* 2006). The Penta-BDE and Octa-BDE commercial formulations have been found to be ubiquitous in Arctic air samples although at levels (282 to 424 pg/m³) lower than in at southern latitudes (AMAP 2005). BDE-47, one of the lower brominated congeners in the Penta-BDE formulation, is found throughout the Arctic. One likely reason is that the atmosphere “distils the most volatile congeners among those present in commercial flame retardant mixtures” (Betts 2002a). Local air emissions may occur from burning of waste in some Canadian Arctic communities (de Wit *et al.* 2006). Mono-, di- and tri-BDEs were found in air samples from Alert, possibly indicating photodegradation of PBDEs during long range transport (CACAR II 2003). Wania and Dugani (2003) deduced that tetra- and penta-brominated BDEs have comparable Arctic accumulation potential to hexa- and hepta-chloroPCBs in air. They used global transport and fate models to study the air flow in the Arctic region. Because they take a long time to break down, PBDEs travel long distances, reaching the Arctic, where they deposit on soil, plant and animal life.

² Cryosphere describes the portions of the surface where water is in solid form including sea, lake and river ice, snow cover, glaciers, ice caps and ice sheets, and frozen ground (including permafrost).

Temporal data show PBDE levels increasing rapidly. For instance, PBDE concentrations in eggs of seabirds collected from Prince Leopold Island increased 10-fold between 1975 and 1998 (AMAP 2005). Total PBDE concentration in ringed seals from the Canadian Arctic increased exponentially from 1981 to 2000 (Ikonomou *et al.* 2002a). PBDEs are accumulating so quickly that they are likely to surpass PCBs to become the most prevalent halogenated compound in Canadian Arctic ringed seals by 2050 (Ikonomou *et al.* 2002a).

1.5.6 Long-Range Transport

Many factors contribute to long-range transport of PBDEs. Penta-BDE has a half-life in air of 19 days (Palm *et al.* 2002). Studies have found PBDEs spread across the Arctic (Peltola *et al.* 2000; AMAP 2002, 2005; Su *et al.* 2007; Jorundsdottir *et al.* 2009), Europe (Harrad and Hunter 2004; Harrad *et al.* 2004; Jaward *et al.* 2004; Lee *et al.* 2004; ter Schure *et al.* 2004b) and North America (Shen *et al.* 2006), the Great Lakes (Song *et al.* 2004; Song *et al.* 2005a, 2005b; Raff and Hites 2007) and far-north Pacific (Wang *et al.* 2005b). Strandberg *et al.* (2001a) and Wania and Dugani (2003) studied long range transport of PBDEs through various environmental compartments (air, water, soil and sediment) using different models. They determined transport distances of the most commonly found BDE congeners until their complete degradation or surface deposition. For instance, they estimated a characteristic transport distance from 1,113 to 2,483 km for tetra-BDE, 608 to 1,349 km for penta-BDE, 525 to 854 km for hexa-BDE and 480 to 735 km for deca-BDE congeners.

Although not often addressed, there is evidence of the “grasshopper” effect (de Wit *et al.* 2006), in which molecules experience multiple hops rather than a single emission-deposition event, and “global fractionation” during long-range transport of organic contaminants (Gouin *et al.* 2004). Long-range transport depends on the environment as well as physical and chemical properties of contaminants (Wania and Mackay 1996; Muir and Howard 2006). Hence, ambient temperature and volatility influence distributions.

1.5.7 Environmental Occurrence

PBDEs have an affinity for soils and sediments (Carson 2001). They are released into the atmosphere from manufacturing and degradation of products containing PBDEs and offgassing over time (Madsen *et al.* 2003; UNEP 2006). Even though both Penta-BDE and Octa-BDE commercial mixtures were phased out at the end of 2004, it is still unknown whether the

congener patterns identified in the environment are due to degradation of these persistent compounds or debromination of DecaBDE (Ahn *et al.* 2006).

Lower-brominated PBDEs have been found in remote locations, e.g. the far North (Danon-Schaffer *et al.* 2005c; Danon-Schaffer *et al.* 2007), and Antarctica. Deca-BDE in North America appears to be related to its point of release, e.g. urban areas and those where PBDE-containing biosolids have been applied (Hale *et al.* 2003). Concentrations in sediments seem to be a function of distance from the source and organic carbon content. Dodder *et al.* (2002) analysed surficial sediment samples in Indiana. BDE-209 congener was present in the highest concentrations, from 19×10^6 to 36×10^6 pg/g dry weight. Other detected congeners, BDE-99, -153, -154, -47 and -100, had concentrations less than 5×10^6 pg/g dry weight.

1.5.7.1 Air/Dust

PBDEs can be released to air from manufacturing plants, thermal degradation of products containing PBDEs and during normal use (Carson 2001). Penta-BDEs are persistent in air with potential long-range transport (see Section 1.5.6). Air emissions from PBDEs in cars, upholstered furniture, textiles, aircraft cabins, TV sets, and personal computers have been reported (Gevao *et al.* 2005; Hazrati and Harrad 2006; Christiansson *et al.* 2008; de Wit *et al.* 2008; Takigami *et al.* 2008; Laglante *et al.* 2009).

Potential point sources can increase PBDE concentrations in indoor air (Carson 2001). For instance, Octa-BDE was found in indoor areas containing electronic products. Electronic products, such as computers and television units containing BFRs, may also contribute to air emissions (Pettersson-Julander *et al.* 2004; Allen *et al.* 2008; Takigami *et al.* 2008; Chen *et al.* 2009), in addition to electronic dismantling facilities (Julander *et al.* 2005). Hale *et al.* (2002) suggested that polyurethane foam flame-retarded by Penta-BDE is one of the major sources in North America, due to the high demand for this product. In addition, Deca-BDE, widely used in the electronics industry, can leach into the environment and subsequently be transported in the atmosphere (Strandberg *et al.* 2001b; Muir *et al.* 2003) reaching the Arctic (Ikonomidou *et al.* 2002a). The high concentrations of total PBDEs (780,000 to 30.1×10^6 pg/g dry mass) in indoor environments could potentially become the typical exposure route (Stapleton *et al.* 2005).

PBDEs have been found in household air dust (Rudel *et al.* 2003; Harrad *et al.* 2004; Sjödin *et al.* 2004b; Costner *et al.* 2005; Allen *et al.* 2006; Gevao *et al.* 2006; Stapleton and Dodder 2006;

Wu *et al.* 2007; Allen *et al.* 2008; Betts 2008c; Cone 2008; Harrad *et al.* 2008; Sjödin *et al.* 2008; Takigami *et al.* 2008; Webster *et al.* 2008a; Webster *et al.* 2008b; Zota *et al.* 2008), carpet vacuuming (Schechter *et al.* 2005b; Sharp and Lunder 2005), clothes dryer lint (Stapleton *et al.*, 2005(Schechter *et al.* 2009b)), computer wipings (Schechter *et al.* 2005b), aircraft cabins (Christiansson *et al.* 2008) and vehicle interiors (Harrad *et al.* 2004; Shoeib *et al.* 2004; Wilford *et al.* 2004; Jones-Otazo *et al.* 2005; Stapleton *et al.* 2005; Gearhart and Posselt 2006; Betts 2008b; Mandalakis *et al.* 2008).

Recent studies by Suzuki *et al.* (2009) and Webster *et al.* (2008 and 2009) used microscopy to find elemental bromine which fingerprints the presence of BFRs in indoor dusts. The results from both studies point to volatilized PBDEs in dust particles. These studies shed light on potential transfer mechanisms of PBDEs.

1.5.7.2 Soil/Sediment

The vast majority of products containing PBDE compounds (~80%) are ultimately disposed of in landfills (or dumpsites) and the rest incinerated (Alcock *et al.* 2003). At present, there are no reported studies quantifying the distribution of PBDEs in landfill soils and the mechanism of leaching of PBDEs from such sites. However, de Boer *et al.* (2003) carried out a study in the Netherlands to determine contaminants in the aquatic environment with the objective of screening this environment for PBDEs. Sediments in water surrounding landfills and sewage treatment facilities in this study showed average BDE concentrations for BDE-47 (range from 300 to 7,100 pg/g, dw), BDE-99 (range from 100 to 700 pg/g dw) and BDE-209 (range from 4,000 to 510,000 pg/g dw), respectively. The deca-BDE concentrations in sediments have been the highest reported to date. In a separate but analogous study, Allchin *et al.* (1999) collected sediment samples in rivers, estuaries and adjacent coastal waters in the vicinity and downstream of suspected sources of commercial PBDE compounds. They found average concentrations of 300 to 368,000 pg/g, dw of BDE-47 and 600 to 898,000 pg/g, dw of BDE-99. These high concentrations suggested local point sources. A recent study (Chen *et al.* 2006) of surface sediments of the Yangtze River Delta suggests that variability in concentrations and geographic distributions of PBDEs from domestic and industrial waste discharge could originate from urban areas. Dilution by water and sediments from upstream could also contribute to low concentrations of PBDEs.

Atmospheric deposition is an important route for PBDE transport to sediments (Hale *et al.* 2003; Song *et al.* 2004). Sediment core samples are useful in recording fluxes of contaminants in the environment (Palm *et al.* 2002; Stern *et al.* 2005).

Higher brominated congeners are associated with sediment and organic matter, while lighter ones volatilize to the atmosphere more readily and are more likely to dissolve in water (Palm *et al.* 2002). As a result, congener-specific partitioning among different sediment particle size and organic content is expected. This could explain why some BDE distribution patterns are similar to those observed in air and water in other parts of the planet (Strandberg *et al.* 2001a; Gouin *et al.* 2002; Ikonomidou *et al.* 2002b). Widely differing ranges of BDE congener distributions in soils and sediments have been reported: 2,000 to 42,000 pg/g dw (Eljarrat *et al.* 2004b) and 10 to 10,600 pg/g dw (Lacorte *et al.* 2006) in Spain; 3,400 to 13,800 pg/g dw in Singapore (Wurl and Obbard 2005); 50 to 2,900 pg/g in Sweden (Nylund *et al.* 1992); 14,000 to 22,000 pg/g dw in the Netherlands (Verslycke *et al.* 2005); ND to 212,000 pg/g dw in the US (Oros *et al.* 2005); and 1,000 to 44,000 pg/g in the Great Lakes region (Song *et al.* 2004; Song *et al.* 2005a, 2005b). Most of these studies reported higher contributions from BDE-99 than from BDE-47, with negligible concentrations of low-BDEs. The differences may be attributable to different commercial Penta-BDE formulations, congener fractionation during movement and/or partitioning into environmental compartments based on volatilization (Chen *et al.* 2006). Sediment total organic carbon (TOC) content also contributes to the dispersion of organic contaminants (Mai *et al.* 2003). Gouin and Harner (2003) and Chen *et al.* (2006) found that PBDEs partition to organic carbon in soil and sediments due to their log K_{ow} and lipophilic properties.

Soil samples collected along a latitudinal transect through Norway and the UK in both remote and rural settings were found to contain the main penta-BDE congeners (BDE-47, -99, -100, -153 and -154) with concentrations between 65 and 12,000 pg/g dry weight (Hassanin *et al.* 2004). These results suggest that materials treated with commercial PBDE product readily transfer the congeners that make up the commercial formula, with little degradation.

Levels of PBDEs in sediment and soil were reported to be between 260 and 244,000 pg/g dry weight (Wang *et al.* 2005a) and 18 to 1,270,000 pg/g dw (Leung *et al.* 2007) in the vicinity of an open electronic waste disposal and recycling facility in Guiyu, China. Leung *et al.* (2007) found

that uncontrolled recycling and disposal of e-waste by simple dismantling, acid treatment and open burning contaminated the soil, causing PBDE migration into a river system.

1.5.7.3 Sewage Sludge

Reductive dehalogenation (e.g. substitution of Br or Cl by a hydrogen atom) can occur in sewage sludge (Gerecke *et al.* 2006). Anaerobic degradation in sewage sludge has been reported for BFRs and other halogenated compounds (Hana *et al.* 2008). PBDEs can also enter the environment via discharge from wastewater treatment plants (Bush 2005; Oliaei 2005) as sewage sludge, treated as biosolids prior to re-applying to land. In most sludges, Penta-BDE and BDE-209 dominate (Hale *et al.* 2006). For example, Hale *et al.* (2003) found sewage sludge concentrations between 1.1×10^6 to 2.2×10^6 pg/g of Penta-BDE, 10 to 100 times higher than found in European sewage sludge (Knoth *et al.* 2007). The major BDE contributors were BDE-47, -99, -100, -153 and -154. North (2004) found similar BDE distributions among the sewage effluent and sludge. Regional differences could be one reason for differing congener profiles (US EPA 2006). Petreas and Oros (2006) analysed wastewater treatment plant sludges and biosolids to determine their PBDE concentrations.

Influent, effluent, activated sludge and biosolids were analysed for total PBDEs from a wastewater treatment plant in the US by desJardins-Anderson and MacRae (2006). PBDEs were detected in the influent (4.2 to 4.3×10^6 pg/L), effluent (0.31 to 0.90×10^6 pg/L), and activated sludge (1.32 to 3.8×10^6 pg/L), but most PBDEs accumulated in the biosolids (2.32 to 3.53×10^6 pg/g dry weight). Sewage sludge has also been analysed in Spain (Fabrellas *et al.* 2004), Sweden (Sellström *et al.* 2005) and the Netherlands (de Boer *et al.* 2003).

Rayne and Ikonomidou (2005) studied the concentrations and patterns of PBDEs (sum of 46 congeners) in a tertiary-level wastewater treatment plant that included UV disinfection. It was found that PBDEs were not degraded significantly by the advanced wastewater treatment process. The levels in the resulting biosolids ($\sim 413 \times 10^6$ pg/L) may be of concern, as they are almost double the range reported for European sewage sludge (105 to 205×10^6 pg/L) (Hale *et al.* 2003).

Sewage sludge was analysed for PBDE concentrations after being applied to agricultural soils (Eljarrat *et al.* 2008). The predominant congener identified was deca-BDE. The study

concluded that a cumulative effect of sludge application contributed to an overall persistence of PBDE concentrations in soils.

1.5.7.4 Leachate

There are few studies comparing leachate quality between landfills containing e-waste and those that do not contain e-waste. This thesis evaluated the migration of PBDEs filtering out of e-waste through landfill leachate and distilled water. A mass balance model this was based on is discussed in detail in Chapters 8 and 9.

There are few studies on the leachability of PBDEs from flame-retarded plastics. Kim *et al.* (2006) investigated the effect of leachate on PBDEs in flame retarded plastic samples in a landfill and a batch leaching test. When plastic pieces were contacted with distilled water, a 20% methanol solution and aqueous humic solution of 1,000 mg/L (based on organic carbon), the leachability resulted from a cosolvency effect and bonding between PBDEs and dissolved humic matter. The authors concluded that leaching of PBDEs in plastics results from diffusion from the surface of the plastics. Osako *et al.* (2004) analysed the leaching of various BFRs from different landfills in Japan and found that overall PBDE contributions were highest from BDE-47, -99 and -100, up to 4,000 pg/L.

Current PBDE levels in the environment could result from leaching first-generation flame-retarded products added long ago to landfills (Oliaei 2005). The PBDEs could also migrate from landfills into ground and surface water, and/or through landfill gases. For instance, polymer foam containing Penta-BDE could transfer to leachate or groundwater from within a landfill. Some Norwegian screening studies (UNEP 2006) report Penta-BDE concentrations in landfill leachate.

Landfills are considered the main entry for municipal wastes containing PBDEs (de la Torre *et al.* 2008). In spite of this, there are few studies that evaluate the fate of PBDE-containing products in landfills. Once PBDEs enter a landfill, they may volatilise, leach and /or diffuse into different environmental compartments.

1.5.7.5 Human Exposure

There is very little information on potential adverse health effects from human exposure to PBDEs. However, there is concern regarding human developmental neurotoxicity (Birnbaum and Staskal 2004; McDonald 2005). Any correlation to potential human development neurotoxicity (0.14 to 1.0 mg/kg/day) (McDonald 2005) relies on animal data (Costa and Giordano 2007). Sub-chronic toxicity studies in rats have a no-observed-effect-level (NOEL) of 1 mg/kg/day for Deca-BDE and less than 10 mg/kg/day for Penta-BDE (Darnerud 2001). Exposure to PBDEs may result in irreparable damage to the nervous and reproductive systems. Toxicological data (Birnbaum and Staskal 2004) show that PBDEs pose serious health effects such as thyrogenic, estrogenic, and dioxin-like activities. Human exposure can occur by inhalation as an occupational air pollutant, by dermal absorption as an occupational hazard, by contact with products containing PBDEs, or by oral ingestion in foods (Carson 2001).

PBDE congeners have been detected in humans in North America with levels of 5 to 10,000 ng/g lipid (Birnbaum and Cohen Hubal 2006), children (Environmental Working Group. 2008a), breast milk (Meironyté *et al.* 1999; Hooper and McDonald 2000; Meironyté Guvenius *et al.* 2003; Schechter *et al.* 2003; Erdogrul *et al.* 2004; Kalantzi *et al.* 2004; Kazda *et al.* 2004; Fangstrom *et al.* 2005; She *et al.* 2005a, 2005b) and blood (Ryan and van Oostdam 2004; Faldt *et al.* 2005; Jakobsson *et al.* 2005; Schechter *et al.* 2005a; Harrad and Porter 2007). The levels in lipid are approximately 10 to 70 times the European or Asian levels, whose average concentrations are 1 to 10 ng/g lipid (Meironyté *et al.* 1999; Strandman *et al.* 2000; Sjödin *et al.* 2001a; Darnerud *et al.* 2002; She *et al.* 2002; Thomsen *et al.* 2002; Petreas *et al.* 2003; Schechter *et al.* 2003; Ingelido *et al.* 2004; Vieth *et al.* 2004; Sjödin *et al.* 2004a; Peele 2006).

An increase in PBDE levels in humans was found in breast milk (Norén and Meironyté 2000). Exposure models indicate children receive up to 300 times more PBDEs than adults, mainly through inadvertent dust and breast milk ingestion (Jones-Otazo *et al.* 2005; Stapleton *et al.* 2005). Concentrations as high as 0.27 ppm were reported in occupationally exposed workers in rubber and electronic recycling facilities (Thuresson *et al.* 2005; Thuresson *et al.* 2006). And e-waste facility workers are now acknowledged as a group exposed to significant concentrations of PBDEs (Schechter *et al.* 2009a) as well as their food intake (Zhao *et al.* 2009).

1.5.7.6 Biota Exposure

Since the early 1980s, a multitude of studies performed on biota (Haglund *et al.* 1997; Allchin *et al.* 1999; Ikonomou *et al.* 2000; de Boer *et al.* 2003; Baker *et al.* 2004; Vorkamp *et al.* 2004; Ikonomou *et al.* 2005; La Guardia *et al.* 2007) indicate that PBDE levels are rising in Canadian biota, especially over the past two decades. A recent study from California indicates possible products of biological debromination in peregrine falcon eggs (Holden *et al.* 2008). Although the highest PBDE levels are found in industrialized regions, the increase in PBDE concentrations in Arctic biota provides evidence of long-range atmospheric transport (Stern and Ikonomou 2000). A recent study from the Beijing area in China (Chen *et al.* 2007) found high concentrations of BDE-209 in birds of prey. High volumes of obsolete e-waste transported to China for recycling may be a major source. It has been estimated (Martin *et al.* 2004) that ~ 145 million pieces of electronic equipment were ‘recycled’ in 2002 in China, containing up to 2.61×10^8 kg of PBDEs.

Temporal trends of PBDEs were analysed in eggs of marine and freshwater birds from British Columbia from 1979 to 2002 (Elliott *et al.* 2005). The highest concentrations were in heron eggs from the Fraser River Estuary. Predominant BDE congeners were consistent with the technical Penta-BDE formulation. PBDEs were analysed in freshwater fish and water samples collected from lakes and rivers in Washington State (Johnson *et al.* 2006). High PBDE concentrations were found in one river with the predominant congeners being BDE-47, -49, -99, -100, -153, and -154. In a recent study (Kimbrough *et al.* 2009), a survey of PBDEs in bivalve tissues and sediments along the U.S. coastal zone was undertaken. The highest concentrations of PBDEs were found near urban and industrial centres, with concentrations directly proportional to human population.

1.5.7.7 Emissions and Releases

Releases of PBDEs could occur during their synthesis, towards the end of the product formation, during the life of a product or during disposal or recycling. All of the PBDEs used in the world are manufactured in very few countries. A Substance Flow Analysis by the Danish government (Lassen *et al.* 1999) reported that most PBDEs are released to the atmosphere through end products and production losses.

In a separate study, emissions of DecaBDE were estimated in Japan (Sakai *et al.* 2006) from textile processing, plastics processing, home appliance recycling and incineration. Emissions of various BFRs (PBDEs, HBCD and TBBPA) were measured for consumer products and building materials in Germany (Kemmllein *et al.* 2003). The results could imply that indoor air quality may be affected and be a source of human exposure. An increase of temperature (from 23 to 80 °C) was found to cause a 500-fold increase in PBDE concentrations.

It is thought that some BFRs and subsequently PBDEs in the environment originate from BFR-flame-retarded polymers, electronic equipment, polyurethane foam (de Boer *et al.*, 2000) and industrial facilities (Alaee *et al.*, 2003). Other sources are municipal, hospital, or hazardous waste incinerators, facilities recycling plastics and metals from electronic devices, final disposal sites, and accidental fires. According to Watanabe and Sakai (2003), a Swedish survey on BFRs in river sediments close to a plastics plant showed higher levels of PBDEs downstream.

1.5.8 BDE Debromination

Deca-BDE degrades in sunlight into lower brominated congeners which are more toxic and bioaccumulative (Birnbaum and Staskal 2004; Eriksson *et al.* 2004; Söderström *et al.* 2004; Stapleton *et al.* 2004a; Stapleton *et al.* 2004b; Gerecke *et al.* 2005; Sharp and Lunder 2005; Stapleton *et al.* 2005; Ahn *et al.* 2006; Environment Canada 2006; Stapleton 2008). It can also be broken down by bacteria in anaerobic environments (Gerecke *et al.* 2005; He *et al.* 2006). Reductive debromination seems to be the preferred phototransformation pathway for deca-BDE in organic solvents (Watanabe and Kashimoto 1983; Hua *et al.* 2003; Palm *et al.* 2004) forming lower brominated BDEs (Environment Canada 2006). A recent study (Tokarz *et al.* 2008) conducted experiments using anaerobic sediment microcosms to determine BDE debromination. Nine new BDE congeners were identified with this method.

The effect of the bromine position on photolytic reaction rates for molecules with fewer than five bromine atoms per carbon ring is unknown. However, molecules with a maximum of five bromine atoms attached to a carbon ring appear to degrade faster (Peele 2006). Studies by Eriksson *et al.* (2004) and Bezares-Cruz *et al.* (2004) on photodegradation suggest that congeners with bromine atoms in the ortho- position are most reactive.

Gerecke *et al.* (2005) found that Deca-BDE slowly degrades under anaerobic conditions in sewage sludge, whereas Parsons *et al.* (2004) reported degradation by anaerobic sediment

microorganisms. In the former study, the decrease in Deca-BDE concentration was consistent with a pseudo-first order degradation rate constant of 0.001/day, corresponding to a half life of 700 days. Lower BDEs were formed by anaerobic degradation. In a more recent study (Gerecke *et al.* 2006), various BFRs were measured for degradation potential. The estimated half-lives of Deca-BDE were between 700 and 1400 days. No degradation to lower BDEs was observed. However, the degradation rate constant of Deca-BDE was found to be at least two orders of magnitude lower than for the other BFRs measured. Gerecke *et al.* (2006) postulated that free concentrations of Deca-BDE in an aqueous environment could be lower than other BFRs. This could become a rate-limiting factor for Deca-BDE degradation.

Photodegradation of BDE-209 on particles could be important when estimating the global distribution of PBDEs (Ahn *et al.* 2006). Ikonomou *et al.* (2002a) suggest that atmospheric transport and sorption onto airborne particulates must be considered as possible factors. Photolysis can result in the cleavage of carbon-bromine bonds, deca-BDE degrade quickly when exposed to UV radiation in the presence of toluene, with a reported half-life of 15 min (de Boer *et al.* 2000a). Toluene is also known to photolytically degrade PBDEs to products that are more toxic and more bioavailable (Carson 2001). Degradation rates vary with the intensity of UV light (de Boer *et al.* 2000a). The rate of UV absorption appears to decrease as the number of bromine atoms in carbon rings decrease (Peele 2006) due to the upper limit on the light wavelength that the molecules absorb. The range of wavelengths absorbed by PBDE molecules decrease as the number of bromine atoms decreases (Peele 2006). The chemical properties of the matrix could also affect the distribution of breakdown products.

1.5.9 Landfills

Solid waste composition is a function of socioeconomic conditions, location, season, waste collection and disposal methods, sampling and sorting procedures. Typical municipal solid waste is composed of paper/cardboard, food and yard waste, plastics, glass, metals, wood/textiles, and inorganics (Confidential 2005; Scott *et al.* 2005). Some e-wastes and other PBDE-containing solid wastes are sent to incinerators, and some bottom ash from these is then sent to landfills as cover (< 25 mm in size). Details are discussed in Section 3.6.

Leachate is generated when water from precipitation, snow and the waste itself percolates through waste layers (Figure 1.3). Rainfall is the largest contributor to leachate production

(Scott *et al.* 2005). Leachate composition varies significantly among landfills depending on waste composition and waste age (Robinson *et al.* 2003). No barrier material is completely impervious to leachate. However, subsurface migration can take many years and improper leachate control may not be noticed until years after deposition.

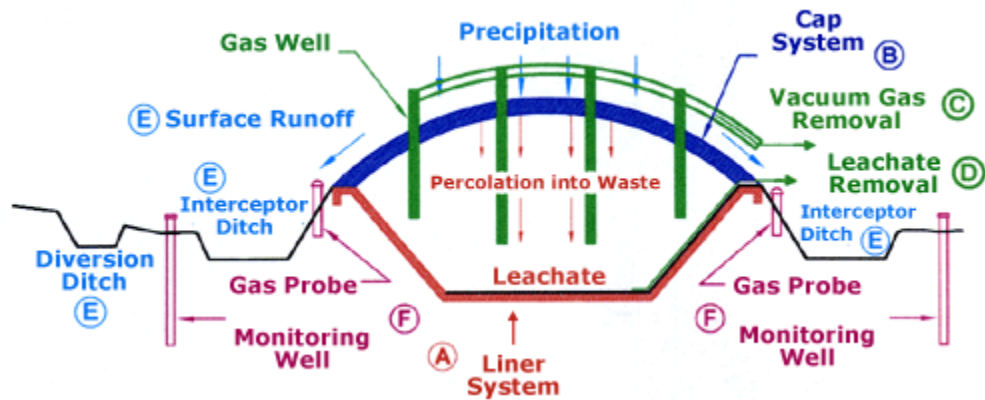


Figure 1.3 Typical sanitary landfill (Pennsylvania Waste Industries Association. 2005)

Mainstream components found in leachate include metals, halogen anions, organic compounds, dissolved organic matter, endocrine-disrupting chemicals and xenobiotic organic compounds (Scott *et al.* 2005). Landfills pass through many phases where oxygen from the atmosphere penetrates deep into the waste, which decomposes over time. As refuse degrades in landfills over many years in a series of cells, it is common for different parts of the landfill to be in different phases of decomposition. Typically, there are four phases of decomposition: a) initial aerobic phase, b) anaerobic acid phase, c) initial methanogenic phase, and d) stable methanogenic phase (Kjeldsen *et al.* 2002). During the acid phase, the leachate may show low pH and high concentrations of many compounds. In the later stable methanogenic phase, the pH increases (Scott *et al.* 2005). The evolution of a landfill environment and any potential changes in leachate composition are strongly affected by the supply of oxygen. Intrusion of oxygen depends on the remaining degradable organic carbon, gas generation rate, cover properties and topography of the landfill. The oxidation/reduction potential is used to determine the ability of a landfill system to facilitate these types of reactions. Micro-organisms transform available oxygen while decomposing waste and create anaerobic conditions. Temperatures within landfills are typically above ambient conditions, affecting bacterial activity, chemical and physical processes, solubilities and adsorption (Scott *et al.* 2005).

Major potential environmental impacts related to landfill leachate are pollution of groundwater and surface water. The risk of groundwater pollution is the most severe impact because most landfills were built without engineered liners or leachate collection systems (Kjeldsen *et al.* 2002). Many were shallow and built in small areas; compaction of deposited wastes was rare (Scott *et al.* 2005). Degradation occurred aerobically, whereas in modern landfills decomposition is usually dominated by anaerobic processes.

1.5.10 Relevant Legislation

In July 2006, it was determined that the congener groups - tetra-BDE, penta-BDE, hexa-BDE, hepta-BDE, octa-BDE, nona-BDE and deca-BDE - meet the dangerous substance criteria under Section 64(a) of the *Canadian Environmental Protection Act* (CEPA 1999). This act determines whether a substance is “entering or may enter the environment in a quantity or concentration or under conditions that constitute or may constitute a danger in Canada to human life or health” (Health Canada 2004; Environment Canada 2006; Berci 2007). It was concluded that all seven BDE congener groups meet the Virtual Elimination (VE) criteria. In addition, these compounds meet the weight of evidence approach under Section 76.1 of CEPA 1999 and the criteria for persistence and/or bioaccumulation and inherent toxicity to non-human organisms under Section 73 of CEPA 1999. A comprehensive ecological screening assessment performed by Environment Canada (2006) concluded that although current concentrations of homologues (BDE congener grouped by bromine number) in commercial DecaBDE do not exceed thresholds measured in the environment, the persistence and potential for bioaccumulation are of concern (Environment Canada 2009b). Moreover, data indicate that the tetra-, penta- and hexa-BDE congeners are very bioaccumulative and satisfy the criteria that define bioaccumulation. Based on these assessments, the proposed PBDE regulations in Canada will prohibit the use, sale, offer for sale and import of tetra-, penta-, and hexa-BDE congener groups, and manufacture of mixtures, polymers and resins containing these substances. The regulations however, do not apply to imported manufactured articles already in use in Canada, i.e. existing electronic equipment or foam (Berci 2007). Environment Canada has since promulgated PBDE Regulations (SOR/SOR/2008-218) (Canada Gazette Part II. 2008).

A second phase of the proposed regulations will prohibit the use, sale, offer for sale, import of mixtures, products or articles containing concentrations of total tetra-, penta-, hexa-, hepta- and octa-BDE congeners >0.1%. The proposed regulations do not include higher brominated BDEs.

This is similar to the WEEE directive in the EU. At the same time, the Government of Canada is considering risk management actions for nona- and deca-BDE to minimize release of commercial Deca-BDE to the environment from textiles and plastic manufacturing operations.

A state-of-the-science report on Deca debromination and bioaccumulation was issued by Environment Canada (2009). It provides an updated analysis of bioaccumulation and transformation of deca-BDE, by summarizing evidence considered in the original Screening of Section 64 under CEPA in July of 2006. A Risk Management Strategy (Environment Canada 2009a) for PBDEs has been promulgated within the state-of-the-science report whereby regulatory controls for nona- and deca-BDE congeners would be established so that the concentration limit of these congeners in electronic equipment does not exceed 0.1% by weight, applying the same criteria as the EU WEEE Directive.

Although the EU and US are in the process of banning some PBDEs (European Parliament Directive, 2003; State of California, Assembly Bill No.302, 2003), past usage and consumption mean that even banned congeners will continue to persist in the environment for several decades at least. The European Court of Justice decided to ban the commercial Deca-BDE effective July 1, 2008 (Betts 2008a). The deca-BDE congener is not yet banned because it is difficult to substitute. It will continue in production and continues to be deployed as a flame retardant, with no early prospect of termination.

1.6 Research Objectives

This thesis addresses some of the issues identified above. The overall goal is to increase the understanding of transfer, accumulation and transport of PBDEs from location to location and among different environmental media. Specific objectives are:

- To determine PBDE levels and congener distributions in e-wastes, landfill leachates and soil at southern and northern sites in Canada;
- To calculate, to the extent possible, mass transfer rates and mechanisms for transfer of PBDEs from e-waste to leachate;
- To prepare a mass balance model and determine inputs/outputs for different environmental media, with particular focus on landfill leachate and e-waste in such a form that improved input parameters and assumptions can be added in the future as

more information becomes available; and

- To provide data and recommendations that can inform and motivate policy changes with respect to the management of PBDEs in electronic waste.

1.7 Plan for Subsequent Chapters

Chapter 2 presents the materials and methodology followed in the experimental component of the work. The experimental set-up is described in detail from bench-scale mini-experiments to an ‘End-over-End’ contacting chamber designed and fabricated for pilot scale experiments.

In **Chapters 3**, the analysis and evaluation of data from the samples obtained in this research are described in detail to assist the reader in interpreting the data presented in subsequent chapters.

Chapter 4 investigates the behaviour of PBDEs across the Canadian North, how they enter and are transferred among landfill leachate, sewage effluent, background water, and soils for sites remote from urbanized centres.

Chapter 5 presents sample concentrations from 27 urban landfill sites across Canada and compares the data with those from Chapter 4. Correlations between PBDE levels and population and latitude are also examined.

Chapter 6 presents results of experiments where crushed e-waste particles derived from waste electronic equipment manufactured in different 5-year periods were contacted with distilled water and leachate in the End-over-End Contactor. These results are used to obtain e-waste-to-liquid mass transfer coefficients. This chapter also discusses the mechanism for transfer of PBDEs from e-waste to different aqueous media.

Chapter 7 briefly considers the potential for PBDEs to be reintroduced to the landfill via incinerator ash in an attempt to obtain more information on possible sources of PBDEs.

Chapter 8 presents the generalized mass balance model and its assumptions, leading to a set of 24 ordinary differential equations (ODEs). Input concentrations, initial concentrations, volume, volumetric flow, surface area and mass transfer, mass transfer coefficients, reaction rates, kinetic constants, half-lives and non e-waste solids (NeWS) are estimated.

Chapter 9 provides predictions and sensitivity analyses of the mass balance model for the evolution of PBDE concentrations at a landfill site corresponding to three scenarios: Scenario 1: past three decades; Scenario 2: future with PBDE bans, and Scenario 3: future with complete termination of PBDE inputs.

Lastly, **Chapter 10** summarizes the experimental findings and mass balance model results. Recommendations for controlling and recycling e-waste and alternative flame retardants, as well as for further studies, are also provided.

CHAPTER 2 - EXPERIMENTAL AND ANALYSIS DESIGN

2.1 Introduction

Experiments were conducted to explore the transfer of PBDEs from e-waste to leachate and to obtain mass transfer coefficients required by the mole balance models, see Chapter 8, Section 8.9. The experiments examined PBDE leaching from e-waste representing different manufacturing periods. In these tests, landfill leachates and distilled water were contacted with crushed e-waste, predominantly computer monitor casings, keyboards, mice, and printers, and analysed for their PBDE concentrations after different contact times. Mass transfer coefficients were obtained in a bench scale solid-liquid End-over-End Contactor in which various plastics derived from e-waste were exposed to leachate obtained from a landfill serving a large urban centre under controlled temperature and other contacting conditions. Over the past three decades, waste material at the urban landfill¹ has been segregated into different parcels, one for each half-decade (5-year) interval, thus facilitating comparison of leachates from wastes added in different time periods. The PBDE concentrations were analysed before and after contacting with the ‘stockpiled’ e-waste. Figure 2.1 depicts the overall workflow for the in-house experiments.

The high cost of analyses limited the number of samples which could be analysed. By the end of this research project, four excellent laboratories across Canada and the U.S. contributed to analysing these samples, including ~10% duplicates².

¹ We are unable to identify the landfill because of its confidentiality provisions

² This means there was at least one replicate sample for every ten samples collected

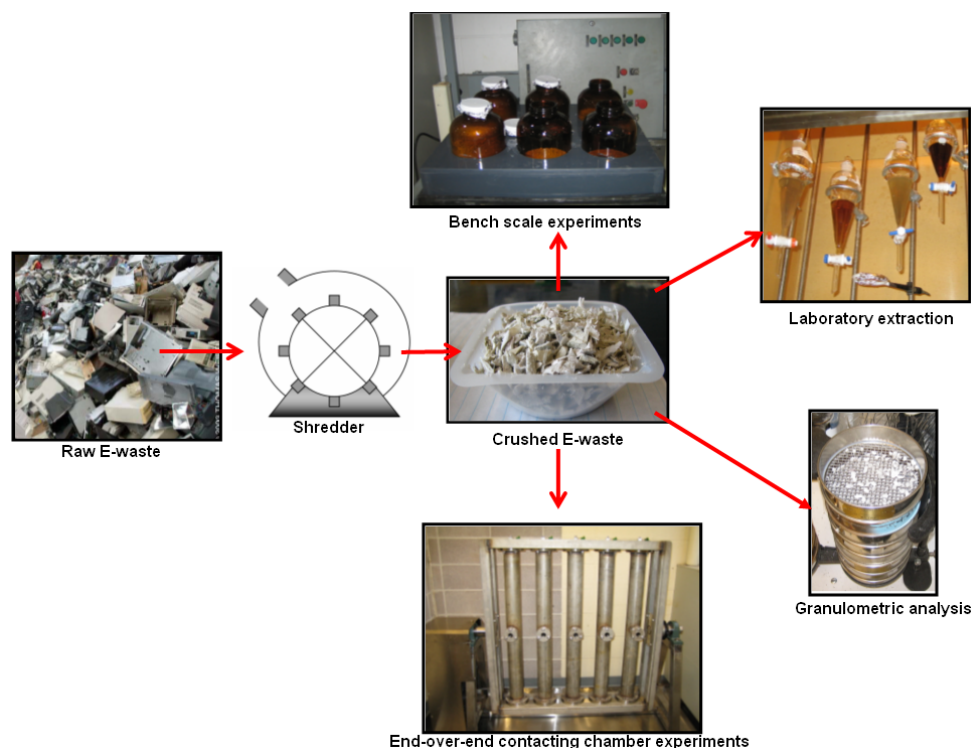


Figure 2.1 Flow diagram for in-house experimental program

2.2 Apparatus/Equipment

2.2.1 Bench Scale Shaker Table

The main objective of the bench scale experiments³ was to determine the transfer of PBDEs from e-waste to leachate. Initial experiments were carried out in a bench scale apparatus with a total volume of 15 L (i.e. six bottles with 2.5 L volume each), shown in Figure 2.2. The e-waste was first separated by decade of manufacture (1980s, 1990s and 2000+) based on information on the name plates. The plastic was then stripped and crushed into pieces of ~2 mm volume-equivalent diameter as described in Section 2.2.2. The pH of the leachate was adjusted with glacial acetic acid or sodium hydroxide to determine the influence of pH on the transfer of PBDEs from the e-waste. The shaker table could handle six 2.5 litre amber glass jars at a time, with a maximum shaking frequency of 30 rpm.

³ This experiment was conducted only once at the beginning of the research.



Figure 2.2. Bench-scale apparatus experiment set-up

The maximum contacting time at the bench scale was 1 hour. Every glass jar was triple-solvent-washed prior to each experiment in the following sequence: acetone → toluene → hexane to eliminate contaminants that could have led to false results in the analyses. The samples were stored at 4°C and shipped to the analytical laboratory in the same amber glass jars in which they were contacted with e-waste plastic pieces on the shaker table. These samples were not subsampled⁴ for analysis.

A number of unforeseen analytical challenges were encountered during the bench scale experiments. For example, when the samples were prepared for analysis, three distinct phases formed – an aqueous phase, an ‘oil-like’ phase and a ‘sludge-like’ phase. The aqueous phase and the ‘oil-like’ phase were analysed, whereas the ‘sludge-like’ phase was discarded. Due to the arduous sample preparation required to minimize PBDE contamination, the Gas Chromatography/High-Resolution Mass Spectrometry (GC/HRMS) analyses were time-consuming. See Section 3.5 for details of the sample preparation methodology.

The results from this experiment were not included in this thesis as they were found to be unreliable due to the extraordinarily high amounts of PBDEs in the samples (in the percent range), such that the lab was not confident that the results accurately reflected the PBDE concentrations.

⁴ This involves taking a sample aliquot from the main sample sent to the lab for analysis.

2.2.2 “End-over-End Contactor”

Various experiments were performed with a custom-built ‘End-over-End Contactor’. A list of all the experiments carried out in the ‘End-over-End Contactor’ appears in Table 2. 1. The first experiment involved crushed e-waste particles contacted with landfill leachate (Appendix B.2) from different time periods (i.e. 1985-89, 1990-94, 1995-99, 2000-05) in this novel pilot-scale contacting device shown in Figure 2.3. The contacting device or ‘End-over-End Contactor’ was designed and constructed to provide accelerated contacting of solid e-waste particles (100 g) with liquid (4 L) (leachate, distilled water or other). The final prototype was built and assembled by the UBC Department of Chemical and Biological Engineering workshop in 2005. The device simultaneously contacted e-waste with liquid in five separate parallel stainless steel vessels at a rotational speed of 8 revolutions per minute. Each vessel has an inside diameter of 76 mm, an inside length of 914 mm and a capacity of 5.0 L. To avoid contamination, every component of the equipment was fabricated from food-grade stainless steel with Buna-N rubber⁵ as packing for the valves to prevent leakage. No polytetrafluoroethylene (PTFE) (i.e. Teflon) was utilised in building or assembling the equipment. Caution was taken to ensure that no materials used to construct the End-over-End Contactor could contaminate the system or interfere with the HRGC/HRMS measurements. A listing of the materials is provided in Table B.1, Appendix B.

100 g of homogenously mixed and shredded plastic from computer housing/monitor hard cases (60%), printers (30%), and keyboards/mice (10%) (e-waste)⁶ were added to each vessel, together with 4 L of leachate. Care was taken to measure the exact volume in each vessel in order to estimate the headspace and to facilitate subsequent calculations.

Since similar experiments have not been reported previously in the literature, the effect of contacting time and the levels of PBDEs expected in the samples were unknown when the first tests were conducted. Hence it was necessary to perform initial “calibration runs” to determine the effect of exposure time. Three vessels were filled with a mixture of leachate and e-waste, each from a different decade (1980s, 1990s, 2000+), or from half-decades (1980-84, 1985-89, 1990-94, 1995-99, 2000-05). For example, in the 1980’s case, the ‘stockpiled’ e-waste was from computers, keyboards, etc. built during that decade, and the leachate was drawn in equal portions from the area of the landfill in contact with waste material from 1980-84 and 1985-89. Each of

⁵ This is a nitrile rubber which is a copolymer of polybutadiene and acrylonitrile

⁶ From various manufacturers

the five stainless steel vessels in parallel in the End-over-End Contactor was triple-solvent-washed prior to each experiment in the sequence: acetone → toluene → hexane, in the same manner as in the bench scale experiments. This washing was performed to remove maximum potential background contaminants. One vessel was filled with de-ionized water as a control. A fourth vessel contained 100 g of “composite waste” prepared by blending equal quantities by weight of particles from each of the above three decades, and then adding landfill leachate. In each case, the head space in the cylinders was ~20% of the overall volume.

Table 2.1 Experiments performed in the “End-over-End Contactor”. Leachate and contact times (1, 24, 96, 168, 654 h), as well as pH (4, 5, 7, and 9), and temperature (10, 20 and 25°C)

Type of experiment	Time interval	PBDE analysis only	Contact time (h) with leachate or distilled water					Parameters				Interlaboratory comparison			
			1	24	96	168	654	pH 4	pH 5	pH 7	pH 9	10°C	20°C	25°C	DFO-IOS & Vista
leachate from urban landfill	pre 1980s 1980-1984 1985-1989 1990-1994 1995-1999 2000-2005	x x x x x x	N/A					N/A				N/A		N/A x x x x x	
crushed e-waste	1980-1984 1985-1989 1990-1994 1995-1999 2000-2005 25 yr composite	x x x x x x	N/A					N/A				N/A		N/A N/A	
crushed e-waste composite	1980-2005	N/A	x	x	x	x	N/A	N/A				N/A		N/A N/A	
e-waste contacted with leachate	1980-1984 1985-1989 1990-1994 1995-1999 2000-2005	N/A	x x x x x	N/A x x N/A N/A				N/A x N/A x x				N/A x N/A x x		N/A x N/A x x	
ewaste contacted with distilled water	1980-1984 1985-1989 1990-1994 1995-1999 2000-2005	N/A	x x x x x	x x N/A x x	x x N/A x x		N/A N/A x x x				N/A N/A x x x		N/A x N/A x N/A		
leachate collection from across Canada	various	x	N/A					N/A				N/A		N/A N/A	
bottom ash/fly ash	2007	x	N/A					N/A				N/A		N/A N/A	
soil from in and around landfills in Northern Canada	2004-2006	x	N/A					N/A				N/A		N/A x	

In each experiment, the end-over-end rotation was initiated and then maintained for one of three different continuous time periods – 1, 24 or 168 hours, with one experiment contacting e-waste with leachate for 654 hours. The operating temperature was varied from 10 to 25°C by cooling or heating to change the temperature of the room in which the apparatus was located at least 12 h prior to the experiment and maintaining the temperature during the entire period of operation. The electrical conductivity and pH of the liquid were measured after completing each contacting and exposure period.



Figure 2.3 Pilot scale End-Over-End Contactor.

2.3 Materials utilised

2.3.1 E-waste Solid Phase Materials

A detailed description of the e-waste tested in the experiments is given in Section 6.1.

2.3.1.1 Particle Properties

A sieve analysis was performed to determine the particle size distributions. Photographs of the sieve stacks and one tray after sieving appear in Figures 2.4 and 2.5. Sieves of different standard sizes (6.3, 4.69, 4, 2.8, 2.36, 2, and 1.4 mm openings) were employed in these analyses. Results for the 1980-84 material appear in Figure 2.6. The sample size for each batch of e-waste was 700 g. The e-waste particles were weighed (ACR plus-1000 scale, Milton Keynes, UK, ADAM Equipment Co. Ltd) before and after shaking for 20 min. The Sauter mean particle diameter (Mayinger and Feldmann 2004) was estimated by $d_{sv} = 1/\Sigma(x_i d_i)$ where x_i is the mass fraction of particles with a representative size of d_i (mm). Most particles were not very angular, although some had sharp edges, as can be seen from Figure 2.5.



Figure 2.4 Stack of sieves used in particle size distribution analysis.



Figure 2.5 E-waste after mechanical shaking prior to weighing for particle size distribution analysis.

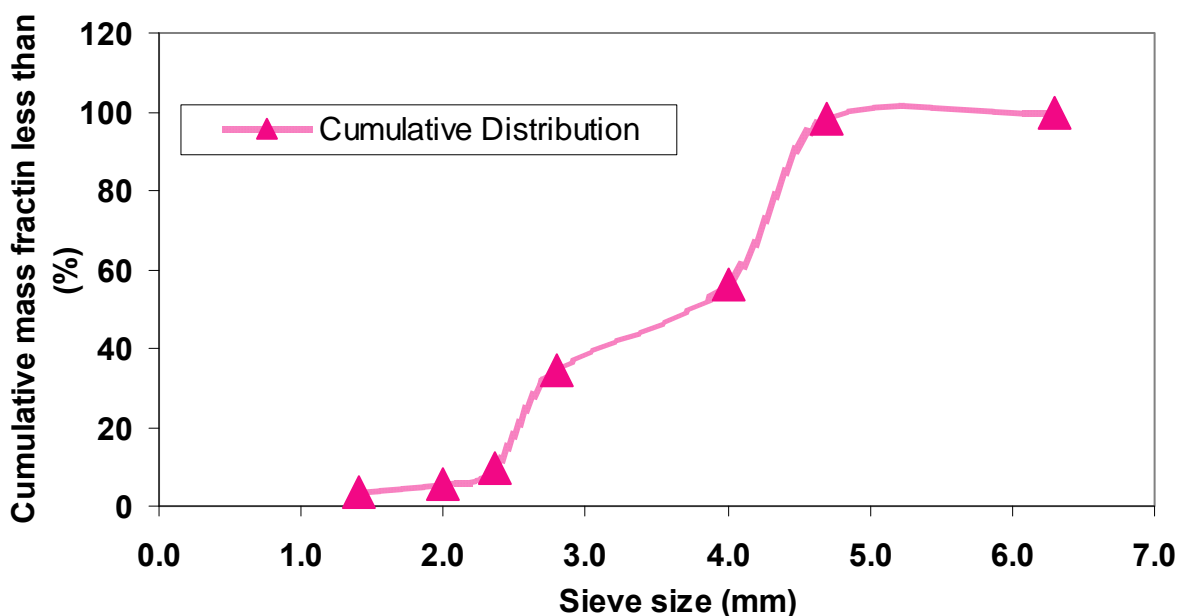


Figure 2.6 Cumulative particle size distribution for e-waste particles from the 1980-1984 time period.

The particle size distributions and corresponding Sauter means are given in Table 2.2.

2.3.2 Aqueous Phase Materials

Landfill leachate and distilled water were the liquids of choice for the experiments, with the latter serving as a control. Prior to contacting (i.e. mixing) landfill leachate from the urban landfill with stockpiled e-waste, landfill leachate samples corresponding to the 5-year time-interval disposal zones were analysed to evaluate the background concentrations of PBDEs and other organic/inorganic components. The landfill leachate collected from each of the 5-year disposal zones corresponded to liquid in contact with the wastes deposited during that 5-year interval. This facilitated analysis of trends over time. Landfill leachate was collected periodically over a period of ~6 months (~May-November 2005) and stored at 4°C until needed for the experiments.

Table 2.2 Particle size distributions for each of the time periods involved in the research (i.e. 1980-84, 1985-89, 1990-94, 1995-99, 2000-2005) together with Sauter means (mm).

Particle Distribution Analyses and			
Sauter means for e-waste Plastic Pieces			
Time Period	x_i	d_i	$d_{sv}=1/\Sigma(x_i/d_i)$
1980-1984	0.0185	5.5	2.79±1.76
	0.4186	4.34	
	0.2186	3.4	
	0.248	2.58	
	0.0418	2.18	
	0.0187	1.7	
	0.0221	0.7	
	0.0127	0.35	
1985-1989	0.0169	5.5	1.89±1.76
	0.2741	4.34	
	0.2084	3.4	
	0.3056	2.58	
	0.0592	2.18	
	0.0314	1.7	
	0.0425	0.7	
	0.0615	0.35	
1990-1994	0.0226	5.5	2.39±1.76
	0.3072	4.34	
	0.234	3.4	
	0.3104	2.58	
	0.0465	2.18	
	0.0236	1.7	
	0.0276	0.7	
	0.0277	0.35	
1995-1999	0.0181	5.5	2.45±1.76
	0.3474	4.34	
	0.196	3.4	
	0.293	2.58	
	0.0594	2.18	
	0.0304	1.7	
	0.0337	0.7	
	0.0208	0.35	
2000-2005	0.0218	5.5	2.46±1.76
	0.3645	4.34	
	0.1931	3.4	
	0.2768	2.58	
	0.0592	2.18	
	0.0288	1.7	
	0.0343	0.7	
	0.0211	0.35	

2.3.3 Types of Samples Collected and Examined

Eight types of sample were collected for this research project: leachate, e-waste, e-waste contacted with leachate, e-waste contacted with distilled water, soil, sewage effluent, background water, and ash from an incinerator (Table 2.3). The samples collected to contact e-waste in the Shaker Table (Section 2.2.1) and in the ‘End-over-End Contactor’ (Section 2.2.2) consisted of leachate from an urban landfill, crushed e-waste and distilled water (for the ‘End-over-End Contactor’ experiments only). Soil, sediment, leachate, sewage effluent and background water samples were collected from Northern Canada by the author as described in Section 2.4. For the Southern Canadian cities landfill project, leachate was collected from 27 jurisdictions as described in Section 2.4.1. Bottom ash, fly ash and waste residue from an incinerator were collected and analysed for PBDEs as well.

One hundred and five leachate, e-waste, e-waste/leachate, e-waste/distilled water and soil samples were analysed from a single urban landfill. In addition there were 85 samples from Northern Canada, 71 from the Southern Canadian cities and 3 from an incinerator in Ontario, for an overall total of 264 samples (Table 2.4). The samples were analysed in different laboratories, allowing some cross-comparison. The following laboratories performed analyses: DFO-IOS (Sydney, BC), Vista Analytical (El Dorado Hills, California), Duke University (Nicholas School of the Environment & Earth Sciences, Durham, NC), and the MOE (Dioxin and Toxic Organics Section of the Laboratory Services Branch of Ontario’s Ministry of Environment, Toronto, ON).

Table 2.3 Summary of all sample types (leachate, e-waste, e-waste/leachate, e-waste/distilled water, soil, sewage effluent, background water, and ash) collected according to equipment used (shaker table and End-over-End Contactor) and waste sources (major urban landfill, Northern Canada, Southern Canada landfills, and incinerator), 2004-2007.

Type of sample	Source*			
	Major Urban Landfill	Northern Canada	Cross - Canada	Incinerator
leachate	40	11	51	n/a
e-waste	6	n/a	n/a	n/a
e-waste/leachate*	29	n/a	n/a	n/a
e-waste/distilled water*	21	n/a	n/a	n/a
soil	1	39	n/a	n/a
sewage effluent	n/a	6	n/a	n/a
background water	n/a	13	n/a	n/a
ash	n/a	n/a	n/a	3
replicates (aqueous-Northern Canada)	n/a	7	n/a	n/a
replicates (soil-Northern Canada)	n/a	3	n/a	n/a
replicate (leachate)	2	6	20	n/a
replicates (e-waste/leachate)	4	n/a	n/a	n/a
replicates (e-waste/distilled water)	2	n/a	n/a	n/a
blanks (aqueous-Northern Canada)	n/a	16	n/a	n/a
blanks (soil-Northern Canada)	n/a	29	n/a	n/a
blanks (leachate)	4	9	26	n/a
blanks (e-waste/leachate)	2	n/a	n/a	n/a
blanks (e-waste/distilled water)	1	4	n/a	n/a
Total (minus blanks)	105	85	71	3
Overall total number of samples analysed (all sources)			264	

n/a = not applicable

* Preliminary experiments were performed in the Shaker Table, all others in the End-over-End Contactor

§ All sources kept anonymous in accordance with agreement from waste facility operators

Table 2.4 Summary of samples analysed (leachate, e-waste, e-waste/leachate, e-waste/distilled water, soil, sewage effluent, background water, and ash) collected and analysed by 4 different laboratories, 2004-2007.

Type of sample	Laboratory				Total No. samples/type
	DFO-IOS	Vista Analytical	Duke U	MOE	
leachate	97	5	n/a	n/a	102
e-waste	n/a	6	n/a	n/a	6
e-waste/leachate*	11	18	n/a	n/a	29
e-waste/distilled water*	2	19	n/a	n/a	21
soil	32	n/a	8	n/a	40
sewage effluent	6	n/a	n/a	n/a	6
background water	13	n/a	n/a	n/a	13
ash	n/a	n/a	n/a	3	3
replicates (aqueous-Northern Canada)	7	n/a	n/a	n/a	7
replicates (soil-Northern Canada)	2	n/a	1	n/a	3
replicate (leachate)	28	n/a	n/a	n/a	28
replicates (e-waste/leachate)	4	n/a	n/a	n/a	4
replicates (e-waste/distilled water)	2	n/a	n/a	n/a	2
blanks (aqueous-Northern Canada)	16	n/a	n/a	n/a	16
blanks (soil-Northern Canada)	29	n/a	n/a	n/a	29
blanks (leachate)	38	1	n/a	n/a	39
blanks (e-waste)	n/a	1	n/a	n/a	1
blanks (e-waste/leachate)	2	n/a	n/a	n/a	2
blanks (e-waste/distilled water)	1	4	n/a	n/a	5
Total (minus blanks)	204	48	9	3	264

n/a = not applicable

* Preliminary experiments were performed in the Shaker Table, all others in the End-over-End Contactor

As discussed in Section 5.3.2 (Chapter 5), the country was divided into four quadrants for data comparison purposes. The numbers of samples from each quadrant are summarized in Table 2.5. In most cases, one sample was collected per jurisdiction, but there were a few jurisdictions where more than one sample was obtained. This allowed for analysis of background samples, as well as leachate evaluation. In some jurisdictions, effluent from wastewater treatment was collected in addition to leachate and background samples.

Table 2.5 Cross-Canada sample locations, divided into NW, SW, NE and SE quadrants, jurisdictions and number of samples collected per jurisdiction (Lab: DFO-IOS, 2005-2006). (For identification of quadrant boundaries, see Section 5.3.2).

Quadrant	Symbol	Sample Locations	Jurisdictions	No. Samples / Jurisdiction
SW	▲	14	6	14
SE	●	6	14	11
NE	○	4	4	16
NW	△	6	3	10
Totals		30	27	51

E-waste samples were analysed in 5-year intervals and crushed to ~2 mm diameter pieces, as explained in Section 2.2.2 and 2.3.1, respectively. A composite sample for the 25 year time period was also prepared with equal solid mass for each 5-year interval. The crushed e-waste was also contacted with leachate and distilled water under different conditions to study the effect of pH, time of contacting, and temperature.

2.4 Experimental Methodology

When the work began, no previous analyses of mass transfer from e-waste particles to leachate and distilled water had been reported (some recent data by Choi *et al.* (2009) is discussed in Chapter 6). Therefore, it was decided to closely follow the Toxicity Characteristic Leachate Procedure (TCLP) under the US EPA (SW846 Method 1311) where 100 g of solid waste are contacted with a prescribed leaching fluid to simulate the conditions that may occur in a landfill as the waste decomposes. For our experiment, 4 L of leaching liquid (either distilled water or leachate) were added to each vessel along with 100 g of solid waste. Rotation at 30 rpm was then immediately started and maintained for different time periods (details provided in Chapter 6). TCLP experiments performed by Townsend *et al.*, (2004) to obtain heavy metals involved rotation at 13 rpm. In their study, they did not find any difference in leaching with a higher speed of rotation.

All leachate samples were collected in glassware previously washed with standard laboratory detergent (Alconox; White Plains, NY) and then rinsed in turn with distilled water, technical grade toluene, technical grade hexane, technical grade dichloromethane, and technical grade acetone, in that order. Glassware was left to dry for at least 2 hours to eliminate solvent residues. This same procedure was applied to both the shaker table and ‘End-over-End Contactor’ experiments.

The main lab analysing the samples vacuum filtered each sample with 0.7 µm filters. The filters were then sent for particulate organic carbon analysis (POC), and the aqueous filtrate was submitted for dissolved organic carbon analysis (DOC). Replicate results were averaged. Data that did not meet the criteria for blank concentrations⁷ were discarded for purposes of this analysis. The POC data were added to the DOC data to obtain Total Organic Carbon (TOC) values, to assist in interpreting the results.

2.4.1 Urban Landfill

Leachate from the urban landfill was collected from different disposal cells within the landfill, corresponding to wastes discarded during five time intervals: 1980-84, 1985-89, 1990-94, 1995-99 and 2000-05. In the landfill, leachate was confined to each disposal cell, i.e. not mixed with that from other cells. Leachate was collected to the depth of the water table using Waterra® tubing, with a foot valve fitted at the bottom. Dark amber glass bottles of 2.5 L volume were used to collect the leachate. Samples were then stored at 4°C until analysis. The leachate samples were then analysed for their PBDE concentrations according to the procedures covered in Section 2.5.

2.4.2 Northern Canada Landfills

The author visited the North in both July-August 2004 and July-August 2006. The 2004 samples were collected in Iqaluit, Cambridge Bay and Yellowknife. These communities were chosen because their geographical location was deemed to be representative of potential contamination in the North. The expanded scope for 2006 included 8 additional communities, as well as the three communities where sampling and collection of background drinking water samples had taken place in 2004. The 11 communities were Iqaluit, Pangnirtung, Cape Dorset, Pond Inlet, Hall Beach, Rankin Inlet and Cambridge Bay in the Territory of Nunavut; Yellowknife, Inuvik and Tuktoyaktuk in the Northwest Territories; and Whitehorse, Yukon. The exact sampling locations are shown in Table B.2, Appendix B.

Soil samples from solid waste disposal and background sites were also collected in order to identify local PBDE concentrations, e.g. due to atmospheric deposition, during both field

⁷ The lab blank criteria is described in detail in Chapter 3. One approach was to subtract two times the value of the blank from the data obtained. If this result is positive, the data is considered verifiable and utilized for interpretation. Otherwise, it is discarded as there could be laboratory interferences that give a false positive result. Another approach was to average all values and apply a standard deviation to compensate for laboratory contamination.

seasons. Soil was collected from a 0-20 cm deep surface layer above the permafrost. Leachate and effluent outfall samples were collected at representative locations and at positions chosen by local authorities. Background water samples were also collected to provide a baseline.

Air transportation was used to travel from community to community in the Arctic, with Iqaluit and Yellowknife as bases. SUV vehicles were rented locally to facilitate the transportation of samples. Initially, employees from each government region accompanied the author to assist in gaining familiarity with the areas of interest. After that, she returned on her own to carry on with the research. Hand trowels were used for both soil and sediment collection. Samples were stored in cool areas and shipped to DFO-IOs. All bottles were wrapped in bubble paper, placed in plastic bags, and surrounded by ice packs for shipment by air transport.

2.4.3 Southern Canada Landfills

Landfill leachates from 27 jurisdictions across Canada were collected in order to obtain some data showing the variability of different landfill sites and the dependence of PBDE concentration (if any) on such factors as population, pH, climate, and latitude/longitude. An example of the confidential letter sent on behalf of the author to ask permission for leachate sampling is found in B.3, Appendix B. These samples were collected by the landfill operators using different collection methods ranging from Waterra® tubing to submerged bailers (Table 2.6). The depth and location of leachate collection varied, with no standardized method of collection. The variations were unavoidable given that each site was separate, with operators performing the sampling as a favour and according to their own local procedures. Some leachate was collected by pumping with Waterra® tubing; as previously described, other leachate was obtained as grab samples using a jar attached to a rod, submerging to different depths (~0.3-10 m). When Waterra® tubing was utilised, leachate was pumped from below the water table. Most of the leachate was collected in the spring (April through June), although in two locations it was collected during the fall (September and October). No leachate was collected during the winter months (November to March).

Table 2.6 Cross-Canada leachate by region, landfill type, landfill origin, method of collection, approximate leachate age (e.g. 1980s, 1998, 2006, etc.), and date collected, 2005-2006 (Lab: DFO-IOS)

Region	Landfill Type	Landfill origin	Collection method	Date sample collected
▲	municipal	2005	Watterra®	spring/summer (2005)
▲	municipal	1960s	Watterra®	fall (2005)
▲	municipal - industrial	1990s	grab sample - jar attached to rod	spring (2006)
▲	municipal	1970s	grab sample - jar attached to rod	spring (2006)
▲	residential - commercial	1970s	unavailable	fall (2005)
▲	unavailable	unavailable	unavailable	spring (2006)
△	municipal	2006	Watterra®	summer (2006)
△	municipal	2000+	bottle submerge	summer (2006)
△	municipal	2006	bottle submerge	summer (2006)
●	municipal + C&D	1990-2006	spigot during tanker truck loading	spring (2006)
●	private	1980-2006	unavailable	spring (2006)
●	municipal	late 1990s	Watterra®	spring (2006)
●	municipal + IC	~ 1940s, most 1970s+	active/inactive portion	summer (2006)
●	municipal	1970s	active/inactive portion	summer (2006)
●	municipal	2002	bucket from leachate pumping station	fall (2005)
●	municipal + 60% IC	early 1970s	bailers	spring (2006)
●	municipal + 60% IC	early 1970s	bailers	spring (2006)
●	municipal + IC	1992	bailer	spring (2006)
●	municipal	1980s	dedicated sampling rope	summer (2006)
●	municipal	1995	active/inactive area, half pre/post-2002	summer (2006)
●	municipal + industrial	1950s-2006	small bucket on rope approx 10 m down	spring (2006)
●	municipal - industrial	1980s	bailer	spring (2006)
●	municipal	1994	bailer	spring (2006)
○	municipal	2000+	bottle submerge	summer (2006)
○	municipal	2006	bottle submerge	summer (2006)
○	municipal	2006	bottle submerge	summer (2006)
○	municipal	2006	bottle submerge	summer (2006)

C&D: construction and debris

IC: industrial and commercial

2.5 PBDE Sample Preparation

The congeners of greatest interest are those prevalent in the three principal PBDE commercial products – Penta, Octa and Deca-BDEs. Nine congeners: BDE-47, -99, -100, -153, -154, -183, -197, -207 and -209 are of particular interest due to their persistence in the environment. These congeners, as well as others, were determined using Gas Chromatography/High Resolution Mass Spectrometry (GC/HRMS).

PBDEs in general, and BDE-209 in particular, appear to be everywhere and also present in laboratory air, equipment, etc. All laboratories are therefore prone to PBDE contamination. However, all labs that analyse PBDEs try to minimize contamination from these compounds as much as possible, by means of many measures, including HEPA⁸ air filtration, air control (i.e. fume hoods and lab environment isolation), dust control, labware measures, glassware quality control (QC), column QC, QC of reference samples, QC of lab blanks, and QC of field blanks. All these steps are good lab practices which help minimize PBDE contamination, but their overall impact cannot be quantified. The measures denoted by 'QC' allow the lab to estimate PBDE contamination at different stages of the analytical process. For example, if the glassware QC samples fail (i.e. show elevated PBDEs), the glassware cannot be used for extraction. If the procedural blanks show contamination, the levels measured in the associated samples are adjusted. A number of sample extraction and cleanup methodologies have been developed by different laboratories to determine the concentrations of PBDEs in environmental samples. In addition, a number of different instrumental analysis techniques based on GC/HRMS have been utilised for the qualitative and quantitative determination of PBDEs in extracts of environmental samples.

The well-established standard method of analysis for brominated diphenyl ethers is by GC/HRMS detection (de Boer and Cojino 2000; Ikonomidou *et al.* 2001a; Schlummer *et al.* 2004). The method is very similar to the method commonly used to analyse for polychlorinated biphenyls (PCBs). All of the analytical methods for detecting PBDEs use a ¹³C₁₂ (Carbon 13) isotopically labelled congener for each homologue group (Macpherson and Kolic 2006). Some of the difficulties encountered during analysis are due to the thermally labile and photosensitive nature of the PBDE congeners, as well as their decomposition. For example, there is a

⁸ High efficiency particulate air filter

possibility of causing debromination of deca-BDE to lower brominated congeners which are more stable, complicating detection and analytical separation. GC/HGMS provides excellent selectivity and sensitivity to detect the high mass range of these compounds (Macpherson and Kolic 2006). Gas chromatograph (GC) columns capable of separating congeners are essential, as is mass spectrometry to detect and measure individual homologues that could co-elute with a particular column.

The methodology followed by the laboratories includes a number of stages - sample storage and pre-treatment, extraction, cleanup, fractionation and analytical evaluation. Strict laboratory protocols must be followed to ensure the quality of the data. Analysing for deca-BDE (i.e. BDE-209) is especially difficult because BDE-209 is unstable at the temperature of operation of the GC. It is also sensitive to degradation by UV light and behaves differently in the mass spectrometer (MS) than lower brominated compounds (de Boer and Cojino 2000; ATSDR 2004). Moreover, it can adsorb easily on small dust particles, resulting in sample contamination (Covaci *et al.* 2003). Details on the methodologies of the various laboratories are described in the next sections.

2.5.1 Fisheries & Oceans Canada – Institute of Ocean Sciences (DFO-IOS) Sidney, BC

The congeners of greatest interest are those prevalent in the three principal PBDE commercial products – Penta, Octa and Deca-BDEs. The nine congeners: BDE-47, -99, -100, -153, -154, -183, -197, -207 and -209 are of particular interest due to their persistence in the environment. This group of congeners was used to interpret the data from leachates collected across Canada, including the North. The data were also grouped by total bromine number and analysed as total mono-BDEs, di-BDES, and so on, up to deca-BDE. Of the 209 possible congeners, a maximum of 62 were analysed by DFO-IOS, 52 by Vista Analytical, 33 by H.M. Stapleton, and 17 by MOE's Dioxin and Toxic Organics Section of the Laboratory Services Branch, Toronto, Ontario). A complete list of congeners analysed by each laboratory appears in Appendix A, A.1.

These congeners are determined using GC/HRMS (de Boer and Cojino 2000; de Boer *et al.* 2000a; Alaei *et al.* 2001; Ikononou *et al.* 2001a; Ikononou *et al.* 2001b; Rayne and Ikononou 2002). The HRGC is a Hewlett-Packard (Palo Alto, CA) model 5890 Series II with split, splitless and on-column injection capabilities. The (MS) is the only on-line detector attached for all the various analyses. The GC column is operated in splitless mode. The temperatures used for the splitless injector port, the direct GC/HRMS interface and the MS's ion source are

described by Ikonomou, *et al.*, (2001). The chromatographic columns used are DB™-5 (60 m x 0.25 mm i.d., 0.1 µm film thickness) (J&W Scientific, Folsom, CA)). Ultra-high-purity helium is used as the carrier gas at a constant head pressure of 172 kPa (25 psi), which maintains a linear flow velocity of 0.35 m/s. The column is positioned in the injection liner at 32 mm for PBDE analyses. The sample volume injected is 1 mm³. The splitless injector purge valve is activated 2 min after injection. The temperature programs for all of the various analyses are given in Ikonomou, *et al.*, (2001). All sample injections were performed via a CTC A200S autosampler (CTC Analytics, Zwingen, Switzerland). Programming and operation of both the GC and the autosampler was controlled from the MS data system, OPUS version 2.1E (FISONS Instruments, VG Analytical, Manchester, UK).

The HRMS utilised is a VG-AutoSpec-S (FISONS Instruments, VG-Analytical, Manchester, UK). This is a sector instrument of the EBE geometry coupled to the GC via a VG-Analytical type interface. For PBDE analysis it was operated under positive EI conditions with the filament in the trap stabilisation mode at 600 µA and an electron energy of 28 to 35 eV. The instrument routinely resolves at 10,000 resolution power (10K RP), and data are acquired in the Single Ion Resolving Mode (SIR) to achieve maximum possible sensitivity. The two most abundant isotope ions, M⁺ and (M+2) in most cases, of known relative abundance are monitored for each homologue series and ¹³C labelled surrogate standards (Ikonomou *et al.* 2001a). To check for possible interferences from PBDEs corresponding ions are monitored for each homologue series. The MS experiment is divided into five time-consecutive functions. Each function is restricted to a m/z (mass-to-charge ratio) range spanning the voltage range 8 - 6 kV in order to maintain 10K RP throughout the m/z range. All hardware and software settings, tuning, scanning and calibration of the MS are conducted in accordance with protocols established in Environment Canada report EPS 1/RM/19 (Anon 1992), for PBDE analysis.

2.5.1.1 Establishment of Sample Blank Correction Approach

An entire chapter (Chapter 3) is dedicated to explaining the blank correction approach taken for this research. This section describes the lab procedures followed in the handling of samples, designed to ascertain realistic blank levels and to maximize PBDE extraction while avoiding contamination.

As mentioned previously, a variety of sample matrices were analysed including leachate and soil samples. Leachate samples were not homogeneous; usually containing a particulate component (of varying proportion) and an aqueous component (of varying complexities). Samples with high and low particulate loads were handled differently to maximize the extraction efficiency while minimizing the process. As a general rule in PBDE analysis, it is now well recognized that the higher degree of sample handling, the higher the probability of introducing background PBDE concentrations in the samples. In this design it was important to consider that these samples *potentially* contained low PBDE levels and would be susceptible to the introduction of background PBDEs through increased handling. For each batch of samples, a lab blank was extracted in parallel to measure any lab influence which could later be addressed through blank correction of sample data.

The leachate samples were treated as follows:

- Samples with little or no visible particles observed were extracted via a liquid/liquid procedure to reduce handling. The corresponding blanks were treated accordingly.
- Samples with particles observed in them were treated in two different ways:
 - a) In the initial stages of the project these samples were filtered using a 0.7 μm filter. The filter was extracted via an accelerated solvent extraction (ASE) and the liquid part of the sample was extracted via liquid-liquid extraction (LL). Two blanks were generated from each sample. This required maximum sample handling and increased the potential for sample contamination.
 - b) For all subsequent extractions, particulate was separated using centrifugation to reduce handling and eliminate filters. The aqueous supernatant portion was extracted via LL and the particulate 'pellet' component was extracted via the ASE. Two blanks were also generated from each sample following these procedures. This was considered an intermediate sample handling procedure.

The soil/sediment samples had a low aqueous component and were therefore extracted via the ASE only to minimize handling. This procedure required only one blank associated with each of the sample batches (although a blank replicate was often included).

As described above, a lab blank was subjected to the exact same extraction steps as the samples to quantify the possible introduction of any PBDEs through sample handling for later blank correction. While the above section presents overview of sample preparation methods with a focus on blanks, these steps are described in more detail in the next sections:

- “A” Samples. These samples consisted of leachate collected in the field (i.e. across Canada) and not exposed to ‘stockpiled’ e-waste.
- “B” Samples. These samples consisted of soil samples collected near or in dumpsites located in Northern Canada.
- “C” Samples. These samples were obtained from the ‘End-over-End Contactor’ experiments. They had significantly higher PBDE concentrations.

2.5.1.2 “A” Samples

Approximately 100 mL of ‘A’-samples were centrifuged at 2300-2500 x g (effective gravitational field due to centrifugal force, dependent on the speed of rotation and diameter of the centrifuge) for 10 minutes to separate the particulate matter from aqueous samples. Centrifuged particulate material was transferred to an aluminum weigh boat. The aqueous portion was transferred to a 250 mL separatory funnel and spiked with a suite of ^{13}C labelled PBDEs purchased from Cambridge Isotope Laboratories (Andover, MA) and extracted by liquid-liquid (LL) extraction using an equal volume of acetone. Samples were shaken vigorously 4 times for 3 to 5 minutes each and allowed to settle for 12 hours. After this time, four layers formed: a solvent layer, an aqueous layer, an emulsion layer (at the solvent-aqueous interphase) and a precipitate layer at the bottom. The emulsion and precipitate were again collected in aluminum weigh-boats and combined with centrifuged particulate material collected from the first step of this procedure, then transferred quantitatively to a mortar/pestle with sodium sulphate, prior to accelerated solvent extraction (ASE) extraction. If the particulate was observed to be very fine, it was quantitatively transferred with sodium sulphate (Na_2SO_4) to the ASE cell without grinding. The remaining aqueous-acetone portion was then extracted three times with 50 mL dichloromethane (DCM) and then acetone (each extraction involving ~ 3 min. shaking), after which any remaining precipitates were added to the weigh boat. This material (composed of emulsion and precipitate) was combined with the centrifuged particulates and extracted with ASE in 80:20 toluene:acetone. The particulate portion of the sample was spiked separately with the same group of PBDE internal standards and ASE extracts, following the

same procedure as described below in Section 2.5.1.3 for the soil samples. For each sample, both extracts (ASE *particulate-based* extract and DCM *aqueous-based* extract) were combined prior to sample cleanup. Details on the sample cleanup procedures and the GC/HRMS analysis protocols are described below in Section 2.5.1.3. Samples were analyzed in batches of 12. Each batch contained one or two procedural blanks. These procedural blanks consisted of 100 mL High Pressure Liquid Chromatography (HPLC) grade water processed the same way as the aqueous samples.

2.5.1.3 “B” Samples

Soil samples were analyzed in batches of 12 each consisting of a procedural blank, an in-house reference sample and nine real samples, out of which *one* was processed and analyzed in duplicate. The extractions were carried out using a Dionex ASE 200 Accelerated Solvent extractor with 33 mL stainless-steel extraction cells. Wet soil samples (average moisture content 17%), approximately 8 to 10 g wet weight (w.w.), were spiked with a suite of ^{13}C labelled PBDEs purchased from Cambridge Isotope Laboratories (Andover, MA), mixed with 40 g of Na_2SO_4 using mortar/pestle and loaded into the ASE extraction cells. The solvent was toluene-acetone (4:1 liquid to liquid ratio, or v/v). Two static extractions were performed and 40 mL of extract were collected for each sample.

2.5.1.4 “C” Samples

Sample preparation was performed at UBC by the author. Approximately 120 g of ground e-waste were first sonicated in an ultrasonic cleaning bath (Bransonic Model B-52, Branson Ultrasonics Corporation, Danbury, Connecticut) of 2 L volume for 2 hours with a power of 200 watts at a frequency of 50 kHz to separate the particles. Sonication was needed to remove the largest e-waste particles prior to preparing the samples for analysis in the laboratory. The sonicator was filled with water to half the height of the bath. The e-waste particles were then poured into two 500 mL beakers filled with distilled water, manually placed inside the bath. After sonication, the ~2 mm-diameter particles which had floated to the top were removed from the distilled water using a stainless steel filter and transferred to a Petri dish for atmospheric drying prior to re-weighing. The particles were next washed with distilled water to remove micro-particles. All other particles separated during sonication were discarded. Typically these were of size similar to coarse salt or sugar (~2 to ~0.5 mm). More e-waste particles were

sonicated than were needed for the experiment to ensure that at least 100 g were available for each experiment once the e-waste had been dried and reweighed. The leachate and e-waste were then combined in the stainless steel vessels columns to 80% capacity with 20% headspace. The pH was not adjusted at this stage, remaining very nearly 7.

Once the vigorous end-over-end contacting was complete, the mixture was decanted into 1 L flasks and double filtered (0.33 mm) to remove the e-waste particles prior to being transferred to an amber glass jar for storage. The stainless steel filter used for this purpose through which the liquid was poured manually was placed on top of a 500 mL beaker. The sample was then decanted to amber glass bottles and frozen until transfer to the laboratory for analysis.

The frozen samples were next transported to DFO-IOS for extraction. After arrival, the IOS carried out a pre-extraction step to remove remaining colloidal e-waste particles from the solution in order to avoid any further contacting, and to prevent possible extraction from e-waste itself which would affect the analytical data. Approximately 50 mL of these-“C” samples were centrifuged at 2300-2500 g for 10 mins (pre-extraction) to remove all particulates. The aqueous supernatant then proceeded to liquid-liquid extraction, following the procedures described above for the “A” samples. Note that the centrifugation process removed any leachate particulates, together with any remaining e-waste particles; these were not recombined with the samples. The aqueous component of the “C” samples was extracted and processed. PBDEs were leached from the e-waste by the leachate. The particles were not processed as it was assumed that in the solid phase of the sample it was likely that fine plastic particles from the e-waste could have been dislodged and be present, causing measured PBDE concentrations to exhibit excessive values.

2.5.1.5 Sample Cleanup and GC/HRMS Analysis

Strict procedures were applied to all cleanup and the GC/HRMS instrumental analysis for the samples (A, B, and C) handled and extracted at the DFO-IOS laboratories.

Sample cleanup took place in three stages: a) silica gel column (with layers of basic, neutral, acidic, neutral silica); b) column filed with copper fillings and Na₂SO₄ (to remove sulphur and residual water); and c) activated neutral alumina column capped with anhydrous Na₂SO₄. Final extracts were concentrated to 10 µL, spiked with ¹³C-labeled PBDE performance standards and analyzed by gas chromatography high-resolution mass spectrometry (GC/HRMS) for PBDEs. To capture all analytes of interest, the final extracts were analyzed on the GC/HRMS system

twice. In the first analysis, all the mono- to hepta-BDEs were measured, whereas in the second, the octa- to deca-BDEs were determined.

The GC conditions used for the mono- to hepta-BDEs analysis were: 15 m DB5-HT x 0.25 mm ID x 0.1 µm film thickness column, and the temperature programmed to 100°C (held for 1 min) followed by ramp at 2°C/min to 140°C, at 4°C/min to 220°C, at 8°C/min to 330°C (held for 0.5 min). The temperatures for the GC injector, GC/MS interface and the MS ion source were 300°C, 260°C, and 300°C, respectively.

The GC conditions for the octa- to deca-BDEs analysis were: 5 m DB5 x 0.25 mm ID x 0.1 µm film thickness column. The temperature program 110°C at 10°C/min to 300°C. Other conditions were the same as for the mono- to hepta-BDEs analysis.

2.5.1.6 Quality Assurance/Quality Control (QA/QC)

The general analysis approach is to have one sample extracted to yield as many quantifiable contaminants as possible. At DFO-IOS, one sample may be analysed for PBDE compounds with a single extraction. In addition to the replicates in the sampling and experimental procedures previously described, all three laboratories subjected their analyses to a quality analysis/quality control (QA/QC) procedure. DFO-IOS ranked batches such that the samples are processed based on preliminary screening, beginning with the least-contaminated sample (generally the procedural blank) and ending with the most contaminated sample. This is also the order in which the samples are analysed. The procedure attempts to minimise the instances of high sample to low sample cross-contamination in both extraction and analytical processes. Each batch consists of 12 samples: 1 procedural blank, 9 samples, 1 replicate sample, and 1 certified reference material (CRM), in order to account for any cross-contamination in the analytical procedure, and to ensure the accuracy and consistency of the results, as well as to minimize trace contamination.

The QA/QC measures followed at DFO-IOS were adapted from guidelines specified by Environment Canada (Anon 1992) and US-EPA Method 1613 (Anon 1994). The GC/HRMS operating conditions are established as described by Ikonomidou, *et al.*, (2001). Cleanup steps are essential to removed compounds that may interfere with PBDE determination. Silica gel chromatography is used to remove matrix interferences and to fractionate samples. The

laboratory procedural blank is part of the QA/QC data for chemical analysis. It is discussed in detail in Chapter 3.

2.5.2 Vista Analytical Laboratory Inc. (formerly Alta Analytical Laboratory), El Dorado Hills, California

Vista Analytical Laboratory Inc (“Vista”) uses the US EPA Draft Method 1614 to determine PBDE congeners in water, soil, sediment and other sample matrices by high resolution gas chromatography, combined with high resolution mass spectrometry (HRGC/HRMS) (US EPA 2003). Vista analysed 52 congeners ranging from mono- to deca-BDEs (Appendix A, A.1 contains the full list). Their GC had a splitless injection port for capillary column (60 m DB-5HT) with an injector temperature of 270°C, interface temperature of 290°C, initial temperature of 100°C, initial time of 3.0 min and the overall programmed temperature of 100°C held for 2 minutes @ 5°C/minute, and a final temperature of 350°C for 10 minutes. All portions of the column that connect the GC to the ion source remained at or above the interface temperature specified above during analysis to preclude condensation of less volatile compounds. These GC conditions were used to analyse all standards, blanks, IPR and ongoing precision and recovery (OPR) standards, and samples. The absolute retention time of BDE 209 exceeded 48 minutes on the 60 m DB-5HT column. Because of the possible congeners analysed, a diluted combined congener solution was injected. The chromatographic conditions were adjusted and scanned until the latest-eluted BDE on the column eluted the mono- through nona- BDEs (US EPA 2003). The retention time for BDE-209 was greater than 10 minutes on the column used to determine BDE-209. Congener BDE-49 was uniquely resolved from congener BDE-71. Unique resolution means a valley height less than 40 percent of the shorter of the two peaks that result when the diluted solution containing the combined congeners is analyzed.

In essence, this method consists of extraction, concentration, cleanup and analysis of samples to determine the presence of PBDEs in environmental matrices and other tissue (human, fauna). For the extraction part, aqueous samples containing <1% solids are spiked into a 1 L sample, while solid samples are spiked with 10 g dry weight of solids. Each sample is extracted using solid-phase extraction, separatory funnel extraction or continuous liquid/liquid extraction.

The leachate samples were filtered with "fast" ashless filter paper prior to extraction with a pore size of 20 µm. Spiked samples were poured into a 2 L separatory funnel and spiked with 1.0 mL of the labelled standard spiking solution into a sample bottle before filtering but after the

extraction process. The bottle was capped and mixed by shaking. The samples were allowed to reach equilibrium in 1 to 2 h, with occasional shaking.

The internal standards used were Ongoing Precision and Recovery (OPR) between 30-200 ng/mL of 13C-BDE-3 up to 13C-BDE-209. The flask was rinsed twice with 5 mL of reagent water and added to the separatory funnel. For the extraction, 60 mL of methylene chloride were added to the empty sample bottle. The bottle was then sealed and shaken for 60 seconds to rinse the inner surface. The solvent was transferred to the separatory funnel, and the sample was extracted by shaking the funnel for 2 minutes with periodic venting. The organic layer was separated from the aqueous phase for a minimum of 10 minutes. If an emulsion formed with more than one-third of the volume of the solvent layer, mechanical techniques were employed to complete the phase separation. The methylene chloride was drained and extracted through a solvent-rinsed glass funnel ~ half-full of granular anhydrous sodium sulphate supported on clean glass-fibre paper into a solvent-rinsed concentration device. The optimum technique to separate the emulsion layer depends upon the sample. It may include stirring, filtration through glass wool or phase separation paper, centrifugation, application of an ultrasonic bath with ice, addition of sodium chloride (NaCl), or other physical methods. Alternatively, solid-phase, continuous liquid/liquid extraction, or other extraction techniques may be used to prevent emulsion formation.

Each water sample was extracted two more times with 60 mL portions of methylene chloride. Each portion was drained through the sodium sulphate into the concentrator. After the third extraction, the separatory funnel was rinsed with ~20 mL of methylene chloride, and drained through the sodium sulphate into the concentrator. This rinse was repeated twice. The funnel was set aside with sodium sulphate if the extract was combined with the extract from the particles.

For the acid alumina preparation, the column was prepared as depicted in Figure 2.7. The column was rinsed with ~20 mL of hexane and the eluate was discarded. The extract to the column was transferred with 2 to 4 small portions of hexane and the eluate, as in the previous step. The column was eluted with ~15 mL of hexane, and the eluate was discarded. Finally the column was eluted with ~30 mL of 20% MeCl₂:hexane. The eluate in this case was collected and concentrated to 2 to 3 mL.

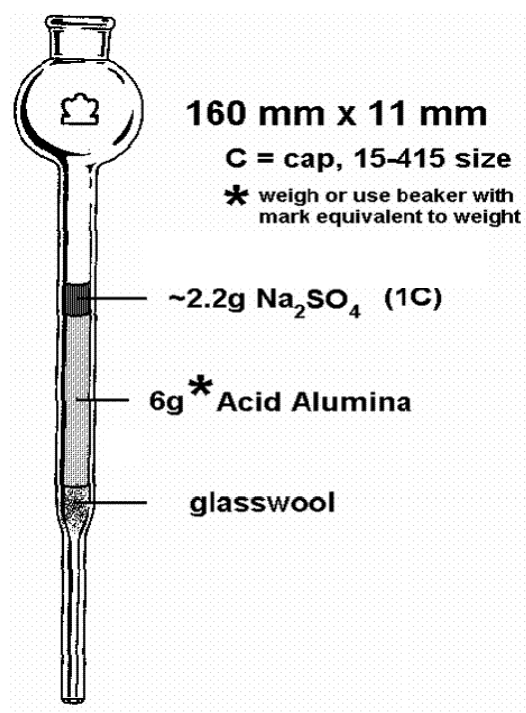


Figure 2.7 Preparation of acid alumina column, Vista Analytical Laboratory, El Dorado Hills, California, 2006.

For the aminobenzamide silica gel column preparation, 25 μ L of a PBDE standard were added. The sample was rotovapped at 45–50°C at a maximum speed of ~120 rpm. The sample was then concentrated to 5 to 10 mL, adjusting the pressure to avoid bubble formation. The column was subsequently prepared as depicted in Figure 2.8. At this point, the extract was transferred to the column with 2 to 4 small portions of 1:1 hexane/DCM, and the eluate was collected. The eluate was next concentrated to ~ 5 mL. 30 – 40 mL of hexane were added and rotovapped to ~ 5 mL. This step was then repeated. When the extract reached the sodium sulphate, 60 mL of 1:1 methylene chloride/hexane were added.

Prior to extraction, the e-waste samples were ground to a consistent size and Soxhlet-extracted with a 1:1 mixture of hexane:methylene chloride. Clean-up followed the same procedure as described above.

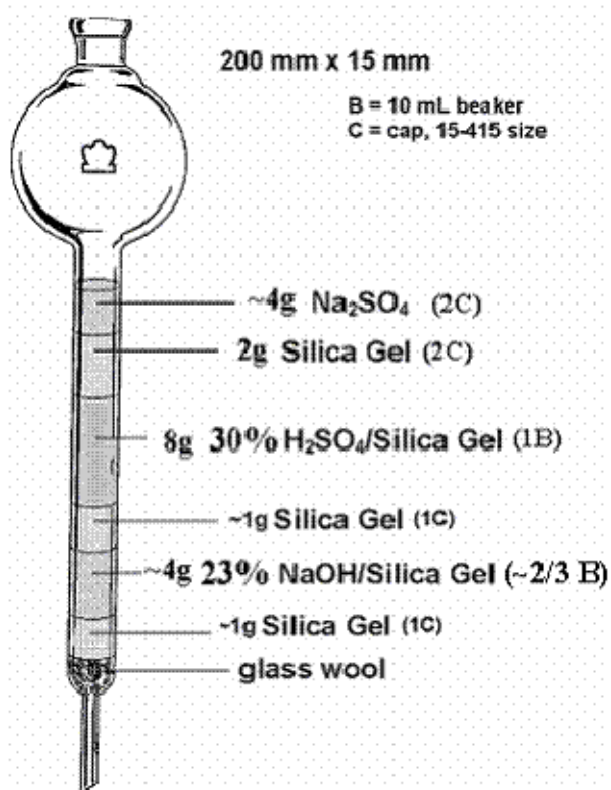


Figure 2.8 Preparation of aminobenzamide silica gel (ABSG) column, Vista Analytical Laboratory, El Dorado Hills, California, 2006.

2.5.3 Ministry of Environment Ontario (MOE), Toronto, Ontario

MOE's Dioxin and Toxic Organics Section of the Laboratory Services Branch ("MOE") analysed fly ash, bottom ash and waste residue from the Algonquin Power incinerator in Brampton, Ontario. Concentrations of tri- to deca-PBDEs were determined in environmental matrices by GC/HRMS (Macpherson and Kolic 2006) with a Hewlett-Packard 6890-Plus GC, equipped with splitless injection system. Both the 30 m and 15 m db5-HT have an internal diameter of 25 mm x 10 µm liquid phase thickness. This instrument included a capillary GC column, fused silica, 5% diphenyl 95% dimethyl polysiloxane (db5-HT), 30 m, 0.25 mm i.d., 0.10 µ film and a 15 m, 0.25 mm i.d., 0.10 µ film thickness. Initial run conditions were 110°C held for 1 min, followed by a ramp of 110 – 200° C at 40°C/min, then held for another minute at 200°C for 1 min, then 240 – 330°C at 10°C per minute, with a final holding time of 5 min at 330°C until the deca-BDE was eluted. MOE analysed 17 congeners (see Appendix A, A.1 for a complete list). Other GC operating conditions included 0.9 mL/min (constant flow) of helium carrier gas, with an injector temperature of 270°C and a transfer-line temperature between 290-300 °C. All samples are fortified with at least one ¹³C₁₂ isotopically labelled congener for each homologue group (Quantification Standard). All PBDEs are quantified against these

corresponding ($^{13}\text{C}_{12}$) labelled internal standards. The instrument detection method is common to the analysis of all matrices.

In most analytical methods for PBDEs, sample extraction is carried out with organic solvents, and sample clean-up or purification by gel permeation or adsorption chromatography. The method described in this research utilised GC-HRMS which is more sensitive than the Electron Capture Detector (ECD). This technique is also more sensitive and selective than Quadrupole or Negative Chemical Ionisation (NCI) techniques. The potential for co-elution of hexa PCBs (PCB 180) to co-elute with tetra BDEs (PBDE 47) exists on 5%-diphenyl-95%-dimethylsiloxane columns. However any losses through the analytical method should be corrected for as this method applies isotope dilution quantification techniques (uses $^{13}\text{C}_{12}$ -labeled Deca BDE as the internal standard).

Samples are air dried, ground, and homogenized. Analytes are extracted from the sample using Soxhlet extraction with Toluene. The extracts are cleaned using a single stage silica (acid/base/ AgNO_3) clean-up. All final extracts are analyzed by Gas Chromatography-High Resolution Mass Spectrometry (GC-HRMS). Brominated diphenyl ethers are susceptible to photodegradation as well as thermal degradation. Instrument sensitivity for deca BDE depends on successful calibration of the HRMS in the mass range, 800 - 1000 amu (atomic mass unit).

2.5.3.1 QA/QC Procedure

Instrument precision was measured by injecting 10 replicates of the Calibration Series 1 (CS1) for tri-heptabromodiphenyl ethers and 10 replicates of Calibration Series 4 (CS4) for decabromodiphenyl ether. All matrices were cleaned up initially via the following chromatographic procedure to remove bulk chemical interferences. The first column was loaded with a glass wool plug and in the order listed below:

1.5 g 10% Silver Nitrate/Silica Packing

1.0 g Activated Silica Packing

2.0 g 33% Sodium Hydroxide/Silica Packing

1.0 g Activated Silica Packing

4.0 g 44% Sulphuric Acid/Silica Packing

2.0 g Activated Silica Packing

2.0 g Anhydrous Sodium Sulphate

The column was tapped to ensure that the packing materials settled. More of these chromatographic packing materials may be provided to accommodate a more heavily contaminated extract. A reservoir was attached to the column. It was then eluted with 50 mL of hexane and the eluate was discarded. A clean 250 mL round bottom flask was placed underneath the column to collect the PBDE fraction. The reservoir was removed from the column. The sample extract was loaded from the original round bottom flask onto the column using a disposable pipette and drained to bed level. The sample flask was rinsed three times with 1 to 2 mL of hexane. Each rinse was added onto the column, allowing the solvent in the column to drain to bed level between additions. The reservoir was re-attached and eluted with 100 mL of hexane, where the eluate was collected in a round bottom flask. The hexane was allowed to drain to bed level. 80 mL of 50:50 (dichloromethane:hexane) solution were added and the eluate was collected. The rotary evaporator water bath temperature was set to 50-55°C. The condenser was rinsed with 150 to 200 mL of hexane. The flask was attached to the rotary evaporator and the sample concentrated to approximately 1 mL. The concentrated sample extract was transferred, followed by 2 hexane and 2 dichloromethane rinses of the round-bottom flask, to a conical vial under a gentle stream of nitrogen. The sample extract and solvent rinses were evaporated to dryness. Finally, the vial was labelled and submitted for GC/HRMS analysis.

2.5.4 Duke University, Nicolas School of the Environment & Earth Sciences, Durham, North Carolina

This laboratory, under the direction of Dr. Heather M. Stapleton, analysed archived soil samples that had been collected in Northern Canada during the summer of 2004. The GC/MS method utilized negative chemical ionization instead of the electron impact employed by the other three labs mentioned above. In order to prepare the samples for analysis, soil samples (~5-10 g) were extracted using an automatic pressurized fluid extractor. Soil was first mixed with a 5:1 ratio (by mass) of pre-cleaned sodium sulphate and then placed into pre-cleaned 34 mL stainless steel extraction cells. For every 10 samples analyzed, one replicate sample and one blank were included. The blank consisted of an ASE cell filled with sodium sulphate. If fewer than 30

samples are analyzed, a minimum of three blank samples are extracted as a QA/QC requirement. Each cell was spiked with two quantification standards, 4'-fluoro-2,3,3',4,5,6-hexabromodiphenyl ether (FBDE 160) and ^{13}C labelled BDE 209. The void volume of all cells was filled with sodium sulphate. Cells were extracted using HPLC grade dichloromethane. Samples were extracted by heating and pressurizing the cells to 100°C and 10,340 kPa (1,500 psi) for 5 min. with the appropriate solvent. Each sample was extracted over three cycles and collected into amber collection vials. Laboratory blanks, consisting of cells filled with sodium sulphate, were extracted alongside the air samples. Each extract was reduced in volume to 1 mL using an accelerated evaporation system (Turbo Vap II) which uses a gentle stream of purified nitrogen gas and a water bath to increase solvent volatilization. Extracts were then cleaned by solid phase extraction using 4.0 g of 6% deactivated alumina and eluted with 35 mL of petroleum ether. Extracts were again reduced in volume to approximately 500 μL and spiked with a recovery standard (4'-fluoro-BDE 69).

Extracts were analyzed for PBDEs using a gas chromatograph (GC, Agilent 5890) coupled to a mass spectrometer (Agilent 5975) operated in electron capture negative ionization (GC/ECNI-MS) mode. A 0.25 mm (i.d.) x 15 m fused silica capillary column coated with a 5% phenyl methylpolysiloxane (0.25 μm film thickness) was used for the separation of PBDE congeners. Pressurized temperature vaporization (PTV) injection was employed in the GC. The inlet was set to a temperature of 50°C for 0.3 min. This was followed by a 700°C/min ramp to 275°C to efficiently transfer the samples to the head of the GC column. The oven temperature was held at 40°C for 1 min followed by a temperature ramp of 18°C/min to 250°C, followed by a further temperature ramp of 1.5°C/min to 260°C, then a final temperature ramp of 25°C/min to 300°C, where it was held for an additional 20 min. The transfer line temperature was maintained at 300°C and the ion source at 200°C. 33 individual BDE congeners were measured in all samples: - 17, 28, 30, 33, 47, 49, 66, 71, 75, 85, 99, 100, 116, 119, 138, 153, 154, 155, 156, 180, 181, 183, 188, 190, 191, 201, 202, 203, 205, 206, 207, 208 and 209 (see also Appendix A, A.1). Tri-through octa-BDE congeners, were quantified by monitoring bromide ions (mass-to-charge ratio, m/z of 79 and 81). All three nona-BDE congeners and BDE 209 were quantified by monitoring molecular ion fragments (m/z 486.6 and 409), while the BDE 209 internal standard was monitored through m/z 494.6 and 415.

2.5.4.1 QA/QC Procedure

As a measure of quality assurance, the recoveries of the two internal standards were measured in each sample with a minimum of 50% recovery being sufficient for reporting. For this set of soil samples, average recoveries were $50 \pm 11\%$ and $90 \pm 20\%$ for F-BDE 69 and ^{13}C BDE 209, respectively. Samples were blank-corrected by subtracting the average blank level (calculated from the three sodium sulphate blanks) from each sample measurement. BDEs 47, 99 and 209 were detected in the blanks and were blank subtracted. Method detection limits (MDLs) are equivalent to instrument detection limits if the congener was not detected in the blank, or equal to the average plus three times the standard deviation of the blank if the congener was detected in the blank samples.

CHAPTER 3 – TREATMENT OF ANALYTICAL DATA

3.1 Introduction

Data analysis for the samples collected in this thesis project is complex due to concentrations close to limits of detection, variations in sample collection techniques, and requirements for extensive quality assurance and quality control (QA/QC) to ensure data integrity and reliability. A large fraction of aqueous samples were found to have low PBDE concentrations (close to background levels or below detection limit), making interpretation of the results difficult. Therefore, it was important to find ways to adequately explain what the values mean. This chapter is devoted to explaining how the data in this thesis were treated.

Environmental analyses are essential to determine background and natural concentrations of chemical compounds in the environment. They are also useful in determining the ambient concentrations of toxic and hazardous constituents (Kayasth and Swain 2004). Analytical techniques such as GC/MS are used to quantify PBDEs in various matrices. Results from environmental analyses are used to monitor compounds in different environmental “compartments”, e.g. air, water, sediment/soil, biota. In this thesis, the three matrices investigated were a) leachate or distilled water (often referred to here as “aqueous” phase), b) soil or sediment, and c) e-waste. Sampling and sample preparation are the first steps required to enable environmental monitoring. A sample needs to be a representative portion of the physical environment for chemical analysis (Kayasth and Swain 2004). This necessitates careful procedures to collect representative samples, free of contamination. Samples should follow acceptable field operating procedures to ensure consistent handling, storage and transport to the laboratory. Chapter 2 provides details of the sampling procedures in this thesis project.

Substances of interest may vary from concentrations below detection limits (BDL) of the analytical methods to very high values. Such was the case with the data from this thesis project. The concentration range, as well as the variety of matrices, presented challenges to the laboratories, as documented by Asmund *et al.* (2004), who emphasize the importance of detailed quality assurance and quality control (QA/QC). This chapter details the procedures employed for analysis, correction and evaluation of data from landfill samples and other samples to assist the reader in interpreting the results in subsequent chapters.

Before being accepted, all data were subjected to a procedural blank correction procedure, as explained in Section 3.2 below. In addition, twelve samples from twelve locations across Canada (four in the Canadian North and eight from Southern Canada) were re-analysed because of concerns that variations in measured PBDE levels could be due to homogenization of sub-samples, to determine whether all sub-samples had the same percentage of particulate. Where there were multiple determinations, the data were averaged (with each value weighted equally), and the replicated values were used to estimate the reproducibility of the data. Data reproducibility and errors are discussed in Section 3.4. An appropriate method for portraying the analytical data is introduced in Section 3.5. Data sets analysed by two different laboratories are compared in Section 3.6, with inter-laboratory comparison data subjected to trend analyses and examination of nine principal congeners.

In order to differentiate and avoid confusion between the BDE congeners and the PBDE commercial products throughout the thesis, the convention is adopted whereby BDE congener names are referred to using lowercase initial letters (e.g. tetra-BDE, penta-BDE), whereas the three technical product mixtures available (or formerly available) in the commercial market are capitalized (Penta-BDE, Octa-BDE, and Deca-BDE).

Throughout the remaining chapters, references to, for example, 1990-94 raw leachate refer to raw leachate collected in 2005 that was in contact with rubbish which had been added to the landfill in 1990-94, rather than raw leachate sampled during the 1990-94 period.

Over sixty congeners were detected during lab analysis. However, nine “principal congeners” are of primary interest throughout the thesis, these being the ones found in highest concentrations here and in many previous studies: BDE-47, -99, -100, -153, -154, -183, -206, -207, and -209. As discussed in Chapter 2, BDE-209 presents special analysis problems, so it is often considered separately from the other principal congeners.

3.2 Procedural Blank Correction Procedure

3.2.1 Overview

Because PBDEs are ubiquitous, it is virtually impossible to achieve PBDE-free analytical laboratory conditions. Criteria advocated by DFO-IOIS to correct background levels of organic molecules are followed in this thesis. Because of uncertainty in the levels due to wide scatter and to varying background levels during different time intervals, as shown by the procedural blank values, judgement must be applied to decide how best to correct for measured procedural blank concentrations, accounting for background lab contamination at the time of analysis. All BDE concentrations were measured by GC-HRMS analysis. However, the other laboratories involved in this research employed somewhat different procedural blank correction protocols, as explained in Section 3.6 below, as well as in Chapters 2, 4, 6 and 7.

Two ways of handling the procedural blanks within this research were applied and are compared below in Sections 3.2.2 and 3.2.3. The difference between the results from the two methods is small enough that one of these methods (Method A, explained in Section 3.3.2) was adopted throughout the rest of the thesis.

The use of laboratory procedural blanks is common as a QA/QC procedure in chemical analysis of low-level contaminants. In this work, each procedural blank consisted of distilled water with volume equal to that of the leachate samples (in most cases 100 mL). These procedural blanks were prepared and extracted in exactly the same manner as the actual samples (i.e. centrifuged, spiked, then liquid-liquid extracted or ASE extracted, as described in Section 2.5.1.5). PBDEs measured in the laboratory procedural blank are considered to have been absorbed from the 'laboratory' environment (glassware, solvents, sorbents, air, dust) during the clean-up and preparation procedures. The PBDEs absorbed from the laboratory are thought to be from PBDEs present through chemical contamination of the samples during the clean-up process. It is assumed that the leachate and procedural blank water samples absorb PBDEs to the same extent, so that the procedural blank levels provide a means of correcting the data from samples for background levels of PBDEs.

Background water samples from drinking sources similar to those detected in the Northern Canada samples were found to have similar (low) PBDE concentrations as the procedural blanks.

The PBDE amounts measured in the procedural blanks associated with the aqueous samples were considered against the long-term record of PBDE background levels documented by the DFO-IOS laboratory. The levels measured in the procedural blanks related to the processing of the samples collected for this thesis were similar to those obtained at about the same time when the DFO-IOS lab analysed data using similar procedures for unrelated samples (e.g. tissues, blubber, sediment, etc.). It is known that a certain amount of PBDEs originates from background contamination. To see how comparable our data was, we compared them with the literature for BDE-47, -99 and -100 congeners. For example, the procedural blanks for BDE-47 ranged from 168 to 209 pg/sample (Wolkers *et al.* 2004), whereas our results were from 149 to 313 pg/sample (Appendix C, Table C.1, Cluster E) and 337 to 744 pg/sample (Appendix C, Table C.1, Cluster D). Christensen *et al.* (2005) reported a procedural blank value of 92.5 pg/sample for BDE-47. Wolkers *et al.* (2004) stated procedural blank levels of 10 to 66 pg/sample of BDE-99 and Christensen *et al.* (2005), 67.9 pg/sample. Our data for this congener were between 80 and 125 pg/sample (Appendix C, Table C.1, Cluster E) and 114 to 298 pg/sample (Appendix C, Table C.1, Cluster D). The procedural blank values for BDE-100 were very close to those of Wolkers *et al.* (2004), who reported 31 to 39 pg/sample. Our data ranged between 33 and 79 pg/sample (Appendix C, Table C.1, Cluster D) and 23 to 40 pg/sample (Appendix C, Table C.1, Cluster E), whereas Christensen *et al.* (2005) reported 167 pg/sample.

For the experiments described in this thesis, the procedural blanks are considered on a *per matrix* basis and evaluated on a *per batch* basis. All procedural blanks within the same matrix were averaged in order to apply one procedural blank value to the results of that particular batch. Standard deviations were calculated when there were three or more procedural blanks in a matrix. Different levels of procedural blanks are assumed to reflect different levels of contamination in the laboratory for samples processed during different periods. In cases where the PBDE concentrations fall below the corresponding procedural blank correction, they are listed as 'below method detection limit' (BMDL) in tables throughout this thesis. When concentrations were found to be below detectable limits, they are listed as 'non detect' (ND). For experimental data which survived the procedural blank correction procedure and had more than two replicates, statistical analyses are performed where possible to determine confidence levels and correlation coefficients.

The matrices (or media) investigated in this research were analysed over a period of four years in the case of the main (DFO-IOS) laboratory. Total PBDE uptakes in the various procedural blanks were compared for the successive analytical batches from our samples and other samples measured in the same period. The background levels, as determined by the procedural blanks, varied significantly over the total time period. Accordingly, there are serious challenges to extract reliable, accurate and comparable data from the measurements. QA/QC procedures must therefore utilize laboratory procedural blanks judiciously to correct for time-varying background levels.

3.2.2 Method A Approach

Method A deals with the *intra*-behaviour of our samples in the lab, by grouping them into *clusters*. Each *cluster* covers a time period during which lab background contamination at the time of analysis appeared to be similar. Blank corrections meant subtracting the value of the procedural blank concentration or twice that value from the BDE result obtained. The procedural blanks were subjected to 1 times, 2 times or no blank correction within the clusters, depending on degree of lab interference at the time.

The approach taken to assess background levels of PBDEs in all matrices was on a ‘*cluster-by-cluster*’ basis, i.e. to gather batches analysed before, during and after the samples collected for this research, in order to assess laboratory contamination in particular time intervals, within the overall sampling and analysis period (2004-2007). This allowed determination of the blank correction levels most appropriate for each of the samples depending on when they were analysed. Blank corrections were made with regards to the procedural blank results from each batch. The procedural blanks represent different batches and often different sample matrices. In some cases, there was only one procedural blank with which to work. In other cases, two or more procedural blank data sets were available from the same time period, enabling an average value to be used and standard deviations to be calculated. The clusters are plotted against picogram (pg) on a *per sample basis* (pg/sample) because it adequately exemplifies lab contamination as a function of time. The clusters are illustrated in Figures 3.1 to 3.5 for six principal congeners (BDE-47, -99-, -100, -153, -154, and -183) and in Figures 3.6 to 3.12 for BDE-206, -207 and -209. BDE-206 and -207 are found in small concentrations with the deca-BDE congener. Hence, BDE-209 (including BDE-206 and -207) is plotted separately because its concentration was typically much higher than for the other principal congeners. Tables 3.1 and

3.2 give a detailed explanation of the clusters, time period, matrices, blank corrections and a justification for the levels of blank correction applied to the data.

3.2.2.1 Procedural blank correction treatment for principal congeners (BDE -47, -99, -100, -153, -154, 183; Clusters A through E)

Clusters A through E below¹ in Figures 3.1 to 3.5 represent procedural blank levels determined by the DFO-IOS lab over portions of the overall time period (2004-07) during which our samples were analysed. The yellow bars represent the procedural blanks for the sum of the six major congeners (BDE-47, -99, -100, -153, -154, and -183) in the samples gathered for this thesis², whereas the blue bars are sums for the same six congeners measured in procedural blanks for other samples analysed by the same laboratory over the same time period. The blank corrections applied to each matrix varied depending on lab contamination at the time of analysis, as well as the resulting PBDE concentrations. Blank corrections meant subtracting the value of the procedural blank, or twice that value, from the BDE result obtained. For example, a blank correction of two times was applied to the leachate matrix from Cluster B (Figure 3.2) but no blank correction was necessary for the leachate + e-waste matrix because the levels were more than an order of magnitude greater than the procedural blank level and the background contamination was low at the time (Cluster C, Figure 3.3). Similarly, no blank correction was needed for the soil matrix because the soil levels were more than an order of magnitude greater than the procedural blank level in Cluster D (Figure 3.4). See Table 3.1 for more discussion.

¹ A full sequence of procedural blank levels is available in Appendix C, Figures C.1 through C.12, from which one can see how the clusters were chosen.

² The procedural blank data grouped by clusters are provided in Appendix C, Table C.1, from which the blank corrections are indicated.

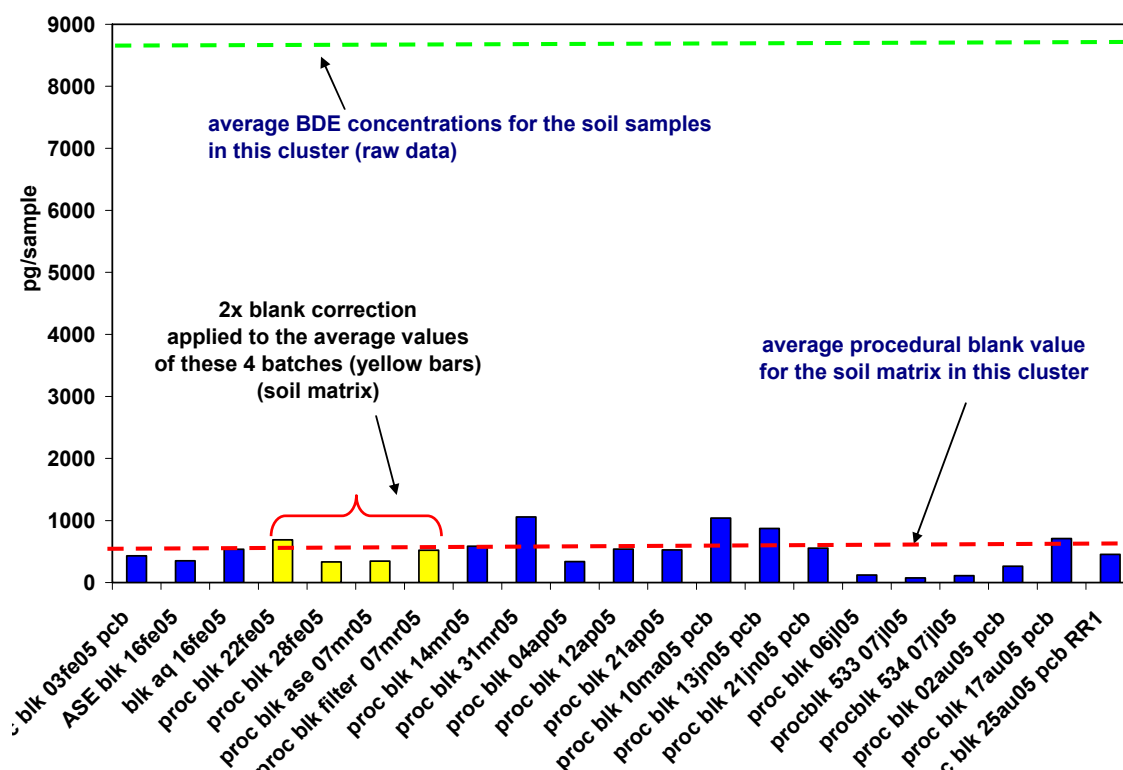


Figure 3.1 *Cluster A*: PBDE levels detected in procedural blanks analysed during February 2005 - August 2005. Sum of concentrations of BDE-47, -99, -100, -153, -154 and -183. The dashed line represents the average of our procedural blank data (soil matrix) in this cluster. The blank correction applied to the four soil samples was 2x (average procedural blank) for each of these six principal congeners.

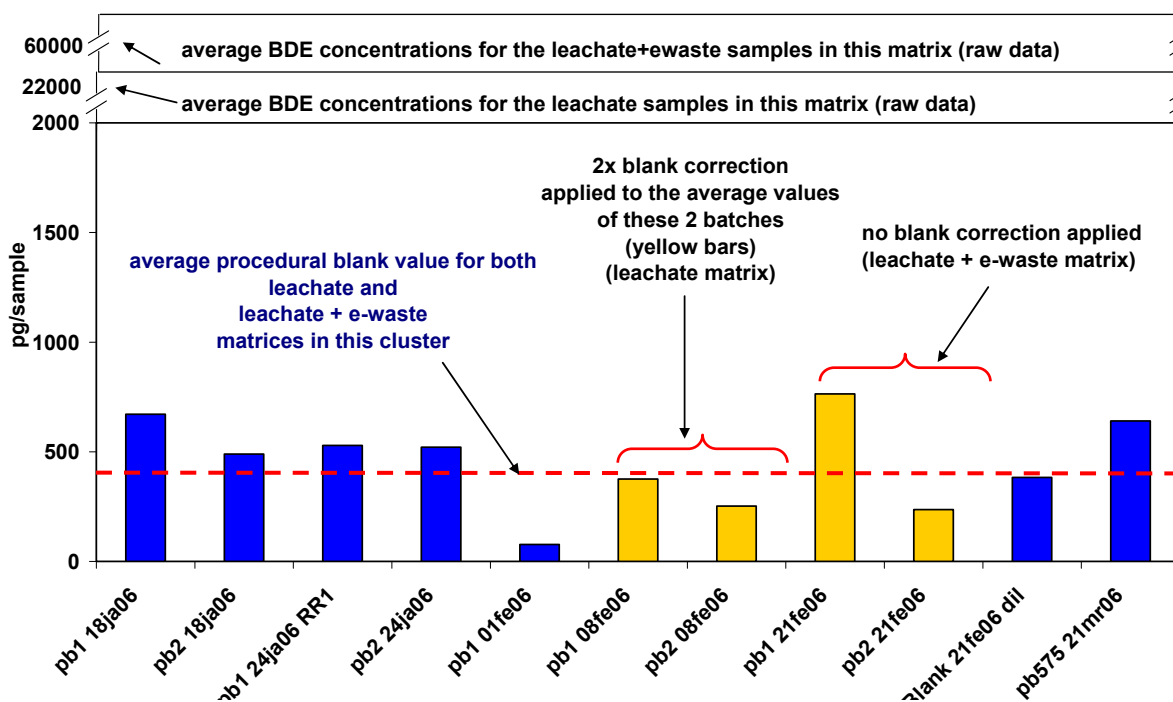


Figure 3.2 *Cluster B*: PBDE levels detected in procedural blanks analysed during January 2006 – August 2006. Sum of concentrations of BDE-47, -99, -100, -153, -154 and -183. The dashed line represents the average of our procedural blank data (leachate and leachate + e-waste matrices) in this cluster. The blank correction applied to the two leachate samples was two times (average procedural blank) for each of these six principal congeners. No blank correction was necessary for the leachate + e-waste matrix because the levels were more than an order of magnitude greater than the average procedural blank level.

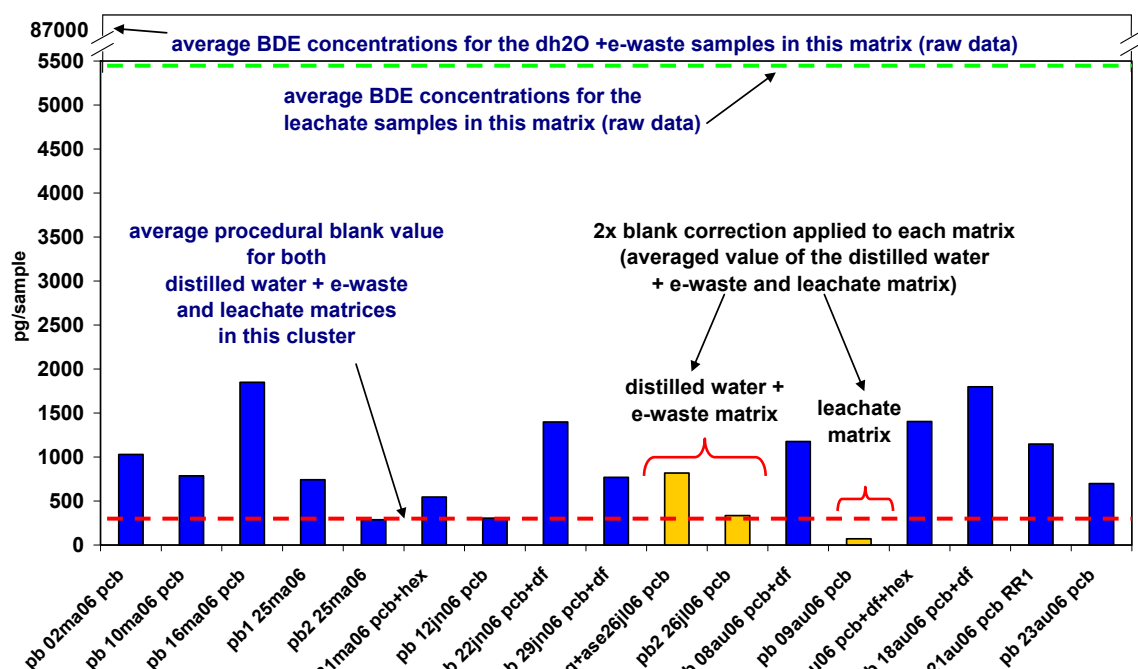


Figure 3.3. Cluster C: PBDE levels detected in procedural blanks analysed during May 2006 – August 2006. Sum of concentrations of BDE-47, -99, -100, -153, -154 and -183. The dashed line represents the average of our procedural blank data (distilled water + e-waste and leachate matrices) in this cluster. The blank correction applied to the two distilled water + e-waste matrix and to the leachate matrix samples was 2x (average procedural blank) for each of these six principal congeners.

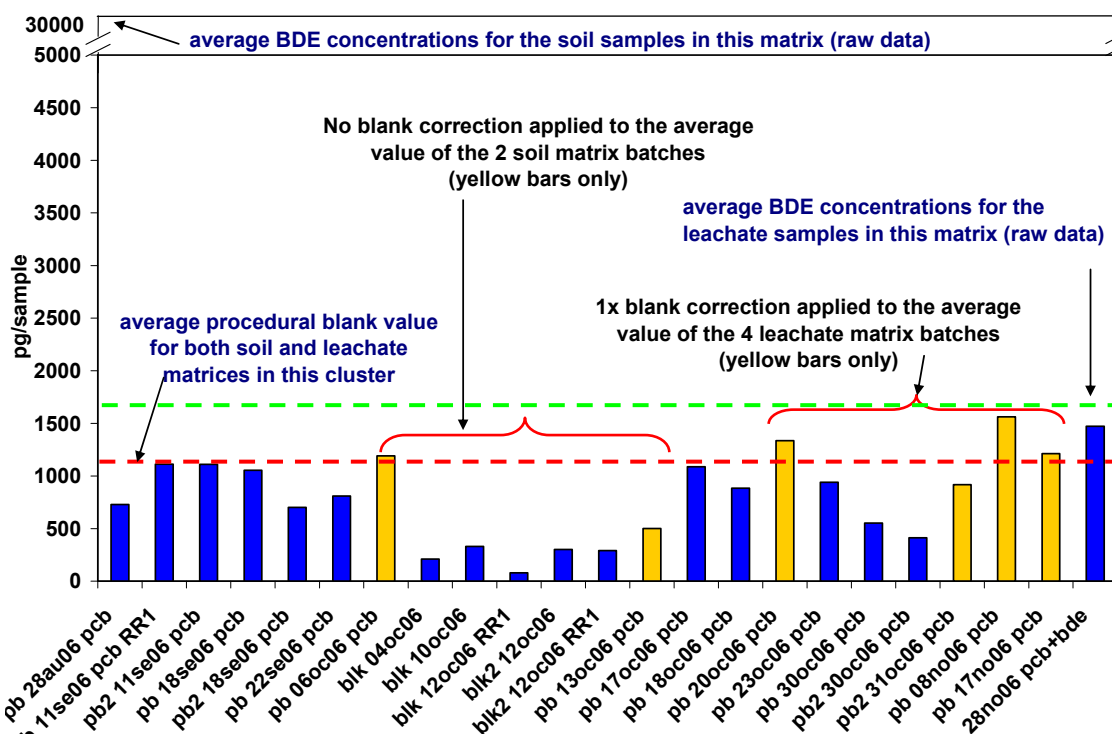


Figure 3.4 Cluster D: PBDE levels detected in procedural blanks analysed during August 2006 – November 2006. Sum of concentrations of BDE-47, -99, -100, -153, -154 and -183. The dashed line represents the average of our procedural blank data (soil and leachate matrices) in this cluster. No blank correction was needed for the soil matrix because the soil levels were more than an order of magnitude greater than the procedural blank level. The blank correction applied to the 32 leachate samples was 1x (average procedural blank) for each of these six principal congeners.

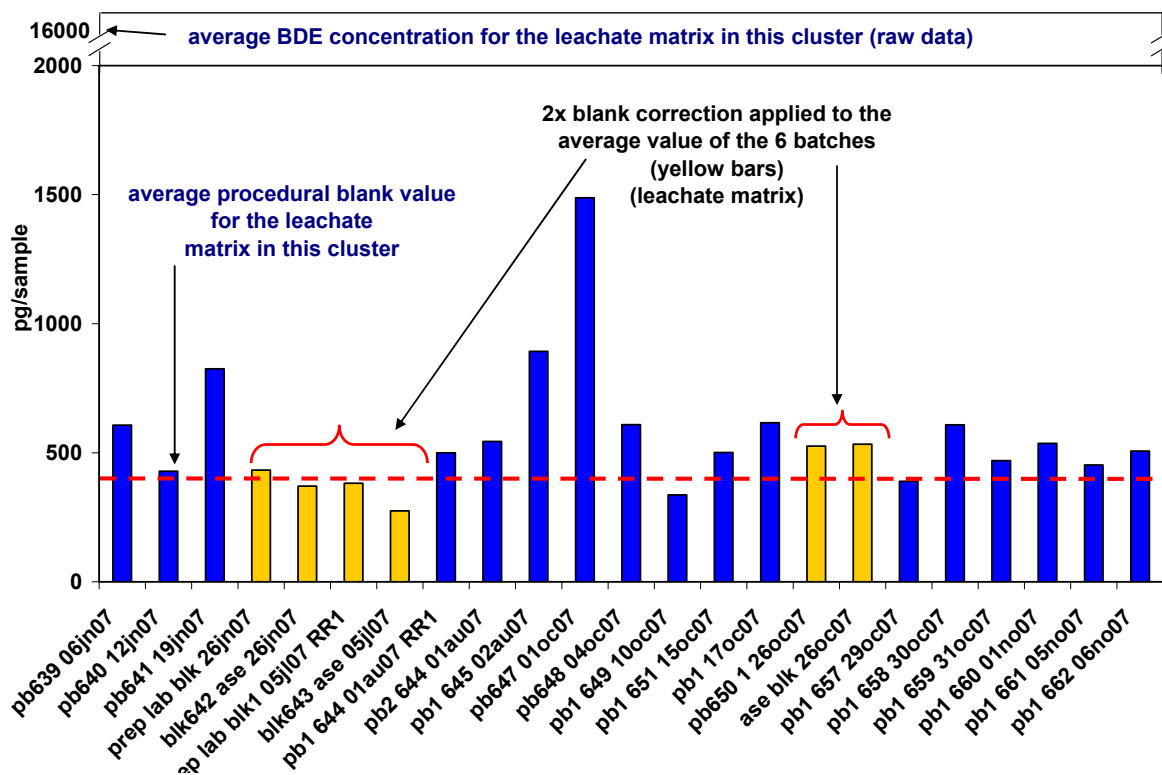


Figure 3.5 *Cluster E*: PBDE levels detected in procedural blanks analysed during June 2007 – November 2007. Sum of concentrations of BDE-47, -99, -100, -153, -154 and -183. The dashed line represents the average of our procedural blank data (leachate matrix) in this cluster. The blank correction applied to the 26 leachate samples was 2x (average procedural blank) for each of these six principal congeners.

Table 3.1 Blank corrections for principal congeners (BDE-47, -99, -100, -153, -154, and -183). The level of blank correction was determined by procedural blank cluster categorization (including procedural blanks for other samples analyzed by the same lab at about the same time), and by matrix (soil, leachate, water and e-waste). See Figures 3.1 – 3.5 for a graphical description and identification of the clusters and corresponding time periods.

Cluster	Lab Identification and Date	Matrix	Blank correction	Justification
A (Feb 2005 – Aug 2005)	problk 22feb05 problk 28feb05	soil	2x	Lab analysis results for procedural blanks before this cluster of data were low. Therefore, 2x blank correction was performed to ensure lab contamination was accounted for. Most values were close to MDL or below except for 1 data set (CAMBY6) which were well above procedural blanks. A procedural blank average plus standard deviations is used to correct the levels in the real samples.
	proc blk ase07mr05 procbk filter07mr05			
B (Jan 2006 – March 2006)	pb1 08feb06	leachate	2x	Samples analysed before and after these had similar procedural blank levels. Therefore, 2x blank correction holds. Average of the 2 procedural blanks from this batch were used.
	pb2 08feb06			
	pb1 21feb06	leachate + e-waste	No blank correction needed	Even though these were analysed in the same cluster as the 08feb06 batch, because of the different matrix, and the very high concentrations measured relative to the procedural blanks, no blank correction was needed.
	pb2 21feb06			
C (May 2006 – August 2006)	pbAq+ase26jl06	distilled H2O + e-waste	2x	Samples analysed before and after ours had higher procedural blank levels but the overall average was similar. 2x blank correction holds to allow for times when there may have been more lab contamination.
	pb226jl06 pcb			
	pb09au06	leachate		
D (Aug 2006 – Nov 2006)	pb06oc06	soil	No blank correction	Samples analysed before this batch had similar procedural blank levels as this one. Background lab interference seemed consistent with these soil batches as well as with batches from other matrices. Therefore, no blank correction was needed.
	pb13oc06			
	pb20oc06	leachate	1x	The procedural blank levels before and after this batch were high and similar in value. Therefore 1x blank correction was decided to be all that was needed to compensate for lab contamination.
	pb2 31oc06			
	pb08nov06			
	pb17no06			
E (June 2007 – Nov 2007)	lab blk26jn07	leachate	2x	Samples preceding this cluster were low. Therefore, 2x blank correction was taken to compensate for lab contamination. A procedural blank average plus standard deviations is used to correct the levels in the real samples.
	blk642ase26jn07			
	lab blk05jl07 RR1			
	blk643ase05jl07			
	pb650 1 26oc07 + ase blk 26oc07			

3.2.2.2 Procedural blank correction treatment for BDE-209 (Clusters F through L)

Clusters were again chosen to group measured procedural blank levels determined by DFO-IOS over a portion of the overall time period (2004-07) during which our data were analysed. The yellow bars represent procedural blank concentrations for BDE-209 in the samples gathered for this thesis, whereas the blue bars are BDE-209 levels in procedural blanks in batches of other sample matrices measured by the same laboratory over the same time period. The same criteria for blank correction applied in Clusters A through E were applied here. BDE-209 values were

significantly higher than for the other principal congeners. For example, no blank correction was necessary for the leachate + e-waste matrix (Cluster F, Figure 3.6) because the BDE-209 concentration was orders of magnitude higher than the procedural blank value and there was little background concentration at the time of analysis. However, for the distilled water + e-waste matrix, a blank correction of one procedural blank was applied due to overall lab contamination and the procedural blank value itself (Cluster G, Figure 3.7). No blank correction was needed for the soil matrix (Cluster H, Figure 3.8) because the BDE-209 concentration levels were more than an order of magnitude greater than the procedural blank level. A one time blank correction was applied to all leachate matrices in Clusters I through L (Figures 3.9-3.12). See Table 3.2 for more discussion.

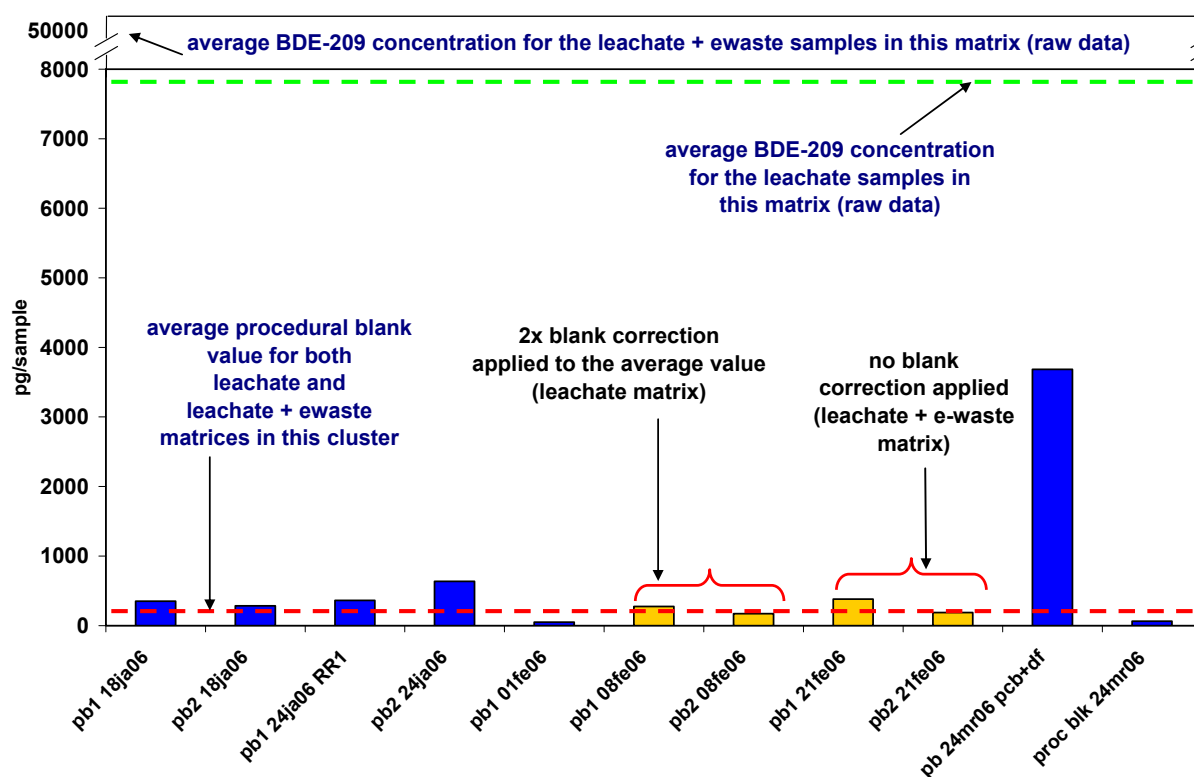


Figure 3.6 Cluster F: PBDE levels detected in procedural blanks analysed during January 2006 – March 2006. BDE-209 illustrated here only. The dashed line represents the average of our procedural blank data (leachate and leachate + e-waste matrices) in this cluster. The blank correction applied to the two leachate samples was 2x (average procedural blank) for the remaining three principal congeners, i.e. BDE-206, -207, and -209. No blank correction was needed for the leachate + e-waste matrix because the levels were more than an order of magnitude greater than the procedural blank level.

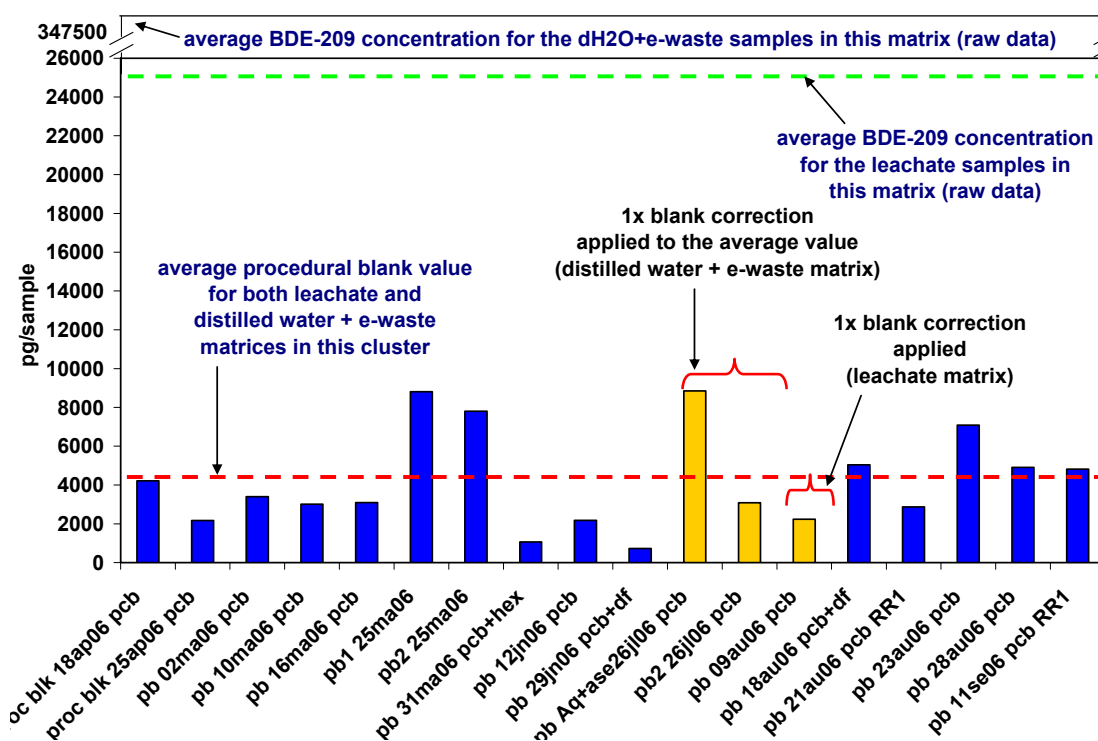


Figure 3.7 Cluster G: PBDE levels detected in procedural blanks analysed during April 2006 – September 2006. BDE-209 illustrated here only. The dashed line represents the average of our procedural blank data (distilled water + e-waste, and leachate matrices) in this cluster. The blank correction applied to the two distilled water + e-waste samples, as well as to the leachate sample, was 1x (average procedural blank) for the remaining three principal congeners, i.e. BDE-206, -207, and -209.

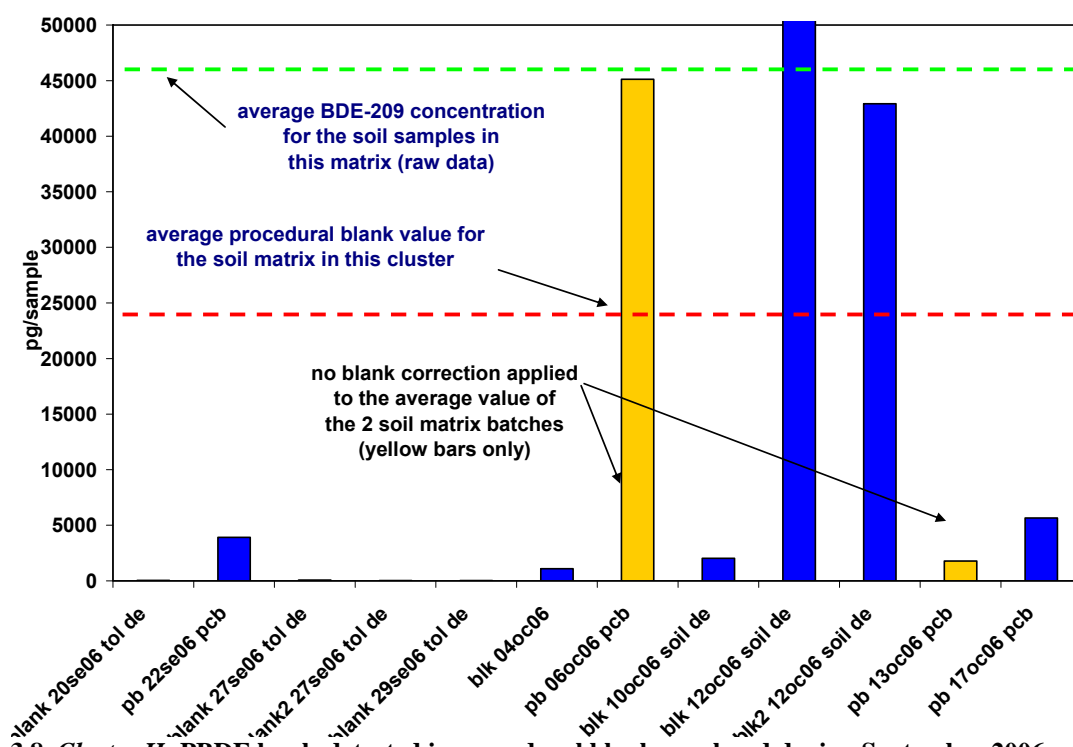


Figure 3.8 Cluster H: PBDE levels detected in procedural blanks analysed during September 2006 – October 2006. BDE-209 illustrated here only. The dashed line represents the average of our procedural blank data (soil matrix) in this cluster. No blank correction was applied to the soil matrix for the remaining three principal congeners, i.e. BDE-206, -207, and -209 because the levels were more than an order of magnitude greater than the average procedural blank level.

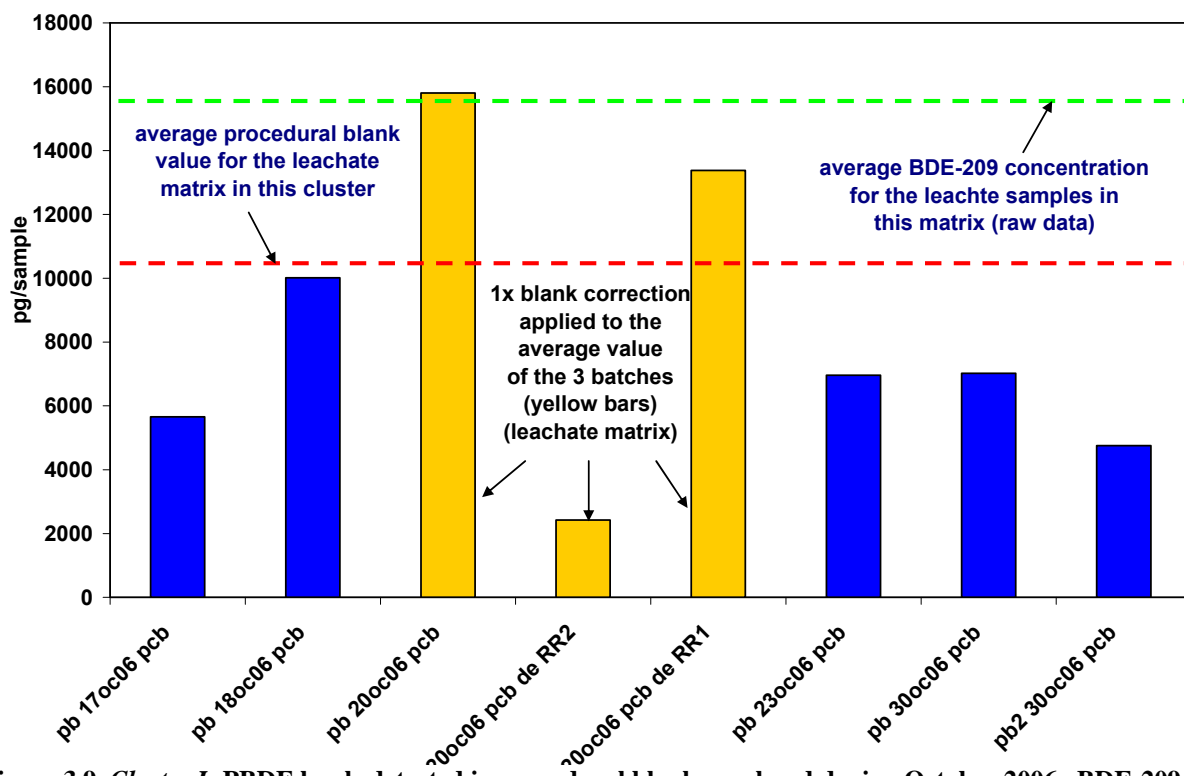


Figure 3.9 *Cluster I*: PBDE levels detected in procedural blanks analysed during October 2006. BDE-209 illustrated here only. The dashed line represents the average of our procedural blank data (leachate matrix) in this cluster. The blank correction applied to the three leachate samples was 1x (average procedural blank) for the remaining three principal congeners, i.e. BDE-206, -207, and -209.

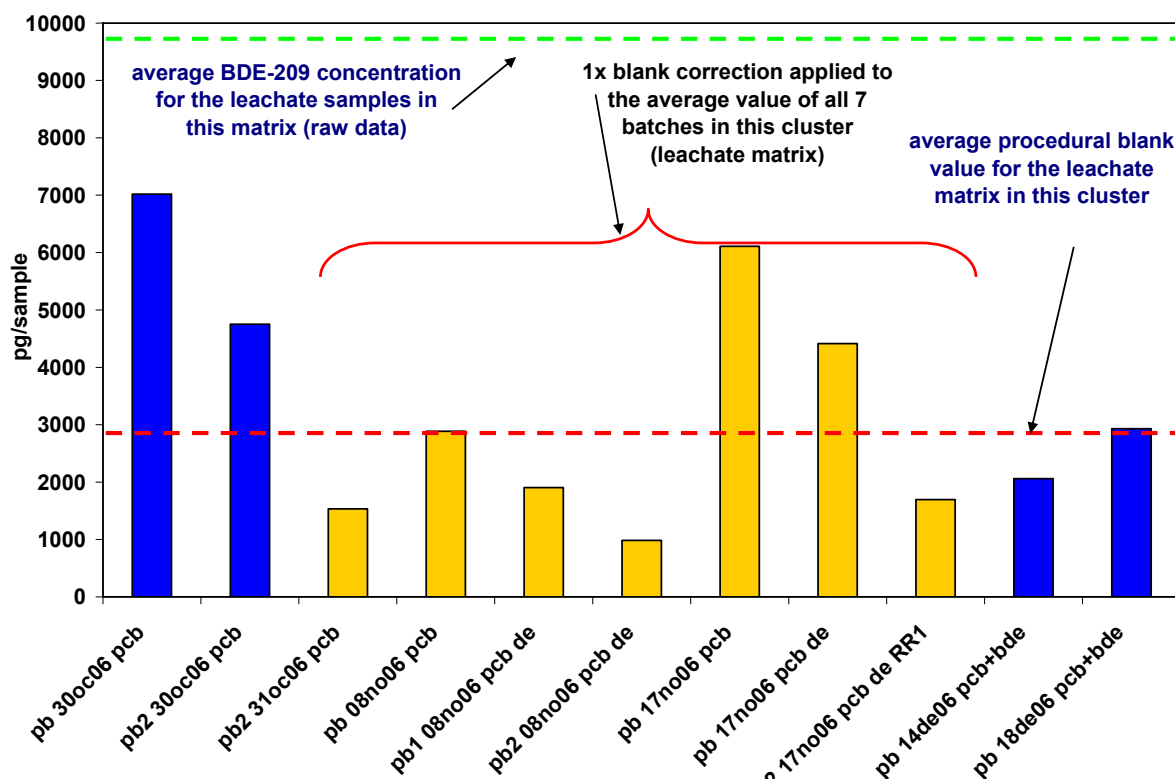


Figure 3.10 *Cluster J*: PBDE levels detected in procedural blanks analysed during October 2006 – December 2006. BDE-209 illustrated here only. The dashed line represents the average of our procedural blank data (leachate matrix) in this cluster. The blank correction applied to the 32 leachate samples was 1x (average procedural blank) for the remaining three principal congeners, i.e. BDE-206, -207, and -209.

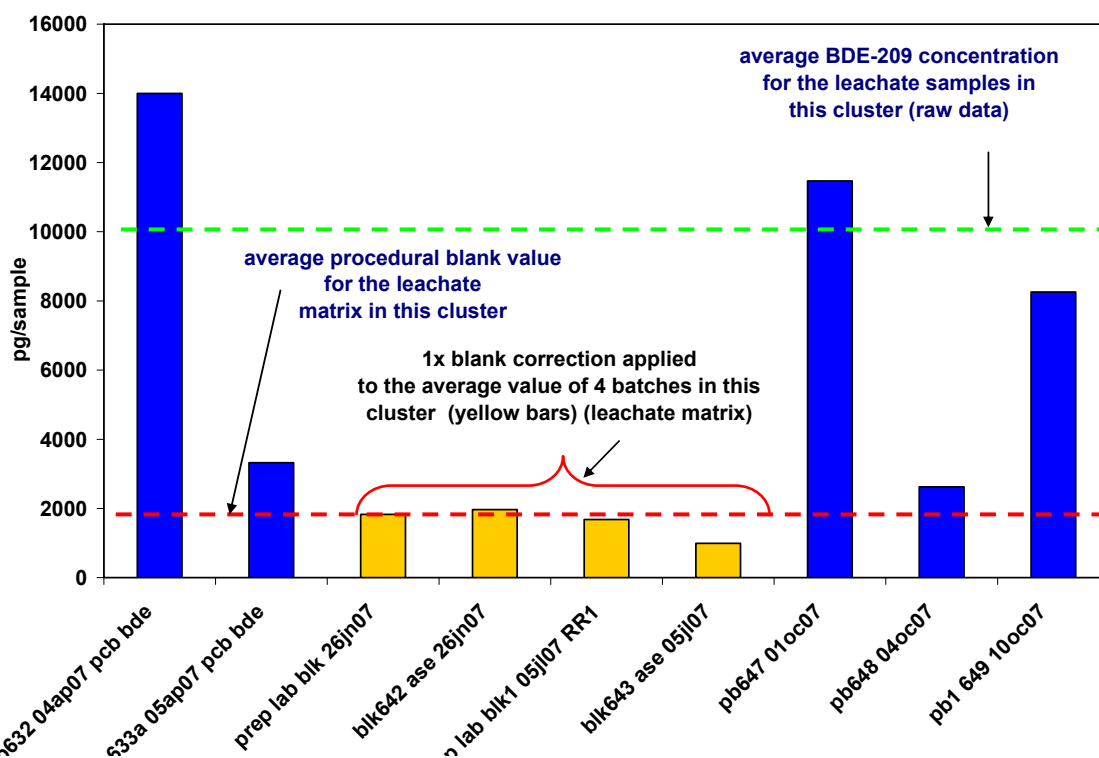


Figure 3.11 Cluster K: PBDE levels detected in procedural blanks analysed during April 2007 - October 2007. BDE-209 illustrated here only. The dashed line represents the average of our procedural blank data (leachate matrix) in this cluster. The blank correction applied to the 26 leachate samples was 1x (average procedural blank) for the remaining three principal congeners, i.e. BDE-206, -207, and -209.

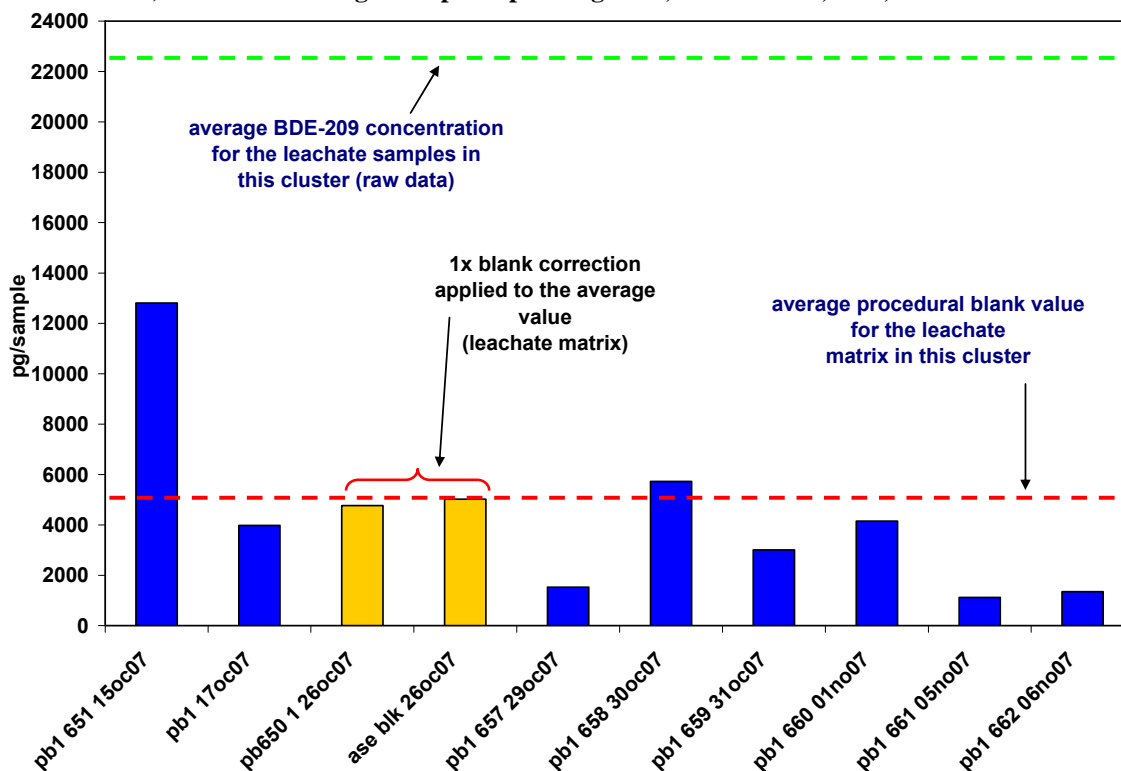


Figure 3.12 Cluster L: PBDE levels detected in procedural blanks analysed during October 2007 - November 2007. BDE-209 illustrated here only. The dashed line represents the average of our procedural blank data (leachate matrix) in this cluster. The blank correction applied to the two leachate samples was 1x (average procedural blank) for the remaining three principal congeners, i.e. BDE-206, -207, and -209.

Table 3.2. Blank corrections applied for BDE-206, -207, and -209. These congeners were analysed separately from the six principal congeners covered in Table 3.1. How much to blank correct the data was determined by procedural blank cluster categorization (including procedural blanks measured for other samples where the data were analysed at about the same time), lab during the same time, and by matrix (soil, leachate, water and e-waste). See Figures 3.6 to 3.12 for a graphical description and identification of the clusters and corresponding time periods.

Cluster	Identification and Date	Matrix	Blank correction	Justification
F	pb1 08feb06; pb2 08feb06	leachate	2x	Procedural blanks analysed before our samples had relatively low concentrations of BDE-209. Therefore, 2x blank correction was necessary to correct for lab variability. Data fell below MDL when applying a blank correction higher than 1x was applied.
(Jan 2006 – March 2006)	pb1 21feb06; pb2 21feb06	leachate + e-waste	No blank correction needed	Even though these were analysed in the same cluster as the 08feb06 batch, because of the different matrix, and very high values found, no blank correction was needed.
G	pbAq+ase26jl06pcb +pb226jl06 pcb	distilled H2O + e-waste	1x	Batches before and after had higher procedural blank levels, but the overall average was similar. 1x blank correction was deemed to be sufficient.
(April 2006 – Sept 2006)	pb09au06	leachate		This batch (pb09au06) was analysed in the same cluster as the previous one (of dH2O+ewaste). Batches before and after had higher procedural blank levels but the overall average was similar. 1x blank correction was applied.
H	pb06oc06	soil	No blank correction	The batch preceding this (not ours) had similar procedural blank levels as this one. Background lab interference seemed consistent with these soil batches as well as with batches from other matrices. Therefore, no blank correction was needed.
(Sept 2006 – Oct 2006)	pb13oc06			
I	pb20oc06; 20oc06pcbRR120oc06pcbRR2	leachate	1x	All procedural blank values were BMDL except for one sample. Similar levels as for Cluster H, but much higher than for Cluster J. This cluster was considered worse case scenario. 1x blank correction was applied as all values fell below MDL with this correction. 1x was sufficient to account for lab contamination. A procedural blank average plus standard deviations is used to correct the levels in the real samples.
J	pb2 31oc06 pcb	leachate	1x	Procedural blank levels before and after this batch were similar and high. Therefore, 1x blank correction was used to compensate for lab contamination. A procedural blank average plus standard deviations is used to correct the levels in the real samples.
(Oct 2006 – Dec 2006)	pb08nov06; pb1 08nov06; pb2 08nov06			
	pb17nov06; pb17no06pcb de			
	pb17no06			
K	lab blk26jn07 blk642ase26jn07	leachate	1x	Procedural blank levels for batches before and after this cluster of data varied. Averaged the procedural blank (the accelerated solvent extraction, or 'ASE') with the other 'ASE' procedural blanks and applied 1x blank correction as the samples in this cluster seemed to have similar and higher values, indicating potentially less lab variability than in other cases. A procedural blank average plus standard deviations is used to correct the levels in the real samples.
(April 2007 – Oct 2007)	lab blk05jl07 RR1 blk643ase05jl07			
L	pb650 1 26oc07 + ase blk 26oc07	leachate	1x	There was considerable variation in the data sets preceding this cluster, but the procedural blank results were higher than for other cluster sets examined. Therefore, 1x blank correction was warranted to correct for lab interference.
(Oct 2007 – Nov 2007)				

3.2.3 Method B Approach

Method B starts with the premise that non-homogenous samples require different levels of treatment in order to determine the maximum concentration of PBDEs. It deals with the *inter*-behaviour of samples in the lab. Data are considered only on a matrix basis, i.e. leachate, soil/sediment, and e-waste. The procedural blanks for each matrix are summed as the liquid blank + the particulate component. Due to the significant amount of particulate in these samples, various approaches were taken. For some samples, the sample was split into 2 or 3 parts and each part was processed separately (see Section 2.5.1.1 for details). Many of the samples also showed low PBDE concentrations, necessitating consistency in the procedural blanks in order to obtain accurate results. As in Method A, the samples were analysed at different times over the 2004-07 time period, and the procedural blanks concentrations were within the same range as detected in blanks of other matrices analysed by the laboratory during the same time period. A detailed discussion of sample handling is given in Section 2.5 of Chapter 2.

Figure 3.13 shows the individual procedural blank totals over time. Given the challenges and difficulties in handling the leachate procedural blanks and lab interference due to the ubiquitous nature of PBDEs, the variability is understandable. The procedural blank corrections are taken as averages for each matrix plus two standard deviations to correct the levels for “real samples”. In Method B, this correction was applied in all plots, figures, tables and interpretation. The use of two standard deviations is considered to be a conservative approach.

Figure 3.14 shows the averages for water and soil/sediment with one standard deviation used as a procedural blank correction for all samples. The use of two standard deviations is used to ensure the procedural blank corrections exceed the influence of the lab for all fluctuations.

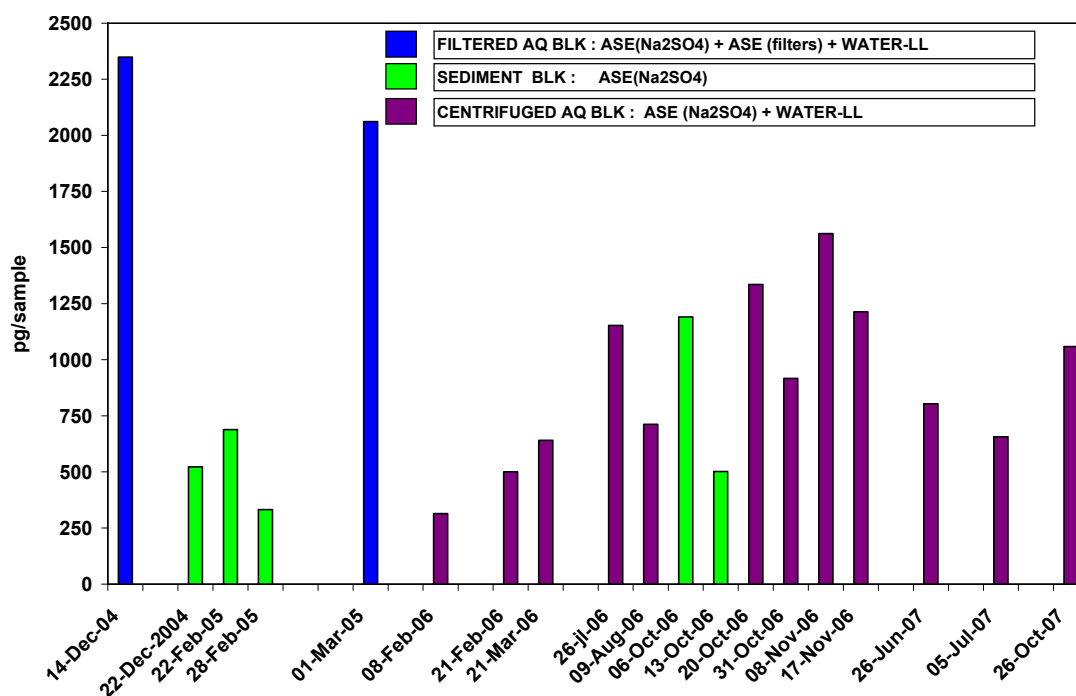


Figure 3.13. Individual procedural blank totals over time used for the Method B approach.

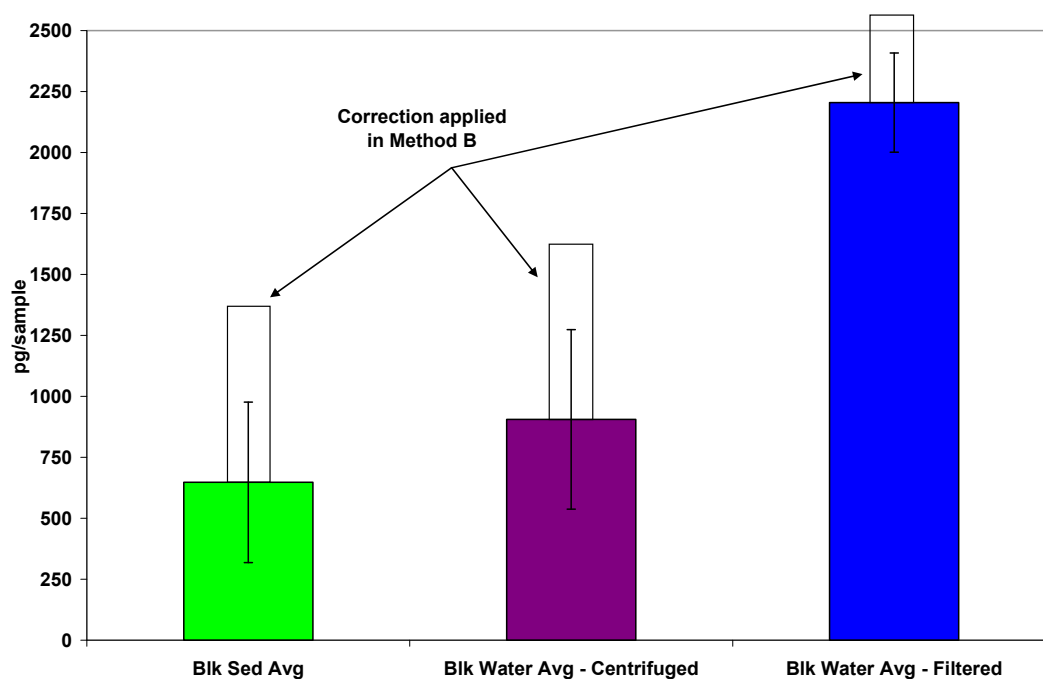


Figure 3.14. The averages for water and sediment with one standard deviation based on data extracted from Figure 3.13 for Method B. The correction illustrated in the figure takes into account the mean \pm 2 standard deviations.

3.2.4 Method A vs. Method B

Both methods attempt to correct for contamination in the lab at the time of analysis. It is not atypical to approach data in several different ways. Method A involves fewer analytical steps than Method B. Particulate handling was the only difference between the soil/sediment and leachate sample preparation.

Because there is more than one way to deal with data treatment, it is important to compare the options before choosing one method over the other. Both methods yielded results within ~5 to 20% of each other and general patterns and conclusions are identical whether based on Method A or Method B. An approximate 5% difference is observed between water samples from Method A to Method B. This percentage was obtained by averaging the procedural blank values used in Clusters B, C, D, E, F, G, J and K from Method A with the average of the centrifuged values at 2 standard deviations from Method B. An approximate 20% difference is observed between the soil/sediment samples of Cluster A from Method A with the average values at 1 standard deviation from Method B. This percentage was obtained in the same way as the centrifuged water samples were obtained. The filtered water values were not used in either Method; therefore they are not compared. Method A was chosen because it makes allowance for changing conditions over time, likely increasing the accuracy of the results, whereas Method B lumps all the data together, i.e. it averaged all procedural blanks from each matrix to obtain a number to which an average, plus two standard deviations, would be applied to obtain the ‘real sample data’. In addition, in Method A, the procedural blank correction subtraction was decided on a cluster basis, to reflect the lab circumstances during preparation, extraction and analysis.

3.3 Reproducibility and Error in PBDE Data

As outlined in Section 2.5, Chapter 2, analysis of PBDEs in leachate and water samples is difficult, especially for the deca (BDE-209) congener. Leachate samples (dilute aqueous solutions containing suspended solids) are very non-homogeneous, making it difficult to obtain precise aliquots during sub-sampling. Most of the errors associated with the concentrations in this thesis, beyond those associated with laboratory contamination, corrected with the aid of procedural blanks as outlined in Section 3.3, are likely due to random analysis errors which can be estimated through replicate analysis of the same samples. In an effort to assess analysis

reproducibility, five samples were analysed twice, three samples thrice, one sample four times, and three samples six times.

When the PBDE levels in the samples are close to method detection limits, primarily determined by the levels measured in the blanks, several factors need to be considered:

- a) The samples had to be processed according to exacting procedures involving many laboratory steps such as sample processing, extraction and cleanup. Since PBDEs are ubiquitous and present in the laboratory, sample contamination in the lab was a major concern. As the number of sample handling steps increases, the extent of sample contamination is likely to increase.
- b) The methodologies used to process the aqueous samples were unique. The lab does not have long-term experience with procedural blanks associated with samples of this type.
- c) The levels measured in the procedural blanks were often similar to those measured in the actual samples.
- d) The PBDE levels measured in the procedural blanks associated with the aqueous samples varied over time, but fell within the range of long-term PBDE background levels found in the DFO-IOIS lab.
- e) Many measured concentrations were low and close to detection limits.
- f) Sample replication was poor because most samples had PBDE levels close to method detection limits as determined from the procedural blanks. Sampling and sub-sampling were no doubt affected by fine dust particles in the leachate samples.

There are a number of possible sources of error in the data, including those associated with lab sampling and sub-sampling, storage, extraction efficiency, and analysis itself. The Canada-wide samples discussed in Chapter 5, were collected by different people at different landfills using different techniques and/or sampling protocols. In addition, not all landfills treat their rubbish in the same manner, nor do they handle leachate in the same way. Some samples were sub-sampled at the lab prior to extraction. In some instances, samples were collected as grab samples, whereas in others Waterra® tubing was used to obtain the samples by mechanical means. Sub-sampling could also have introduced discrepancies as it was difficult to sub-sample every

leachate sample with complete consistency. In addition, homogeneity of sub-sampling plays an essential role. It is not possible to link the data unless the samples are homogenous. Particulate mixed in the water samples could have differed from sample to sample as it was difficult to obtain identical subsamples, and PBDEs are known to bind to particles (Hazrati and Harrad 2007; Yushan *et al.* 2007). In order to compare samples, the data can be standardized through total organic carbon (TOC) (discussed in detail in Chapter 5).

Table 3.3 gives the replicate values for the nine principal congeners in cases where there were two or more replicates. In each of these cases, the mean, median, standard deviation, standard error and 90% confidence intervals are tabulated. (Medians are only included when there were three or more determinations.) All statistical analyses were performed using Excel. BMDL values were taken as zero in calculating these values. Most data have large standard errors (SE) reflecting the uncertainty of the data. From the table, it is clear that the relative errors are greatest for the lower-brominated congeners. Low-concentration congeners tend to have larger standard errors than high-concentration BDE congeners. This trend is expected since low BDE concentrations are more prone to background contamination, to procedural blank corrections, and to contamination during sampling and sub-sampling.

Figure 3.15 plots the cumulative distribution of means and the $\pm 90\%$ confidence intervals for the case where there were 6 replicates to illustrate the degree of confidence for figures of this type in the following chapters. The bands bounded by the upper and lower 90% confidence intervals are broad. In view of this, it is clear that considerable caution is needed when assessing the data in subsequent chapters and when evaluating the influence of key variables.

Table 3.3 Principal congeners in cases where there were replicates with mean, median, standard deviation and confidence intervals. BMDL numbers were taken as zero in these calculations. In order to keep the locations confidential, the jurisdictions have been coded by letter.

A									
No. determinations = 6	BDE-47	BDE-99	BDE-100	BDE-153	BDE-154	BDE-183	BDE-206	BDE-207	BDE-209
Mean	143,062	302,126	73,058	59,197	68,028	7,178	8,619	8,788	35,057
Median	171,666	363,528	89,280	70,222	84,920	7,071	2,551	2,499	21,720
Standard Deviation	70,808	139,427	35,049	26,914	32,590	1,899	16,687	17,250	32,031
90%C.I. (conf. interval)	143,062±82,814	302,126±163,067	73,058±40,992	59,197±31,477	68,028±38,116	7,178±2,221	8,619±19,516	8,788±20,175	35,057±37,462
B									
No. determinations = 3	BDE-47	BDE-99	BDE-100	BDE-153	BDE-154	BDE-183	BDE-206	BDE-207	BDE-209
Mean	4,326	2,039	58	154	93	317	2,300	1,467	108,532
Median	6,489	3,058	851	232	140	476	1,636	534	76,586
Standard Deviation	3,236	555	303	3	17	181	2,159	1,909	107,581
90%C.I. (conf. interval)	4,326±3,784	2,039±649	568±355	154±4	93±20	317±212	2,300±2,525	1,467±2,232	108,532±125,822
C									
No. determinations = 6	BDE-47	BDE-99	BDE-100	BDE-153	BDE-154	BDE-183	BDE-206	BDE-207	BDE-209
Mean	4,978	19,701	3,549	4,296	2,771	11,202	19,445	21,308	305,031
Median	4,969	19,813	3,520	3,112	2,890	1,836	4,516	4,356	316,533
Standard Deviation	3,479	5,738	1,205	3,737	1,218	20,651	34,511	27,985	187,672
90%C.I. (conf. interval)	4,978±4,069	19,701±6,710	3,549±1,409	4,296±4,371	2,771±1,424	11,202±24,153	19,445±40,363	21,308±32,730	305,031±219,493
D									
No. determinations = 4	BDE-47	BDE-99	BDE-100	BDE-153	BDE-154	BDE-183	BDE-206	BDE-207	BDE-209
Mean	27,105	21,739	13,772	10,857	11,606	6,689	14,241	12,043	287,069
Median	24,739	17,619	13,882	11,482	13,347	3,161	12,191	15,974	102,279
Standard Deviation	9,166	11,327	1,543	2,658	4,552	7,966	20,326	13,982	412,823
90%C.I. (conf. interval)	27,105±10,720	21,739±13,247	13,772±1,805	10,857±3,109	11,606±5,324	6,689±9,317	14,241±23,773	12,043±16,353	287,069±482,818

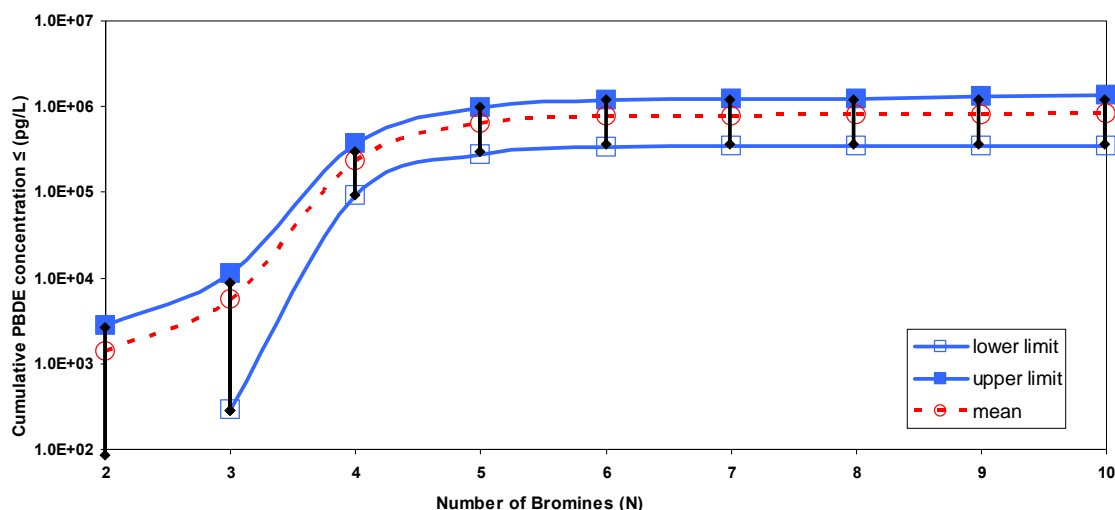


Figure 3.15 Cumulative distribution curves including mean lower and upper 90% confidence intervals for BDE groups where there were 6 replicate analyses. (Site A)

3.4 Presentation of Data in Cumulative Form

In the experimental chapters of this thesis (Chapters 4-7), many of the PBDE plots (with an example given in Figure 3.15) are cumulative distributions of BDE congener concentrations in pg/L or pg/g on a logarithmic ordinate scale. Cumulative distributions are often used in chemical engineering, e.g. in plotting particle size distributions. The ordinate axis at a given value of N (number of bromines) then gives the total concentration of all congeners with N or fewer bromines attached, with BMDL values counted as 0 in determining the cumulative levels.

These cumulative distributions are useful because they smooth out unimportant apparent fluctuations that appear in differential distributions such as bar graphs. They also facilitate rapid comparison of total PBDE concentrations (by looking at the N=10 levels along the axis at the right side), while also allowing the reader to see at a glance which congener groups are contributing most. At the same time, the logarithmic scale visually suppresses the importance of the deca-BDE congener, known to be measured least accurately, but often the largest contributor to the total PBDEs, as discussed in Chapter 2.

Other data plots in the succeeding chapters focus on the principal congeners identified in Section 3.3, often with BDE-209 plotted separately from the other congeners in view of its high levels and its difficulties in analysis.

3.5 Inter-laboratory comparison: Introduction

Unfortunately, it was not possible to fully compare analysis by the DFO-IOS and Vista labs because their extraction and filtration procedures differed³ with regards to leachate analysis. DFO-IOS analysed the particles in the filter, whereas Vista did not. See Section 2.5, Chapter 2, for details on sample filtration. Nevertheless, the data from these two laboratories were similar during two time periods, as noted in Table C.2, Appendix C. A third laboratory (Duke University-Nicholas School of the Environment & Earth Sciences, hereafter referred to as ‘Duke’) analysed duplicate soil samples collected in the Canadian North. As stated earlier in the chapter, homogenization amongst samples was difficult to achieve. This creates a challenge when trying to compare results between labs. Duke mixed the samples with a 5:1 sodium sulphate ratio and subsequently extracted with standard protocols using ASE and dichloromethane. The soil samples provided for analysis were very heterogeneous in composition, increasing the variability. These factors could explain differences between the two labs. The results are compared below in Section 3.5.1.

3.5.1 Inter-Laboratory comparison (DFO-IOS vs. Duke)

Soil samples collected in the Canadian North in 2004 were analysed by both DFO-IOS and Duke. Raw data appear in Appendix C, Tables C.3 and C.4. Total BDE congeners, sample site descriptions, and concentration of the principal congeners measured in soil samples collected in 2004 are shown in Table 3.4. In the case of the Duke analyses, the recoveries of the two internal standards were measured in each sample with a minimum of 50% recovery acceptable for reporting. Samples were blank corrected by subtracting the average procedural blank level (calculated from three sodium sulphate procedural blanks) from each sample measurement. BDEs 47, 99 and 209 were detected in the procedural blanks and were corrected by subtracting two times the blank values. Method detection limits (MDLs) were considered equivalent to instrument detection limits if the congener was absent from the blank, or equal to the average plus three times the standard deviation of the blank if the congener was detected in the blank samples.

³ DFO-IOS used a 0.7 µm filter, whereas Vista Analytical used a 20 µm filter.

Table 3.4 Summary of inter-laboratory comparison of northern soil data collected during the summer of 2004, pg/g Raw data are found in Tables C.3 and C.4, Appendix C (Labs: DFO-IOS and Nicolas School of the Environment & Earth Sciences, Duke University)

Duke University analyses - Arctic soil samples from 2004										
Location sampled	Description	Total tri-BDEs	Total tetra-BDEs	Total penta-BDEs	Total hexa-BDEs	Total hepta-BDEs	Total octa-BDEs	Total nona-BDEs	Total deca-BDEs	Total PBDEs
YELL01	Old dumping area of landfill, 2 samples averaged	BMDL	147	198	147	BMDL	BMDL	BMDL	1,098	1,558
IQ-2	Apex Flats in tidal zone ~400 m from shore, background	BMDL	106	37	48	BMDL	32	BMDL	212	434
IQ7	Former military scrap from 1940s	1,993	24,235	32,473	4,905	95	1,771	1,787	2,915	70,172
IQ2W40	West 40 current landfill	51	1,360	2,243	425	16	189	BMDL	200	4,485
CAMBY2	Sewage effluent drainage area	BMDL	1,004	1,660	572	74	321	2,012	16,885	22,507
CAMBY3	Municipal dump	17	289	951	343	33	371	723	3,401	6,127
CAMBY6	Metal dump, auto and other vehicle scrap, etc.	78	997	2,264	873	97	1,902	3,046	17,482	26,738
CAMBY7	Midtown	BMDL	72	37	67	BMDL	BMDL	74	1,301	1,551

DFO analyses - Arctic soil samples from 2004										
Location sampled	Description	Total tri-BDEs	Total tetra-BDEs	Total penta-BDEs	Total hexa-BDEs	Total hepta-BDEs	Total octa-BDEs	Total nona-BDEs	Total deca-BDEs	Total PBDEs
YELL01	Old dumping area of landfill, 2 samples averaged	6	96	122	21	4	31	25	435	741
IQ-2	Apex Flats in tidal zone ~400 m from shore, background	3	39	24	2	BMDL	BMDL	15	347	431
IQ7	Former military scrap from 1940s	NA	NA	NA	NA	NA	NA	NA	NA	NA
IQ2W40	West 40 current landfill	134	1,491	2,226	412	76	36	53	656	5,130
CAMBY2	Sewage effluent drainage area	318	1,930	2,468	526	178	269	1,789	20,568	28,180
CAMBY3	Municipal dump	470	1,856	3,752	1,086	261	669	429	5,517	14,259
CAMBY6	Metal dump, auto and other vehicle scrap, etc.	328	2,251	3,573	1,393	795	1,471	783	18,759	29,432
CAMBY7	Midtown	5	50	36	7	5	28	43	1,021	1,198

BMDL - below method detection limit; NA - not available

The soil BDE totals for each congener group measured by DFO-IOS are plotted against the corresponding values determined by Duke in Figure 3.16. While there is scatter, the 45° parity line gives a reasonable fit, with similar numbers of points above and below the line. Only three samples determined by the two labs had different orders of magnitude, these being at the low end where it is most difficult to measure accurately. The remaining samples compare quite well given the difficulties in analysis, with an average relative deviation of ~20%, indicating acceptable compatibility between the two laboratories, seen in Table 3.5.

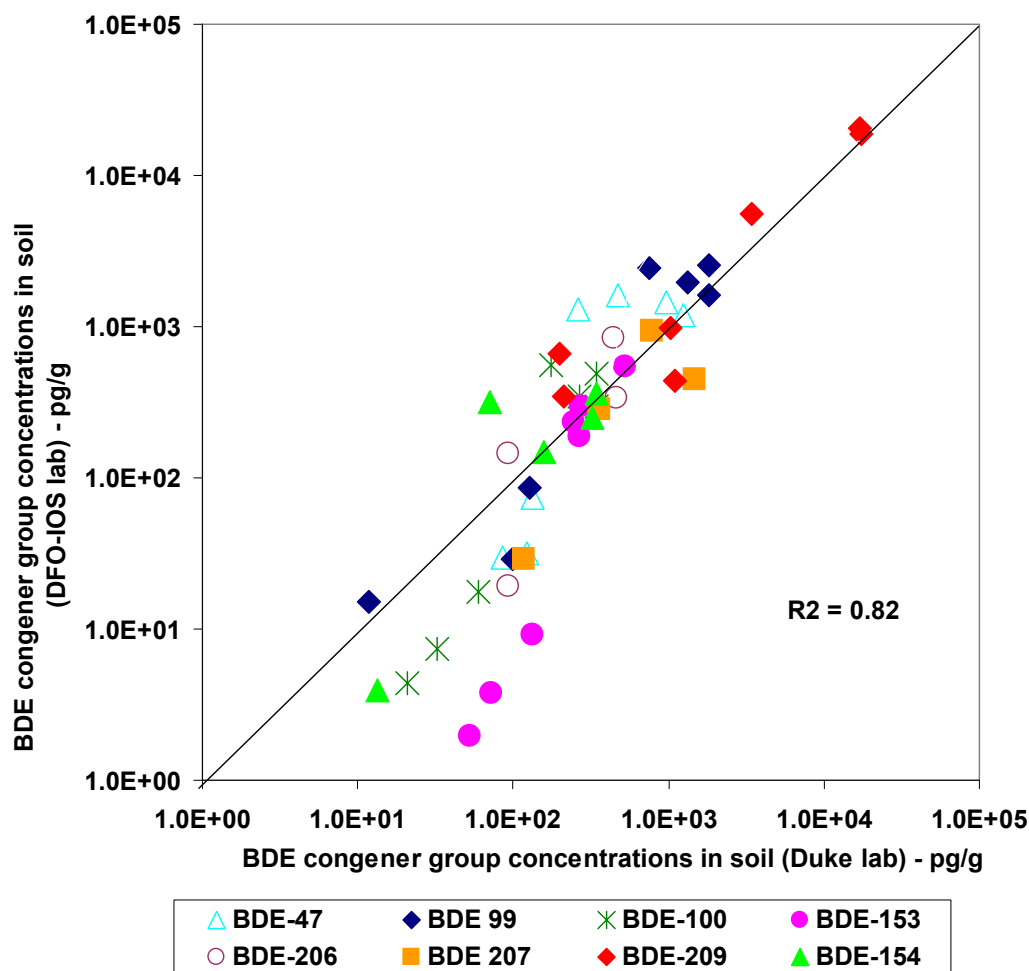


Figure 3.16 Inter-laboratory comparison of northern soil samples collected in 2004 for total BDE congeners based on data from Table 3.5. The samples were collected from Yellowknife (YELL01), Iqaluit (IQ2, IQ2W40) and Cambridge Bay (CAMBY2, CAMBY3, CAMBY6, CAMBY7).

Table 3.5 Inter-laboratory comparison of total PBDE concentrations from 2004 northern Canada soil samples (pg/g)

Laboratory:	Duke	DFO-IOs	20% Relative Standard Deviation*	Significant Difference**
Sample ID	Total PBDEs			
YELL01	1,558	741	312	yes
IQ2W40	4,485	5,130	897	no
IQ-2	434	431	87	no
CAMBY2	22,507	28,180	4,501	no
CAMBY3	6,127	14,259	1,225	yes
CAMBY6	26,738	29,432	5,348	no
CAMBY7	1,551	1,198	310	no

* 20% of Duke value

**Confidence level of 80%

3.5.1.1 Results and Discussion

The concentrations measured in the soil samples by each of the laboratories for the eight major PBDE congeners are plotted in Figure 3.16. Considering the many variables such as: consistent sampling protocols in the field; sample homogeneity; sample sub-sampling; sample handling in the laboratory; chemical analysis variables; and most importantly inherent background lab contamination, that could effect data quality, the agreement between the values measured by the two laboratories is remarkable resulting in a R^2 value of $R^2 = 0.82$. With the exception of BDE-153, at low concentrations, all other congeners correlate very well and the correlation would improve significantly if BDE-153 was to be excluded from the inter-comparison. It is also important to observe that the correlation is perfect for all congeners when the concentrations in the samples measured are higher than 200 pg/g, see Figure 3.16.

The deviation observed for BDE-153 and others at concentrations lower than 200 pg/g could be due to a couple of factors and those are explored below. The higher concentrations measured by the Duke laboratory for this congener could be attributed to laboratory contamination. It seems that the lowest concentration that the Duke laboratory could measure for this congener is about 80 pg/g while the DFO-IOS Laboratory could measure this congener at much lower levels, i.e. down to 2 to 3 pg/g. This suggests that the higher concentrations measured by Duke laboratory are due to background contamination which is between 80 and 200 pg/g as is evident from the three data points in the plot which have concentration lower than 200 pg/g. The same argument holds for all the other congeners with concentrations lower than 200 pg/g. In each case the Duke laboratory is measuring higher concentrations than the DFO-IOS laboratory.

Another factor that could be explored regarding the poor correlation for the low concentration congeners, is the sample extraction efficiency achieved by the analytical methods used by each of the two laboratories. Since the Duke laboratory is consistently measuring higher concentrations one can argue that the extraction efficiency for these congeners is much more effective by the analytical method used by Duke in comparison to DFO-IOS. However, if that was the case the concentrations measured by Duke should always be higher than DFO-IOS for the entire concentration range. This is not true however as Duke and DFO-IOS are measuring identical concentrations for all congeners when the concentrations in the samples are higher than 200 pg/g. One way to explore extraction efficiency for each laboratory is to examine the BDE-

153 concentrations measured as a function of the concentration measured for other congeners with identical, lower and higher level of bromination where possible, i.e. compare with congeners with similar physico-chemical properties. The following correlations were explored with data from each of the laboratories: BDE-47/BDE-153, BDE-99/BDE-153 and BDE-99/BDE-47. When examining the BDE-47/BDE-153 ratio, Duke has an $R^2 = 0.18$ whilst DFO-IOIS has an $R^2 = 0.81$. Similarly on close examination of the BDE-99/BDE-153 ratio, Duke had an $R^2 = 0.73$, whereas $R^2 = 0.86$ for DFO-IOIS and for the BDE-99/BDE-47 correlation, Duke had an $R^2 = 0.69$ whilst for DFO-IOIS the $R^2 = 0.96$. In all cases that DFO-IOIS had superior R^2 values than Duke. These findings suggest that DFO-IOIS is extracting the BDE-153 congener with the same efficiency as the other two congeners which have very similar physico-chemical properties. Furthermore, as the BDE-47 and BDE-99 data between DFO-IOIS and Duke correlate perfectly this suggests that the methods used by the two labs have very similar extraction efficiencies.

As the analytical methods used by the two laboratories seem to have similar extraction efficiencies, it is clear that the higher concentrations measured by Duke in the low end of the concentration range (lower than 200 pg/g) are due to background contamination associated with the sample handling and/or the chemical analysis procedures of that laboratory. The greatest deviations are noted in the data with the lowest BDE concentrations. This is expected, as accuracy and precision decrease substantially when the sample concentrations are close to the method detection limits.

Table 3.6 Inter-lab comparison of PBDE concentrations measured in soil samples collected during the summer of 2004 by two laboratories, DFO-IOS and Nicolas School of the Environment & Earth Sciences, Duke University. Principal congeners are bolded. Duke data are highlighted in blue. Raw data are found in Tables C.3 and C.4, Appendix C. All data in pg/g.

Sample ID	CAMBY2	CAMBY3	CAMBY6	CAMBY7	IQ2W40	IQ-2	YELL01
BDE Congeners	Sewage effluent drainage area	Municipal dump	Metal dump, auto and other vehicle scrap	Midtown	West 40 current landfill	Apex Flats in tidal zone, ~400m from shore	Old dumping area of landfill
BDE 30	BMDL	4	11	BMDL	BMDL	BMDL	BMDL
BDE 25	BMDL	BMDL	72	BMDL	BMDL	BMDL	BMDL
BDE 28,33	BMDL	14	BMDL	8	57	7	BMDL
Total tri (Duke)	BMDL	19	84	8	57	7	BMDL
BDE 30	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL
BDE 17	237	54	56	2	29	BMDL	2
BDE 25	15	40	30	BMDL	8	BMDL	BMDL
BDE 28,33	53	93	120	3	59	2	3
Total tri (DFO)	305	188	206	5	96	2	5
BDE 75	BMDL	BMDL	259	19	BMDL	21	BMDL
BDE 49	BMDL	BMDL	176	40	BMDL	BMDL	BMDL
BDE 47	971	260	469	122	1,255	86	133
BDE 66	33	29	93	34	104	BMDL	14
Total tetra (Duke)	1,004	289	997	168	1,360	107	147
BDE 75	BMDL	56	56	BMDL	5	BMDL	BMDL
BDE 49	357	219	267	45	88	1	6
BDE 71	73	42	124	13	16	BMDL	1
BDE 47	1,460	1,299	1,622	32	1,201	30	73
BDE 66	41	166	167	1	60	1	3
Total tetra (DFO)	1,930	1,782	2,235	84	1,371	32	82
BDE 100	267	176	341	33	344	21	60
BDE 99	1,336	743	1,829	100	1,826	12	128
BDE 85,155	57	32	94	3	73	4	10
Total penta (Duke)	1,660	951	2,264	134	2,243	37	198
BDE 100	347	552	490	7	295	4	18
BDE 99	1,946	2,412	2,556	29	1,614	15	85
BDE 85,155	76	151	143	1	2	2	88
Total penta (DFO)	2,369	3,115	3,189	38	1,911	21	191
BDE 154	324	71	345	13	157	BMDL	15
BDE 153	248	272	528	73	268	52	132
BDE 138	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	-
Total hexa (Duke)	572	343	873	86	425	52	147
BDE 154	248	316	357	4	147	2	7
BDE 153	235	299	543	4	187	2	9
BDE 138	16	46	98	1	22	1	1
Total hexa (DFO)	499	661	998	8	356	4	18
BDE 183	74	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL
BDE 190	BMDL	33	97	BMDL	16	BMDL	BMDL
Total hepta (Duke)	74	33	97	BMDL	16	BMDL	BMDL
BDE 183	137	199	701	4	66	BMDL	3
BDE 190	20	29	57	BMDL	4	BMDL	BMDL
Total hepta (DFO)	157	228	759	4	70	BMDL	3
BDE 202	50	36	218	29	BMDL	BMDL	BMDL
BDE 201	BMDL	72	112	10	BMDL	BMDL	BMDL
BDE 197	BMDL	106	683	43	81	32	BMDL
BDE 203,200	BMDL	37	195	30	19	BMDL	BMDL
BDE 196	136	81	590	67	89	BMDL	BMDL
BDE 205	135	39	104	32	BMDL	BMDL	BMDL
Total octa (Duke)	321	371	1,902	211	189	32	BMDL
BDE 201	42	77	110	4	1	BMDL	3
BDE 197	68	147	414	8	11	BMDL	8
BDE 203,200	55	173	380	10	8	BMDL	6
BDE 196	37	105	311	7	7	BMDL	5
BDE 205	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL
Total octa (DFO)	202	502	1,216	28	28	BMDL	23
BDE 208	783	271	1,107	185	BMDL	BMDL	BMDL
BDE 207	784	359	1,477	117	BMDL	BMDL	BMDL
BDE 206	445	92	461	93	BMDL	BMDL	BMDL
Total nona (Duke)	2,012	723	3,046	256	BMDL	BMDL	BMDL
BDE 207	943	285	447	29	30	8	14
BDE 206	845	144	336	19	18	4	7
Total nona (DFO)	1,789	429	783	48	49	12	22
BDE 209	16,885	3,401	17,482	1,029	200	212	1,098
Total deca (Duke)	16,885	3,401	17,482	1,029	200	212	1,098
BDE 209	20,568	5,517	18,759	978	656	347	435
Total deca (DFO)	20,568	5,517	18,759	978	656	347	435
Total PBDES (Duke)	22,529	6,128	26,744	1,893	4,491	448	1,607
Total PBDES (DFO)	27,819	12,421	28,145	1,195	4,536	418	778
sum congeners	21,334	5,374	22,932	1,486	4,051	383	1,565
sum congeners	26,730	11,022	25,812	1,107	4,215	412	652
% of total PBDEs	94.7	87.7	85.7	78.5	90.2	85.6	97.4
% of total PBDEs	96.1	88.7	91.7	92.6	92.9	98.5	83.9

3.6 Conclusions

This chapter provides background information on the extraction and data analysis procedures. Treatment of the data required attention to several key factors. To compensate for background levels of PBDEs, procedural blanks from the lab are utilized to correct the data for background levels of BDEs in the laboratory. Two methods of procedural blank correction are presented. Both gave similar results. Method A is chosen over Method B, as the former describes the different matrices and corresponding procedural blanks in more detail than Method B.

Some samples were re-extracted and analysed in order to provide intra-lab analysis and replicates, allowing errors and uncertainty to be estimated for the 9 principal BDE congeners identified as having the highest concentrations. The reproducibility of the data was tested for cases where there were replicate analyses indicating that there is considerable scatter and uncertainty in the measured concentrations.

Other conclusions are as follows:

- Plotting the data in cumulative form (versus number of bromines) provides a useful method of comparing the overall profile of PBDEs.
- In cases where there were replicate data, variability is high, leading to wide confidence intervals. Caution must therefore be exercised when assessing the differences between results and the influence of various factors in subsequent chapters.

CHAPTER 4 – EXPERIMENTAL RESULTS: INVESTIGATION OF PBDES, DISTRIBUTION IN LANDFILLS AND SEWAGE TREATMENT IN NORTHERN CANADA

4.1 Introduction

Given the health risks of PBDEs and their widespread appearance, including ‘alarming’ levels reported in marine mammals (Ikonomou *et al.* 2002b) and in Canada’s far northern communities increasing at an exponential rate, doubling every 4-5 years (Ikonomou *et al.* 2002a), mass balances are needed to indicate the sources, transfer and accumulation of the various congeners in air, water and soil. Increasing concentrations of PBDEs in the environment and potential ecological and human health risks also require early implementation of best-management practices to contain PBDEs. Studying the leachability of PBDEs from e-wastes and examination of landfill sites to determine the fate and transport of PBDEs are logical starting points. Such factors as the nature and extent of PBDE contamination, potential mobility, bio-availability and cumulative amounts in vegetation, soil and drainage water are important. The spatial distribution of PBDE contamination around landfill areas could assist in determining the sources and spread of PBDEs.

PBDE levels in the environment are increasing (Ikonomou *et al.* 2002a; Rayne *et al.* 2003a; Hites 2004a). Although the EU, Canada and some US states have banned, or are in the process of banning, some PBDEs (2003; European Commission 2005; European Commission Directorate 2006; Peele 2006; Canada Gazette Part I. 2006 (December); Canada Gazette Part II. 2008; Environment Canada 2009; Environment Canada. 2009; State of California, 2003; State of Hawaii, 2004; State of Illinois, 2005; State of Maine, 2003; State of Maryland, 2005; State of Michigan, 2004; State of New York, 2004; State of Oregon, 2005), past usage and consumption of PBDEs mean that even banned congeners will persist in the environment for several decades at least. Moreover, the deca (-209) BDE congener, not yet banned because it is so difficult to replace, will continue in production and is still being deployed as a flame retardant, with no early prospect of being terminated and replaced. The estimated annual global consumption of PBDEs in 2001 was 67,390 tonnes, including 56,100 tonnes of Decabromodiphenyl ether (Deca-BDE), 3,790 tonnes of Octabromodiphenyl ether (Octa-BDE), and 7,500 tonnes of Pentabromodiphenyl ether (Penta-BDE) (BSEF 2003a).

In the present study we examine profiles of PBDEs in soil samples collected in sites near three major urban centres in the Canadian North and in background locations. The selected sites (landfills and dumpsites) were assessed in an effort to identify local sources of PBDEs distinct from long-range atmospheric deposition.

To the best of our knowledge, this is the first study in the Canadian North to investigate PBDE congener patterns in aqueous media (leachate, effluent and background water), and in soil. It was intended to assist in filling gaps in mass balance models and in determining the fate and assessing the risk of industrial and municipal facilities involving disposal on land and in landfills. The North was selected because landfills and dumpsites are relatively isolated there. The long term objectives of northern sampling were to investigate how PBDEs are entering and being transferred among landfill (dumpsite) leachates and soils in the Canadian North and in other parts of Canada. A second long term objective was to provide some data from locations well removed from population and industries. Another aim of this chapter is to provide better understanding of the leachability of PBDEs from e-wastes and other PBDE-containing products, and the mobility of PBDEs in soils, with special relevance to Canada's North.

To meet these objectives, soil, leachate, effluent and background aqueous samples were collected from northern Canadian dumpsites and nearby areas. These compounds are difficult to analyse accurately at low concentrations, in part due to the heterogeneous nature of the samples, and, most important, due to the ubiquitous presence of PBDEs at low background levels in, or on, water, soil and experimental equipment, as explained in Chapter 3.

4.2 Experimental Details

4.2.1 Study Region

An initial field trip was made to three northern Canadian locations (Yellowknife, Iqaluit, and Cambridge Bay) during July and August of 2004. A second field trip to eleven landfill sites in the North, including all three locations visited in 2004, was completed during July and August 2006. All sampling locations were identified with GPS coordinates (Table B.2, Appendix B). A map indicating sample locations is shown in Figure 4.1. Leachate, background water and soil

samples were collected on both occasions and sent for analysis to DFO-IOs to determine the concentrations of measurable PBDE congeners¹.

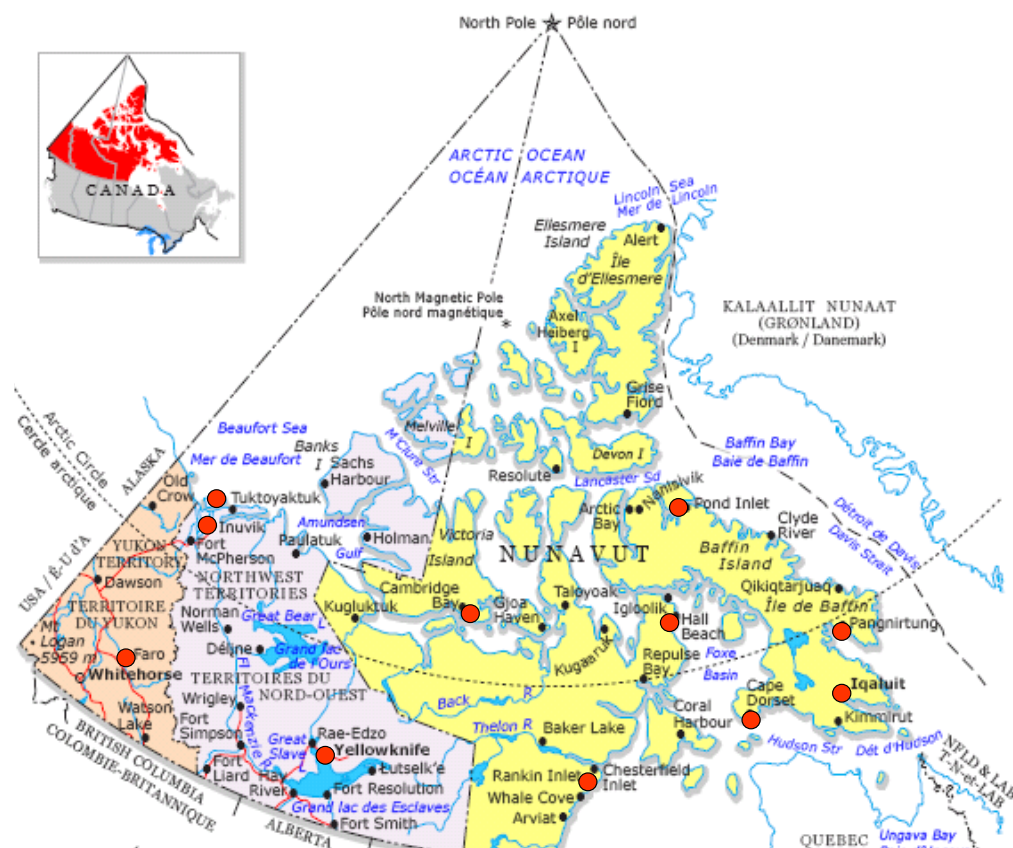


Figure 4.1 Map of Northern Canada (commences at parallel 60 N). Red dots indicate communities where samples were collected.

The author carried out all sampling in the North herself to ensure a uniform sampling methodology. Details on the sampling protocol and procedures are provided in Section 2.5.3. A photograph of one of the landfill sites visited appears in Figure 4.2. Sampling sites, types of sample collected, nature of the dumpsites, latitude/longitude and populations of the communities served, are specified in Tables D.1 and D.2 (Appendix D). Note that none of the dumpsites had liners or covers.

¹ Leachate and background data from 2004 are not discussed in the chapter, but are found in Tables D.10 and D.11, Appendix D. They are not included in the main analysis, due to the few samples collected and the wide variability. Because the 2006 samples could not be collected in precisely the same locations, no comparison is made between the 2004 and 2006 data.



Figure 4.2 Whitehorse (Yukon) landfill

4.2.2 Analytical Protocols

Accurate analysis is especially difficult for BDE-209, which requires different clean-up and GC analysis than lower brominated congeners (de Boer 2004). The deca-BDE data presented in this thesis have been subjected to comprehensive laboratory blank criteria for credibility, total organic carbon (TOC), and, where possible, tested for consistency between two principal laboratories (see Section 2.5). In addition, statistical analyses were performed on the replicate data. BDE-209 tended to have higher standard errors than the other congener groups as shown in Table 3.3.

Cumulative plots are used where possible to illustrate overall PBDE concentration trends in the samples. The main congeners (BDE-47, -99, -100, -153, -154, -183, -206, -207, and -209) are also included as they usually represented over 90% of the total PBDE concentrations in any sample. Where BDE data had to be eliminated due to detection limits and blank corrections, these data are counted as zero when calculating totals and for plotting purposes. Method A explained in detail in Chapter 3, was used for the procedural blank correction approach. As long as the blank-corrected cumulative concentration continues to increase, the cumulative PBDE levels are plotted. This convention is used throughout this chapter.

As explained in Chapter 3, PBDE concentrations were corrected by subtracting either one or two times the procedural blank values for aqueous samples. Many of the measured concentrations were found to be close to the detection limits (i.e. lab blanks), indicating barely detectable or even undetectable PBDE concentrations in these samples. The PBDE aqueous data were

compared with total organic carbon content (TOC) (see Chapter 5) in an effort to better characterize the samples. They were also trying to see whether there is any correlation between PBDE levels and TOC since PBDE molecules are likely to bind to, and travel with, other carbon-based molecules. In addition, aqueous samples that contained few particles were extracted via a simple liquid/liquid process which required minimum handling. On the other hand, aqueous samples containing particles required more extraction steps beginning with filtration, which then followed two different extraction paths. This in turn generated two procedural blanks, followed by centrifugation. The extra handling steps increased the potential for sample contamination as discussed in Section 2.5 of Chapter 2.

4.2.3 Sample Methods and Collection

Due to the cost of sampling and analysis, replicate data were available in only a small number of cases: a) leachate samples from Iqaluit, Hall Beach and Yellowknife (Table D.3, Appendix D), b) sewage effluent samples from Cape Dorset and Pangnirtung (Table D.4, Appendix D), c) background water samples from Cambridge Bay² (Section 4.2.3 and Table D.5, Appendix D), and d) soil from Yellowknife (Section 4.2.4 and Table D.6, Appendix D). Raw data are compiled for individual congeners in Tables D.7 and D.8 (Appendix D) and in groups by bromine number, presented as total BDE groups, i.e. total tri-BDEs, total tetra-BDEs, total penta-BDEs, etc.

Of the 60 congeners measured, only the nine “principal congeners”, found in the highest concentrations, are discussed here. The sum of these nine congeners constituted more than 90% of the total PBDE measured in most aqueous and soil samples. The tables in this chapter describe the nine major congeners identified (BDE-47, -99, -100, -153, -154, -183, -206, -207, and -209) for each of the media investigated.

4.2.3.1 Aqueous (background water and leachate) Samples

As outlined in Chapter 2, all aqueous (background water and leachate) samples were collected in 2.5 litre glass amber bottles previously washed with standard laboratory detergent (Alconox; White Plains, NY) and then rinsed in turn with distilled water, technical grade toluene, technical grade hexane, technical grade dichloromethane, and technical grade acetone. Most leachate

² Also known as Ikaluktutiak

samples were collected below the top of the groundwater table using Waterra® tubing, with a foot valve fitted at the bottom to dark amber glass bottles of 2.5 L volume. In cases where this was not possible, an amber glass bottle was submerged into leachate collection areas allowing the bottle to fill. The effluent samples were collected at the outfall points by placing the amber glass bottle directly under the flow. For the background samples, the amber glass bottles were submerged in the lake, ocean or pond to fill the bottle, similar to some of the leachate collection. Samples were then stored at 4°C until analysis (see Section 2.4 for more details).

4.2.3.2 Soil samples

Soil samples were collected from various sites within Yellowknife, Cambridge Bay, and Iqaluit (see map in Figure 4.3 and Table B.2, Appendix B). These samples were gathered to characterize soils in areas close to known sources of contamination (i.e. landfills, dumps) in Canada's north. Metal dumps are common in Northern Canada. However, they are typically not located close to municipal dumps and can be found inside town boundaries or haphazardly situated in remote areas, often adjacent to a major body of water.

Sixteen surface soil samples were collected at depths of 0-200 mm below surface in the summers of 2004³ and 2006. The 3 communities sampled were Iqaluit (IQ), Cambridge Bay (CAMBY), and Yellowknife (YELL) shown on the map of Figure 4.3. Multiple samples were collected at random areas within both the Iqaluit and Yellowknife landfills (dumpsites). The dumpsite in Cambridge Bay (CAMBY3) was much smaller than the other sample sites (CAMBY2, CAMBY5, CAMBY6 and CAMBY7), and only one representative sample was taken there. The other samples were drawn from various sites, including close to wastewater effluent discharge areas. Most sampling sites contained sewage effluent or leachate discharging into the water body nearest each site. Hand trowels were used for soil collection. They were cleaned between each collection point by triple washing with deionized water, standard laboratory detergent (Alconox, White Plains, NY) and deionized water, followed by rinsing with isopropanol. Similar to the aqueous sample handling, the soil samples were stored in ice-packed coolers until they were delivered to the laboratory where they were then refrigerated at 4°C until analysis.

PBDE analysis of all samples was performed using well-established GC/HRMS-based analytical methods, details of which are presented by (Ikonomou *et al.* 2001). The soil samples were

³Results from 2004 compared with those of 2006 are found in Tables D.10 and D.11, Appendix D.

extracted once, thus, only one procedural blank was associated with each sample and minimum sample handling was required. Only samples with concentrations higher than in the procedural blanks are presented. Typical concentrations measured in procedural blanks are shown in Figure 4.3. All PBDE data for soil are expressed on a dry weight (dw) basis to standardize the comparison with the literature.

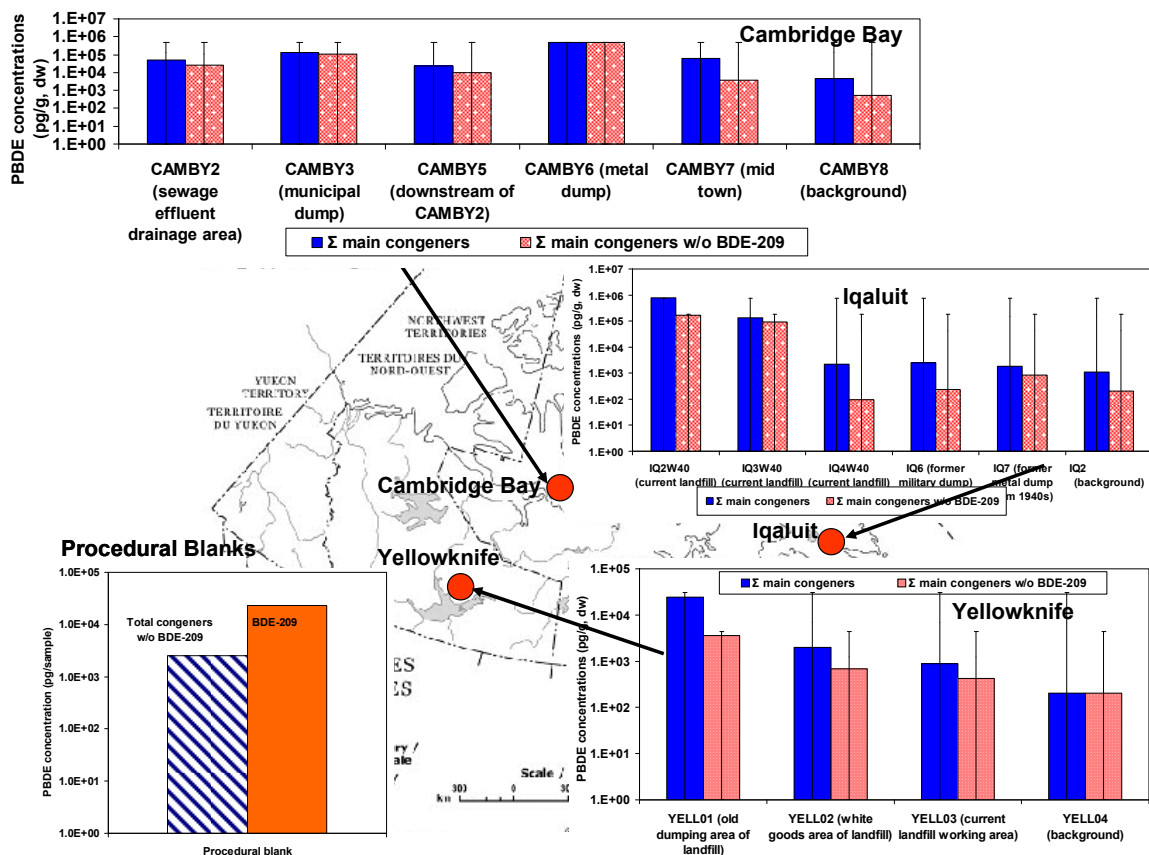


Figure 4.3 Sampling sites, locations and total PBDE concentrations in surface soil samples for Northern Canada (pg/g) (2006 data). Error bars indicate two standard deviations.

4.3 Results and Discussion

4.3.1 Leachate Samples

Ten leachate samples were collected from different locations in the Canadian North in 2006. As shown in Table 4.1, three locations (Hall Beach, Cape Dorset and Whitehorse WEP) had measurable concentrations of BDE-47, whereas the remainder were BMDL. BDE-209 was analysed with BDE-206 and -207, in the manner described in Chapter 3. All sites had measurable BDE-209 concentrations, although three samples were BMDL for BDE-47. Hence, although analyzing BDE-209 presented particular challenges of lab contamination and interference (as

explained in Chapter 3), measurable values were obtained. Iqaluit and Hall Beach samples were re-extracted and the new values were averaged with those from the first extraction and are shown in Table 4.1. The re-extracted raw data are included in Table D.9, Appendix D. A full set of data from the leachate samples collected from the different areas within each community or settlement are presented in Table D.3, Appendix D.

Compared to all other leachate samples, Hall Beach (HB-01) seems to have had a unique concentration profile (Table 4.1 and Figure 4.4). The trend of higher-brominated congeners having elevated PBDE concentrations is apparent. One reason may be due to the fact that the leachate was ponded in a low lying area. The Cape Dorset (CD-2) sample was also collected in a ponded area where the leachate could have been more concentrated. The Whitehorse (WEP) sample was collected from a depth of approximately 25 m. That location is known to have old leachate (i.e. 20 years or more), so that high PBDE concentrations are not surprising given the incorporation of PBDEs in products over time as discussed in Chapter 1. The volume of leachate in the Iqaluit landfill was much greater than that at either Hall Beach or Cape Dorset.

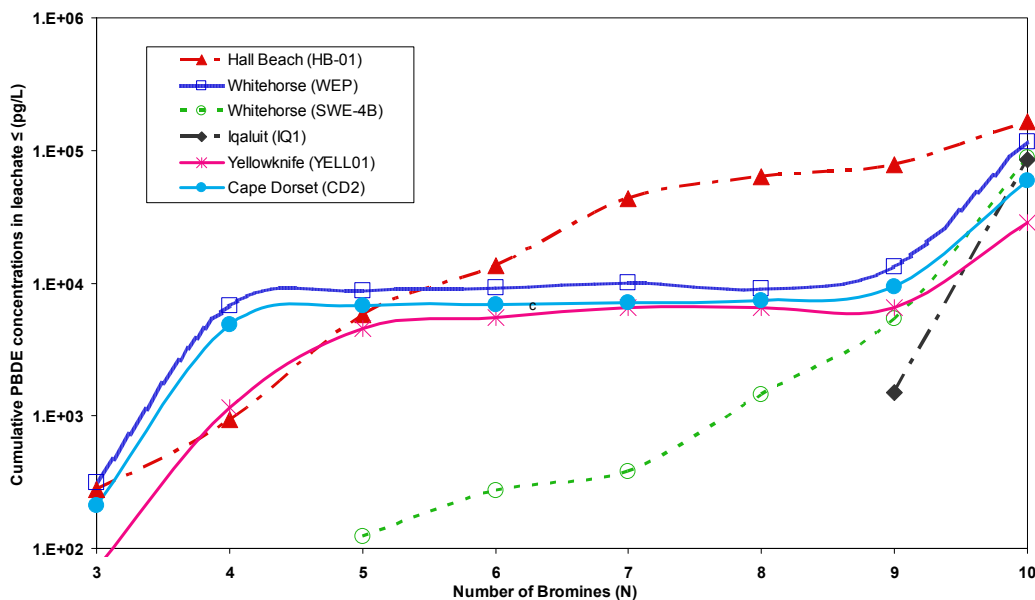


Figure 4.4 PBDE concentrations in blank-corrected leachates from Northern Canada, summer 2006 (Lab: DFO-IOIS). Ordinates give cumulative PBDE concentrations, i.e. sum of concentrations of all PBDE congeners having N or fewer attached bromines. The principal congeners discussed throughout this thesis, i.e. BDE-47 (N=4), -99 and -100 (N=5), -153 and -154 (N=6), -183 (N=7), -206 and -207 (N=9), and -209 (N=10), account for >80% of the total PBDEs.

4.3.2 Distribution and Congener Patterns of PBDEs in Leachate

The highest PBDE concentrations were measured in Hall Beach HB-01 (164,235 pg/L) and Whitehorse, WEP (150,090 pg/L) leachates. The major PBDE congener measured in all of these

leachate samples was BDE-209, ranging between 52 and 98% of the total BDEs, except for Inuvik (INUVIK2) and Tuktoyaktuk (TUK-2, TUK-3) (see Table 4.1). The major congeners were present in the samples collected from Hall Beach (HB-01), Cape Dorset (CD-2) and Whitehorse (WEP). In addition, replicate samples were analysed for YELLO1, IQ1 and HB-01: three, six and two duplicates, respectively, increasing the reliability of these results. The highest concentration of BDE-183, a major component of the Octa-BDE commercial product, was measured in HB-01 (28,429 pg/L). Large variations between the lowest and highest concentrations measured in these samples are likely due to a combination of factors, including the diversity of materials entering the dumpsites, different community characteristics, differences in rainfall and soil permeability and analytic errors, especially when the levels are low.

The HB-01 sample may have contained all three commercial formulations (Penta, Octa and Deca-BDE), as all 9 principal congeners were present in measurable quantities. This also applies to the WEP sample. For CD-2 and Whitehorse (SWE-4B), the presence of the commercial Deca-BDE product is more apparent, as BDE-207 and -206 patterns are similar, and Deca-BDE is known to contain small amounts of these congeners in its formula (see Table 4.5 for product congener distributions.) However, CD-2 was found to have approximately 7% of BDE-47, one of the more persistent congeners found in the Penta-BDE product, (typically between 28 and 30% by weight.) This may also indicate a degraded Penta-BDE formulation. With the exception of HB-01 and WEP, BDE-209 is the major contributor to the BDE concentrations found in these leachate samples.

Table 4.1 Major BDE congeners found in leachate samples from the Canadian North (pg/L). One time procedural blank corrected except where noted (corresponds to Clusters D and J described in Chapter 3). (Lab: DFO-IOS)

Location sampled	Description	BDE-47	BDE-99	BDE-100	BDE-153	BDE-154	BDE-183	BDE-206	BDE-207	BDE-209	Σ 9 main congeners	Total BDEs	BDE-209 as % of Total BDEs
Yellowknife (YELL-01)*	Leachate from landfill	BMDL	BMDL	502	214	157	207	BMDL	BMDL	22,152	23,232	26,755	83
Iqaluit (IQ1)*ξ	West 40 landfill (current)	BMDL	BMDL	BMDL	BMDL	40	BMDL	BMDL	1,508	83,137	84,685	84,756	98
Cambridge Bay (CAMBY4)	Leachate and effluent discharge to ocean	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	509	BMDL	13,628	14,137	14,137	96
Hall Beach (HB01)*ξ	Ponded water at municipal dump, edge of town	702	2,461	2,587	3,840	2,398	28,429	4,411	7,310	85,582	137,719	164,235	52
Cape Dorset (CD2)	Runoff from garbage dump	4,117	1,132	483	141	ND	BMDL	1,605	886	49,764	58,128	59,253	84
Whitehorse (SWE-4B)	Current leachate collection at landfill	BMDL	BMDL	BMDL	10	BMDL	BMDL	2,453	1,770	83,420	87,653	88,871	94
Whitehorse (WEP)	War Eagle Pit, historical leachate, 25 m depth	6,199	1,990	407	277	167	806	934	2,420	103,873	117,073	150,090	69
Inuvik (INUVIK2)	Downgradient from dump at Finning Lake	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	NA
Tuktoyaktuk (TUK-2)	Adjacent to main water body, received leachate from dump and discharges directly to ocean	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	ND	ND	ND	BMDL	BMDL	NA
Tuktoyaktuk (TUK-3)	Ponded leachate at dumpsite, subsequently drains to ocean	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	NA

*Average; BMDL - below method detection limit; ND - not detected

ξ These samples were re-extracted. Procedural blank correction for the re-extracted batches corresponds to 2 times procedural blank correction for the first 6 congeners of the table (corresponds to Cluster E described in Chapter 3) and to 1 time procedural blank extraction for the remaining 3 congeners (BDE-206, -207, and -209) (corresponds to Cluster K described in Chapter 3). Values presented in this table were averaged with the first extraction.

4.3.3 Sewage Effluent Samples

In order to confirm data quality, the lab completed a round of replicate analysis, which is presented in Table D.9, Appendix D. Data from four effluent discharge areas are presented in Table 4.2 and plotted in Figure 4.5, with raw data provided in Table D.4 and D.9, Appendix D. It is seen that the results for re-extraction of the main congeners was good (Table 4.2) when compared to the first extraction (Appendix D, Table D.9). For example, triplicate samples were taken for both Cape Dorset (CD-3) and Pangnirtung (PANG2) locations.

Table 4.2 Major BDE congeners found in sewage effluent samples from the Canadian North (pg/L). One time procedural blank corrected except where noted (corresponding to Clusters D and J described in Chapter 3). (Lab: DFO-IOS)

Location sampled	Description	BDE-47	BDE-99	BDE-100	BDE-153	BDE-154	BDE-183	BDE-206	BDE-207	BDE-209	Σ of main congeners	Total BDEs	BDE-209 as % of Total BDEs
Cape Dorset (CD3)*ξ	Sewage outfall prior to entering Arctic Ocean at Telik Inlet	1,258	5,306	863	617	480	38	1,296	803	36,783	47,444	56,013	66
Pangnirtung (PANG1)	Outflow from secondary wastewater treatment plant	15,959	24,950	5,252	2,990	2,447	495	8,225	4,146	313,126	377,589	381,049	82
Pangnirtung (PANG2)*ξ	Further down from PANG1 outflow before ocean discharge	15,921	27,043	4,925	3,009	2,147	492	6,398	3,534	219,541	283,009	299,212	73
Cambridge Bay (CAMBY1)	Entrance to effluent drainage area	BMDL	3,426	636	779	714	325	2,209	1,975	78,031	88,096	90,587	86

*Average; BMDL - below method detection limit

ξ These samples were re-extracted. Procedural blank correction for the re-extracted batches corresponds to 2 times procedural blank correction for the first 6 congeners of the table (corresponds to Cluster E described in Chapter 3) and to 1 time procedural blank extraction for the remaining 3 congeners (BDE-206, -207, and -209) (corresponds to Cluster K described in Chapter 3). Values presented in this table were averaged with the first extraction.

As noted in Table 4.2, some BDE congeners were higher for PANG2 than for PANG1, which seems surprising given that PANG1 samples were collected at the outflow from the secondary sewage treatment plant (STP), whereas PANG2 was from at least 100 m downstream, prior to ocean discharge. There was no rainfall on the day of sampling, nor on several previous days, so that dilution is unlikely to have been a factor. Note that the only STP in the northern communities is located in Pangnirtung, but, the highest PBDE levels were measured at Pangnirtung. (Several other communities have lagoons where settling, i.e. primary treatment, is carried out.) The BDE levels measured here are low compared to the PBDE effluent concentrations (920×10^6 pg/L and 310×10^6 pg/L of deca-BDE) determined in a Dutch sewage effluent study (de Boer *et al.* 2003), but two orders of magnitude higher (24,950 pg/L of BDE-99 for PANG1) than a wastewater treatment study (11,200 pg/L of BDE-99) performed in the US

(North 2004). No other communities in the Canadian North (north of 60°) have secondary sewage treatment plants.

Both Cape Dorset (CD-3) and Cambridge Bay (CAMBY1) samples were collected from effluent drainage (runoff) areas. These two drainage areas appear to be similar, both ponded areas where the effluent sits prior to discharge. In the case of Pangnirtung, the effluent comes directly from a pipe leading out of the STP. The CD-3 samples were collected from a sewage lagoon outfall prior to discharge into the Arctic Ocean. Differences in BDE concentrations among these locations could also be due to differences in the source and origin of rubbish and runoff in these widely separated communities. However, these factors are very difficult to quantify.

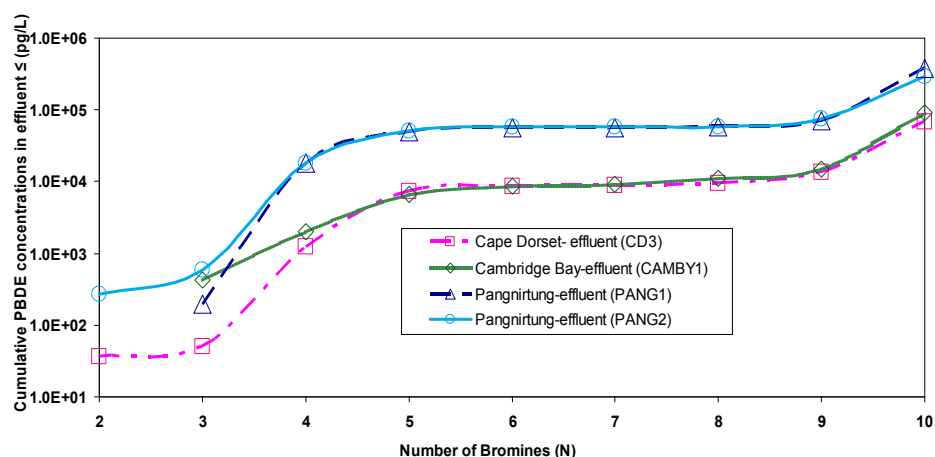


Figure 4.5 Cumulative blank-corrected PBDE concentrations in *sewage effluent* samples from Northern Canada, summer 2006 (Lab: DFO-IOS). Ordinates give cumulative PBDE concentrations, i.e. sum of concentrations of all PBDE congeners having N or fewer attached bromines. The principal congeners discussed throughout this thesis, i.e. BDE-47 (N=4), -99 and -100 (N=5), -153 and -154 (N=6), -183 (N=7), -206 and -207 (N=9), and -209 (N=10), account for >80% of the total PBDEs.

4.3.4 Distribution and Congener Patterns of PBDEs in Sewage Effluent

The concentrations of the nine major BDE congeners are presented for the four effluent samples in Table 4.2. The total BDE concentration from the summation of these congeners represents 85 to 99% of the total PBDE concentrations. The highest measured PBDE concentrations were those from Pangnirtung (PANG1) (381,049 pg/L), followed by PANG2 (299,212 pg/L), which was approximately 100 m downstream from the pipe leading out of the STP, then CAMBY1 (90,587 pg/L) followed by Cape Dorset (CD-3) (56,013 pg/L).

A clear congener pattern emerges for the Deca-BDE product amongst the four effluent samples, when compared to the commercial mixture (see Table 4.5), although the deca-BDE congener only represents 66% of the total BDEs in the CD-3 sample and 73% of total BDEs in the

CAMBY1 sample. It is possible that Deca-BDE has degraded and the observed pattern contains weathered Deca-BDE. Both PANG1 and PANG2 samples have very similar profiles for BDE-153, -154 and -183, whereas the same congeners in CD-3 and CAMBY1 have low concentrations. Interestingly, the profiles for BDE-47 are similar in both PANG1 and PANG2 (4.1 % and 5.3 %, respectively, of total BDEs) and in BDE-100, where the concentrations range between 0.7 to 1.6 % of total BDEs. All BDE congeners reported in the Pangnirtung samples were at least two times higher than levels reported in the literature (North 2004). Other studies have also reported PBDE concentrations from wastewater treatment plants (de Boer *et al.* 2003; North 2004; Bush 2005; Rayne and Ikonomou 2005a, 2005b; Song *et al.* 2006; Vogelsang *et al.* 2006). However, for both CD-3 and CAMBY1, the congeners were all lower when compared to the North (2004) study, with the exception of BDE-206, -207 and -209, which indicates the presence of the Deca-BDE product.

4.3.5 Background Water Samples

The procedure to prepare the background samples for analysis differed from that of the leachate samples, described in detail in Section 2.5, Chapter 2, and earlier in this chapter. Briefly, these samples were determined to contain few if any, particles so they were extracted via a liquid/liquid procedure. The corresponding procedural blanks were treated in the same manner. The potential for lab contamination to be introduced through this process was considered small due to the few steps involved in extracting the samples. In addition, consistency of PBDE levels in the lab procedural blanks was very important in order to provide accurate results given the expected low concentrations of PBDEs from the samples.

The background sample sites were chosen because they were thought to be free of contaminants (Iqaluit: IQAX-3 and IQ5W40; Pangnirtung: PANG3; Cape Dorset: CD1; Hall Beach: HB-02; Pond Inlet: PI-1; Cambridge Bay: CAMBY7 and CAMBY8; Inuvik: INUVIK1 and INUVIK2; Tuktoyaktuk: TUK-1; Rankin Inlet; and Whitehorse: WHT-PC). Most are used as a drinking water source for the community in which they were drawn. In total, thirteen background water samples were collected. Most of these data (Table 4.3) were BMDL. Data from background samples of water sources near dump sites are summarized in Table D.5 (Appendix D).

No clear pattern emerges from the samples that reported measurable BDE concentrations, with the exception of Cape Dorset (CD1) and Whitehorse (WHT-PCT). A profile similar to the Deca-

BDE commercial product is observed for these two samples with BDE-209, comprising between 93-97%, BDE-206 with 1.3%, and BDE-207 ranging from 1.08 to 1.93%. The profile for Tuktoyaktuk (TUK-1) may indicate degradation of Deca-BDE down to the high- and mid-level congeners (i.e. BDE-153, -154, -183, -206, and -207), even though the total PBDE concentration was low (1,512 pg/L). These two sites are situated at similar latitudes, 68°48' and 69°24' respectively, but they are thousands of kilometres apart. It is important to note that each sample represents a point in space and time and must not be regarded as being representative of an entire location or region.

The total PBDE concentrations from the sum of the nine principal congeners in the background water samples constitute all of the PBDEs measured. Only five of the 13 locations analysed show measurable concentrations of BDE-209. One possible explanation for finding deca-BDE is that it is more persistent and may be carried north via atmospheric currents and/or by water as fine particulates.

Both Table 4.3 and Figure 4.6 indicate that the background water sample from Whitehorse (WHT-PC) was the only sample to survive the procedural blank correction for all of the BDE congeners. It is shown alongside the sample from Tuktoyaktuk (TUK-1) in Figure 4.6. Given the extremely low solubility of deca-BDE in water (see Section 1.5.2), the measured concentrations likely reflect fine particulates in the water, but it is also possible that the solubility itself could have been increased by humic substances or other components.

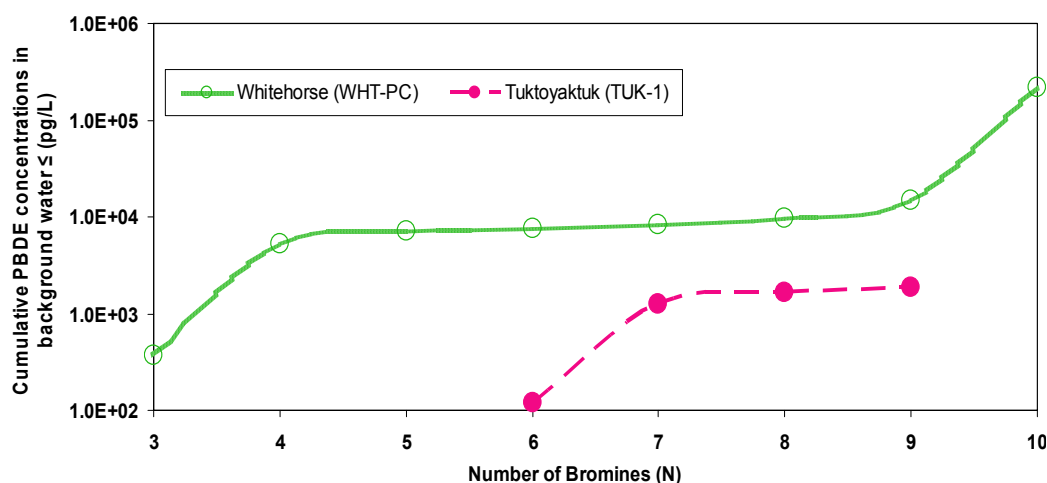


Figure 4.6 Cumulative blank-corrected PBDE concentrations in background water samples from different locations in Northern Canada, summer 2006 (Lab: DFO-IOS). Ordinates give cumulative PBDE concentrations, i.e. sum of concentrations of all PBDE congeners having N or fewer attached bromines. The principal congeners discussed throughout this thesis, i.e. BDE-47 (N=4), -99 and -100 (N=5), -153 and -154 (N=6), -183 (N=7), -206 and -207 (N=9), and -209 (N=10), account for >80% of the total PBDEs.

Table 4.3 Major BDE congeners found in background water samples from the Canadian North (pg/L). One time procedural blank corrected except where noted (corresponds to Clusters D and J described in Chapter 3). (Lab: DFO-IOs)

Location sampled	Description	BDE-47	BDE-99	BDE-100	BDE-153	BDE-154	BDE-183	BDE-206	BDE-207	BDE-209	Σ 9 main congeners	Total BDEs	BDE-209 as % of Total BDEs
Iqaluit (IQAX-3)	Apex Flats	BMDL	BMDL	BMDL	BMDL	ND	BMDL	BMDL	BMDL	62,083	62,083	62,083	100
(Iqaluit (IQ5W40)	Upgradient from W40 landfill (current)	BMDL	BMDL	BMDL	BMDL	ND	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	N/A
Pangnirtung (PANG3)	Upstream river, drinking water source	BMDL	BMDL	BMDL	BMDL	ND	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL
Cape Dorset (CD1)	Tellik Inlet (Arctic Ocean)	BMDL	BMDL	BMDL	BMDL	ND	BMDL	447	659	32,929	34,035	34,035	97
Hall Beach (HB-02)	Drinking water source for town, lake adjacent to DEW line clean up and close to airport	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	6,391	6,391	6,391	100
Pond Inlet (P1-1)	Primary water source for town, ~ 5km away	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	N/A
Cambridge Bay (CAMBY 7)	Background water	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	N/A
Cambridge Bay (CAMBY 8)*	Towards Mt. Pelly, out of town	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL
Inuvik (INUVIK1)	"Road's End" golf course	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	334	15,843	16,177	16,177	98
Inuvik (INUVIK 3)	Boot Lake	BMDL	BMDL	BMDL	ND	ND	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL
Tuktoyaktuk (TUK-1)	Former drinking water source for town, "Water Lake"	BMDL	BMDL	BMDL	88	13	848	142	421	BMDL	1,512	1,512	BMDL
Nipissar Lake (Rankin Inlet)	Background source	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	N/A	N/A	N/A	BMDL	BMDL	N/A
Whitehorse (WHT-PC) ^ξ	Upstream at Porter Creek, prior to entering landfill	4,610	350	1,508	127	165	725	2,849	2,378	204,219	216,929	219,029	93

*Average; BMDL - below method detection limit; ND - not detected; N/A - not available

^ξ This sample was subjected to 2 times procedural blank correction for the first 6 congeners of this table (corresponds to Cluster C described in Chapter 3) and to 1 time procedural blank extraction for the remaining (BDE-206, -207, and -209) (corresponds to Cluster G described in Chapter 3).

4.3.6 Distribution and Congener Patterns of PBDEs in Soil

The concentrations of the nine major PBDE congeners measured in the soil samples of the disposal sites are reported in Table 4.4. No blank corrections were needed for these samples because the concentrations were more than an order of magnitude greater than the procedural blank values. The total PBDE concentrations from the summation of these nine congeners are shown in Figure 4.3. The overall highest total PBDE concentrations measured in the soil samples from the major dumpsites were those from Iqaluit (1,102 to 766,494 pg/g, avg. 153,806) followed by Cambridge Bay (4,540 to 514,874 pg/g, avg. 132,364) and Yellowknife (888 to 24,418 pg/g, avg. 6,852) (Table 4.4). These levels were significantly higher than those measured in corresponding background sites: CAMBY8 = 4,540 pg/g; IQ2 = 1,102 pg/g; and YELL04 = 903 pg/g. The large difference in concentrations between the landfill and background soil samples suggest that PBDEs are being leached from the landfill. The low levels found in background soil samples indicate there has been no activity at these locations for a long time. The background sample sites were chosen to be representative of clean undisturbed soils (Table 4.4). The congener pattern of the background samples was similar in all three instances, the exception was BDE-47 in CAMBY8, which contained 2% of the total PBDE concentration, compared with 10 and 11%, respectively, for IQ2 and YELL04. The BDE-209 contribution for the background sites ranged between 74 and 88%, suggesting that other products were more prevalent and/or BDE-209 had degraded somewhat to the lower brominated congeners. There were large variations between the lowest and highest concentrations in the soil samples within each disposal site, with higher BDE concentrations as expected in currently active dumpsites than in inactive historical dumpsites. These can be attributed to multiple factors, including the historical movement of material within each area and the drainage characteristics of the site. It is important to note, however, that the major PBDE congener measured in most of the disposal site soil samples (except for CAMBY-3 and -6) was BDE-209, ranging between 40 and 96% of the total PBDEs and at concentrations up to 597,263 pg/g. Other major congeners detected in the soil samples of almost all sites were those of the Penta commercial mixture, i.e. BDE-47, -85, -99, -100, -153 and -154. An exception was the soil sample from CAMBY6 (metal dump area) which exhibited a very high concentration of BDE-183, a major component of the Octa commercial mixture.

The profile that emerges from the impacted sites appears to reflect the Penta-BDE product when studying the contribution to BDE-47, -99 and -100 from YELL03, IQ3W40, IQ7 CAMBY2, and CAMBY3 (Table 4.4).

4.3.6.1 BDE Ratios

The dominant BDE congeners in the Penta-BDE commercial product are BDE-47, BDE-99 and BDE-100 (Stapleton *et al.* 2005). They are also the most common congeners found in human tissue (Hites 2004a). For the data, the ratio of BDE-47 to BDE-99 and BDE-47 to BDE-100 are plotted for the three locations where soil samples were collected in the Canadian North (Yellowknife, Cambridge Bay and Iqaluit) and compared to the corresponding ratio in the Penta-BDE commercial product. As observed in Figure 4.7, the ratio of BDE-47/BDE-99 in the commercial Penta-BDE product DE-71 is 0.6 (Rayne and Ikonomou 2002), and in Figure 4.8, the ratio of BDE-47/BDE-100 in the commercial Penta-BDE product DE-71 is 3.5 (Rayne and Ikonomou 2002; ENVIRON 2003a). In each case, the same 10 of 16 soil samples collected exhibited ratios close to those of the commercial product, except at very low concentrations where the differences are large, likely due to lack of accuracy in the values. Both ratios also indicate that the characteristics of the samples are similar, suggesting that they share similar fingerprints. The soil sample (IQ2) with the ratios furthest from the commercial mixture (2.9 for BDE-47/BDE-99 and 9.6 for BDE-47/BDE-100) was a background sample (Table 4.4). As well, each of the ten soil samples giving ratios close to the commercial product (i.e. DE-71) were very similar, e.g. CAMBY3: 0.6 (identical to the DE-71 ratio for BDE-47/BDE-99) and 3.3 (where 3.5 is the DE-71 ratio for BDE-47/BDE-100). Other samples that had similar or identical ratios to that of the Penta-BDE product were: YELL01, YELL02 and IQ2W40, with a ratio for BDE-47/BDE-99 of 0.6, 0.7 and 0.6, respectively, and a ratio for BDE-47/BDE-100 of 3.0, 3.6 and 3.2, respectively (Table 4.4). The ranges of soil samples varied (0.6 to 2.9 for the BDE-47/BDE-99 ratio and 2.6 to 9.6 in the BDE-47/BDE-100 ratio), suggesting that other mechanisms such as debromination may have contributed to degradation of these three congeners (BDE-47, -99 and -100). The fact that some of the measured ratios fall below the commercial product line could indicate debromination to lower BDE congeners.

Interestingly, several samples that have almost the same BDE-47 to BDE-99 ratio as the Penta-BDE product, have similar fingerprints. These are: IQ7, CAMBY3, and CAMBY6. The exception is YELL01, which, although it has the same ratio as the Penta-BDE product, has a

fingerprint which may or may not be that of the Penta-BDE commercial mixture, as the resulting concentrations indicate weathering of the sample, which could contain any or all three of the commercial PBDE products.

Three samples (IQW3W40, CAMBY3 and CAMBY7) exhibited identical ratios to the DE-71 (BDE-47/BDE-100 ratio). The first two of these also had very similar BDE-47/BDE-99 ratios (Figures 4.7 and 4.8).

Some studies have demonstrated that BDE congeners can debrominate as a result of exposure to UV rays (Eriksson *et al.* 2004; Söderström *et al.* 2004). However, the decomposition products were not identified in these papers. Stapleton *et al.* (2005) indicated that BDE-47 could be formed by the removal of a bromine atom from the BDE-99 congener. Note that BDE-47 could diffuse out of the treated product at a faster rate than BDE-99 because BDE-47 has a higher potential for long range transport relative to BDE-99 (Gouin and Harner 2003). Although BDE-100 was not mentioned in the Gouin and Harner (2003) study, its decomposition rate is expected to be comparable to that of BDE-99 given the structural similarity of these two congeners (Stapleton *et al.* 2005).

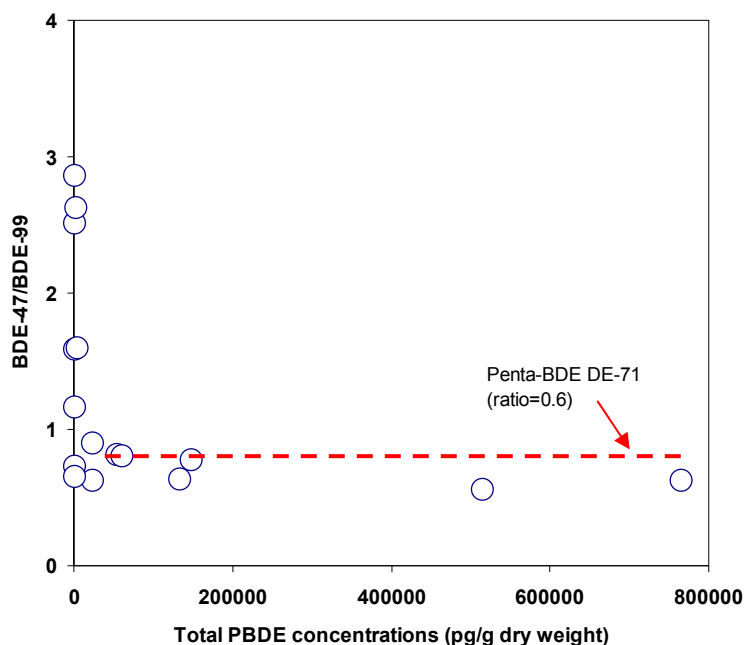


Figure 4.7 Ratio of BDE-47 to BDE-99 measured in three soil locations of Canada's North (Yellowknife, Iqaluit and Cambridge Bay) vs. total PBDE concentration. Dashed line represents ratio in commercial Penta-BDE product, DE-71 (0.6) (Rayne and Ikononou 2002). Symbols correspond to all samples listed in Table 4.4.

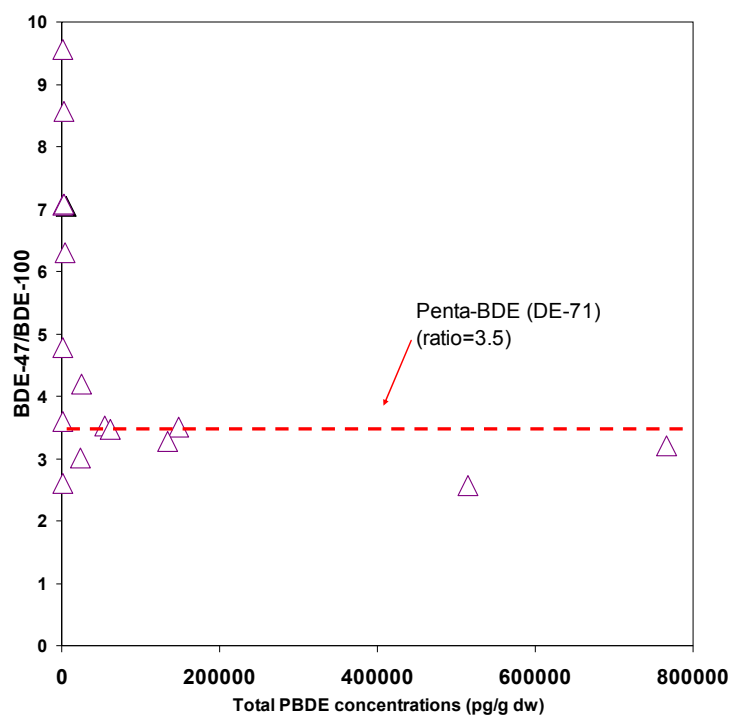


Figure 4.8 Ratio of BDE-47 to BDE-100 measured in three soil locations of Canada's North (Yellowknife, Iqaluit and Cambridge Bay) vs. total PBDE concentration. Dashed line represents ratio in commercial Penta-BDE product, DE-71 (3.5) (Rayne and Ikonomou 2002; ENVIRON 2003a). Symbols correspond to all samples listed in Table 4.4.

Table 4.4 Major BDE congeners found in surface soil samples from the Canadian North (pg/g, dw)

Location sampled	Description	BDE-47	BDE-99	BDE-100	BDE-153	BDE-154	BDE-183	BDE-206	BDE-207	BDE-209	Total PBDEs [§]	BDE-209 as % of Total PBDE	BDE-47 / BDE-99	BDE-47 / BDE-100
YELL01	Old dumping area of landfill; 2 samples averaged**	528	847	175	110	72	101	568	612	20,816	24,418	85.2	0.6	3.0
YELL02	White goods area of landfill; 2 samples averaged**	132	183	37	27	16	33	43	71	1,322	2,010	65.8	0.7	3.6
YELL03	Current landfill working area**	160	138	33	10	9	7	13	12	449	888	50.5	1.2	4.8
YELL04	2 km downstream from landfill boundary; background*	99	62	14	5	3	8	11	24	666	903	73.8	1.6	7.1
IQ2W40	West 40 landfill (current)**	35,448	56,663	11,056	6,608	5,070	4,740	19,764	7,550	597,263	766,494	77.9	0.6	3.2
IQ3W40	West 40 landfill (current)**	27,743	36,003	7,910	3,755	3,238	999	ND	ND	42,499	148,617	28.6	0.8	3.5
IQ4W40	West 40 landfill (current)**	55	22	8	2	1	2	ND	ND	2,143	2,313	92.7	2.5	7.1
IQ6	Former military dump end of old runway**	71	27	8	2	1	6	47	32	2,295	2,502	91.7	2.6	8.6
IQ7	Former military scrap from 1940s**	191	295	73	34	29	33	34	50	960	1,810	53.0	0.6	2.6
IQ2	Apex flats, in tidal zone ~400m from shore; background*	109	38	11	2	2	4	21	10	890	1,102	80.8	2.9	9.6
CAMBY2	Sewage effluent drainage area**	5,139	6,359	1,462	1,169	1,023	813	947	1,267	25,901	54,478	47.5	0.8	3.5
CAMBY3	Municipal dump**	26,648	42,364	8,124	4,858	3,429	1,361	825	1,040	29,063	133,659	21.7	0.6	3.3
CAMBY5	Downstream of CAMBY2, prior to ocean discharge**	2,231	2,495	531	313	297	241	664	571	14,315	24,849	57.6	0.9	4.2
CAMBY6	Metal dump, auto and other vehicle scrap, etc.**	8,569	15,344	3,332	47,350	11,970	199,344	2,531	32,457	14,275	514,874	2.8	0.6	2.6
CAMBY7	Mid town**	420	521	121	58	57	61	1,062	588	58,275	61,784	94.3	0.8	3.5
CAMBY8	Enroute to Mt Pelly 5km NE of town; background*	100	62	16	7	5	33	99	89	4,011	4,540	88.3	1.6	6.3
Average: sites - tested (13)		8,256	12,405	2,529	4,946	1,939	15,980	2,038	3,404	62,275	133,746	46.6		
Average background (3)		102	54	14	5	4	15	40	33	1,634	2,182	74.9		

ND - non detect; * - background; ** - test sites

§ - Total of all detectable congeners, not just the 9 principal ones listed here.

4.3.7 Distribution and Congener Patterns of PBDEs in Yellowknife Soil

In general, the soil samples from Yellowknife exhibited PBDE concentration patterns similar to those of both Cambridge Bay and Iqaluit, but with a variation of ~1 order of magnitude among its four sites, as shown in Figure 4.9. Most concentrations were low, close to procedural blanks, in particular for YELL04. Almost all YELL04 BDE values were below the minimum acceptance levels once the blank correction criteria were applied. Raw data appear in Table D.6, Appendix D). Once again, deca-BDE is the major contributor to the overall measured PBDE concentrations.

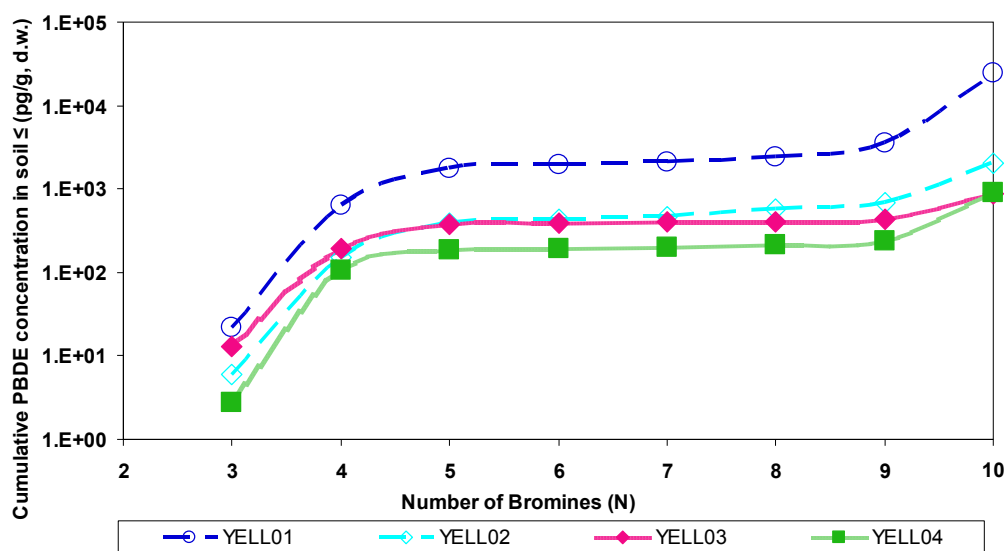


Figure 4.9 Cumulative PBDE concentrations in soil from Yellowknife, summer 2006 (Lab: DFO-IOS). Ordinates give cumulative PBDE concentrations, i.e. sum of concentrations of all PBDE congeners having N or fewer attached bromines. The principal congeners discussed throughout this thesis, i.e. BDE-47 (N=4), -99 and -100 (N=5), -153 and -154 (N=6), -183 (N=7), -206 and -207 (N=9), and -209 (N=10), account for >80% of the total PBDEs.

Soil samples were collected at three sites (YELL01, 02 and 03) within the landfill and at one background site approximately 1 km away from the landfill, on the other side of the highway (YELL04) (Table 4.4), with duplicate samples for YELL01 and 02. The replication obtained from the analyses of the duplicate samples (Table D.6, Appendix D) from these two sites ranged between 5 and 20% for most congeners (Table D6, Appendix D). Two of the sites (YELL02 and 03) had extremely low PBDE concentrations, close to those measured in background samples. This was unexpected considering the characteristics of the site (inside the active part of the landfill). The PBDE concentrations measured at the third sample site, YELL01, were approximately 10 times higher than at the other two sites. These findings suggest that site

morphology, drainage characteristics, and management of the materials in the landfill and/or dumpsite play important roles with respect to the PBDEs in the soil of the specific site. In all samples examined from this site, BDE-209 was the major congener contributing to the total PBDE concentration.

4.3.8 Distribution and Congener Patterns of PBDEs in Iqaluit Soil

As shown in Figure 4.10, four of the six Iqaluit samples, IQ4W40, IQ2, IQ6 and IQ7, were found to have very low BDE overall concentrations. The remaining sites had appreciable nona- and deca-BDE concentrations, with the major BDE contributor being deca-BDE in IQ2W40. These two sample sites had similar concentration profiles among the tetra- to hexa-BDE congener groups. Full data appear in Table D.6, Appendix D.

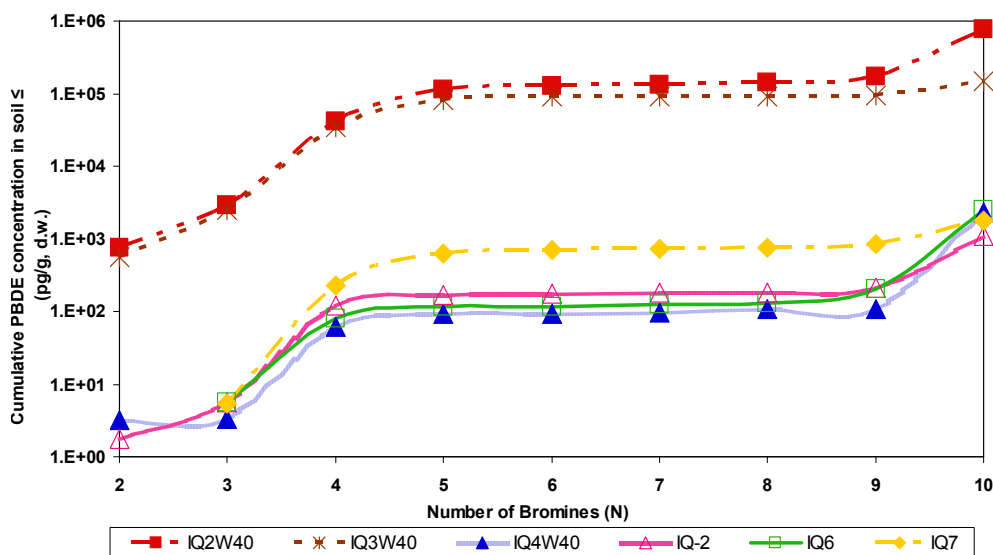


Figure 4.10 Cumulative PBDE concentrations in soil from Iqaluit, summer 2006 (Lab: DFO-IOS). Ordinates give cumulative PBDE concentrations, i.e. sum of concentrations of all PBDE congeners having N or fewer attached bromines. The principal congeners discussed throughout this thesis, i.e. BDE-47 (N=4), -99 and -100 (N=5), -153 and -154 (N=6), -183 (N=7), -206 and -207 (N=9), and -209 (N=10), account for >80% of the total PBDEs.

As in Yellowknife, three sites IQ2W40, IQ3W40, and IQ4W40, were sampled within the current landfill (known as West 40) in operation at Iqaluit, with the remaining three sites located at other dumpsites in Iqaluit. The measured PBDE concentrations are presented in Table 4.4. Once again, concentration differences were observed in the PBDE concentrations among the soil samples from the current landfill in Iqaluit (West 40). IQ4W40 had PBDE levels close to that observed in background sites. The total PBDE levels detected in the other two sites were orders of magnitude higher, with IQ2W40 at 766,494 pg/g and IQ3W40 at 148,617 pg/g. BDE-209 was

the major congener in all three soil samples, and the relative profiles of the other eight PBDE congeners were very similar among these three samples. The total PBDE concentrations measured at IQ6 (a decommissioned military dumpsite) and IQ7 (a former metal dump from the 1940s) were close to the levels typically measured in the Iqaluit background sites examined, suggesting atmospheric deposition. It should be pointed out that IQ6 and IQ7 were between 2 and 5 km from the main landfill in Iqaluit. The materials deposited at IQ6 and IQ7 were primarily metal drums etc., not likely to contain PBDEs as they were placed there in the 1940s, prior to the PBDE era.

4.3.9 Distribution and Congener Patterns in Cambridge Bay Soil

Full data on Cambridge Bay appear in Table D.6, Appendix D. Most BDE concentrations were 1 to 3 orders of magnitude higher than for CAMBY8 (background), as indicated in Figure 4.11.

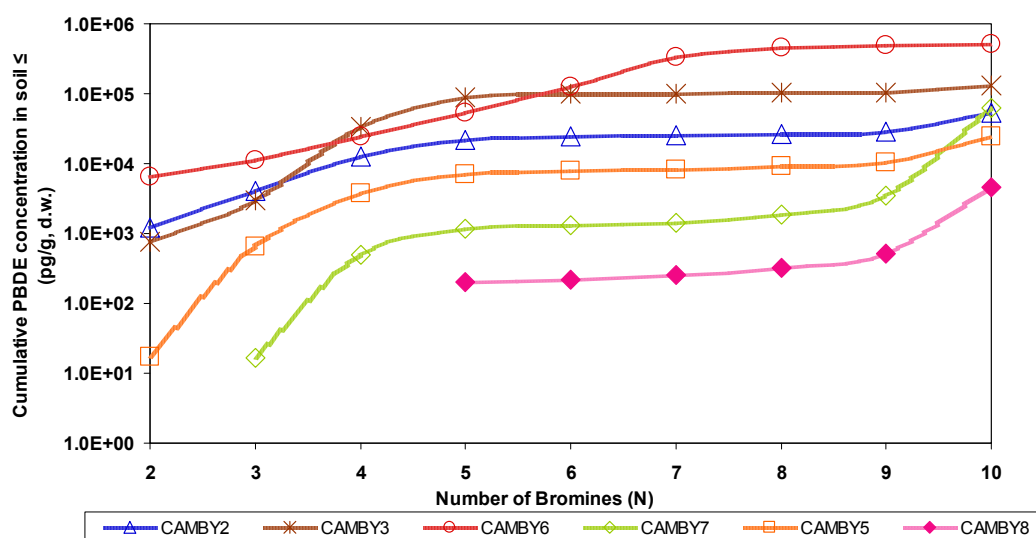


Figure 4.11 Cumulative PBDE concentrations in soil from Cambridge Bay, summer 2006 (Lab: DFO-IOS). Ordinates give cumulative PBDE concentrations, i.e. sum of concentrations of all PBDE congeners having N or fewer attached bromines. The principal congeners discussed throughout this thesis, i.e. BDE-47 (N=4), -99 and -100 (N=5), -153 and -154 (N=6), -183 (N=7), -206 and -207 (N=9), and -209 (N=10), account for >80% of the total PBDEs.

Several samples were collected around the old town site of Cambridge Bay in an attempt to characterize the soils for PBDEs. There was only one municipal dump and one metal dump in the area, approximately 11 km from each other. The soil samples collected from the municipal dump (CAMBY3) and the metal dump (CAMBY6) had the highest overall PBDE concentrations, 133,659 and 514,874 pg/g, respectively (see Table 4.4). The CAMBY6 sample contained significant levels of mid- to higher-brominated congeners found in the Octa-BDE commercial mixture (i.e. ~9.2% of BDE-153 compared to 14.35% in the Octa-BDE product,

2.33% of BDE-154 compared to 2.37% in the Octa-BDE product, ~39% of BDE-183, and 6.3% of BDE-207 compared to 11% in the Octa-BDE product). The high levels measured in CAMBY6 are not unexpected considering that this dumpsite primarily holds vehicle wreckages whose upholstery, foam and plastic are likely to contain large amounts of PBDEs (ENVIRON 2003a; ATSDR 2004; United Nations Economic and Social Council 2006). The PBDE profiles of CAMBY6 (Table 4.4) were unique among the sixteen samples examined in the Canadian North. BDE-183 was the major congener, constituting ~39% of the total PBDE levels measured. BDE-209 was not the major constituent in this sample, and the profiles of the other eight congeners appear to reflect those of the Penta- and Octa-BDE commercial mixtures (Table 4.5) which could originate from the leaching of PBDEs from the discarded vehicles.

CAMBY7 was a mid-town site, an area which might be expected to be free of PBDE sources. However, the total PBDE concentration measured at this site was 61,784 pg/g, with BDE-209 representing 94% of the total measured PBDEs (Table 4.4). The PBDEs at this site likely originated from particle fallout from the town. The other two sites sampled, CAMBY2 and CAMBY5, were in a sewage effluent drainage area, with CAMBY5 downstream from CAMBY2. The total PBDE concentrations measured at the upstream site (CAMBY2) were more than twice (total PBDEs: 54,478 pg/g dw) those at the downstream site (CAMBY5) (total PBDEs: 24,849 pg/g dw) prior to discharge. The congener concentrations for CAMBY2 (BDE-47: 5,139 pg/g dw, BDE-99: 6,359 pg/g dw, BDE-153: 1,169 pg/g dw, BDE-209: 25,901 pg/g dw) and for CAMBY5 (BDE-47: 2,231 pg/g dw, BDE-99: 2,495 pg/g dw, BDE-153: 313 pg/g dw, BDE-209: 14,315 pg/g dw) were compared to other studies that have well documented the presence of PBDEs in sewage effluents (de Boer *et al.* 2003; North 2004). For example, in the de Boer *et al.* (2003) study, particulate matter from the effluent was reported in BDE-47 (22,000 pg/g dw), BDE-99 (<1,000 pg/g dw), BDE-153 (<5,000 pg/g dw), and BDE-209 (350,000 pg/g dw). North (2004) reported values of BDE-47 (757,000 pg/g dw), BDE-99 (944,000 pg/g dw), BDE-153 (88,000 pg/g dw), and BDE-209 ($1,183 \times 10^6$ pg/g dw). Our results support those findings, while also demonstrating significant contamination in soil from sewage effluent drainage areas.

4.3.10 PBDE Distributions in Soil Compared to Commercial Products

The major BDE congeners found in surface soil sampled from the 16 sample sites at three locations in the North are presented in Table 4.4. Total concentrations range from non-detect

(ND) to 766,494 pg/g (dw). BDE-209 contributed more than 60% of the total PBDE concentrations for 8 of the 16 sites, suggesting widespread deca-BDE. The distributions of BDE congeners from IQ2W40, IQ3W40, CAMBY2 and CAMBY3 appear to be similar to that of the commercial Penta-BDE formulation (DE-71, Great Lakes Chemical Corp.), as shown in Figure 4.12 and Table 4.5. Some debromination may have occurred, and uncertainties associated with Deca-values (see Chapter 3) also obscure the trends somewhat, but the Penta commercial product appears to have been present given the elevated percentages of total tetra- and penta-BDE congeners, the main components of the commercial mixture.

The congener profile from the CAMBY6 dumpsite in Figure 4.13 and Table 4.5 reflects similarities with the profile of the Octa-BDE commercial formulation (DE-79, Great Lakes Chemical Corp.). Evaluating the signature for the CAMBY3 dumpsite vis-à-vis the Penta-BDE commercial product and the CAMBY6 dumpsite in comparison with the Octa-BDE commercial product, one can observe differences between these two nearby sites. CAMBY3 is the municipal dump, whereas CAMBY6 is the metal dump. The finding that these two sample sites differ substantially, with apparent predomination of different commercial products, suggests local sources of PBDEs. To the best of our knowledge, this is the first time that potential commercial Penta-BDE and Octa-BDE have been reported in soil samples in the Canadian North.

Table 4.5 Principal congener distributions compared to Penta, Octa and Deca commercial mixtures.

Location and description	%BDE-47	%BDE-99	%BDE-100	%BDE-154	%BDE-153	%BDE-183	%BDE-206	%BDE-207	%BDE-209
IQ2W40 (West 40 landfill, current)	4.63	7.39	1.44	0.66	0.86	0.62	2.58	0.99	77.93
IQ3W40 (West 40 landfill, current)	18.69	24.24	5.33	2.18	2.53	0.67	N/A	N/A	28.63
CAMBY 2 (sewage effluent drainage area)	9.52	11.74	2.71	1.89	2.17	1.50	1.75	2.35	47.97
CAMBY 3 (municipal dump)	21.56	34.22	6.57	2.77	3.93	1.10	0.67	0.84	23.51
Penta-BDE commercial DE-71 (Great Lakes Chemical Corp.)	28.01	43.71	8.02	3.97	6.03	N/A	N/A	N/A	N/A
Penta-BDE commercial 70-5DE (Bromkal)	30.57	46.45	7.6	2.1	3.50	N/A	N/A	N/A	N/A
CAMBY 6 (metal dump, auto and other vehicle scrap)	1.67	2.98	0.65	2.33	9.21	38.76	0.49	6.31	2.78
Octa commercial DE-79 (Great Lakes Chemical Corp)	0.09	0.13	0.00	2.37	14.35	30.00	1.38	11.50	1.31
Octa commercial 79-8DE (Bromkal)	0.00	2.4	0.00	4.08	3.23	N/A	7.66	11.20	N/A
Deca-BDE Saytex 102E (Albermarle)							2.19	0.24	96.80
Deca-BDE 82-ODE (Bromkal)							5.13	4.10	91.60
Source for BDE-47, BDE-99, BDE-100, BDE-153, BDE-154: Rayne and Ikonomou, 2002									
Source for BDE-206, BDE-207 and BDE-209: La Guardia, et al 2006									
Notes: N/A - not available									

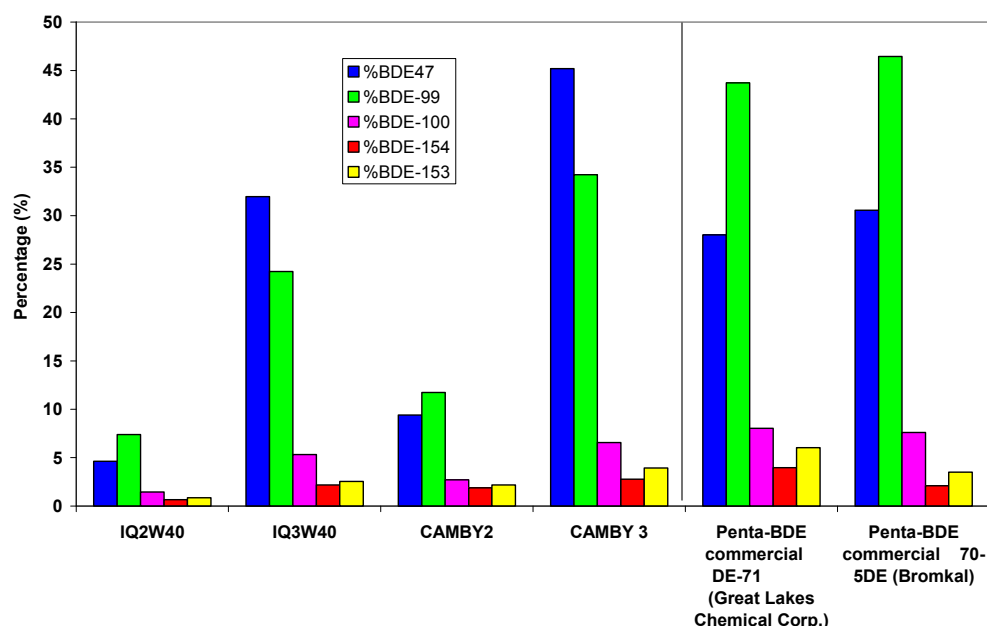


Figure 4.12 Penta-BDE (DE-71, 70-5DE) commercial product relative fractions of principal congeners (Rayne and Ikononou 2002) compared to four soil samples collected in this work. BDE congeners are included in the commercial formulation only where they were reported to be present.

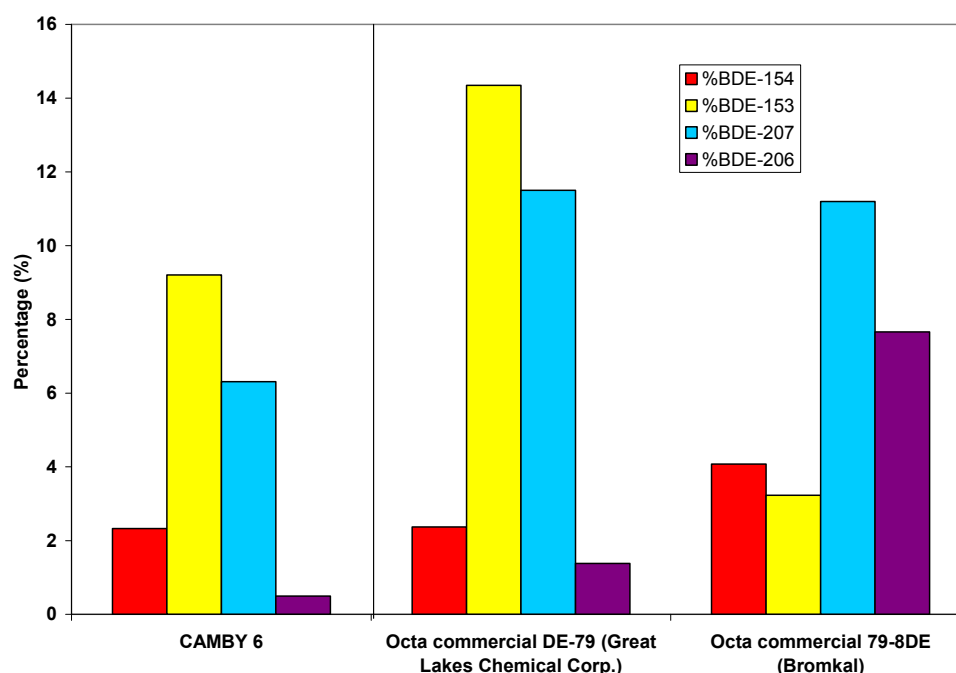


Figure 4.13 Octa-BDE (DE-79, 79-8DE) commercial product relative fractions of principal congeners (the source for BDE-153 and -154 congeners: Rayne and Ikononou, 2002; the source for BDE-206 and -207: La Guardia et al. 2006) compared to soil samples collected in this work. BDE congeners are included in the commercial formulation only where they were reported to be present.

4.3.11 Congener-specific PBDE Concentrations in Soil Compared to Other Jurisdictions

PBDE data from the same sixteen northern soil sample sites were averaged so that they could be compared with other jurisdictions around the world. This averaging was carried out because the information available in the literature is presented in that manner. PBDE levels in soils from

these jurisdictions are provided in Table 4.6. Note that they are difficult to compare with one another since each laboratory treats and reports data differently. Different laboratories also follow different methodologies, making comparison challenging. In spite of this, it is notable that the highest concentrations have been found in samples collected close to e-waste recycling facilities (Wang *et al.* 2005b; Cai and Jiang 2006).

The measured concentrations depended on the site characteristics. Substantial concentrations of PBDEs were present in the soil of all sites in the Canadian North likely to have been subjected to landfill leachates, sewage effluents, city fallout, and/or vehicle disposal. The concentrations of PBDEs measured in soils from this study are compared in this section to PBDE concentrations measured in soils from other countries. The data are divided according to background samples or potential source receptors. Averages of our three background samples and the thirteen ‘test’ sites are presented in Table 4.6. The data available reported from elsewhere are also divided into background and ‘test’ sites and also appear in Table 4.6. In order to make the data comparable, 7 of the 9 principal congeners common to all of the jurisdictions reporting PBDE concentrations in soil were selected: BDE-47, -99, -100, 153, -154, -183 and -209. The concentrations measured in the background samples from our Canadian North sites are similar to those measured in background samples from north European jurisdictions (Hassanin *et al.* 2004; Sellström *et al.* 2005). As anticipated, the highest PBDE concentrations were at sites close to electronic waste facilities, i.e. the data from China (Wang *et al.* 2005a; Cai and Jiang 2006) in Table 4.6. The PBDE levels measured at the Canadian North locations are appreciable, even though they were not collected in major urban centres. Soil samples from other jurisdictions around the globe from populated areas such as the Pearl River Delta (Zou *et al.* 2007) and soils near industrial facilities, like the foam plant in the US (Hale *et al.* 2002), had, on average, lower PBDE levels than those observed in the soil samples from the Canadian North.

PBDEs in landfill leachate and landfill soils samples have not been widely investigated. Our data suggest that substantial amounts of PBDEs are deposited in soils in and around landfills and dumpsites, allowing them to leach into the aquatic environment.

Table 4.6 Comparison of average PBDE levels in soils from different countries, separated into test and background samples (pg/g, dw). The number of samples averaged is indicated in brackets.

Country	Impacted sites	BDE-47	BDE-99	BDE-100	BDE-153	BDE-154	BDE-183	BDE-209	Total PBDEs
Canada	Canadian North (13) ^{*1}	8,257	12,403	2,528	4,946	1,939	15,980	62,275	133,746±235,944
U.S.	Foam manufacturing plant (2) ²	20,000	23,000	2,000	N/A	N/A	N/A	N/A	45,000
China	Close to e-waste recycling site (2) ³	125,000	315,000	46,000	127,000	40,500	420,000	N/A	1,073,500
China	Close to e-waste recycling site (6) ⁴	177,400	552,000	N/A	62,500	49,000	12,300	N/A	853,200
China	Watershed soils (Pearl River Delta) (33) ⁵	630	140	30	45	30	35	13,800	14,710
China	Close to e-waste recycling site (3) ⁶	1,050	1,580	200	850	350	3,700	70,500	78,230
	Background sites								
Canada	Canadian North (3) ^{*7}	103	53	14	5	3	15	1,856	2,182±2,045
U.K.	Grasslands / woodlands (21) ⁸	275	590	730	140	60	50	N/A	1,845
Norway	Woodlands (24) ⁹	250	360	60	50	50	25	N/A	795
Sweden	Research stations (5) ¹⁰	35	50	15	10	10	10	480	600

*Canadian North sites, values taken from **Table 4.4**

1 - This research; 2- Hale et al. 2002; 3 - Wang et al. 2005a; 4 - Cai et al. 2005; 5 & 6 - Zou et al. 2007; 7 - This research; 8 & 9 - Hassanin et al. 2004;

10 - Sellström et al. 2006

4.4 Conclusions

PBDE concentrations were measured in leachate, effluent, background water, and soil samples drawn from Northern Canadian locations in 2004 and in 2006. Only 2006 data are discussed in this chapter. For the leachate samples, PBDE concentrations were primarily determined to be the BDE-209 congener. A similar pattern emerged for the background water samples, with BDE-209 as the major contributor. The concentrations were surprisingly high from Pangnirtung, the only community in the Canadian North that operates a secondary sewage treatment plant, indicating that its wastewater treatment plant did not efficiently remove PBDEs.

For soils, BDE-209 was again the predominant congener at all locations except one where BDE-183 constituted the major congener. Significant PBDE contamination was found in soil from sewage effluent drainage areas. The ratios of BDE-47/BDE-99 and BDE-47/BDE-100 measured in the three Northern locations indicated a similar fingerprint to the Penta-BDE commercial product DE-71 in ten of the sixteen samples collected. The commercial PBDE Penta-BDE and Octa-BDE product in the environment were also potentially identified at two of the sampling locations. More monitoring and duplicate sampling are needed to augment the data set and to study potential temporal trends and other variables. Given this and the analytical uncertainties described previously, it is impossible at this stage to fully define the sources of PBDEs in the northern dumpsites or to be able to interpret them in more detail. The findings also point to the need to collect soil samples underneath the mounds of disposed materials for more comprehensive site evaluations.

CHAPTER 5 – CANADA-WIDE LANDFILLS

5.1 Introduction

The vast majority of commercial products containing PBDE compounds (electronics, mattresses, polyurethane foam, vehicle interiors, etc.) enter waste streams; currently up to 85% of discarded electronic products are ultimately disposed of in landfills (~80%) and the rest incinerated (Alcock *et al.* 2003). At present, there are no reported studies quantifying the distribution of PBDEs in landfill leachate. This chapter presents PBDE concentrations for samples obtained from urban landfill sites across Canada, and compares these with the data reported in Chapter 4 from landfills and dump sites in the Canadian north. These data are then used to determine whether there is any correlation between PBDE levels and such factors as population served and landfill tonnage. The factors affecting PBDE concentrations in leachate samples are also discussed. To the best of our knowledge, this is the first Canadian study to investigate PBDE congener patterns in landfill leachates.

5.1.1 Landfilling

Landfilling has been the most common way to dispose of municipal solid waste (MSW) in many countries for many decades. MSW is landfilled to reduce environmental impacts to a minimum (Francois *et al.* 2006). Waste is normally landfilled in horizontal layers and subsequently compacted mechanically. The composition of waste deposited in landfills is typically determined by consumption habits and waste management systems of the community where they are located, as well as by changes in product usage (e.g. plastics introduced in the 1960s) (Sormunen *et al.* 2008). Daily cover at a landfill normally consists of soil layers and bottom ash from incineration operations (see Chapter 7 of this thesis), used to minimize transfer as dust into the air. Depending upon the jurisdiction, daily cover may vary and consist of auto-shredder residue and/or shredded upholstery (Petreas *et al.* 2005). Landfills store heterogeneous materials over time, compacted to a density of 800 to 1,000 kg/m³ (Sormunen *et al.* 2008). The degree of compaction influences the aerobic decay, temperature, homogeneity and rates of settlement across the landfill site (Campbell 1993).

The final quality of the waste cover is significant to prevent contaminant release to the environment. Environmental management of leachate should include leachate quality and

quantity monitoring, as well as the quality of the receiving environment (Campbell 1993). A landfill should be designed to contain leachate collection and treatment either internally or externally. Some release may occur, no matter how well engineered a landfill is (e.g. with impermeable liners and caps, leachate and gas collection systems).

The behaviour of landfilled PBDE-containing products is poorly understood. Increasing amounts of e-waste continue to enter the final disposal stream as faster equipment replaces older devices considered to be obsolete. Most discarded items enter landfills and/or incinerators for final disposal (US National Safety Council. 1999; EnviroRIS 2000; Cal/EPA Integrated Waste Management Board 2001; Puckett *et al.* 2002; RIS International Ltd. 2003; Puckett *et al.* 2005; UNEP 2005a; Grossman 2006; Hileman 2006; US EPA 2007; Wong *et al.* 2007; US EPA 2008; Ni and Zeng 2009). It has also been found that sediments in the water surrounding landfill and sewage treatment facilities contain nanogram/gram (ng/g) range concentrations of PBDEs (Allchin *et al.* 1999; de Boer *et al.* 2003). Currently, there are no reported studies quantifying the distribution of PBDEs in landfill soils and the mechanism of leaching of PBDEs from such sites.

5.1.2 Leachate

Landfill leachate is produced from precipitation that falls on the site and percolates through the landfill into the waste. It can also come from moisture in the waste that is slowly released or produced as more waste or cover is placed on top of the MSW. Compounds contained in the original waste, as well as products resulting from waste degradation, can be found in the leachate. Conditions that affect the degradation process include site geometry, waste types and input rates, as well as weather and operational practices (Campbell 1993). Degradation processes are also influenced by such parameters as waste density, moisture content and temperature (Campbell 1993). In engineered landfills, geomembrane liners are typically placed on the bottom of the landfill to prevent leachate migration. Collection pipes carry the leachate out of the landfill to an external collection system for future treatment, to a wastewater treatment plant, or for direct discharge to a body of water (Camobreco *et al.* 1999; Sormunen *et al.* 2008). Monitoring wells are placed in the body of the landfill to characterize the leachate quality at chosen locations.

Leachate quality depends on the age of the landfill, the stage of waste degradation, and the organic matter, chloride, heavy metals and other organic/inorganic compounds contained in the wastes (Sormunen et al. 2008). The easiest way to characterize leachate is by identifying the main waste decomposition phases in a MSW landfill, these being the acid and methanogenic phases (Spalvins et al. 2008). Proper leachate management is critical for any landfill, given the potential for contamination of aquifers, groundwater and surface water (Campbell 1993).

In addition to anaerobic processes which affect leachate inside landfills, leachate composition may be influenced by redox reactions, oxygen-demanding biological degradation, volatilization, dilution, sorption, ion exchange and precipitation (Öman and Junestedt 2007). Öman and Junestedt (2007) also found that other factors can also affect leachate composition, including the rate of degradation and landfill height.

5.1.3 Previous Studies

Data on PBDEs in leachates are sparse. Öman and Junestedt (2007) characterized landfill leachates in Sweden for compounds that had not been analysed in the past including PBDEs. Their samples were collected adjacent to waste deposit areas in order to obtain representative samples that would either migrate to surrounding areas or be treated in a sewage treatment plant. Reported PBDE levels in their study were low relative to most of those reported in this thesis.

Oliaei (2005) conducted a leachate study in Minnesota to investigate PBDE contamination in five landfills and sewage treatment plants, finding an average of 23,762 pg/L total PBDEs in the landfills (Table 5.1). In another study, Osako *et al.* (2004) analysed leachate from seven municipal and industrial landfills in Japan that contained bulk waste material plus crushed e-waste. The concentrations of PBDEs in leachate from that study varied widely among the seven landfills studied, with relatively high concentrations of PBDEs at landfills that contained large volume of organic material. Due to the hydrophobicity of PBDEs, it is possible that their levels (<8 to 50,000 pg/L) could have been influenced by the presence of dissolved humic substances in the leachate (Osako *et al.* 2004). The respective ranges for major congeners analyzed in previous work are compared in Table 5.1. Two jurisdictions where samples were collected (Sweden and Japan: (Osako *et al.* 2004; Öman and Junestedt 2007), appear to have had low concentrations (see Table 5.1).

Table 5.1. Summary of previous PBDE concentrations in leachates from the literature. In order to facilitate comparison and interpretation of the data, only six congeners common to all jurisdictions are included in this table: BDE-47, -99, -100, -154, -207 and -209.

Reference	This work	Oliaei, 2005	Öman & Junestedt, 2007	Osako, et al, 2004	Odusanya, et al 2008
Location	Canada-wide	Minnesota, USA	Sweden	Japan	South Africa
Type of landfill	municipal	municipal, industrial, demolition	municipal	municipal and industrial	65
Extraction method	liquid-liquid	N/A	liquid-liquid	liquid-liquid	liquid-liquid
Type of sample	leachate - grab	leachate	leachate - grab	leachate	leachate - grab
Filtered	yes	N/A	N/A	yes	N/A
Filter size	0.7 µm	N/A	N/A	1 µm	N/A
Solvent	dichloromethane, accelerated solvent extraction (ASE)	N/A	methylene chloride	dichloromethane, Soxhlet with toluene	hexane, dichloromethane, petroleum ether, acetone
Unit	pg/L	pg/L	pg/L	pg/L	pg/L
BDE congener	range	range	range	range	range
BDE-47	BMDL-194,000	180-5,000	1700	<8 - <500	1,470-9,800
BDE-99	BMDL-500,000	230-7,500	NA	<8 - 1,800	440-5,200
BDE-100	BMDL-100,000	50-1,550	1100	<8 - <500	240-2,160
BDE-154	BMDL-81,700	20-870	1	<8 - 1,200	140-2,180
BDE-207	BMDL-21,300	140-1,500	290	NA	NA
BDE-209	BMDL-460,000	24,000-244,000	1100	<800 - < 50,000	NA
Σ total of 6 congeners (range)	BMDL-1,357,000	24,620-260,420	1-1,700	<8-50,000	2,290-19,340
Total PBDEs (background sites)*	56,538	N/A	N/A	N/A	N/A
Total PBDEs (municipal landfills)**	231,713	83,055	838	10,702	22,543

N/A - not available

*Background samples collected in the Canadian North, see Section 4.3.5

**Landfill leachate averages from 20 sites across Canada, see Table E1, Appendix E for data

5.2 Sampling and Analysis Details

This study involved collection of leachate samples from various Canadian jurisdictions south of parallel 60. None of the leachate samples was homogenous, and thus they were subjected to various extraction steps to ensure that PBDEs were efficiently extracted from these matrices. In addition, the samples were full of particulates requiring extra steps at the extraction stage. Analytical protocols are discussed in Sections 2.4 and 2.5 of Chapter 2. Some of the leachate samples contained very low concentrations of PBDEs, and therefore special attention to procedural blanks was essential. Chapter 3 discusses the procedural blank correction method in detail. In order to compare the leachate samples and assist with the interpretation of the data, standardization via total organic carbon (TOC) was necessary.

5.2.1 Canada-Wide Samples

Many jurisdictions across southern Canada were contacted in an effort to obtain leachate samples. A confidential letter (see Appendix B.3) was sent to 50 jurisdictions to request that they provide leachate samples for PBDE analysis. In the end, 27 of these landfills provided leachate samples from operating landfills and closed landfills still being monitored for groundwater quality. PBDE concentrations were analysed from these 27 samples, and TOC values (discussed below in Section 5.2.2) were obtained from 20 of them. All of the samples from southern Canada were obtained between fall (September to November) of 2005 and spring (April to June) of 2006. Individualized data were provided to each of the 27 respondents. Variables such as population ($<10,000$ to $> 10^6$) served by the landfill, age of waste in contact with leachate, type of landfill (municipal, industrial, other), leachate collection method (Table 2.7, Chapter 2), pH, and conductivity were recorded in an effort to determine whether they were correlated with the measured PBDE concentration levels. Note that each location in southern Canada did its own sampling based on its own sampling protocol, chosen by the landfill operators. Hence, lack of comparability and inherent biases are likely to have been introduced by different sampling procedures at different sites, added to variability caused by different waste compositions and varying landfilling procedures in different provinces and municipalities. Some variability may also be due to weather-related events, such as recent rainfall and prolonged drought, as well as different dates of sampling.

Complete data from the different jurisdictions where leachate was collected are presented in Tables E.1 and E.2, Appendix E. The names of the cities and towns are withheld to comply with the terms of the invitations to participate in the study. Instead, sample locations are identified by an unrelated uppercase letter. There is considerable variability in location, population, weather, etc. among the sites from across Canada, associated largely with the various factors enumerated in the previous paragraphs. The raw data, procedural blank correction and final values are listed in Tables E.1 and E.2, Appendix E. In addition, samples from across southern Canada were analysed by DFO-IOs, and all data are blank-corrected as described in Chapter 3. Chapter 3 also outlines how laboratory differences in sampling at different times were treated. In addition, it details how procedural blanks were handled to produce reliable data for interpretation. Recall from that chapter that most leachate samples were re-analyzed to confirm the PBDE levels and to assess factors affecting reproducibility, in particular to assess sub-sampling due to the lack of

homogeneity because of the significant loading of particles in the leachate samples. Further, these leachate samples were not homogeneous and therefore it was necessary to treat the samples with more extraction steps than samples containing few particles.

5.2.2 Total Organic Carbon (TOC) and Data Normalization

Total organic carbon (TOC) is defined as the concentration of carbon present in organic compounds, such as PBDEs. In this thesis, it is a measure of the organic carbon in the particulate removed from the leachate samples. The raw PBDE data in the thesis, even after procedural blank correction, were extremely variable. TOC is primarily influenced by particle size, analytical extraction efficiency and sampling/sub-sampling, all of which can lead to inaccuracies in data. Since particles rich in organic carbon have the greatest potential to bind PBDEs, and since PBDEs (Environment Canada. 2006) preferentially bind to particulate when in water, the lab measured the concentration of TOC in the samples to examine whether there was any correlation between the measured PBDE levels and the TOC levels.

The samples were analysed for TOC on a Control Equipment Corporation (CEC) 240-XA Elemental Analyzer (Leeman Labs, Inc.) with standardization and procedural blank determination using a CAHN Electrobalance (Model 4400) (Knap *et al.* 1994). Total organic carbon (TOC) content is the sum of the dissolved organic carbon (DOC) and particulate organic carbon (POC), in units of g/L.

TOC values were evaluated for the 20 leachate samples which survived the procedural blank-correction procedures. Procedural blanks were subtracted from the TOC following analogous procedures to Method A in Section 3.2, leading to a one-times (1x) procedural blank correction for seven of the 20 samples and a two times (2x) procedural blank subtraction for the others, depending on the degree of lab contamination/interference at the time of analysis. The results are listed in Table 5.2 together with the principal congener BDE values and total PBDE concentrations for the same samples. They are also plotted in Figures 5.1 and 5.2. Figure 5.1 plots total principal PBDEs (excluding BDE-209) *vs.* TOC in these samples. Most of the data indicate a correlation between TOC and PBDE concentration. However, there are some outliers, notably two identified as SE and SW regions (with relatively large populations) and the other two from the NE regions, with low populations, all identified by arrows. Those with similar TOC levels but different PBDE concentrations may indicate different point sources. Figure 5.2

plots the BDE-209 values against TOC. With the exception of two locations (see Table 5.2), BDE-209 is the congener that contributes the most to the total PBDE concentrations. Three outliers are identified in this plot. However, two of these three have similar populations (>100,000) and are located in urban centres, while the third outlier is remote with a small population (<10,000).

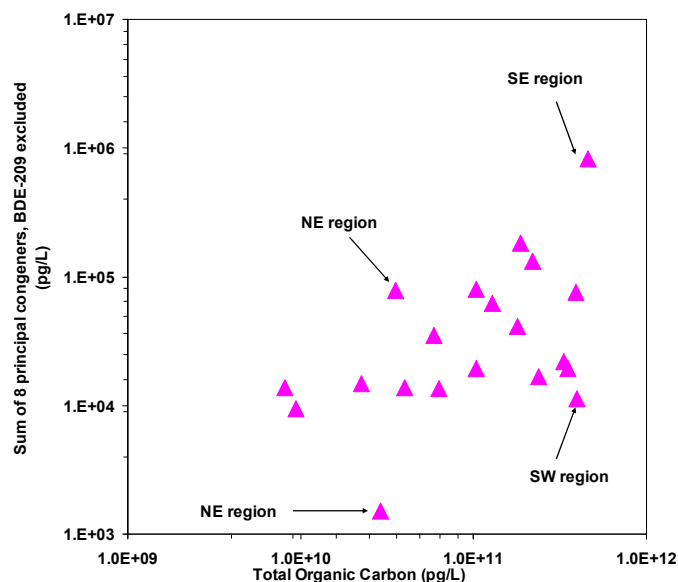


Figure 5.1 Lechate samples collected from landfill sites in major cities across Canada in 2005-2006. Sum of the eight principal congeners (BDE-47, -99, -100, -153, -154, -183, -206, and -207), BDE-209 not included, from Canada-wide aqueous samples vs. total organic carbon (TOC) levels (pg/L). The outliers are indicated by the arrows (Lab: DFO-IOS).

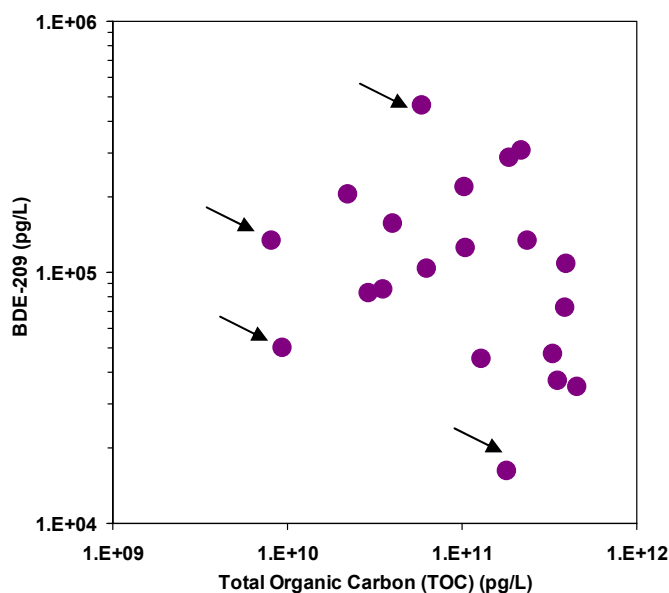


Figure 5.2 BDE-209 concentrations from Canada-wide aqueous samples vs. total organic carbon levels (TOC) (pg/L) (Lab: DFO-IOS). Note that there are fewer points than sites analysed due to BMDL (below minimum detection level) concentration values. The arrows indicate samples that behaved differently from the rest because the sources of these samples were very different from one another.

Table 5.2 Procedural blank-corrected sample principal BDE congener concentrations (pg/L) in order of decreasing total organic carbon (TOC) (also in pg/L) content levels from 20 landfill leachates across Canada¹. For full data including procedural blank-corrections applied, see Tables E.1 and E.2, Appendix E.

Location	tetra-BDE	penta-BDE		hexa-BDE		hepta-BDE	nona-BDE		deca-BDE	Sum congeners w/o BDE209 (pg/L) ¹	Sum of 9 congeners (pg/L) ²	Total PBDEs (pg/L) ³	% congeners ⁴	Total Organic Carbon (TOC) (pg/L)	Total PBDE concentration normalized by TOC	Normalized TOC data
	BDE-47	BDE-99	BDE-100	BDE-153	BDE-154	BDE-183	BDE-206	BDE-207	BDE-209							
A	150,593	316,891	76,683	62,105	71,744	7,600	6,433	7,142	19,205	699,190	718,395	867,805	83	4.56E+11	2.10E-06	1.90E-06
B	4,485	2,397	696	218	154	428	2,460	1,841	99,621	12,679	112,300	134,182	84	3.95E+11	6.00E-07	3.40E-07
V	19,090	26,047	7,252	7,696	6,642	3,358	2,514	2,213	71,343	74,811	146,154	163,594	89	3.89E+11	2.42E-07	4.20E-07
E	895	2,555	356	482	393	81	1,773	892	27,272	7,427	34,699	36,107	96	3.52E+11	7.07E-08	1.02E-07
F	9,083	4,248	3,160	1,552	1,338	2,509	1,438	1,765	51,235	25,093	76,328	86,916	88	3.33E+11	2.84E-07	2.61E-07
G	5,567	6,025	1,376	810	692	934	3,176	3,770	149,684	22,351	172,035	177,024	97	2.39E+11	7.27E-07	7.41E-07
C	5,489	13,355	11,440	3,299	5,162	17,302	22,476	11,453	279,044	89,975	369,019	400,523	92	2.20E+11	2.32E-06	1.82E-06
D	29,098	32,867	16,699	14,696	15,102	7,587	12,413	10,341	255,028	138,802	393,830	457,050	86	1.88E+11	6.29E-06	2.43E-06
H	6,862	7,958	2,305	4,008	2,966	6,862	95	627	BMDL	31,683	31,683	39,335	81	1.81E+11	2.18E-07	2.18E-07
I	15,491	26,122	7,616	5,677	5,822	1,535	1,902	2,188	45,120	66,353	111,473	127,366	88	1.29E+11	8.37E-07	9.86E-07
J	5,970	4,137	1,076	1,414	1,202	607	680	867	102,208	15,953	118,161	118,161	100	1.04E+11	1.13E-06	1.14E-06
K	14,159	22,470	9,826	2,862	2,315	611	7,720	5,504	230,356	65,468	295,823	308,236	96	1.04E+11	1.39E-06	2.97E-06
L	6,199	1,990	407	277	167	806	934	2,420	103,873	13,200	117,073	117,288	100	6.31E+10	1.86E-06	1.86E-06
M	BMDL	BMDL	BMDL	45	66	406	11,571	12,184	429,294	24,275	453,568	453,565	100	5.86E+10	7.83E-06	7.74E-06
N	5,885	1,814	609	148	120	413	666	1,471	134,754	11,125	145,879	146,607	100	4.01E+10	3.65E-06	3.65E-06
O	788	2,450	560	5,067	1,146	28,350	2,025	10,326	35,012	50,712	85,724	110,428	78	3.53E+10	1.22E-06	3.12E-06
P	BMDL	41	14	50	25	105	802	1,149	59,813	2,187	62,000	62,720	99	2.91E+10	8.12E-06	2.16E-06
Q	4,610	1,507	350	164	128	725	1,799	1,600	181,858	10,884	192,742	193,502	100	2.23E+10	8.66E-06	8.66E-06
R	BMDL	BMDL	BMDL	341	BMDL	628	BMDL	BMDL	BMDL	969	969	969	100	9.45E+09	1.03E-07	1.03E-07
S	6,301	1,748	568	150	90	254	898	1,504	112,085	11,513	123,598	124,076	100	8.11E+09	1.53E-05	1.53E-05

*Average from replicates; BMDL - below method detection limit

1. Sum of congeners = sum of 8 principal congeners w/o BDE-209: BDE-47, -99, -100, -153, -154, -183, -206, -207 (out of a possible 60 congeners identified during lab analysis)

2. Sum of congeners = sum of 9 principal congeners: BDE-47, -99, -100, -153, -154, -183, -206, -207, and -209

3. Total PBDEs = sum of all PBDE congeners analysed, which includes the 9 principal congeners

4. % congeners = sum of the 9 principal congeners divided by the total PBDEs measure and then multiplied by 100

¹ TOC levels were not calculated for Sites T, U, W, X, Y, Z, AA or BB that appear in Table 5.6

To see whether there is a significant relationship between the measured PBDE and TOC levels, BDE concentrations were correlated against TOC concentrations for each of the 9 principal congeners. BDE-47 was plotted against TOC in Figure 5.3 to illustrate this potential correlation. The result obtained was a Pearson coefficient, R , of 0.15, indicative of large sampling and sub-sampling variations. When all samples are included in the correlation, the degree of correlation decreases in most congeners, as shown in the bottom row of Table 5.3. There is no apparent difference in the results from the samples that contained particulate and those that did not (see Cluster D, Figure 3.4). Table 5.3 shows a much greater correlation between PBDEs and TOC levels if subsets of the data are taken with the highest measured PBDE concentrations (5, 6, 7 or 11 sites).

The principal congeners for which data are plotted in Figure 5.4 provide the greatest confidence levels and are generally least subject to error due to their high concentrations, being less prone to laboratory interference. Seven sites were taken as the best subset of data to plot. There is good correlation between PBDE concentrations and TOC levels for most of the “principal” congeners in the samples where the highest PBDE concentrations were found, but the degree of correlation decreases as the degree of bromination increases.

One possible option considered was to normalize all the PBDE concentrations throughout the thesis with the corresponding TOC concentration, i.e., to divide all PBDE concentrations by the corresponding TOC concentrations, in order to express the PBDEs as mass fractions of the organic carbon present. However, since the correlation with TOC was weak, except for the locations (Table 5.3) with the highest PBDE levels, it was decided to treat the data in a dimensional (i.e. not normalized) manner throughout the later chapters of this thesis when presenting and interpreting data.

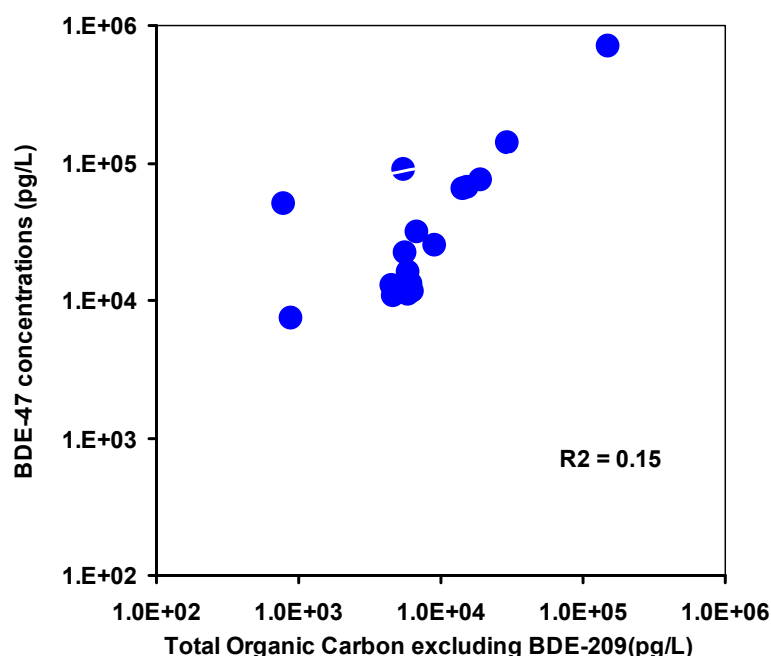


Figure 5.3 BDE-47 vs. total organic carbon (TOC). Leachate samples across Canada. There is a correlation in spite of the large sampling and subsampling variations encountered in the analysis process.

Table 5.3 Pearson correlation coefficients for procedural blank-corrected BDE concentrations and corresponding TOC levels when up to 20 locations from the Canada-wide sample set are considered at which TOC levels were determined.

# sites	BDE 47	BDE 100	BDE 99	BDE 154	BDE 153	BDE 183	BDE 207	BDE 206	BDE 209
5	0.97	0.65	0.66	0.68	0.65	-0.09	0.73	-0.32	-0.15
6	0.67	0.68	0.68	0.71	0.69	-0.18	0.26	-0.37	0.00
7	0.65	0.58	0.69	0.72	0.70	-0.27	0.34	-0.17	0.09
11	0.54	0.49	0.49	0.60	0.58	-0.01	0.22	-0.09	0.11
21*	0.46	0.49	0.49	0.49	0.50	-0.10	-0.03	-0.17	-0.22

* or as many as survived the procedural blank correction procedure

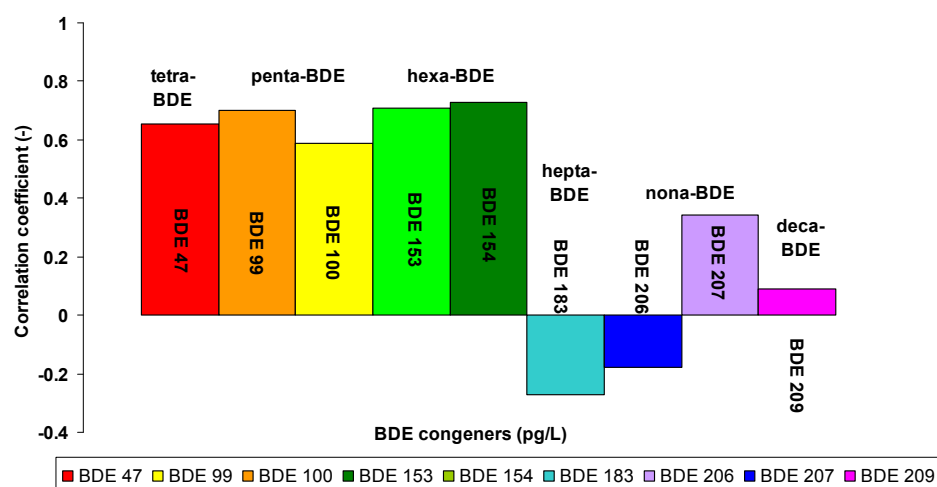


Figure 5.4 Pearson correlation coefficients for procedural blank-corrected BDE concentrations and corresponding TOC levels for all measurements surviving blank correction procedures from up to 20 locations in the Canada-wide sample sets at which TOC levels were determined. The data plotted here correspond to 7 sites. See Table 5.2 for data and Table 5.3 for the Pearson correlation coefficients.

5.3 Results and Discussion

The total PBDE concentrations measured in the samples varied substantially from location to location, ranging from below method detection limit (BMDL) to 867,805 pg/L, as shown in Table 5.2. Major congeners detected in the leachate samples of all sites included those prominent in the Penta commercial mixture (BDE-47, -99, -100, -153, and -154), as seen in Figure 5.5 below. Thirteen of the sites reported (out of a possible 27) indicated BDE-209 values between 60 and 92% of total PBDE concentrations. Five sites not included in Figure 5.5 were excluded because their congener values were BMDL after procedural blank correction.

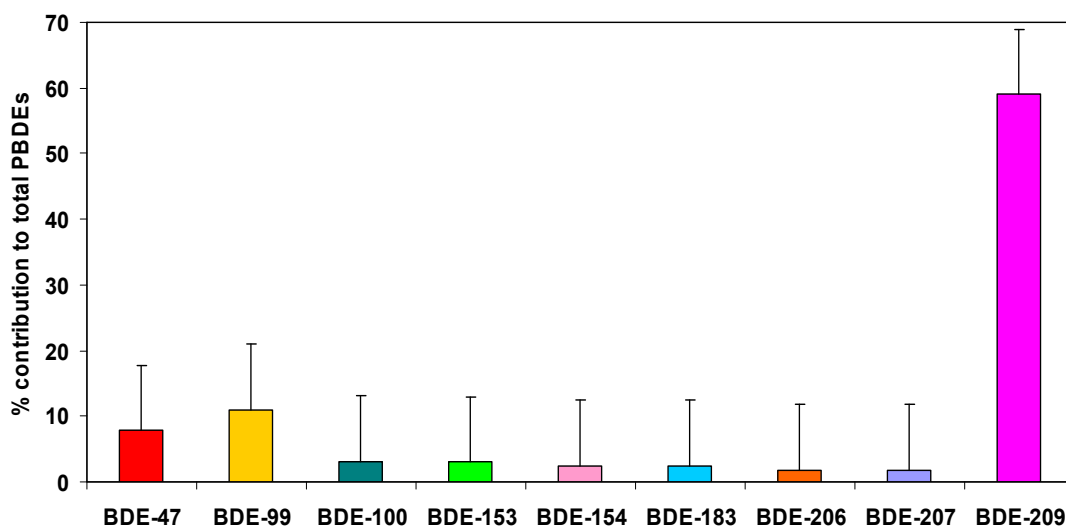


Figure 5.5 Mean principal BDE congeners in Canada-wide leachate relative to total PBDEs. Five sites that fell below method detection limits after procedural blank correction are excluded from the averages.

5.3.1 BDE Ratios Compared with Commercial Product

As discussed in Chapter 4, Section 4.3.7, the dominant BDE congeners in the Penta-BDE commercial product are BDE-47, BDE-99 and BDE-100 (Stapleton *et al.* 2005). The ratios of concentrations of BDE-47 to BDE-99 and of BDE-47 to BDE-100 are plotted in Figures 5.6 and 5.7, respectively, against total PBDE concentrations from leachate in landfills across Canada and compared to the corresponding ratios in the Penta-BDE commercial product (Table A.2, Appendix A). As observed in Figure 5.6, the BDE-47/BDE-99 ratio in the commercial Penta-BDE product DE-71 is 0.6, whereas in Figure 5.7 the BDE-47/BDE-100 ratio in the commercial Penta-BDE product DE-71 is 3.5. In each case, the same leachate samples collected exhibited ratios close to those of the commercial product, the exception being samples with the lowest total PBDE concentrations. Both ratios also indicate that the characteristics of the samples are

similar. This suggests that wastes from which the PBDEs originated contained the Penta-BDE product and, were discarded recently enough for the congener pattern to still be recognizable.

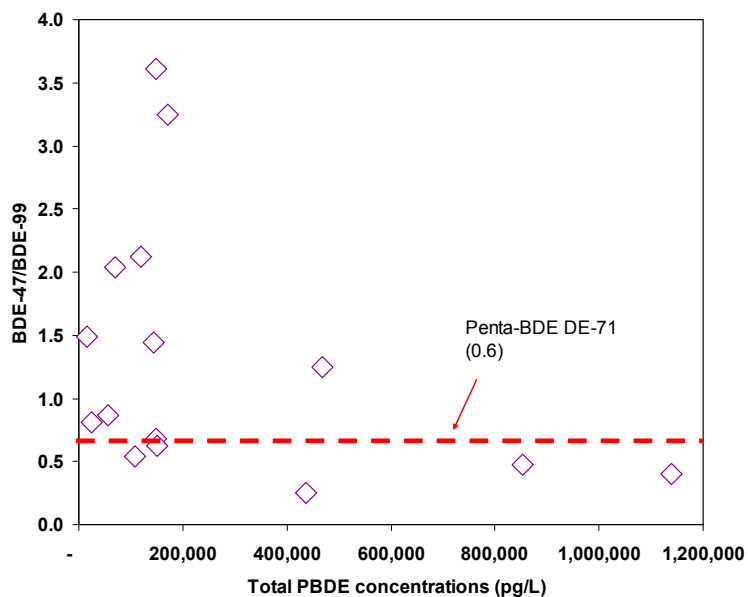


Figure 5.6. Ratio of BDE-47 to BDE-99 measured in landfill leachates from across Canada vs. total PBDE concentration. The dashed line represents the ratio observed in the commercial Penta-BDE product, DE-71 (0.6) (Rayne and Ikononou 2002). The symbols represent fifteen of the twenty samples listed in Table E.3, Appendix E. The other five samples were BMDL after procedural blank correction.

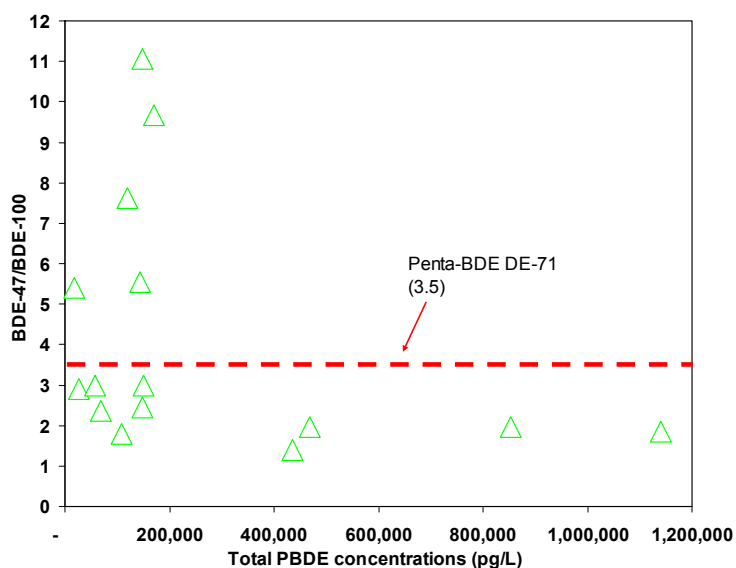


Figure 5.7. Ratio of BDE-47 to BDE-100 measured in landfill leachates from across Canada vs. the total PBDE concentration. The dashed line represents the ratio observed in the commercial Penta-BDE product, DE-71 (3.5) (Rayne and Ikononou 2002; ENVIRON 2003a). The symbols represent fifteen of the twenty samples listed in Table E.3, Appendix E. The other five samples were BMDL after procedural blank correction.

5.3.2 Population as a Determinant of PBDE Concentrations in Landfill Leachate

To create a larger data set for the rest of this chapter, the Canada-wide data are combined with the Northern Canada data from Chapter 4 for the rest of this chapter. More consistent sampling procedures were followed in Northern Canada, as described in Chapter 2. For purposes of presentation of the data, Canada is divided into four quadrants as described in Chapter 2: northwest (Δ), southwest (\blacktriangle), northeast (\circ), and southeast (\bullet), where the dividing line between east and west is taken as the Manitoba-Ontario border, whereas the division between north and south is the 60th parallel (also coinciding with the northern boundaries of BC, Alberta, Saskatchewan and Manitoba). Populations are 2006 census values.

In order to show the possible effect of population of the corresponding city/town, both principal congeners and total PBDE concentrations are considered in relation to population. As expected, there is a strong correlation ($R = 0.83$) between population served and annual mass flow of wastes sent to the local landfill (tonnes/year). When the correlation of total PBDE concentrations to population is explored, the correlation coefficient is 0.26, as shown in Table 5.4. This indicates some correlation between PBDEs in landfills and population served, presumably because larger centres tend to be bigger consumers of electronic products and other manufactured goods, as well as being located further south. However, the relationship also depends on how the waste is handled and how representative are the leachate samples. The small number of sites, variation in sampling procedures and general scatter in the data probably account for why the correlation with population is not stronger.

Table 5.4. Pearson correlation coefficient of population vs. total PBDE concentrations and population vs. landfill tonnage. Population values are from Statistics Canada 2006 census. Total PBDE concentrations from sampling data in this thesis. Landfill tonnage data reported for each landfill are from 2005-06².

Location	Landfill refuse mass flow (tonnes/yr)	Total PBDEs (pg/L)
T	1,200,000	1,139,532
F	900,000	69,011
U	740,000	23,719
I	250,000	108,165
V	165,000	147,749
S	163,000	148,244
N	160,000	170,775
A	160,000	853,568
H	156,000	57,237
B	100,000	119,796
J	80,000	143,788
G	67,000	151,082
W	47,000	25,480
D	40,000	468,563
X	40,000	27,755
Y	38,000	237
Z	26,000	16,643
L	25,000	117,288
AA	12,700	30,848
P	10,000	84,756
BB	10,000	26,755
Correlation coefficient of population to total PBDEs: 0.26		
Correlation coefficient of population to landfill refuse volume: 0.83		

Possible correlations were also considered by quadrant and by combinations of quadrants (south, north, east, west), with the results given in Table 5.5. The mid-to-lower brominated congeners (BDE-47, -99, -100, -153- and -154) correlated the best amongst the south (average R = 0.42) and west regions (average R = 0.40).

² Tonnage data was not available for Sites C, E, K, M, O, Q, or R listed in Table 5.2

Table 5.5 Pearson (correlation) coefficients for BDE congener concentrations in leachate from 27 Canada-wide sites vs. population. Coefficients are also estimated for different regions of the country (northwest (Δ), southwest (\blacktriangle), northeast (O), southeast (\bullet), north ($\Delta+O$), south ($\blacktriangle+\bullet$), west ($\blacktriangle+\Delta$), and east ($\bullet+O$)).

By population/region:		\blacktriangle	Δ	\bullet	O	$\Delta+O$	$\blacktriangle+\bullet$	$\blacktriangle+\Delta$	$\bullet+O$
BDE congener	No. of sites:	SW	NW	SE	NE	North	South	West	East
	all 27	6	3	14	4	7	20	10	17
(tetra) BDE-47	0.38	N/A	N/A	0.17	N/A	0.18	0.44	N/A	0.22
(penta) BDE-99	0.38	0.32	N/A	0.17	-0.89	-0.17	0.44	0.41	0.21
(penta) BDE-100	0.38	N/A	N/A	0.16	-0.71	-0.35	0.43	0.40	0.21
(hexa) BDE-153	0.36	N/A	0.56	0.13	N/A	-0.38	0.40	0.40	0.17
(hexa) BDE-154	0.35	0.33	N/A	0.13	N/A	-0.37	0.39	0.41	0.17
(hepta) BDE-183	0.14	0.22	N/A	0.14	N/A	-0.40	0.13	0.36	-0.10
(nona) BDE-206	0.09	-0.17	N/A	0.06	-0.83	-0.18	0.03	N/A	0.10
(nona) BDE-207	0.14	-0.10	N/A	0.12	-0.50	-0.24	N/A	0.06	0.13
(deca) BDE-209	0.05	-0.22	0.78	0.04	0.36	0.32	0.01	-0.10	0.08
Total PBDEs	0.35	0.25	0.73	0.14	-0.37	0.14	0.38	0.36	0.19

N/A: No correlation is possible in cases where N/A appears because, when BMDL values are excluded, there are too few values left to apply a correlation

Although the PBDE concentrations are generally lower in the northern communities, some northern levels are similar to those of urban centres south of parallel 60. The remaining southern Canada samples were between one and three orders of magnitude higher in total PBDE concentrations than for the northern Canada samples. It is important to put this into perspective. The landfills examined were not homogeneous in terms of the types of materials disposed, depth, nor in the methodologies used for sampling, thus resulting in heterogeneous samples. These factors undoubtedly contributed to the observed scatter and low correlations. However, as discussed previously, some correlation was found within the regions supporting the hypothesis of higher PBDE concentrations with higher refuse tonnage.

Total PBDEs (including BDE-209) are plotted against population in Figure 5.8. The outliers in Figure 5.8 all correspond to populations less than 50,000. In Figure 5.9, concentrations of the BDE-47, -99 and -100 congeners are plotted against population, thereby removing the difficult-to-measure BDE-209. The data suggest, albeit with considerable scatter, that a larger population tends to result in higher PBDE concentrations in leachate. The correlation appears to be better for BDE-47 than for BDE-99 or -100. Comparing Figure 5.8 with Figure 5.9 provides an indication of how much BDE-209 influences the total PBDE concentration.

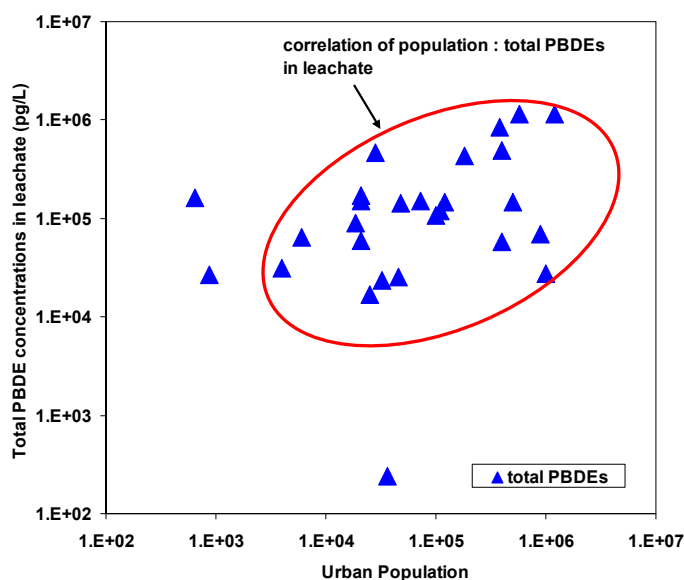


Figure 5.8 Total PBDE concentrations in leachate as a function of population of municipality served by the landfill or dumpsite

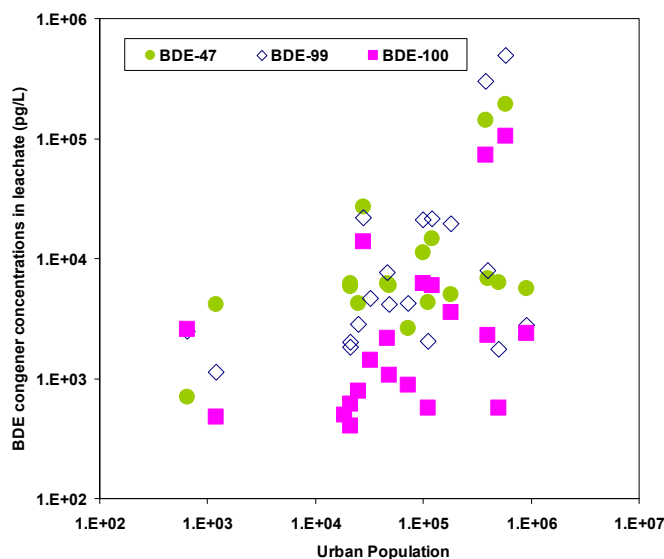


Figure 5.9 BDE-47, -99 and -100 congener concentrations as a function of population.

5.3.3 Latitude as a Possible Determinant of PBDE Concentrations in Landfill Leachate

Average total PBDE concentrations are plotted for landfill leachate samples from southern and northern Canada against location sector in Figure 5.10. It is seen that the concentration tends to be smaller for more northerly sites (red vs. yellow bars). Naturally, there is a strong negative correlation between population and latitude, so that at least part of the north-vs.-south effect is no doubt due to population, as portrayed by Figure 5.8. However, it is likely that the concentrations being lower in Northern Canada than in Southern Canada also reflect, to some extent, the greater use of plastics and electronic products in the south, and limits in north-south atmospheric and

water-based dispersion. When data are considered by quadrant, northeast is somewhat higher than northwest, and southwest higher than southeast. It is not clear whether these trends are meaningful or, if so, how they can be explained.

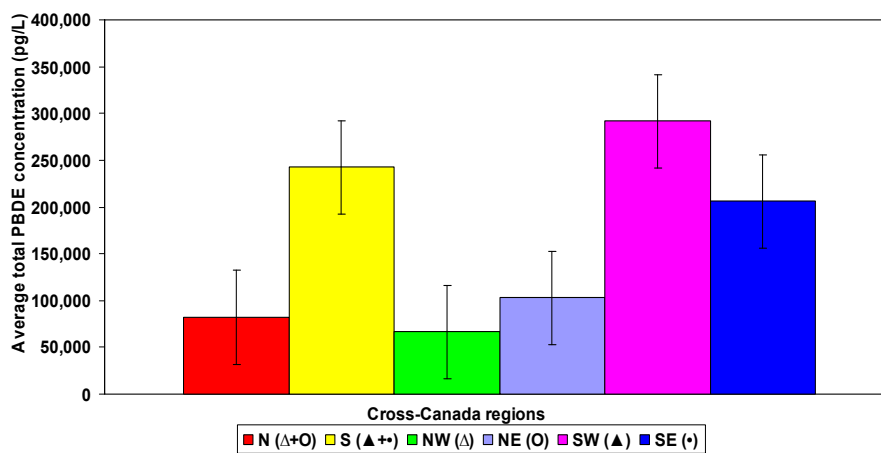


Figure 5.10. Total PBDE concentrations vs. location in Canada.

5.3.4 Consequence of PBDEs Leaching into the Aquatic Environment

Leachate containing PBDEs may enter water bodies from landfills, sewage treatment plants (STP), migration from groundwater, and atmospheric deposition. The concentration of PBDEs entering the aquatic environment may depend on whether or not the leachate is treated prior to discharge. In a worst case scenario, PBDEs will enter the water table without any STP treatment and/or with negligible removal by STPs (see Chapter 4, section 4.3.3). To illustrate this, an annual estimate of PBDE levels entering the receiving environment from a jurisdiction studied in this research project was calculated. A constant volumetric flow rate of $1.8 \times 10^6 \text{ m}^3/\text{year}$ was used³. The total PBDE loading from this landfill is approximately 2.0 kg/year, calculated from the mass flow for the landfill, the total PBDE concentration found in the leachate for the landfill in question and the leachate produced per tonne of solid waste. While this amount may appear to be limited, it is best to reduce all exposure and loadings to the environment, regardless of the magnitude.

5.4 Conclusions

The total PBDE concentrations measured in samples from landfills in southern Canada varied substantially, from below method detection limit to 867,805 pg/L. The principal congeners

³ Obtained from this urban sewage treatment plant. The identity of the STP is confidential. 2006 data.

BDE-47, -99, -100, -153 -154, -183, -206, -207 excluding BDE-209, contributed less than 40% of the total PBDEs, while BDE-209 contributed between 60 and 92% of the total for the nine principal BDEs. The large variability in the data from different locations presented unique challenges in interpreting the data. Some factors that no doubt influenced reproducibility were different sampling procedures, variable weather, different waste dumping regulations and procedures, different types of waste material disposed at the various sites, and inconsistencies in sub-sampling.

Despite all of the possible factors that influence leachate in a landfill, the variability of the PBDE data, and the non-homogeneous samples containing high amounts of particles, some reasonable correlations were found. When the total PBDE concentration was correlated against urban population served by the landfill, including the data from Chapter 4 for Northern Canada, there was an overall Pearson coefficient, R , of 0.26. There was a clear tendency for landfills in Northern Canada to have lower PBDE concentrations than in Southern Canada.

Total organic carbon (TOC) was determined for 21 sites, and 20 sites survived after procedural blank correction criteria were applied. In these cases, PBDE data were compared with the TOC measurements. Total PBDE and TOC values correlated well only when the samples were restricted to a small subset of locations with the highest PBDE levels. As a result, and also because some TOC values were below minimum detectable levels, it was decided not to normalize PBDE concentrations by TOC concentrations.

Leachates sampled from landfills across Canada on average show considerably higher PBDE concentrations in leachate than reported in the small number of previous landfill studies published in the open literature, which are from the U.S., Japan, Sweden, and South Africa.

The data presented in this chapter suggest that measurable amounts of PBDEs appear in leachate from landfills, whether in Southern or Northern Canada. Landfill leachate could therefore provide one source of PBDEs in the environment at large. More work is needed to obtain more accurate data and to determine the processes which lead to leaching, degradation and spread of PBDEs from landfills.

CHAPTER 6 – E-WASTE CONTACTING EXPERIMENTS

6.1 Introduction

E-wastes have become more and more significant over recent years. As more and more electronic equipment becomes outdated with planned obsolescence, discarding this waste properly is challenging. This chapter presents the results of the experiments in which crushed e-waste was contacted with aqueous media (distilled water and leachate) to shed light on the concentrations of PBDEs entering the environment from discarded electronic equipment. The data also provide input for the simulation model in Chapters 8 and 9.

6.1.1 E-waste

E-waste has become a major environmental concern in recent years. Discussion of the environmental impact of discarding electronic waste in landfills is ongoing (Spalvins *et al.* 2008). Some studies contend that sanitary landfills can safely contain contaminants migrating out of electronic equipment (Skinner 2000; Akatiff 2002; Spalvins *et al.* 2008), whereas others declare that groundwater contamination will occur (Puckett *et al.* 2002; Scanlon 2004). Two distinct e-waste problems exist: the volume of computers and related electronic waste (e-waste/e-scrap) improperly deposited in landfills, and the toxic nature of both the computer chip manufacturing process and the computer itself as a waste product. Electronic goods such as computers have an average in-service life span of only 3-4 years (RIS International Ltd. 2003; SVTC 2004). This must be added to the time of retailing and the time (e.g. stored in warehouses or on shelves) from the completion of service to ultimate discard, creating massive volumes of e-waste. The occurrence of PBDEs in e-waste is discussed in Section 1.5.4, and end-of-life issues are described in Section 1.5.4.1. Over the past three decades, BFRs have been incorporated into thermoplastics, thermosets and elastomers (Menad *et al.* 1998) in electronic products. The use of computer equipment in particular has expanded by several orders of magnitude since the 1980s, making e-waste a likely major source of PBDEs in the environment (Choi *et al.* 2009). Morf *et al.* (2005) determined that e-waste accounts for the largest volume of BFRs, in particular, PBDEs. Of the three commercial PBDE products, only Deca-BDE is still widely used, although restrictions continue to be debated in the EU and North America (see Section 1.5.10 for details). Although many manufacturers have already substituted, or will soon phase out, BFRs contained in earlier electronic equipment, many older models known to contain substantial quantities of

BFRs, up to 30% by weight are still entering the disposal or end-of-useful life phase (Danish-EPA 1999).

According to the United Nations Environmental Programme (2005), between 20 to 50 million metric tonnes of e-waste per year are discarded worldwide. Based on recent estimates from the Guangzhou Institute of Geochemistry (Stone 2009), roughly 76,000 metric tonnes per year of PBDEs are released from e-waste in China. China processes approximately 70% of the world's e-waste or 24.5 million metric tonnes (Stone 2009) (if an average of 35 million metric tonnes is taken from the range of 20 to 50 million metric tonnes.). Hence, based on the amount of e-waste processed in China, approximately 110,000 metric tonnes of PBDEs per year are released into the environment worldwide from e-waste.

The occurrence of BFRs in e-waste is troublesome as they are endocrine-disrupting chemicals (Vos *et al.* 2003; Lokke 2006; Gerecke *et al.* 2008; Hwang *et al.* 2008; Morf *et al.* 2008; Rudel and Perovich 2009). The management of the e-waste stream is therefore important. When they are separated from the main waste stream (landfills, incinerators) and recycled, these plastics should be identified as containing flame retardant additives and controlled so that they will not harm humans or the environment.

PBDEs can leach out of products in which they are found (Manchester-Neesvig *et al.* 2001; Rahman *et al.* 2001; de Wit 2002; Kim *et al.* 2006; Choi *et al.* 2009). PBDEs may also leach from solid wastes in landfills, but few studies have addressed this issue. Information regarding PBDE leaching from e-waste is sparse. A recent leachate study involving time-dependent tests for PBDEs in e-waste plastic was performed by Choi *et al.* (2009). The findings of that study showed that BFRs can leach in the presence of organic matter. The objective of this chapter is to examine the leaching of PBDEs from e-waste exposed to two different aqueous media (distilled water and leachate) for different times, different pH and different temperature. These experiments were intended to help elucidate the transfer of PBDEs from electronic waste in landfills. Crushed e-waste particles were derived from electronic equipment manufactured over twenty-five years (split into different 5-year periods for purposes of the experiments). Mostly e-waste particles from the 1985-89 time period were used in the experiments as they were found (see below) to have by far the highest PBDE concentrations of all time periods. The goal was to determine the mass transfer of PBDEs to distilled water and leachate.

6.1.2 Leachate

In a previous study with e-waste of unknown age, otherwise similar to the one carried out in this research project, but over a period of five days (Kim *et al.* 2006), the leaching concentration of PBDEs from flame-retarded plastic (e.g. TV casings and monitors) was 2,000 pg/g for hexa-BDEs, 3,000 pg/g for hepta-BDEs, 12,000 pg/g for octa-BDEs, 42×10^6 pg/g for nona-BDEs and 21×10^6 pg/g for deca-BDE (where the g refers to grams of e-waste plastic). The Kim *et al.* (2006) study postulated that the leaching of PBDEs from flame-retarded plastics could result from diffusion of solute caused by dissolution. The leachability of PBDEs from e-waste appeared to be influenced by dissolved organic matter. In a somewhat similar study, Choi *et al.* (2009) contacted e-waste with dissolved humic solution based on organic carbon (1,000 mg OC/litre), 20% methanol solution and the balance distilled water, with a liquid-to-solid ratio of 100:1. Choi *et al.* (2009) found that the leaching concentration of PBDEs from e-waste followed first order degradation rates. In a related study, Osako *et al.* (2004) took leachate samples from waste electric and electronic-containing landfills. They obtained concentrations of 2,200 pg/L for BDE-47, 1,800 pg/L for BDE-99 and <500 pg/L for BDE-100.

Other constituents are also likely to be present in landfill leachate (Kjeldsen *et al.* 2002), such as inorganic components (calcium, magnesium, sodium, sulphate, hydrogen carbonate, etc.), heavy metals (e.g. cadmium, chromium, lead, nickel, and zinc), and xenobiotic organic compounds, i.e. household or industrial chemicals present at concentrations < 1 mg/L (e.g. aromatic hydrocarbons, phenols, chlorinated aliphatics, pesticides, plasticizers) with possible, but unknown, impact on transfer of PBDEs to the aqueous phase.

6.2 Experimental Details

Electronic waste (e-waste) was the key constituent of each experiment described in this chapter. In order to prepare the e-waste for analysis, various steps were involved. Similar to the soil sample analysis protocol described in Chapter 3, the e-waste samples were subjected to a liquid / liquid extraction procedure, and therefore only one procedural blank was associated with each of the samples. Details of sample handling are discussed in Section 2.5.2 of Chapter 2, and of the preparation of the e-waste in Section 6.2.1. Samples of the e-waste particles from the five 5-year periods (1980-84, 1985-89, 1990-94, 1995-99, 2000-05) were analysed for PBDEs by Vista Analytical. The data were not blank corrected as the concentrations were up to 6 orders of

magnitude higher than the procedural blanks. In this respect only, the analytical data were treated differently from those in previous chapters.

6.2.1 E-waste Origin and Preparation

The e-waste was provided by Genesis Recycling Ltd. of Aldergrove, British Columbia. The items included monitor hard cases and computer housings (~60% by weight), printers (~30% by weight) and keyboards/mice (~10% by weight). These items came from offices and warehouses where they had not been exposed to the outdoors. In an effort to establish historical trends, the source materials were grouped (based on name-plate date-of-manufacture labels) into batches corresponding to 5-year intervals: 1980-84, 1985-89, 1990-94, 1995-99 and 2000-05. In addition, a composite sample of this 25-year overall period (1980-2005) was prepared (containing an equal mass of plastic from each of the 5-year time intervals.) All metal components were set aside, and the plastic parts of the units were initially cut into ~ 250 mm x 100 mm strips to reduce the size entering the granulator grinder (TRIA granulator, 320 mm rotor diameter, 600 mm width, 3 rotor knives, 18.5 kw drive capacity, Manufacturer: TRIA, Italy) to facilitate production of pieces (hereafter referred to as particles) of final size ~2 mm volume-equivalent diameter. Photographs appear in Figure 6.1. The granulator grinder was cleaned after processing each batch to avoid cross-contamination. After grinding, the e-waste pieces were stored in air-tight plastic containers, one container for each 5-year interval. Every step of the process was logged to ensure reproducibility and proper documentation.

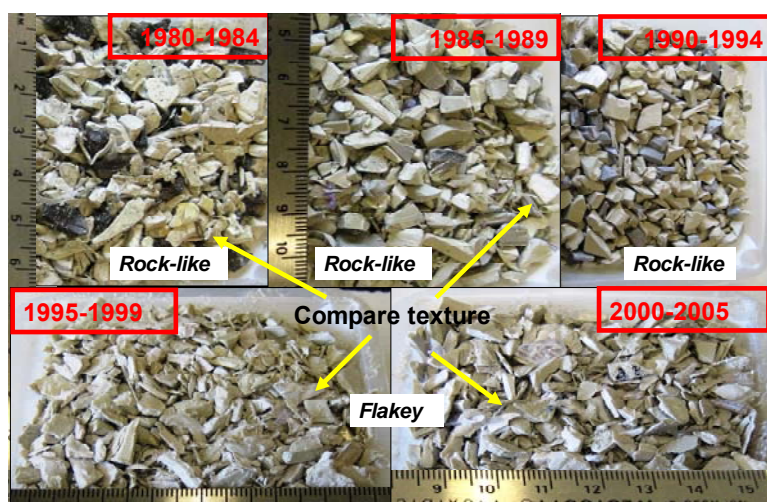


Figure 6.1 Shredded e-waste divided into 5-year time periods of manufacture.

6.2.2 PBDE Concentrations in E-waste

As previously mentioned, samples of the e-waste particles from the five 5-year periods (1980-84, 1985-89, 1990-94, 1995-99, 2000-05) were analysed for PBDEs by Vista Analytical. Section 2.5.2 of Chapter 2 explains how the samples were prepared and analysed by this lab. The raw data are presented in Table F.1, Appendix F. The e-waste analytical results in Table 6.1 and Figure 6.2 indicate that the PBDE concentrations corresponding to the waste from the 1985-89 time period were three to six orders of magnitude higher than for any of the other four 5-year periods. This appears to reflect much higher incorporation of PBDEs into plastics during the second half of the 1980s than in the previous and subsequent 5-year intervals. The composite sample (containing equal proportions by mass from each of the five time periods) also exhibited extremely high concentrations, clearly due to the overwhelming contribution of PBDEs from the late 1980s. These two cumulative lines in Figure 6.2 are nearly parallel, due to the dominance of the 1985-89 particles. One observes a dramatic drop in e-waste PBDE concentrations by the late 1990s. Because the e-waste from the 1985-89 time period was so much higher than from all other intervals, it was used as the base e-waste with which to conduct most of the experiments described in this chapter. The composite e-waste sample was used as well, given its lesser, but still high PBDE concentrations.

Table 6.1 PBDE concentrations (pg/g) of crushed e-waste for different 5-year manufacturing time periods (1980-2005) and a 25-year composite. Total BDE and principal congeners are tabulated. ND: not detectable (Lab: Vista Analytical).

Sample ID	Principal Congeners								Total PBDEs
	tetra-BDE	penta-BDE		hexa-BDE		hepta-BDE	nona-BDE	deca-BDE	
	BDE-47	BDE-99	BDE-100	BDE-153	BDE-154	BDE-183	BDE-207	BDE-209	
1980-84 e-waste	4.79E+03	7.26E+03	1.15E+03	3.19E+05	4.07E+04	1.51E+06	6.20E+05	7.53E+06	1.19E+07
1985-89 e-waste	6.80E+05	1.34E+07	7.36E+05	1.26E+09	1.43E+08	1.87E+09	1.79E+09	1.67E+09	1.24E+10
1990-94 e-waste	5.00E+02	ND	ND	1.93E+03	2.53E+02	1.90E+04	2.12E+04	2.68E+05	3.48E+05
1995-99 e-waste	2.24E+03	3.03E+03	6.56E+02	5.82E+03	1.74E+03	2.59E+04	ND	4.12E+04	1.01E+05
2000-05 e-waste	7.60E+02	4.66E+02	1.67E+02	8.56E+02	3.12E+02	4.21E+03	ND	ND	9.68E+03
e-waste COMPOSITE	1.03E+05	5.36E+06	4.13E+08	3.67E+08	3.74E+07	4.64E+08	6.08E+08	2.14E+08	4.03E+09

The PBDE concentrations in the 1985-89 e-waste particle sample and the composite e-waste particle sample were so high that the laboratory which performed the analysis (Vista Analytical) was only able to analyse lower congeners, i.e. mono- through the penta-BDEs, in its first analysis of these samples (Chapter 2, Section 2.5.2). Vista re-ran the analysis to ensure quality control from the first batch and confirmed that the results were essentially the same.

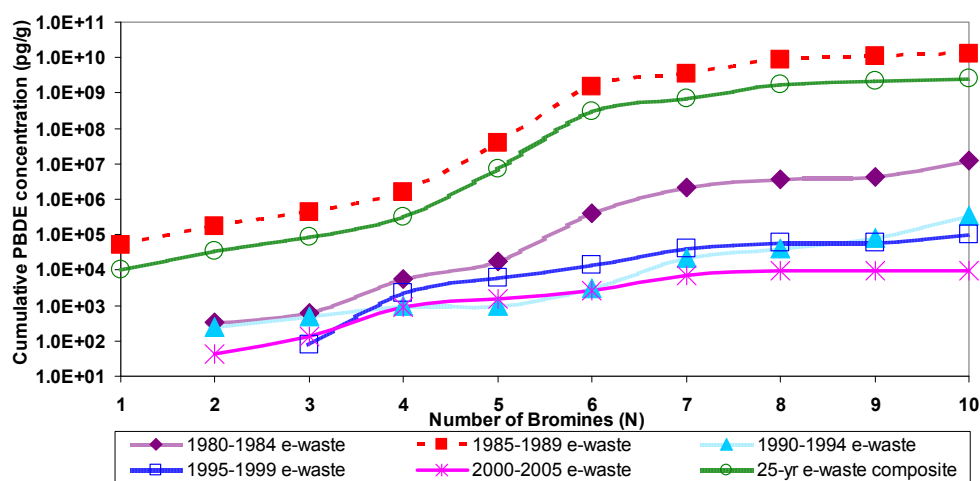


Figure 6.2 Blank corrected *crushed e-waste composition* for 5-year intervals over 25 years (1980-2005) (Lab: Vista Analytical). Ordinates give cumulative PBDE concentrations, i.e. sum of concentrations of all PBDE congeners having N or fewer attached bromines. The principal congeners discussed throughout this thesis, i.e. BDE-47 (N=4), -99 and -100 (N=5), -153 and -154 (N=6), -183 (N=7), -206 and -207 (N=9), and -209 (N=10), account for >80% of the totals.

6.2.3 Distilled Water

The distilled water used in the experiments was produced in the UBC Department of Chemical and Biological Engineering. Tap water was first filtered through a 75 µm pre-filter to remove suspended solids. It was then distilled by vaporization and condensation in a Barnstead water still. Following this, the distilled water was collected in two large high-density polyethylene tanks (neither tank contains PBDEs in the plastic composition), each with a 200 L capacity and fed throughout the building. Forty-litre plastic (high-density polyethylene) jugs were filled and transported to the lab for use during the experiments.

6.2.4 Urban Landfill Leachate

Table 6.2 gives the properties of the raw leachate used for the contacting tests described below in Sections 6.3.1, 6.3.2 and 6.3.3. It was obtained from an urban landfill site (Site T, Chapter 5) in the zone occupied by solid waste deposited during the 1985-89 interval and collected in 2006. The location of the landfill cannot be identified as required by the urban landfill operator. A sample was analysed for the presence of calcium, magnesium, sodium, sulphate, and metals, as well as surfactants. For comparison, the data are compared in Table 6.2 to the Canadian Drinking Water Guidelines (2003) and to a post-contacting liquid experiment (covered in Section 6.3.1). Surfactants were analysed because they could influence the transfer of PBDEs. The levels of surfactants found in this leachate/e-waste sample (5.0×10^8 pg/L) were below those of

another study (Feijtel and van de Plassche 1995) for raw wastewater measured on a rainy day (3.0×10^9 pg/L). It is well known that surfactants can influence mass transfer between bubbles and liquids (Clift *et al.* 2005). They could also affect the wetting of the particles, and this could influence the transfer.

The urban landfill from which leachate samples were obtained for the experiments was divided into sections according to the half-decades during which rubbish was disposed. All samples were filtered, as discussed in Chapter 2.

Table 6.2 Analysis of inorganic compounds, metals and surfactants for samples of landfill leachate in contact with solid waste from the 1985-89 time period. This leachate was contacted for 24 h with discarded wastes from 1985-89 and e-waste manufactured during the same time period in the end-over-end contactor at 20°C and pH 7. (Lab: ALS Environmental)

Parameters analysed	Units	Leachate (1985-89 time period)	Leachate + e waste contacted for 24 h	Regulatory criteria*	Metals analysed (pg/L)	Leachate (1985-89 time period)	Leachate + e waste contacted for 24 h	Regulatory criteria*
Physical Tests					Total Metals			
Colour	CU	157	747	15 CU	Aluminum	6.49E+07	2.80E+08	NG
Conductivity	µS/cm	3390	10300	NG	Antimony	<5.0E+05	3.66E+08	6.00E+06
Total Dissolved Solids	pg/L	1.52E+12	4.55E+12	5.00E+11	Arsenic	2.60E+06	1.23E+07	2.50E+07
Hardness (as CaCO ₃)	pg/L	7.81E+11	6.18E+11	NG	Barium	2.22E+08	2.50E+08	1.00E+09
pH		7.14	8.44	8.5	Boron	3.81E+09	2.40E+09	5.00E+09
Turbidity	NTU	40	523	5	Cadmium	<2.5E+05	<2.0E+06	5.00E+06
Dissolved Anions					Calcium	2.12E+11	1.00E+11	NG
Alkalinity-Total (CaCO ₃)	pg/L	1.58E+12	4.52E+12	NG	Chromium	5.90E+06	<20E+06	5.00E+07
Chloride	pg/L	1.82E+11	1.12E+12	2.50E+11	Copper	2.06E+06	4.10E+07	1.00E+09
Fluoride	pg/L	1.10E+09	<2.0E09	1.50E+09	Iron	1.20E+10	2.75E+10	3.00E+08
Sulphate	pg/L	<2.5E+08	9.40E+10	5.00E+11	Lead	<1.7E+06	1.30E+07	1.00E+07
Nutrients					Magnesium	6.08E+10	8.92E+10	NG
Nitrate Nitrogen	pg/L	9.30E+08	<10E+09	1.00E+10	Manganese	3.60E+09	3.70E+08	5.00E+07
Nitrite Nitrogen	pg/L	1.77E+08	2.80E+10	1.00E+09	Mercury	<1.0E+05	<1.0E+05	1.00E+06
Organic Parameters					Potassium	8.14E+10	5.34E+11	NG
Surfactants (LAS)**	pg/L	3.00E+08	5.00E+08	NG	Selenium	<5.0E+06	<14E+06	1.00E+07
CU: colour units; µS/cm: umhos/cm; NTU: nephelometric turbidity units					Sodium	2.03E+11	7.29E+11	2.00E+11
LAS: Linear Alkylbenzene Sulphonate					Uranium	<5.0E+04	<1.0E+06	2.00E+07
NG: no guideline					Zinc	1.83E+07	5.90E+08	5.00E+09
* Guidelines for Canadian Drinking Water Quality, 2003, Health Canada.								
**Different sample used to analyse. Sample contained distilled water with e-waste manufactured from the 1980s								
All limits are maximum acceptable concentrations								

6.3 Experimental Results

Although PBDEs have been found to have very low solubilities in water (see Chapter 1, Tables 1.2 and 1.3), some experiments were conducted to determine PBDE transfer from e-waste to distilled water in the absence of other agents, e.g. humic substances, solvents or surfactants, all known to be present in landfill leachates and possible contributors to the leachability of PBDEs from plastic materials. Figure 6.3 illustrates the order in which the experiments were performed, beginning with analysis of crushed e-waste manufactured in different time intervals and leachate

in contact with wastes from the 5-year time periods. In all experiments either distilled water or leachate was contacted with e-waste in the end-over-end contactor, described in Chapter 2. 100 g of e-waste particles to 4 L of liquid were the proportions used for all these experiments. The experiments are explained in the following sections. The results include a discussion of the principal BDE congeners identified in the previous chapters.

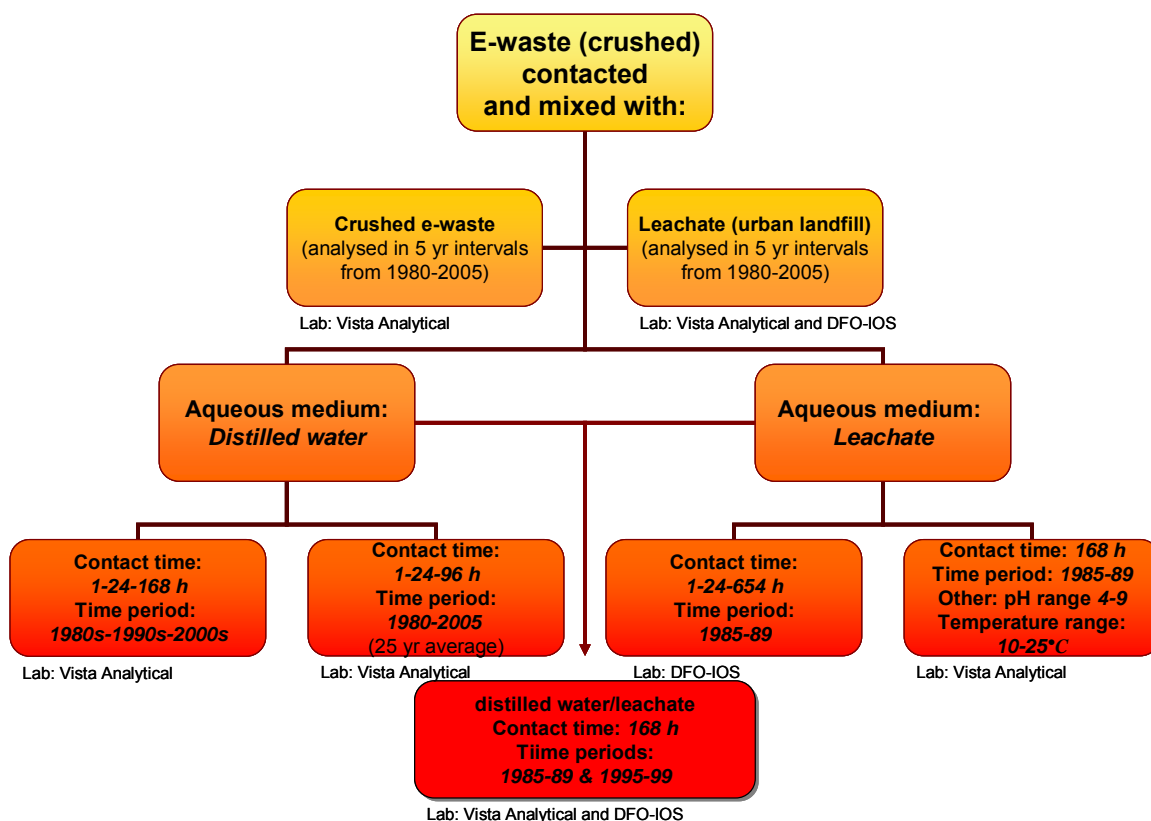


Figure 6.3 Schematic of sequence of e-waste experiments in end-over-end contactor.

6.3.1 PBDEs in E-waste Contacted by Distilled Water

6.3.1.1 1 – 24 – 168 hour Contacting Time

The samples from this experiment followed the analysis protocol previously described in Section 6.2. These experiments used e-wastes from two 5-year periods, combined by decade, so that, for example, the 1980s decade comprised equal proportions of e-waste from 1980-84 and 1985-89. In addition, the e-waste was contacted for various times (1, 24, and 168 h) with distilled water. The raw data are presented in Table F.2, Appendix F. The samples were collected immediately after each contacting period was completed. The results show much higher PBDE concentrations in the aqueous phase for wastes from the 1980s than for the later decades, with the 1980s levels typically 2-4 orders of magnitude higher than for e-wastes from the 1990s and

2000s, consistent with the very different concentrations of PBDEs in the corresponding plastic particles (see Table 6.1). A recent and similar study over a five-day period by Choi *et al.* (2009) showed broadly similar trends to ours, but with PBDE concentrations differing by up to 1 to 2 orders of magnitude. They suggested that PBDEs followed first order degradation kinetics and that this could possibly be due to an unexpected diffusion of trace organic chemicals, additives or monomers from the plastic itself, which can increase the solubility of PBDEs by an order of magnitude or more.

All principal congeners showed high aqueous-phase concentrations after contacting with e-waste from the 1980s (Table 6.3). These patterns are interpreted by time periods (1980s, 1990s and 2000s) and by contact time (1, 4 and 168 h). The 1980s clearly led to the highest levels of PBDEs, typically 2-4 orders of magnitude greater (total PBDEs = 1.28×10^8 pg/L for 1 h, 1.51×10^8 pg/L for 24 h, and 5.9×10^7 pg/L for 168 h contacting time) than the other time periods (total PBDEs = 1.25×10^5 pg/L for the 1990s and 2.36×10^4 pg/L for the 2000s, for 168 h contacting time). The concentrations of the mid-to-higher brominated congeners (BDE-153, -154, -183, -207, and -209) were 3 to 4 orders of magnitude greater than those of the lower brominated congeners (BDE-47, -99 and -100). The pattern of BDE-47, -99 and -100 resembled that of the commercial Penta-BDE, which was used in large quantities in electronic equipment during that decade. The 1990s had 2 to 4 orders of magnitude lower BDE concentration (total PBDEs = 8.88×10^4 pg/L for 1 h contacting time) compared to the 1980s time period (total PBDEs = 1.28×10^8 for 1 h contacting time). In general, the contact time between e-waste and distilled water had little influence on the concentrations, whether looking at the pattern of total PBDEs or the individual congeners (total PBDEs = 2.08×10^5 pg/L for 24 h and 1.25×10^5 for 168 h contacting time and sample from the 1990s, total PBDEs = 4.93×10^4 pg/L for 24 h and 2.36×10^4 pg/L for 168 h contacting time with particles corresponding to the 1980s (total PBDEs = 1.51×10^8 pg/L for 24 h and 5.9×10^7 pg/L for 168 h contacting time). For the 2000s time period, the PBDE concentrations dropped off compared to the 1980s, but were somewhat similar to the 1990s, and one order of magnitude lower in some instances. In particular, the BDE-47, -99 and -100 congeners, were either not detected or found to have low or non-detect concentrations for the 2000s e-waste. The overall decrease in PBDE concentration for the 1990s and 2000s indicated the downward shift in PBDE usage for plastics in electronic equipment compared to the 1980s.

Table 6.3 Blank-corrected BDE concentrations (pg/L) in aqueous phase after distilled water was contacted with e-waste from the 1980s, 1990s and 2000s for 1, 24 and 168 h in the end-over-end contactor (Lab: Vista Analytical).

Principal Congeners									
Contact time / time period	tetra-BDE	penta-BDE		hexa-BDE		hepta-BDE	nona-BDE	deca-BDE	Total PBDEs
	BDE-47	BDE-99	BDE-100	BDE-153	BDE-154	BDE-183	BDE-207	BDE-209	
1h 1980s	2.65E+03	3.62E+04	4.34E+03	1.04E+07	1.09E+06	3.12E+07	1.51E+07	1.32E+07	1.28E+08
24h 1980s	ND	4.64E+04	2.22E+04	1.64E+07	1.60E+06	3.72E+07	1.89E+07	9.80E+06	1.51E+08
168h 1980s	5.98E+03	4.47E+04	4.52E+03	9.04E+06	1.11E+06	2.17E+07	3.98E+06	1.74E+06	5.90E+07
1h 1990s	ND	1.17E+02	ND	3.27E+03	ND	1.96E+04	1.42E+04	1.75E+04	8.88E+04
24h 1990s	ND	3.19E+02	3.48E+01	7.01E+03	7.61E+02	4.79E+04	3.60E+04	2.90E+04	2.08E+05
168h 1990s	ND	4.40E+01	6.00E-01	8.57E+03	1.06E+03	4.29E+04	1.57E+04	9.24E+03	1.25E+05
1h 2000s	ND	2.81E+02	2.19E+01	6.66E+02	1.26E+02	1.73E+03	2.14E+03	1.36E+04	2.18E+04
24h 2000s	5.25E+02	1.02E+03	1.60E+02	2.01E+03	3.44E+02	7.62E+03	4.56E+03	2.71E+04	4.93E+04
168h 2000s	ND	ND	ND	1.84E+03	3.12E+02	5.83E+03	2.81E+03	7.01E+03	2.36E+04

ND - not detected

6.3.1.2 1 – 24 – 96 hour Contacting Time

Another experiment was carried out in the end-over-end contactor where distilled water contacted a 25-year composite of the e-waste (equal portions by mass from each decade) for 1, 24 and 96 h (Figure 6.4). The results are presented in Table 6.4. The raw data are presented in Table F.3, Appendix F. The measured concentrations appeared to be levelling off in the final 72 hours of contact, as this resulted in a much smaller increase in concentration than extending the contacting from 1 to 24 h. From the similar shape of the cumulative curves in Figure 6.4, it is clear that the congener distributions were similar for all three contacting times. In particular, the concentration in five of the BDE congeners (BDE-100, -153, -154, -207 and -209) increased by one order of magnitude from 1 h contacting time (i.e. BDE-100 = 103 pg/L) to either 24 or 96 h contacting time (i.e. BDE-100 = 1,680 pg/L), with the exception of BDE-47 (27 pg/L), BDE-99 (728 pg/L) and BDE-183 (5.33×10^5 pg/L), which increased two-fold over the 96 h contacting time (BDE-47 = 4,110 pg/L) (Table 6.4).

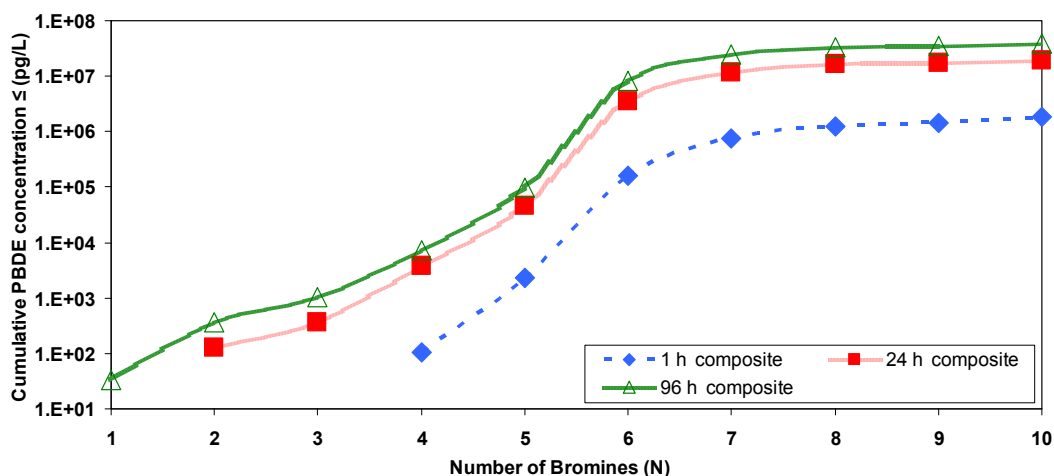


Figure 6.4 Blank-corrected PBDE cumulative concentration profiles for aqueous phase after e-waste 25-year composite was contacted with distilled water in the end-over-end contactor for 1, 24 and 96 h, at 20°C, and pH 7, (Lab: Vista Analytical). Ordinates give cumulative PBDE concentrations, i.e. sum of concentrations of all PBDE congeners having N or fewer attached bromines. The principal congeners discussed throughout this thesis, i.e. BDE-47 (N=4), -99 and -100 (N=5), -153 and -154 (N=6), -183 (N=7), -206 and -207 (N=9), and -209 (N=10), account for >80% of the totals.

Table 6.4 Blank-corrected 25-year composite (1980-2005) e-waste data (in pg/L) after contacting in end-over-end apparatus with distilled water for 1, 24 and 96 h at 20°C and pH 7 (Lab: Vista Analytical).

Principal Congeners									
Contact time	tetra-BDE	penta-BDE		hexa-BDE		hepta-BDE	nona-BDE	deca-BDE	TOTAL PBDEs
	BDE-47	BDE-99	BDE-100	BDE-153	BDE-154	BDE-183	BDE-207	BDE-209	
1 h	2.70E+01	7.28E+02	1.03E+02	1.30E+05	1.67E+04	5.33E+05	1.60E+05	4.21E+05	1.83E+06
24 h	2.35E+03	1.35E+04	1.68E+03	2.96E+06	3.53E+05	7.53E+06	9.63E+05	2.34E+06	1.96E+07
96 h	4.11E+03	2.71E+04	3.00E+03	6.70E+06	8.64E+05	1.50E+07	1.69E+06	2.74E+06	3.84E+07

6.3.2 PBDEs in E-waste Contacted by Leachate

Experiments were next performed in which e-waste particles were contacted with landfill leachate for contacting times from 1 to 654 h. The samples were prepared for analysis the same way as was discussed in Chapter 3, i.e. with extra extraction steps due to the presence of particulates and their non-homogeneous appearance. Leachate from the major urban landfill compartment containing wastes discarded in 1985-89 was utilised for these experiments, and all resulting concentrations were analysed by DFO-IOS.

According to the landfill operator, e-waste made up only a small portion (~5-6%) of the solid material discarded in each of the 5-year periods. Other components of the waste stream such as mattresses likely also contained PBDEs, in variable proportions.

6.3.2.1 *Effect of Contacting Time*

When leachate was contacted with e-waste from items manufactured in 1985-89 for 1, 24 and 654 h, results shown in Table 6.5 were broadly similar to those for the crushed e-waste/distilled water studies (Section 6.3.1.1 and Table 6.3). There was an overall increase between one to two orders of magnitude from 1 h contact time (total PBDEs = 1.58×10^5 pg/L) to 654 h contact time (total PBDEs = 7.32×10^6 pg/L). In particular, the mid-to-lower brominated congeners (BDE-100 = BMDL for 1 h and 125 pg/L for 654 h contacting time, BDE-153 = 8,630 pg/L for 1 h and 8.08×10^5 pg/L for 654 h contacting time, BDE-154 = 1,220 pg/L for 1 h and 1.17×10^5 pg/L for 654 h contacting time, and BDE-183 = 4.17×10^4 pg/L for 1 h and 3.3×10^6 pg/L for 654 h contacting time) were two orders of magnitude higher from 1 h of contact time to 654 h of contact time. The higher brominated congeners (BDE-206, -207 and -209) were one order of magnitude higher (i.e. BDE-209 = 4.23×10^4 pg/L for 1 h and 8.1×10^5 pg/L for 654 h contacting time). Relatively little PBDE was transferred to the leachate during the last 630 h beyond what was measured after 24 h of contact, a finding similar to that for the distilled water where there was little difference between 24 and 168 hours. BDE-47 and -99 concentration levels fell below detection limits after procedural blank corrections. No PBDEs could be detected for the lower brominated congeners (mono- and di-BDE) for any of the contacting times.

In an effort to shed light on the origin of the BDEs transferred from the e-waste to the liquid, the composition of the e-waste manufactured in the 1985-89 time period is compared with results from the experiments where leachate was contacted with e-waste from components manufactured in the same time period. Figure 6.5 indicates that the proportions of penta-, hexa- and hepta-BDE are higher in the liquid after end-over-end contacting than in the solid waste, whereas the fractions of octa-, nona- and deca-BDE tend to be lower. The yellow bars (PBDE concentrations of raw leachate) were added to the figure to enhance comparison of the various experiments conducted with leachate and e-waste contacted at different times. No statistical analyses were possible due to the lack of replicate samples analysed by the same laboratory.

The samples from the raw e-waste/leachate contacting experiments appear to show the presence of commercial Octa-BDE and Deca-BDE products, regardless of the contacting time. It may also indicate that PBDEs in this e-waste/leachate sample could be from other sources or degradation, not from the e-waste only. Leachate at $t=0$ indicates the concentration of PBDEs measured before e-waste particles were added to the leachate, i.e. before contacting in the end-

over-end chamber. The leachate contains the lower brominated congeners of BDE-47, -99 and -100, as noted by the yellow bars in Figure 6.5. The profile of these congeners, even after contacting for 654 h, indicates the persistence of BDEs in the mid-to-lower number of attached bromines.

Table 6.5 Blank-corrected BDE congener group concentrations (pg/L) in raw leachate after contact with e-wastes manufactured in 1985-89 for 1, 24, and 654 h, at 20°C and pH 7. Lab: DFO-IOS.

1985-1989 e-waste/leachate contacted for 1-24-654 hrs										
Principal Congeners										
Contact time	tetra-BDE	penta-BDE		hexa-BDE		hepta-BDE	nona-BDE		deca-BDE	Total PBDEs
	BDE-47	BDE-99	BDE-100	BDE-153	BDE-154	BDE-183	BDE-207	BDE-206	BDE-209	
0	5.50E+01	2.14E+02	4.60E+01	6.87E+02	1.67E+02	1.30E+03	2.28E+03	N/A	5.30E+03	9.99E+03
1 h	BMDL	BMDL	BMDL	8.63E+03	1.22E+03	4.17E+04	1.68E+04	2.11E+03	4.23E+04	1.58E+05
24 h	BMDL	BMDL	BMDL	3.50E+05	5.05E+04	1.75E+06	3.60E+05	2.92E+04	2.05E+05	3.72E+06
654 h	BMDL	BMDL	1.25E+02	8.08E+05	1.17E+05	3.30E+06	5.59E+05	5.46E+04	8.10E+05	7.32E+06

BMDL - below method detection limit

N/A - not available

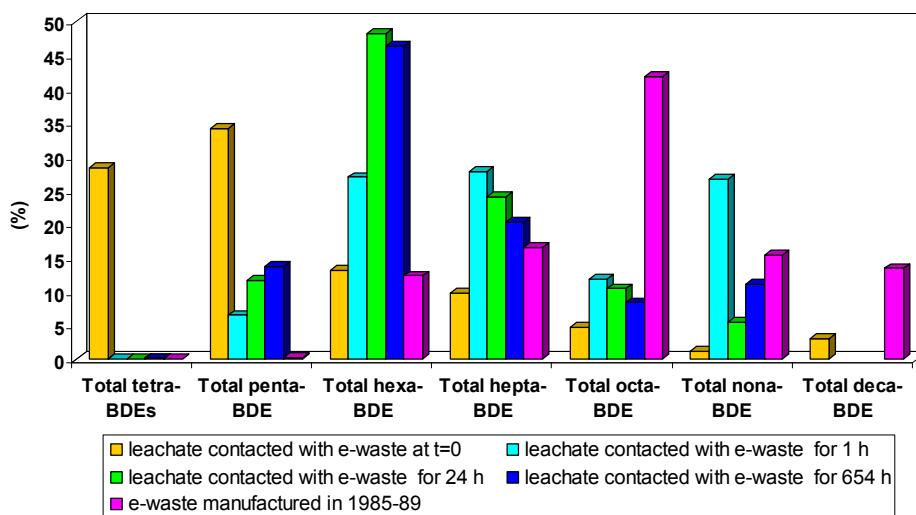


Figure 6.5 Blank-corrected percentages of total BDE by congener group in e-waste manufactured in 1985-89 vs. those in leachate after 1, 24 and 654 h of contact time, as well as raw leachate. Experiments conducted in the end-over-end contactor. Lab: Vista Analytical for the crushed e-waste and DFO-IOS for the leachate/e-waste experiment.

6.3.2.2 Effects of pH and Temperature

Tests were conducted to determine whether pH and temperature influence the transfer of PBDEs to leachate. This study utilised pH values of 4, 5, 7 and 9, covering the range of practical interest for the vast majority of landfills. Three temperatures were investigated, 10, 20 and 25°C.

Experiments at different pH levels with 1985-89 leachate and 1985-89 e-waste in the end-over-end contactor for 168 h are compared in Figure 6.6 for a temperature of 20°C. At a pH of 4, the

PBDE concentrations are initially much higher for low BDEs, but become increasingly similar to those for the other pH levels as the number of bromines increases. Overall, the highest concentrations in the leachate correspond to a pH of 5. All brominated congener groups show similar concentration trends for the higher brominated congener groups (penta- to deca-BDE). Only the di- and tri-BDE congener groups are higher for a pH of 4 than for a pH of 5, but concentrations of these two congener groups are so low that they are unlikely to be very accurate.

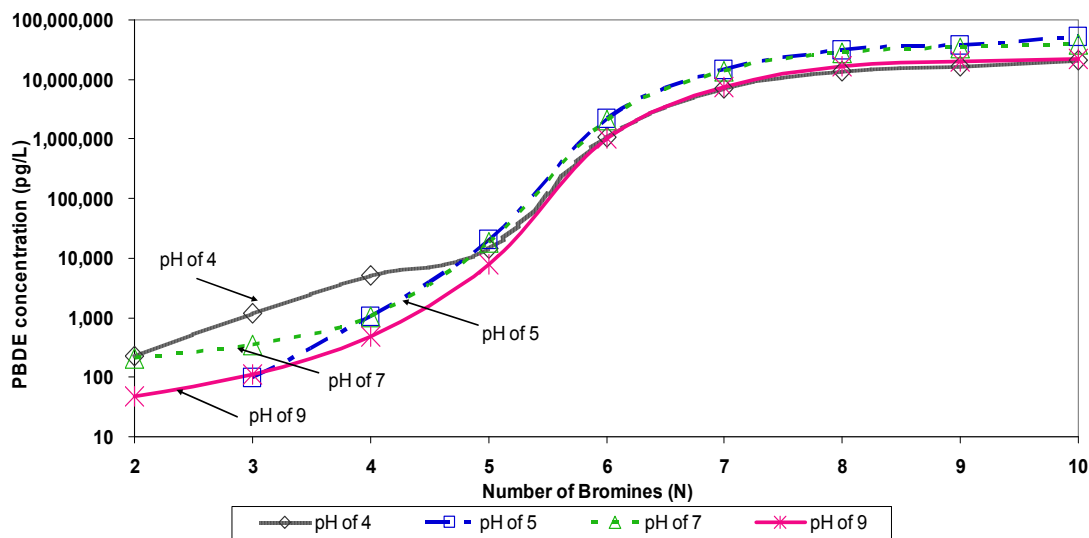


Figure 6.6 Effect of *pH* on blank-corrected cumulative PBDE concentration profiles for e-waste manufactured in 1985-89 contacted with raw leachate in contact with wastes from the same era in the end-over-end contactor for 168 h at 20°C (Lab: Vista Analytical). Ordinates give cumulative PBDE concentrations, i.e. sum of concentrations of all PBDE congeners having N or fewer attached bromines. The principal congeners discussed throughout this thesis, i.e. BDE-47 (N=4), -99 and -100 (N=5), -153 and -154 (N=6), -183 (N=7), -206 and -207 (N=9), and -209 (N=10), account for >80% of the totals.

As shown in Table 6.6, in almost every case there is a correlation between principal congener concentration and pH at constant temperature, with the minimum Pearson correlation coefficient ($R=0.75$) from BDE-47 occurring at the lowest temperature of 10°C. For all other congeners at all temperatures, the Pearson correlation coefficient ranges between $R=0.78$ and 0.98 , which indicates a strong influence of pH. When studying the concentration of each congener at different temperature and pH (Table 6.7), with all other parameters unchanged (168 h of contacting e-waste manufactured during 1985-89 with leachate from the region of the landfill where the waste was added during the 1985-89 interval), the more acidic pH values typically resulted in more PBDEs being transferred to the leachate.

Table 6.6 Correlation coefficient for principal congener concentrations and pH, at three constant temperatures (10, 20 and 25°C) for pH from 4 to 9. Values are given only when at least three PBDE concentrations were other than non-detect (ND).

Temperature (°C)	BDE-47	BDE-99	BDE-100	BDE-153	BDE-154	BDE-183	BDE-207	BDE-209	BDE principal congener average
10	0.75	0.92	0.85	0.94	0.91	0.95	0.95	0.82	0.88
20	-0.51	0.94	0.78	0.97	0.95	0.98	0.92	0.90	0.74
25	ND	0.99	0.96	1.00	0.97	0.99	0.94	0.99	0.98

ND - non detect

Table 6.7 Blank-corrected PBDE concentrations (pg/L) by BDE groups and principal congeners for e-waste manufactured in 1985-89 contacted with leachate drawn from the compartment containing discarded waste manufactured in the same time period at pH 4, 5, 7 and 9 for 168 h and different temperatures. (Lab: Vista Analytical)

Principal Congeners (pg/L)										
pH	Temp (°C)	BDE-47	BDE-99	BDE-100	BDE-153	BDE-154	BDE-183	BDE-207	BDE-209	Total PBDEs
4	10	5.70E+02	4.66E+03	7.62E+02	1.73E+06	1.71E+05	1.03E+07	2.60E+06	2.31E+07	5.56E+07
	20	3.89E+03	2.74E+03	6.22E+02	8.95E+05	1.06E+05	5.45E+06	2.50E+06	4.51E+06	2.11E+07
	25	ND	9.37E+03	1.59E+03	3.28E+06	3.59E+05	1.91E+07	5.82E+06	4.75E+07	1.12E+08
5	10	3.70E+02	2.78E+03	5.54E+02	1.06E+06	1.17E+05	6.30E+06	1.55E+06	1.20E+07	3.23E+07
	20	7.00E+02	4.98E+03	7.97E+02	1.87E+06	1.96E+05	1.16E+07	5.03E+06	1.31E+07	5.06E+07
	25	9.51E+02	9.67E+03	1.41E+03	3.56E+06	3.29E+05	1.94E+07	5.33E+06	6.58E+07	1.32E+08
7	10	3.43E+02	1.33E+03	3.37E+02	5.54E+05	6.16E+04	3.47E+06	9.05E+05	1.78E+07	2.94E+07
	20	5.66E+02	4.09E+03	7.44E+02	1.73E+06	1.89E+05	1.07E+07	4.70E+06	5.65E+06	3.92E+07
	25	5.11E+02	3.86E+03	6.82E+02	1.34E+06	1.40E+05	8.08E+06	2.04E+06	1.78E+07	4.27E+07
9	10	5.11E+02	2.65E+03	5.57E+02	9.02E+05	9.64E+04	5.43E+06	1.46E+06	1.41E+07	3.10E+07
	20	3.71E+02	1.71E+03	3.32E+02	8.41E+05	9.67E+04	5.91E+06	3.54E+06	2.14E+06	2.25E+07
	25	ND	7.04E+02	2.54E+02	3.93E+05	4.78E+04	2.56E+06	ND	4.04E+06	1.16E+07

ND - non detect

The results do not show a consistent trend with respect to temperature. At a pH of 9, the total PBDE concentration decreases with increasing temperature (3.1×10^7 pg/L at 10° C, 2.23×10^7 pg/L at 20° C and 1.16×10^7 pg/L at 25° C), but the opposite trend was found for the lower pH values of 4 (total PBDEs = 5.56×10^7 pg/L at 10° C, 2.11×10^7 pg/L at 20° C, and 1.12×10^8 pg/L at 25° C), 5 (total PBDEs = 3.23×10^7 pg/L at 10° C, 5.06×10^7 pg/L at 20° C, and 1.32×10^8 pg/L at 25° C) and 7 (total PBDEs = 2.94×10^7 at 10° C, 3.95×10^7 pg/L at 20° C, and 4.27×10^7 pg/L at 25° C). In most cases, the PBDE level decreases with increasing pH for a given temperature. Very similar patterns were found for all three temperatures at pH 7 in the cumulative profiles, as seen in Figure 6.7. It is likely that pH affects solubility, and also the plastic mechanical properties that would influence the degree of fines dislodgement (see section 6.4 below).

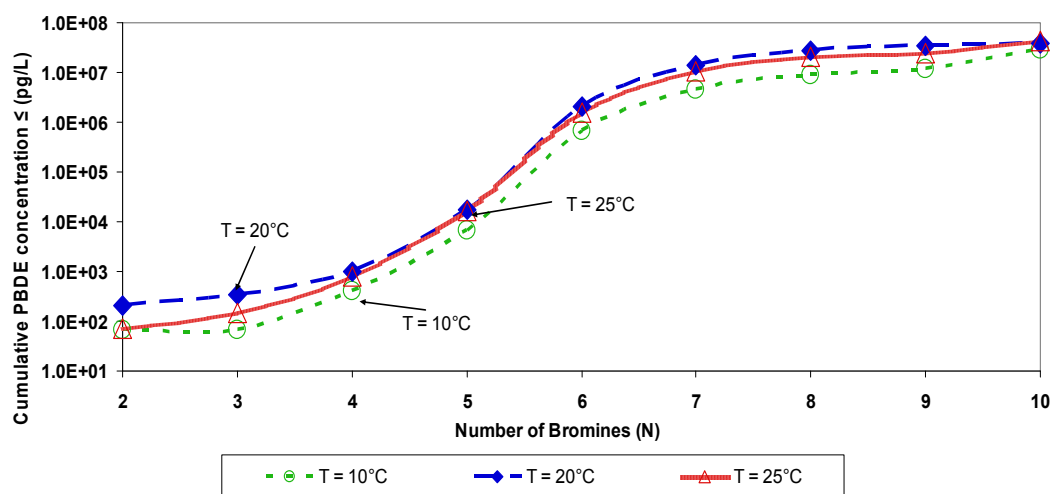


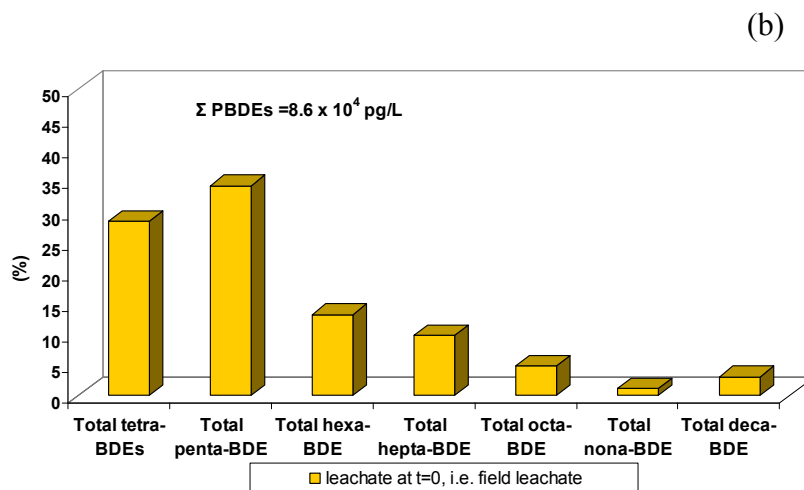
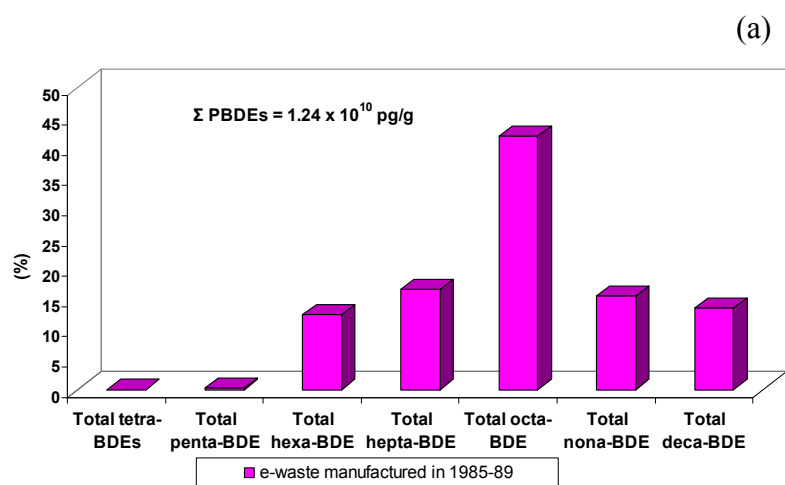
Figure 6.7 Effect of temperature on blank-corrected cumulative PBDE concentrations for e-waste manufactured in 1980-85 contacted with raw leachate from 1985-89 in the end-over-end contactor for 168 h at a pH of 7 (Lab: Vista Analytical). Ordinates give cumulative PBDE concentrations, i.e. sum of concentrations of all PBDE congeners having N or fewer attached bromines. The principal congeners discussed throughout this thesis, i.e. BDE-47 (N=4), -99 and -100 (N=5), -153 and -154 (N=6), -183 (N=7), -206 and -207 (N=9), and -209 (N=10), account for >80% of the totals.

6.3.3 Comparison of PBDEs in E-waste Contacted by Both Distilled Water and Leachate

Figure 6.8 compares the distribution of congener groups for the raw e-waste (a), field leachate (b), and leachate after contacting with e-waste for 1 h (c), 24 h (d), and 654 h (e). Figure 6.9 provides similar information for the aqueous phase after contacting with distilled water, for contacting times of 1 and 24 h. With the exception of the field leachate, the penta- and tetra-BDEs were negligible. None of the lower BDE congeners (tri-, di- and mono-) are plotted because their values consistently fell below detection limits after blank correction. The high proportion of octa-BDE in the raw e-waste is indicative of the commercial Octa-BDE product used in electronic plastics over the 1985-89 time period.

After the field leachate was contacted for 1 h with the e-waste, the influence of PBDEs in the higher brominated congeners (~30% each for hepta-, octa-, and deca, and ~15% for nona-) from the e-waste plastics was noticeable (Figure 6.8 c). When the contacting time increased to 24 h (Figure 6.8 d), the distribution changed and degradation of deca-BDE appears to have taken place. However, when the contacting time was extended to 654 h, the profiles did not change much, indicating that the patterns of the BDE congeners remain constant over long periods. This is explored further in Chapters 8 and 9, where the behaviour of this e-waste in a landfill is modelled.

Figures 6.8 c and d can be compared with Figures 6.9 a and b for the same contacting times of 1 and 24 h with e-waste manufactured in 1980-89, the difference being that the contacting liquid was leachate in Figures 6.8 c and d, but distilled water in Figures 6.9 a and b. The influence of leachate contacted with e-waste is evident over time for these time periods, whereas the distilled water had little if any effect on the degradation of PBDEs from e-waste (compare Figures 6.8. a and 6.9 a). However, some deca-BDE appears to have degraded in the distilled water/e-waste when contacted for 24 h (Figure 6.9 b). The similarity of the distributions for distilled water and leachate is one of the factors considered when discussing dissolution *vs.* dislodgement of ultra-fine particulates as the source of transfer in Section 6.4 below.



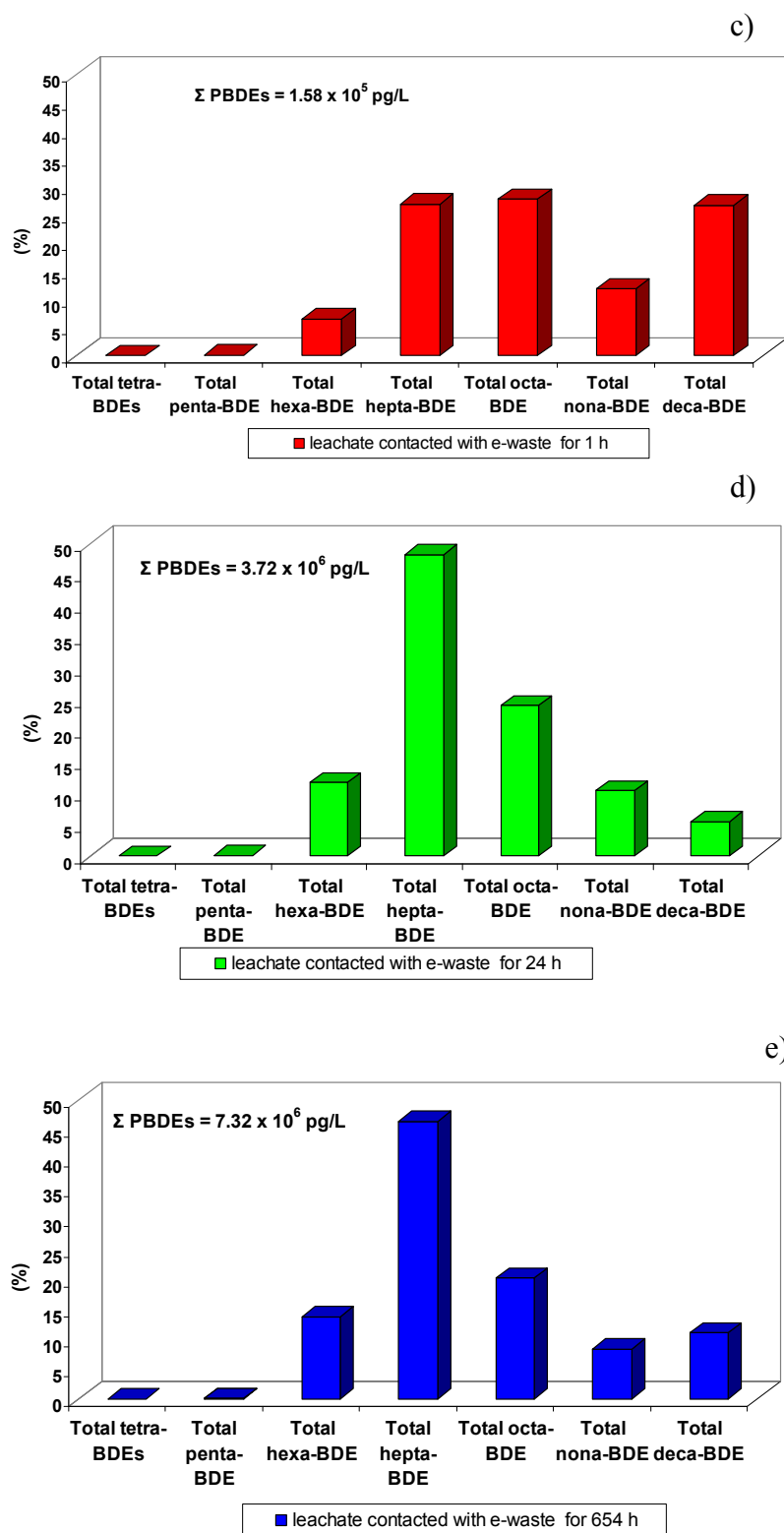


Figure 6.8. Percentage distribution of congener groups for blank-corrected BDE concentrations for 5 cases: a) e-waste manufactured in 1985-89; b, c, d, and e) leachate after contact with e-wastes manufactured in 1985-89 for 1, 24 and 654 h. All experiments were at 20°C and pH 7 (Lab: DFO-IOS).

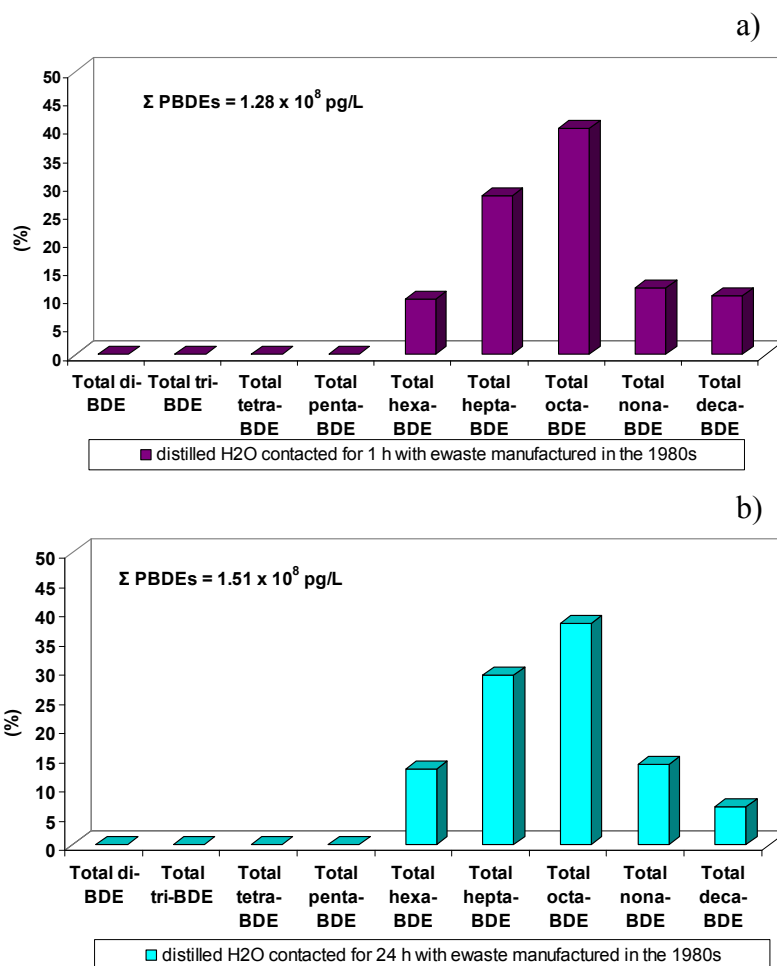


Figure 6.9. Percentage distribution of congener groups for blank-corrected BDE concentrations for 2 cases where distilled water was contacted with e-waste manufactured in 1985-89 for a) 1 h and b) 24 h. All experiments were at 20°C and pH 7 (Lab: Vista Analytical).

6.4 Discussion

The contacting experiments in the end-over-end contactor were intended to provide quantitative data related to mass transfer of PBDEs from landfill solids and e-wastes to leachate. The results for leachate in combination with those for distilled water, have, in addition, led to an important qualitative result. This is that ultra-fine particulate matter may be an important contributor to the transfer of PBDEs to the aqueous phase, as explained in Section 6.4.1 below.

6.4.1 Profiles of PBDEs in E-waste and Physical Appearance

The composition of plastics in electronic equipment changed radically over the 25-year period of e-waste manufacture studied in this research, as indicated in Table 6.2. Over this (1980-2005) period, there could also have been surficial changes which could affect ultra-fine particle

generation, whether by dust dislodgement, abrasion or dissolution. Indeed, the texture of the e-waste particles appears to have changed over this time period – very firm and “rock-like” in the eighties to “flakey” and lighter in appearance by the late 1990s, whereas the texture of the e-waste in the late 1990s and 2000+ era is more “flakey”, as indicated in Figure 6.1. This may be due to the changes in composition over time, or due to different manufacturing methods. As shown in Table 6.8, plastics in electronic equipment manufactured in the 1980s and early 1990s were primarily acrylonitrile butadiene styrene (ABS), high-impact polystyrene (HIPS) and some polyphenylene oxide (PPO). During the 1990s the percentage of ABS in the plastics incorporated in electronic equipment decreased, but was still substantial, whereas HIPS increased in some cases. Both physical and chemical factors could be important when studying the effects of PBDE leaching from these different plastics as these changes over time could have influenced the degradation capability of PBDEs.

Table 6.8 Plastics composition (% by mass) in end-of-life electronic equipment. Most data are from the US. Canadian compositions are likely to be very similar to these US values.

Type of plastic	Time periods								
	late 1980s ^a	1990-94 ^{ab}	1990s ^{ac}	1990s ^d	1995-99 ^e	1995-99 ^{fff}	2007 ^{ggg}	2006 ^{hhh}	2000-current ⁱⁱⁱⁱ
ABS*	76		65				32	30	
HIPS		5	16.0	19	25		29	25	50
ABS		57	36.7	26	39				
PPO		36	3.1	8	17				
PVC			4.0	5	5	4		3	
ABS/PC		2	13.4	16	10		13	9	50
PP or PE					3			8	
ABS/ASA/SAN						33			
PS/HIPS						19			
PPO/PS							18		
PS								3	
PPE/HIPS								7	
PU			0.2			8			
EP						4			
PP			0.7	4		18			
UP						3			
PA						3		3	
POM						2			
PE			0.2			1			
PBT						1		2	
ABS/PVC			18.2				9		
PC			5.6	6				10	
PMMA				4					
SAN				2					
other			1.9		<1				
unidentified			0.08	10	0				
Location	U.S.					Western Europe		UK	Canada

* Bolded and italicized acronyms have the highest percentage found in plastics over the years

** ABS percentages not included in total percent by mass sum

***Reported data only add up to 96%

**** Includes ABS percentage in sum of total percent

***** PC/ABS composition reported on all monitors; HIPS composition reported for all printers

a - Stuart Williams, et al., 2006; b - APC, 2000 (data collected in 1995); c- Arola, et al., 1999; d- MBA Polymers, 1999

e - Fisher, 2000; Fisher, et al., 2005; f- Fisher, et al., 2005; g - Schlummer et al, 2007; h - Freegard, et al, 2006

i - pers comms B. Monesmith, 36ZeroWasteGroup Inc, 2008

ABS-acrylonitrile butadiene styrene; HIPS-high impact polystyrene; PPO-polyphenylene oxide; PVC-polyvinylchloride

PC/ABS- polycarbonate/acrylonitrile butadiene styrene; PP-polypropylene; PE- polyethylene; SAN-styrene acrylonitrile

PS-polystyrene; PU-polyurethane; EP-epoxy; UP-unsaturated polyester; PA-polyamide (nylon); POM-polyacetal

PBT-polybutylene terephthalate; PMMA-polymethyl methacrylate; ASA-copolymer of acrylonitrile, styrene+acrylate rubber

6.4.2 Effects of PBDEs in E-waste Contacted by Both Distilled Water and Leachate

Notwithstanding the surfactants and organic material in the leachate (and not in the distilled water), levels of the less soluble higher BDE congeners tend to be similar for distilled water and leachate for the same contacting duration and physical conditions for the 1985-89 wastes, and sometimes even to be higher for distilled water than for leachate for identical contacting conditions (time, pH, temperature, particle composition, particle loading.) This suggests that particulate dislodgement is a significant mechanism of transfer of PBDEs from the solids into the aqueous phase. The finding that the results are not well correlated with temperature, whereas pH plays a strong role, are consistent with this suggestion, since solubility is likely to be a strong function of temperature and pH. Physical properties and adhesion of fines are more likely to be pH-dependent for the ranges covered. In addition, if fine particles carrying PBDEs are dislodged such that they can pass through the filters, they will contribute to the measured transfer rates.

For a contact time of 1 hour, the PBDE concentrations in the leachate or distilled water were low. As the contact time increased to 24 hours, the concentrations increased substantially in both leachate and distilled water. After 24 hours of contacting time, the concentration increases became minimal (e.g. see Figure 6.9). It seems likely that in the first 24 hours most of the fine particles were dislodged, after which the rate of dislodgment decreased as most loosely-bound particles had already been dislodged.

6.4.3 Solubilities of PBDEs in E-waste

Table 6.9 compares solubilities at 25°C reported by Tittlemier *et al.* (2002) with the maximum measured concentrations in the water after 96 hours of end-over-end contacting (Table 6.4). The likely explanation for the very significant levels of measured PBDEs in higher-brominated congeners (BDE-153, BDE-154 and BDE-183), in excess of their solubilities, is due to a combination of e-waste particle dissolution in the aqueous medium and dislodgement of very fine dust on the surface of the e-waste (finer than the 20 µm filter size used by Vista Analytical in their analysis of the liquid resulting from end-over-end contacting with the distilled water.) These elevated values may have been caused by surface abrasion as particles tumble over each other during the vigorous end-over-end motion. The high values for BDEs -153, -154 and -183 could be due to the fact that BDE-154 being more particle-bound than other congeners. In spite of this, a small amount of BDE-47 was measured in the distilled water sample (BDE-47 = 4,100

pg/L compared to 1.5×10^7 pg/L solubility). If solubility were important, one would expect more soluble congeners to show up preferentially in the aqueous phase. This did not happen.

Table 6.9 Comparison of BDE homologue group solubilities in distilled water at 25°C (World Health Organization and Environmental Health Criteria 162 1994; Tittlemier *et al.* 2002) to concentrations of PBDEs in leachate (pg/L), maximum measured concentrations from the experiments (pg/L), and PBDE concentrations of crushed e-waste for the 1985-89 time period (pg/g). Bolded congeners are principal congeners.

BDE Congener	Solubility in water(25°C) [§]	leachate concentrations (1985-89 time period) ^a	Maximum measured concentrations in distilled water contacting in our experiment (e-waste composite contacted with dH ₂ O for 1, 24, and 96 h) (see Table 6.4 for details) ^a	PBDE concentrations of crushed e-waste for the 1985-1989 time period (see Table 6.1 for details) ⁶
	(pg/L)			pg/g
BDE-15 (di-BDE)	1.3E+08 ± 2E+07	2.9E+01	1.1E+02	3.2E+04
BDE-28 (tri-BDE)	7E+07 ± 1.0E+07	0.0E+00	3.2E+02	1.0E+05
BDE-47 (tetra-BDE)	1.5E+07 ± 2.0E+06	4.4E+02	4.1E+03	6.8E+05
BDE-66 (tetra-BDE)	1.8E+07 ± 3E+06	0.0E+00	6.3E+02	9.4E+04
BDE-77 (tetra-BDE)	6.0E+06 ± 1E+05	0.0E+00	1.4E+02	1.6E+04
BDE-85 (penta-BDE)	6.0E+06 ± 1E+05	0.0E+00	5.9E+02	4.3E+05
BDE-99 (penta-BDE)	9.4E+06 ± 8.0E+05	5.3E+02	2.7E+04	1.3E+07
BDE-100 (penta-BDE)	4.0E+07 ± 1.0E+07	1.2E+02	3.0E+03	7.4E+05
BDE-153 (hexa-BDE)	8.7E+05 ± 6.0E+04	6.9E+02	6.7E+06	1.3E+09
BDE-154 (hexa-BDE)	8.7E+05 ± 9.0E+04	1.7E+02	8.6E+05	1.4E+08
BDE-183 (hepta-BDE)	1.5E+06 ± 3.0E+05 ^d	2.2E+03	1.5E+07	1.9E+09
BDE-209 (deca-BDE)*	2.0E+07 ± 3.0E+07	5.3E+03	2.7E+06	1.7E+09

[§]Reference: Tittlemier et al., 2002 except for BDE-209

^aReference: Vista Analytical, this research

⁶Reference: Vista Analytical, this research

*Reference: World Health Organization, IPCS, EHC 162, 1994

^dConfidence interval: 0 to 4.5E+05

6.4.4 Dislodgement of Ultra-fine Particles

To the extent that ultra-fine particles are responsible for the observed transfer rates, it would appear that they resulted from dislodgement of fine dust adhering to the surface of the plastic or from abrasion which occurred when the e-waste particles rubbed against each other and scraped against the walls of the columns as the end-over-end contacting was carried out. Dislodgement could be consistent with the finding that the apparent PBDE concentrations tended to increase with increasing time of contact. For most BDE congeners, dissolution was slow, as solution saturation was not reached. If dissolution were the dominant transfer mechanism, one would expect to see continuously increasing concentrations for each of the congeners until saturation is reached, with decreasing transfer as the difference between the solubility and actual concentration decreased. We postulate that dislodgement is responsible for the measured PBDE

concentration exceeding solubility. A recent paper by Gorgy *et al.* (2009) studied the effects of fine and ultrafine particles associated with PBDE dislodgement in biosolids. This study found that ultrafine particles absorbed more than twice the amount of PBDEs per unit mass than the fines. Gorgy *et al.* (2009) also hypothesized that this could be related to higher organic carbon content in smaller particles. However, more work is needed in the future to compare the dissolution and ultra-fine particle transfer mechanisms and to determine the physical properties (such as particle size distribution, density and shape) of the ultra-fine particles.

The likely presence of ultra-fine particles (in particular those $<0.5\ \mu\text{m}$ in diameter and hence able to pass through the finest filter used in the DFO-IOS lab) is important. These particles would be too small to be captured in water treatment facilities or to be filtered out in human (or animal, fish, etc.) physiological ingestion and breathing systems. They are also so small that they would be unlikely to settle under gravity in water or air systems and hence could be carried over great distances. These ultra-fine particles containing PBDEs are bio-available¹ (Huwe *et al.* 2007; Shaw *et al.* 2008; Vigano *et al.* 2009) and thus can enter organisms through food, water and inhalation.

6.5 Conclusions

Experiments were carried out in which plastic particles derived from e-wastes were contacted with both distilled water and field leachate. The concentrations and proportions of different congeners were similar for the distilled water and leachate experiments despite the higher solubilities expected for the leachate. Results obtained, in particular concentrations exceeding solubility and different analytical results from laboratories that used different grades of filters are explained by postulating that fine particles played a major role. In particular, it is postulated that the findings reflect ultra-fine plastic particles containing PBDEs entering the aqueous phase. This could be due to: a) dislodgement of dust from the surface of e-waste particles, or b) grinding or abrasion during contacting. Some ultra-fine particles may be small enough to pass through 0.5 micron filters. They would therefore end up in drinking water, as well as other domestic and waterway systems.

Other conclusions are as follows:

¹ Bio-availability of organic contaminants is an important parameter used to estimate the fate and transport of contaminants in the environment. It is necessary to quantify in order to evaluate the hazard associated with the presence of a contaminant (Dudal, *et al.* 2003).

- Contacting the composite e-waste with distilled water did not show a significant increase in levels of PBDEs in distilled water for waste from all 5-year time intervals beyond 24 hours. PBDE concentrations between 24 and 168 h were very similar.
- When raw leachate was exposed to crushed e-waste, the measured concentrations of PBDEs in the raw leachate generally increased significantly with time. Differences between 1 and 24 h values were generally much greater than between concentrations corresponding to 24 and 654 h contacting time.
- Transfer of PBDEs into leachate was similar for the three temperatures (10, 20 and 25°C) investigated, with somewhat lower transfer at lower temperatures, except at the highest pH (9) where the trend reversed.
- The data in this chapter are preliminary. Very little information is available for comparison in the literature. Thus, future work is needed to fill in gaps and obtain a better understanding of PBDE behaviour in e-waste and other media.

CHAPTER 7 – PBDEs IN ASH FROM WASTE-TO-ENERGY FACILITY

7.1 Introduction

In an effort to obtain more information on the possible sources of PBDEs entering landfills and the environment, samples were collected from a waste-to-energy (WTE) facility in Ontario and analysed by the Dioxin & Toxic Organics Section, Laboratory Services Branch of the Ontario Ministry of Environment (MOE). The criterion used by the Ontario MOE for blank correction is that if the raw concentration measured is equal to or greater than 3 times the blank values, then the data is considered valid and the measured value is used for interpretation without subtracting a multiple of the corresponding measured blank concentration. This differs from the DFO-IOs procedure (Chapter 3) which is to subtract one or two times the blank value as outlined in Chapter 3 and also from the Duke procedure (Chapter 3), which is to subtract the average procedural blank level (calculated from three sodium sulphate procedural blanks) from each sample measurement. Since the waste-to-energy ash data were only analysed by a single laboratory, it was not possible to perform inter-laboratory comparisons for these data.

Some e-wastes and other PBDE-containing solid wastes are sent to incinerators. For example, approximately 20% of Vancouver's solid waste goes directly to incineration. Some of the bottom ash from incinerators (< 25.4 mm in size in the case for the Ontario facility discussed here) is sent to landfills as cover. The remaining bottom ash is disposed at the landfill. Hence ash from waste-to-energy facilities provides one possible way that PBDEs may enter landfills and end up in landfill leachate and soil.

While the work covered in this brief chapter is very preliminary in nature, it was undertaken to get a sense of the potential order of magnitude of PBDEs in incinerator ash from an urban incinerator. Ash samples were collected from the Algonquin Power Energy from Waste Inc. facility in the Region of Peel, Regional Municipality of Mississauga, Brampton and Town of Caledon, Ontario. Boiler (or fly) ash, bottom (or processed) ash from the baghouse and residue or waste (Air Pollution Control or APC) were sampled for PBDEs. This facility processes municipal solid waste from the Region of Peel (~160,000 tonnes/yr), as well as Pearson International Airport waste and industrial/commercial/institutional waste (~14,000 tonnes/yr). It operates a two-stage incineration process: The first stage is a fluidized bed incinerator with

temperatures from 800 to 1100°C, whereas the second involves cyclonic combustion, with operating temperatures between 870 and 1200°C. The bottom ash represents ~26-30% of the mass of the waste processed. The total fly ash represents ~2% of the processed waste. 150% of the stoichiometric air needed for complete combustion is used in the process.

According to Algonquin Power, approximately 25,000-30,000 tonnes/year of <25.4 mm bottom ash are sent to a landfill as cover, while ~ 7,000-8,000 tonnes/year of >25.4 mm bottom ash are sent to the landfill for disposal, ~ 3,000 tonnes/year of ferrous material to recycling, and ~3,000 tonnes/yr of APC residue are generated (Hatton, 2007). The residue is considered hazardous because it contains significant quantities of lead and cadmium. The residue is treated to render it non-toxic prior to disposal in a high-security cell at a landfill. Ash and residue samples were collected by technicians at the waste-to-energy facility and then sent to the Ministry of Environment Ontario's Dioxin laboratory for analysis with a GC-HRMS. The results are plotted in Figure 7.1 and tabulated in Table 7.1. Raw data are summarized in Table F.1, Appendix F.

The acid-washed¹ boiler ash (or fly ash) data contained PBDE concentrations six orders of magnitude lower (Table 7.1) than found in crushed e-waste manufactured in 1985-89 (compare Table 6.1, Chapter 6), the 5-year period with the highest concentration. Most fly ash from the baghouse and waste residue had low PBDE concentrations or were below the detection limit. Although few samples were obtained from the WTE facility, it is clear that more work is needed to assess the risk of PBDEs being introduced into the landfill via bottom ash leading to potential accumulation in leachate and soil.

¹ This is a 1M hydrochloric acid solution to decompose the sample matrix.

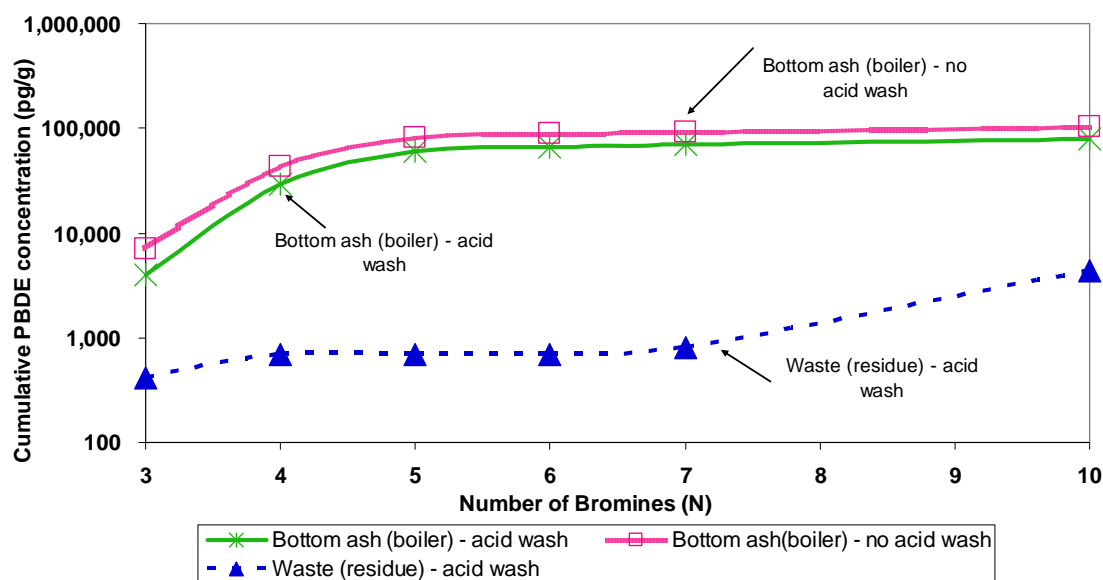


Figure 7.1 Blank-corrected cumulative PBDE concentrations of bottom ash and residue at a waste-to-energy facility, pg/g (Lab: MOE). Ordinate gives cumulative PBDE concentrations, i.e. sum of concentrations of all PBDE congeners having N or fewer attached bromines. The principal congeners discussed throughout this thesis, i.e. BDE-47 (N=4), -99 and -100 (N=5), -153 and -154 (N=6), -183 (N=7), -206 and -207 (N=9), and -209 (N=10), account for >80% of the totals.

Table 7.1. Data from bottom ash and waste (residue) collected at a waste-to-energy facility in Canada (Lab: MOE) (pg/g)

BDE groups	total tri-BDEs	total tetra-BDEs	total penta-BDEs	total hexa-BDEs	total hepta-BDEs	total deca-BDEs
<i>Bottom ash (boiler) - acid wash</i>	4,000	25,630	30,890	6,200	2,610	9,300
<i>Bottom ash(boiler) - no acid wash</i>	7,100	36,170	38,500	7,300	2,800	11,000
<i>Fly ash (baghouse) - acid wash</i>	BMDL	BMDL	BMDL	BMDL	BMDL	2,500
<i>Fly ash (baghouse)- no acid wash</i>	BMDL	BMDL	BMDL	BMDL	BMDL	1,900
<i>Waste (residue) - acid wash</i>	410	274	BMDL	BMDL	110	3,500
<i>Waste (residue) - no acid wash</i>	340	BMDL	BMDL	BMDL	BMDL	BMDL

BMDL - below method detection limit

Principal congeners	tetra-BDE	penta-BDE		hexa-BDE		hepta-BDE	deca-BDE
	BDE 49	BDE 99	BDE 100	BDE 153	BDE 154	BDE 183	BDE 209
<i>Bottom ash (boiler) - acid wash</i>	2,500	24,000	4,700	3,300	2,900	2,000	9,300
<i>Bottom ash(boiler) - no acid wash</i>	4,200	30,000	5,900	4,100	3,200	2,200	11,000
<i>Fly ash (baghouse) - acid wash</i>	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	2,500
<i>Fly ash (baghouse)- no acid wash</i>	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	1,900
<i>Waste (residue) - acid wash</i>	BMDL	BMDL	BMDL	BMDL	BMDL	110	3,500
<i>Waste (residue) - no acid wash</i>	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL

BMDL - below method detection limit

CHAPTER 8 – MASS BALANCE MODEL FORMULATION

8.1 Introduction

Mass, mole and energy balances are frequently written in engineering to account for the conservation of substances within a designated control volume. These balances involve equating the rate of accumulation of a component, a species or energy to the difference between its rates of entering and leaving the volume plus the net rate of generation within the control volume. This approach has in recent decades also become common as a basis for environmental modelling (Diamond *et al.* 1992; Mackay and Wania 1995; Mackay 2005) and models that predict the fate of chemicals in the environment (Mackay and Reid 2008; Reid and Mackay 2008).

Simplifying assumptions are needed to apply this approach to PBDE modeling because essential information on PBDE behaviour, fate and transport in the environment is lacking. The assumptions adopted in this thesis are described in detail in Section 8.5 below. A landfill model is proposed which is intended to track PBDEs originating with e-waste and Non-e-Waste Solids (abbreviated NeWS hereafter) through to their stepwise debromination over time. The concentration data input into the model are from analytical results obtained by Vista Analytical Laboratory and the Department of Ecology from the State of Washington. The unsteady ‘accumulation’ term becomes critical in applying the model, given that large amounts of e-waste (and NeWS) are currently both in use and stockpiled awaiting disposal, with the bulk volume increasing over the years. Air is formally included in the modeling program of the software, but in reality it is excluded from subsequent consideration due to lack of data. As more data become available in the future, it should be possible to include the air compartment, as well as to improve the assumptions underlying the other three compartments considered in Section 8.5 below.

A typical modern solid waste landfill contains municipal solid waste (e.g. household waste), construction and demolition debris, industrial waste, some hazardous waste materials, composting areas and landfill gas recovery. They also normally have leachate collection and removal systems, geo-membrane layers, and groundwater monitoring schedules. For the purposes of this research, a typical landfill system is illustrated in Figure 8.1. The mass balance model is based on a simplification of this landfill as described in the subsequent sections.

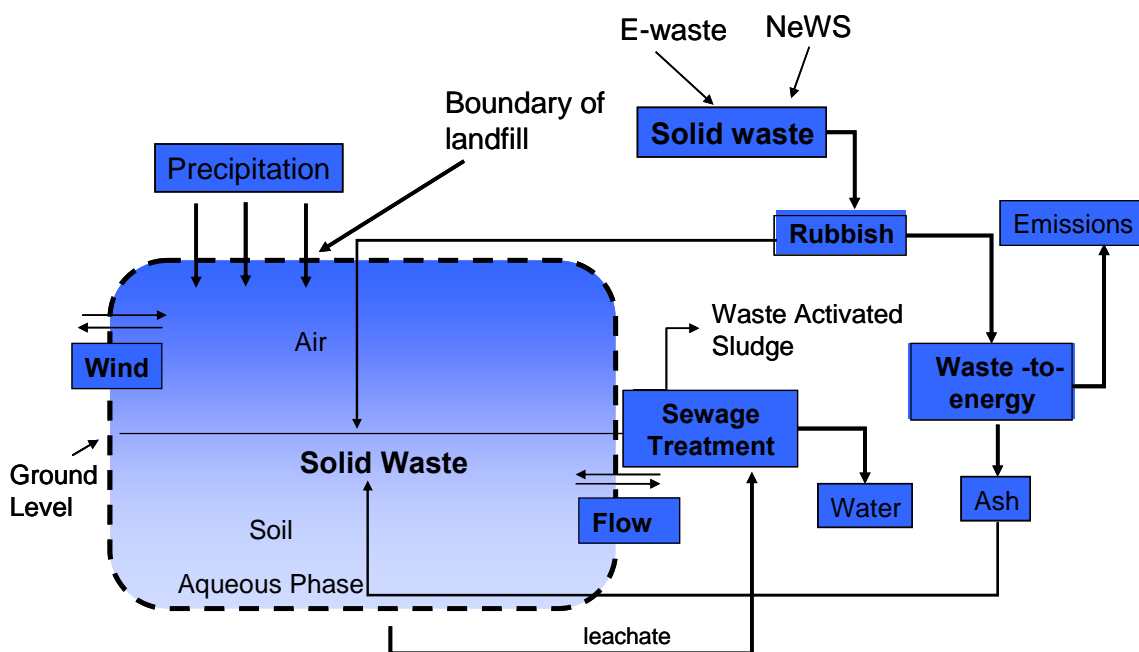


Figure 8.1. Schematic of a typical landfill.

8.2 Mechanistic Modeling of a Landfill: Subsystems

The comprehensive mechanistic mass balance landfill model was developed in collaboration with Dr. Andrés Mahecha-Botero. It is intended to predict the environmental fate of polybrominated diphenyl ethers (PBDEs) in landfills, with possible extension to other systems. Mass balances are applied to eight homologue groups and to the three subsystems (e-waste, aqueous and NeWS) specified below in Section 8.4. Included in the model are input and output streams, decomposition reactions, transfer between subsystems and accumulation. The NeWS subsystem consists of all solids rubbish except the e-waste. Table 8.1a lists the assumed composition of the NeWS stream based on data from the urban landfill system (whose identity must remain confidential), which is the reference site for purposes of illustration. Although the refuse category includes soil and sand, these are used as landfill cover. Inputs to the landfill are assumed to include e-wastes (containing PBDEs in the concentrations measured in Chapter 6) and NeWS (also containing some PBDEs). The e-waste includes discarded personal computers, printers, hard drives, circuit boards, keyboards and mice. The model predicts time-dependant variation of species or group concentrations in the three subsystems considered (e-waste, aqueous phase and NeWS). Landfill conditions are obtained from field measurements obtained by the landfill operator, best available data and estimates. Key mass transfer parameters are

estimated from the experiments described in Chapter 6, conducted in the solid-liquid contacting chamber with crushed electronic equipment exposed to landfill leachate and water.

Table 8.1. a) NeWS composition for 2004-2005 as provided by the organization overseeing the urban landfill site used as the reference site. The only categories assumed to contain PBDEs are the mattresses and sofas, and small appliances; and b) NeWS, calculated based on percentages from Table 8.1 a), and includes the amount of PBDEs found in sofas and mattresses. References (WHO-EHC 162 1994; ENVIRON 2003a; Washington State Department of Ecology 2005).

a)

Refuse Category	Composition of NeWS (% of mass)	
paper/paperboard	14	75% of total refuse
plastics	7	
compostables	35	
metals	3	
glass (SiO ₂)	1	
hazardous waste	1	
inorganic waste	2	
mattresses and sofas*	5	
small appliances	4	
household hygiene	2	
fines	1	
soil	24	25% of total refuse
sand	1	
Total	100	

* defined as bulky objects in the landfill category

b)

NeWS: Non e-Waste Solids				
Mattresses and Sofas+soil+sand+refuse				
BDE congener	Molecular weight (g/mole)	NeWS (pg of BDE congener / g of NeWS)*	Composition of Commercial PentaBDE (1980-2004 formulation) (%)**	Composition of Commercial DecaBDE (%)***
tri-BDEs	328.1	3.92E+05	0.5	0
tetra-BDEs	485.8	2.43E+07	31	0
penta-BDEs	564.8	4.39E+07	56	0
hexa-BDEs	643.6	6.28E+06	8	0
hepta-BDEs	722.3	0	0	0
octa-BDEs	801.5	0	0	0
nona-BDEs	880.4	0	0	2.5
deca-BDEs	959.2	0	0	97.5

* Washington State Department of Ecology. Internal Document: PBDEs in vehicles, mattresses landfills, TVs, carpet padding and biosolids (2005).

** ENVIRON, "Voluntary children's chemical evaluation program pilot. Tier 1 assessment of the potential health risks to children associated with exposure to the commercial pentabromodiphenyl ENVIRON Int. Corp., Emeryville, California (2003a)

***World Health Organization, Environmental Health Criteria 162, International Programme on Chemical Safety (IPCS) 1994.

A general approach is implemented to describe the variation of contaminant concentrations with time. The proposed approach is comprehensive enough to deal with different contaminants, and the model could be adapted to accommodate other scenarios. For modeling purposes, each of the subsystems is treated as being in contact with the other two subsystems considered (as well as with air). Figure 8.2 represents the key subsystems schematically. E-waste contains a mixture of different PBDE congeners of different molecular weights.

Contaminated disposed goods undergo several simultaneous processes that affect the surrounding region. Mass transfer phenomena in a landfill system among subsystems are shown schematically in Figure 8.3. There are multiple reactions, with chemical species debrominating stepwise over time, thereby generating new chemical species. These species may also transfer to or from adjacent subsystems, e.g. back and forth between the aqueous phase and NeWS in the case of the NeWS subsystem.

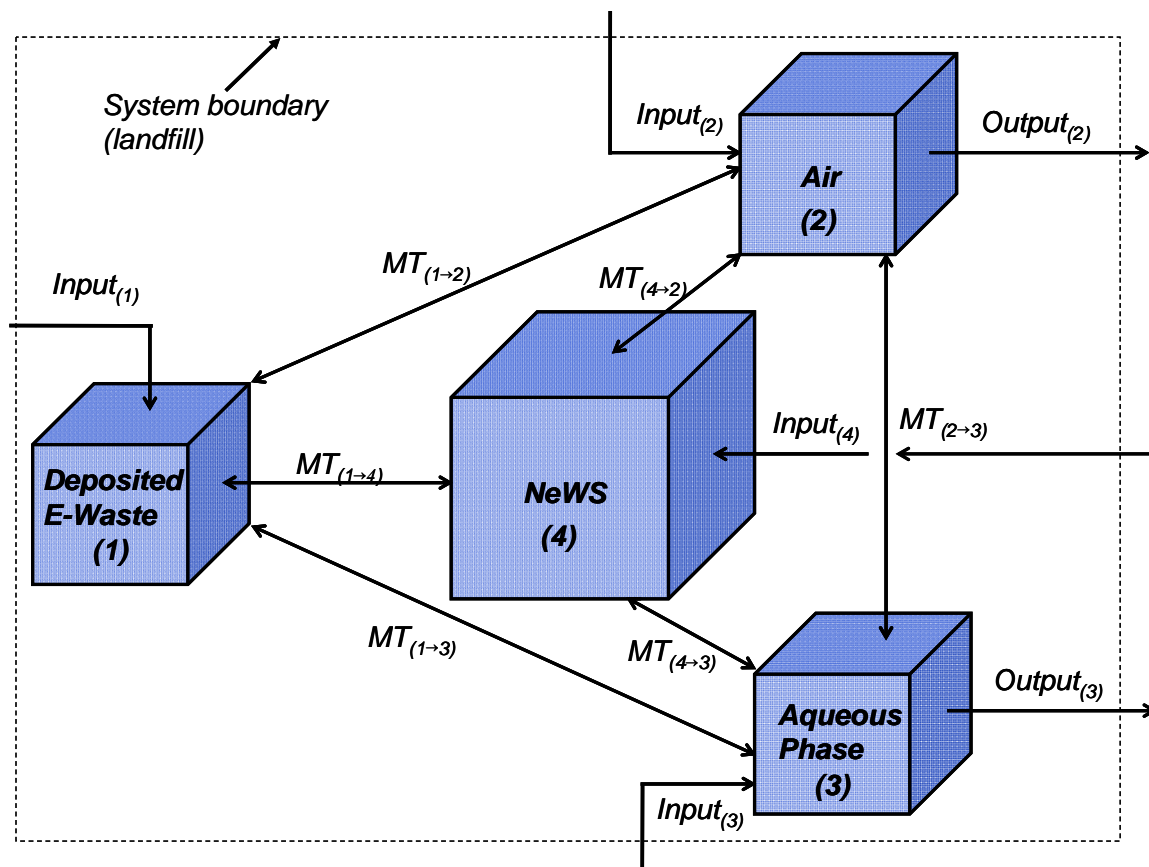


Figure 8.2. Schematic of the various mass transfer (MT) and input/output steps for the subsystems in the landfill model. NeWS is defined as non-electronic waste solids, including sand and soil added as cover materials.

In order to account for all possible chemical species, but not have to deal with all 209 individual congeners, eight PBDE homologue groups are utilised – deca-BDE, nona-BDE, octa-BDE,

hepta-BDE, hexa-BDE, penta-BDE, tetra-BDE and tri-BDE¹ brominated congeners. Molecular weights are assigned to each of these congener groups. For example, the nona-BDE group has a molecular weight of 880.4 g/mole, the octa-BDE group 801.5 g/mole, and so on down to the tri-BDEs, where the molecular weight is taken as the average for tri-, di- and mono-BDEs, i.e. 328.1 g/mole.

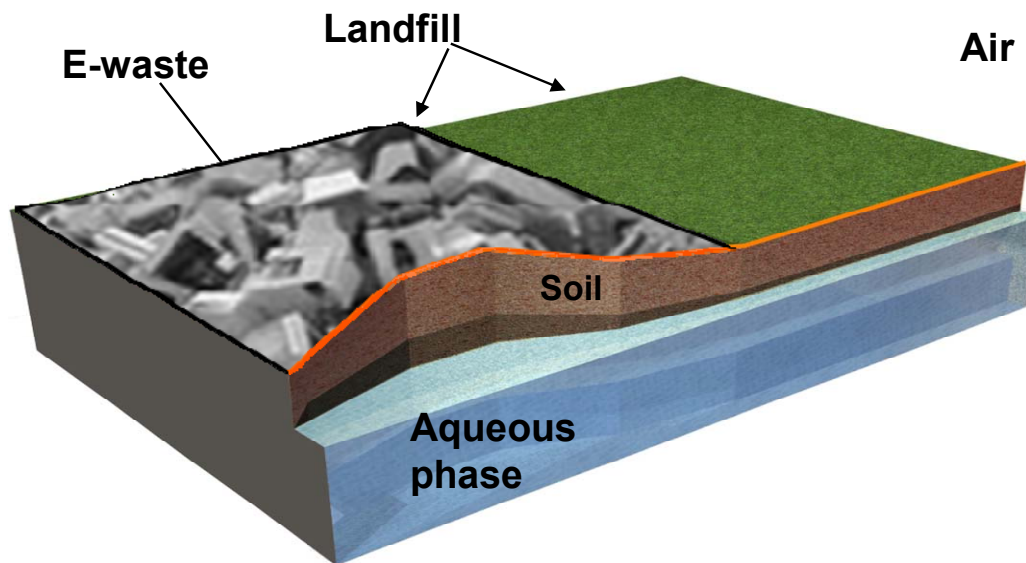


Figure 8.3. Schematic of a landfill system.

8.3 General Mass Balance for a Landfill Subsystem

Modeling is commonly used in chemical engineering to simulate complex mass transfer-reaction problems (Aris 1961, 1995, 1999; Bird *et al.* 2002; Mahecha-Botero *et al.* 2006; Mahecha-Botero *et al.* 2007). A number of assumptions are made in the current model due to a lack of available information. For example, as an initial approximation, each subsystem is treated as a lumped (well-mixed) subsystem, so that the concentration of each species is assumed to be uniform throughout the subsystem, and equal to the actual exit concentration from the subsystem. In addition, the system is assumed to be isothermal.

With these approximations, the mass balance for the i^{th} species in subsystem φ can be written:

¹ Tri-, di- and mono-BDE are lumped together under this label, as the values for di- and mono-BDE were either negligible or so low they were not considered important.

$$[External\ input - Output\ to\ the\ outside]_{\varphi} + [Net\ input\ by\ exchange\ with\ other\ Subsystems]_{\varphi} + [Generation\ due\ to\ chemical\ reaction]_{\varphi} = [Accumulation\ rate]_{\varphi}$$

There are two mechanisms for the exchange of species between subsystems, one based on a concentration driving force (diffusion) and the other based on a deposition flux (convective transport). In terms of concentration, the general mass balance can then be written:

$$\underbrace{\left[v_{f\varphi} C_{if\varphi} - v_{\varphi} \cdot C_{i\varphi} \right]}_{\text{Input} \quad \quad \quad \text{Output}} + \underbrace{\left[V_{\varphi} \cdot \sum_{j=1}^{N_R} \nu_{ij} \cdot r_{j\varphi} \right]}_{\text{Generation}} + \underbrace{\left[V_{\varphi} \cdot \sum_{n \neq \varphi}^{N_{\varphi}} a_{I(n \rightarrow \varphi)} \cdot k_{ci(n \rightarrow \varphi)} \cdot (C_{i_n} - C_{i\varphi}) \right]}_{\text{Mass transfer exchange input}}$$

$$\underbrace{\left[\sum_{n \neq \varphi}^{N_{\varphi}} A_{(n \rightarrow \varphi)} \cdot [DF_{i(n \rightarrow \varphi)} - E_{i(n \rightarrow \varphi)}] \right]}_{\text{Deposition minus entrainment flux input}} = \underbrace{\left[\frac{d}{dt} (V_{\varphi} \cdot C_{i\varphi}) \right]}_{\text{Accumulation}} \quad (8-1)$$

$$i = 1, 2, \dots, N_C; \quad \varphi = 1, 2, \dots, N_{\varphi}$$

where $v_{f\varphi}$ is the total volumetric flow of feed stream into subsystem φ , $C_{if\varphi}$ is the corresponding concentration of component i in that feed stream, v_{φ} is the volumetric flow rate out of subsystem φ , $C_{i\varphi}$ the instantaneous concentration of species i in subsystem φ , V_{φ} the total volume of subsystem φ , ν_{ij} the stoichiometric coefficient of species i in reaction j (positive when i is a product and negative when i is a reactant), $r_{j\varphi}$ the rate of reaction j per unit volume, $a_{I(n \rightarrow \varphi)}$ the interphase transfer area per unit volume between subsystems φ and n , k_{ci} the interphase mass transfer coefficient, and C_{i_n} the concentration of species i in an adjacent subsystem n in contact with subsystem φ , $A_{(n \rightarrow \varphi)}$ is the contact surface area between subsystems n and φ , $DF_{i(n \rightarrow \varphi)}$ is the deposition flux of species i from subsystem n to subsystem φ . $E_{i(n \rightarrow \varphi)}$ is the entrainment flux of species i from subsystem n to subsystem φ . N_C is the number of chemical species and N_{φ} the number of subsystems.

The dynamic (accumulation) term in the above mass balances is expanded to account for any change in volume for each subsystem as follows:

$$\left[\frac{d}{dt} (V_{\varphi} \cdot C_{i_{\varphi}}) \right] = V_{\varphi} \frac{d}{dt} (C_{i_{\varphi}}) + C_{i_{\varphi}} \frac{d}{dt} (V_{\varphi}) \quad (8-2)$$

$i = 1, 2, \dots, N_C; \varphi = 1, 2, \dots, N_{\varphi}$

8.4 Model Equations for a Landfill

Equation (8-1) can be applied simultaneously to all four subsystems in the landfill system. The subsystem and their subscripts are designated by:

$\varphi = 1$: E-waste

$\varphi = 2$: Air

$\varphi = 3$: Aqueous phase

$\varphi = 4$: NeWS

PBDEs contained in the input feed of electronic waste and NeWS are likely to be the principal sources of PDBE congeners entering the landfill system. The concentration of PBDEs in the e-waste is determined from e-waste samples as described in Chapter 6. The flow of PBDEs to the landfill originating from e-waste is estimated from the input concentration of PBDEs in the e-waste times the input volumetric flow of e-waste. Similarly, the flow of PBDEs to the landfill from non-e-waste solids, NeWS, is set equal to the input concentration of PBDEs in the NeWS times the input volumetric flow of the NeWS. It is assumed that only air (if it were to be included) and the aqueous phase have output convective flow (i.e. $v_{(\varphi)} = 0$, for $\varphi = 1$ and 4).

Hence, in chemical reaction engineering terminology, the overall system is a “semi-batch system”. The air subsystem is not considered in the modeling except for the inclusion of the deposition flux, needed in Chapter 9 to be consistent with some of the Northern Canada findings. Water input/output to the aqueous subsystem is calculated by a water balance accounting for precipitation, runoff, leaching and evaporation as reported by the organization overseeing the reference urban landfill site. Mass transfer occurs between each pair of subsystems, with mass transfer parameters estimated from analysis of experimental data (Section 8.9.5.2). In addition,

the model accounts for decomposition of brominated components to form lower congeners as described in Section 8.6 below. Because the reactions involve changes in the numbers of moles, the balances carried out are mole balances rather than mass balances. However, for ease of comparison with experimental data, all tables and figures use mass (rather than molar) concentrations (i.e. pg/g or pg/L).

Application of Equation (1) to each of the three subsystems considered and to all 8 brominated congener groups designated above, yields 24 simultaneous nonlinear ordinary differential equations (ODEs), in which the independent variable is time (expressed here in hours). The input parameters required to simulate the system are estimated and/or specified in the following sections. The initial conditions are:

$$\text{At } t=0; \quad C_{i_\varphi}^o = C_{i_\varphi}^o \quad \text{for } i=1,2,\dots,8 \quad (8-3)$$

where $C_{i_\varphi}^o$ is the concentration of homologue i in subsystem φ at time zero.

8.5 Assumptions Underlying the Mass Balance Model

Information for estimating chemical and physical properties in the model is very sparse and limited. As a result, it is extremely difficult to obtain accurate PBDE data and model parameters. Some parameters needed for the model are estimated based on the in-house mass-transfer experiments (Chapter 6). Others come from best estimates and literature review. Furthermore, comprehensive specific intrinsic chemical degradation kinetics and pathways for all PBDE congeners are currently not available in the published literature. The model is written to be flexible enough that new information and improved estimates of parameters can be incorporated as they become available in the future. To overcome the limitations in input data and understanding, the following assumptions are adopted:

1. Since distributed values are not available, each of the three environmental subsystems is assumed to be well mixed (i.e. lumped) as noted above.
2. All PBDE congeners are combined into homologue groups based on the bromination number, with 8 groups: deca-BDE, nona-BDEs, octa-BDEs, hepta-BDEs, hexa-BDEs, penta-BDEs, tetra-BDEs and tri-BDEs, as noted above.
3. A simplified degradation pathway is utilized as discussed in Section 8.6 below.

4. Degradation kinetics are obtained from an updated version (v3.12) of the EPI Suite (US EPA 2000, 2007a) estimation program. Table 8.2 compares the Wania and Dugani (2003) values with the most recent software version. The software estimates the rate at which a chemical group biodegrades under aerobic conditions with mixed cultures of micro-organisms (Howard *et al.* 1992; Boethling *et al.* 1994) and hydroxyl radical and ozone rate constants for atmospheric oxidation (Howard *et al.* 1992; Meylan and Howard 1993; Gouin *et al.* 2004). There are undoubtedly differences between degradation rates of aerobic and anaerobic organisms in landfills. However, for simplicity and in the absence of accurate data, first order kinetics are assumed, with first-order degradation rate constants estimated from the half-lives, $t_{0.5}$, of the EPI Suite program in air, soil and water, i.e. $k = -[\ln 0.5]/t_{0.5}$. The percent differences between the Wania and Dugani (2003) study and the EPI Suite calculations vary from -1% to +58.3%. Gouin *et al.* (2004) compared the methods for obtaining degradation half-lives to the earlier EPI Suite program based on half-life data found in handbooks (Mackay 1994; Mackay and Calcott 1998; Mackay 2000; Mackay *et al.* 2000). They found that the EPI Suite program underestimates the half-lives of some POPs. The default settings in the EPI Suite program allocate half-lives in water and soil of 3600 h, for all BDE congener groups. It is assumed that these values incorporate allowance for all factors, including photodegradation, which cause breakdown of the BDE congeners. In spite of its simplified and approximate nature, the EPI Suite remains a popular and useful software program to estimate half-lives in soil, water, and sediment.

Reaction rate constants estimated from half-life data in the literature (Wania and Dugani 2003) and from the EPI Suite v3.12 software (US EPA 2007a) are compared in Table 8.2. All EPI Suite v3.12 values appear to be computer-generated from an estimation program (US EPA 2007a) (with the exception of air values, which are not considered here.)

5. The net deposition flux (DF_i) term (i.e. deposition minus entrainment, E_i) is assumed to be negligible between all pairs of subsystems except where the air subsystem is one of them, i.e. $DF_{i(1 \rightarrow 4)} - E_{i(1 \rightarrow 4)} = DF_{i(3 \rightarrow 4)} - E_{i(3 \rightarrow 4)} = DF_{i(1 \rightarrow 3)} - E_{i(1 \rightarrow 3)} = 0$

For the air subsystem we adopt an overall Net Deposition Flux (NDF) value (i.e.

$$DF_{(1 \rightarrow 2)} - E_{(1 \rightarrow 2)} = DF_{(3 \rightarrow 2)} - E_{(3 \rightarrow 2)} = DF_{(4 \rightarrow 2)} - E_{(4 \rightarrow 2)} = 28.5 \cdots ng/m^2 y$$

based on the results reported by Stern *et al.* (2005). The values from Stern *et al.* (2005) are also used as a first approximation to estimate the Net Deposition Flux (NDF). Although this flux was originally estimated by Stern *et al.* (2005) as the Deposition Flux from air to soil, it is used in this model as a low-end estimate for the net deposition flux from the e-waste, aqueous and NeWS subsystems to the air subsystem (i.e. deposition from air to the other landfill compartments is negligible and the e-waste, aqueous and NeWS subsystems are a source of PBDEs to the air subsystem via entrainment). However, the distribution of BDE congeners was not provided by Stern *et al.* (2005). Therefore, the deposition flux is assumed to be distributed among the congeners in the same manner as provided in Table 6.1. An extensive literature search was performed to look for data on air, but there was no information available for the transfer of PBDEs to and from air to other subsystems. The relative concentrations of different PBDEs in congener groups are related to the soil ratio from the 2004 and 2006 data in Table 8.3. It is assumed that the distribution of congeners in the particles deposited from the air is the same as those found in our soil measurements, since the dust presumably originated from the ground surface.

6. It is assumed that the mass transfer coefficients between e-waste and NeWS subsystems and between the aqueous phase and both the e-waste and NeWS subsystems are the same as those experimentally derived in Chapter 6 for the e-waste to aqueous phase subsystem. This assumption is clearly a gross approximation and the coefficients are likely to be substantially lower. This approximation is investigated by means of a sensitivity analysis in Chapter 9. See also Section 8.9.5 for further discussion.
7. For the NeWS (Non e-Waste Solids) and e-waste subsystems, it is assumed that ~ 35,000 tonnes/month of soil, sand and bottom ash (Confidential 2005) are added continuously as cover to the landfill. Only soil and sand, but not bottom ash, are considered to be PBDE-free (see Chapter 7 for details.)
8. There is evidence in the literature (Stapleton 2006a; Stapleton and Dodder 2007) that UV radiation can contribute to degradation of PBDEs. In addition, there are strong seasonal temperature variations in Canada, and it is well known that kinetic rate constants tend to depend strongly on temperature. At Canadian latitudes, and especially in the north, these factors, as well as snow coverage, no doubt cause seasonal variations in degradation kinetics. Allowance for seasonal variations is beyond the scope of the current model, i.e. these factors are ignored.

9. It is assumed that there is no net accumulation in the aqueous subsystem. Also, as already noted, there is inflow into, but no outflow from, both the e-waste and the NeWS subsystems. Hence, with solid and liquid densities assumed to be constant,

$$\frac{d}{dt}(V_{(1)}) = v_{f(1)}, \quad \frac{d}{dt}(V_{(3)}) = 0 \quad \text{and} \quad \frac{d}{dt}(V_{(4)}) = v_{f(4)} \quad (8-4)$$

10. Isothermal behaviour is assumed since the system is dilute enough that heats of reaction are not expected to have a significant effect, and thermal dispersion is likely to be much faster than mass dispersion.

Table 8.2. Reaction rate constants grouped by total BDE congeners for e-waste, NeWS, and aqueous subsystems, based on both Wania & Dugani (2003) and EPA (2007) half-life data. The half lives used here are taken from the EPA (2007), and it is assumed that the half-life of e-waste equals the half-life of soil (NeWS subsystem).

E-Waste (1) and NeWS (4)						
Congener decomposing	Kinetic Constants	$t_{1/2}$ (h) (Wania & Dugani, 2003)	$k = -(\ln(0.5))/t_{1/2}$ (Wania & Dugani, 2003) (h^{-1})	$t_{1/2}$ (h) (EPA, 2007)	$k = -(\ln(0.5))/t_{1/2}$ (h^{-1}) (EPA, 2007)	% diff.*
tri-BDE	N/A	N/A	N/A	2880	2.41E-04	N/A
tetra-BDE	k_7	3600	1.93E-04	8640	8.02E-05	58.3
penta-BDE	k_6	3600	1.93E-04	8640	8.02E-05	58.3
hexa-BDE	k_5	3600	1.93E-04	8640	8.02E-05	58.3
hepta-BDE	k_4	3600	1.93E-04	8640	8.02E-05	58.3
octa-BDE	k_3	N/A	N/A	8640	8.02E-05	58.3
nona-BDE	k_2	N/A	N/A	8640	8.02E-05	58.3
deca-BDE	k_1	3600	1.93E-04	8640	8.02E-05	58.3

Air (2)					
Congener decomposing	Kinetic Constants	$t_{1/2}$ (h) (Wania & Dugani, 2003)	$k = -(\ln(0.5))/t_{1/2}$ (Wania & Dugani, 2003) (h^{-1})	$t_{1/2}$ (h) (EPA, 2007)	$k = -(\ln(0.5))/t_{1/2}$ (h^{-1}) (EPA, 2007)
tri-BDE	N/A	N/A	N/A	173	4.01E-03
tetra-BDE	k_7	256	2.71E-03	171	4.05E-03
penta-BDE	k_6	412	1.68E-03	467	1.48E-03
hexa-BDE	k_5	1110	6.24E-04	731	9.48E-04
hepta-BDE	k_4	1540	4.50E-04	852	8.14E-04
octa-BDE	k_3	1824	3.80E-04	2250	3.08E-04
nona-BDE	k_2	N/A	N/A	3860	1.80E-04
deca-BDE	k_1	7620	9.10E-05	7620	9.10E-05

* (2007 value - 2003 value)/(2007 value)

N/A - not available

Table 8.2 (concluded). Reaction rate constants grouped by total BDE congeners for e-waste, NeWS, and aqueous subsystems, based on both Wania & Dugani (2003) and EPA (2007) half-life data. The half lives used here are taken from the EPA (2007), and it is assumed that the half-life of e-waste equals the half-life of soil (NeWS subsystem).

Aqueous phase (3)						
Congener decomposing	Kinetic Constants	$t_{1/2}$ (h) (Wania & Dugani, 2003)	$k = -(\ln(0.5))/t_{1/2}$ (Wania & Dugani, 2003) (h^{-1})	$t_{1/2}$ (h) (used in this thesis) [§]	$k = -(\ln(0.5))/t_{1/2}$ (used in this thesis) (h^{-1})	% diff.*
tri-BDE	N/A	N/A	N/A	1440	4.81E-04	N/A
tetra-BDE	k_7	3600	1.93E-04	4320	1.60E-04	16.7
penta-BDE	k_6	3600	1.93E-04	4320	1.60E-04	16.7
hexa-BDE	k_5	3600	1.93E-04	4320	1.60E-04	16.7
hepta-BDE	k_4	3600	1.93E-04	4320	1.60E-04	16.7
octa-BDE	k_3	N/A	N/A	4320	1.60E-04	16.7
nona-BDE	k_2	N/A	N/A	4320	1.60E-04	16.7
deca-BDE	k_1	3600	1.93E-04	4320	1.60E-04	16.7

* $(2007 \text{ value} - 2003 \text{ value}) / (2007 \text{ value})$

N/A - not available

Table 8.3. PBDE concentrations in soil from 2004 and 2006 data collected in the Canadian North (pg/g) (Lab: DFO-IOs)

Canadian North SOIL samples - 2004 and 2006 (pg/g)																				
Sample ID	di-BDEs		tri-BDEs		tetra-BDEs		penta-BDEs		hexa-BDEs		hepta-BDEs		octa-BDEs		nona-BDEs		deca-BDEs		Total PBDEs	
Yellowknife, NWT	2004	2006	2004	2006	2004	2006	2004	2006	2004	2006	2004	2006	2004	2006	2004	2006	2004	2006	2004	2006
YELL01	1.03E+00	ND	5.91E+00	2.21E+01	9.61E+01	6.08E+02	1.22E+02	1.12E+03	2.11E+01	2.36E+02	3.75E+00	1.25E+02	3.11E+01	3.05E+02	2.53E+01	1.18E+03	4.35E+02	2.08E+04	7.41E+02	2.44E+04
Procedural blank	1.41E+00	ND	2.13E+00	6.04E+00	1.96E+01	8.10E+01	1.09E+01	3.77E+01	1.83E+00	3.74E+00	1.83E+00	0.00E+00	ND	3.05E+01	8.10E+00	3.30E+02	1.85E+02	4.51E+03	N/A	N/A
Value after blank correction	BMDL	ND	3.78E+00	9.99E+00	7.65E+01	4.46E+02	1.11E+02	1.05E+03	1.93E+01	2.29E+02	1.92E+00	1.25E+02	3.11E+01	2.44E+02	1.72E+01	5.21E+02	2.50E+02	1.18E+04	5.11E+02	1.44E+04
YELL02	2.10E+01	ND	1.87E+02	5.99E+00	5.41E+03	1.46E+02	8.11E+03	2.35E+02	3.09E+03	4.90E+01	7.08E+03	3.49E+01	2.89E+03	1.03E+02	1.61E+03	1.14E+02	2.85E+04	1.32E+03	5.69E+04	2.01E+03
Procedural blank	1.41E+00	ND	2.13E+00	ND	1.96E+01	3.56E+01	1.09E+01	1.48E+01	1.83E+00	ND	1.83E+00	ND	ND	3.64E+00	8.10E+00	9.44E+00	1.85E+02	1.78E+02	N/A	N/A
Value after blank correction	1.95E+01	ND	1.85E+02	5.99E+00	5.39E+03	1.11E+02	8.10E+03	2.20E+02	3.09E+03	4.90E+01	7.07E+03	3.49E+01	2.89E+03	9.93E+01	1.60E+03	1.05E+02	2.83E+04	1.14E+03	5.67E+04	1.77E+03
YELL03	N/A	6.46E+00	N/A	1.29E+01	N/A	1.79E+02	N/A	1.81E+02	N/A	2.04E+01	N/A	6.90E+00	N/A	8.08E+00	N/A	2.50E+01	N/A	4.49E+02	N/A	8.88E+02
Procedural blank	N/A	ND	N/A	ND	N/A	3.56E+01	N/A	1.48E+01	N/A	ND	N/A	ND	N/A	3.64E+00	N/A	9.44E+00	N/A	1.78E+02	N/A	N/A
Value after blank correction	N/A	6.46E+00	N/A	1.29E+01	N/A	1.43E+02	N/A	1.66E+02	N/A	2.04E+01	N/A	6.90E+00	N/A	4.44E+00	N/A	1.56E+01	N/A	2.71E+02	N/A	6.47E+02
YELL04	1.71E+00	ND	2.26E+00	2.80E+00	4.03E+01	1.05E+02	3.19E+01	7.69E+01	4.69E+00	7.95E+00	4.27E+00	7.99E+00	ND	1.14E+01	1.90E+01	2.42E+01	4.16E+02	6.66E+02	5.21E+02	9.03E+02
Procedural blank	3.10E+00	ND	5.31E+00	6.04E+00	4.50E+01	8.10E+01	2.32E+01	3.77E+01	5.73E+00	3.74E+00	4.39E+00	ND	ND	3.05E+01	ND	3.30E+02	5.92E+00	4.51E+03	N/A	N/A
Value after blank correction	BMDL	ND	BMDL	BMDL	BMDL	BMDL	8.78E+00	1.50E+00	BMDL	BMDL	BMDL	7.99E+00	ND	BMDL	1.90E+01	BMDL	4.10E+02	BMDL	4.38E+02	9.49E+00
Iqaluit, Nunavut																				
IQ2W40	4.62E+01	7.63E+02	1.34E+02	2.11E+03	1.49E+03	3.91E+04	2.23E+03	7.33E+04	4.12E+02	1.38E+04	7.58E+01	5.21E+03	3.58E+01	7.63E+03	5.31E+01	2.73E+04	6.56E+02	5.97E+05	5.13E+03	7.66E+05
Procedural blank	1.41E+00	ND	2.13E+00	ND	1.96E+01	3.56E+01	1.09E+01	1.48E+01	1.83E+00	ND	1.83E+00	ND	ND	3.64E+00	8.10E+00	9.44E+00	1.85E+02	1.78E+02	ND	N/A
Value after blank correction	4.48E+01	7.63E+02	1.32E+02	2.11E+03	1.47E+03	3.91E+04	2.22E+03	7.33E+04	4.10E+02	1.38E+04	7.40E+01	5.21E+03	3.58E+01	7.62E+03	5.30E+01	2.73E+04	6.56E+02	5.97E+05	4.90E+03	7.66E+05
IQ3W40	4.47E+00	5.63E+02	1.23E+01	1.97E+03	1.37E+02	3.23E+04	1.91E+02	4.75E+04	4.24E+01	7.88E+03	8.03E+00	1.10E+03	1.48E+01	1.06E+03	1.40E+01	2.30E+03	5.22E+02	5.40E+04	9.46E+02	1.49E+05
Procedural blank	1.41E+00	ND	2.13E+00	ND	1.96E+01	3.56E+01	1.09E+01	1.48E+01	1.83E+00	1.50E+01	1.83E+00	ND	ND	3.64E+00	8.10E+00	9.44E+00	1.85E+02	1.78E+02	N/A	N/A
Value after blank correction	3.06E+00	5.63E+02	1.01E+01	1.97E+03	1.17E+02	3.22E+04	1.80E+02	4.75E+04	4.06E+01	7.86E+03	6.20E+00	1.10E+03	1.48E+01	1.05E+03	5.89E+00	2.29E+03	3.37E+02	5.38E+04	7.15E+02	1.48E+05
IQ4W40	N/A	3.19E+00	N/A	ND	N/A	5.78E+01	N/A	3.03E+01	N/A	2.42E+00	N/A	2.27E+00	N/A	1.00E+01	N/A	BMDL	N/A	2.21E+03	N/A	2.31E+03
Procedural blank	N/A	BMDL	N/A	BMDL	N/A	3.56E+01	N/A	1.48E+01	N/A	BMDL	N/A	BMDL	N/A	3.64E+00	N/A	9.44E+00	N/A	1.78E+02	N/A	N/A
Value after blank correction	N/A	3.19E+00	N/A	ND	N/A	2.22E+01	N/A	1.55E+01	N/A	2.42E+00	N/A	2.27E+00	N/A	6.40E+00	N/A	BMDL	N/A	2.03E+03	N/A	2.08E+03
IQ6	ND	ND	6.35E+00	5.65E+00	ND	7.41E+01	5.51E+01	3.55E+01	1.47E+01	2.98E+00	8.49E+00	5.16E+00	ND	5.04E+00	4.65E+01	7.87E+01	8.21E+02	2.29E+03	9.52E+02	2.50E+03
Procedural blank	1.41E+00	ND	2.13E+00	6.04E+00	1.96E+01	8.10E+01	1.09E+01	3.77E+01	1.83E+00	3.74E+00	1.83E+00	ND	ND	3.05E+01	8.10E+00	3.30E+02	1.85E+02	4.51E+03	N/A	N/A
Value after blank correction	BMDL	ND	4.22E+00	BMDL	BMDL	BMDL	4.42E+01	BMDL	1.29E+01	BMDL	6.66E+00	5.16E+00	ND	BMDL	3.84E+01	BMDL	6.36E+02	BMDL	7.43E+02	5.16E+00
IQ7	N/A	ND	N/A	5.46E+00	N/A	2.19E+02	N/A	3.94E+02	N/A	7.15E+01	N/A	3.50E+01	N/A	4.14E+01	N/A	8.37E+01	N/A	9.60E+02	N/A	1.81E+03
Procedural blank	N/A	ND	N/A	ND	N/A	3.56E+01	N/A	1.48E+01	N/A	ND	N/A	ND	N/A	3.64E+00	N/A	9.44E+00	N/A	1.78E+02	N/A	N/A
Value after blank correction	N/A	BMDL	N/A	5.46E+00	N/A	1.83E+02	N/A	3.80E+02	N/A	7.15E+01	N/A	3.50E+01	N/A	3.78E+01	N/A	7.42E+01	N/A	7.82E+02	N/A	1.57E+03
IQ-2	1.44E+00	1.78E+00	2.70E+00	3.79E+00	3.89E+01	1.16E+02	2.39E+01	4.94E+01	2.41E+00	4.69E+00	N/A	3.60E+00	N/A	1.65E+00	1.47E+01	3.10E+01	3.47E+02	8.90E+02	4.31E+02	1.10E+03
Procedural blank	3.10E+00	ND	5.31E+00	ND	4.50E+01	3.56E+01	2.32E+01	1.48E+01	5.73E+00	0.00E+00	4.39E+00	ND	ND	3.64E+00	2.20E-01	9.44E+00	5.92E+00	1.78E+02	N/A	N/A
Value after blank correction	BMDL	1.78E+00	BMDL	3.79E+00	BMDL	8.00E+01	7.05E-01	3.46E+01	BMDL	4.69E+00	BMDL	3.60E+00	BMDL	BMDL	1.42E+01	2.16E+01	3.41E+02	7.12E+02	3.56E+02	8.62E+02
Cambridge Bay, Nunavut																				
CAMBY 2	1.35E+02	1.20E+03	3.18E+02	2.86E+03	1.93E+03	8.43E+03	2.47E+03	9.19E+03	5.26E+02	2.72E+03	1.78E+02	9.02E+02	2.69E+02	1.06E+03	1.79E+03	2.21E+03	2.06E+04	2.59E+04	2.82E+04	5.45E+04
Procedural blank	1.41E+00	ND	2.13E+00	ND	1.96E+01	3.56E+01	1.09E+01	1.48E+01	1.83E+00	0.00E+00	1.83E+00	ND	ND	3.64E+00	8.10E+00	9.44E+00	1.85E+02	1.78E+02	N/A	N/A
Value after blank correction	1.32E+02	1.20E+03	3.13E+02	2.86E+03	1.89E+03	8.39E+03	2.45E+03	9.17E+03	5.22E+02	2.72E+03	1.74E+02	9.02E+02	2.69E+02	1.06E+03	1.77E+03	2.20E+03	2.02E+04	2.57E+04	2.77E+04	5.42E+04
CAMBY 3	2.18E+02	7.64E+02	4.70E+02	2.26E+03	1.86E+03	3.08E+04	3.75E+03	5.60E+04	1.09E+03	9.79E+03	2.61E+02	1.59E+03	6.69E+02	1.61E+03	4.29E+02	1.87E+03	5.52E+03	2.91E+04	1.43E+04	1.34E+05
Procedural blank	1.41E+00	ND	2.13E+00	6.04E+00	1.96E+01	8.10E+01	1.09E+01	3.77E+01	1.83E+00	3.74E+00	1.83E+00	0.00E+00	ND	3.05E+01	8.10E+00	3.30E+02	1.85E+02	4.51E+03	N/A	N/A
Value after blank correction	2.16E+02	7.64E+02	4.66E+02	2.25E+03	1.82E+03	3.06E+04	3.73E+03	5.59E+04	1.08E+03	9.78E+03	2.57E+02	1.59E+03	6.69E+02	1.55E+03	4.13E+02	1.21E+03	5.15E+03	2.00E+04	1.38E+04	1.24E+05
CAMBY 5	1.20E+02	1.75E+01	1.48E+02	6.40E+02	4.35E+02	3.05E+03	5.43E+02	3.35E+03	1.35E+02	7.90E+02	6.91E+01	3.21E+02	2.01E+02	1.13E+03	3.29E+02	1.23E+03	2.05E+03	1.43E+04	4.03E+03	2.48E+04
Procedural blank	3.10E+00	ND	5.31E+00	6.04E+00	4.50E+01	8.10E+01	2.32E+01	3.77E+01	5.73E+00	3.74E+00	4.39E+00	0.00E+00	ND	3.05E+01	2.20E-01	3.30E+02	5.92E+00	4.51E+03	N/A	N/A
Value after blank correction	1.14E+02	1.75E+01	1.38E+02	6.28E+02	3.45E+02	2.89E+03	4.97E+02	3.28E+03	1.24E+02	7.82E+02	6.03E+01	3.21E+02	2.01E+02	1.07E+03	3.29E+02	5.75E+02	2.04E+03	5.29E+03	3.85E+03	1.48E+04
CAMBY 6	7.99E+01	6.41E+03	3.28E+02	4.75E+03	2.25E+03	1.37E+04	3.57E+03	2.83E+04	1.39E+03	7.15E+04	7.95E+02	2.09E+05	1.47E+03	1.32E+05	7.83E+02	3.50E+04	1.88E+04	1.43E+04	2.94E+04	5.15E+05
Procedural blank	1.41E+00	ND	2.13E+00	ND	1.96E+01	3.56E+01	1.09E+01	1.48E+01	1.83E+00	0.00E+00	1.83E+00	0.00E+00	ND	3.64E+00	8.10E+00	9.44E+00	1.85E+02	1.78E+02	N/A	N/A
Value after blank correction	7.85E+01	6.41E+03	3.25E+02	4.75E+03	2.23E+03	1.36E+04	3.56E+03	2.83E+04	1.39E+03	7.15E+04	7.93E+02	2.09E+05	1.47E+03	1.32E+05	7.75E+02	3.50E+04	1.86E+04	1.41E+04	2.92E+04	5.15E+05
CAMBY 7	2.43E+00	ND	5.05E+00	1.65E+01	4.99E+01	4.70E+02	3.58E+01	6.83E+02	7.31E+00	1.65E+02	5.25E+00	9.30E+01	2.81E+01	4.32E+02	4.33E+01	1.65E+03	1.02E+03	5.83E+04	1.20E+03	6.18E+04
Procedural blank	3.10E+00	ND	5.31E+00	6.04E+00	4.50E+01	8.10E+01	2.32E+01	3.77E+01	5.73E+00	3.74E+00	4.39E+00	0.00E+00	ND	3.05E+01	2.20E-01	3.30E+02	5.92E+00	4.51E+03	N/A	N/A
Value after blank correction	BMDL	BMDL	BMDL	4.43E+00	BMDL	3.08E+02	BMDL	6.08E+02	BMDL	1.58E+02	BMDL	9.30E+01	2.81E+01	3.71E+02	42.81	9.90E+02	1009.45	4.93E+04	1.08E+03	5.18E+04
CAMBY 8	1.30E+00	ND	2.83E+00																	

8.6 Degradation Pathways and Kinetics of the Debromination Process

A sequential degradation path is proposed to account for the generation and consumption of PBDEs of different molecular weights. PBDE congeners lose their attached bromines due to photochemical degradation (a form of reductive debromination) (Watanabe and Kashimoto 1983; Watanabe and Tatsukawa 1987; Hua *et al.* 2003; Birnbaum and Staskal 2004; Eriksson *et al.* 2004; Palm *et al.* 2004; Söderström *et al.* 2004; Stapleton *et al.* 2004a; Stapleton *et al.* 2004b; Gerecke *et al.* 2005; Sharp and Lunder 2005; Stapleton *et al.* 2005; Ahn *et al.* 2006; Environment Canada 2006; Stapleton and Dodder 2008). Breakdown due to bacteria in anaerobic environments (Gerecke *et al.* 2005; He *et al.* 2006) also occurs via reductive debromination. In the proposed reaction sequence, deca-BDE (the most common commercial brominated compound still used in electronic equipment) releases a bromine atom to produce nona-BDEs. While there are three different nona congeners, these are lumped together for the purpose of modelling, given the lack of detailed kinetic data for individual congeners and reactions. The debromination of the *-meta* and *-para* positions in the deca-BDE are assumed to quickly degrade to BDE-208 and BDE-207, respectively (Nose *et al.* 2007). The *-ortho* position in the deca-BDE molecule forms BDE-206, albeit at a rate seven times slower than for the other two positions, *-meta* and *-para*, demonstrating that the latter two reactivities are higher than for the *-ortho* bromine (Nose *et al.* 2007). Nona-BDEs degrade to octa-BDEs, hepta-BDEs to hexa-BDEs, hexa-BDEs to penta-BDEs, penta-BDEs to tetra-BDEs, stepwise (Rayne *et al.* 2006). This debromination sequence repeats itself down to the tri-BDE congeners, which ultimately undergo photohydrodebromination to transform into HBr and diphenylether (DE), where the rate-limiting step is the reduction of BDE-15 to BDE-3 (Rayne *et al.* 2003b; Palm *et al.* 2004; Rayne *et al.* 2006). BDE-15 undergoes reductive sequential debromination by replacing a bromine atom by a hydrogen atom, leading to unknown by-products (Rayne *et al.* 2003b).

Rayne *et al.* (2003b) assumed that debromination occurs stepwise, with one bromine atom lost in each step. They also assumed that half-lives via anaerobic microbial and photochemical degradation were in the order of 30 min to 6 hours. A fixed-film plug flow bioreactor was used to conduct those experiments. Hexa-BDE congeners were difficult to detect after 100 min. Eriksson *et al.* (2004) determined the rate of decomposition of PBDEs in methanol/water solutions. Each of the 3 nona-BDEs produced various octa-BDEs. Hepta-BDEs, hexa-BDEs

and penta-BDEs down to the mono-BDEs also formed, as indicated in Table 8.4. It was found that the rate of PBDE photodegradation by UV light depends on the degree of bromination. Tri-BDEs (e.g. BDE-77) degrade up to 700 times more slowly than highly brominated congeners (BDE-209). However, Palm *et al.* (2004) studied half-lives due to photolysis of BDEs in tetrahydrofuran in the presence of sunlight and found that the half-life for deca-BDE is ~ 10 minutes, increasing to beyond 1 year for bromo-BDE-4. They also found that the half-lives of other BDEs increased with decreasing sunlight intensities during the winter season.

Table 8.4. Proposed deca-BDE degradation pathway

Reaction path	Corresponding BDE congener	Reference
r ₈	tri-BDE	(Rayne <i>et al.</i> , 2006)
r ₇	tetra-BDE	
r ₆	penta-BDE	
r ₅	hexa-BDE	(Eriksson <i>et al.</i> , 2004; Rayne <i>et al.</i> , 2006)
r ₄	hepta-BDE	(Eriksson <i>et al.</i> , 2004; Nose <i>et al.</i> , 2007)
r ₃	octa-BDE	
r ₂	nona-BDE	
r ₁	deca-BDE	

8.6.1 Apparent Kinetics of the Debromination Process

The BDE degradation pathway assumed in the model is greatly simplified from the literature (Rayne *et al.* 2003b; Palm *et al.* 2004; Söderström *et al.* 2004; Gerecke *et al.* 2005; Sanchez-Prado *et al.* 2005; Gandhi *et al.* 2006; He *et al.* 2006; Rayne *et al.* 2006; Nose *et al.* 2007).

Details of previous studies on degradation pathways are described in Table 8.5 below. Although there are 209 possible congeners, only ~60 congeners are identifiable by GC/MS, and only those are included in the analysis here. All reactions are assumed to be first order, with rate constants, k_i , where subscript i designates the specific reaction.

Table 8.5. PBDE degradation pathways from the literature.

Reference	Description
(Söderström <i>et al.</i> , 2004)	Photolytic debromination of deca-BDE studied in silica gel, sand, sediment and soil using artificial and natural sunlight.
(Gerecke <i>et al.</i> , 2005)	Anaerobic degradation of deca-BDE in <i>-para</i> and <i>-meta</i> positions from sewage sludge used as a medium.
(Sanchez-Prado <i>et al.</i> , 2005)	Photodegradation of PBDEs with photo solid-phase microextraction (photo-SPME). Seven penta-BDEs, ten tetra-BDEs, five tri-BDEs, four di-BDEs and two mono-BDEs were identified with this method.
(Gandhi <i>et al.</i> , 2006)	Studied the biotransformation pathways of four BDE congeners (BDE-47, -99, -100 and -153).
(He <i>et al.</i> , 2006)	Microbial potential to degrade PBDEs. Potential pathways for BDEs -207, -203, -196, -183, -153 and -208.
(Rayne <i>et al.</i> , 2006)	Studied photochemistry of BDE-153 in various media (distilled water and seawater) and found three main debromination products (BDE -99, -101 and -118) degrade to BDE -47, -49, -66- and -77.

Little information has been reported on the stoichiometry or kinetics of the various reactions (Rayne and Ikononou 2002; Rayne *et al.* 2006). Barontini *et al.* (2005) assumed that the debromination reactions yield HBr as a by-product, and perhaps free bromide ions when debromination occurs in solution. A simplification of their study is as follows:

(r_1)	$decaBDEs \xrightarrow{r_1} nonaBDEs + HBr$
(r_2)	$nonaBDEs \xrightarrow{r_2} nonaBDEs + HBr$
(r_3)	$octaBDEs \xrightarrow{r_3} heptaBDEs + HBr$
(r_4)	$heptaBDEs \xrightarrow{r_4} hexaBDEs + HBr$
(r_5)	$hexaBDEs \xrightarrow{r_5} pentaBDEs + HBr$
(r_6)	$pentaBDEs \xrightarrow{r_6} tetraBDEs + HBr$
(r_7)	$tetraBDEs \xrightarrow{r_7} triBDEs + HBr$
(r_8)	$triBDEs \xrightarrow{r_8} lowerBDEs + DiphenylEther + HBr$

Note: lowerBDEs were not detected in significant amounts during our experimental measurements. Therefore, mole balances are not included for lowerBDEs (i.e. the smallest molecule modelled was the triBDE congener)

Because of the incomplete kinetic data, this scheme is adopted here, and the debromination process is represented in an even simpler form in Figure 8.4. This is a crude first approximation for what is, to the best of our knowledge, the first attempt to model PBDEs in a landfill system. As more kinetic data and improved understanding of the mechanisms and kinetics become available, they can be incorporated into the model. To account for the uncertainty of the kinetic values, a sensitivity analysis on the debromination kinetic rate constants is performed in Chapter 9 with the kinetic constants adjusted by two orders of magnitude (i.e. to one order above and one below the base case values).

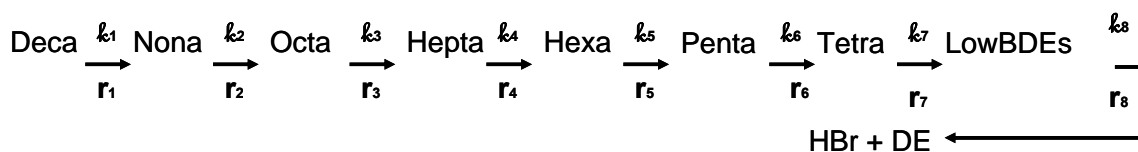


Figure 8.4 Simplified degradation scheme for use in the Mass Balance Model. The k_i are first order rate constants, whereas the r_j are rates of reaction. DE is diphenyl ether. The subscripts refer to reaction numbers.

As noted above, the kinetic rate constants are estimated as a first approximation using the EPI Suite software (US EPA 2007a). For more details see Section 8.5, Assumption #4.

This approach again constitutes a gross simplification in the way that the chemical kinetics are treated. For example, all congeners with an equal number of bromines are treated as a single species. Moreover, the mono-, di-, and tri- congeners are all lumped together with a single average rate constant. Nevertheless, treatments like this are not uncommon as a first approximation in modeling complex physical, chemical and biological systems (e.g. in lumping hydrocarbons to model components in petro-chemical reactions.) Ultraviolet radiation, while undoubtedly important and possibly critical to the degradation process, as discussed above, is not explicitly accounted for here. Moreover, the kinetic expressions (but not the kinetic parameters in the case of the aqueous subsystem) are assumed to be the same for the aqueous, e-waste and NeWS subsystems. The default half-lives in the EPI Suite program indicate a slow degradation of PBDEs, whereas those found in the literature (from 0.5 to 6 h) follow faster degradation paths (Rayne *et al.* 2003b) via photodegradation, which is considered in this model.

No tri/di/mono-BDE data were reported in the Wania & Dugani (2003) study for any of the subsystems. Hence, the tri--BDE (tri/di/mono) rate constants were assumed equal to the tetra value in the model, even though we lumped them together. On the other hand, the EPI Suite

software includes individual half-life estimates for the lower brominated congeners. The half-lives assumed for the aqueous phase for this thesis are half the value reported for the e-waste and NeWS subsystems since the software assigns the half-life in soil to be twice that estimated for the aqueous phase. For the purposes of the model, half-life values for e-waste are assumed to be the same as the corresponding half-lives in NeWS, both being obtained from the default soil values in the EPI Suite program.

In reality, we expect reaction rates to be functions of temperature. However, no activation energies are available and no data which would allow the temperature dependency to be estimated. Hence, the temperature dependence is ignored at this stage.

8.7 Input Parameters

Input parameters to the mass balance model for each subsystem include initial and input concentrations, subsystem volume, input and output volumetric flow, mass transfer coefficients, kinetic rate constants and surface area per unit volume. Details are provided below.

The PBDE mass transfer coefficients assumed for each species are described in Section 8.9.5. The total landfill physical values (such as surface area) are based on the same actual landfill (whose identity is confidential as required by the landfill operators) located near a large urban centre in Canada, as was the referenced landfill in Chapter 6.

8.7.1 Scenarios

To simulate and study the chosen landfill using different assumptions, three scenarios containing fourteen cases are considered (Table 8.6). The scenarios are classified according to the time interval that each simulates. Scenario 1 begins in 1980 and extends to the end of 2007, with 5-year averages considered for the feed of discarded e-waste. The second Scenario (2) again commences in 1980, but extends into the future with ongoing addition of PBDE-containing accumulated e-waste beyond 2008, to virtually total debromination. This case considers the hypothetical case where no new e-waste containing PBDEs will be produced after 2009. In this Scenario, addition of PBDEs from the NeWS input would continue unabated, with the composition of this input stream having changed radically in 2005 after the Penta-BDE formulation was taken out of production. Although PBDEs are banned from e-waste in this scenario, existing equipment would still contain these compounds and would continue to be

problematic over time. Additionally, six more sensitivity analyses are included to investigate the possible effects of uncertainties in the kinetic rate constants, mass transfer between two subsystems (e-waste and NeWS) and between three subsystems (e-waste, NeWS and aqueous phase). Scenario 3 commences in 2008 and extends into the future without any further addition of PBDEs from any source to show the effect of current stockpiled PBDEs even if there were to be no future additions.

Table 8.6. Simulation characteristics for the sensitivity analysis.

Simulation Cases		Characteristics
Scenario 1 1980-2007	A	Constant input flow and input PBDE concentrations over the entire 27-year period (based on 27-year averages)
	B	Input flows and concentrations held constant during 5-year intervals (Section 8.10.1). The probability distribution for disposal of electronics, $P(\tau)$ was not introduced in this case.
	C	As in Scenario B except that the probability distribution for disposal of electronics, $P(\tau)$ (Section 8.10.4) is included to account for the age distribution of discarded units.
Scenario 2 1980-2150	A (1980-2100)	The (1980-2007) time period is simulated using the same assumptions as for case 1-C. In 2009 all PBDE manufacture is banned at the source, and the simulation is continued until 2100. The probability distribution for disposal of NeWS, $P_{NeWS}(\tau)$ was not introduced in this case because a constant input concentration was assumed for NeWS.
	B (2008-2090)	The probability distribution for disposal of NeWS, $P_{NeWS}(\tau)$ and $P(\tau)$ was introduced in this case Other assumptions are the same as those used in case 2-C.
	C (1980 ~2036)	The kinetic rate constant, k_p , is one order of magnitude greater than the base case (2-B.)
	D (1980-2150+)	The kinetic rate constant, k_p , is one order of magnitude less than the base case (2-B.)
	E (1980-2090)	Mass transfer term between the e-waste and NeWS subsystems: $a_{I(1 \rightarrow 4)} \cdot k_{ci(1 \rightarrow 4)}$ and is one order of magnitude greater than for 2-B.
	F (1980-2090)	Mass transfer term between the e-waste and NeWS subsystems: $a_{I(1 \rightarrow 4)} \cdot k_{ci(1 \rightarrow 4)}$ and is one order of magnitude less than for 2-B.
	G (1980-2090)	Mass transfer terms between all subsystems one order of magnitude greater than for 2-B: $a_{I(1 \rightarrow 4)} \cdot k_{ci(1 \rightarrow 4)} \quad a_{I(1 \rightarrow 3)} \cdot k_{ci(1 \rightarrow 3)} \quad a_{I(3 \rightarrow 4)} \cdot k_{ci(3 \rightarrow 4)}$
	H (1980-2090)	Mass transfer terms between all subsystems one order of magnitude less than for 2-B: $a_{I(1 \rightarrow 4)} \cdot k_{ci(1 \rightarrow 4)} \quad a_{I(1 \rightarrow 3)} \cdot k_{ci(1 \rightarrow 3)} \quad a_{I(3 \rightarrow 4)} \cdot k_{ci(3 \rightarrow 4)}$
		Common to all three cases: Hypothetical case of a global and immediate PBDE ban and removal from all waste stream to the total landfill system
Scenario 3 2008-2070	A (2008-2065)	Initial values are exit values from Scenario 1-A.
	B (2008-2065)	Initial values are exit values from Scenario 1-B.
	C (2008-2070)	Initial values are exit values from Scenario 1-C.

8.8 Time-Dependent Input to Landfill System

8.8.1 Time Dependence of Input E-waste Flow

The input volumetric flow rate of goods to the e-waste subsystem of the total landfill system has increased almost monotonically with time since 1980 as shown in Figure 8.5.

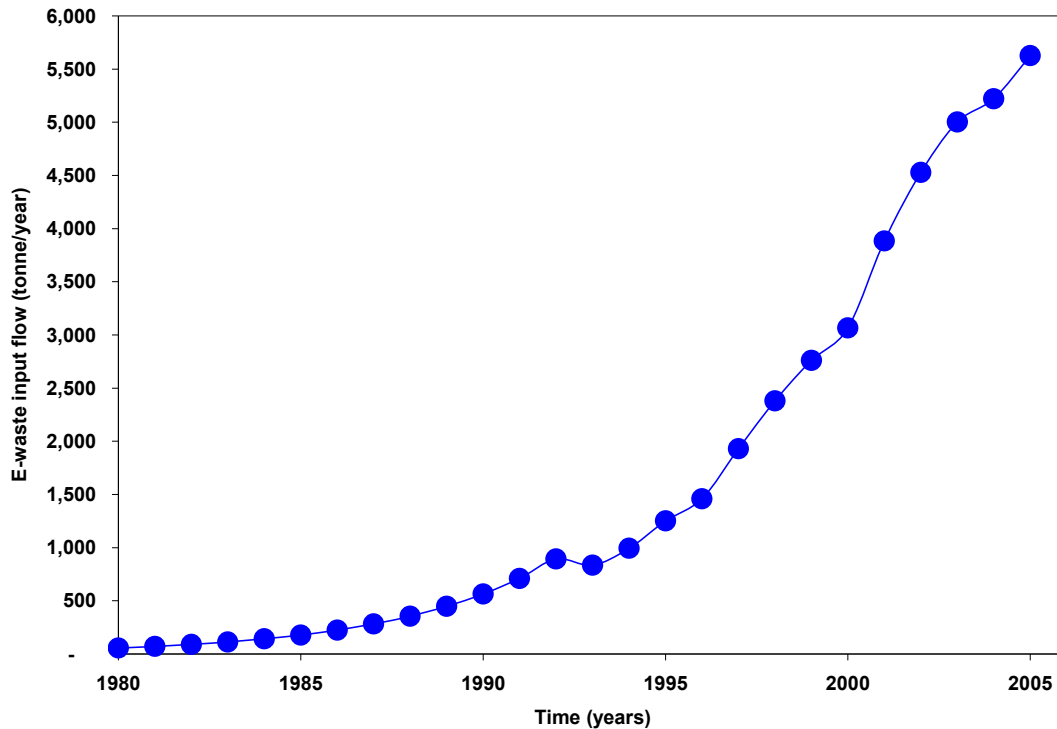


Figure 8.5. Input volumetric flowrate of e-waste to landfill system vs. time according to data provided by landfill operator.

These input data were fitted using a cubic spline interpolation subroutine to generate a continuous function over time. Similar interpolations were performed for all time-dependent functions in the model code, such as system volume, input flow and concentrations.

8.8.2 Time Distribution of Total Input to Landfill

The input total flow rate of rubbish to the landfill system varied with time as shown in Figure 8.6. The decrease in refuse disposal to the landfill in 1987 was likely due to opening another landfill, as well as an incinerator, and the introduction of a recycling program. For purposes of the simulations in Scenarios 2 and 3, the input flow is assumed to be constant after 2006. The NeWS input flow is plotted against time in Figure 8.7. These curves were again fitted to landfill

data provided by the operator using a cubic spline interpolation subroutine to generate continuous functions.

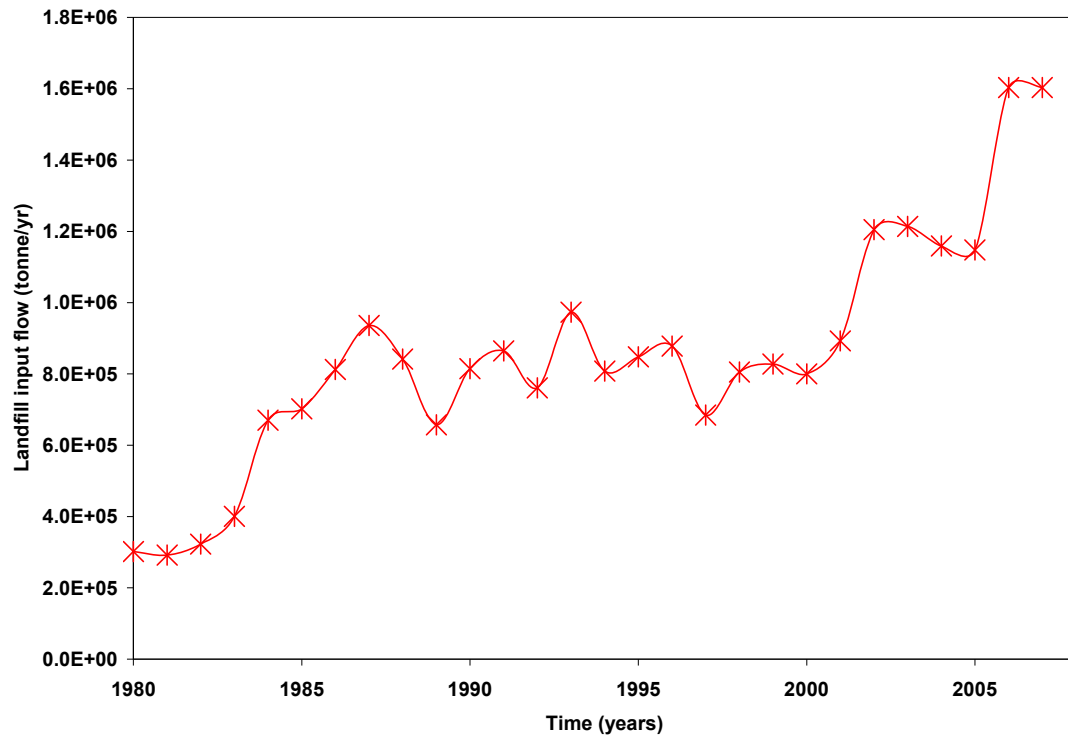


Figure 8.6. Input flowrate of goods to the total landfill system vs. time. Data provided by the landfill operator.

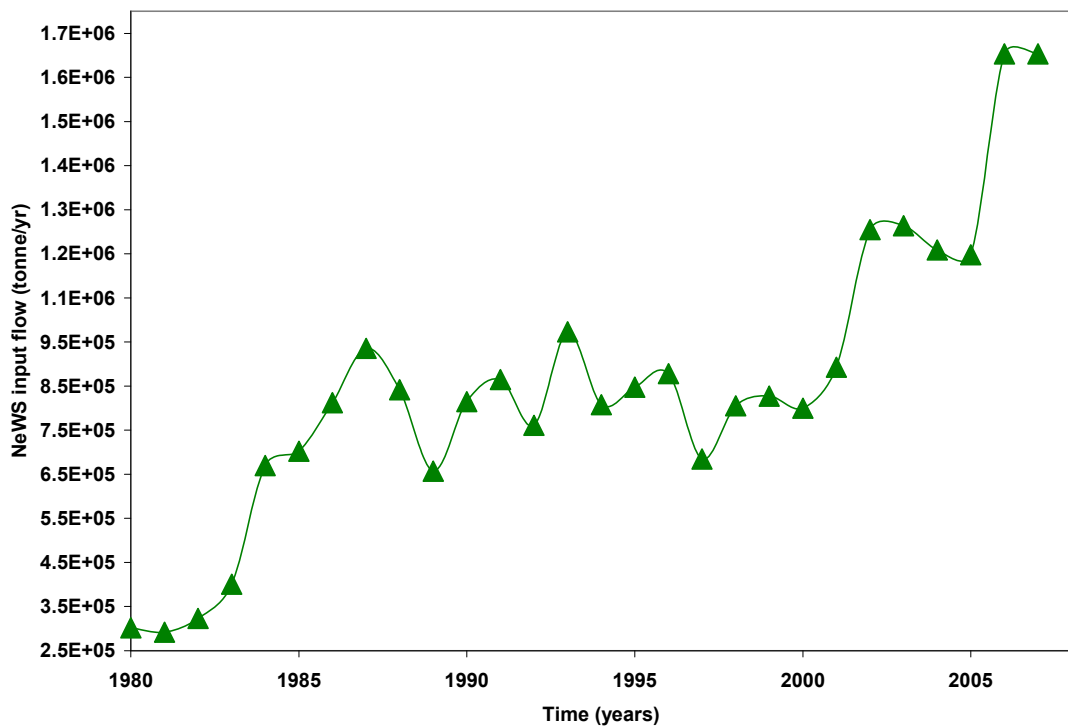


Figure 8.7. Input flowrate of NeWs to the total landfill system vs. time. Data provided by the landfill operator.

8.8.3 Time Distribution of Measured E-waste Concentration

The PBDE concentration in e-waste is based on the solid e-waste experimental measurements for different 5-year time periods presented in Chapter 6. The fitted function is shown in Figure 8.8.

This provides input to the landfill model.

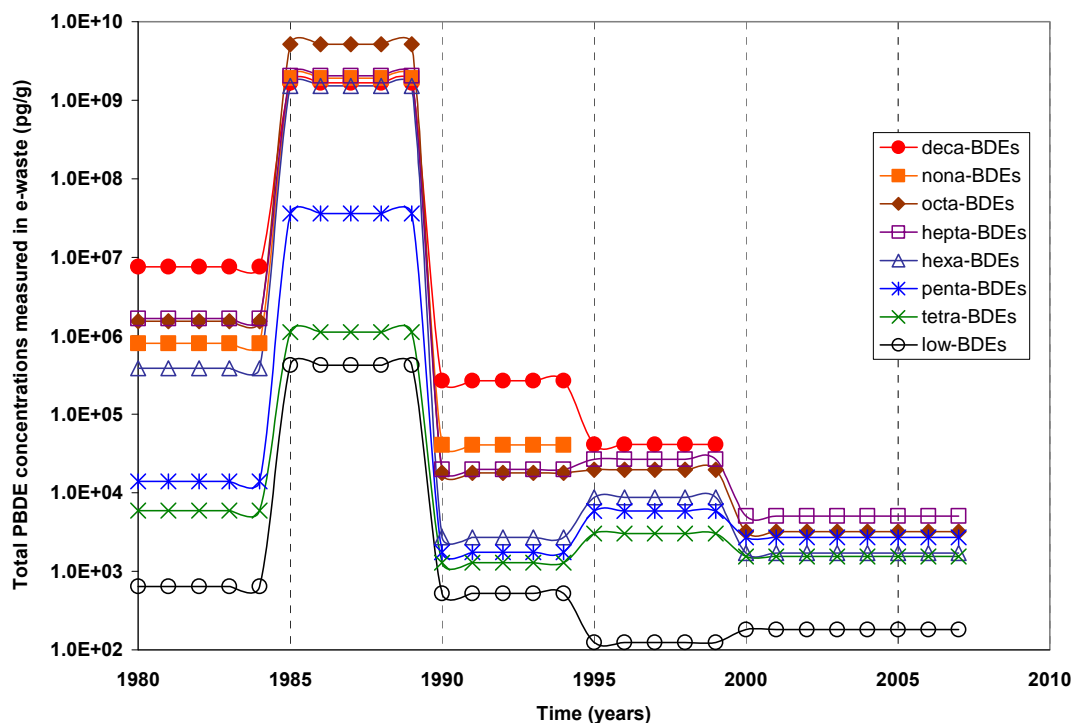


Figure 8.8. Fitted PBDE concentrations in e-waste manufactured in different time periods vs. time, based on the measurements presented in Table 6.1, and as per Case 1-B. (Note that some congeners for the 1995-2005 time period were non-detect and hence are excluded for that period in the totals shown on the ordinate axis. The curves show interpolated values via a cubic spline subroutine.

The analyses carried out by Vista Analytical Lab indicate an extraordinary spike in PBDE concentrations in the 1985-1990 time interval, with these concentrations being several orders of magnitude higher than for all other 5-year time intervals². This is likely due to a much larger amount of PBDEs being incorporated in electronic equipment manufactured during those years. The total concentration then (based on the analysis of our crushed e-waste) resembles the ~30% by weight (mass) of computer weight in electronic equipment during that era (~1985-1989 and into the 1990s) referred to in some sources (WHO-EHC 162 1994; World Health Organization and Environmental Health Criteria 162 1994; BSEF 2000, 2001; Alaei *et al.* 2003; BSEF 2003; ATSDR 2004a; Mack 2004; Prevedouros *et al.* 2004). Consumption of PBDEs increased significantly in the late 1980s due to their widespread adoption for reducing fire hazards (WHO-

² Another laboratory confirmed these high values as discussed in Chapter 6.

EHC 162 1994; World Health Organization and Environmental Health Criteria 162 1994). The World Health Organization also reported that demand in Japan increased from 2,500 metric tonnes in 1975 to 22,100 metric tonnes in 1987. By 2001, ~70,000 metric tonnes of PBDEs were manufactured worldwide (BSEF 2003). According to Grossman (2006) and Birnbaum & Staskal (2004), “consumption has escalated on a timeline that coincides with the proliferation of high-tech electronics”³. Another issue that points to a huge increase in PBDEs during the late 1980s and 1990s is the well-documented levels in breast milk, where concentrations increased continuously between 1972 and 1997 (Meironytė *et al.* 1999; Norén and Meironytė 2000; Betts 2001; Kucher and Purvis 2004). There were also exponential increases in arctic ringed seals from 1981-2000, similar to worldwide PBDE commercial production (Ikonomou *et al.* 2002a).

It is surprising to see such high concentrations of PBDEs in electronic equipment, but, as noted above, the volume of electronics manufactured increased in an extraordinary manner in the 1980s, as did (see Chapter 6) the proportion of brominated flame retardants added to plastic parts. See Appendix H.1, for details on BFRs in plastics.

8.8.4 Time Distribution of PBDE Concentrations in Manufactured NeWS Products

The Penta-BDE commercial formulation was the only PBDE product used in the NeWS category from 1980-2004 (ATSDR 2004a). Its predominant use was in mattresses and polyurethane foam (for upholstered products) (ENVIRON 2003a). Approximately 95% of the commercial formulation was incorporated in polyurethane foam used as cushioning in upholstery (ATSDR 2004b). Its production was voluntarily discontinued in 2004 in the United States (where all of the North American manufacturers are located). The concentrations for the 1980-2004 and for 2004 to 2007 appear in Table 8.7. The literature provides conflicting data on the percentages and types of furniture where Penta-BDE was applied (ATSDR 2004a; Washington State Department of Ecology 2005; UNEP 2006; United Nations Economic and Social Council 2006; United Nations Economic and Social Council. 2006). For example, the US Agency for Toxic Substances and Disease Registry (2004) states that upholstered furniture may contain 18-27% Deca-BDE by weight, whereas the United Nations Economic and Social Council (2006) said that polyurethane foam can contain an average of between 10-18% Penta-BDE by weight. In an

³Great efforts were made to examine whether PBDE usage increased or decreased over this time. Limited information is available. However, worldwide tonnage volumes for BFRs from 1989 were estimated to be 103,200 tonnes (Mack, 2004).

internal document prepared by the State of Washington Department of Ecology (2006), ~140 g of Deca-BDE were found in a single mattress⁴. The input utilized in the model were based on the State of Washington Department of Ecology values because this was the only reference found in the literature where the amount of BFRs per mattress was specified as a single average value, whereas the other references gave wide ranges. Therefore, for purposes of the present simulations, mattresses and sofas are taken as the only sources of PBDEs in the NeWS stream. The overall input of Penta-BDE is obtained from the sum of those in mattresses and sofas, with the distribution and percentage of Penta-BDE based on its commercial formulation. However, Deca-BDE was not included for the 2005-2007 time interval in the NeWS stream. Instead, it was assumed that the NeWS contained the Penta-BDE commercial formulation when products were disposed to the landfill, given that a negligible fraction of mattresses and sofas manufactured in 2005 or later were discarded by 2008.

Table 8.7 PBDE concentrations in manufactured compounds found in the NeWS subsystem vs. time. The concentrations shown for penta-, tetra- and tri-BDEs correspond to the Penta-BDE commercial formulation used during the 1980-2004 time period⁵. The nona- and deca-BDE concentrations indicate switching to the Deca-BDE commercial formulation after incorporation of Penta-BDE was terminated in 2004.

BDE congeners	1980-2004	2004-2007
	pg/g	
total tri-BDEs	3.92E+05	0.00E+00
total tetra-BDEs	2.43E+07	0.00E+00
total penta-BDEs	4.39E+07	0.00E+00
total hexa-BDEs	6.27E+06	0.00E+00
total hepta-BDEs	0.00E+00	0.00E+00
total octa-BDEs	0.00E+00	0.00E+00
total nona-BDEs	0.00E+00	2.83E+09
total deca-BDE	0.00E+00	1.10E+11

8.8.5 Probability Distribution for Age of Electronics and NeWS at Disposal

It is important to estimate the pre-disposal life of electronic equipment in determining the input to the landfill in the model. The age distribution in the model is introduced via a function $P(\tau)$,

⁴ For purposes of the calculations, an average sofa weight of 40 kg was taken and an average of mattress weights (60.61 kg) was estimated from the literature: FRN. (2005). Furniture Re-use Network. Retrieved 31 July 2007, from www.cm.org.uk/projects/tonnage/frnweights2005.pdf. The 60.61 kg mass used was derived from a weighted average of the following mattress sizes and weights: twin (38 kg) + twin XL (40.45 kg) + full (55 kg) + queen (65.45 kg) + king (84 kg).

⁵ The Penta commercial composition is found in the ENVIRON 2003a and 2003b references. The concentration of PBDEs used was taken from a Washington State of Ecology (2006) internal document. The author estimated the loading of NeWS to the landfill subsystem with this information. There is no available information regarding the concentrations in Canada. However, for purposes of simplicity, we have assumed the concentrations reported in the Washington State of Ecology report are the same as in Canada.

defined as the probability of an electronic device being disposed in a landfill system in the τ^{th} year of its existence (EnvirosRIS 2000, 2001), and by $P_{NeWS}(\tau)$, the probability distribution for disposal of non e-waste solids (NeWS), defined in a similar manner. Both the $P(\tau)$ and $P_{NeWS}(\tau)$ functions are similar to the residence time function, $E(\tau)$, often used to characterize mixing in chemical reactors. Note that if it is assumed that all ultimate disposal is via landfills, then $\int_0^{\infty} P(\tau) d\tau = 1$ and $\int_0^{\infty} P_{NeWS}(\tau) d\tau = 1$. Therefore both probability distribution curves were normalized. The probability at $\tau = 0$ is equal to zero (because the device is brand new). As τ increases, $P(\tau)$ and $P_{NeWS}(\tau)$ initially increase, i.e., the probability of disposal increases, but ultimately the items become obsolete and rare, so $P(\tau)$ and $P_{NeWS}(\tau)$ decrease. Hence, when τ greatly exceeds the mean useful lifetime, $P(\tau)$ and $P_{NeWS}(\tau)$ approach 0. In order to build this probability function, we approximate the life of electronic equipment from information provided by recycling company representatives (Lussier 2007; Monesmith 2007) as summarized in Table 8.8. The resulting probability function is plotted in Figure 8.9.

Table 8.8. Age distribution of e-waste found in the items reaching two electronic waste-handling groups in Western Canada. These proportions are assumed to be representative of overall percentages across Canada. This provides an estimate of obsolete computers, monitors, hard drives and printers received at e-waste recycling facilities based on tonnage per month. (Source: Genesis Recycling Ltd. Aldergrove, BC; 36ZeroWaste Group Inc., Calgary, AB)

Age distribution over 25 years (1980-2005) (includes monitors, hard drives, printers)				
Year	Genesis Recycling Ltd.*		36ZeroWaste Group Inc.‡	
	%	tonnes/month of e-waste received	%	tonnes/month of e-waste received
1980-84	5	4.8	0	0
1985-89	10	9.5	5	2
1990-94	30	28.5	35	14
1995-99	45	42.8	50	20
2000-05	10	9.5	10	4

* 2004: pers. comms. B. Monesmith, Genesis Recycling Ltd, BC

‡ 2007: pers. comms. M. Lussier, 36ZeroWaste Group Inc., Calgary, AB
based on: 95 tonnes/mo. and 40 tonnes/mo., respectively.

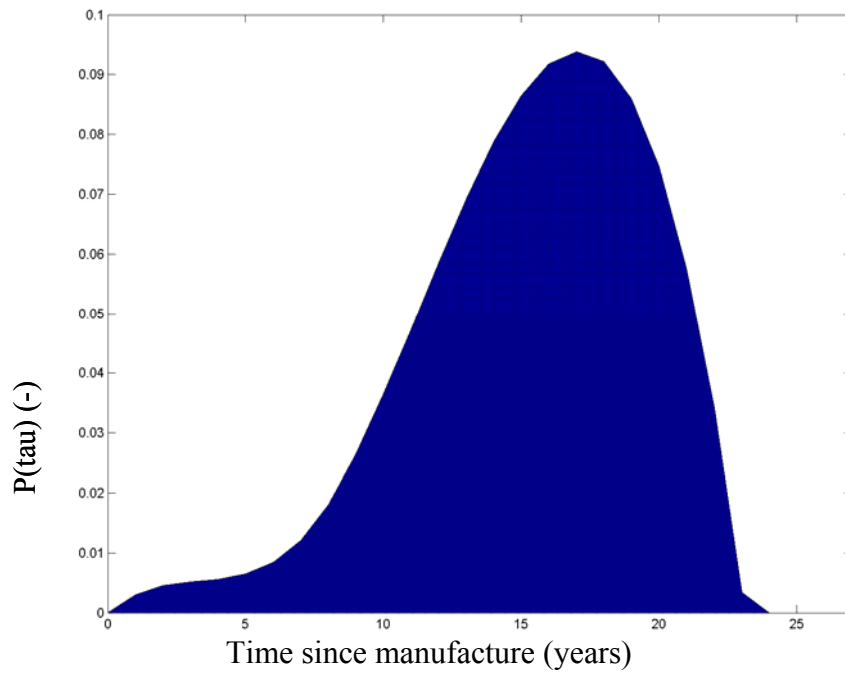


Figure 8.9 Fit of the Age Distribution for Disposal of Electronic items (normalized curve) based on data averaged from Lussier (2007) and Monesmith (2007). After 25 years, $P(\tau)$ is taken as zero, i.e. it is assumed that all electronic goods have been discarded within 25 years of their initial manufacture.

For the distribution of NeWS in a landfill, it was assumed that all items would be disposed after ~47 years (US EPA 2007b) (Figure 8.10). For simplicity, the congener age distribution rate for NeWS was assumed to have the same shape as for the e-waste.

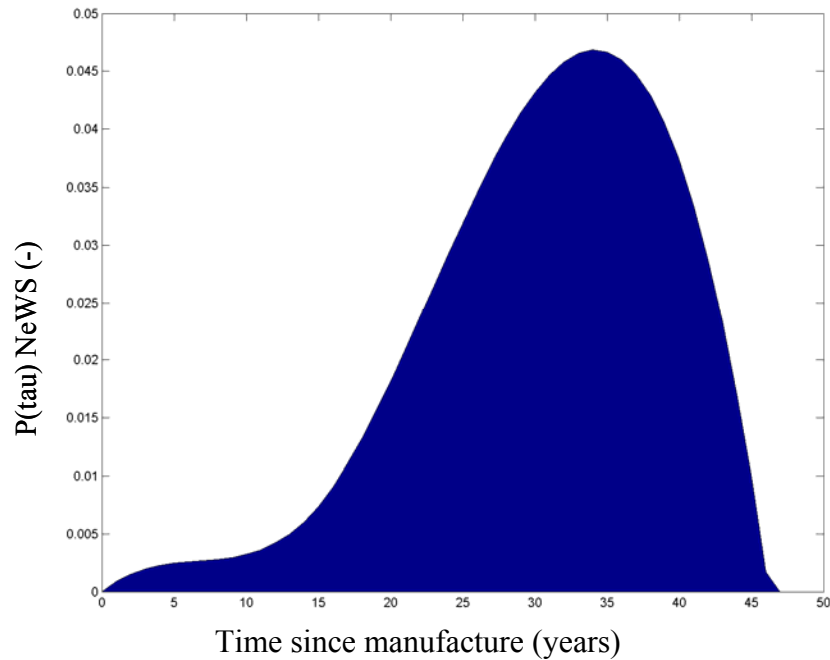


Figure 8.10 Pre-disposal age distribution assumed for disposal of Non-e-waste Solids (NeWS) (normalized curve).

8.8.6 Time Distribution of Input E-waste PBDE Concentration

The model takes 1980 as the starting point, i.e. it assumes that PBDEs started to be incorporated in electronic products in the year 1980, denoted t_o . Suppose that we wish to find the input concentration of n-BDE in year t , designated $C_{in,n}(t)$. To illustrate, consider 1984. Then

$$C_{in,n}(1984) = C_n(1980) \times P(4) + C_n(1981) \times P(3) + C_n(1982) \times P(2) + C_n(1983) \times P(1) \quad (4)$$

In general, $C_{in,n}(t) = \sum_{\tau=1}^{\tau=t-t_o} C_n(t-\tau)P(\tau)$ where $C_n(t)$ is the concentration of n-BDE of electronic goods manufactured in year t , and τ is a dummy time variable.

Note that any chemical (degradation) reaction during the pre-landfill-disposal time period is neglected for all items in these input calculations. This assumption is supported by evidence (Stapleton 2006b; Stapleton and Dodder 2007) that most chemical degradation occurs when the goods are exposed to outdoor elements such as moisture and sunlight. The assumption could be modified in the future if it were found that there is appreciable PBDE degradation while the equipment is in operation or held in offices or storage facilities.

Figure 8.11 shows the resulting time distribution (with inclusion of the $P(\tau)$ term) of input e-waste stream PBDE concentration for the eight designated PBDE congener groups. Note the sharp rise in PBDE input beginning in 1985, corresponding to the sharp rise in e-waste BDE concentrations, i.e. $C_n(t)$, for the 1985-89 time interval. However, inclusion of the $P(\tau)$ function modulates the influence of the very high 1985-89 concentrations, since the disposal of units manufactured during that period is spread over an extended (25-year) time period.

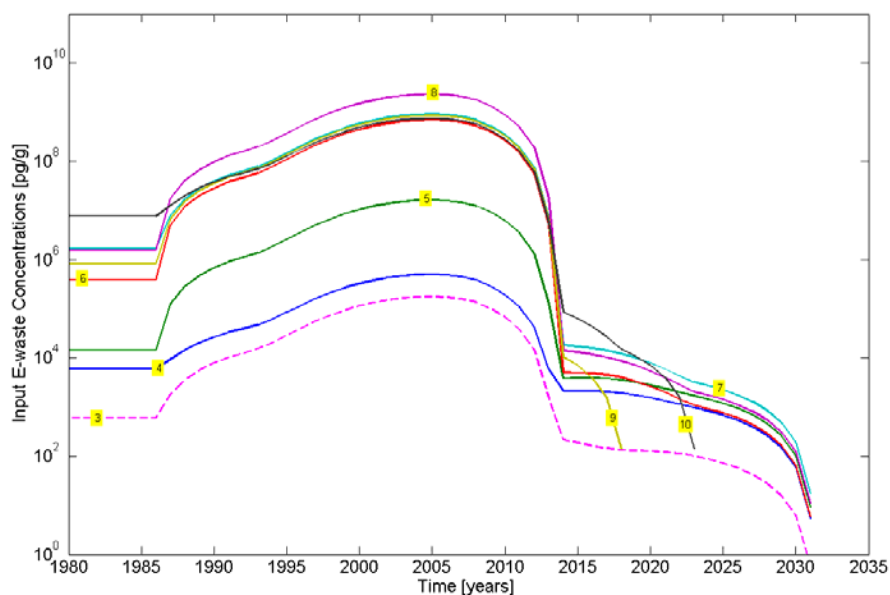


Figure 8.11. Time distribution of *input e-waste stream PBDE concentration*, $C_i(t)$, (Scenario 2, Case 2-B) for the scenarios to be considered in Chapter 9. Semi-log plot. The numbers on the curves indicate the number of bromine atoms, n , of each congener group (with 3 designating tri-BDEs). Note that it is assumed that the manufacture of all PBDEs will stop after 2008.

8.8.7 Time Distribution of Input NeWS Concentration

The inclusion of $P_{NeWS}(\tau)$ facilitates simulation of the phasing out of Penta-BDEs from NeWS after the incorporation of PBDEs is discontinued. $P_{NeWS}(\tau)$ gives the probability of non-electronic waste solids being disposed in a landfill system in the τ^{th} year after manufacture. Figure 8.12 shows the resulting time distribution (with inclusion of the $P_{NeWS}(\tau)$ term) of the input NeWS stream PBDE concentration for the eight PBDE congener groups. The peculiar patterns after 2005 arise between the different PBDE commercial formulations, one (Penta) terminated by the end of 2004, while the production of DecaBDE, another commercial formulation, increased after 2005 as summarized in Table 8.6.

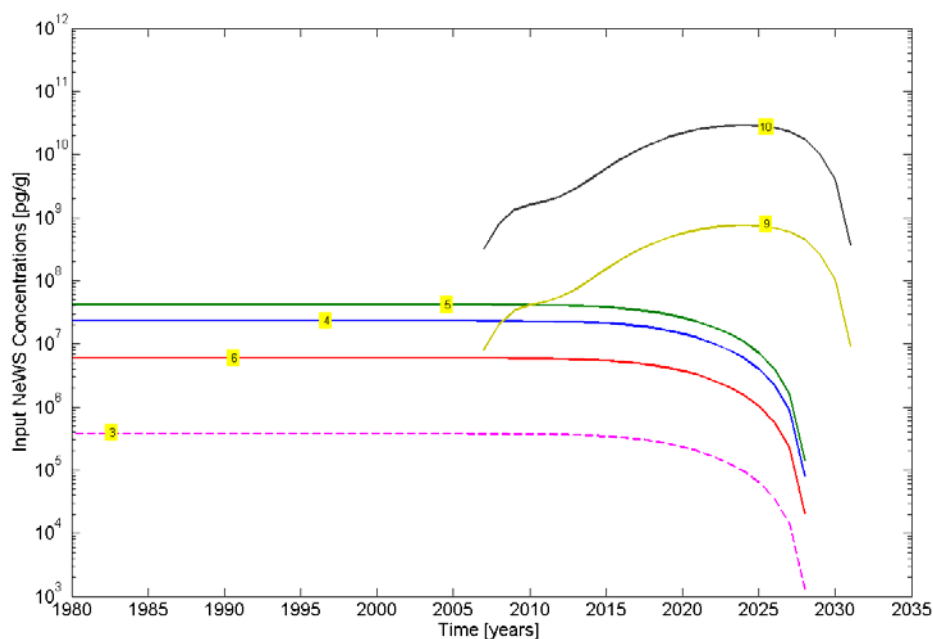
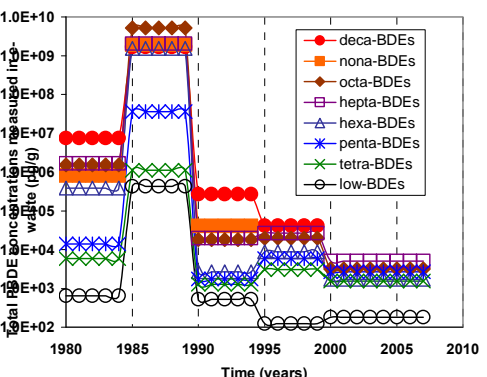
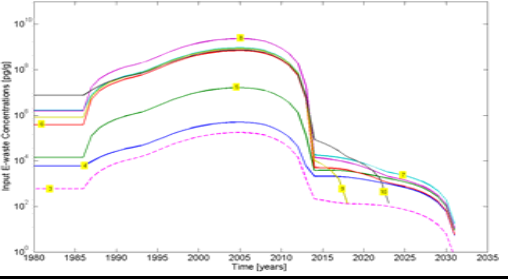


Figure 8.12 Time distribution of *input NeWS* stream PBDE concentration, $C_i(t)$, for Scenario 3. The numbers on the curves indicate the number of bromine atoms, n , of each congener group (with 3 = tri-BDEs). Note that this graph considers the scenario where the manufacture, but not the disposal of PBDEs will cease after 2008.

8.9 Initial Conditions

It is assumed that no e-waste entered the landfill system prior to 1980. Therefore, the initial (1980) concentrations of the e-waste subsystem for Scenarios 1 and 2 are taken as 0. For the aqueous phase and NeWS subsystems, it is assumed that all initial concentrations for Scenarios 1 and 2 are also equal to zero, whereas Scenario 3 adopts the output values from Scenario 1 as the initial values for 2008.

Summary of Input conditions for all 14 cases					
Scenario	Period covered	Initial concentrations	BDE congener group	E-waste input concentration (pg/g)	NeWS input concentration (pg/g)
#1, Case 1-A	1980-2007	0	tri-BDEs tetra-BDE penta-BDE hexa-BDE hepta-BDE octa-BDE nona-BDE deca-BDE	4.87E+04 1.54E+05 3.94E+06 4.35E+08 5.20E+08 1.71E+09 6.38E+08 2.14E+08	3.92E+05 2.43E+07 4.39E+07 6.28E+06 0.00E+00 0.00E+00 0.00E+00 0.00E+00
#1, Case 1-B	1980-2007	0	tri-BDEs tetra-BDE penta-BDE hexa-BDE hepta-BDE octa-BDE nona-BDE deca-BDE		3.92E+05 2.43E+07 4.39E+07 6.28E+06 0.00E+00 0.00E+00 0.00E+00 0.00E+00
#1, Case 1-C	1980-2007	0	tri-BDEs tetra-BDE penta-BDE hexa-BDE hepta-BDE octa-BDE nona-BDE deca-BDE		3.92E+05 2.43E+07 4.39E+07 6.28E+06 0.00E+00 0.00E+00 0.00E+00 0.00E+00
#3, Case 3-A	2008-2065	2007 Scenario #1, Case 1-A final values	N/A	0	0
#3, Case 3-B	2008-2065	2007 Scenario #1, Case 1-B final values	N/A	0	0
#3, Case 3-C	2008-2070	2007 Scenario #1, Case 1-C final values	N/A	0	0

N/A - not available

Figure 8.13. Initial concentrations, e-waste and NeWS input concentrations for three scenarios and 14 cases.

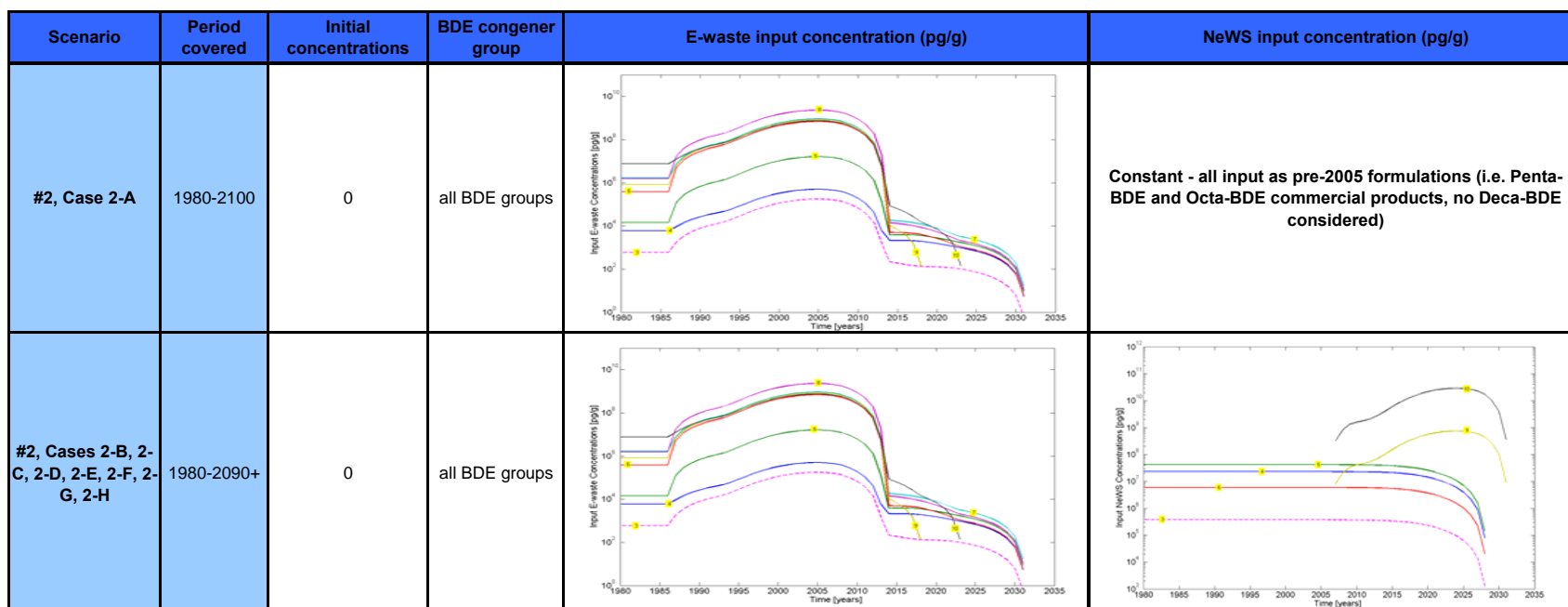


Figure 8.13. (concluded) Initial concentrations, e-waste and NeWS input concentrations for three scenarios and 14 cases.

8.9.1 Concentrations of Input Streams

8.9.1.1 E-waste Input

Input e-waste concentrations prior to 1980 are assumed to be 0. From 1980 to 2007, concentrations are based on the measurements of Chapter 6, with scenarios as follows:

Scenario 1, Case 1-A: Values are averaged from the five 5-year periods covered in Chapter 6 (see Table 6.1) for each of the eight congener groups. Values appear in Table 8.9 and Figure 8.11. In this Scenario, the input concentrations are taken to be constant over the entire simulation period, i.e. 1980-2007.

Table 8.9. Input concentrations for each subsystem (pg/g) in Scenario 1-A. E-waste values are arithmetic averages over the 1980-2005 time interval from those determined in Chapter 6.

Input concentrations for each subsystem (pg/g)			
Scenario #1-A			
Component	E-Waste (1)	Aqueous phase (3)	NeWS (4)
tri-BDEs	4.87E+04	0	3.92E+05
tetra-BDE	1.54E+05	0	2.43E+07
penta-BDE	3.94E+06	0	4.39E+07
hexa-BDE	4.35E+08	0	6.28E+06
hepta-BDE	5.20E+08	0	0.00E+00
octa-BDE	1.71E+09	0	0.00E+00
nona-BDE	6.38E+08	0	0.00E+00
deca-BDE	2.14E+08	0	0.00E+00

Scenario 1, Case 1-B: In this Scenario, concentrations are given step changes in 1980, 1985, 1990, 1995, and 2000 to the average values measured for the 5-year periods beginning in those years as tabulated in Chapter 6 (see Table 6.1) and as plotted in Figure 8.8. Note the high concentrations in the 1985-89 time period.

Scenario 1, Case 1-C: For this case, the pre-disposal (age) time-distribution function $P(\tau)$, discussed in Section 8.7.6 is utilized to account for the distribution of delay times before units built in a given year are discarded. This delay accounts for the period while they are being sold, used and stored, before they are discarded.

Scenario 2, Case 2-A: This scenario is the same as Scenario 1, Case 1-C for the 1980-2007 time period. It is then assumed that no more PBDEs are included in electronic goods being manufactured, beginning in 2008, but that accumulated units still in use, not yet purchased, or in storage prior to discard continue to find their way to landfills according to the $P(\tau)$ time distribution in the future, as in Scenario 1, Case 1-C.

Scenario 2, Case 2-B: This scenario uses the same time-dependent e-waste input as Scenario 2, Case 2-A. Furthermore, it deals with NeWS input using a time distribution $P_{NeWS}(\tau)$ as described in Section 8.8.4 above.

Scenario 2, Cases 2-C, 2-D, 2-E, 2-F, 2-G, and 2-H: These scenarios use the same features as Case 2-B, but the kinetic rate constants were either increased by a factor of 10 or decreased by one order of magnitude to test the sensitivity to the assumed kinetic rate constants for decomposition.

Scenario 3, Cases 3-A, 3-B, and 3-C: These scenarios only deal with the future. They begin with initial values derived from the 2008 final values predicted from Scenario 1, Case 1-A, 1-B, and 1-C, respectively. Then it is assumed that no further BDEs enter the landfill beginning in 2009 in order to show the effect of PBDEs already present in the landfill.

8.9.1.2 Aqueous Input

Precipitation (as tabulated by the organization overseeing the urban landfill site) is assumed to enter the aqueous subsystem. This precipitation is assumed to be free of PBDEs. Hence the external input concentrations via the aqueous subsystem for all scenarios is taken to be zero.

8.9.1.3 NeWS Input

Scenario 1, Cases 1-A, 1-B and 1-C: In these three cases, the input concentrations for the NeWS stream are taken as zero.

Scenario 2, Case 2-A: The age distribution, $P(\tau)$, is utilized in this case. From 2005 onward, values of NeWS concentration are constant and equal to those of the pre-2005 PBDE commercial product formulations (Table A.2, Appendix A).

Scenario 2, Cases 2-B, 2-C, 2-D, 2-E, 2-F, 2-G, and 2-H: The age distribution, $P_{NeWS}(\tau)$, is applied in this scenario, evaluated assuming that the manufacture of PBDEs is discontinued after 2008.

Scenario 3, Cases 3-A, 3-B, and 3-C: These scenarios only deal with the future. They begin with initial values derived from the 2008 final values predicted from Cases 1-A, 1-B, and 1-C, respectively. It is assumed that no further BDEs enter the landfill beginning in 2009.

8.9.2 Other Parameters and Input Data

The e-waste subsystem volume was estimated based on the total accumulated e-waste mass divided by the average overall computer density. The total computer weight (~32 kg) was obtained by weighing a typical desktop PC that included a monitor, CPU and peripherals. The total computer volume was calculated as the sum of the monitor volume plus the CPU volume plus the volume of peripherals (0.11 m³). These values are reasonably consistent with referenced values (weight of ~23 kg, and volume of ~0.1 m³) reported by Kuehr & Williams, 2004. Each overall computer is assumed to be a mixture of metals, glass and plastic, so the density is a weighted density. Values used in the calculations are summarized in Table 8.10.

Table 8.10. Total initial volume of all subsystems (e-waste, aqueous phase and NeWS) in litres (L) for Cases (1-A, B, C and 2-A through 2-H). Cases 3-A, 3-B, and 3-C use as initial values whatever final values come from Cases 1-A, 1-B or 1-C. (For consistency with experimental data units of pg/L, all volumes are expressed in L instead of m³.)

For all Scenarios and all Subsystems					
E-Waste (1)		Aqueous (3)		NeWS (4)	
V_1 (L)	2.89E+07	V_3 (L)	3.61E+10	V_4 (L)	3.28E+10
Total Computer Weight	32 kg				
Total Computer Volume (L)	113	Landfill Area - 410 Ha			
Overall Computer Density (includes air space) (kg/L)	0.283	Depth of water table	20 m	Depth of Landfill	8 m
Overall Computer Density (excludes air space) (kg/L)	1.581	Voidage (ε)	0.44		

The aqueous phase subsystem volume was determined by multiplying the total landfill area (subtracting the areas occupied by the e-waste and NeWS subsystems) by the depth of the water table. The total landfill area is based on that of the same major urban landfill as the one from which the greatest number of samples were obtained for PBDE analysis. The depth of the water table, 20 m, was provided by the landfill operator. The NeWS subsystem volume was again obtained from

the landfill operator, who also provided information on the volume of soil, landfill dimensions and depth of the landfill wastes.

8.9.3 Volumetric Flows

For Scenarios 2 and 3, it is assumed that the input volumetric flows will remain constant after 2009. The input volumetric flow for the e-waste subsystem was obtained from the mass flow of e-waste (obtained from the landfill operator), divided by the weighted density (as calculated above). The water volumetric inflow was taken from a confidential landfill report produced in 2005.

In the NeWS subsystem, the input volumetric flow to the total landfill system was estimated as the sum of all mass flows of refuse categories, excluding the e-waste, divided by the overall refuse density. The refuse density ($1,586 \text{ kg/m}^3$) was derived from the literature for each refuse category (Lemay *et al.* 1994; Lide 1996; Suzuki *et al.* 1997; Altdorf *et al.* 2000; Oida *et al.* 2001; Confidential 2005; Solid Waste Management 2005; Colan Technology in Textiles 2006; Fang *et al.* 2006; Zimmels *et al.* 2006), with values from these sources averaged.

As noted above, it is assumed that there is no output flow for either the e-waste or NeWS subsystems. In the case of the aqueous phase subsystem, the output volumetric flow (leachate outflow) is assumed to be the same as the input volumetric flow. The latter was estimated from data provided in the confidential Solid Waste Management (2005) landfill report.

8.9.4 Contact Surface Area between Subsystems

The surface area per unit bulk volume of e-waste was derived from the approximate size of e-waste “particles” and the void fraction, giving $6(1-\epsilon)/d$, where d is the equivalent diameter of the particle (taken as 0.0024 m)⁶, and ϵ is taken as 0.44, a typical void fraction for loosely packed coarse particulates. These values were assumed for transfer to/from all subsystems in contact with e-waste, i.e. e-waste to NeWS, and e-waste to aqueous phase. The value of $0.55 \text{ m}^2/\text{m}^3$ was arrived at by assuming that the e-waste particles were equally in contact with the other 3 subsystems (i.e. by dividing the total area by 3.) A sensitivity analysis is performed in Chapter 9 to investigate the sensitivity of the model to the contact area between subsystems.

⁶ This number was derived from the experimental Sauter mean distribution. See Chapter 2 for details.

8.9.5 Mass Transfer Coefficients

8.9.5.1 Calculated Mass Transfer Coefficients, k_c from End-over-End Contactor

A mass balance was applied to the PBDEs in the solid-liquid end-over-end contactor described in Section 2.2.2 to calculate the aqueous phase-to-e-waste effective mass transfer coefficients. The mass balance for brominated congeners in the aqueous phase (batch mode with no inflow and no outflow) is:

$$\left[V_{(3)} \cdot a_{I(1 \rightarrow 3)} \cdot k_{c_i} \cdot (C_{i(1)} - C_{i(3)}) \right] = \left[\frac{d}{dt} (V_{(3)} \cdot C_{i(3)}) \right] \quad (8-5)$$

$i = 1, 2, \dots, N_C$

This equation is a simplification of the general mass balance from Equation (8-1) (no inflow, as well as no outflow and no deposition flux). Since degradation reactions (occurring in the dark) are slow (judging from the EPI Suite software), especially for the limited times (hours) allowed for the contacting experiments, chemical reactions during the mass transfer experiments are neglected. In addition, the experimental chamber is modeled as a perfectly-mixed system (uniform concentrations at all times throughout the volume). See Appendix H.2, for mass transfer coefficient equation and calculations, leading to order-of-magnitude estimates for each of the eight BDE congener groups, derived from the end-over-end contactor experimental data in Chapter 6.

8.9.5.2 Experimental Mass Transfer Coefficients, k_c

In the End-over-End Contactor experiments (Chapter 6), concentrations were measured at times 0, 1, 24 and 96 h for e-waste in contact with distilled water and at times = 0, 1, 24, and 654 h for e-waste in contact with leachate. The mass transfer coefficients, k_{c_i} , were obtained by least-squares fitting Equation (8-5) to the experimental data. The mass transfer coefficients differed for the 8 homologue groups, i.e. a unique value was derived for each homologue group. Table 8.11 shows the experimental effective mass transfer coefficients compared to the approximate values estimated from mass transfer correlations (Reid *et al.* 1976; Treybal 1980; Fogler 2002), with molecular diffusivities from the empirical diffusivity correlation of Wilke and Chang (1949, 1955) (Appendix H.2). These empirical correlation predictions are based on a Sauter mean particle diameter of 0.0024 m,

estimated from the particle size distribution analysis of crushed e-waste (Section 2.3.1.1). The hindered settling velocity was used instead of fluid velocity in the calculations.

Table 8.11. Calculated and experimental mass transfer coefficient values, m/s, based on empirical data. Experimental values estimated with e-waste composite of 25 years contacted in the end-over-end contactor with distilled water for 1, 24 and 96 h at a pH of 7 and a temperature of 20°C experiment (Lab: Vista Analytical).

System	Calculated values for from standard mass transfer correlations (m/s)	Experimental values for effective mass transfer (m/s)
tri-BDEs-H2O	9.54E-06	1.27E-12
tetraBDE-H2O	8.90E-06	2.17E-12
pentaBDE-H2O	8.62E-06	1.11E-12
hexaBDE-H2O	8.68E-06	9.01E-13
heptaBDE-H2O	8.23E-06	1.57E-12
octaBDE-H2O	7.63E-06	2.55E-13
nonaBDE-H2O	7.76E-06	1.40E-13
decaBDE-H2O	7.61E-06	6.78E-13

When solids are exposed to a liquid, mass transfer generally occurs by soluble components dissolving over time with mass transfer continuing until the concentrations of all soluble species reaches their respective solubilities. The “driving force” for mass transfer (dissolution) of component i at time t is then $(C_{i_{eq}} - C_i)$ where C_i is a function of time. If the concentration of species i is 0 at time 0, and if the product of the mass transfer coefficient, k_c and the interfacial area per unit volume, a , is constant, then C_i is given by

$$C_i(t) = C_{i_{eq}} (1 - e^{-k_c a t}) \quad (8-6)$$

In the above case, it is clear that C_i could not exceed $C_{i_{eq}}$ since k_c , a and t must all be positive. In Chapter 6, however, it was found that the measured concentrations of some PBDE congeners exceeded the corresponding solubility values when end-over-end contacting experiments were carried out with crushed e-waste particles exposed to both leachate and distilled water. This was ascribed in Chapter 6 to dislodgement of fine dust from the surface of particles as they were contacted vigorously by the liquid. Clearly, equation (8-6) is unable to usefully fit such data. As a result, we assume that the data can be represented by an equation of the form

$$C_i(t) = C_{i_{eq}} (1 - e^{-k_c a t}) + C_{i_{eff}} (1 - e^{-k_{eff} a t}) \quad (8-7)$$

with the first of the two terms on the right side only playing a significant role in the early stages of the contacting. For cases where C_i exceeds $C_{i_{eq}}$, we assume that the second term is the dominant one for times of interest (hours, days, or longer), so that only the second term is of interest, i.e.

$$C_i(t) = C_{i_{eff}} (1 - e^{-k_{eff}at}) \quad (8-8)$$

This covers situations when the experimental mass transfer coefficients in Table 8.10 differs by up to 6 orders of magnitude from the predicted ones from usual mass transfer correlations. The latter may well be relevant to the k_c in equation (8-7), but the long term transfer is apparently due to an altogether different mechanism (dislodgement and/or fine particle generation), which proceeds very slowly over a much longer time period.

Given the two mechanisms and the long time periods of interest in modelling landfill systems, it can be argued that it is the dislodgement mechanism which is of primary interest, and this is what is assumed here in utilizing the Chapter 6 results to make predictions in Chapter 9. At the same time, it is recognized that the vigorous and continuous physical mixing which must have prevailed in the end-over-end contactor is unlikely to be representative of the physical conditions in a landfill where disposed solids are likely to be mostly stagnant over long periods with occasional or periodic disruption as machinery turns over, compresses or covers the material previously deposited.

There are three possible mass transfer combinations in the total landfill model, i.e. e-waste-to-NeWS, aqueous phase-to-NeWS, and e-waste-to-aqueous phase. As shown in Table 8.12, the mass transfer coefficients between the NeWS and the aqueous phase are taken as being equal to those between e-waste and the aqueous phase. While this is also a gross approximation, there are no data which could allow better estimates at this stage. Given the uncertainty, a sensitivity analysis is implemented in Chapter 9 to test this assumption.

Table 8.12. Experimental mass transfer coefficients, k_c , applied in all cases, except for 2-E, 2-F, 2-G, and 2-H (m/s).

Congener group	For subsystem exchange (E-waste to NeWS, Aqueous to NeWS, E-Waste to Aqueous)
tri-BDE	$k_c \text{ lowBDE} = 1.27 \text{ E-12}$
tetra-BDE	$k_c \text{ tet} = 2.17 \text{ E-12}$
penta-BDE	$k_c \text{ pen} = 1.11 \text{ E-12}$
hexa-BDE	$k_c \text{ hex} = 9.01 \text{ E-13}$
hepta-BDE	$k_c \text{ hep} = 1.57 \text{ E-12}$
octa-BDE	$k_c \text{ oct} = 2.55 \text{ E-13}$
nona-BDE	$k_c \text{ non} = 1.4 \text{ E-13}$
deca-BDE	$k_c \text{ dec} = 6.78 \text{ E-13}$

The distilled water contacted with e-waste (a composite of 25 years, 1980-2005) gave a least squares fitting of equation (4-5) for k_c (R^2 typically between 0.7-0.9⁷). However, when attempting to calculate k_c from the experiments where leachate was contacted with e-waste, least square fittings were extremely poor. Various factors may account for this, such as the fact that the solid concentration and the fluid concentration results were taken from two different laboratories which, as explained in Chapter 3 (Section 3.5), gave different results due to differences in methodology, although the trends are similar for the two laboratories. Five of the eight congener groups showed no correlation at all with total PBDE concentrations when calculating the k_c for the leachate experiments. Therefore those values were excluded in the k_c calculations⁸.

8.10 Change in Volume of E-waste and NeWS Subsystems

The input flow to the NeWS subsystem increased during the overall period studied (1980-2005). The e-waste and NeWS subsystems have no output flow. Hence the e-waste subsystem accumulated electronic goods, whereas the NeWS subsystem accumulated non e-waste refuse over time. The total volume of both of these subsystems therefore expanded as depicted in Figure 8.14. In this

⁷ When plotting area per unit volume of e-waste particles vs. concentration in e-waste particle minus concentration of the fluid

⁸ If we were to violate the above and perform calculations using data from two different laboratories, two of the BDE groups give a negative k_c and seven out of the eight BDE groups give $R^2 < 0.3$.

figure, any dissolution, evaporation and biological consumption of the e-wastes and NeWS are neglected.

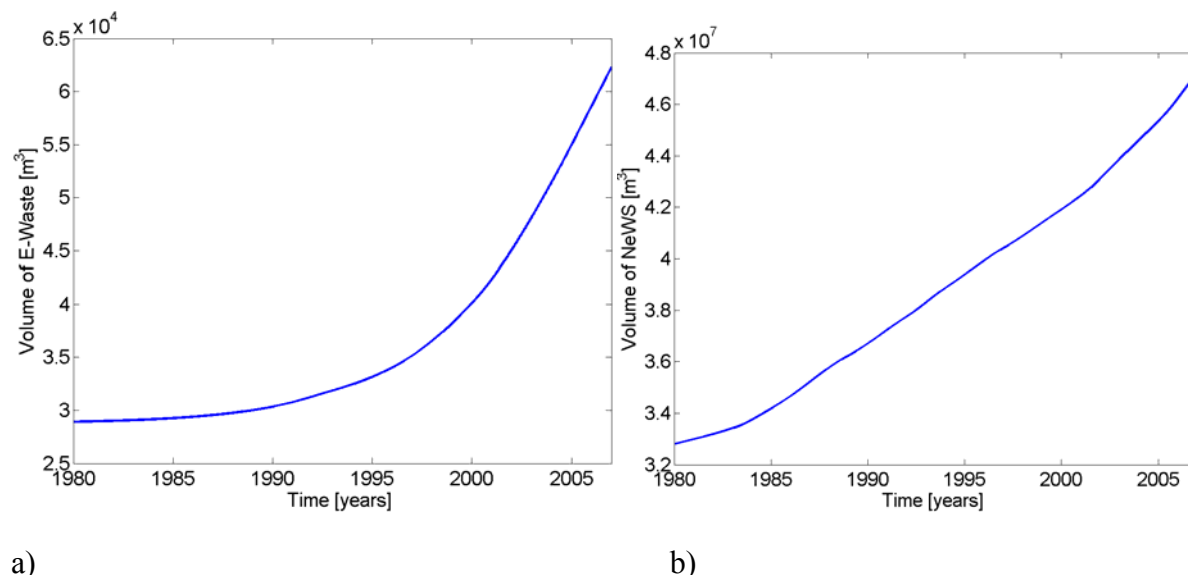


Figure 8.14. Increase in volume in accumulated (a) e-waste and (b) NeWS subsystems for the landfill, for Scenario 1 (i.e. 1980-2007).

8.11 Numerical Solution Procedure

A code was written in Matlab 7.5 to solve the set of nonlinear stiff differential equations. The Matlab solver uses several routines, including an ode15s solver for stiff differential equations which uses higher order methods and smaller step size when the solution varies rapidly. It uses numerical differentiation formulas of up to order 5. A tolerance of 1×10^{-12} was implemented to provide smooth output curves. In addition, all the time-dependent input parameters were fitted by continuous functions by means of an interpolation subroutine using cubic splines.

8.12 Summary and Conclusions

A mechanistic mass balance landfill model is developed in this chapter to predict the environmental fate of polybrominated diphenyl ethers (PBDEs). The resulting set of 24 parallel ordinary differential equations is based on mass balances for three subsystems (e-waste, aqueous phase, and non-e-waste solids) in a landfill system. The fourth subsystem, air, is not considered in the model at this time, although it is formally included. All concentrations are assumed to have been 0 in 1980 when PBDEs first began to be incorporated in a significant manner in electronic and other products. The resulting set of equations and corresponding initial conditions are then written in a form which

can be integrated numerically. Actual landfill data and experimental data are used where possible to estimate the required model parameters to simulate an existing urban landfill system. However, many approximations had to be adopted in order to allow predictions to be made. The model is written in a general enough manner that improved parameter estimates and input data can be implemented as they become available. Three scenarios and fourteen cases are prepared to test sensitivity and different scenarios given the uncertainty surrounding the model with different combinations of assumptions and parameter values. The various scenarios and cases are summarized in Table 8.13. The model is solved using the Runge-Kutta algorithm in Matlab 7.5. Predictions are presented in the next chapter.

Table 8.13. Simulation characteristics for 3 scenarios with 14 cases.

Scenario s and Cases	Simulates 1980-2007	Simulates 2007- future	Uses constant PBDE input averaged over 1980-2006 period	Uses 5-year step changes in PBDE input	Simulates using P(τ) for e- waste	Simulates using P(τ) for NeWS	Uses constant PBDE input with pre- 2005 formulation for NeWS	Initial values in 2008	Policy after 2008	PBDEs eliminated from landfill system
1-A (1980- 2008)	yes	no	yes	no	no	no	yes	N/A	N/A	N/A
1-B (1980- 2008)	yes	no	no	yes	no	no	yes	N/A	N/A	N/A
1-C (1980- 2008)	yes	no	no	no	yes	no	yes	N/A	N/A	N/A
2-A (1980- 2100)	yes	yes	no	no	yes	no	yes	N/A	PBDE ban at manufacture for e-waste only	- 2060 for hepta and higher BDEs - hexa- and lower BDEs do not eliminate
2-B (2008- 2090)	yes	yes	no	no	yes	yes	no	N/A	PBDE ban at manufacture for e-waste and NeWS	~2090
2-C (2008- 2090)	yes	yes	no	no	yes	yes	no	N/A	PBDE ban at source for e-waste and NeWS	~2090
2-D (2008- 2090)	yes	yes	no	no	yes	yes	no	N/A	PBDE ban at source for e-waste and NeWS	~2090
2-E (2008- 2090)	yes	yes	no	no	yes	yes	no	N/A	PBDE ban at source for e-waste and NeWS	~2090
2-F (2008- 2090)	yes	yes	no	no	yes	yes	no	N/A	PBDE ban at source for e-waste and NeWS	~2090
2-G (2008- 2090)	yes	yes	no	no	yes	yes	no	N/A	PBDE ban at source for e-waste and NeWS	~2090
2-H (2008- 2090)	yes	yes	no	no	yes	yes	no	N/A	PBDE ban at source for e-waste and NeWS	~2090
3-A (2008- 2065)	no	yes	no	no	no	no	no	from Case 1-A	Total PBDE ban in ewaste and NeWS	~2065
3-B (2008- 2065)	no	yes	no	no	no	no	no	from Case #1-B	Total PBDE ban in ewaste and NeWS	~2065
3-C (2008- 2070)	no	yes	no	no	no	no	no	from Case #1-C	Total PBDE ban in ewaste and NeWS	~2070

N/A - not applicable

CHAPTER 9 - MASS BALANCE MODEL SIMULATIONS

9.1 Introduction

In this chapter, the model developed in the previous chapter with parameters and initial conditions specified there is solved numerically using the Runge-Kutta integration capabilities of Matlab 7.5. Results for three scenarios and fourteen different cases are described in detail.

Table 8.13 summarizes the various simulation cases used to investigate the behaviour of the different alternatives, depending on the input to the landfill system. Cases 1-A, 1-B, and 1-C, provide estimates of the evolution of concentration profiles of PBDEs in an urban landfill over the period since it began to receive PBDEs in 1981 up to 2008. Cases 2-A and 2-B predict the fate of PBDEs in all subsystems from 1981 until 2008 in a manner similar to Case 1-C, but with the assumption that no PBDEs would be incorporated after 2008 in newly manufactured items (electronics only in 2-A or all goods in 2-B), although units manufactured up to and including 2008 containing PBDEs would continue to enter the landfill. Cases 2-C through 2-H describe the results of different kinetic rate constants and mass transfer between two and three subsystems by increasing or decreasing tenfold their values from the base case (2-B). Cases 3-A, 3-B and 3-C, on the other hand, predict the concentration evolution for PBDEs in the same landfill system for the hypothetical case of a global, immediate and effective PBDE ban on all waste entering the landfill. Effectively, it considers the future effects of PBDEs which have already entered the landfill.

Recall that the air subsystem is omitted from consideration in this chapter. As more data become available for the transfer of PBDEs to/from air, the air compartment can be included in the simulations. Currently, the sole inclusion of air is the adoption of a constant net deposition flux (NDF) from Stern *et al.* (2005) as described in Section 8.4.

Throughout the chapter, bromine numbers 10, 9, 8, 7, 6, 5, 4, and 3, in all of the figures indicate the number of bromine atoms for each congener group. The exception is number 3, which represents tri-, di- and mono-BDEs.

9.2 Scenario 1 – Past Three Decades

Scenario 1 simulates the landfill system containing no PBDEs initially (at $t = 0$, i.e. 1980). This starting date coincides with the year when PBDEs began to be incorporated to a significant degree in electronic equipment and products. The model predictions are presented below in Sections 9.2.1, 9.2.2 and 9.2.3 for the e-waste, aqueous phase and NeWS subsystems, respectively.

Even though the Deca-BDE commercial product is likely to have become more prevalent after 2004, for these calculations, Deca-BDE was not included for the 2005-2007 time interval in the NeWS stream (because mattresses and furniture have a long pre-disposal life (typically >20 years)). Instead, it was assumed that the NeWS still contained Penta-BDE commercial product when it was disposed to the landfill during this period. See Table 8.12 for details.

9.2.1. Case 1-A (1981-2008)

For Case 1-A, all input values (i.e. feed rate, concentrations) were held constant at average values over the entire 27-year period. Therefore, the analysis is simplified in order to illustrate the underlying reaction and mass transfer phenomena. In Figure 9.1, the concentration of deca-BDE in the e-waste subsystem is predicted to increase gradually from its initial value due to the continuous PBDE input until it reaches a maximum value and then declines slowly due to dilution in combination with decomposition. The concentration of nona-BDE increases until it too reaches a maximum value, but with a time-delay relative to the deca. Lower congeners show similar behaviour but with longer time constants, due to the time taken for all higher congeners to react. The relative spacing of the curves depends on the respective first order rate constants.

For the aqueous subsystem, the concentration of deca-BDE in the e-waste is predicted to gradually increase due to mass transfer from the e-waste and NeWS subsystems (Figure 9.2). However, when the concentration of deca-BDE in the e-waste and NeWS drops, so too does the mass transfer driving force that transfers deca-BDE from the e-waste and NeWS to the aqueous phase. The resulting reduction in mass transfer, coupled with continuing decomposition to nona-BDE and dilution, causes a rise, and then a decay, in the predicted deca-BDE concentration. Similar trends apply to the other brominated congeners in the aqueous phase, though with greater time delays due to the increasing number of preceding decomposition reactions. It is seen in the

aqueous subsystems that the predicted concentrations of hexa-, penta-, tetra- and tri--BDEs soon exceed those for the higher BDE congener groups due to the high mass transfer from the NeWS subsystem, which has a higher concentration of tri- BDE congeners (i.e. penta-BDEs and below). Furthermore, as discussed in Chapter 8, the mass transfer coefficients of the tri- BDE congeners are higher than those from the higher BDE congener groups, increasing their mass transfer to the aqueous phase.

For the NeWS subsystem, for which predictions appear in Figure 9.3, the predicted concentrations of PBDEs in the soil follow dynamics similar to those for the aqueous phase. The decomposition of higher congeners affects the lighter congeners due to the series of stepwise reactions. The time required to reach a maximum concentration increases in a stepwise manner as the degree of bromination decreases. As a result, the predicted time needed for deca-BDE to achieve its maximum value is ~5 years, while the corresponding time for the tri--BDEs is ~ 8 years for the NeWS subsystem.

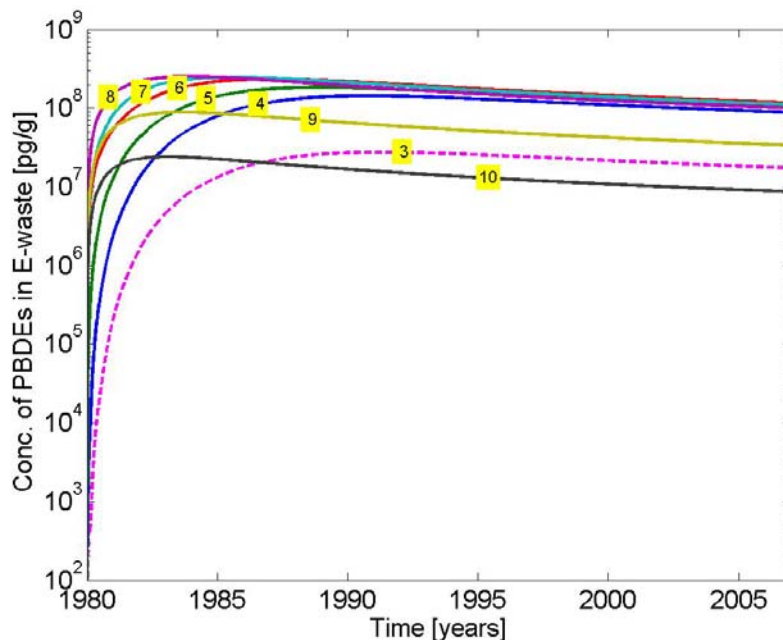


Figure 9.1. Predicted PBDE concentrations of the eight congener groups in the *e-waste* subsystem vs. time for *Case 1-A*. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.12 and 8.15.

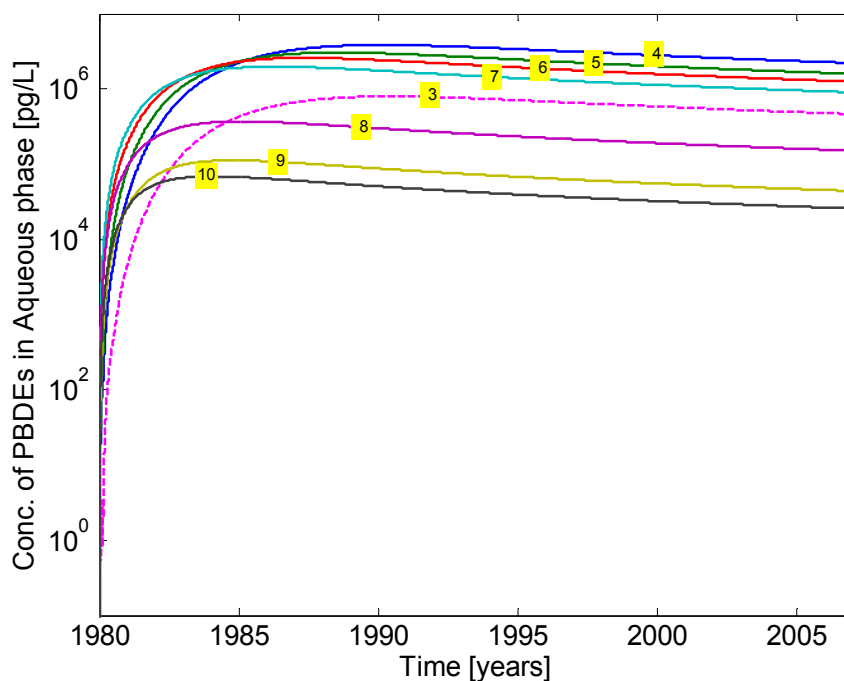


Figure 9.2. Predicted PBDE concentrations of the eight congener groups in the *aqueous* subsystem vs. time for *Case 1-A*. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

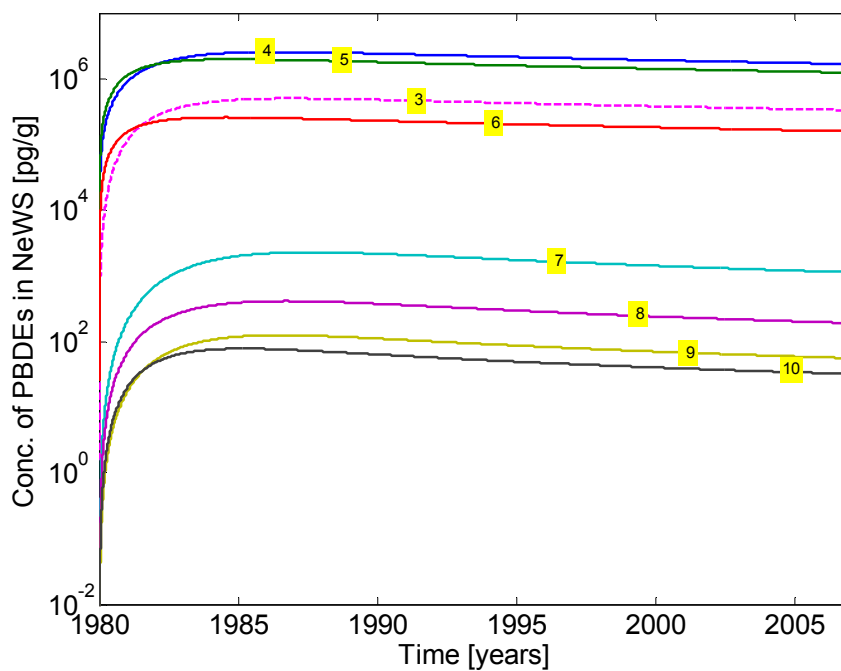


Figure 9.3. Predicted PBDE concentrations of total congener groups in the *NeWS* subsystem vs. time for *Case 1-A*. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

9.2.2 Case 1-B (1980-2007)

Case 1-B simulates the same landfill, but with all inputs undergoing step changes at 5-year intervals. The input PBDE concentrations vary during the different time periods as shown in Figure 8.11. As in the previous section, the probability distribution $P(\tau)$ for disposal of electronics (Section 8.8.5) is not included in this case.

The simulation predictions, plotted for the e-waste compartment in Figure 9.4, show a strong dependence on the input e-waste concentrations, in particular responding to the very high PBDE concentration of equipment manufactured during the 1985-1989 time period (see Section 8.8.3), several orders of magnitude higher than for any other time period. As a result, the model predicts a sharp concentration increase after 1985, influencing the dynamics of the system, in contrast to Case 1-A where input values were assumed to be constant and equal to average values over the entire 27-year period.

For the e-waste subsystem, the concentration of deca-BDE is predicted to increase from its initial value in 1980-84 due to PBDE input. In 1985 the input concentration increases abruptly (see Figure 8.8), and this causes a rapid rise in all PBDE concentrations. As the input concentrations decrease after 1990, the predicted output PBDE concentrations decrease as well. Again, deca is the first BDE congener group to reach a maximum concentration in the late 1980s, whereas it is predicted to have the lowest value at the end of 2007 when the simulation is terminated. As above, the PBDE congener groups reach maximum concentrations later for lower bromine numbers due to stepwise debromination.

The mass transfer to the other compartments is again affected by the large changes in input e-waste PBDE concentrations (upward in 1985 and downward in 1990), resulting in similar profiles for the aqueous phase subsystem as shown in Figure 9.5 where the trend is similar to that in Figure 9.4 for e-waste PBDE concentrations due to mass transfer from the e-waste and NeWS to the aqueous subsystem.

For the NeWS subsystem (Figure 9.6), two overlapping phenomena are observed. For the higher BDE congeners (hepta- and higher), the concentration profiles follow the same trend as for the e-waste subsystem due to direct mass transfer between compartments. It is important to note that the input flow of NeWS only contains tri- to hexa-BDE congeners in this case, as shown in Table

8.6. As a result, mass transfer from the other compartments is masked by the constant rate of input flow to the NeWS subsystem for the lower BDE congeners (hexa- and below).

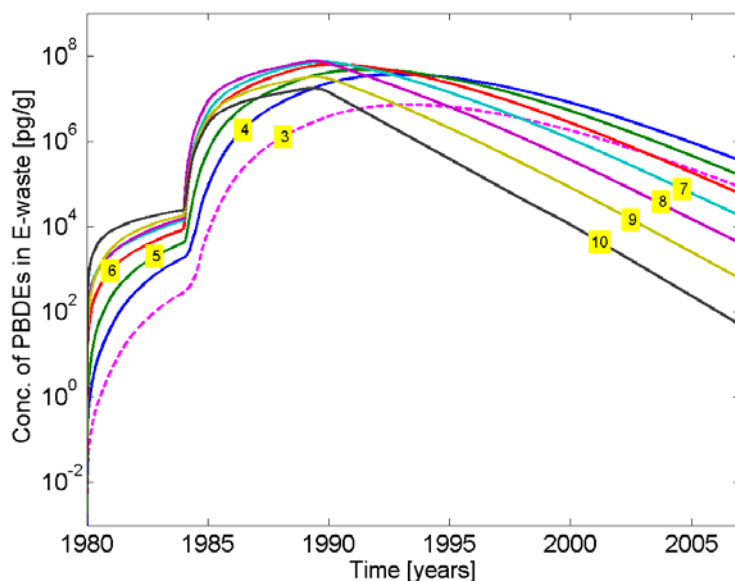


Figure 9.4. Predicted PBDE concentrations for the eight congener groups in *e-waste* subsystem vs. time for *Case 1-B*. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

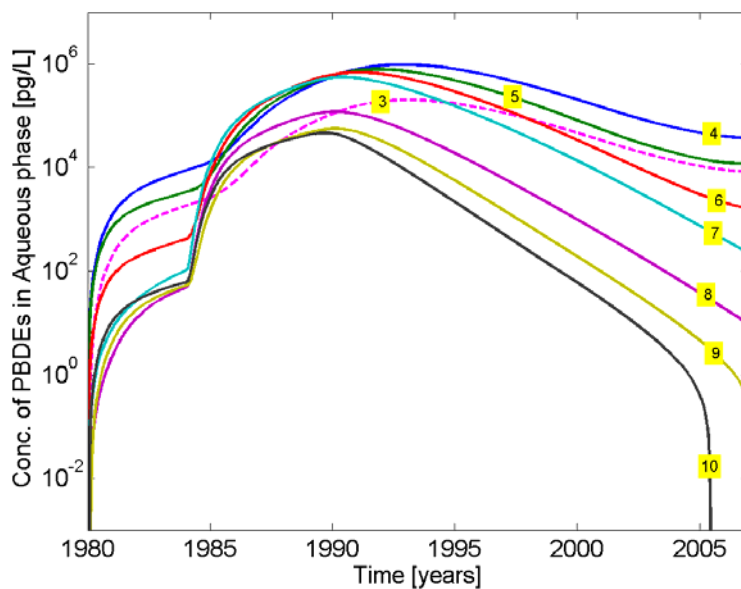


Figure 9.5. Predicted PBDE concentrations for the eight congener groups in the *aqueous* subsystem vs. time for *Case 1-B*. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

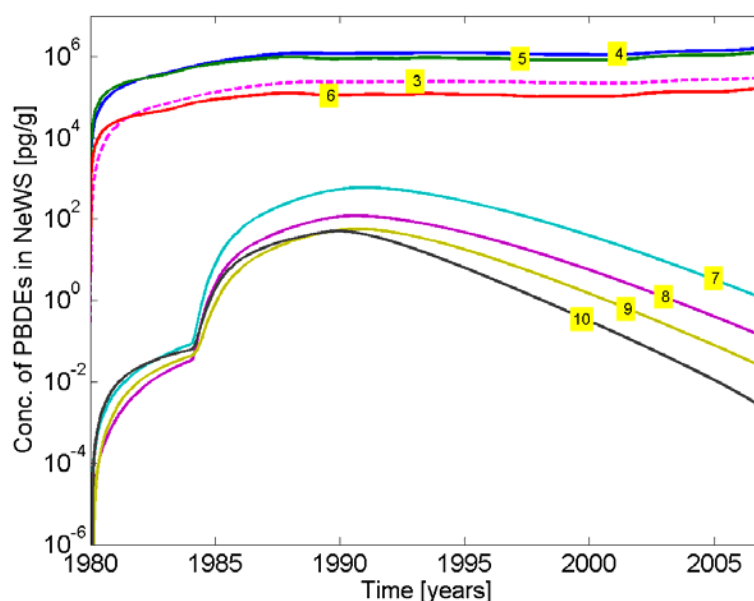


Figure 9.6. Predicted PBDE concentrations for the eight congener groups in the *NeWS* subsystem vs. time for *Case 1-B*. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

9.2.3 Case 1-C (1980-2007)

This case simulates the landfill with all input values time-dependent and with the disposal age distribution of electronic products included, i.e. it includes the age distribution for disposal of electronic products, $P(\tau)$. The parameters are calculated as described in Section 8.7. Once again, the predictions are greatly affected by the elevated concentrations corresponding to items manufactured in 1985-1989, although there is considerable modulation since the age distribution means that the input PBDE concentrations for all time periods contribute to the overall simulation results at all subsequent times. $P(\tau)$ acts as a delay function, spreading the dominant effect of the 1985-1989 input over a considerably longer period.

For the e-waste subsystem as shown in Figure 9.7, the concentration of deca-BDE in the e-waste is predicted to gradually increase due to PBDE input. The large input of PBDE during the 1985-1989 time interval affects the subsystem's concentration trajectories, causing a change in slope after 1985, with the concentrations increasing, though less sharply than in Case #1-B (compare Figure 9.4) due to the inclusion of the $P(\tau)$ age distribution.

For the aqueous phase (Figure 9.8), the concentration of deca-BDE is predicted to increase due to mass transfer from the e-waste and *NeWS* subsystems. The predicted behaviour of the PBDE concentrations in this subsystem resembles that for the e-waste subsystem, but the magnitudes

are modulated by the mass transfer, as well as by transfer from the NeWS subsystem. Predicted 2008 concentrations differ from Cases #1-A and #1-B due to the time-dependent variation in e-waste PBDE input concentrations and the inclusion of the age distribution ($P(\tau)$) function.

In the NeWS subsystem (Figure 9.9), two groupings appear in BDE congener concentrations, similar to those in Figure 9.6 for the NeWS subsystem for Case #1-B. For the higher BDE congeners (hepta- and above), the concentration profiles follow the same trend as for the e-waste subsystem, giving a monotonic increase at first, followed by a later decline. The similarity is due to mass transfer between compartments. The behaviour for the tri- BDE congeners is remarkably similar to that in Case 1-B (Figure 9.6), where $P(\tau)$ was not yet introduced. The mass transfer from the other compartments continues to be masked by the continuous input to the NeWS subsystem containing only the hexa- and other lower congeners.

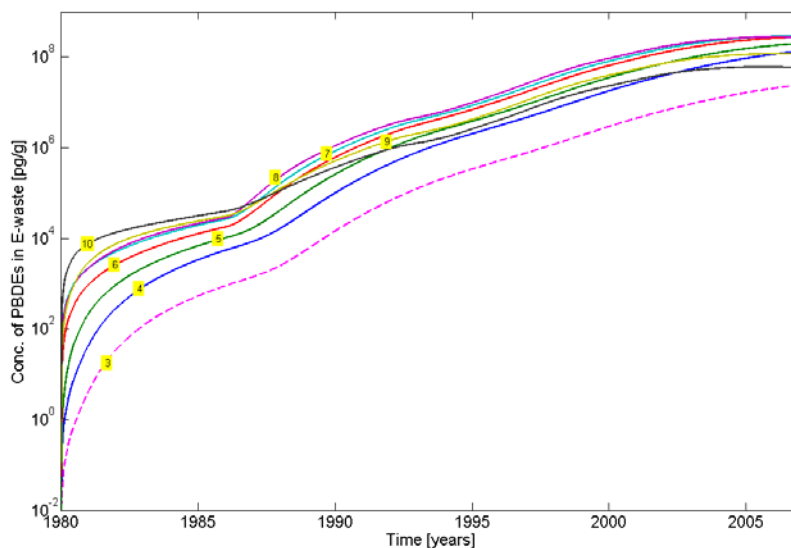


Figure 9.7. Predicted PBDE concentrations of the eight congener groups in *e-waste* subsystem vs. time for *Case 1-C*. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

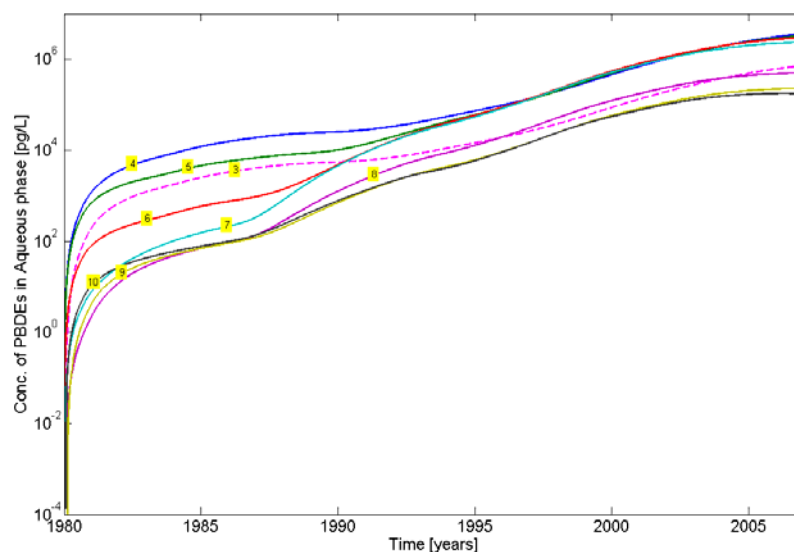


Figure 9.8. Predicted PBDE concentrations of the eight congener groups in the *aqueous* subsystem vs. time for *Case 1-C*. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

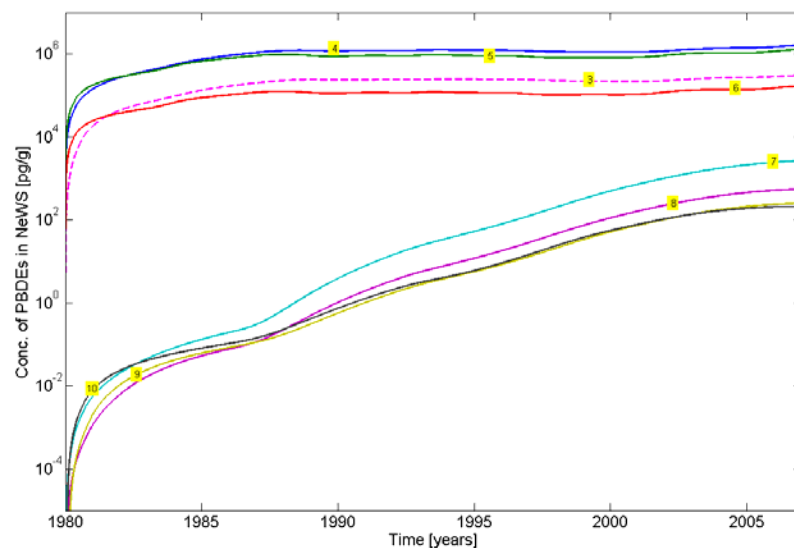


Figure 9.9. Predicted PBDE concentrations of the eight congener groups in the *NeWS* subsystem vs. time for *Case 1-C*. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

9.2.4 Comparison of predictions for Cases 1-A, 1-B and 1-C in 2005 with experimental values

The model contains many assumptions due to the lack of precise values of properties, the heterogeneous nature of the landfill and uncertain parameter information (as explained in Chapter 8). The differences between experimental values and their simulated values from Cases 1-A, 1-B and 1-C were determined in order to compare the simulation results from the model

with field measurements. Comparison of the results from Scenarios 2 and 3 is not possible at this time since they simulate different possible futures.

As seen in Table 9.1, there are wide differences between the predictions of the simulation model and the 2005 field data. One major reason for the high predicted values from Scenario 1 are that the concentration of PBDEs entering the e-waste in the late 1980s were extraordinarily high, and these dominate the input function, especially for Case 1-A. Another major reason for these differences may be that soil values are compared with the NeWS predicted values.

Some of the factors leading to the wide divergence observed between model predictions and actual field data can be summarized as follows:

- Simplifications in the model, e.g. the ‘lumping’ (perfect mixing) assumption, and the division into four discrete homogeneous subsystems (compartments).
- Almost ignoring the air subsystem.
- Simplified and limited characterized kinetics of decomposition: reaction sequence, assumption of first order reactions, and approximate rate constants.
- Inability to include many factors, e.g. the role of photochemical reactions and the effect of temperature.
- Mass transfer based on idealized (“end-over-end” contactor) experiments (Chapter 6) where the contacting is likely to differ from that in the landfill.
- Lumping of congeners into discrete congener homologue groups, and combining all lower congeners ($N \leq 3$) into a single group.
- Characterization of e-waste limited to 5-year time intervals.
- Absence of accounting explicitly for fine particulates and their transport by water, and probably air.
- Chemical kinetics simplified due to the limited data available in the literature.

- Difficulties in sampling and in analysing the landfill, leading to large scatter and uncertainties in the experimental data.
- Additional inaccuracies in BDE-209 analytical experimental results as explained in Chapter 3.

Given these factors and the large discrepancies between predictions and landfill data, the current model must be regarded as a rough first approximation at best. One could “fit” the model to the field data by adjusting some of the empirical parameters. However, we chose not to do this, as the modeling would then become a curve-fitting exercise. Instead, the predictions are left “as is”, with full recognition that future improvements and refinements are needed to improve the quantitative predictive ability of the model.

Despite the weak quantitative agreement, the model is still likely to have utility for qualitative predictions, for example in forecasting trend, if the inputs of PBDEs were to be curtailed in the future. Hence, Scenario 2 considers what would happen if the manufacture of all e-wastes containing PBDEs were to be halted immediately. Similarly, Scenario 3 examines the future behaviour of the landfill with only the current stock of PBDEs, i.e. if no more PBDEs were to enter. Since part of the inaccuracy is no doubt due to the uncertainty in the key kinetics and inter-compartment mass transfer data utilized in the model, some of the cases analysed in this chapter test the sensitivity to kinetic rate constants and mass transfer coefficients.

Table 9.1. Comparison between experimental congener concentrations and values predicted from the simulation in 2005 for Cases 1-A, 1-B and 1-C for the e-waste, aqueous phase and NeWS subsystems (pg/L).

Subsystem	BDE congener group	SCENARIO #1 FINAL VALUES (1980-2007)			Actual data (experimental)	
		Scenario 1A	Scenario 1B	Scenario 1C	2005 value (pg/L)	Observations
		Value (from simulation) pg/L	Value (from simulation) pg/L	Value (from simulation) pg/L		
E-waste	triBDEs	1.8E+10	9.1E+07	2.6E+10	N/A	No data were available for the degraded e-waste
	tetraBDEs	9.2E+10	3.8E+08	1.5E+11	N/A	
	pentaBDEs	1.1E+11	1.7E+08	2.2E+11	N/A	
	hexaBDEs	1.2E+11	6.3E+07	3.0E+11	N/A	
	heptaBDEs	1.2E+11	1.9E+07	3.2E+11	N/A	
	octaBDEs	1.0E+11	4.4E+06	3.0E+11	N/A	
	nonaBDEs	3.5E+10	6.5E+05	1.2E+11	N/A	
	decaBDEs	9.1E+09	5.4E+04	6.3E+10	N/A	

Subsystem	BDE congener group	SCENARIO #1 FINAL VALUES (1980-2007)			Actual data (experimental)	
		Scenario 1A	Scenario 1B	Scenario 1C	2005 value (pg/L)	Observations
		Value (from simulation) pg/L	Value (from simulation) pg/L	Value (from simulation) pg/L		
Aqueous Phase	triBDEs	4.5E+05	8.2E+03	7.3E+05	7.2E+03	Leachate from 2005, analysed by Vista Analytical laboratory
	tetraBDEs	2.1E+06	3.7E+04	3.7E+06	3.5E+05	
	pentaBDEs	1.5E+06	1.2E+04	3.3E+06	7.4E+05	
	hexaBDEs	1.2E+06	1.6E+03	3.0E+06	2.6E+05	
	heptaBDEs	8.8E+05	2.2E+02	2.4E+06	2.0E+04	
	octaBDEs	1.5E+05	9.4E+00	5.0E+05	1.7E+04	
	nonaBDEs	4.3E+04	3.2E-01	2.3E+05	1.2E+04	
	decaBDEs	2.5E+04	-7.3E-01	1.7E+05	5.7E+04	

Subsystem	BDE congener group	SCENARIO #1 FINAL VALUES (1980-2007)			Actual data (experimental)	
		Scenario 1A	Scenario 1B	Scenario 1C	2005 value (pg/L)	Observations
		Value (from simulation) pg/L	Value (from simulation) pg/L	Value (from simulation) pg/L		
NeWS	triBDEs	4.97E+08	5.07E+08	5.08E+08	2.54E+05	Experimental values were taken from soil analyses at the urban landfill in 2005.
	tetraBDEs	2.50E+09	2.65E+09	4.47E+02	1.67E+06	
	pentaBDEs	1.85E+09	2.12E+09	3.07E+02	1.53E+06	
	hexaBDEs	2.37E+08	2.73E+08	5.76E+01	5.62E+05	
	heptaBDEs	1.83E+06	1.81E+03	1.21E+00	5.60E+01	
	octaBDEs	3.09E+05	2.12E+02	3.15E-01	9.93E+01	
	nonaBDEs	9.01E+04	3.69E+01	1.74E-01	1.09E+02	
	decaBDEs	5.18E+04	3.58E+00	1.67E-01	7.78E+06	

N/A - no data available

9.3 Scenario 2: Future with PBDE Bans and Sensitivity Analyses

Scenario 2 considers what would happen if there had been a total ban on manufacture of PBDEs at the end of 2008. It is assumed that all PBDE production stopped immediately, but that products already manufactured and in existence will continue to make their way into the waste stream. An accumulated stream would still exist, even through the inclusion of PBDEs in the manufacturing of electronic equipment and NeWS would have immediately ceased. Therefore, given the life expectancy of electric and electronic equipment (EEE) and NeWS items, this stream would continue to be problematic over an extended time period. To extrapolate the parameters into the future, it is assumed that the input volumetric flows for all subsystems remain constant after 2008. This assumption is made because there is no reliable quantitative method to predict future inflows. The deposition flux from the air is treated the same way as in Scenario 1.

9.3.1 Case 2-A (1980-2100)

In this case, the probability of electronic devices being disposed in a landfill, i.e. $P(\tau)$ (Section 8.8) is again utilised. $P(\tau)$ modulates the input e-waste concentration, as indicated in Figure 8.11, for Case 1-C above. For Case 2-A, the predictions are extended into the future to simulate the conditions beyond 2008. Because this case considers a situation where all PBDE production in e-waste stopped at the end of 2008, a continuous decrease in the input PBDE concentration after year 27 (i.e. 2008) would occur as indicated in Figure 8.11. The tail-end residual input would then virtually disappear ~25 years after 2008 (more than 50 years after the simulation starting point in 1980). For this case a constant input of PBDE-containing NeWS is assumed, in order to investigate the effect of banning PBDEs from electronic equipment only, i.e., it is assumed that the NeWS stream will continue to contain PBDEs so that input from this stream will continue undiminished into the future.

For this case, the predicted concentrations for the 1981-2008 time period are identical to those for Case 1-C, i.e. Figures 9.7, 9.8 and 9.9 for the e-waste, aqueous and NeWS subsystems, respectively. This case does not use $P_{NeWS}(\tau)$, and, it assumes that the input NeWS concentration is constant. Beyond 2008, as the e-waste input PBDE concentrations start to decrease, a continuous reduction of PBDEs is predicted for the e-waste subsystem until ~2060.

After that, a split between the higher-brominated congeners (deca-, nona-, octa-, and hepta-) and the mid- to lower brominated congeners develops, since there is no further input of higher-brominated congeners. Hence, the higher-brominated congeners are predicted to be virtually removed completely by ~2060, whereas there is a continuous input of hexa-, penta-, tetra- and tri- BDEs due to continuing mass transfer from the NeWS compartment. Predictions for the NeWS subsystem are depicted in Figure 9.10.

For the aqueous subsystem (Figure 9.11) there is a similar trend to that predicted for the e-waste subsystem, but with faster dynamics and lower predicted absolute BDE values. For the NeWS subsystem (Figure 9.12) the pattern is similar to the profile for deca-, nona-, octa-, and hepta-BDEs pertaining to the aqueous subsystem (Figure 9.11). These congener groups are predicted to be almost completely removed by ~2040. A significant decrease in the concentration of the remaining BDE congeners is also predicted, with continued input from the NeWS waste stream. See Table 8.12 for details.

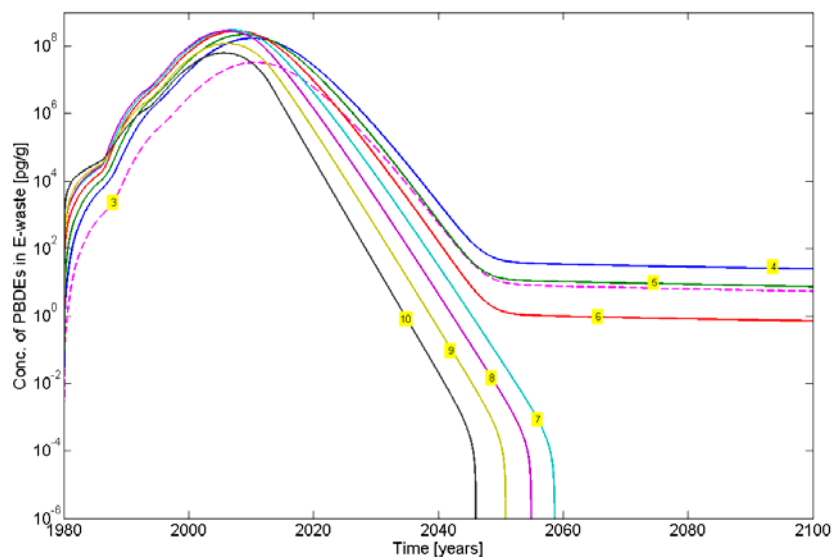


Figure 9.10. Predicted PBDE concentrations for the eight congener groups in the *e-waste* subsystem vs. time for *Case 2-A*. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

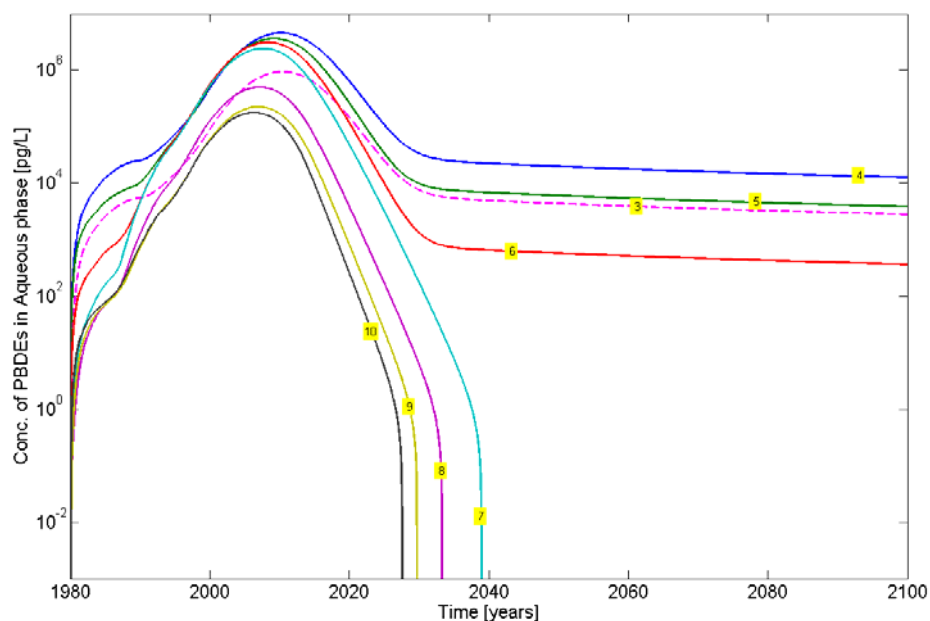


Figure 9.11. Predicted PBDE concentrations for the eight congener groups in the *aqueous* phase subsystem vs. time for *Case 2-A*. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

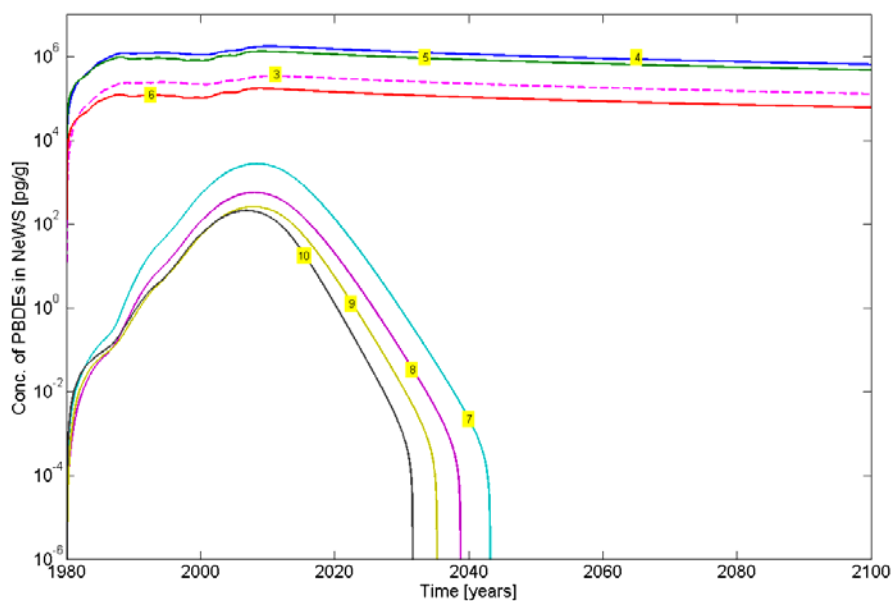


Figure 9.12. Predicted PBDE concentrations for the eight congener groups in the *NeWS* subsystem vs. time for *Case 2-A*. The numbers indicate the number of bromine atoms of each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

9.3.2 Case 2-B (2008-2090)

For Case 2-B, the life expectancy of NeWS before being disposed in a landfill is included by means of the $P_{NeWS}(\tau)$ function, to investigate the effect of phasing out of PBDEs from NeWS. Figure 8.12 depicts the assumed time-dependent input concentration for the NeWS subsystem.

Note that the incorporation of Penta-BDE commercial product formulation in such products as sofas and mattresses ended in 2004, whereas incorporation of the Deca-BDE commercial product formulation began in 2005. This switch accounts for the sharp increase in the profiles for the higher congener groups after 2004. Note that no octa- nor hepta-BDE is contained in the NeWS feedstream at any time. The inclusion of the $P_{NeWS}(\tau)$ function causes a ‘smoothing’ of the curves due to spreading the disposal of NeWS over time as sofas and mattresses are progressively discarded after being in service for significant periods of time.

For all subsystems Figures 9.13 to 9.15 show similar trends as for the previous case for the 1981-2008 time period. After 2008 for Case 2-B, the inclusion of the age distribution for disposal of NeWS, $P_{NeWS}(\tau)$ leads to no split between the higher and lower brominated congeners, unlike Case 2-A, where a division was observed. For Case 2-B, in the e-waste subsystem shown in Figure 9.13, BDEs are predicted to virtually disappear by the end of the simulation (~2080) due to discontinuance of PBDEs from both the NeWS and e-waste disposal streams.

For the aqueous subsystem (see Figure 9.14) the trend is similar to that for the e-waste subsystem, due to mass transfer between these subsystems. The faster dynamics and lower absolute values of the aqueous phase conditions to apply.

In the NeWS subsystem portrayed in Figure 9.15, there is a jump in the concentration of high BDE congeners in 2005 due to the change in the PBDE formulation for the NeWS goods in the time-dependent input concentration profile (Figure 8.12). The predicted time when all PBDEs would virtually disappear in this landfill compartment is ~2085.

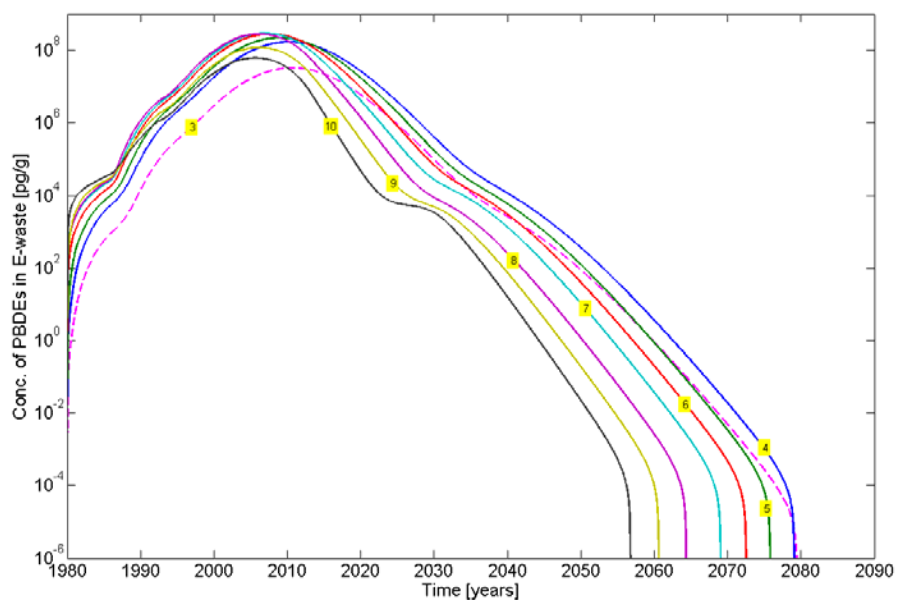


Figure 9.13. Predicted PBDE concentrations for the eight congener groups in the *e-waste* subsystem vs. time for *Case 2-B*. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

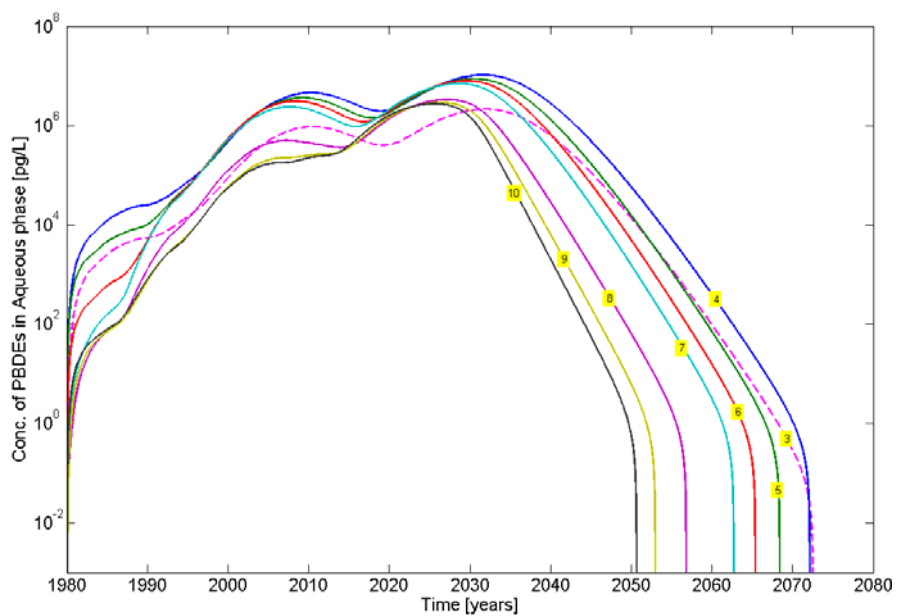


Figure 9.14. Predicted PBDE concentrations for the eight congener groups in the *aqueous* phase subsystem vs. time for *Case 2-B*. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

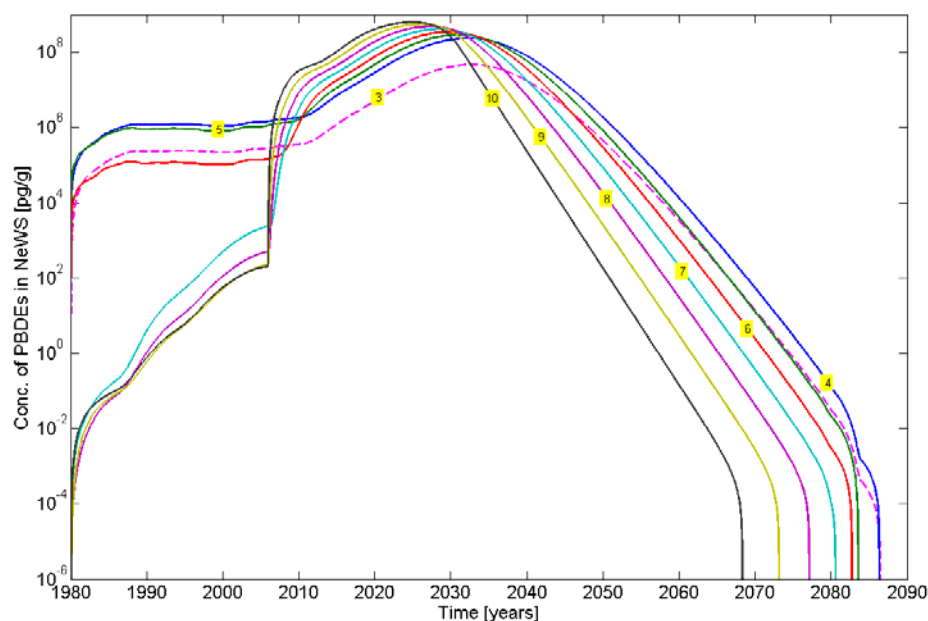


Figure 9.15. Predicted PBDE concentrations for the eight congener groups in the *NeWS* subsystem vs. time for Case 2-B. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

9.3.3 Cases 2-C and 2-D: Sensitivity to Kinetic Rate Constants

Case 2-C is based on the same input parameters and assumptions as Case 2-B. However, Case 2-C is the first of six sensitivity analyses (with 2-D, -E, -F, -G, and -H) to test the sensitivity to key model assumptions and parameters. In Case 2-C, all kinetic constants are increased tenfold, so that the rates of decomposition of all PBDEs are assumed to be ten times faster than in the base case (2-B).

For all three subsystems within Case 2-C, the changes over time are qualitatively similar to those of 2-B. However, virtual total debromination occurs much more quickly for Case 2-B (~45 years faster). Furthermore, the predicted maximum concentrations for all congener groups are reduced by ~ one order of magnitude. As shown in Figures 9.16, 9.17 and 9.18, the stepwise debromination for Case 2-C follows the same order as in Case 2-B of Figures 9.13, 9.14 and 9.15. However, in 2-C, BDE groups reach near total decomposition in a shorter time span than in Case 2-B. The faster decomposition chemical kinetics therefore accelerate the disappearance of PBDEs from the landfill, with virtual disappearance by ~ 2040 rather than ~2085.

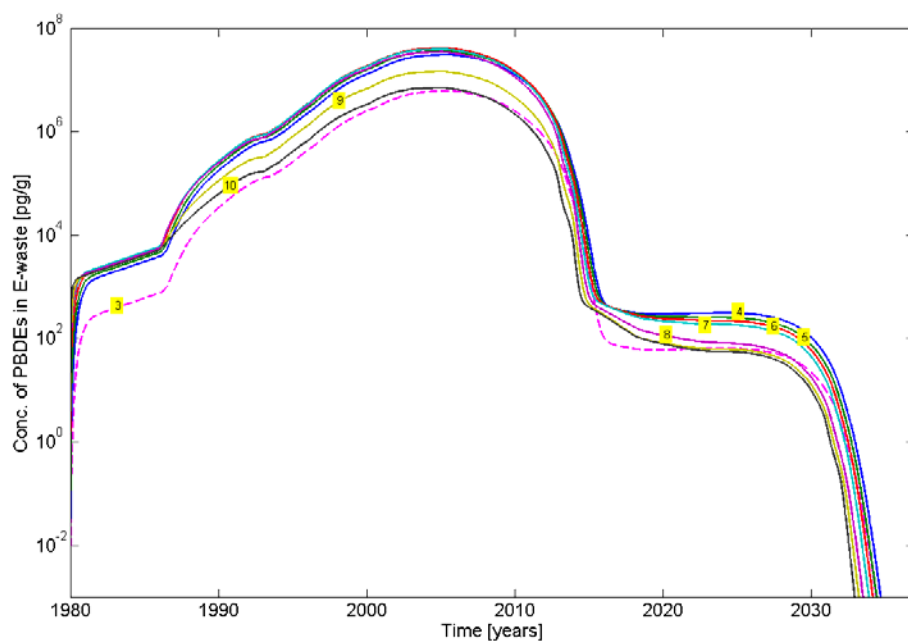


Figure 9.16. Predicted PBDE concentrations for the eight congener groups in the *e-waste* subsystem vs. time for *Case 2-C*. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

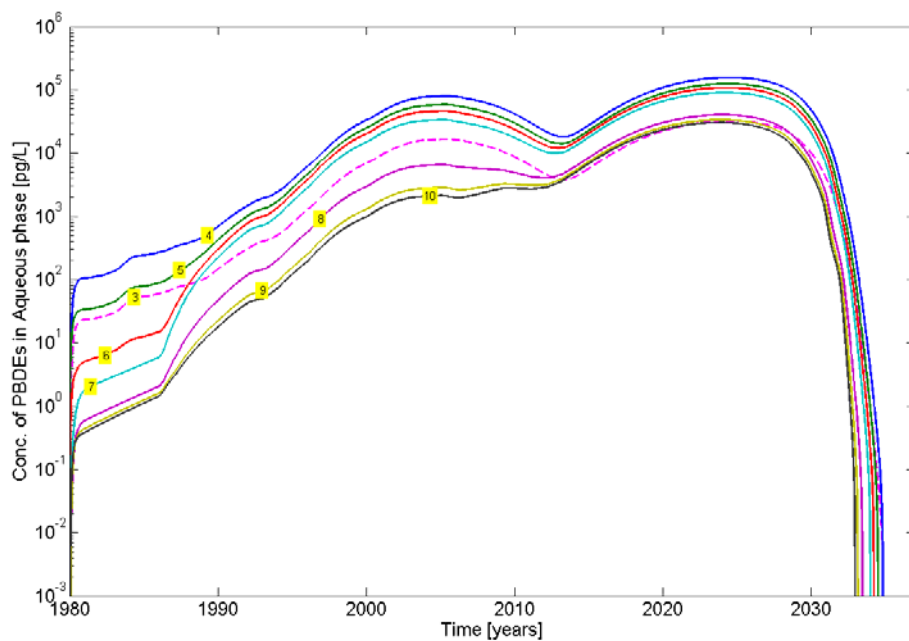


Figure 9.17. Predicted PBDE concentrations for the eight congener groups in the *aqueous* phase subsystem vs. time for *Case 2-C*. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

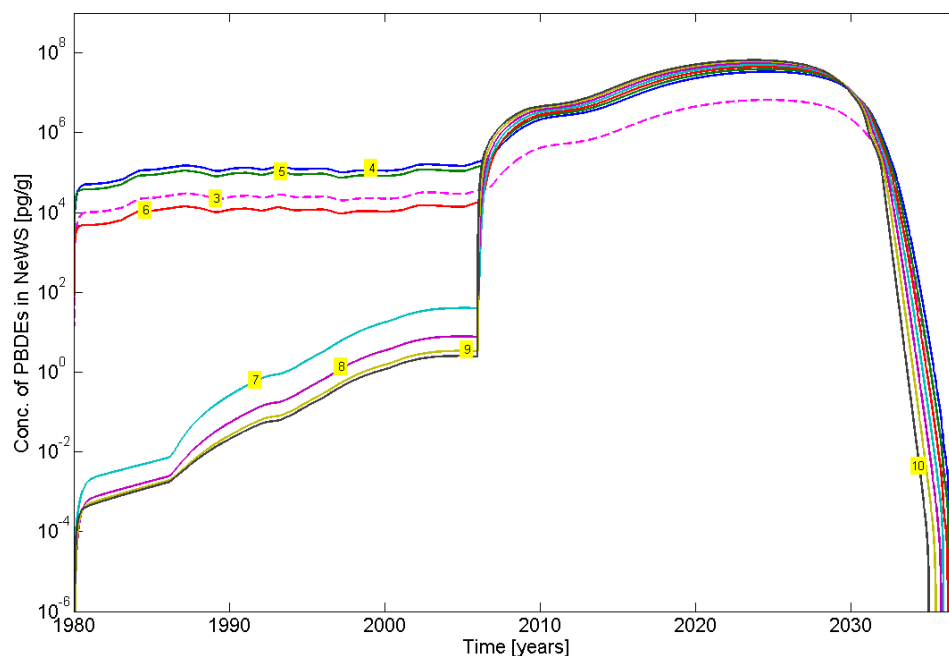


Figure 9.18. Predicted PBDE concentrations for the eight congener groups in the *NeWS* subsystem vs. time for Case 2-C. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

Case 2-D is similar to Case 2-B, with the same input parameters and assumptions, except that all kinetic rate constants are now decreased tenfold, i.e. with all rate constants of BDE decomposition ten times slower than for the base case and one hundred times slower than for Case 2-C. This is again to test the sensitivity to the rate constants, which are subject to considerable uncertainty.

For all three subsystems within Case 2-D, the trends are again similar to those in Case 2-B. However, as expected, the time interval required to achieve virtual elimination of all PBDEs was much longer than for Case 2-B (i.e. ~100+ years slower). Furthermore, as shown by comparing Figures 9.19, 9.20 and 9.21 with Figures 9.13, 9.14 and 9.15, respectively, the maximum concentrations of all chemical species increased by ~ one order of magnitude. The stepwise sequence follows the same order as for Case 2-B. However, in Case 2-D, the differences between the concentrations of successive congener groups are much larger, due to the much slower transfer from each congener family to the next (i.e. decrease of N by 1) as a result of the much lower kinetic rate constants.

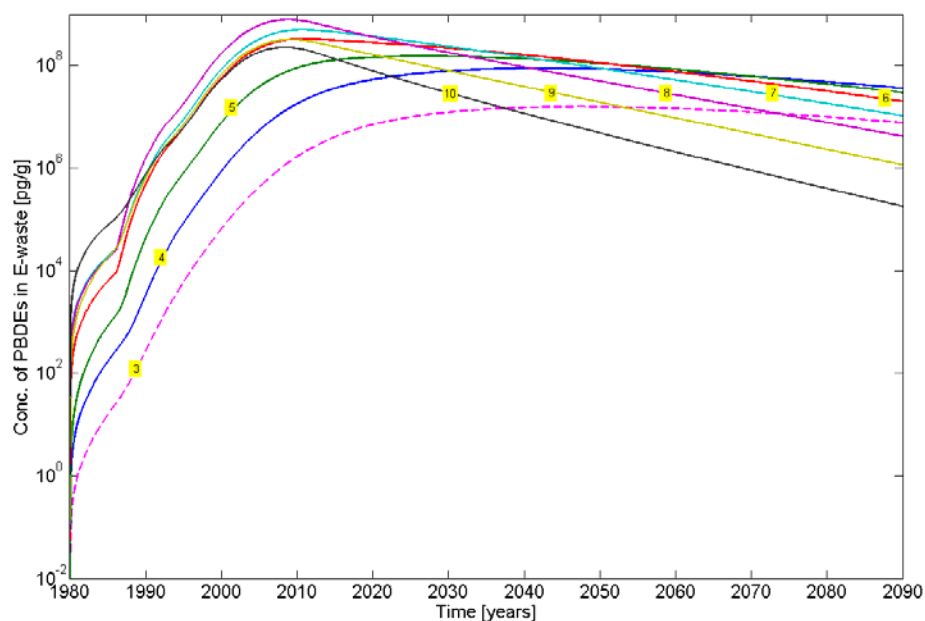


Figure 9.19. Predicted PBDE concentrations for the eight congener groups in the *e-waste* subsystem vs. time for *Case 2-D*. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

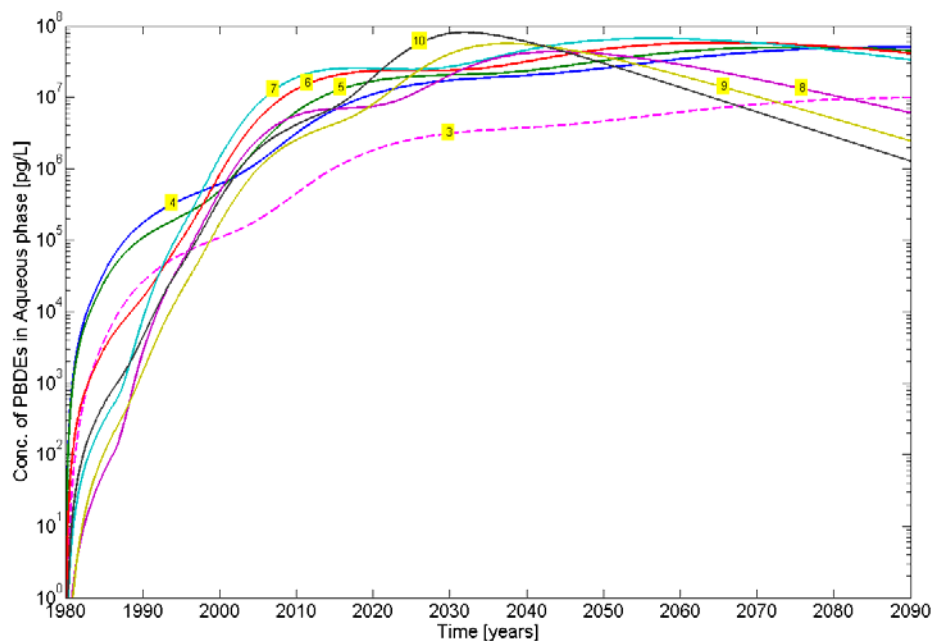


Figure 9.20. Predicted PBDE concentrations for the eight congener groups in the *aqueous* phase subsystem vs. time for *Case 2-D*. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

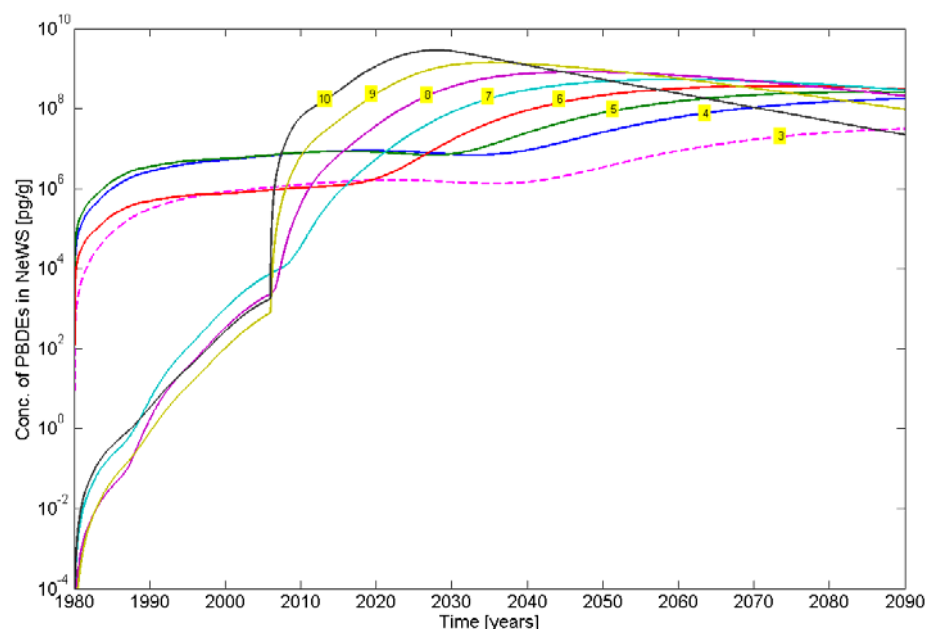


Figure 9.21. Predicted PBDE concentrations for the eight congener groups in the *NeWS* subsystem vs. time for Case 2-D. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

9.3.4 Cases 2-E and 2-F: Sensitivity to NeWS/e-waste Mass Transfer

The next two cases were tested because of the considerable uncertainty in the mass transfer between the subsystems. The product (e-waste to NeWS volumetric mass transfer coefficient, $k_{ci(1 \rightarrow 4)} a_{I(1 \rightarrow 4)}$), determines the total rate of mass exchange between the e-waste and NeWS subsystems, lumping together two parameters that influence mass transfer of all species between compartments. Errors or variations in particle size, particle shape, or mass transfer coefficient, would directly affect this mass transfer term. In Case 2-E, the baseline value of $k_{ci} a_I$ was increased by one order of magnitude for e-waste to NeWS exchange.

From comparison of Figure 9.22 with Figure 9.13 (e-waste subsystem), Figure 9.23 with 9.14 (aqueous subsystem) and Figure 9.6 with 9.15 (NeWS subsystem), we see that there was negligible effect of increasing the rate of e-waste to NeWS mass transfer by a factor of 10.

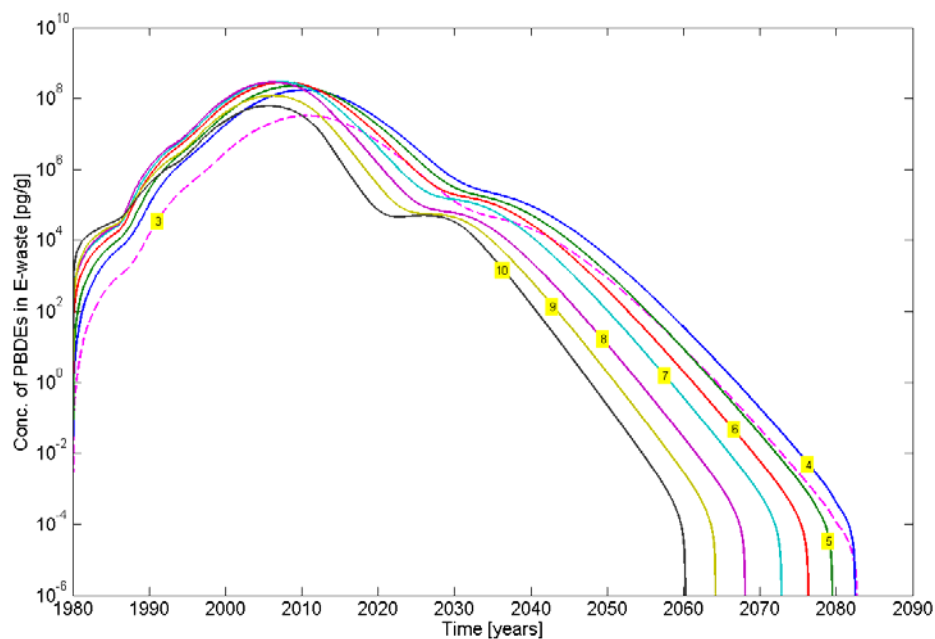


Figure 9.22. Predicted PBDE concentrations for the eight congener groups in the *e-waste* subsystem vs. time for Case 2-E. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

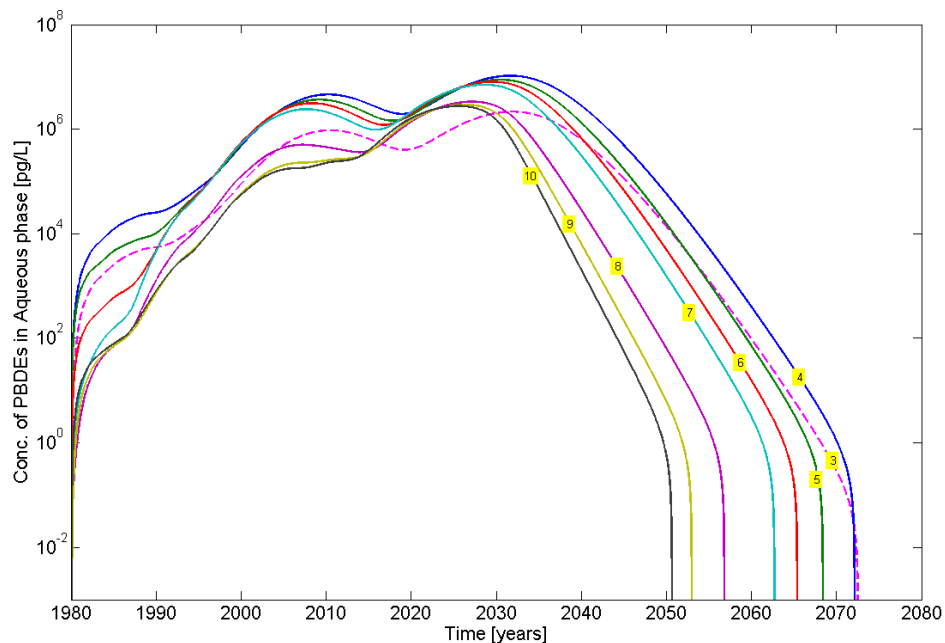


Figure 9.23. Predicted PBDE concentrations for the eight congener groups in the *aqueous* phase subsystem vs. time for Case 2-E. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

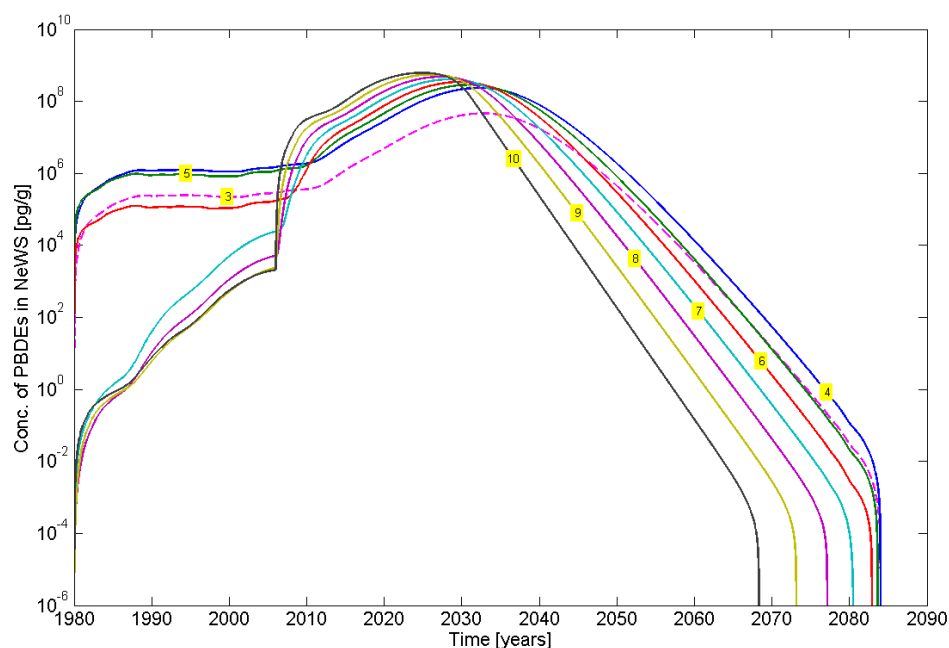


Figure 9.24. Predicted PBDE concentrations for the eight congener groups in the *NeWS* subsystem vs. time for Case 2-E. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

In Case 2-F, all values of $k_{ci}a_i$ were decreased by one order of magnitude, so that they are also two orders of magnitude smaller than in Case 2-E. Predictions for this case are plotted in Figures 9.25, 9.26 and to 9.27. These curves again behaved in a similar manner as those in Case 2-B, i.e. to Figures 9.13, 9.14 and 9.15, respectively, with only a small increase in the total debromination times compared to Case 2-B. From Cases 2-E and 2-F, we infer that the mass transfer rate between the e-waste and the NeWS subsystems is not rate-determining. Even a large error in the assumed value of $k_{ci(1 \rightarrow 4)}a_{I(1 \rightarrow 4)}$ would cause little error in the predictions.

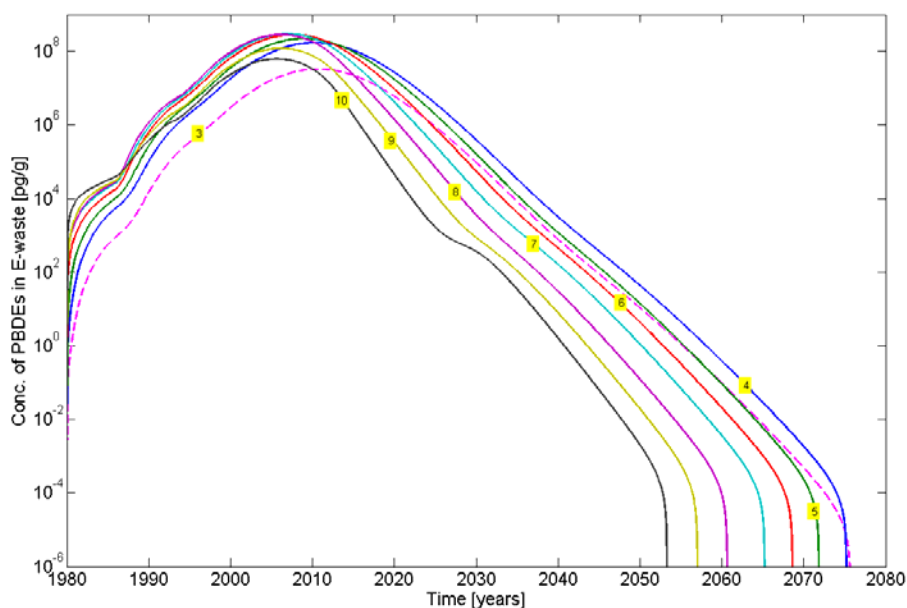


Figure 9.25. Predicted PBDE concentrations for the eight congener groups in the *e-waste* subsystem vs. time for *Case 2-F*. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

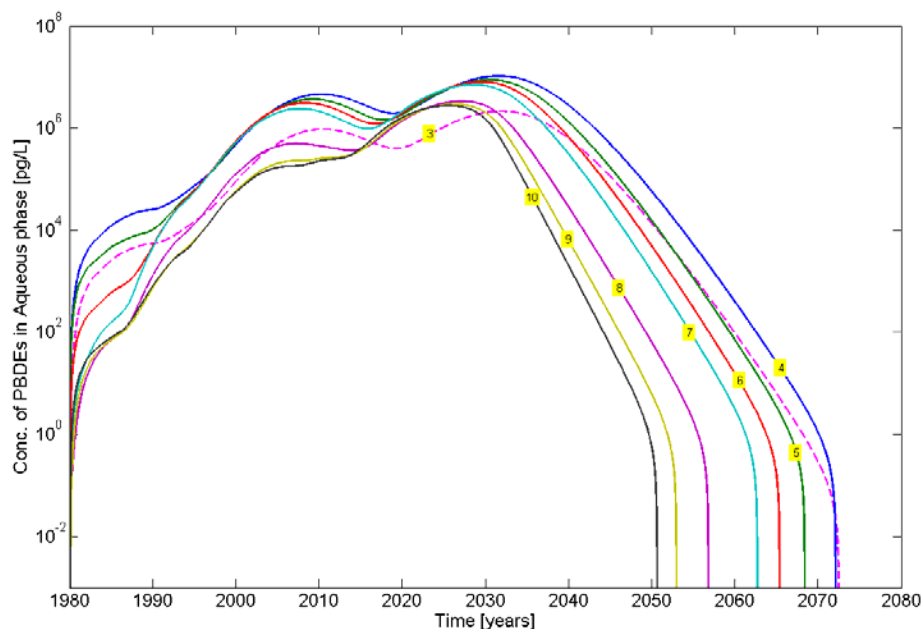


Figure 9.26. Predicted PBDE concentrations for the eight congener groups in the *aqueous* phase subsystem vs. time for *Case 2-F*. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

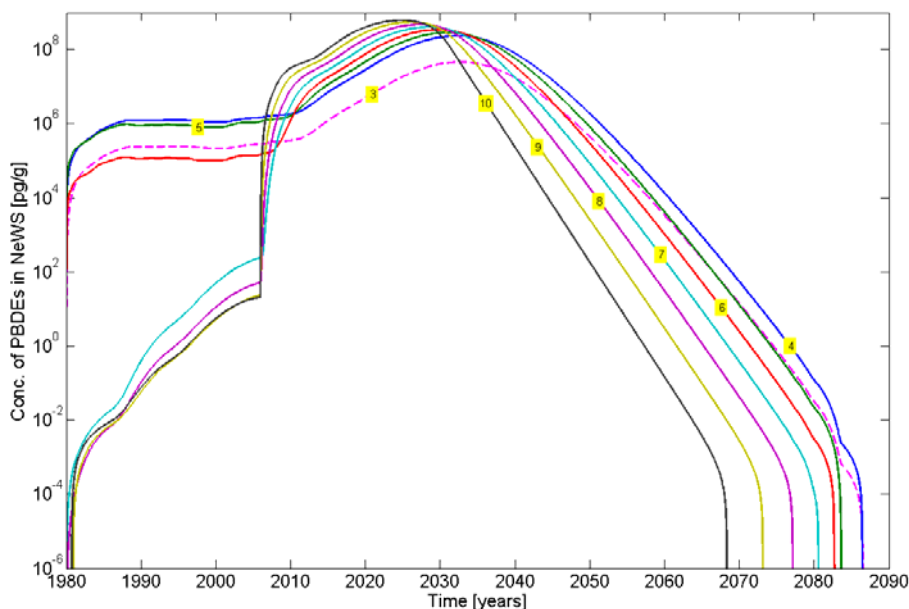


Figure 9.27. Predicted PBDE concentrations for the eight congener groups in the *NeWS* subsystem vs. time for Case 2-F. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

9.3.5 Cases 2-G and 2-H: Sensitivity to All Mass Transfer Rates

Cases 2-G and 2-H again examine variations in Case 2-B, but the aim in this case is to test the sensitivity to the rate of mass transfer between all three active subsystems. Hence, the three mass transfer volumetric coefficients (e-waste / aqueous, aqueous / *NeWS*, and *NeWS* / e-waste) were increased tenfold in Case 2-G and decreased tenfold in Case 2-H.

Predictions for Case 2-G appear in Figures 9.28, 9.29 and 9.30. The shapes of all curves are virtually the same as for Case 2-B (Figures 9.13, 9.14 and 9.15). A small increase in total debromination time for the e-waste subsystem is visible when Figures 9.28 and 9.13 (e-waste subsystem) are compared. In the *NeWS* subsystem (Figure 9.29) the time for virtual elimination of all PBDEs is almost the same as in Case 2-B, but increases by ~2 years in the aqueous subsystem (Figure 9.30). There are also small changes in the deca-, nona-, octa- and hepta-curves for Case 2-G relative to 2-B. For the first 27 years of simulation, the concentrations of these BDE congeners are somewhat higher in the *NeWS* subsystem because the only source of these higher BDE congeners is via mass transfer (see Figure 8.12). The difference is less visible after ~2008 when high BDE congeners are introduced via the input to the *NeWS* compartment. The largest change occurs in the aqueous compartment where the maximum concentrations of all BDE species increase by ~ one order of magnitude for Case 2-G compared to 2-B. However,

mass transfer again does not appear to be rate-limiting given the similar overall times for virtual disappearance of all PBDEs from the landfill.

Since the greatest uncertainty in modelling is likely to be with the estimate of mass transfer, and the e-waste particles in a landfill are nearly stationary after being added, whereas those in the end-over-end contactor were periodically disturbed, additional sensitivity analyses were conducted with the mass transfer coefficient decreased by factors of 100 (Scenario 2-I) and 1000 (Scenario 2-J). These two cases gave results very similar to those for the other cases where only the mass transfer coefficient was larger, again indicating that mass transfer is not rate controlling.

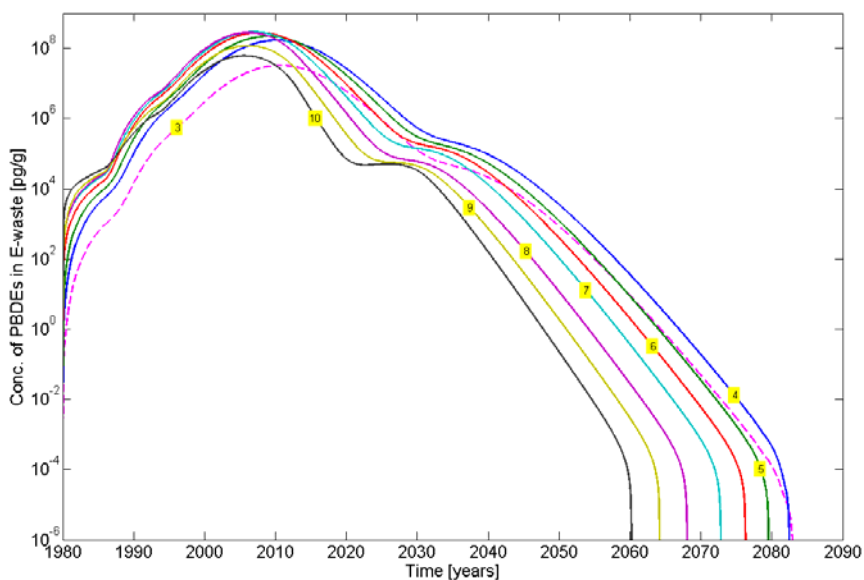


Figure 9.28. Predicted PBDE concentrations for the eight congener groups in the *e-waste* subsystem vs. time for Case 2-G. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

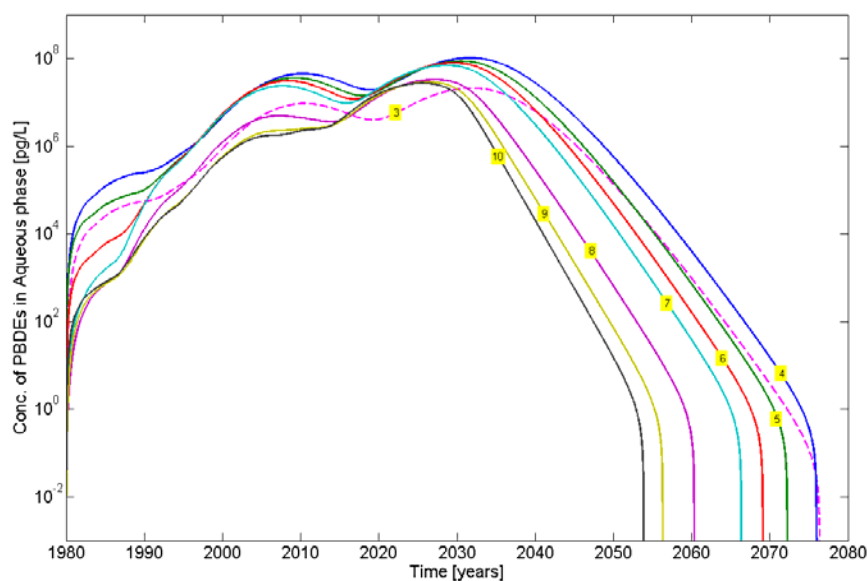


Figure 9.29. Predicted PBDE concentrations for the eight congener groups in the *aqueous* phase subsystem vs. time for Case 2-G. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

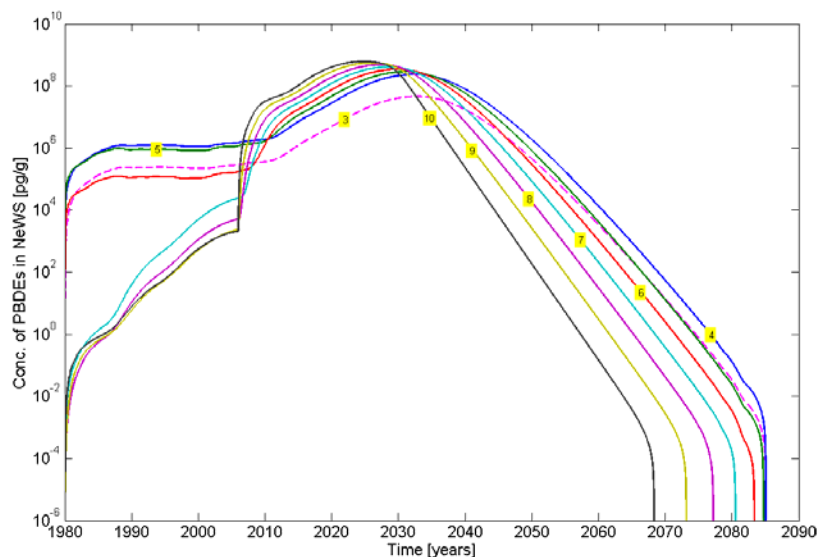


Figure 9.30. Predicted PBDE concentrations for the eight congener groups in the *NeWS* subsystem vs. time for Case 2-G. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

In Case 2-H where all mass transfer coefficients are decreased by one order of magnitude, i.e. by a factor of 10 relative to Case 2-B, the shapes of the predicted concentration vs. time curves shown in Figures 9.31, 9.32 and 9.33 are again similar to those for Cases 2-B (Figures 9.13, 9.14 and 9.15, respectively). A small decrease in total time for virtual elimination of PBDEs from the e-waste subsystem is visible if one compares Figures 9.13 and 9.31. In the NeWS subsystem (Figure 9.33), the total debromination time is almost the same as for case 2-B (Figure 9.15), but there is a decrease of ~2 years for the aqueous subsystem (Figure 9.14 and 9.32).

A similar phenomenon occurs in the e-waste compartment as for Case 2-G, but in the opposite direction, i.e. there is a decrease in higher-brominated congeners (deca, nona, octa, and hepta) for the first ~ 27 years of simulation. The largest change is in the aqueous compartment (Figures 9.14 and 9.32). However, the sensitivity analysis again demonstrates that the effect of inter-compartment mass transfer on the timing of virtual disappearance of PBDEs from the landfill is again small.

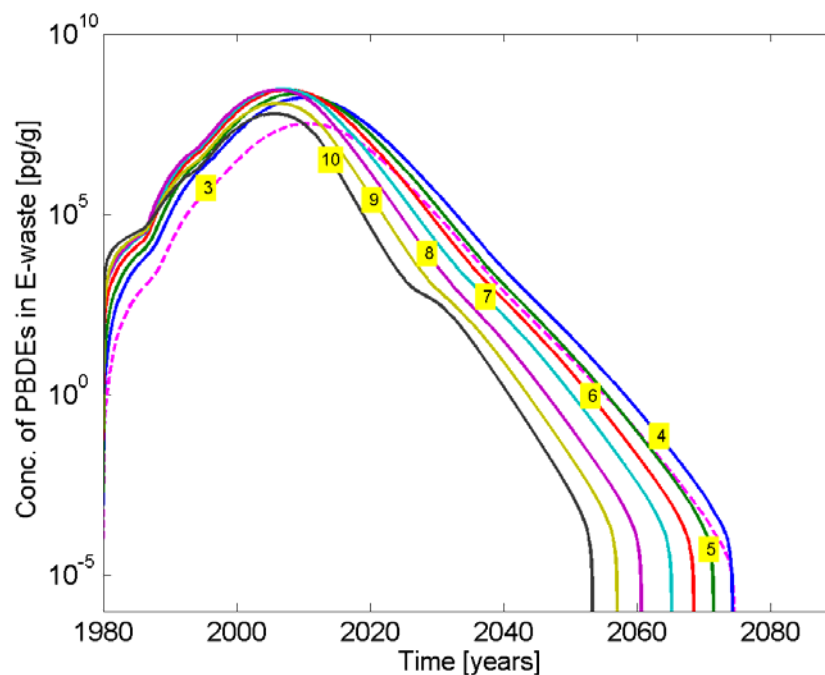


Figure 9.31. Predicted PBDE concentrations for the eight congener groups in the *e-waste* subsystem vs. time for *Case 2-H*. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

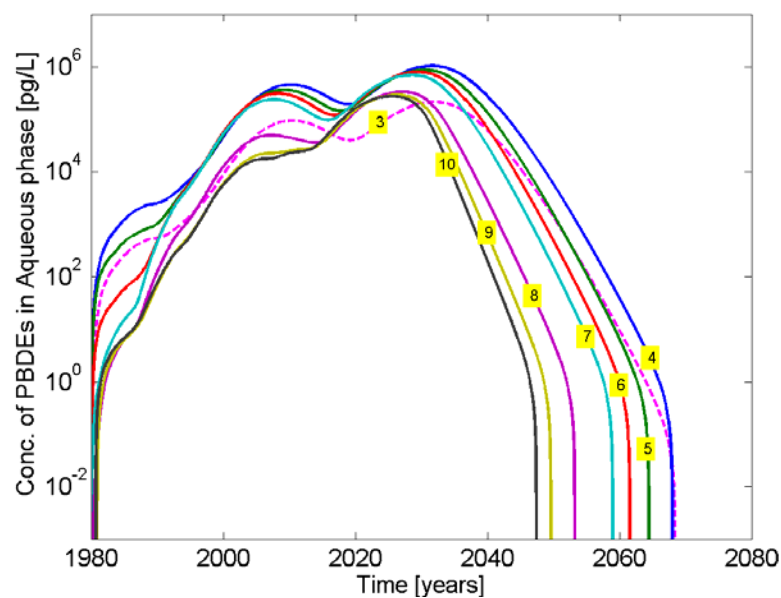


Figure 9.32. Predicted PBDE concentrations for the eight congener groups in the *aqueous* phase subsystem *vs.* time for *Case 2-H*. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

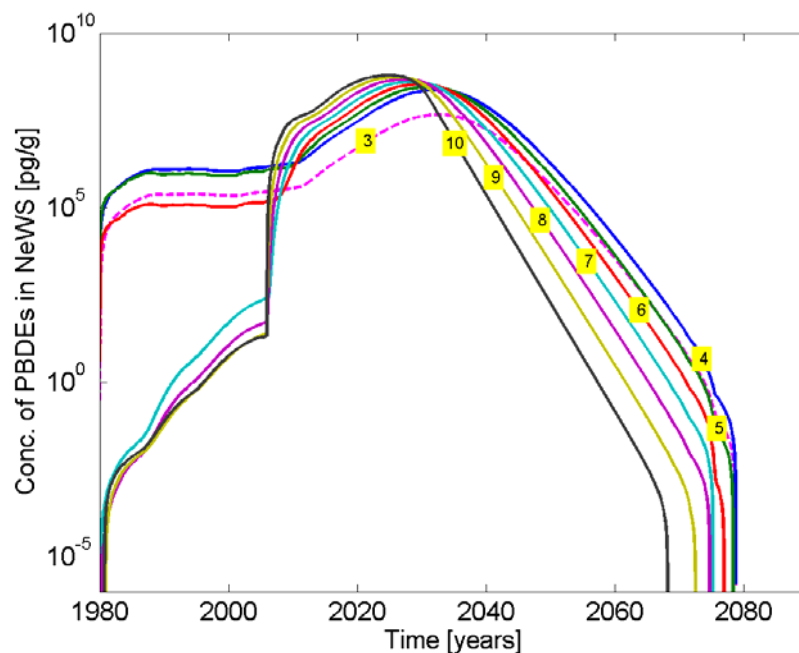


Figure 9.33. Predicted PBDE concentrations for the eight congener groups in the *NeWS* subsystem *vs.* time for *Case 2-H*. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

9.4 Scenario 3: Future with Complete Termination of PBDE Inputs

Scenario 3 simulates the same landfill system starting in 2008 based on the same model as in the previous scenarios, but with initial conditions derived from the final (2008) concentrations predicted by Scenario 1, as listed in Table 9.1. Cases 3-A, 3-B, and 3-C begin with the

concentrations of all PBDEs derived from Cases 1-A, 1-B or 1-C, respectively. The input concentrations for all subsystems are assumed to have become negligible after 2008, to simulate what could happen if there were to be a global and immediate ban on adding brominated flame retardants to landfills. This scenario therefore allows the longevity of PBDEs already in the landfill to be estimated. For this scenario, it is assumed that not only has the manufacture of PBDEs been discontinued, but that all remaining PBDE-containing products are chemically treated or incinerated so that they no longer enter landfills. Table 8.5 gives the simulation conditions.

Not surprisingly, the simulation predicts that it takes longer for the PBDE concentrations to decline to given concentrations for cases with higher initial concentrations. The aqueous subsystem is consistently the first compartment to essentially eliminate PBDEs. This occurs because all PBDE input to the aqueous phase originates from mass transfer from the NeWS and e-waste subsystems as well as the faster kinetics assumed for the aqueous phase (Table 8.2).

Initial values for Case 3-A are the 2008 predicted values from Case 1-A. Predictions are depicted in Figure 9.34. All subsystems follow similar dynamics. After inputs of all brominated components were terminated, all homologue group concentrations drop over time. Most of this decrease is due to chemical decomposition of brominated species to lower molecular weight compounds. The continuous circulation of the aqueous phase acts as a carrier that transfers PBDEs beyond the system's boundary. There is output via the aqueous and air subsystems. The higher-molecular-weight BDEs disappear much earlier than the lighter PBDEs, with the order in which the BDE congener groups decrease in concentration following the sequence of debromination reactions. The time needed to eliminate almost all of the deca-BDE in e-waste is predicted to be ~30 years, whereas for penta- it is ~50 years, and for tetra- and tri-BDEs ~55 years. It is clear that the lowest BDE congeners are the most persistent of all PBDE homologues, because of the assumed sequential debromination.

A similar pattern is predicted for the aqueous subsystem, but virtual elimination is predicted to be reached ~20 years earlier, as shown by comparing Figure 9.35 (aqueous subsystem, Case 3-A) with Figure 9.14 (Case 2-B). Comparing Figure 9.36 (NeWS subsystem, Case 3-A) with Figure 9.15 (Case 2-B), we see that the predicted time for PBDE near-elimination in the NeWS subsystems lies between the corresponding times for the e-waste and aqueous phase subsystems.

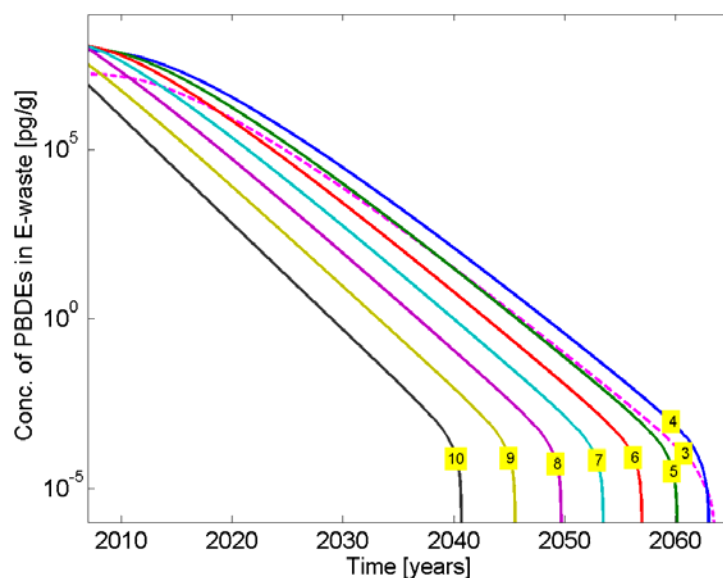


Figure 9.34. Predicted PBDE concentrations for the eight congener groups in the *e-waste* subsystem vs. time for *Case 3-A*. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

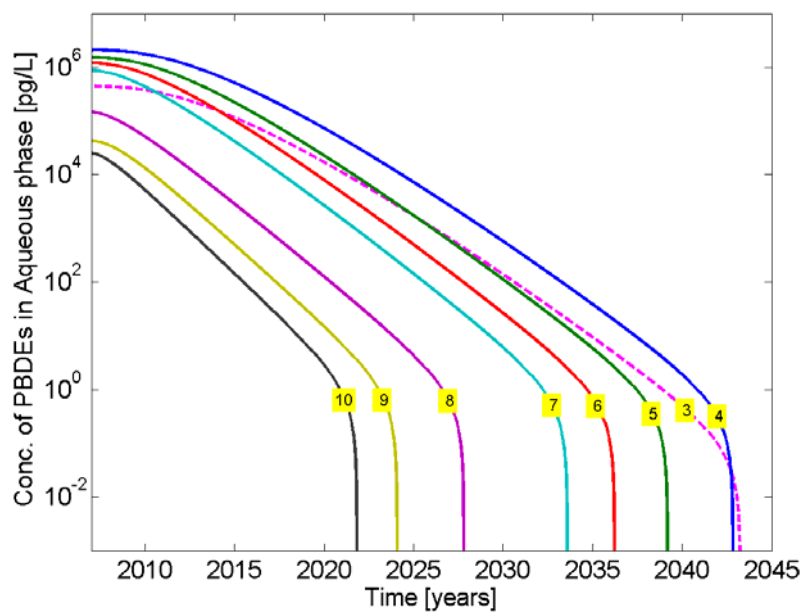


Figure 9.35. Predicted PBDE concentrations for the eight congener groups in the *aqueous* phase subsystem vs. time for *Case 3-A*. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

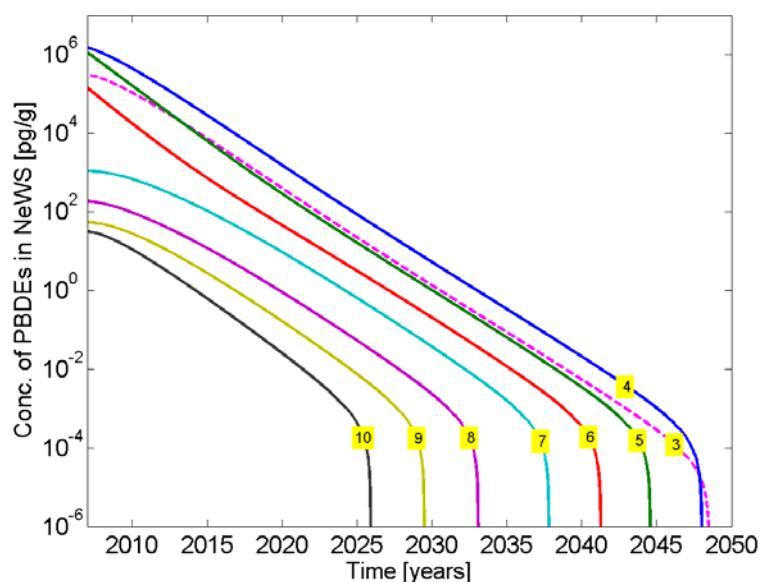


Figure 9.36. Predicted PBDE concentrations for the eight congener groups in the NeWS subsystem vs. time for Case 3-A. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

Case 3-B simulates the natural removal of PBDEs in a landfill system using as initial values the 2008 simulation predictions from Case 1-B. In the case of deca-BDE, the initial value in the aqueous phase subsystem is predicted as zero. For all subsystems in this case, the convective PBDE input is eliminated from 2009 onward, but mass transfer continues to apply among the three compartments. As in the other sections, the air subsystem is effectively not considered in the modeling except for the inclusion of the deposition flux, needed to explain the Northern Canada findings.

For the e-waste system, given the lower starting concentrations compared with Case 3-A, faster disappearance is predicted, as shown in Figure 9.37. The time needed to eliminate almost all of the deca-BDE originating from e-waste is predicted to be ~15 years (starting in 2008), whereas the time to virtually eliminate penta- is ~35 years, and that for tetra- and tri--BDEs ~35 years. The tri- BDE congeners persist longer because they form by debromination of the higher congeners.

Predictions for the aqueous subsystem appear in Figure 9.38. The higher and mid-BDE congeners are predicted to be virtually eliminated within ~10-15 years, whereas the penta-, tetra- and tri-BDEs virtually disappear in 15 to 19 years. For the NeWS subsystem (Figure 9.39) there is a split between the higher BDE and mid-to-tri- BDE congeners, similar to the PBDE concentration profiles predicted for Case 1-B, due to the influence of the initial values (final values from Case 1-B).

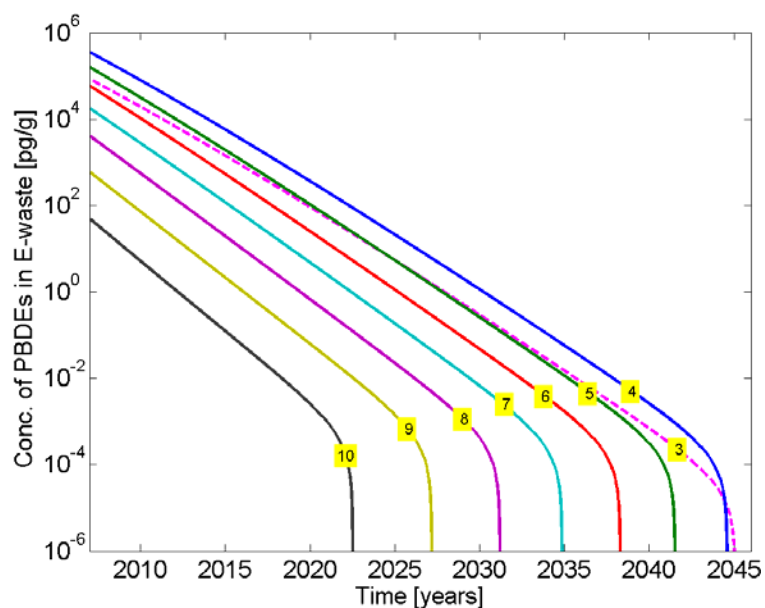


Figure 9.37. Predicted PBDE concentrations for the eight congener groups in the *e-waste* subsystem vs. time for *Case 3-B*. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

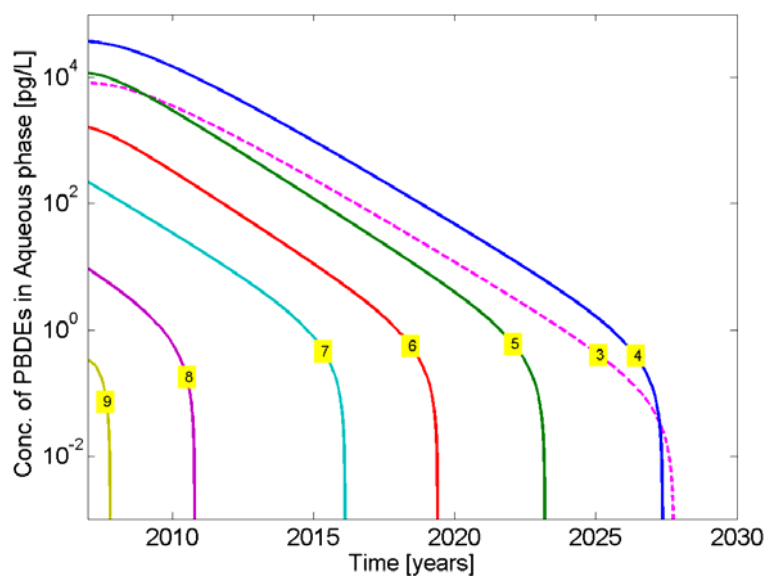


Figure 9.38. Predicted PBDE concentrations for the eight congener groups in the *aqueous* phase subsystem vs. time for *Case 3-B*. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

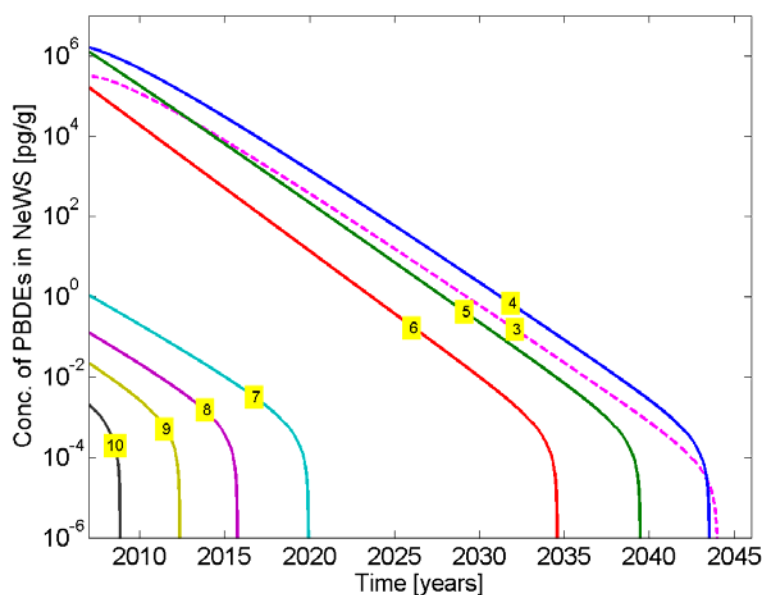


Figure 9.39. Predicted PBDE concentrations for the eight congener groups in the *NeWS* subsystem vs. time for Case 3-B. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

Case 3-C predicts the rate of removal of PBDEs in a landfill system using as initial values the 2008 simulation predictions from Case 1-C, again with all PBDE input terminated thereafter.

For the e-waste system as shown in Figure 9.40, deca- again declines most rapidly. The predicted time needed to eliminate virtually all deca-BDE from the e-waste compartment is predicted to be ~37 years, whereas the time to nearly eliminate tetra- and tri-BDE is ~60 years. The lower BDE congeners are again predicted to be the most persistent of all PBDE homologues.

In the aqueous subsystem, deca- BDE is predicted to be virtually eliminated within ~20 years, nona-BDEs in ~21 years and the octa-BDEs in ~24 years; the remaining BDEs are predicted to be effectively eliminated in ~32-40 years, as displayed in Figure 9.41. The predictions in Figure 9.42 for the *NeWS* subsystem display similar behaviour, i.e. the time to almost eliminate all PBDE congener groups is virtually the same.

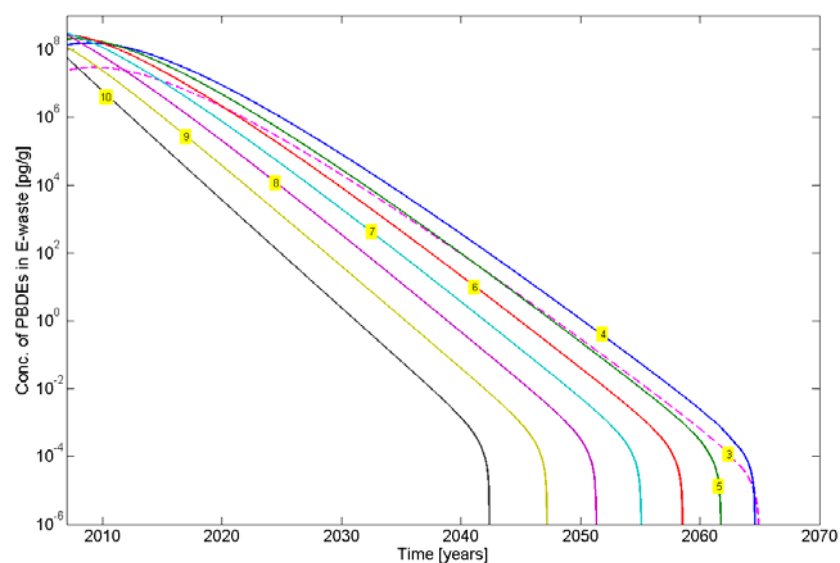


Figure 9.40. Predicted PBDE concentrations for the eight congener groups in the *e-waste* subsystem vs. time for Case 3-C. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

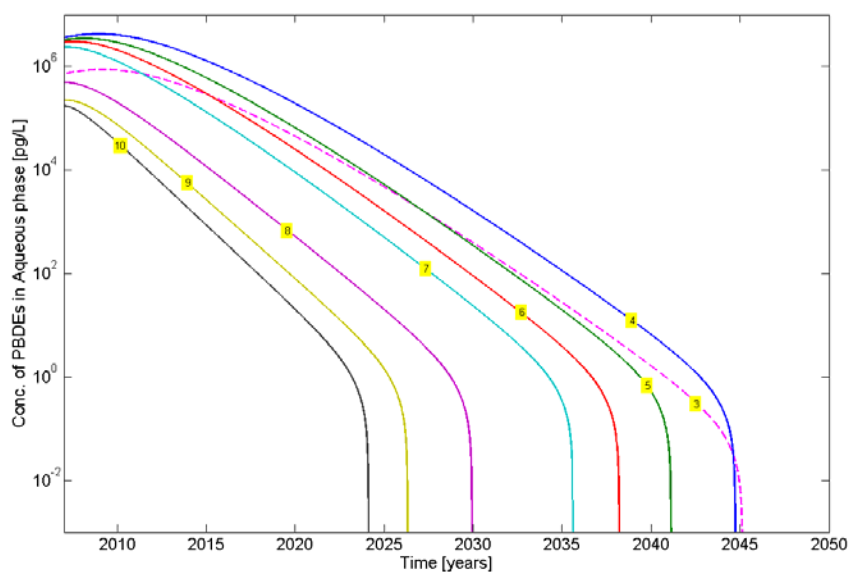


Figure 9.41. Predicted PBDEs concentrations for the eight congener groups in the *aqueous* subsystem vs. time for Case 3-C. The numbers indicate the number of bromine atoms of each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

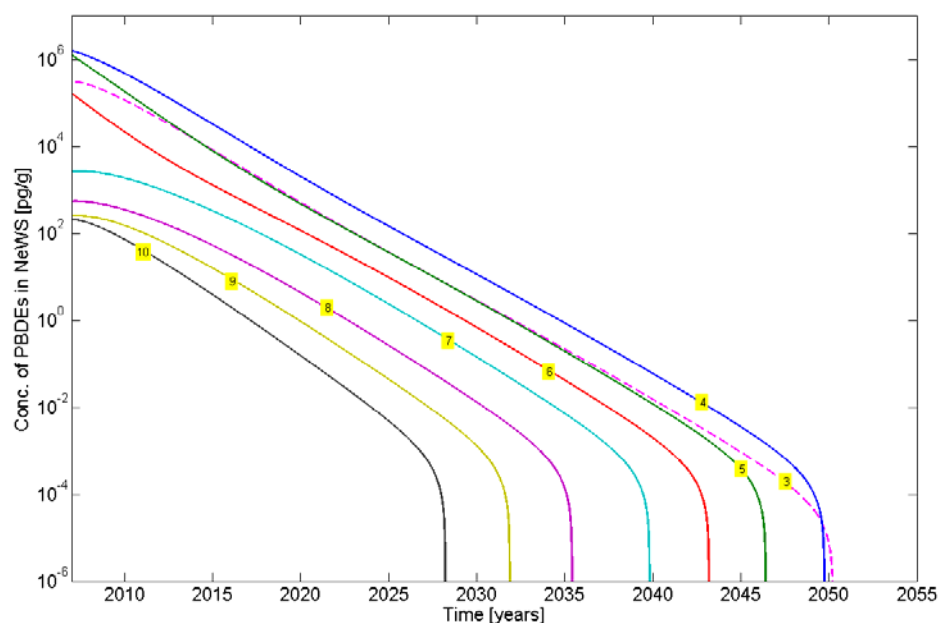


Figure 9.42. Predicted PBDE concentrations of total congener groups in the *NeWS* subsystem vs. time for Case 3-C. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs). For simulation conditions see Tables 8.5 and 8.12.

9.5 Conclusions

Fourteen simulations investigated a variety of conditions under which PBDEs leaching from e-waste and NeWS would vary over time. For convenience, the predictions are summarized in Figures 9.43 to 9.48. More accurate data on debromination reaction kinetics and improvements in other aspects of the model are needed to improve the quantitative predictability of the model. A number of general conclusions can, however, be drawn from these simulations:

For all cases the lower-brominated BDEs take longer to disappear than high-molecular weight PBDEs, due to the debromination of PBDEs taking place in a stepwise manner, according to the simplified debromination reaction scheme adopted. Mass transfer caused the patterns of decay to be similar in all compartments.

The aqueous phase subsystem is predicted in all cases to be the first of the three compartments considered to virtually eliminate PBDEs if input to the landfill were to be stopped. The NeWS compartment would be next, followed by the e-waste subsystem.

The model contains many approximations and simplifying assumptions. Since there is also considerable scatter in the measured landfill concentrations, there are large discrepancies between predictions and experimental values. The key value of the model is therefore to provide qualitative understanding of trends and of the influence of key variables.

The model simulations indicate that it is essential to determine accurate chemical kinetics (and pathways) of the debromination reactions. Mass transfer phenomena turns out to be less important in determining the concentrations of BDEs in landfills over the long term.

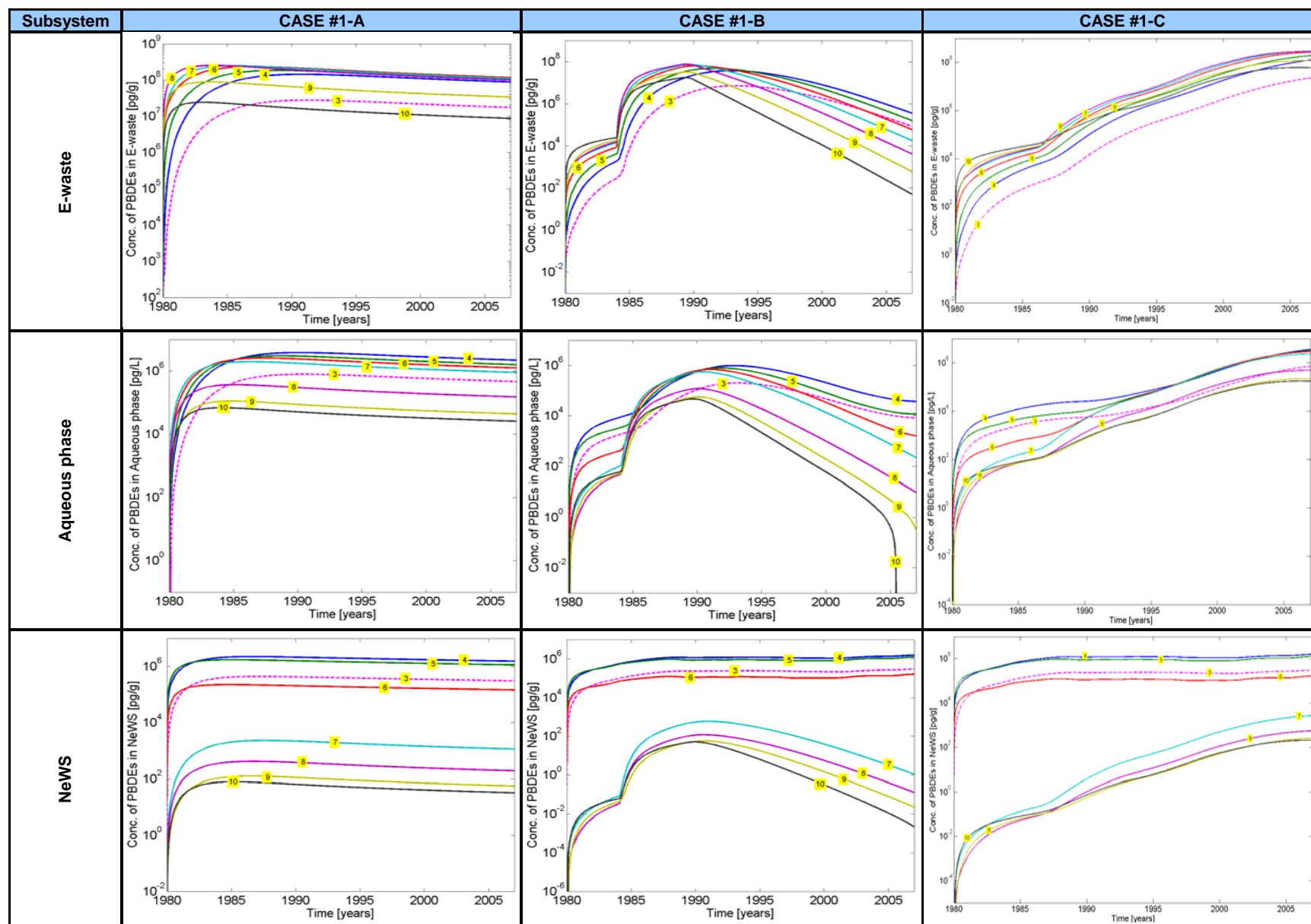


Figure 9.43 Mass balance simulation results for *Case 1-A*, *1-B*, and *1-C* showing the effect of input function. Predicted PBDE concentrations of the eight congener groups in the 3 subsystems vs. time. Numbers indicate the number of bromine atoms for each congener group (3=tri-, di- and mono-BDEs)

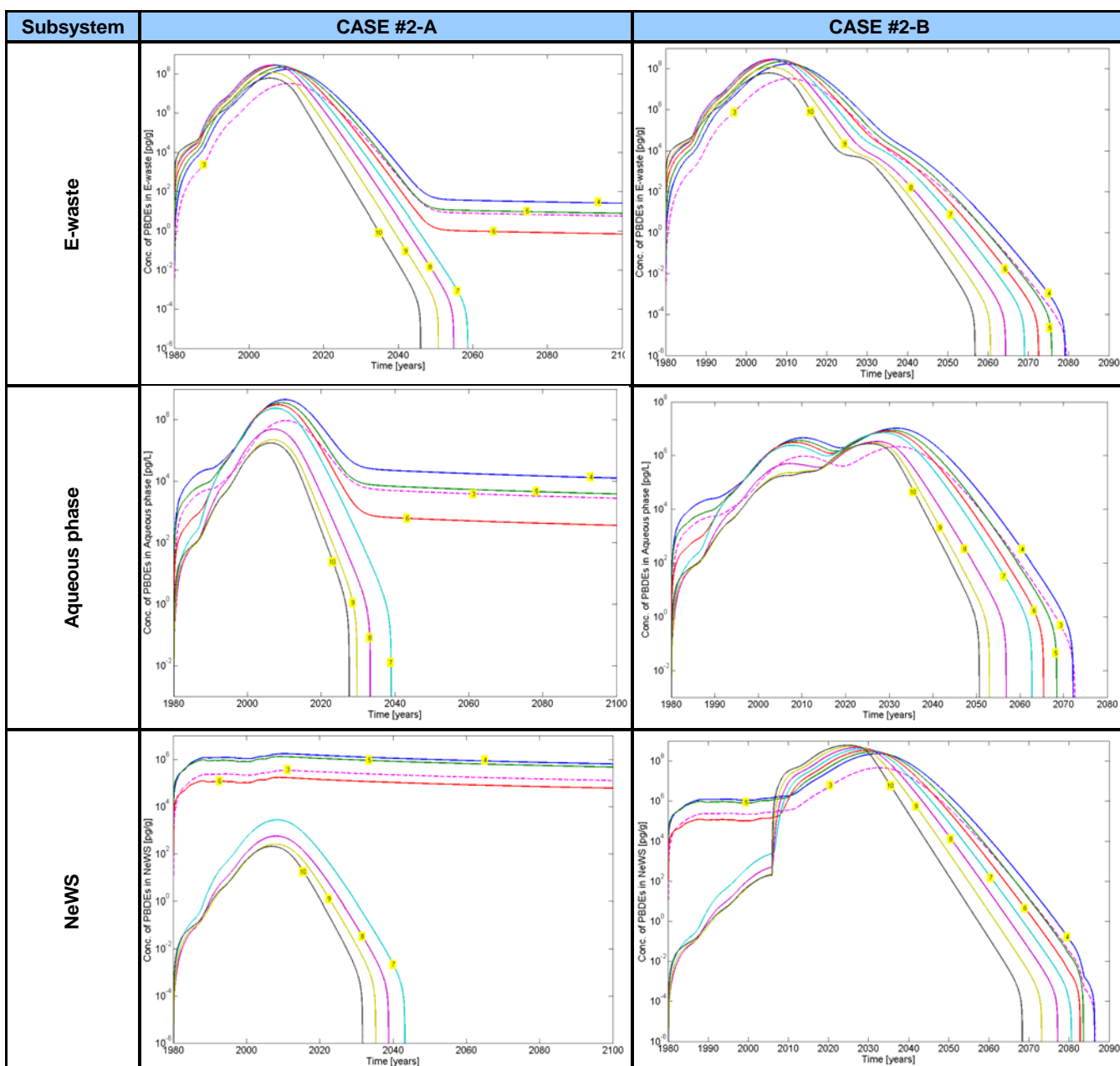


Figure 9.44 Mass balance simulation results for *Cases 2-A* and *2-B*, projecting forward if incorporation of PBDEs in e-waste were to stop. Predicted PBDE concentrations of the eight congener groups in the 3 subsystems vs. time. Numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs).

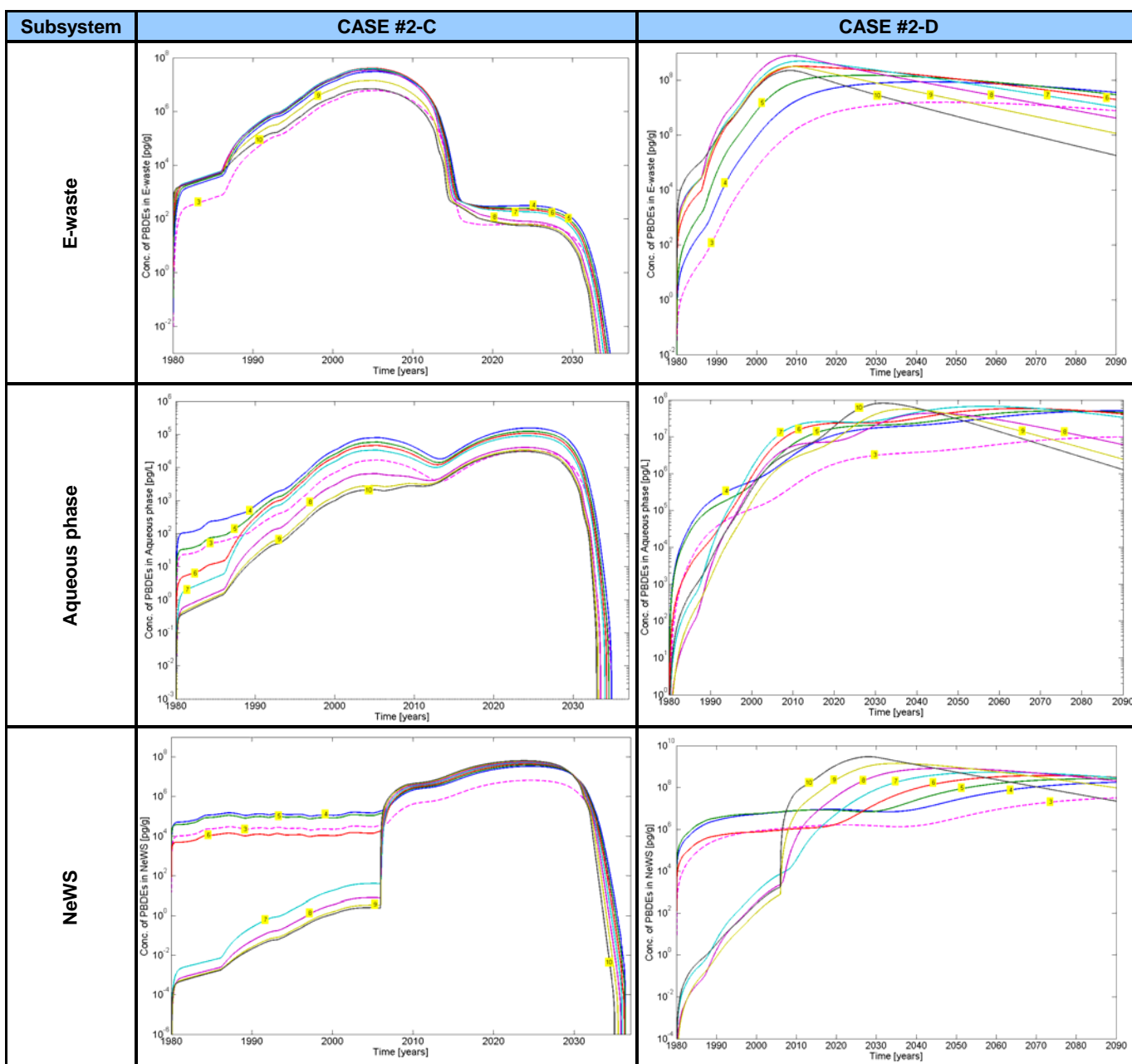


Figure 9.45. Mass balance simulations for *Cases 2-C* and *2-D*, showing sensitivity to debromination rate constants. Predicted PBDE concentrations of the eight congener groups in the 3 subsystems vs. time. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs).

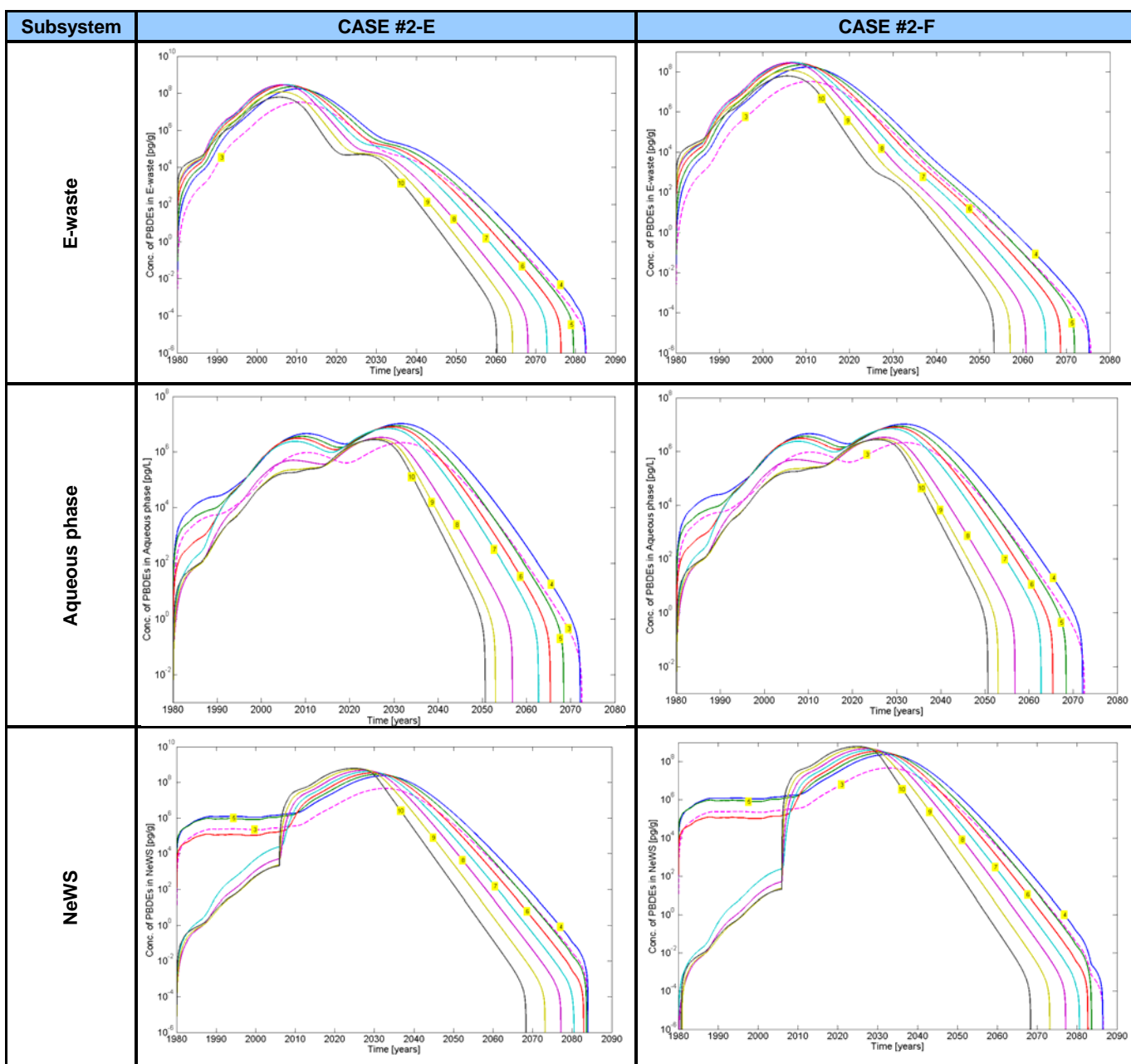


Figure 9.46. Mass balance simulation results for *Cases 2-E* and *2-F* showing predicted PBDE concentrations of the eight congener groups in the 3 subsystems vs. time. Numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs).

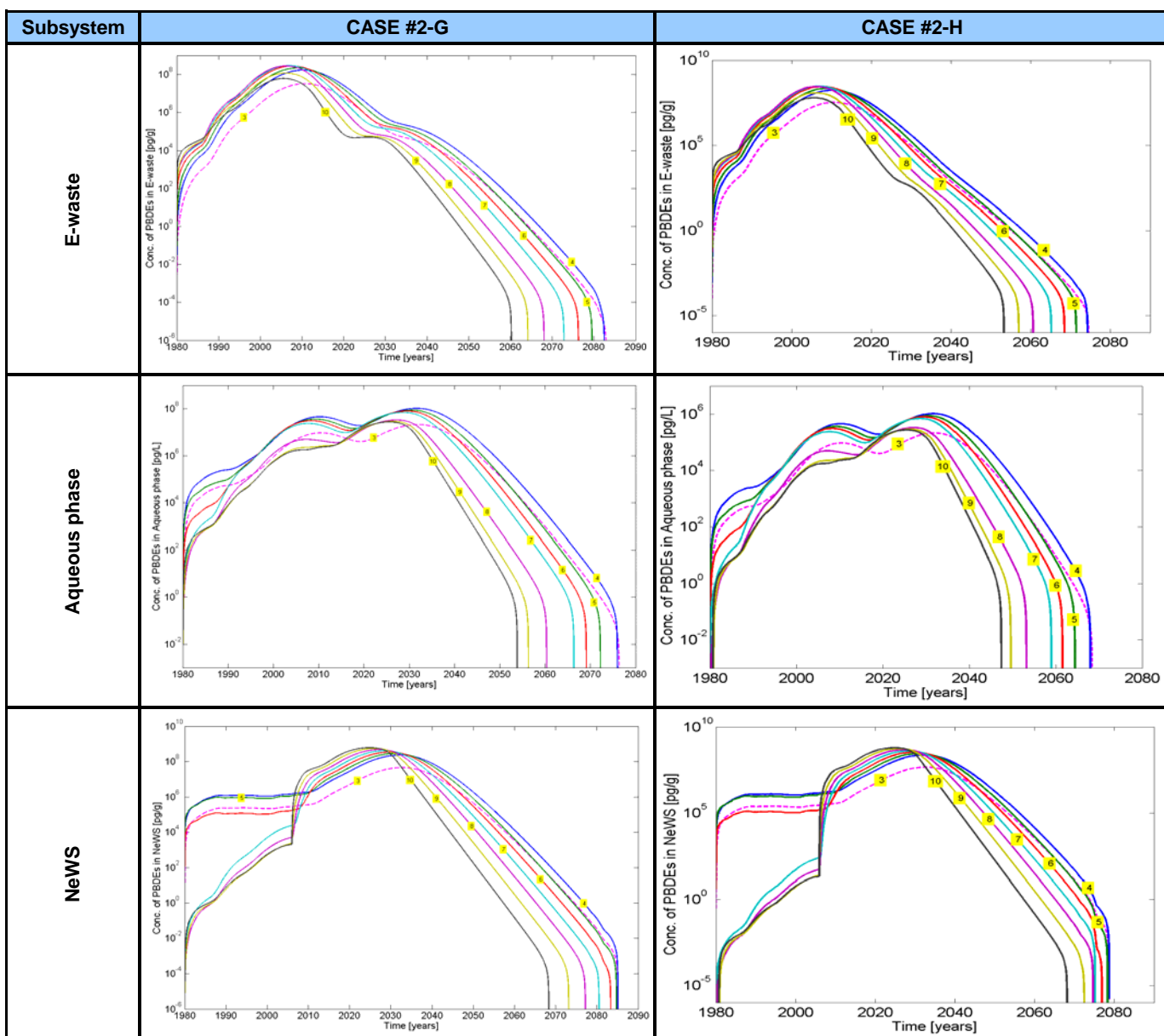


Figure 9.47. Mass balance simulation results for *Cases 2-G* and *2-H*, showing predicted PBDE concentrations of the eight congener groups in the 3 subsystems vs. time. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs).

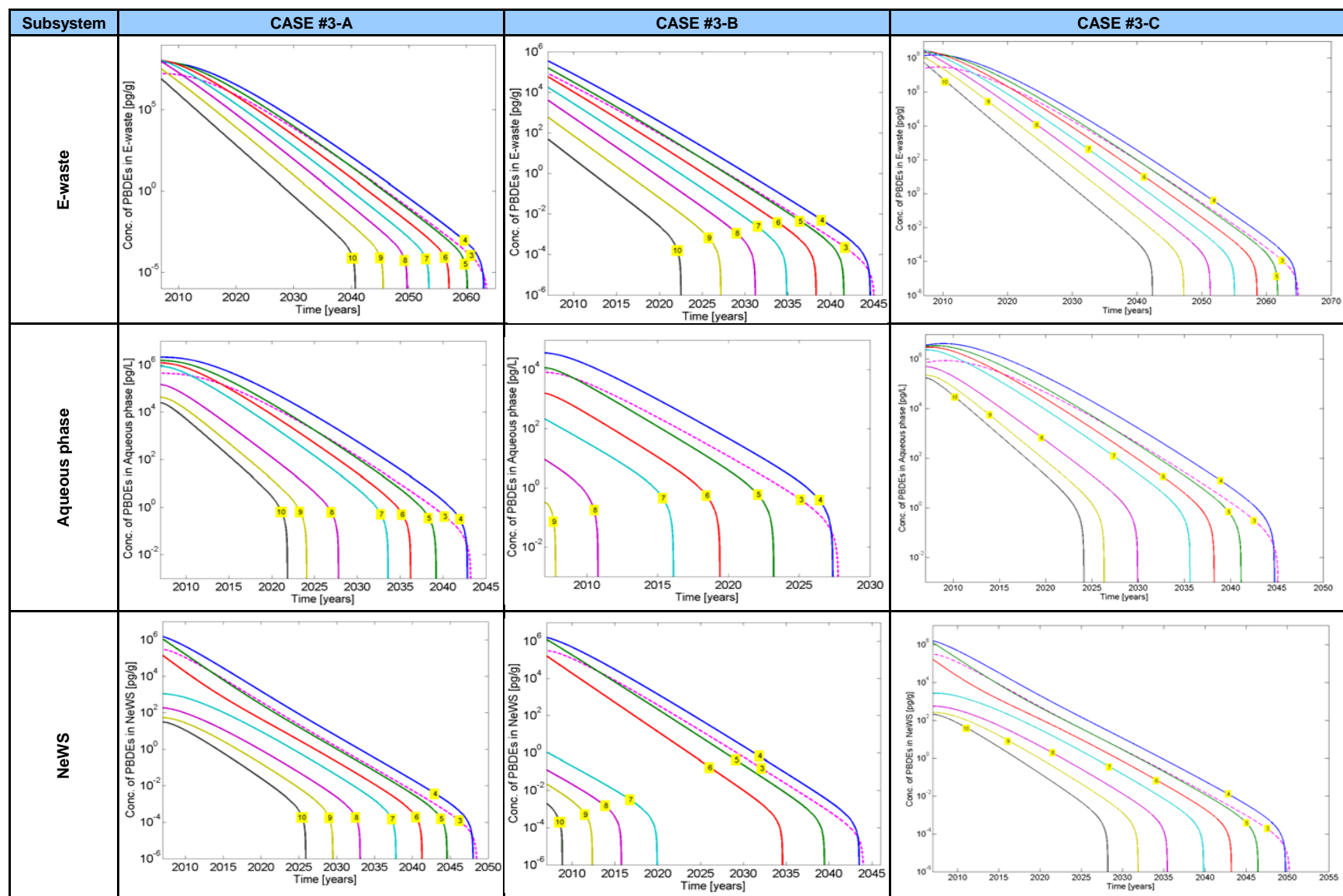


Figure 9.48 Mass balance simulation results for Cases 3-A, 3-B, and 3C, showing predicted PBDE concentrations of the eight congener groups in the 3 subsystems vs. time. The numbers indicate the number of bromine atoms for each congener group (3 = tri-, di- and mono-BDEs)

CHAPTER 10 - CONCLUSIONS

10.1 Summary of Major Conclusions

- Experimentally measured PBDE concentrations in leachate, soil and background water from Canadian landfill sites, were most affected by the measured BDE-209 congener.
- There were significant differences in PBDE levels reported by different laboratories, likely due to variations in analytical procedures, in particular related to differences in how fine particles were filtered. Despite the quantitative differences, trends from the data analysed by different labs were similar.
- Contacting of crushed electronic wastes with both distilled water and landfill leachate led to appreciable transfer of PBDEs from solid to liquid. Given the low solubilities of PBDEs in water, the distilled water results probably reflect dislodgement or generation of dust during the contacting. For leachate, transfer of PBDEs from e-waste to the aqueous phase increased with decreasing pH, decreased with increasing temperature and increased with time of contact.
- Leachate samples collected from across Canada varied widely in PBDE levels (<100 to >1,000,000 pg/L of total PBDEs) and in congener distributions (BDE-209 was usually the dominant congener, whereas different locations showed a spread in other main congeners). This variation was no doubt due, at least in part, to uncontrolled variables such as the method and location of sampling, weather variations, collection methods, and rubbish composition.
- The ratios of BDE-47/BDE-99 (0.6 to 0.9 for commercial Penta-BDE DE-71) and BDE-47/BDE-100 (2.6 to 4.2 for commercial Penta-BDE DE-71) measured in the three Northern locations were similar to the Penta-BDE commercial product DE-71 in ten of the sixteen samples collected.
- The commercial Penta-BDE and Octa-BDE products also appeared to be sources of PBDEs at two of the locations where sampling was conducted.
- Dumpsites in Northern Canada generally had lower PBDE concentrations (range from ~25,000 to 150,000 pg/L of total PBDEs) than Canadian landfills south of latitude 60 (range from ~25,000 to 1,100,000 pg/L of total PBDEs).
- There was a moderate correlation between total PBDE concentration and urban population served by the landfill or dumpsite.

- When experiments were carried out in which plastic particles derived from e-wastes were contacted with both distilled water and landfill leachate, the concentrations and proportions of different congeners were similar for the distilled water and leachate experiments, despite the higher solubilities expected for the leachate. This is postulated to be due to ultra-fine particles containing PBDEs entering the aqueous phase, e.g. because of dislodgement of dust from the surface of e-waste particles or abrasion during contacting.
- Contacting composite e-waste with distilled water did not show a significant increase in levels of PBDEs in distilled water beyond 24 hours.
- Higher PBDE concentrations were found at lower pH in the pH 4-9 range investigated.
- Transfer of PBDEs into leachate was similar for the three temperatures (10, 20 and 25°C) investigated, with somewhat lower transfer at lower temperatures, except at the highest pH (9) where the trend reversed.
- Preliminary results from bottom ash, fly ash and residue analysis from a major incinerator show PBDE concentrations in the boiler (bottom ash) and waste (residue) comparable to PBDEs found in leachate from landfills. PBDE concentrations were very low in the fly ash.
- A mechanistic mass balance model was developed to predict the environmental fate of PBDEs from electronic waste streams. A set of first-order ordinary differential equations was developed based on unsteady mass balances for four subsystems (e-waste, air, aqueous stream and non e-waste solids) in the landfill. However, the air compartment was not utilized due to lack of data. Key parameters needed by the model were based on best estimates. PBDE concentrations are predicted at landfills as a function of time for given initial conditions and waste stream characteristics. The time to virtually eliminate PBDEs from existing e-waste added to the landfills is predicted to be ~100 years for the higher brominated congeners. Even if there were to be a total ban on PBDEs so that no further additions were made to newly manufactured products, the accumulated active products would, given their life expectancy, continue to result in PBDEs entering and contaminating landfills for several decades.
- For all scenarios investigated, it is predicted that less-brominated BDEs will take longer to disappear than higher molecular weight PBDEs, due to the lower ones being intermediates in the debromination series of reactions, with debromination taking place in a stepwise manner in the reaction scheme adopted.

- It is predicted that the aqueous phase subsystem will be the first to virtually eliminate PBDEs after no more are added to landfills, followed by the non e-waste solids (NeWS) compartment and lastly the e-waste subsystem.

10.2 Recommendations for Future Work

10.2.1 Extension of this Research

- It would be useful to have more standardized methodologies for PBDE analysis to provide greater consistency in data.
- Experiments should be conducted where e-waste particles are exposed to distilled water for at least 168 h without agitation or motion to shed light on the abrasion hypothesis.
- Monitoring, sampling and analysis of levels of PBDEs should be conducted on a regular basis in urban landfills, sewage treatment plants or waste-to-energy facilities.
- The model simulations indicate that it is essential to determine accurate chemical kinetics (and pathways) of the debromination reactions. Mass transfer phenomena turns out to be less important in determining the concentrations of BDEs in landfills over the long term.
- More research should be conducted to understand the fate, effects, transport, degradation potential, toxicity, and other properties of PBDEs in the environment.
- Quantification of PBDEs in e-waste is important. Research is needed to better estimate PBDE concentrations in mattresses, polyurethane foam, textiles, and auto shredder residues.
- Studies are required to determine the effect of PBDEs in soil.
- More work is needed to obtain more accurate data and to determine the processes which lead to leaching, degradation and spread of PBDEs from landfills.
- More monitoring and duplicate sampling are needed to increase the extent and accuracy of the data set and to elucidate temporal trends.
- Analysis of PBDEs in flue gas from urban waste-to-energy facilities and incinerators is recommended for comparison with landfills.
- It appears that fine particulates can carry PBDEs over long distances. More studies are needed to confirm this and to investigate air and water transport.
- The preliminary model developed here should be improved as further knowledge is gained with respect to estimated quantities.

- The model should also be extended to other contaminants such as Perfluorooctane sulphonate (PFOS) and Perfluorooctanoic Acid (PFOAs).

10.2.2 Policy Recommendations

- Given the ubiquitous nature and harmful properties of PBDEs, special measures are needed to minimize their release into the environment. Official procedures to log the usage, inventories, entry and exit in to landfills of these compounds, either as raw materials or in finished products, should be instituted. Accumulation in the Canadian North should continue to be monitored and tracked in the soil, sediment, water and air. Measures should be adopted to limit PBDEs from entering the environment.
- Banning only some PBDE congener groups (those believed to be the most toxic) is insufficient. High-molecular-weight PBDEs continuously degrade in a sequential manner, thus generating a spectrum of more toxic lower brominated congeners. Thus any ban should also include deca- and other higher-brominated congeners/products.
- The widespread occurrence of Deca-BDE in the environment and the high level of disposal of electronic equipment require proper management of existing items containing this compound. Urgent attention is required regarding its substitution by less harmful flame retardants.
- PBDE destruction in waste-to-energy facilities is preferred over landfilling so long as the system has the capacity to completely destroy the PBDEs and not recombine them to form other toxic compounds such as brominated dioxins or furans. In addition, PBDEs should be eliminated in all new products.

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Table A.1 Total congeners analysed per laboratory used in this thesis.

Congener	Laboratory				Congener	Laboratory			
	DFO-IOS	Vista	Duke U	MOE		DFO-IOS	Vista	Duke U	MOE
mono- { BDE-1 BDE-2 BDE-3	x x x	x x x			hexa- { BDE-155 BDE-154 BDE-153 BDE-140 BDE-138/166 BDE-156/169 BDE-139 Hx(1) Hx(2)	x x x x x x x x x	x x x x x x x x x	x x x x x x x x x	
di- { BDE-10 BDE-7 BDE-8/11 BDE-12 BDE-13 BDE-15 Di(1)	x x x x x x x	x x x x x x x			hepta- { BDE-183 BDE-176 BDE-181 BDE-190 BDE-179 BDE-188 BDE-180 BDE-191	x x x x x x x x	x x x x x x x x	x x x x x x x x	x
tri- { Tr(1) Tr(2) BDE-30 BDE-32 BDE-17 BDE-25 BDE-28/33 BDE-35 BDE-37	x x x x x x x x x		x		octa- { BDE-196 BDE-201 BDE-204/197 BDE-203 BDE-202 BDE-205	x x x x x x	x x x x x x	x x x x x x	
tetra- { BDE-75 BDE-49 BDE-71 BDE-47 BDE-66 BDE-77	x x x x x x	x x x x x x	x x x x x x	x x x x x x	nona- { BDE-208 BDE-207 BDE-206	x x x	x x x	x x x	
penta- { BDE-100 BDE-119 BDE-99 BDE-116 BDE-85 BDE-105 BDE-126 BDE-82 BDE-104 Pe(3) Pe(4) Pe(5) Pe(6) BDE-101 Pe(7) Pe(8) BDE-118	x x x x x x x x x x x x x x x x x	x x x x x x x x x x x x x x x x	x x x x x x x x x x x x x x x x	x x x x x x x x x x x x x x x x	deca- BDE-209	x	x	x	x
Total congeners analysed in this thesis	59	53	33	17					
Total possible congeners analysed/lab	62	53	33	17					
* Numbers in brackets indicate unidentified congener									
Empty cells indicate congener not analysed by that particular laboratory									

Table A.2 Penta-BDE commercial product profile from various manufacturers

BDE congeners		Penta-BDE (%)					
		DE-71		DE-71B		Bromkal 70-5DE	
		DE-71 (La Guardia et al, 2006)	DE-71 (Dodder, et al, 2000)	DE-71B late 70s/early 80s) (ENVIRON, 2003)	DE-71B (2002 formula) (ENVIRON, 2003)	Bromkal 70-5DE (La Guardia, et al, 2006)	Bromkal 70-5DE (Sjodin, et al, 1998)
tri-BDEs	-17	0.07				0.05	0.022
	-28/33	0.25			>1	0.10	0.11
total tri-BDEs		0.32		not reported	0-1	0.15	0.13
tetra-BDEs	-47/74	38.20	27.00		28.00	42.80	37.00
	-49	0.74	not reported		<1	0.36	
	-66/42	0.53	not reported		<1	0.21	0.22
total tetra-BDEs		39.47	27.00	24.60	24-38	43.37	37.22
penta-BDEs	-102	0.15	not reported			nd	nd
	-100	13.10	10.00		8.00	7.82	6.80
	-99	48.60	43.00		43.00	44.80	35.00
	-97/118	<0.02	not reported			0.12	nd
	-85	2.96	not reported		not reported	2.16	1.60
	-126/155	0.21	not reported			0.67	nd
total penta-BDEs		65.02	53.00	58.10	50-62	55.57	43.40
hexa-BDEs	-144	nd	not reported			nd	
	-153	5.44	8.00		6.00	5.32	3.90
	-154	4.54	9.00		4.00	2.68	2.50
	-139	0.80	not reported			0.38	
	-140	0.17	not reported			0.10	
	-138	0.73	not reported			0.53	0.41
total hexa-BDEs		11.68	17.00	13.30	4-12	9.01	6.81
hepta-BDEs	-184	<0.02	nd		not reported	nd	nd
	-175/183	0.10				0.33	
	-180	nd				nd	
	-171	nd				nd	
total hepta-BDEs		0.10		2.60		0.33	
octa-BDEs	-197	nd				nd	
	-203						
	-196						
	-201						
total octa-BDEs				0.30			
nona-BDEs	-206						
	-207						
	-208						
total nona-BDEs				0.20			
deca-BDE	-209			0.80			

Table A.2 (continued) Octa-BDE commercial product profile from various manufacturers

BDE congeners		Octa-BDE (%)			
		DE-79	DE79B		Bromkal 79-8DE
			late 1970s/early 1980s	2002 formula	
		(La Guardia, et al, 2006)	(Environ, 2003)	(Environ, 2003)	(La Guardia, et al, 2006)
tri-BDEs	-17	nd	nd	nd	nd
	-28/33	↓	↓	↓	↓
total tri-BDEs					
tetra-BDEs	-47/74	↓	↓	<1	↓
	-49	↓	↓	nd	↓
	-66/42	↓	↓	↓	↓
total tetra-BDEs					
penta-BDEs	-102	↓	↓	↓	↓
	-100	↓	↓	↓	↓
	-99	↓	↓	↓	↓
	-97/118	↓	↓	nd	↓
	-85	↓	↓	↓	↓
	-126/155	↓	↓	↓	↓
total penta-BDEs			1.10	<0.5	
hexa-BDEs	-144	0.10	nd	not reported	0.12
	-153	8.66	↓	14.00	0.15
	-154	1.07	↓	2.00	0.04
	-139	nd	↓	not reported	nd
	-140	<0.02	↓	↓	nd
	-138	0.62	↓	↓	nd
total hexa-BDEs		10.45	8.50	<12	0.31
hepta-BDEs	-184	<0.02	↓	not reported	<0.02
	-175/183	42.00	↓	↓	12.60
	-180	1.70	↓	↓	nd
	-171	1.81	↓	↓	0.17
total hepta-BDEs		45.51	45.10	<45	12.77
octa-BDEs	-197	22.20	↓	not reported	10.50
	-203	4.40	↓	↓	8.14
	-196	10.50	↓	↓	3.12
	-201	0.78	↓	↓	<0.02
total octa-BDEs		37.88	30.70	<33	21.76
nona-BDEs	-206	1.38	↓	not reported	7.66
	-207	11.50	↓	not reported	11.20
	-208	0.19	↓	not reported	<0.02
total nona-BDEs		13.07	13.00	<10	18.86
deca-BDE	-209	1.31	1.60	<0.7	49.60

Table A.2 (continued) Deca-BDE commercial product profile from various manufacturers

BDE congeners	Deca-BDE (%)		
	Saytex 102E	Bromkal 82-ODE	DE83R and DE83B
	(La Guardia, et al, 2006)	La Guardia et al., 2006	ENVIRON, 2003
tri-BDEs	nd	nd	nd
-17			
-28/33			
<i>total tri-BDEs</i>			
tetra-BDEs			
-47/74			
-49			
-66/42			
<i>total tetra-BDEs</i>			
penta-BDEs			
-102			
-100			
-99			
-97/118			
-85			
-126/155			
<i>total penta-BDEs</i>			
hexa-BDEs			
-144			
-153			
-154			
-139			
-140			
-138			
<i>total hexa-BDEs</i>			
hepta-BDEs			
-184			
-175/183			
-180			
-171			
<i>total hepta-BDEs</i>			
octa-BDEs			
-197		0.03	
-203		0.07	
-196		0.46	
-201			
<i>total octa-BDEs</i>			
nona-BDEs			
-206	2.19	5.13	
-207	0.24	4.10	
-208	0.06	0.07	
<i>total nona-BDEs</i>			
deca-BDE	-209	96.80	91.60
			>98

Table B.1. End-over-End contacting chamber raw materials used

Material	Specs	Quantity	Supplier/location
square and angle stainless steel iron	51mm x 610mm x 3.1mm	various	Rustan Metals, Vancouver, BC, Canada
Schedule 10 - 316 stainless steel pipe	7.62 cm diameter	6 m	ABC Traders Ltd., Richmond, BC, Canada; www.abc-traders.com
stainless steel flanges, water cut	15.24 cm x 20.32 cm x 1.27 cm	10	Viking Profile Inc., Richmond, BC, Canada
stainless steel #304 sheet metal	122 cm x 243 cm x 0.812 cm	1	Unified Alloys, Richmond, BC, Canada
borosilicate glass discs	0.95 cm thickness	8	McMaster Carr, catalogue #8477K82, Santa Fe Springs, California, USA; www.mcmaster.com
Buna-N 'O' rings	#N70216; No. 239; 2.85 cm ID and 3.5 cm OD	various	Wriason Seals, Vancouver, BC, Canada
Buna-N 'O' rings	Cat. No. 216; 10.8 cm ID with 11.5 cm OD, 0.15 cm diameter width, and 9.2 cm ID with 10 cm OD	various	McMaster Carr, Santa Fe Springs, CA, USA, www.mcmaster.com)
Buna-N elastomeric rubber for seal plugs	0.317 cm thick	various	Wriason Seals, Vancouver, BC, Canada
Redi-rod NC stainless steel, #304	0.63 cm diameter x 182 cm length, and 0.95 cm diameter x 182 cm length	various	Pacific Fasteners, Burnaby, BC, Canada
stainless steel washers and nuts		various	Pacific Fasteners, Burnaby, BC, Canada
stainless steel Schedule 316 bolts	3.8 cm length x 0.95 cm diameter	various	Pacific Fasteners, Burnaby, BC, Canada
pillow blocks	5 cm internal diameter	2	(BC Bearing Engineering Ltd., Burnaby, BC, Canada
Swagelok stainless steel plug valves, 8P6T-TE	1.27 cm	5	(Columbia Valve & Fitting Inc., Burnaby, BC, Canada; http://www.swagelok.com
stainless steel Bellows valves, 4H, 0.63 cm and stainless steel 4-TA-1-8 male NPT	0.63 cm tube to 0.15 cm	6	Columbia Valve & Fitting Inc., Burnaby, BC, Canada; http://www.swagelok.com
Baldor motor, KL3404, P/N 24357 (1725 rpm, ¼ HP, single phase, 120 V)		1	BC Bearing Engineering Ltd, Burnaby, BC, Canada
Baldor speed reducer FD8918-913-200-B5	Cat. No. CF4018AG/GR01320019	1	BC Bearing Engineering Ltd., Burnaby, BC, Canada
stainless steel female to female NPT	1.9 cm	various	Bartle and Gibson Co. Ltd., Burnaby, BC, Canada; Mustang Place, Port Coquitlam, BC, Canada
stainless steel shaft	30.48 cm x 6.35 cm	1	Nedco, Drummondville, QC, Canada
GH40B and GH26B sprockets		various	Nedco, Drummondville, QC, Canada
#40 stainless steel chain		1	Nedco, Drummondville, QC, Canada
Hubbell plug #2421		1	Nedco, Drummondville, QC, Canada
Hubbell connector #2423		1	Nedco, Drummondville, QC, Canada
cabwire SOW12 awg/4C		1	Nedco, Drummondville, QC, Canada

Table B2. Sample locations identified by GPS coordinates in Northern Canada (July-August 2006)

LOCATION					
Inuvik, NWT					
Observations: Management of dumpsite seems to be good, no liner. Grizzly bears seen close to the body of water adjacent to the Finning building, but none noted in the past 2 weeks.					
Sample ID	Lat/Lon	Description	Matrix	Depth	Date collected
INUVK 1	N 68° 21.194' W 133° 41.129'	Sort of background sample located down the "Roads End" golf course access, to the left side	Water pH=8.3 μ= >2000 μm		10.08.06
INUVK 2	N 68° 20.550' W 133° 40.662'	Down from dump at closest body of water – access from Finning building, main road to airport	Water pH=7.6 μ= 539 μm		10.08.06
INUVK 3	N 68° 21.038' W 133° 41.971'	Background sample – Boot Lake. Access straight across from 'Roads End' golf course	Water pH= 7.4 μ= 383 μm		10.08.06
Tuktoyaktuk, NWT					
Observations: uncontrolled dumping; all of the garbage ends up in a ponded area which flows directly to the ocean					
Sample ID	Lat/Lon	Description	Matrix	Depth	Date collected
TUK 1	N 69° 24.610' W 133° 01.514'	Former drinking water source for the town, called Water Lake	Water pH=9.0 μ= 1200 μm		11.08.06
TUK 2	N 69° 25.338' W 133° 02.022'	Adjacent to main water body that receives leachate from the dump, on the other side and ends up in the ocean	Water pH=8.3 μ= >2000 μm		11.08.06
TUK 3	N 69° 25.301' W 133° 02.014'	Dumpsite itself; ponded water that the garbage flows to	Water		11.08.06
Cambridge Bay, Nunavut					
Observations: Computers are not widely used in this community, therefore, the likelihood of finding PBDEs in local sources may not be significant. However, they are known to be used in polyurethane foam, mattresses and textiles, which are more prevalent in northern Canada. This sample collection involved returning to the same locations as the Summer '04 research, and added more water sample locations					
Sample ID	Lat/Lon	Description	Matrix	Depth	Date collected
CAMBY 1	N 69° 07.654' W 105° 02.033'	Was CAM03 (Summer'04) – entrance to effluent drainage area	water		07.08.06
CAMBY 2	N 69° 07.603' W 105° 01.884'	Was CAM04 (Summer'04) – close to effluent drainage area	Soil/sediment	Surface (0-0.15m)	07.08.06
CAMBY 3	N 69° 07.521' W 105° 01.954'	Was CAM01 (Summer'04) – garbage dump	soil		07.08.06
CAMBY 4	N 69° 07.327' W 105° 02.251'	Was CAM05 (Summer'04) – effluent discharge to ocean	Water pH=7.9 μ= ND	Approx 0.5 m	07.08.06
CAMBY 5	N 69° 07.323' W 105° 02.250'	Was CAM06 (Summer '04) – area of effluent discharge to ocean	sediment	pH approx 6 conductivity = 582 microS	07.08.06
CAMBY 6	N 69° 07.483'	Was CAM02 (Summer '04) –	soil	Approx 0.4 m; very	07.08.06

Table B2. Sample locations identified by GPS coordinates in Northern Canada (July-August 2006)

	W 105° 01.493'	metal waste dump		pebbly	
CAMBY 7	N 69° 06.847' W 105° 03.384'	Was CAM07 (Summer '04) - Background sample	Soil/sediment & water pH=8.6 $\mu = >2000 \mu\text{m}$	Approx 0.4 m, composite	08.08.06
CAMBY 8	N 69° 07.533' W 105° 00.664'	Was CAM08 (Summer '04) - Water hamlet just out of town heading towards Mount Pelly	Soil/sediment & water pH=8.6 $\mu = >2000 \mu\text{m}$	Approx 0.4 m	08.08.06
Iqaluit, Nunavut					
Observations: <ul style="list-style-type: none"> • Six landfills (dumps) in Iqaluit – 5 former military dumps, 1 currently in operation (but also contained a military dump). • Most of the landfills contain waste metal. No computer waste was observed, however it is possible it could be mixed in with the domestic garbage deposited in the current landfill. • Mattresses and couches are shredded and currently used as landfill cover (West 40 landfill) 					
Sample ID	Lat/Lon	Description	Matrix	Depth	Date collected
IQ01	N 63° 43.570' W 68° 26.054'	<i>Apex south</i> – tidal flats Sample collected approximately 200 m from shore Broke en route to lab	Sediment	Approx 30m	03.08.04
IQA02	N 63° 43.547' W 68° 25.999'	<i>Apex south</i> – tidal flats Sample collected approximately 260 m from shore	Sediment	Approx 30m	03.08.04
IQA03	N 63° 43.504' W 68° 25.900'	<i>Apex south</i> – tidal flats Sample collected approximately 380 m from shore Broke en route to lab	Sediment	Approx 30m	03.08.04
IQA08	N 63° 43.463' W 68° 25.836'	<i>Apex south</i> – tidal flats Sample collected approximately 470 m from shore	Sediment	Approx 30m	04.08.04
IQA09	N 63° 43.417' W 68° 25.829'	<i>Apex south</i> – tidal flats Sample collected approximately 560 m from shore	Sediment	Approx 30m	04.08.04
IQA12	N 63° 43.251' W 68° 25.730'	<i>Apex south</i> – tidal flats Sample collected approximately 920 m from shore	Sediment	Approx 30m	04.08.04
IQA13	N 63° 43.142' W 68° 25.755'	<i>Apex south</i> – tidal flats Sample collected approximately 1110 m from shore	Sediment	Approx 30m	04.08.04
IQA04	N 63° 45.897' W 68° 32.883'	<i>North 40 metal dump</i> – old metal dump net to old asphalt plant, close to airport	Soil	Surface (0-0.15m)	04.08.04
IQA16	N 63° 44.159' W 68° 32.021'	<i>Town landfill</i> from 1970-1985	Soil	Surface (0-0.15m)	05.08.04
IQA17	N 63° 43.788' W 68° 32.161'	<i>Early military landfill</i> – circa 1950s (joint US-Canada waste); causeway, road military landfill, adjacent to current landfill on other side of road	Soil	Surface (0-0.15m)	05.08.04
IQA05	N 63° 43.894'	<i>West 40 landfill</i> : from early	Soil	Surface (0-0.15m)	04.08.04

Table B2. Sample locations identified by GPS coordinates in Northern Canada (July-August 2006)

	W 68° 32.032'	1990s to present plus old military landfill Main area			
IOA06	N 63° 43.902' W 68° 32.029'	<i>West 40 landfill</i> : from early 1990s to present plus old military landfill Dump metal side	Sediment	Surface (0-0.15m)	04.08.04
IOA07	N 63° 43.841' W 68° 32.051'	<i>West 40 landfill</i> : from early 1990s to present plus old military landfill Former open pit burn area, current landfill	Soil	From the pile – depth unknown	04.08.04
IOA14	N 63° 44.283' W 68° 33.440'	<i>Old military landfill, 1940s-1960s</i> , joint US-Canada operation Base old military dump, contamination confined due to local geology	Soil	Surface (0-0.15m)	05.08.04
IOA15	N 63° 44.216' W 68° 33.312'	<i>Old military landfill, 1940s-1960s</i> , joint US-Canada operation Base old military dump, sample collected next to water runoff from dump	Soil	Surface (0-0.15m)	05.08.04

B.3 Confidential letter sent to landfill operators

Department of Chemical and Biological Engineering
2360 East Mall
Vancouver, B.C. Canada V6T 1Z3

Tel: 604-822-3121

Fax: 604-822-6003

October 19, 2005

City of xxx
Works Department – Solid Waste Management Division
xx Street
xxx, ON Postal Code

Attention: xxx, Landfill Operator

RE: Request for xx Landfill to assist in Sample Collection for UBC Graduate Student

Dear Sir/Madam,

Many thanks for your willingness to assist us with our doctoral research project at UBC. We would like to ask if the City of xxx would consider helping us collect leachate samples on a one time basis at the xxx Landfill (Landfill).

The overall goal of the project is to obtain scientific data related to brominated flame retardants (specifically, polybrominated diphenyl ethers - PBDEs) including their generation, consumption and accumulation patterns in order to increase the understanding of global transport of these compounds in different environmental media. Landfill leachate is especially important due to the disposal of electronic wastes containing these fire retardants. We will use the information obtained from these samples to develop mass balance models which can be applied to landfills in general. It is thought that PBDEs may be present in landfills, but few studies on the fate of these compounds in waste disposal streams such as landfills, have been carried out.

We would be grateful for your assistance and cooperation. As well, we appreciate your good will in allowing us to obtain samples from the Landfill at your earliest convenience. If you prefer, we are willing to keep the identity and location of your landfill and those of other landfills confidential when the data are presented and discussed in our research.

We thank you in advance for your readiness to help us in this important research.

Sincerely,

John Grace, PhD., P.Eng.
Professor
Chemical & Biological Engineering
University of British Columbia

Monica N. Danon-Schaffer, P.Eng.
PhD Candidate
Chemical & Biological Engineering
University of British Columbia

cc. xxx, Manager Landfill Management

Table C.1. Procedural blank data grouped by Clusters for this thesis project (pg/sample)

2x blank correction to use		BDE-47	BDE-100	BDE-99	BDE-154	BDE-153	BDE-183
CLUSTER A (pg/g)							
proc blk 22fe05		417.0	47.5	164.0	14.4	21.9	23.7
proc blk 28fe05		196.1	24.0	84.7	ND	8.9	18.3
proc blk ase 07mr05		194.1	25.4	95.2	8.6	11.1	10.1
proc blk filter 07mr05		298.3	39.4	151.5	ND	15.4	16.7
PRO BLANK AVG - SOIL MATRIX	blk correction values to use	276	34	124	12	14	17
2x blank correction to use		BDE-47	BDE-100	BDE-99	BDE-154	BDE-153	BDE-183
CLUSTER B (pg/L)							
pb1 08fe06		193.5	28.0	89.0	12.5	21.5	31.5
pb2 08fe06		152.5	19.0	58.0	ND	6.0	16.5
PRO BLK AVG LEACHATE MATRIX	avg	173	24	74	13	14	24
PRO BLK AVG LEACHATE MATRIX	blk correction values to use	3,460	470	1,470	125	275	480
pb1 21fe06		154.0	21.5	78.5	23.5	76.0	410.5
pb2 21fe06		130.5	19.0	59.5	ND	9.0	18.0
PRO BLK AVG LEACHATE+EWASTE		142	20	69	24	43	214
No blank correction needed							
PRO BLK AVG LEACHATE+EW	blk correction values to use	2,845	405	1,380	235	850	4,285
2x blank correction to use		BDE-47	BDE-100	BDE-99	BDE-154	BDE-153	BDE-183
CLUSTER C (pg/L)							
pb Aq+ase26jl06 pcb		498.4	62.5	194.6	11.7	22.9	28.6
pb2 26jl06 pcb		179.9	31.7	99.8	ND	ND	22.7
PRO BLK AVG dH2O+EWASTE		339.2	47.1	147.2	11.7	22.9	25.6
PRO BLK AVG dH2O+EWASTE	blk correction values to use	3,392	471	1,472	58	114	256
pb 09au06 pcb		30.5	4.8	14.3	1.1	1.6	18.9
PRO BLK LEACHATE MATRIX		30.5	4.8	14.3	1.1	1.6	18.9
PRO BLK LEACHATE MATRIX	blk correction values to use	305	48	143	11	16	189
		BDE-47	BDE-100	BDE-99	BDE-154	BDE-153	BDE-183
CLUSTER D (pg/g soil and pg/L leachate)							
pb 06oc06 pcb		744.8	79.2	297.6	14.8	22.6	32.0
PRO BLANK - SOIL MATRIX	blk correction values to use	745	79	298	15	23	32
pb 13oc06 pcb		337.2	33.3	114.4	ND	ND	17.0
PRO BLANK - SOIL MATRIX	blk correction values to use	337.2	33.3	114.4	ND	ND	17.0
2x blank correction to use							
AVG OF BOTH SOIL MATRICES	blk correction values to use	541	56	206	15	23	25
pb 20oc06 pcb		809.2	100.6	255.6	11.5	21.8	136.7
PRO BLK LEACHATE MATRIX-X-CAN	blk correction values to use	8,092	1,006	2,556	115	218	1,367
pb2 31oc06 pcb		603.7	59.5	206.4	ND	16.6	30.6
PRO BLK LEACHATE MATRIX-Arctic	blk correction values to use	6,037	595	2,064	ND	166	306
pb 08no06 pcb		1032.2	120.5	322.5	14.5	22.3	49.7
PRO BLK LEACHATE MATRIX-Arctic	blk correction values to use	10,322	1,205	3,225	145	223	497
pb 17no06 pcb		797.8	86.0	249.2	11.4	19.2	49.5
PRO BLK LEACHATE MATRIX-Arctic	blk correction values to use	7,978	860	2,492	114	192	495
1x blank correction to use							
AVG OF ALL 4 LEACHATE MATRICES	blk correction values to use	8,107	916	2,584	125	200	666
2x blank correction to use		BDE-47	BDE-100	BDE-99	BDE-154	BDE-153	BDE-183
CLUSTER E (pg/L)							
prep lab blk 26jn07		254.4	31.3	114.5	4.3	6.2	21.9
blk642 ase 26jn07		216.5	30.7	96.0	5.6	10.0	12.1
PRO BLK LEACHATE MATRIX-Arctic	avg of the 2 batches	235.5	31.0	105.3	5.0	8.1	17.0
PRO BLK LEACHATE MATRIX-Arctic	blk correction values to use	2,355	310	1,053	50	81	170
prep lab blk1 05jl07 RR1		237.7	24.5	96.7	5.0	9.2	9.0
blk643 ase 05jl07		148.9	22.8	80.3	3.7	7.2	11.5
PRO BLK LEACHATE MATRIX-X-CAN	avg of the 2 batches	193.3	23.6	88.5	4.3	8.2	10.3
PRO BLK LEACHATE MATRIX-X-CAN	blk correction values to use	1,933	236	885	43	82	103
pb650 1 26oc07		292.7	38.4	112.7	8.1	16.6	57.1
ase blk 26oc07		313.5	40.8	125.0	5.8	7.7	40.4
PRO BLK LEACHATE MATRIX-X-CAN	avg of the 2 batches	303.1	39.6	118.8	6.9	12.2	48.7
PRO BLK LEACHATE MATRIX-X-CAN	blk correction values to use	3,031	396	1,188	69	122	487
AVG OF 6 X-Can LEACHATE MATRICES	blk correction values to use	2,440	314	1,042	54	95	253

Table C.1. Procedural blank data grouped by Clusters for this thesis project (pg/sample)

	BDE-207	BDE-206	BDE-209
CLUSTER F: (pg/L)			
pb1 08fe06	22	15	274
pb2 08fe06	23	10	172
PRO BLK AVG LEACHATE MATRIX	22	12	223
PRO BLK AVG LEACHATE MATRIX values to use for blk correction	445	245	4,454
pb1 21fe06	102	18	382
pb2 21fe06	11	8	187
PRO BLK AVG LEACHATE+EWASTE	56	13	285
PRO BLK AVG LEACHATE+EW values to use for blk correction	1,129	263	5,694
	BDE-207	BDE-206	BDE-209
CLUSTER G: (pg/L)			
pb Aq+ase26jl06 pcb	207	252	8,854
pb2 26jl06 pcb	146	74	3,085
PRO BLK dH2O+ewaste	177	163	5,970
PRO BLK dH2O+ewaste values to use for blk correction	1,765	1,632	59,696
pb 09au06 pcb	125	58	2,236
PRO BLK LEACHATE MATRIX	125	58	2,236
PRO BLK LEACHATE MATRIX values to use for blk correction	1,249	579	22,361
	BDE-207	BDE-206	BDE-209
CLUSTER H: (pg/g)			
pb 06oc06 pcb	2,054	1,242	45,117
PRO BLANK - SOIL MATRIX values to use for blk correction	2,054	1,242	45,117
pb 13oc06 pcb	50	44	1,780
PRO BLANK - SOIL MATRIX values to use for blk correction	50	44	1,780
AVERAGE OF BOTH SOIL MATRICES values to use for blk correction	1,052	643	23,448
	BDE-207	BDE-206	BDE-209
CLUSTER I: (pg/L)			
pb 20oc06 pcb	210	347	15,803
pb 20oc06 pcb de RR2	39	54	2,423
pb2 20oc06 pcb de RR1	171	293	13,380
PRO BLK LEACHATE MATRIX-X-CAN	140	231	10,536
PRO BLK LEACHATE MATRIX-X-CAN values to use for blk correction	1,400	2,314	105,355
	BDE-207	BDE-206	BDE-209
CLUSTER J: (pg/L)			
pb2 31oc06 pcb	131	78	1,533
pb 08no06 pcb	362	151	2,886
pb1 08no06 pcb de	285	119	1,904
pb2 08no06 pcb de	77	31	983
PRO BLK LEACHATE MATRIX-ARCTIC	214	95	1,826
PRO BLK LEACHATE MATRIX-ARCTIC values to use for blk correction	2,138	948	18,263
pb 17no06 pcb	261	266	6,109
pb 17no06 pcb de	141	193	4,414
pb2 17no06 pcb de RR1	120	73	1,695
PRO BLK LEACHATE MATRIX- X-CAN + ARCTIC	174	177	4,073
PRO BLK LEACHATE MATRIX- X-CAN + ARCTIC values to use for blk correction	1,738	1,772	40,727
AVERAGE OF ALL LEACHATE MATRICES values to use for blk correction	1,938	1,360	29,495
	BDE-207	BDE-206	BDE-209
CLUSTER K: (pg/L)			
prep lab blk 26jn07	55	82	1,829
blk642 ase 26jn07	43	104	1,967
PRO BLK LEACHATE MATRIX-ARCTIC	49	93	1,898
PRO BLK LEACHATE MATRIX-ARCTIC values to use for blk correction	489	928	18,979
prep lab blk1 05jl07 RR1	37	68	1,682
blk643 ase 05jl07	17	44	992
pb647 01oc07	2,858	3,613	11,467
pb648 04oc07	422	616	2,624
PRO BLK LEACHATE MATRIX-X-CAN	834	1,086	4,191
PRO BLK LEACHATE MATRIX-X-CAN values to use for blk correction	8,337	10,856	41,911
AVERAGE OF ALL LEACHATE MATRICES values to use for blk correction	4,413	5,892	30,445
	BDE-207	BDE-206	BDE-209
CLUSTER L: (pg/L)			
pb650 1 26oc07	905	1,122	4,765
ase blk 26oc07	143	191	5,018
PRO BLK LEACHATE MATRIX-X-CAN	524	657	4,892

Table C.2. Inter-laboratory comparison of procedural blank corrected total BDE congener groups classified by time intervals. Data from the 1990-94 time period were discarded from calculations due to predominance of values close to procedural blanks.

Leachate	pg/L	mono-BDEs	di-BDEs	tri-BDEs	tetra-BDEs	penta-BDEs	hexa-BDEs	hepta-BDEs	octa-BDEs	nona-BDEs	deca-BDEs	tot BDEs
Lab: DFO-IOS	avg pre-80s	ND	ND	95	585	465	BMDL	BMDL	BMDL	88	10,632	11,865
	1980-84	ND	400	1,970	17,770	16,560	5,060	2,120	821	120	4,233	49,054
	1985-89	ND	860	3,910	24,480	29,500	11,360	8,420	4,133	950	2,629	86,242
	1990-94	ND	ND	210	2,110	360	BMDL	BMDL	BMDL	BMDL	BMDL	2,680
	1995-99	ND	1,390	3,750	40,750	61,810	25,660	12,120	7,280	1,996	3,688	158,444
	2000-05	ND	2,275	5,355	252,245	613,440	188,480	20,275	16,927	10,905	52,759	1,162,661
Leachate	pg/L	mono-BDEs	di-BDEs	tri-BDEs	tetra-BDEs	penta-BDEs	hexa-BDEs	hepta-BDEs	octa-BDEs	nona-BDEs	deca-BDEs	tot BDEs
Lab: Vista Analytical	1980-84	42	6	BMDL	BMDL	8	ND	326	BMDL	ND	ND	382
	1985-89	4	24	BMDL	136	258	855	1,296	2,806	2,280	5,300	12,959
	1990-94	19	6	BMDL	7	BMDL	390	13	806	966	2,710	4,917
	1995-99	128	331	882	14,914	35,314	13,800	3,756	3,406	2,550	10,000	85,080
	2000-05	202	618	6,395	354,614	742,614	257,000	19,506	17,156	11,500	56,700	1,466,304

data discarded from both labs for purposes of interpretation due to low values obtained after blank corrections

BMDL - Below method detection limit values

ND - Not detected during analysis

Appendix C – Treatment of Analytical Data

Table C.3 Raw soil data from the Canadian North, summer 2004 (pg/g) (Lab: DFO-IOS)

SAMPLE #	DSO FILE #	SPECIES	SITE	CLIENT	SAMPLER AFFILIATION	DATE OF CAPTURE	DATE RECEIVED	CONTRACT LAB	CONTRACT LAB #	SC COLUMN ME	SAMPLE WT SUBMITTED (µg)	SAMPLE WT ANALYZED (µg)	DATE SUBMITTED	INT CAL DATE	DATE ANALYSED	
proc bk 22605	pp/g	Proc Blank	N/A			03-Aug-04	N/A	22-Feb-05	I.O.S. Regional Contaminants Labors b0192-17	D05-HT-15m Ultima	10.00	10.00	22-Feb-05	04-Mar-05	04-Mar-05	
63635 22605	pp/g	Sediment - 1QA12	Apex Flats - d-30m @ 920m from shore	MDS	Monica Daron-Schaffer	03-Aug-04	11-Aug-04	22-Feb-05	I.O.S. Regional Contaminants Labors b0192-20	D05-HT-15m Ultima	10.12	10.12	22-Feb-05	04-Mar-05	04-Mar-05	
63635 22605	pp/g	Sediment - 1QA09	Apex Flats - d-30m @ 950m from shore	MDS	Monica Daron-Schaffer	03-Aug-04	11-Aug-04	22-Feb-05	I.O.S. Regional Contaminants Labors b0192-13	D05-HT-15m Ultima	9.90	9.90	22-Feb-05	03-Apr-05	03-Apr-05	
63635 22605 RR2	pp/g	Sediment - 1QA02	Apex Flats - d-30m @ 920m from shore	MDS	Monica Daron-Schaffer	04-Aug-04	11-Aug-04	22-Feb-05	I.O.S. Regional Contaminants Labors b0192-34	D05-HT-15m Ultima	10.13	10.13	22-Feb-05	14-Apr-05	14-Apr-05	
63485 22605	pp/g	Sediment - 1QA02	Apex Flats - d-30m @ 920m from shore	MDS	Monica Daron-Schaffer	03-Aug-04	11-Aug-04	22-Feb-05	I.O.S. Regional Contaminants Labors b0192-32	D05-HT-15m Ultima	10.11	10.11	22-Feb-05	04-Mar-05	04-Mar-05	
63485 22605	pp/g	Sediment - CAM08	Inlet to ocean	MDS	Monica Daron-Schaffer	31-Jul-04	05-Aug-04	22-Feb-05	I.O.S. Regional Contaminants Labors b0192-33	D05-HT-15m Ultima	10.75	10.75	22-Feb-05	04-Mar-05	04-Mar-05	
63485 22605	pp/g	Sediment - CAM06	Discharge to ocean	MDS	Monica Daron-Schaffer	30-Jul-04	05-Aug-04	22-Feb-05	I.O.S. Regional Contaminants Labors b0192-34	D05-HT-15m Ultima	10.28	10.28	22-Feb-05	04-Mar-05	04-Mar-05	
63655 22605 RR2	pp/g	Sediment - 1QA13	Base - old military dump - confined cont	MDS	Monica Daron-Schaffer	04-Aug-04	11-Aug-04	22-Feb-05	I.O.S. Regional Contaminants Labors b0215-41	D05-HT-15m Ultima	10.28	10.28	22-Feb-05	14-Apr-05	14-Apr-05	
63445 22605 RR1	pp/g	Sediment - CAM07	inlet to ocean	MDS	Monica Daron-Schaffer	30-Jul-04	05-Aug-04	22-Feb-05	I.O.S. Regional Contaminants Labors b0210-12	D05-HT-15m Ultima	15.23	15.23	22-Feb-05	07-Apr-05	07-Apr-05	
63445 22605	pp/g	Sediment - CAM07	Background sample	MDS	Monica Daron-Schaffer	30-Jul-04	05-Aug-04	22-Feb-05	I.O.S. Regional Contaminants Labors b0192-12	D05-HT-15m Ultima	15.38	15.38	22-Feb-05	04-Mar-05	04-Mar-05	
63395 22605	pp/g	Sediment - YELLO4	Background sample (across road)	MDS	Monica Daron-Schaffer	28-Jul-04	30-Jul-04	22-Feb-05	I.O.S. Regional Contaminants Labors b0192-14	D05-HT-15m Ultima	13.79	13.79	22-Feb-05	04-Mar-05	04-Mar-05	
proc bk 22605	pp/g	Procedural Blank	N/A			30-Jul-04	N/A	28-Feb-05	I.O.S. Regional Contaminants Labors b0196-04	D05-HT-15m Ultima	8.45	8.45	28-Feb-05	10-Mar-05	10-Mar-05	
63425 28605 dl bd	pp/g	Sediment - CAM04	discharge to ocean	MDS	Monica Daron-Schaffer	30-Jul-04	05-Aug-04	28-Feb-05	I.O.S. Regional Contaminants Labors b0210-21	D05-HT-15m Ultima	9.28	9.28	28-Feb-05	07-Apr-05	07-Apr-05	
63395 28605	pp/g	Sol - YELLO2	white goods storage	MDS	Monica Daron-Schaffer	30-Jul-04	05-Aug-04	28-Feb-05	I.O.S. Regional Contaminants Labors b0196-17	D05-HT-15m Ultima	8.63	8.63	28-Feb-05	10-Mar-05	10-Mar-05	
63415 28605	pp/g	Sediment - CAM02	close to effluent discharge	MDS	Monica Daron-Schaffer	05-Aug-04	11-Aug-04	28-Feb-05	I.O.S. Regional Contaminants Labors b0196-06	D05-HT-15m Ultima	9.34	9.34	28-Feb-05	10-Mar-05	10-Mar-05	
63665 28605 pcb	pp/g	Sol - 1QA14	Northern Samples - Yell. Cam. In	MDS	Monica Daron-Schaffer	05-Aug-04	11-Aug-04	28-Feb-05	I.O.S. Regional Contaminants Labors b0216-32	D05-HT-15m Ultima	9.37	9.37	28-Feb-05	18-Apr-05	18-Apr-05	
63665 28605	pp/g	Sediment - CAM02	Open Pitblowing @ West 40 Dump (ash)	MDS	Monica Daron-Schaffer	04-Aug-04	11-Aug-04	28-Feb-05	I.O.S. Regional Contaminants Labors b0196-17	D05-HT-15m Ultima	8.63	8.63	28-Feb-05	10-Mar-05	10-Mar-05	
63495 28605	pp/g	Sol - 1QA05	West 40 Dump - Metastable	MDS	Monica Daron-Schaffer	04-Aug-04	11-Aug-04	28-Feb-05	I.O.S. Regional Contaminants Labors b0196-16	D05-HT-15m Ultima	10.07	10.07	28-Feb-05	10-Mar-05	10-Mar-05	
63495 28605	pp/g	Sol - CAM01	metal waste	MDS	Monica Daron-Schaffer	30-Jul-04	05-Aug-04	28-Feb-05	I.O.S. Regional Contaminants Labors b0196-05	D05-HT-15m Ultima	8.68	8.68	28-Feb-05	10-Mar-05	10-Mar-05	
63375 28605	pp/g	Sediment - YELLO1	old dumping area	MDS	Monica Daron-Schaffer	27-Jul-04	30-Jul-04	28-Feb-05	I.O.S. Regional Contaminants Labors b0196-15	D05-HT-15m Ultima	9.99	9.99	28-Feb-05	10-Mar-05	10-Mar-05	
63615 28605	pp/g	Sol - 1QA07	Apex Flats - d-30m @ 8470m from shore	MDS	Monica Daron-Schaffer	04-Aug-04	11-Aug-04	28-Feb-05	I.O.S. Regional Contaminants Labors b0196-08	D05-HT-15m Ultima	9.01	9.01	28-Feb-05	10-Mar-05	10-Mar-05	
63615 28605 pcb RR1	pp/g	Sol - 1QA07	Apex Flats - d-30m @ 8470m from shore	MDS	Monica Daron-Schaffer	04-Aug-04	11-Aug-04	28-Feb-05	I.O.S. Regional Contaminants Labors b0196-36	D05-HT-15m Ultima	8.53	8.53	28-Feb-05	18-Apr-05	18-Apr-05	
proc bk use 07/m05	pp/g	pp/sample	Sediment Blank Ref for 63465ed	N/A			N/A	01-Mar-05	I.O.S. Regional Contaminants Labors b0211-05	D05-HT-15m Ultima	N/A	N/A	01-Mar-05	09-Apr-05	09-Apr-05	
SAMPLE #	DSO FILE #	SPECIES	SITE	2-BDE-1	2-BDE-1 DL	3-BDE-2	3-BDE-2 DL	4-BDE-3	4-BDE-3 DL	26-BDE-10	26-BDE-10 DL	24-BDE-7	24-BDE-7 DL	24/33-BDE-6/11	24/33-BDE-6/11 DL	34-BDE-12
proc bk 22605	pp/g	Proc Blank	N/A	ND	13.2	ND	13.2	ND	13.2	ND	0.2	ND	0.2	ND	0.2	ND
63635 22605	pp/g	Sediment - 1QA12	Apex Flats - d-30m @ 920m from shore	ND	9.2	ND	9.2	ND	9.2	ND	0.2	ND	0.2	ND	0.2	ND
63635 22605	pp/g	Sediment - 1QA09	Apex Flats - d-30m @ 950m from shore	ND	25.6	ND	0.3	ND	0.3	ND	0.3	ND	0.3	ND	0.3	ND
63635 22605 RR2	pp/g	Sediment - 1QA08	Apex Flats - d-30m @ 950m from shore	ND	16.2	ND	16.2	ND	16.2	ND	0.1	ND	0.1	ND	0.1	ND
63485 22605	pp/g	Sediment - 1QA02	Apex Flats - d-30m @ 920m from shore	ND	12.2	ND	12.2	ND	12.2	ND	0.2	ND	0.2	ND	0.2	ND
63485 22605	pp/g	Sediment - CAM08	Inlet to ocean	ND	33.1	ND	33.1	ND	33.1	ND	0.3	ND	0.3	ND	0.3	ND
63485 22605	pp/g	Sediment - CAM06	Discharge to ocean	ND	12.1	ND	12.1	ND	12.1	ND	0.4	ND	0.4	ND	0.4	ND
63655 22605 RR2	pp/g	Sediment - 1QA13	Base - old military dump - confined cont	ND	19.1	ND	19.1	ND	19.1	ND	0.1	ND	0.1	ND	0.1	ND
63445 22605 RR1	pp/g	Sediment - CAM07	inlet to ocean	ND	21.0	ND	21.0	ND	21.0	ND	0.3	ND	0.3	ND	0.3	ND
63445 22605	pp/g	Sediment - CAM07	Background sample	ND	14.9	ND	14.9	ND	14.9	ND	0.2	ND	0.2	ND	0.2	ND
proc bk 22605	pp/g	Sediment - YELLO4	Background sample (across road)	ND	36.4	ND	36.4	ND	36.4	ND	0.2	ND	0.2	ND	0.2	ND
63425 28605 dl bd	pp/g	Procedural Blank	N/A	ND	43.8	ND	43.8	ND	43.8	ND	0.5	ND	0.5	ND	0.5	ND
63395 28605	pp/g	Sediment - CAM04	discharge to ocean	ND	434.6	ND	434.6	ND	10.1	ND	47.7	ND	47.7	ND	47.7	ND
63395 28605	pp/g	Sol - YELLO2	white goods storage	ND	60.3	ND	60.3	ND	60.3	ND	1.5	ND	1.5	ND	1.5	ND
63415 28605	pp/g	Sediment - CAM02	close to effluent discharge	ND	21.5	ND	21.5	ND	21.5	ND	0.7	ND	0.7	ND	0.7	ND
63665 28605 pcb	pp/g	Sol - 1QA14	Northern Samples - Yell. Cam. In	ND	128.7	ND	128.7	ND	3.3	ND	3.3	ND	3.3	ND	3.3	ND
63665 28605	pp/g	Sediment - CAM02	Open Pitblowing @ West 40 Dump (ash)	ND	16.3	ND	16.3	ND	16.3	ND	0.5	ND	0.5	ND	0.5	ND
63495 28605	pp/g	Sol - 1QA05	West 40 Dump - Metastable	ND	16.0	ND	16.0	ND	0.2	ND	0.2	ND	0.2	ND	0.2	ND
63495 28605	pp/g	Sol - CAM01	metal waste	ND	33.2	ND	33.2	ND	0.8	ND	0.8	ND	0.8	ND	0.8	ND
63375 28605	pp/g	Sediment - YELLO1	old dumping area	ND	14.2	ND	14.2	ND	0.3	ND	0.3	ND	0.3	ND	0.3	ND
63615 28605	pp/g	Sol - 1QA07	Apex Flats - d-30m @ 8470m from shore	167.7	20.5	ND	20.5	ND	20.5	4.4	1.0	ND	320.5	1.0	674.0	36.6
63615 28605 pcb RR1	pp/g	Sol - 1QA07	Apex Flats - d-30m @ 8470m from shore	ND	126.7	ND	126.7	ND	286.4	ND	5.8	ND	372.0	5.8	1059.6	69.8
proc bk use 07/m05	pp/g	pp/sample	Sediment Blank Ref for 63465ed	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SAMPLE #	DSO FILE #	SPECIES	SITE	34-BDE-12 DL	34-BDE-13	34-BDE-13 DL	44-BDE-15	44-BDE-15 DL	246-BDE-30	246-BDE-30 DL	246-BDE-32	246-BDE-32 DL	224-BDE-17	224-BDE-17 DL	224-BDE-25	224-BDE-25 DL
proc bk 22605	pp/g	Proc Blank	N/A	0.2	ND	0.2	3.1	0.2	ND	0.8	ND	0.8	1.2	0.8	ND	0.8
63635 22605	pp/g	Sediment - 1QA12	Apex Flats - d-30m @ 920m from shore	0.2	ND	0.2	1.5	0.2	ND	0.7	ND	0.7	1.4	0.7	ND	0.7
63635 22605	pp/g	Sediment - 1QA09	Apex Flats - d-30m @ 950m from shore	0.3	ND	0.3	1.8	0.3	ND	0.8	ND	0.8	ND	0.8	ND	0.8
63635 22605 RR2	pp/g	Sediment - 1QA08	Apex Flats - d-30m @ 950m from shore	0.1	ND	0.1	1.3	0.1	ND	0.4	ND	0.4	0.5	0.4	ND	0.4
63485 22605	pp/g	Sediment - 1QA02	Apex Flats - d-30m @ 920m from shore	0.2	ND	0.2	1.2	0.2	ND	0.6	ND	0.6	0.6	0.6	ND	0.6
63485 22605	pp/g	Sediment - CAM08	Inlet to ocean	0.3	ND	0.3	1.3	0.3	ND	0.7	ND	0.7	0.8	0.7	ND	0.7
63485 22605	pp/g	Sediment - CAM06	Discharge to ocean	0.4	ND	0.4	4.6	0.4	ND	0.7	ND	0.7	54.3	0.7	4.2	0.7
63655 22605 RR2	pp/g	Sediment - 1QA13	Base - old military dump - confined cont	0.1	ND	0.1	0.5	0.1	ND	0.5	ND	0.5	0.5	0.5	ND	0.5
63445 22605 RR1	pp/g	Sediment - CAM07	inlet to ocean	0.3	ND	0.3	1.6	0.3	ND	0.6	ND	0.6	2.0	0.6	ND	0.6
63445 22605	pp/g	Sediment - CAM07	Background sample	0.2	ND	0.2	1.6	0.2	ND	0.5	ND	0.5	2.9	0.5	ND	0.5
63395 22605	pp/g	Sediment - YELLO4	Background sample (across road)	0.2	ND	0.2	1.1	0.2	ND	0.6	ND	0.6	0.6	0.6	ND	0.6
proc bk 22605	pp/g	Procedural Blank	N/A	0.5	ND	0.5	1.4	0.5	ND	1.0	ND	1.0	1.0	1.0	ND	1.0
63425 28605 dl bd	pp/g	Sediment - CAM04	discharge to ocean	4.7	ND	4.7	ND	ND	ND	7.1	ND	7.1	237.2	7.1	14.6	7.1
63395 28605	pp/g	Sol - YELLO2	white goods storage	1.5	ND	1.5	11.1	1.5	ND	3.7	ND	3.7	34.5	3.7	6.9	3.7
63415 28605	pp/g	Sediment - CAM02	close to effluent discharge	0.7	ND	0.7	18.5	0.7	ND	1.8	ND	1.8	56.8	1.8	30.1	1.8
63665 28605 pcb	pp/g	Sol - 1QA14	Northern Samples - Yell. Cam. In	3.3	ND	3.3	ND	3.3	ND	4.6	ND	4.6	ND	4.6	ND	4.6
63665 28605	pp/g	Sediment - CAM02	Open Pitblowing @ West 40 Dump (ash)	0.5	ND	0.5	18.4	0.5	ND	1.4	ND	1.4	28.9	1.4	8.4	1.4
63495 28605	pp/g	Sol - 1QA05	West 40 Dump - Metastable	0.2	ND	0.2	2.2	0.2	ND	0.8	ND	0.8	2.9	0.8	1.0	0.8
63495 28605	pp/g	Sol - CAM01	metal waste	0.9	ND	0.9	74.4	0.9	ND	4.1	ND	4.1	54.2	4.1	40.2	4.1
63375 28605	pp/g	Sediment - YELLO1	old dumping area	0.3	ND	0.3	0.9	0.3	ND	0.9	ND	0.9	2.4	0.9	0.7	0.9
63615 28605	pp/g	Sol - 1QA07	Apex Flats - d-30m @ 8470m from shore	1.0	ND	1.0	354.3	1.0	ND	21.0	ND	21.0	1250.0	3.1	261.8	3.1
63615 28605 pcb RR1	pp/g	Sol - 1QA07	Apex Flats - d-30m @ 8470m from shore	5.8	ND	5.8	592.8	5.8	ND	48.2	ND	48.2	10.7	128.6	340.1	10.7
proc bk use 07/m05	pp/g	pp/sample	Sediment Blank Ref for 63465ed	N/A	N/A	N/A	N/A	N/A	N/A	8.4	ND	8.4	ND	8.4	ND	8.4
SAMPLE #	DSO FILE #	SPECIES	SITE	244/234-BDE-38/33	244/234-BDE-38/33 DL	334-BDE-36	334-BDE-36 DL	344-BDE-37	344-BDE-37 DL	244-BDE-75	244-BDE-75 DL	224-BDE-49	224-BDE-49 DL	244-BDE-71	244-BDE-71 DL	224-BDE-47
proc bk 22605	pp/g	Proc Blank	N/A	4.1	0.8	ND	3.9	ND	3.9	ND	0.3	1.3	0.3	ND	0.3	41.7
63635 22605	pp/g	Sediment - 1QA12	Apex Flats - d-30m @ 920m from shore	2.9	0.7	ND	3.3	ND	3.3	ND						

Table C.3 (continued) Raw soil data from the Canadian North, summer 2004 (pg/g) (Lab: DFO-IOS)

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Appendix C – Treatment of Analytical Data

Table C.3 (continued) Raw soil data from the Canadian North, summer 2004 (pg/g) (Lab: DFO-IOS)

Sample #	DOC FILE #	SPECIES	SITE	Pb(1)	Pb(1) DL	Pb(2)	Pb(2) DL	Pb(3)	Pb(3) DL	Pb(4)	Pb(4) DL	Pb(5)	Pb(5) DL	Pb(6)	Pb(6) DL	22-455-BDE-101*	
6303S 226e05	ppg	Proc Blank	N/A	ND	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.5	ND	
6304S 226e05	ppg	Sediment - 1QA12	Apex Flats - d-30m @ 920m from shore	ND	0.4	ND	0.4	ND	0.4	ND	0.4	ND	0.4	ND	0.4	ND	
6303S 226e05	ppg	Sediment - 1QA09	Apex Flats - d-30m @ 950m from shore	ND	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.5	ND	
6303S 226e05 RR2	ppg	Sediment - 1QA08	Apex Flats - d-30m @ 950m from shore	ND	0.2	ND	0.2	ND	0.2	ND	0.2	ND	0.2	ND	0.2	ND	
6304S 226e05	ppg	Sediment - 1QA02	Apex Flats - d-30m @ 920m from shore	ND	0.4	ND	0.4	ND	0.4	ND	0.4	ND	0.4	ND	0.4	ND	
6304S 226e05	ppg	Sediment - CAM08	Inlet to ocean	ND	0.6	ND	0.6	ND	0.6	ND	0.6	ND	0.6	ND	0.6	ND	
6304S 226e05	ppg	Sediment - CAM06	Discharge to ocean	ND	0.8	ND	0.8	ND	0.8	ND	0.8	ND	0.8	ND	0.8	ND	
6305S 226e05 RR2	ppg	Sediment - 1QA13	Base - old military dump - confined cont	ND	0.3	ND	0.3	ND	0.3	ND	0.3	ND	0.3	ND	0.3	ND	
6304S 226e05 RR1	ppg	Sediment - CAM07	inlet to ocean	ND	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.5	ND	
6304S 226e05	ppg	Sediment - YELLO4	Background sample	ND	0.7	ND	0.7	ND	0.7	ND	0.7	ND	0.7	ND	0.7	ND	
proc bk 226e05	ppg	Procedural Blank	N/A	ND	0.7	ND	0.7	ND	0.7	ND	0.7	ND	0.7	ND	0.7	ND	
6304S 226e05 dl bd	ppg	Sediment - CAM04	discharge to ocean	ND	6.5	ND	6.5	ND	6.5	ND	6.5	ND	6.5	ND	6.5	ND	
6304S 226e05	ppg	Soil - YELLO2	white goods storage	ND	26.1	ND	26.1	ND	26.1	ND	26.1	ND	26.1	ND	26.1	ND	
6304S 226e05	ppg	Sediment - CAM02	close to effluent discharge	ND	2.9	ND	2.9	ND	2.9	ND	2.9	ND	2.9	ND	2.9	ND	
6304S 226e05 pcb	ppg	Soil - 1QA14	Northern Samples - Yell. Cam. In	ND	4.1	ND	4.1	ND	4.1	ND	4.1	ND	4.1	ND	4.1	ND	
6304S 226e05	ppg	Sediment - 1QA06	Open Pitblasting @ West 40 Dump (ash)	ND	1.4	ND	1.4	ND	1.4	ND	1.4	ND	1.4	ND	1.4	ND	
6304S 226e05	ppg	Soil - 1QA05	West 40 Dump - Metastide	ND	0.6	ND	0.6	ND	0.6	ND	0.6	ND	0.6	ND	0.6	ND	
6304S 226e05	ppg	Soil - CAM01	metal waste	ND	8.5	ND	8.5	ND	8.5	ND	8.5	ND	8.5	ND	8.5	ND	
6307S 226e05	ppg	Sediment - YELLO1	old dumping area	ND	3.4	ND	3.4	ND	3.4	ND	3.4	ND	3.4	ND	3.4	ND	
6305S 226e05	ppg	Soil - 1QA07	Apex Flats - d-30m @ 470m from shore	18.5	7.3	140.7	8.2	7.3	240.0	7.3	77.6	7.3	423.1	0.6	0.6	ND	
6305S 226e05 pcb RR1	ppg	Soil - 1QA07	Apex Flats - d-30m @ 470m from shore	24.3	12.1	132.5	12.1	12.1	604.3	12.1	89.7	12.1	413.2	12.1	12.1	537.6	
proc bk ase 07m05	ppg	ase Blank	Sediment Blank Ref for 6304Sed	ND	5.9	ND	5.9	ND	5.9	ND	5.9	ND	5.9	ND	5.9	ND	
Sample #	DOC FILE #	SPECIES	SITE	Pb(7)	Pb(7) DL	Pb(8)	Pb(8) DL	Pb(9)	Pb(9) DL	Pb(10)	Pb(10) DL	Pb(11)	Pb(11) DL	Pb(12)	Pb(12) DL	Oct(1)	Oct(1) DL
6303S 226e05	ppg	Proc Blank	N/A	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.3	ND	0.3	ND	0.3	ND
6304S 226e05	ppg	Sediment - 1QA12	Apex Flats - d-30m @ 920m from shore	ND	0.4	ND	0.4	ND	0.4	ND	0.4	ND	0.4	ND	0.4	ND	0.1
6303S 226e05	ppg	Sediment - 1QA09	Apex Flats - d-30m @ 950m from shore	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.5	N/A
6303S 226e05 RR2	ppg	Sediment - 1QA08	Apex Flats - d-30m @ 950m from shore	0.2	ND	0.2	ND	0.2	ND	0.2	ND	0.2	ND	0.2	ND	0.2	1.6
6304S 226e05	ppg	Sediment - 1QA02	Apex Flats - d-30m @ 920m from shore	0.4	ND	0.4	ND	0.4	ND	0.4	ND	0.3	ND	0.3	ND	0.3	1.6
6304S 226e05	ppg	Sediment - CAM08	Inlet to ocean	0.6	ND	0.6	ND	0.6	ND	0.6	ND	0.6	ND	0.6	ND	0.6	3.1
6304S 226e05	ppg	Sediment - CAM06	Discharge to ocean	0.8	ND	0.8	ND	0.8	ND	0.8	ND	0.8	ND	0.8	ND	0.8	26.0
6305S 226e05 RR2	ppg	Sediment - 1QA13	Base - old military dump - confined cont	0.3	ND	0.3	ND	0.3	ND	0.3	ND	0.3	ND	0.3	ND	0.3	1.8
6304S 226e05 RR1	ppg	Sediment - CAM07	inlet to ocean	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.4	1.4	0.4	1.4	0.4	3.2
6304S 226e05	ppg	Sediment - CAM07	Background sample	0.5	ND	0.5	ND	0.5	ND	0.5	ND	0.3	1.1	0.3	1.1	0.3	4.6
6303S 226e05	ppg	Sediment - YELLO4	Background sample (across road)	0.7	ND	0.7	ND	0.7	ND	0.7	ND	0.3	0.3	0.3	0.3	0.3	ND
proc bk 226e05	ppg	Procedural Blank	N/A	0.7	ND	0.7	ND	0.7	ND	0.7	ND	0.3	0.3	0.3	0.3	0.3	ND
6304S 226e05 dl bd	ppg	Sediment - CAM04	discharge to ocean	6.5	ND	6.5	ND	6.5	ND	6.5	ND	6.2	19.6	6.2	19.6	6.2	27.8
6304S 226e05	ppg	Soil - YELLO2	white goods storage	4.8	ND	4.8	ND	4.8	ND	4.8	ND	4.2	118.2	4.2	118.2	4.2	42.6
6304S 226e05	ppg	Sediment - CAM02	close to effluent discharge	2.9	ND	2.9	ND	2.9	ND	2.9	ND	3.6	119.0	3.6	119.0	3.6	3.1
6304S 226e05 pcb	ppg	Soil - 1QA14	Northern Samples - Yell. Cam. In	4.1	ND	4.1	ND	4.1	ND	4.1	ND	2.1	ND	2.1	ND	2.1	0.3
6304S 226e05	ppg	Sediment - 1QA06	Open Pitblasting @ West 40 Dump (ash)	1.4	ND	1.4	ND	1.4	ND	1.4	ND	1.0	12.8	1.0	12.8	1.0	1.0
6304S 226e05	ppg	Soil - 1QA05	West 40 Dump - Metastide	0.6	ND	0.6	ND	0.6	ND	0.6	ND	0.6	2.5	0.6	2.5	0.6	2.0
6304S 226e05	ppg	Soil - CAM01	metal waste	3.4	35.0	3.4	71.9	3.4	53.6	3.4	318.1	3.9	318.1	3.9	318.1	3.9	76.8
6307S 226e05	ppg	Sediment - YELLO1	old dumping area	0.6	ND	0.6	ND	0.6	ND	0.6	ND	0.4	0.4	0.4	0.4	0.4	3.2
6305S 226e05	ppg	Soil - 1QA07	Apex Flats - d-30m @ 470m from shore	7.3	47.6	7.3	109.1	7.3	38.7	3.6	639.2	3.6	639.2	3.6	639.2	3.6	77.1
6305S 226e05 pcb RR1	ppg	Soil - 1QA07	Apex Flats - d-30m @ 470m from shore	12.1	ND	12.1	136.1	12.1	37.2	12.1	51.1	9.6	945.7	9.6	945.7	9.6	68.6
proc bk ase 07m05	ppg	ase Blank	Sediment Blank Ref for 6304Sed	5.9	ND	5.9	ND	5.9	ND	5.9	ND	4.7	ND	4.7	ND	4.7	ND
Sample #	DOC FILE #	SPECIES	SITE	Oct	Oct DL	Oct	Oct DL	Oct	Oct DL	Oct	Oct DL	22-3344556-BDE-208	22-3344556-BDE-208 DL	22-3344556-BDE-207	22-3344556-BDE-207 DL	22-3344556-BDE-206	22-3344556-BDE-206 DL
6303S 226e05	ppg	Proc Blank	N/A	ND	0.1	ND	0.1	ND	0.1	ND	0.1	N/A	N/A	N/A	0.1	0.1	0.1
6304S 226e05	ppg	Sediment - 1QA12	Apex Flats - d-30m @ 920m from shore	ND	2.0	ND	2.0	ND	2.0	ND	2.0	N/A	N/A	N/A	8.0	1.7	4.3
6303S 226e05	ppg	Sediment - 1QA09	Apex Flats - d-30m @ 950m from shore	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6303S 226e05 RR2	ppg	Sediment - 1QA08	Apex Flats - d-30m @ 950m from shore	ND	1.6	ND	1.6	ND	1.6	ND	1.6	N/A	N/A	N/A	10.8	1.1	5.0
6304S 226e05	ppg	Sediment - 1QA02	Apex Flats - d-30m @ 920m from shore	ND	1.6	ND	1.6	ND	1.6	ND	1.6	N/A	N/A	N/A	7.8	1.7	4.6
6304S 226e05	ppg	Sediment - CAM08	Inlet to ocean	8.1	3.1	9.0	3.1	5.9	3.1	5.6	3.1	N/A	N/A	N/A	82.7	5.3	46.5
6304S 226e05	ppg	Sediment - CAM06	Discharge to ocean	22.3	2.6	49.7	2.6	23.0	2.6	23.0	2.6	N/A	N/A	N/A	237.9	5.7	91.1
6305S 226e05 RR2	ppg	Sediment - 1QA13	Base - old military dump - confined cont	ND	1.8	ND	1.8	ND	1.8	ND	1.8	N/A	N/A	N/A	9.8	2.8	3.6
6304S 226e05 RR1	ppg	Sediment - CAM07	inlet to ocean	7.5	1.9	6.6	1.9	1.9	1.9	1.9	1.9	N/A	N/A	N/A	26.1	1.4	17.2
6304S 226e05	ppg	Sediment - CAM07	Background sample	9.3	1.8	10.1	1.8	9.2	1.8	9.2	1.8	N/A	N/A	N/A	32.2	1.8	7.2
6303S 226e05	ppg	Sediment - YELLO4	Background sample (across road)	ND	3.3	ND	3.3	ND	3.3	ND	3.3	N/A	N/A	N/A	8.9	2.2	2.9
proc bk 226e05	ppg	Procedural Blank	N/A	ND	2.1	ND	2.1	ND	2.1	ND	2.1	N/A	N/A	N/A	4.9	0.8	3.2
6304S 226e05 dl bd	ppg	Sediment - CAM04	discharge to ocean	66.9	27.6	68.0	27.6	68.0	27.6	68.0	27.6	N/A	N/A	N/A	843.3	34.1	845.5
6304S 226e05	ppg	Soil - YELLO2	white goods storage	162.8	3.1	1589.7	3.1	326.9	3.1	326.9	3.1	N/A	N/A	N/A	887.9	23.2	409.9
6304S 226e05	ppg	Sediment - CAM02	close to effluent discharge	2.2	2.2	414.1	2.2	311.4	2.2	311.4	2.2	N/A	N/A	N/A	447.2	1.2	335.7
6304S 226e05 pcb	ppg	Soil - 1QA14	Northern Samples - Yell. Cam. In	ND	9.3	ND	9.3	ND	9.3	ND	9.3	N/A	N/A	N/A	12.5	10.0	25.8
6304S 226e05	ppg	Sediment - 1QA06	Open Pitblasting @ West 40 Dump (ash)	5.0	0.9	6.9	0.9	6.9	0.9	6.9	0.9	N/A	N/A	N/A	30.5	1.1	18.4
6304S 226e05	ppg	Soil - 1QA05	West 40 Dump - Metastide	2.6	2.0	2.0	2.0	2.0	2.0	2.0	2.0	N/A	N/A	N/A	8.7	0.7	4.5
6304S 226e05	ppg	Soil - CAM01	metal waste	167.8	1.7	146.7	1.7	104.6	1.7	104.6	1.7	N/A	N/A	N/A	284.9	1.4	144.1
6307S 226e05	ppg	Sediment - YELLO1	old dumping area	4.0	3.2	6.4	3.2	4.6	3.2	4.6	3.2	N/A	N/A	N/A	14.4	1.2	7.2
6305S 226e05	ppg	Soil - 1QA07	Apex Flats - d-30m @ 470m from shore	190.4	10.1	212.7	10.1	17.1	10.1	17.1	10.1	N/A	N/A	N/A	665.3	17.7	275.8
6305S 226e05 pcb RR1	ppg	Soil - 1QA07	Apex Flats - d-30m @ 470m from shore	194.2	3.8	640.9	3.8	207.5	3.8	207.5	3.8	N/A	N/A	N/A	471.8	2.5	168.0
proc bk ase 07m05	ppg	ase Blank	Sediment Blank Ref for 6304Sed	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Sample #	DOC FILE #	SPECIES	SITE	22-3344556-BDE-206 DL	22-3344556-BDE-206 DL	22-3344556-BDE-206 DL	22-3344556-BDE-206 DL	22-3344556-BDE-206 DL	22-3344556-BDE-206 DL	22-3344556-BDE-206 DL	22-3344556-BDE-206 DL	22-3344556-BDE-206 DL	22-3344556-BDE-206 DL	22-3344556-BDE-206 DL	22-3344556-BDE-206 DL	22-3344556-BDE-206 DL	22-3344556-BDE-206 DL
6303S 226e05	ppg	Proc Blank	N/A	0.1	5.9	0.1	6250	80	12686	80	1000	proc bk 226e05 de	bd199-15	D86-5m Ultima	22-Feb-05	18-Mar-05	
6304S 226e05	ppg	Sediment - 1QA12	Apex Flats - d-30m @ 920m from shore	1.7	208.4	6.0	6250	97	12686	97	1000	6304S 226e05 de	bd199-24	D86-5m Ultima	22-Feb-05	18-Mar-05	
6303S 226e05	ppg	Sediment - 1QA09	Apex Flats - d-30m @ 950m from shore	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	6304S 226e05 de	bd199-24	D86-5m Ultima	22-Feb-05	18-Mar-05	
6303S 226e05 RR2	ppg	Sediment - 1QA08	Apex Flats - d-30m @ 950m from shore	1.1	343.6	3.8	616	73	12686	73	1000	6302S 226e05 de	bd199-23	D86-5m Ultima	22-Feb-05	18-Mar-05	
6304S 226e05	ppg	Sediment - 1QA02	Apex Flats - d-30m @														

Table C.3 (continued) Raw soil data from the Canadian North, summer 2004 (pg/g) (Lab: DFO-IOS)

SAMPLE #	DIOS FILE #	SPECIES	SITE	13C-4-BDE-3PG	13C-4-BDE-3 REC	13C-44'-BDE-15PG	13C-44'-BDE-15 REC	13C-23445-BDE-118PG	13C-23445-BDE-118 REC	13C-224455-BDE-153PG	13C-224455-BDE-153 REC
proc blk 22fe05	pg/g	Proc Blank	N/A	2500	25	2500	59	3750	58	5000	68
6354S 22fe05	pg/g	Sediment - 1QA12	Apex Flats - d-30m @920m from shore	2500	34	2500	65	3750	69	5000	75
6353S 22fe05	pg/g	Sediment - 1QA09	Apex Flats - d-30m @ 560m from shore	2500	34	2500	59	3750	46	5000	52
6352S 22fe05 RR2	pg/g	Sediment - 1QA08	Apex Flats - d-30m @ 560m from shore	2500	46	2500	79	3750	76	5000	84
6348S 22fe05	pg/g	Sediment - 1QA02	Apex Flats - d-30m @ 260m from shore	2500	43	2500	79	3750	79	5000	88
6345S 22fe05	pg/g	Sediment - CAM08	Inlet to ocean	2500	26	2500	43	3750	49	5000	50
6343S 22fe05	pg/g	Sediment - CAM06	Discharge to ocean	2500	22	2500	50	3750	60	5000	64
6353S 22fe05 RR2	pg/g	Sediment - 1QA13	Base - old military dump - confined cont	2500	36	2500	61	3750	53	5000	52
6344S 22fe05 RR1	pg/g	Sediment - CAM07	Inlet to ocean	2500	25	2500	42	3750	51	5000	59
6344Srep 22fe05	pg/g	Sediment - CAM07	Background sample	2500	26	2500	45	3750	51	5000	59
6339S 22fe05	pg/g	Sediment - YELL04	Background sample (across road)	2500	18	2500	39	3750	48	5000	57
proc blk 28fe05	pg/g	Procedural Blank	N/A	2500	20	2500	38	3750	42	5000	55
6342S 28fe05 dil bd	pg/g	Sediment - CAM04	discharge to ocean	2500	25	2500	33	3750	41	5000	42
6338S 28fe05	pg/g	Soil - YELL02	white goods storage	5000	42	5000	73	7500	103	10000	119
6341S 28fe05	pg/g	Sediment - CAM02	close to effluent discharge	2500	34	2500	60	3750	70	5000	90
6356S 28fe05 pcb	pg/g	Soil - 1QA14	Northern Samples - Yell, Cam, In	5000	51	5000	58	7500	71	10000	87
6350S 28fe05	pg/g	Sediment - 1QA06	Open Pitburning @ West 40 Dump (ash)	5000	32	5000	61	7500	79	10000	94
6349S 28fe05	pg/g	Soil - 1QA05	West 40 Dump - Metalside	2500	27	2500	59	3750	67	5000	80
6340S 28fe05	pg/g	Soil - CAM01	metal waste	2500	27	2500	46	3750	53	5000	66
6337S 28fe05	pg/g	Sediment - YELL01	old dumping area	2500	37	2500	61	3750	76	5000	96
6351S 28fe05	pg/g	Soil - 1QA07	Apex Flats - d-30m @470m from shore	2500	27	2500	50	3750	60	5000	69
6351Srep 28fe05 pcb RR1pg/g	pg/g	Soil - 1QA07	Apex Flats - d-30m @470m from shore	2500	45	2500	50	3750	72	5000	81
proc blk ase 07mr05	pg/sample	Ase Blank	Sediment Blank Ref for 6346Sed	N/A	N/A	N/A	N/A	3750	96	5000	99

Table C.4 Raw soil data from the Canadian North, summer 2004 (pg/g) (Lab: Duke)

Mass extracted (g)	34	18.16	14.38	11.12	10.87	9.45	8.06	8.14	5.36
Concentration (ng/g)	CAM01	CAM02	CAM07	CAM07	1QA07	1QA06	CAM04	1QA02	YELL01
	<u>Sample A</u>	<u>B</u>	<u>C</u>	<u>D</u>	<u>E</u>	<u>F</u>	<u>G</u>	<u>H</u>	<u>I</u>
BDE 30	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BDE 17	0.00	0.00	0.00	0.00	0.75	0.00	0.00	0.00	0.00
BDE 25	0.00	0.07	0.00	0.00	0.00	0.00	0.01	0.01	0.01
BDE 28,33	0.01	0.01	0.00	0.01	1.24	0.06	0.01	0.01	0.02
BDE 75	0.00	0.26	0.02	0.00	0.00	0.00	0.00	0.02	0.00
BDE 49	0.00	0.18	0.00	0.04	0.00	0.00	0.00	0.00	0.00
BDE 71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BDE 47	0.26	0.47	0.06	0.18	23.16	1.26	0.97	0.09	0.13
BDE 66	0.03	0.09	0.01	0.03	1.08	0.10	0.03	0.00	0.01
BDE 100	0.18	0.34	0.01	0.05	4.72	0.34	0.27	0.02	0.06
BDE 99	0.74	1.83	0.02	0.18	26.75	1.83	1.34	0.01	0.13
BDE 116	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BDE 85,155	0.03	0.09	0.00	0.00	1.01	0.07	0.06	0.00	0.01
BDE 154	0.07	0.35	0.00	0.02	2.01	0.16	0.32	0.00	0.01
BDE 153	0.27	0.53	0.06	0.08	2.90	0.27	0.25	0.05	0.13
BDE 138	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BDE 156	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BDE 183	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00
BDE 191	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BDE 190	0.03	0.10	0.00	0.00	0.09	0.02	0.00	0.00	0.00
BDE 202	0.04	0.22	0.00	0.03	0.11	0.00	0.05	0.00	0.00
BDE 201	0.07	0.11	0.00	0.01	0.22	0.00	0.00	0.00	0.00
BDE 197	0.11	0.68	0.00	0.04	0.88	0.08	0.00	0.03	0.00
BDE 203,200	0.04	0.20	0.00	0.03	0.04	0.02	0.00	0.00	0.00
BDE 196	0.08	0.59	0.00	0.07	0.51	0.09	0.14	0.00	0.00
BDE 205	0.04	0.10	0.00	0.03	0.00	0.00	0.14	0.00	0.00
BDE 208	0.27	1.11	0.00	0.19	0.55	0.00	0.78	0.00	0.00
BDE 207	0.36	1.48	0.07	0.16	0.97	0.00	0.78	0.00	0.00
BDE 206	0.09	0.46	0.00	0.09	0.27	0.00	0.45	0.00	0.00
BDE 209	3.40	17.48	1.30	0.76	2.91	0.20	16.89	0.21	1.10
Total	6.13	26.74	1.55	2.00	70.17	4.48	32.13	0.43	1.56

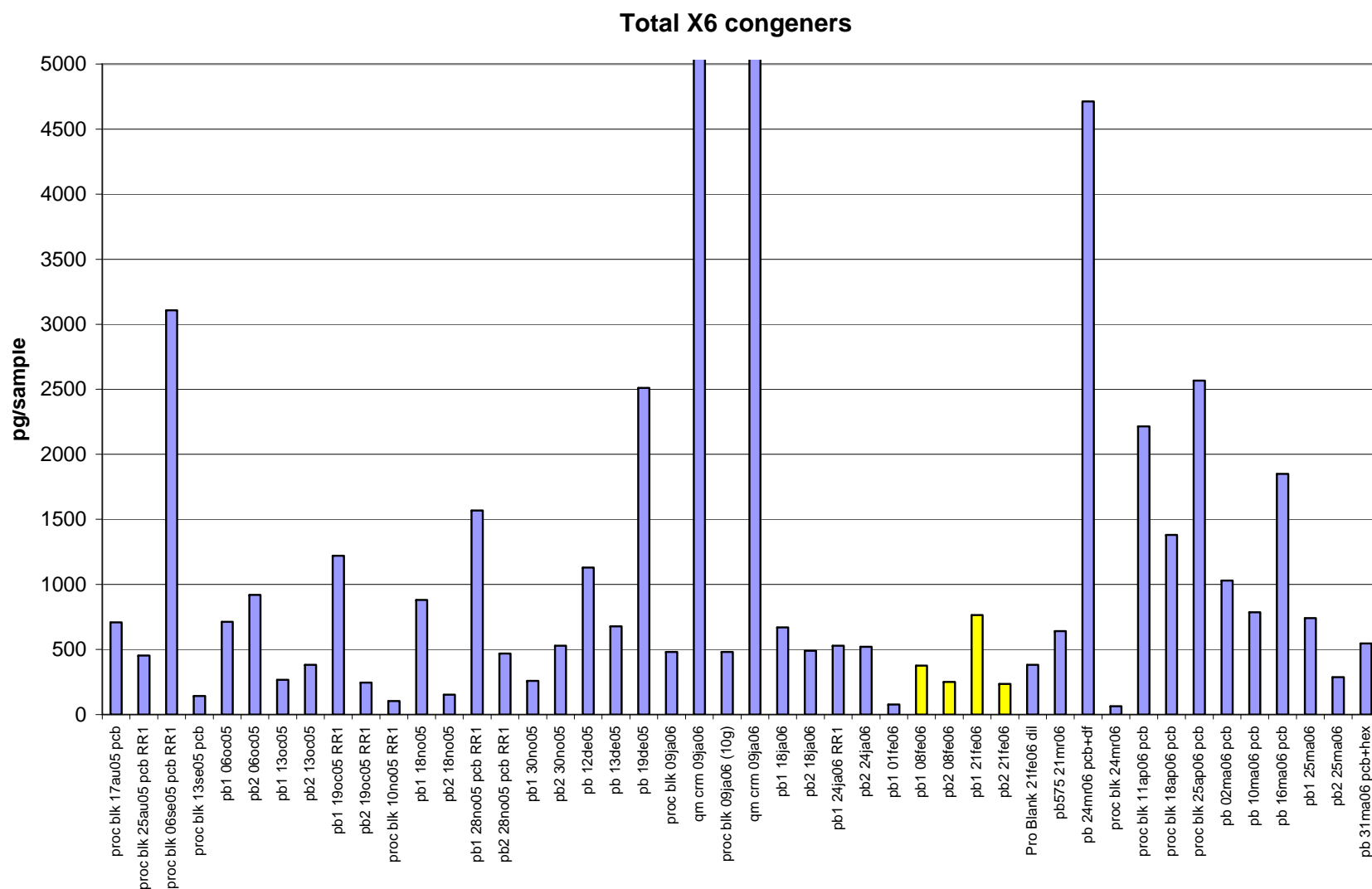


Figure C.1. Full sequence of DFO-IOS PBDE data from which the Clusters in Chapter 3 were derived. Yellow bars correspond to samples collected for this thesis project, whereas blue bars are for other samples.

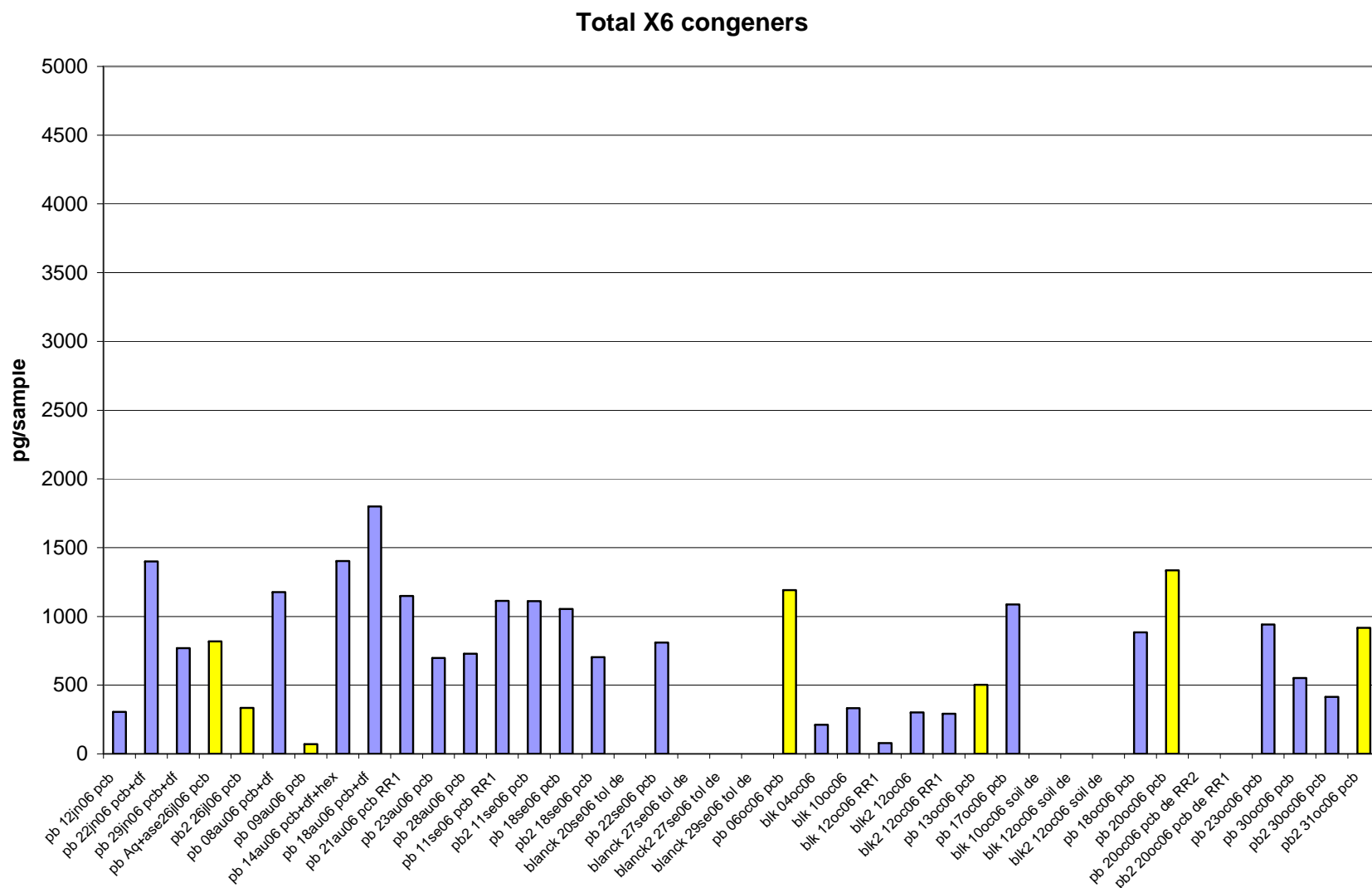


Figure C.2. Full sequence of DFO-IOB PBDE data from which the Clusters in Chapter 3 were derived. Yellow bars correspond to samples collected for this thesis project, whereas blue bars are for other samples.

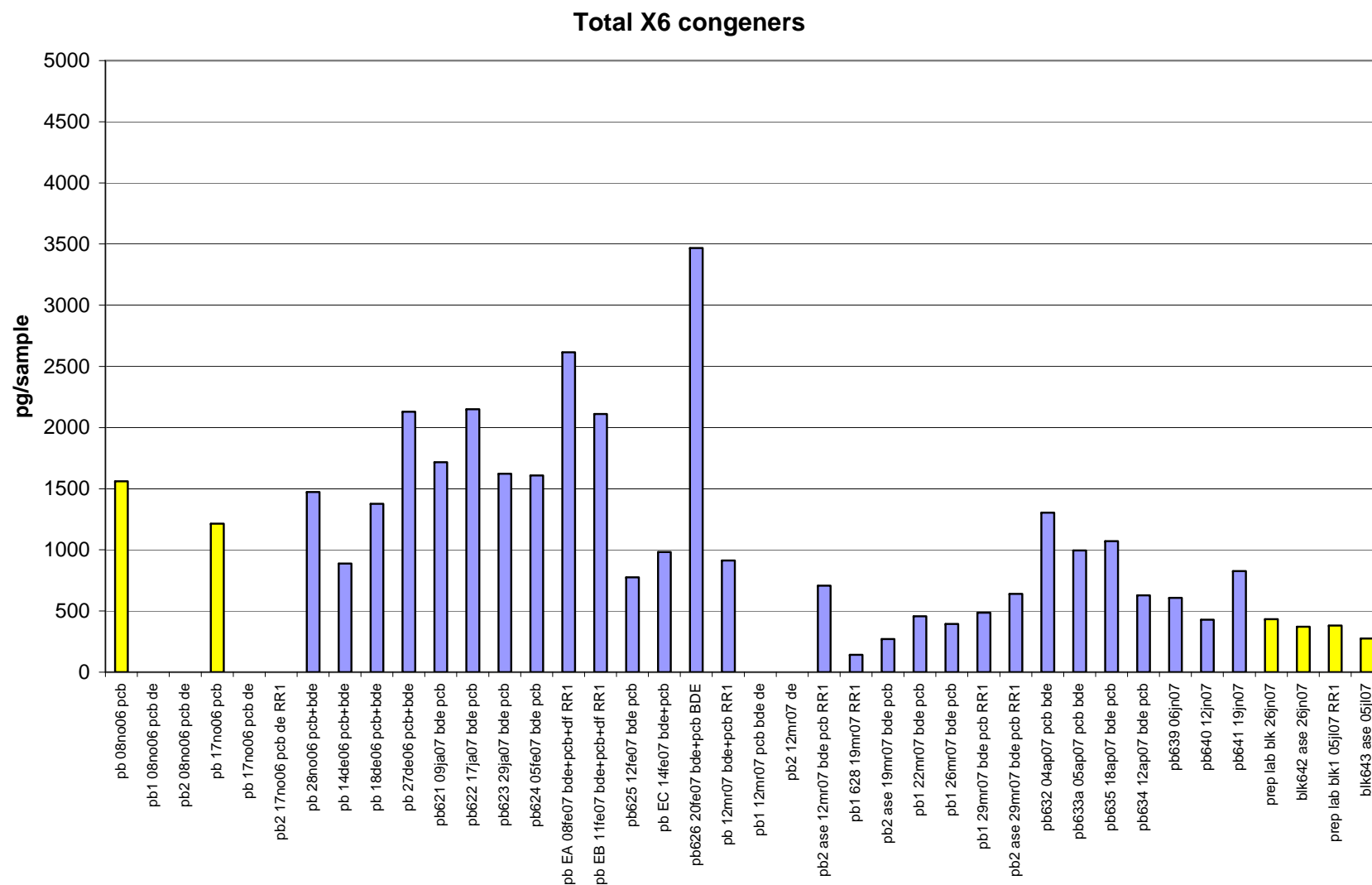


Figure C.3. Full sequence of DFO-IOS PBDE data from which the Clusters in Chapter 3 were derived. Yellow bars correspond to samples collected for this thesis project, whereas blue bars are for other samples.

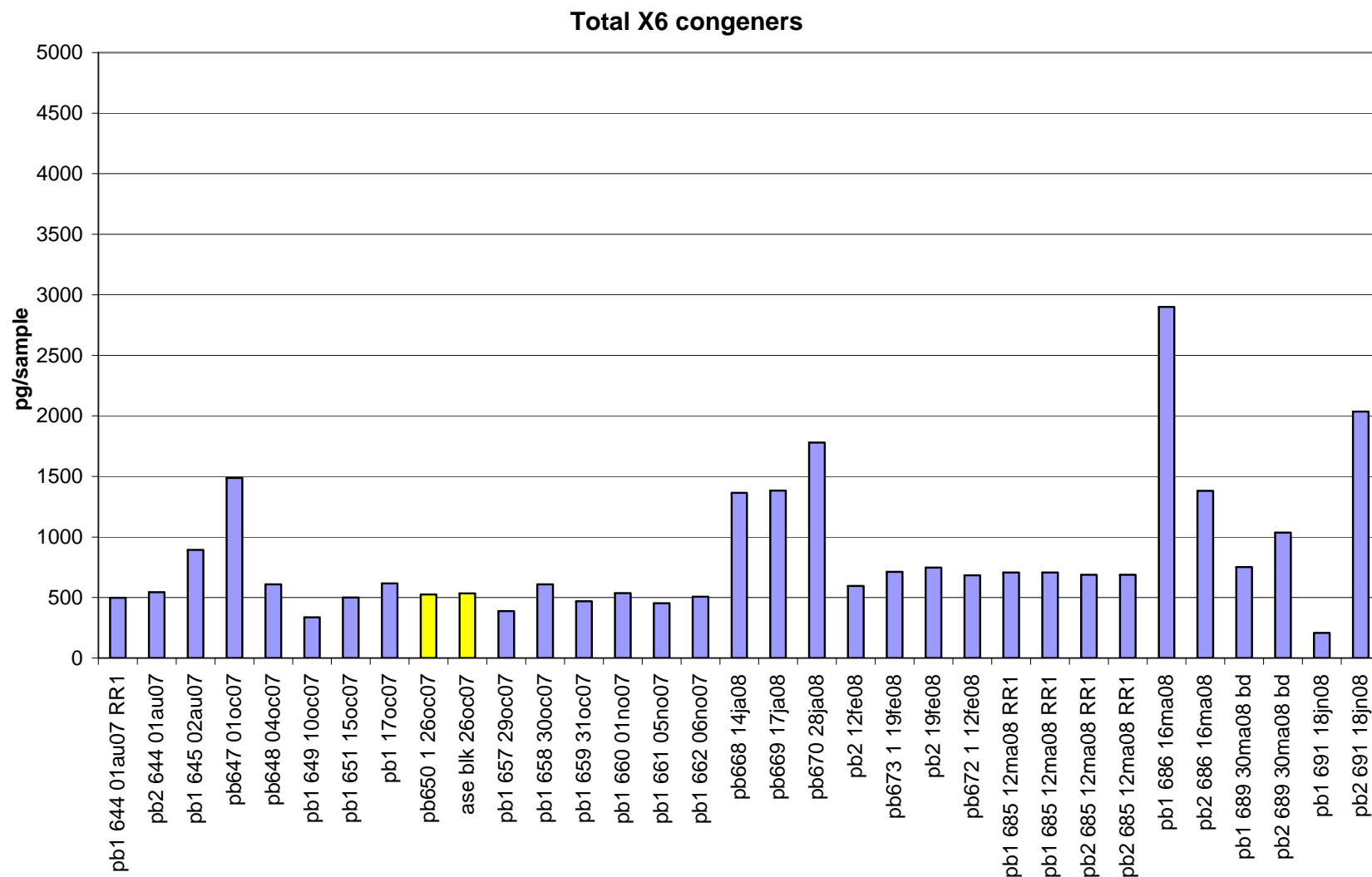


Figure C.4. Full sequence of DFO-IOS PBDE data from which the Clusters in Chapter 3 were derived. Yellow bars correspond to samples collected for this thesis project, whereas blue bars are for other samples.

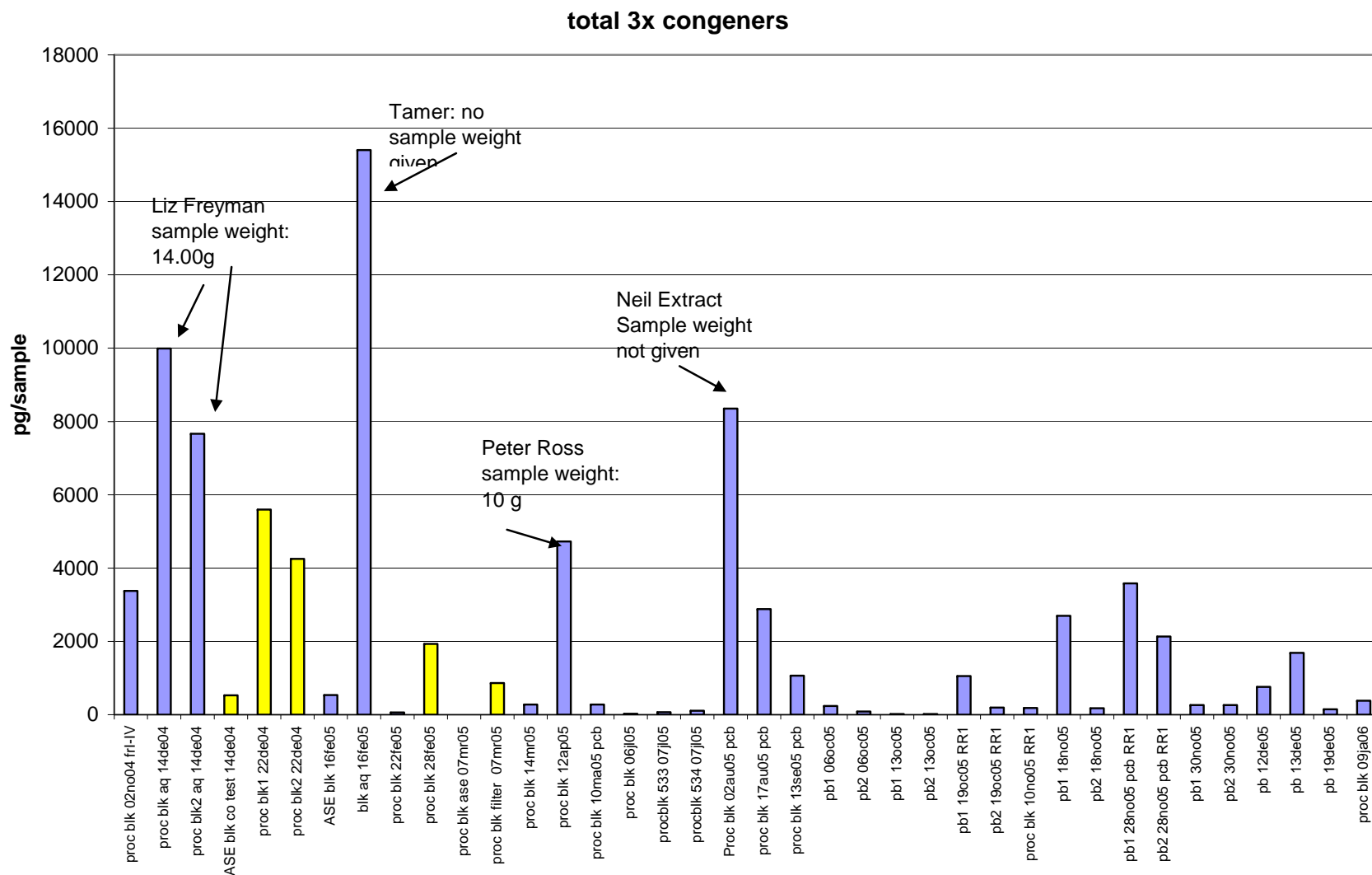


Figure C.5. Full sequence of DFO-IOS PBDE data from which the Clusters in Chapter 3 were derived. Yellow bars correspond to samples collected for this thesis project, whereas blue bars are for other samples.

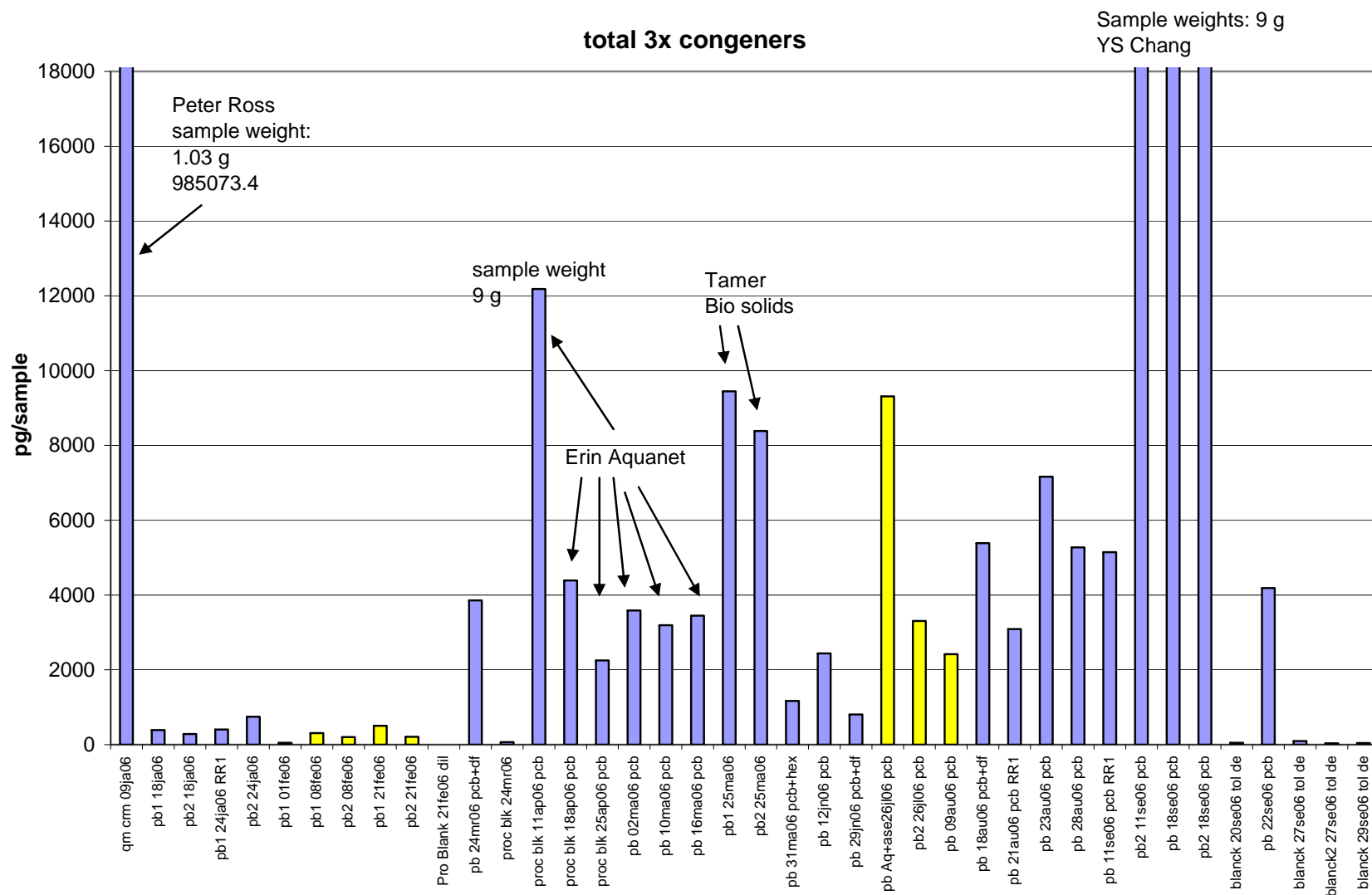


Figure C.6. Full sequence of DFO-IOB PBDE data from which the Clusters in Chapter 3 were derived. Yellow bars correspond to samples collected for this thesis project, whereas blue bars are for other samples.

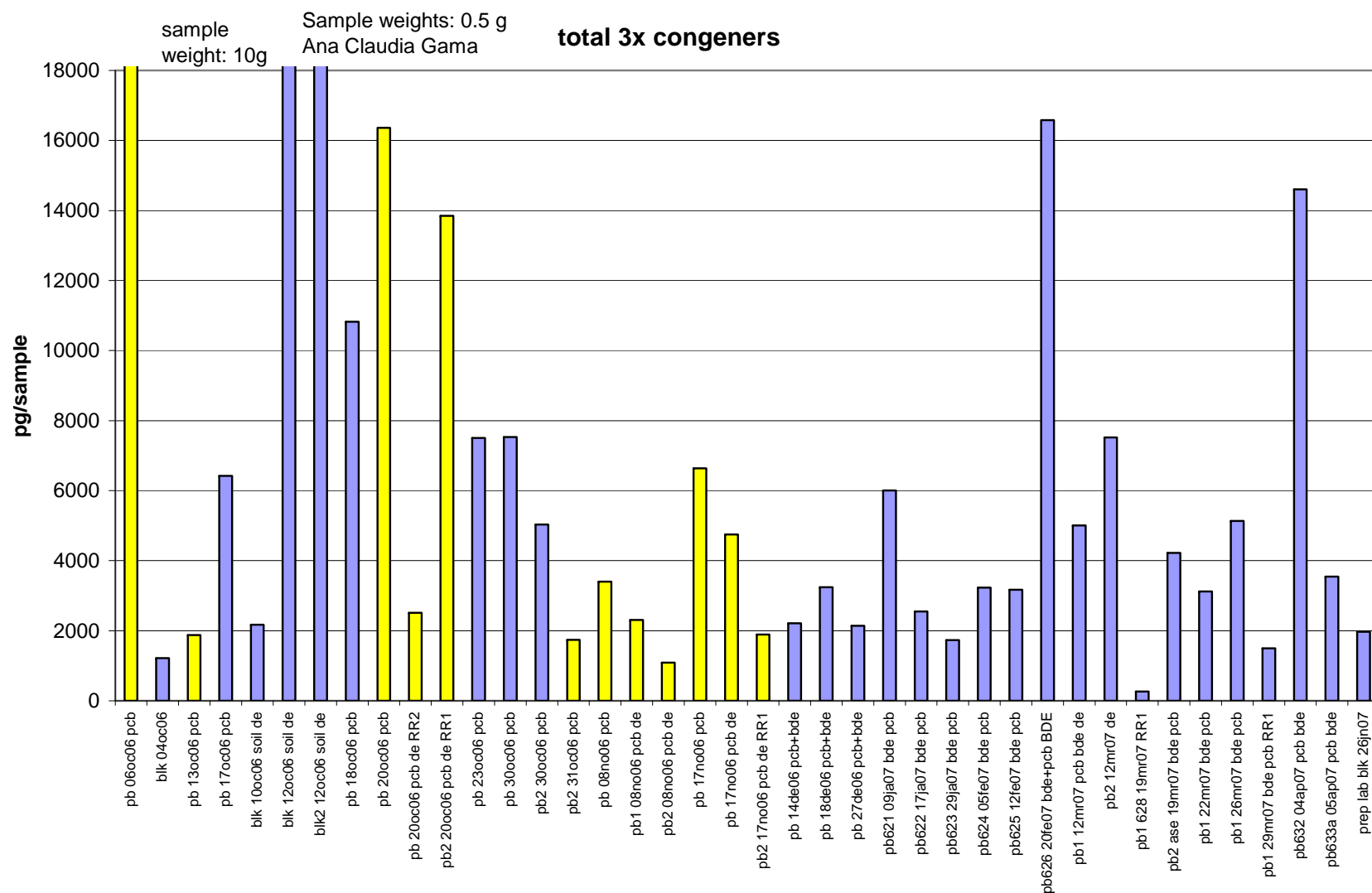


Figure C.7. Full sequence of DFO-IOB PBDE data from which the Clusters in Chapter 3 were derived. Yellow bars correspond to samples collected for this thesis project, whereas blue bars are for other samples.

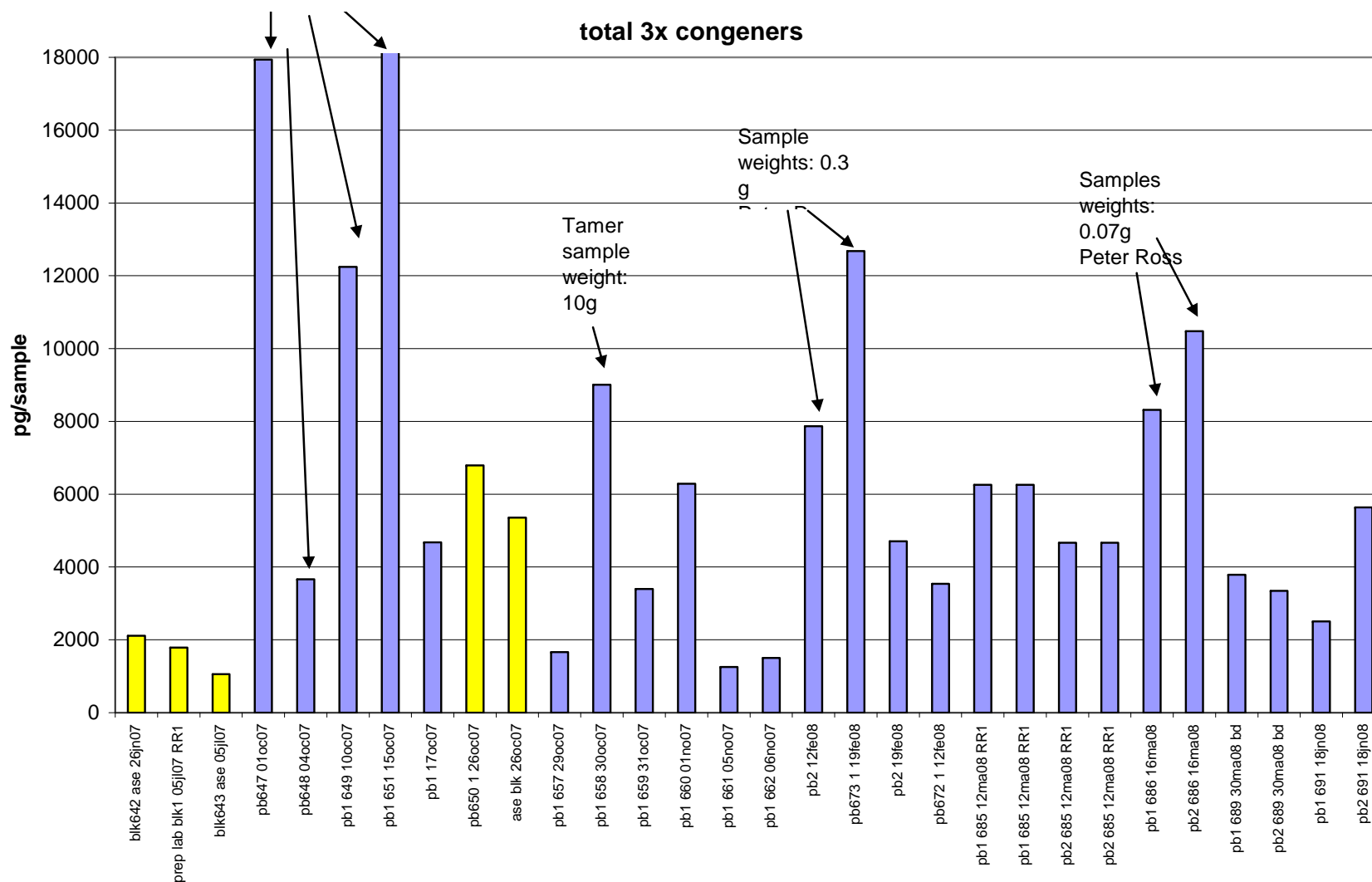


Figure C.8. Full sequence of DFO-IOS PBDE data from which the Clusters in Chapter 3 were derived. Yellow bars correspond to samples collected for this thesis project, whereas blue bars are for other samples.

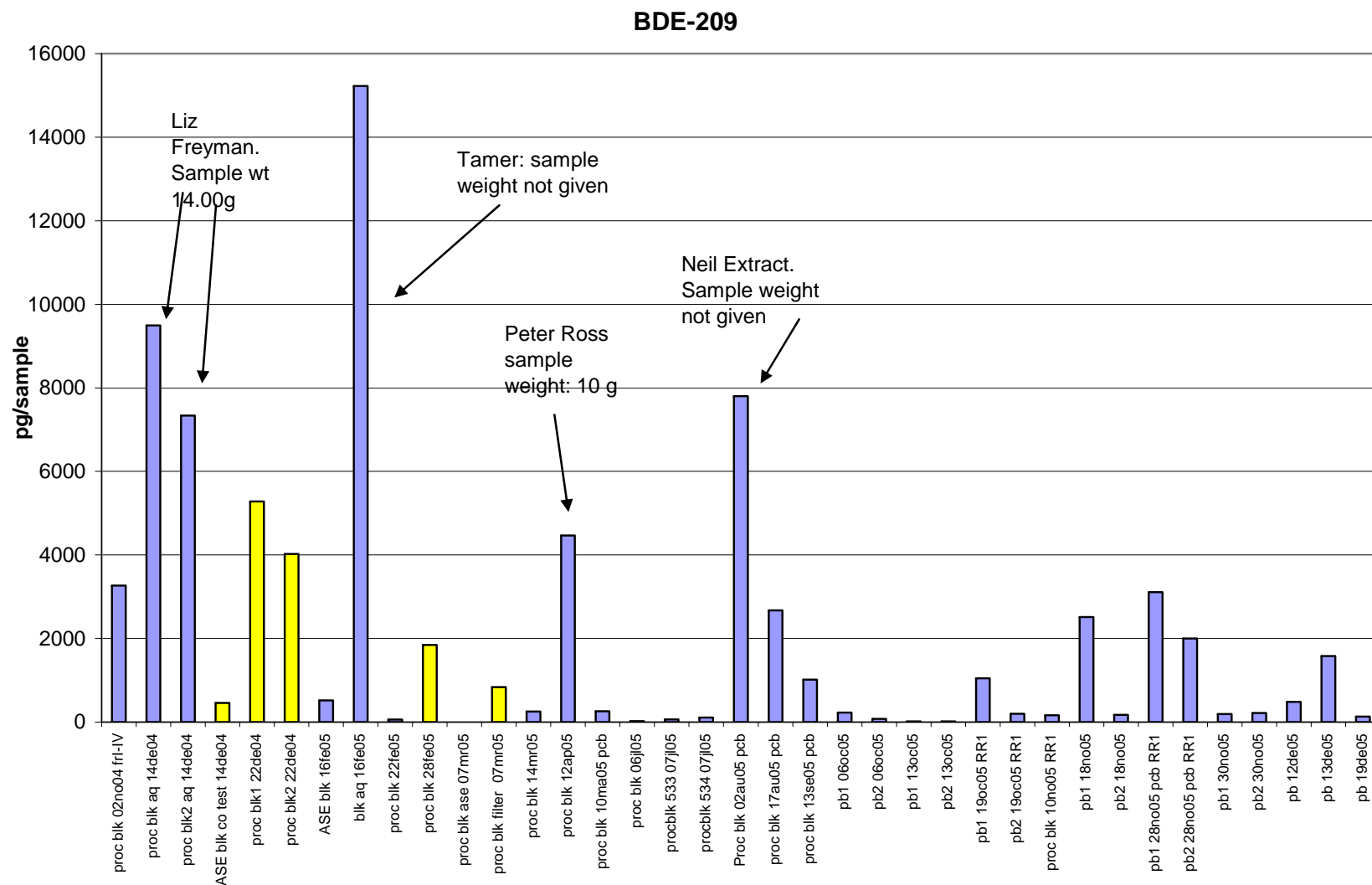


Figure C.9. Full sequence of DFO-IOB PBDE data from which the Clusters in Chapter 3 were derived. Yellow bars correspond to samples collected for this thesis project, whereas blue bars are for other samples.

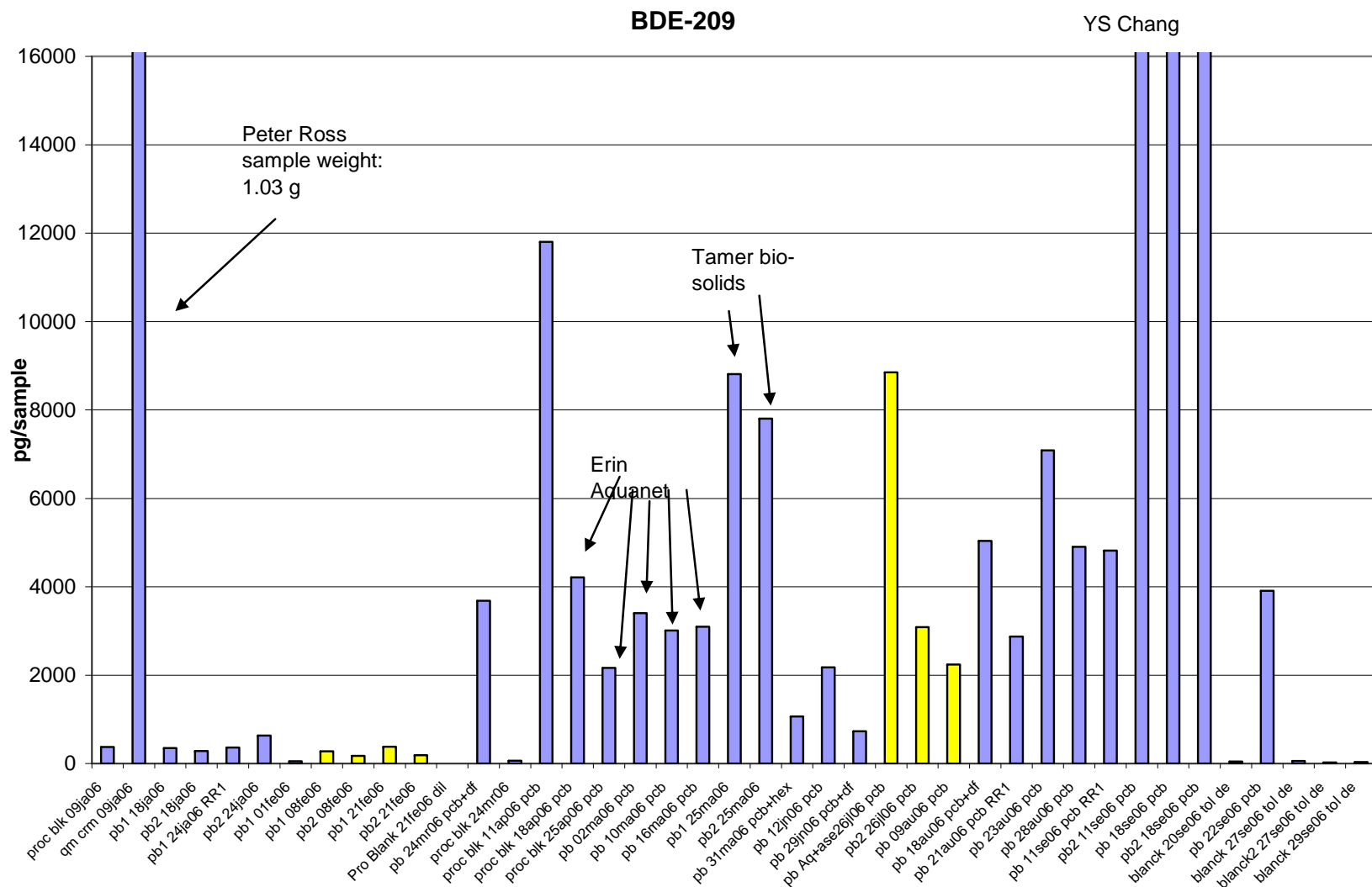


Figure C.10. Full sequence of DFO-IOS PBDE data from which the Clusters in Chapter 3 were derived. Yellow bars correspond to samples collected for this thesis project, whereas blue bars are for other samples.

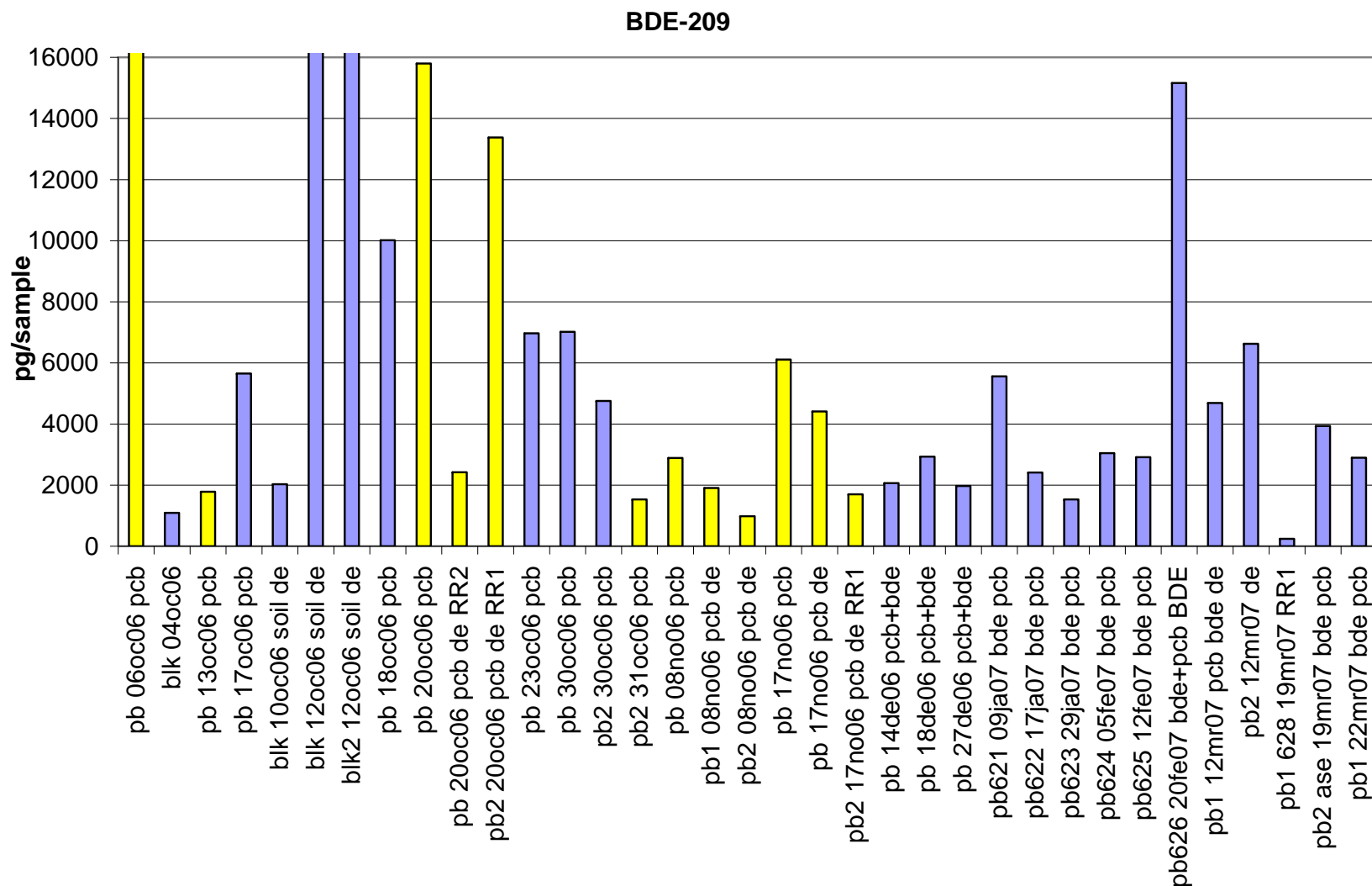


Figure C.11. Full sequence of DFO-IOS PBDE data from which the Clusters in Chapter 3 were derived. Yellow bars correspond to samples collected for this thesis project, whereas blue bars are for other samples.

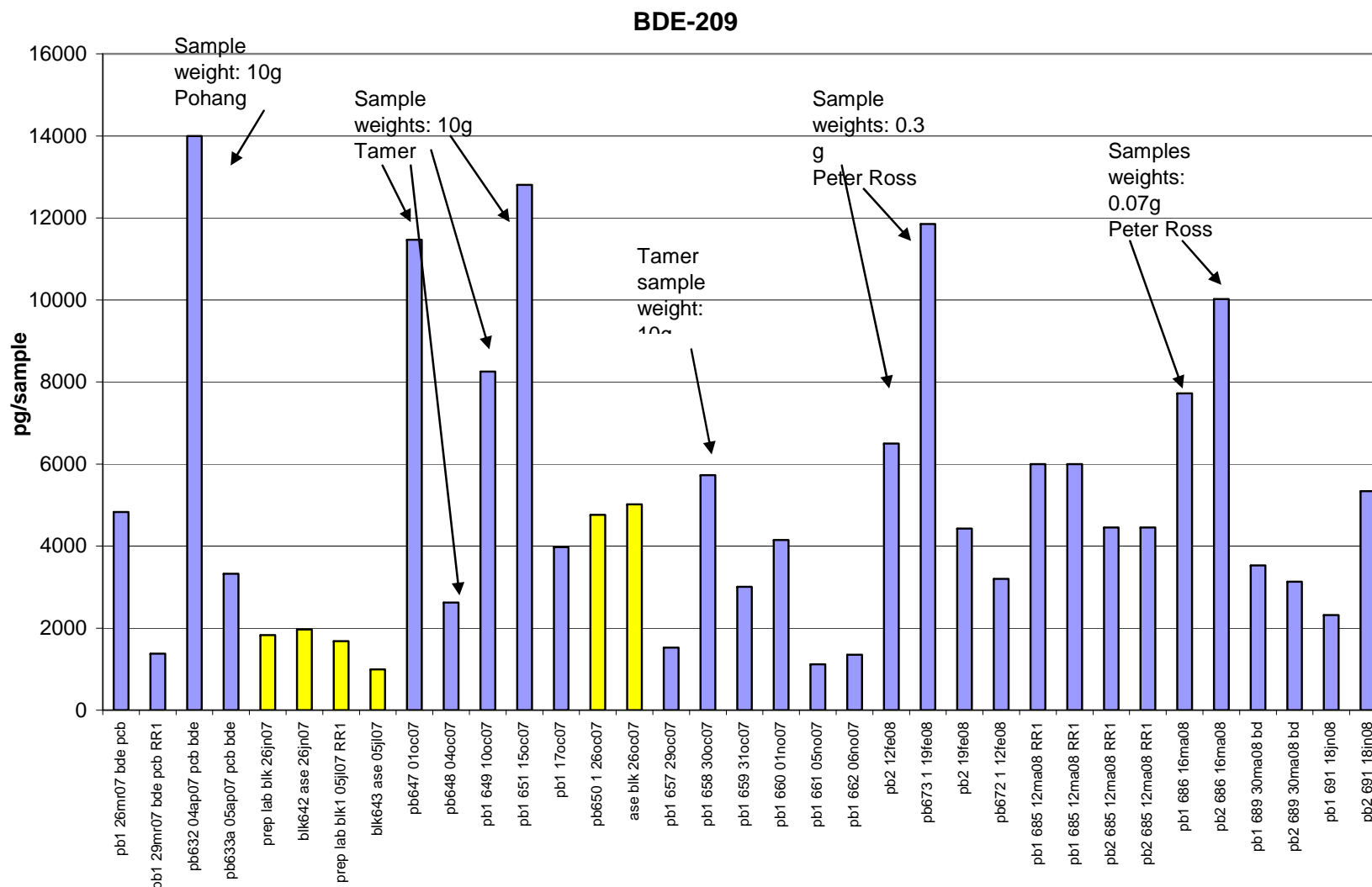


Figure C.12. Full sequence of DFO-IOS PBDE data from which the Clusters in Chapter 3 were derived. Yellow bars correspond to samples collected for this thesis project, whereas blue bars are for other samples.

Appendix D – Experimental Results: Investigation of PBDEs, Distribution in Landfills and Sewage Treatment in Northern Canada

Table D.1. Sample site details for all locations where samples were collected in the Canadian North

Iqaluit, Nunavut	Latitude N	Longitude W	leachate	effluent	background water	soil	Comments
West 40 landfill (IQ2W40-IQ1)	63°43.902'	68°32.109'	x		x	x	surface sample, same 2004 location (IQA06 in 2004)
West 40 landfill (IQ3W40)	63°43.894'	68°32.037'				x	surface sample, same 2004 location (IQA05 in 2004)
West 40 landfill (IQ4W40)	63°43.788'	68°32.161'				x	surface sample, same 2004 location (IQA17)
West 40 landfill (IQ5W40)	63°44.084'	68°32.229'					upgradient from West 40 landfill, pH=6
Former military dump (IQ6)	63°44.283'	68°32.435'				x	original landing strip; metal dump at end of runway (IQA14 in 2004)
Metal dumpsite (IQ7)	63°45.900'	68°32.889'				x	military scrap from 1940s (IQA04 in 2004)
Apex flats (IQAX-1)	63°43.548'	68°26.000'				x	~260 m from shore, sediment sample (IQA02 in 2004)
Apex flats (IQAX-2)	63°43.530'	68°25.929'				x	~400 m from shore, sediment sample
Apex flats (IQAX-3)	63°43.551'	68°26.024'			x		collected from same location as IQAX-2
Pangnirtung, Nunavut	Latitude N	Longitude W	leachate	effluent	background water	soil	Comments
wastewater treatment plant (PANG1)	66°09.307'	65°40.529'		x			collected at first outfall from wastewater treatment plant, pH~7.8
wastewater treatment plant (PANG2)	66°09.358'	65°40.588'		x			second outfall from wastewater treatment plant, prior to ocean entry, pH~8.1
water from the glacier (PANG3)	66°08.836'	65°41.037'			x		upstream drinking water for town, freezes in winter; pH~7.4
Cape Dorset, Nunavut	Latitude N	Longitude W	leachate	effluent	background water	soil	Comments
Tellik Inlet, Arctic Ocean (CD1)	64°13.986'	76°32.865'			x		collected at low tide
dumpsite (CD2)	64°13.679'	76°34.387'	x				garbage is burned, runoff flows above and below ground down to sewage lagoon
sewage lagoon (CD3)	64°13.748'	76°32.709'		x			outfall pipe prior to Arctic Ocean entry
Hall Beach, Nunavut	Latitude N	Longitude W	leachate	effluent	background water	soil	Comments
dumpsite (HB01)	68°48.347'	81°16.135'	x				dump at end of town, ~ 5km from airport, wire fence, no liner
drinking water lake (HB02)	68°45.878'	81°14.359'			x		adjacent to airport and DEW line site
Pont Inlet, Nunavut	Latitude N	Longitude W	leachate	effluent	background water	soil	Comments
drinking water lake (PI-1)	72°40.251'	77°55.670'			x		primary source of drinking water to community. ~ 5 km NE of town, pH~8.7
Rankin Inlet, Nunavut	Latitude N	Longitude W	leachate	effluent	background water	soil	Comments
Nipissar Lake (Rankin Inlet 1)	69°49.05'	92°07'			x		~middle of Nipissar Lake

Appendix D – Experimental Results: Investigation of PBDEs, Distribution in Landfills and Sewage Treatment in Northern Canada

Table D.1 (continued). Sample site details for all locations where samples were collected in the Canadian North

Cambridge Bay, Nunavut	Latitude N	Longitude W	leachate	effluent	background water	soil	Comments
effluent drainage area (CAMBY 1)	69°07.654'	105°02.033'	x	x			discharge to ocean effluent drainage area (CAMO3 in 2004)
drainage area (CAMBY 2)	69°07.603'	105°01.884'				x	soil sample close to effluent drainage area (CAMO4 in 2004)
garbage dump (CAMBY 3)	69°07.521'	105°01.954'				x	dumpsite not fenced, no liner (CAMO1 in 2004)
prior to ocean entry (CAMBY 4)	69°07.327'	105°02.251'		x			effluent discharge to ocean (CAMO5 in 2004)
area of effluent discharge (CAMBY 5)	69°07.323'	105°02.250'				x	sediment sample (CAMO6 in 2004)
metal dump (CAMBY 6)	69°07.483'	105°01.493'				x	not fenced, no liner (CAMO2 in 2004)
mid town location (CAMBY 7)	69°06.847'	105°03.384'				x	background soil sample (CAMO7 in 2004)
mid town location (CAMBY 7)	69°06.847'	105°03.384'		x			background water sample, pH~8.6 (CAMO7 in 2004)
enroute to Mt Pelly 15km northeast of the town (CAMBY 8)	69°07.533'	105°00.664'				x	background soil sample
enroute to Mt Pelly 15km northeast of the town (CAMBY 8)	69°07.533'	105°00.664'		x			background water sample
Inuvik, Northwest Territories	Latitude N	Longitude W	leachate	effluent	background water	soil	Comments
near the "Roads End" golf course (INUVK1)	68°21.194'	133°41.129'	x		x		background water sample, pH~8.3
close to Finning Lake (INUVK2)	68°20.550'	133°40.662'			x		down from dump at closest body of water (aka Finning Lake), pH~7.6
Boot Lake (INUVK3)	68°21.038'	133°41.971'			x		background water sample
Tuktoyaktuk, Northwest Territories	Latitude N	Longitude W	leachate	effluent	background water	soil	Comments
Water Lake (TUK-1)	69°24.610'	133°01.514'	x		x		former drinking water source for community, ~ 3 km away
dumpsite/effluent combined (TUK-2)	69°24.610'	133°01.514'					adjacent to main water body that receives leachate from dumpsite, discharge to ocean; permeable soil barrier; located at ocean entrance
dumpsite (TUK-3)	69°24.610'	133°01.514'					dumpsite, no liner, fenced, permeable soil barrier, adjacent to ocean entrance
Yellowknife, Northwest Territories	Latitude N	Longitude W	leachate	effluent	background water	soil	Comments
old dumping area of landfill (YELL01)	62°28.470'	114°22.684'	x			x	soil sample collected close to YELL01 (2004) location but not exact due to scrap metal placed since then
white goods area of landfill (YELL02)	62°28.514'	114°22.728'				x	freshly covered with soil but same as YELL02 (2004)
current landfill working area (YELL03)	62°28.576'	114°23.071'				x	soil sample; landfill without liner, wire fenced all around
across highway from landfill (YELL04)	62°28.385'	114°22.038'				x	background soil sample across road from landfill at ski club
landfill (YE-01)	62°28.558'	114°22.607'					leachate from landfill
Whitehorse, Yukon	Latitude N	Longitude W	leachate	effluent	background water	soil	Comments
inside landfill: War Eagle Pit (WHITE-WEP)	60°44.052'	135°10.557'	x		x		historical leachate, former copper mine pit; depth to groundwater ~25 m
Porter Creek (WHT-PC)	60°44.140'	135°09.680'					upstream from landfill, considered background water
middle of landfill (SWE-4B)	60°44.057'	135°09.089'	x				current leachate collection

Table D.2 Latitude, longitude and population (2006 census data) for sites where samples were collected in the Canadian North

Location	Population	Latitude (N)	Longitude (W)
Whitehorse, Yukon	21,000	60°43'	135°30'
Yellowknife, NWT	18,700	62°28'	114°23'
Inuvik, NWT	4,000	68°21'	133°41'
Tuktoyaktuk, NWT	870	69°24'	133°01'
Cambridge Bay, Nunavut	1,500	69°07'	105°02'
Rankin Inlet, Nunavut	2,300	62°49'	92°15'
Iqaluit, Nunavut	6,000	63°43'	68°32'
Pangnirtung, Nunavut	1,300	66°09'	65°40'
Cape Dorset, Nunavut	1,200	64°13'	76°32'
Hall Beach, Nunavut	650	68°48'	81°16'
Pond Inlet, Nunavut	1,300	72°40'	77°55'

Table D.3 BDE concentrations in leachate samples collected in the Canadian North, summer 2006 (pg/L). Analysis by DFO-IOS

Sample ID	di-BDEs	tri-BDEs	tetra-BDEs	penta-BDEs	hexa-BDEs	hepta-BDEs	octa-BDEs	nona-BDEs	deca-BDEs	Total PBDEs
Iqaluit, Nunavut										
IQ1	2.04E+02	2.72E+02	9.00E+03	3.16E+03	2.55E+02	3.30E+02	5.52E+02	4.63E+03	1.78E+05	1.96E+05
Procedural blank	ND	3.03E+02	8.34E+03	3.35E+03	ND	ND	1.33E+03	5.26E+03	6.11E+04	N/A
IQ1-dup 1	ND	2.40E+02	7.96E+03	3.00E+03	ND	2.88E+02	6.12E+02	2.82E+03	6.47E+04	7.96E+04
Procedural blank	ND	3.03E+02	8.34E+03	3.35E+03	ND	ND	1.33E+03	5.26E+03	6.11E+04	N/A
IQ-landfill - dup 2	7.91E+01	1.62E+02	4.66E+03	2.06E+03	2.43E+02	2.86E+02	5.33E+02	9.17E+03	2.61E+05	2.78E+05
Procedural blank	ND	ND	6.22E+03	2.66E+03	1.66E+02	3.06E+02	8.46E+02	2.09E+03	1.53E+04	N/A
Procedural blank average	ND	3.03E+02	7.28E+03	3.01E+03	1.66E+02	3.06E+02	1.09E+03	3.68E+03	3.82E+04	
Iqaluit - average values before blank correction	1.41E+02	2.44E+02	7.49E+03	2.89E+03	2.49E+02	3.01E+02	7.57E+02	5.47E+03	1.41E+05	1.85E+05
Iqaluit - average values after blank correction	1.41E+02	BMDL	2.11E+02	BMDL	8.28E+01	BMDL	BMDL	1.79E+03	1.03E+05	105,108
Raw data - 2nd analysis - dup 1	1.65E+02	2.13E+02	4.42E+03	3.19E+03	4.25E+02	3.54E+02	1.05E+03	6.37E+03	7.62E+04	9.24E+04
Procedural blank	7.60E+01	1.42E+02	2.54E+03	1.43E+03	1.31E+02	1.70E+02	4.22E+02	2.10E+03	1.90E+04	N/A
2nd analysis - dup 1 value after blank correction	1.27E+01	BMDL	BMDL	3.40E+02	1.64E+02	1.38E+01	2.05E+02	2.18E+03	3.83E+04	4.12E+04
Raw data - 2nd analysis - dup 2	1.43E+02	1.83E+02	4.47E+03	2.86E+03	2.50E+02	2.71E+02	7.29E+02	8.14E+03	7.28E+04	8.98E+04
Procedural blank	7.60E+01	1.42E+02	2.55E+03	1.43E+03	1.31E+02	1.70E+02	4.22E+02	2.10E+03	1.90E+04	N/A
2nd analysis - dup 2 value after blank correction	BMDL	BMDL	BMDL	4.00E+00	BMDL	BMDL	BMDL	3.95E+03	3.48E+04	3.88E+04
Raw data - 2nd analysis - dup 3	1.30E+02	1.60E+02	3.69E+03	2.44E+03	2.64E+02	2.39E+02	1.56E+03	8.03E+03	2.35E+04	4.00E+04
Procedural blank	7.60E+01	1.42E+02	2.55E+03	1.43E+03	1.31E+02	1.70E+02	4.22E+02	2.10E+03	1.90E+04	N/A
2nd analysis - dup 3 value after blank correction	BMDL	BMDL	BMDL	BMDL	3.00E+00	BMDL	7.13E+02	3.84E+03	BMDL	4.55E+03
Iqaluit 2nd analysis- avg values before blank corr	1.46E+02	1.85E+02	4.20E+03	2.83E+03	3.13E+02	2.88E+02	1.11E+03	7.51E+03	5.75E+04	7.41E+04
Procedural blank	7.60E+01	1.42E+02	2.55E+03	1.43E+03	1.31E+02	1.70E+02	4.22E+02	2.10E+03	1.90E+04	N/A
Iqaluit 2nd analysis- avg values after blank corr	BMDL	BMDL	BMDL	BMDL	5.18E+01	BMDL	2.68E+02	3.32E+03	1.96E+04	2.32E+04
Total Iqaluit avg and after blk correction	71	BMDL	106	BMDL	67	BMDL	134	2.56E+03	6.12E+04	6.42E+04
Iqaluit final after blank corrections	71	BMDL	BMDL	BMDL	40	BMDL	BMDL	1.51E+03	8.31E+04	8.48E+04
Cape Dorset, Nunavut										
CD2	ND	4.01E+02	1.26E+04	5.12E+03	3.41E+02	6.28E+02	1.54E+03	5.79E+03	8.17E+04	1.08E+05
Procedural blank	ND	191	7.92E+03	3.29E+03	1.68E+02	3.87E+02	1.33E+03	3.64E+03	3.19E+04	N/A
Value after blank correction	ND	2.10E+02	4.69E+03	1.82E+03	3.41E+02	6.28E+02	2.07E+02	2.14E+03	4.98E+04	5.98E+04
Hall Beach, Nunavut										
HB-01	ND	3.71E+02	7.47E+03	6.35E+03	5.33E+03	1.91E+04	1.25E+04	1.45E+04	1.29E+05	1.94E+05
Procedural blank	ND	1.91E+02	7.92E+03	3.29E+03	1.68E+02	3.87E+02	1.33E+03	3.64E+03	3.19E+04	N/A
Value after blank correction	ND	1.80E+02	BMDL	3.06E+03	5.33E+03	1.91E+04	1.12E+04	1.08E+04	9.67E+04	1.46E+05
Raw data - rep analysis - dup 1	2.91E+02	3.42E+02	6.97E+03	9.53E+03	1.08E+04	4.18E+04	3.28E+04	2.58E+04	1.02E+05	2.30E+05
Procedural blank	7.60E+01	1.42E+02	2.54E+03	1.43E+03	1.31E+02	1.70E+02	4.22E+02	2.10E+03	1.90E+04	N/A
Value after blank correction	1.39E+02	5.83E+01	1.89E+03	6.68E+03	1.05E+04	4.15E+04	3.20E+04	2.16E+04	6.36E+04	1.78E+05
HB-01 - average values after blank correction	6.94E+01	1.19E+02	9.46E+02	4.87E+03	7.92E+03	3.03E+04	2.16E+04	1.62E+04	8.01E+04	1.62E+05
Cambridge Bay, Nunavut										
CAMBY 4	ND	1.82E+02	5.95E+03	2.55E+03	2.23E+02	3.14E+02	1.08E+03	3.81E+03	4.31E+04	5.72E+04
Procedural blank	ND	ND	1.07E+04	4.48E+03	3.68E+02	4.97E+02	2.11E+03	5.13E+03	2.89E+04	N/A
Value after blank correction	ND	1.82E+02	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	1.43E+04	1.44E+04

Sample ID: Iqaluit, NT (IQ-landfill); Cape Dorset, NT (CD2); Hall Beach, NT (HB-01); Cambridge Bay, NT (CAMBY4); Inuvik, NWT (INUVIK2); Tuktoyaktuk, NWT (TUK-2, TUK-3); Yellowknife, NWT (YELL-01); Whitehorse, Y
 ND - not detected; N/A - not available ; BMDL - below method detection limit

Appendix D – Experimental Results: Investigation of PBDEs, Distribution in Landfills and Sewage Treatment in Northern Canada

Table D.3 (continued)

Sample ID	di-BDEs	tri-BDEs	tetra-BDEs	penta-BDEs	hexa-BDEs	hepta-BDEs	octa-BDEs	nona-BDEs	deca-BDEs	Total PBDEs
Inuvik, Northwest Territories										
INUVIK2	ND	1.77E+02	5.66E+03	2.39E+03	1.39E+02	2.52E+02	6.22E+02	1.34E+03	1.89E+04	2.95E+04
Procedural blank	ND	1.91E+02	7.92E+03	3.29E+03	1.68E+02	3.87E+02	1.33E+03	3.64E+03	3.19E+04	N/A
Value after blank correction	ND	1.77E+02	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	1.77E+02
Tuktoyaktuk, Northwest Territories										
TUK-2	ND	1.60E+02	5.37E+03	2.10E+03	2.20E+02	2.51E+02	2.23E+02	6.44E+02	1.56E+04	2.46E+04
Procedural blank	ND	1.91E+02	7.92E+03	3.29E+03	1.68E+02	3.87E+02	1.33E+03	3.64E+03	3.19E+04	N/A
Value after blank correction	ND	1.60E+02	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	1.60E+02
TUK-3	ND	ND	3.51E+03	1.40E+03	5.67E+01	9.44E+01	3.25E+02	4.31E+02	8.24E+03	1.41E+04
Procedural blank	ND	1.91E+02	7.92E+03	3.29E+03	1.68E+02	3.87E+02	1.33E+03	3.64E+03	3.19E+04	N/A
Value after blank correction	ND	BMDL	BMDL	BMDL	5.70E+01	9.40E+01	BMDL	BMDL	BMDL	1.51E+02
Yellowknife, Northwest Territories										
YELL-01	1.33E+04	1.13E+04	1.89E+03	2.75E+03	ND	1.02E+02	1.22E+03	1.47E+03	2.55E+04	5.76E+04
Procedural blank	ND	1.91E+02	7.92E+03	3.29E+03	1.68E+02	3.87E+02	1.33E+03	3.64E+03	3.19E+04	N/A
Value after blank correction	1.33E+04	1.13E+04	BMDL	BMDL	ND	BMDL	1.22E+03	BMDL	BMDL	2.58E+04
YELL (dup1)	ND	ND	6.51E+03	3.98E+03	5.77E+02	6.96E+02	5.45E+02	2.22E+03	5.27E+04	6.72E+04
Procedural blank	ND	1.91E+02	7.92E+03	3.29E+03	1.68E+02	3.87E+02	1.33E+03	3.64E+03	3.19E+04	N/A
Value after blank correction	ND	ND	BMDL	BMDL	2.41E+02	-7.75E+01	5.45E+02	BMDL	BMDL	7.08E+02
YELL (dup2)	ND	2.21E+02	6.80E+03	4.98E+03	8.14E+02	1.05E+03	4.99E+02	3.47E+03	7.67E+04	9.46E+04
Procedural blank	ND	1.91E+02	7.92E+03	3.29E+03	1.68E+02	3.87E+02	1.33E+03	3.64E+03	3.19E+04	N/A
Value after blank correction	ND	-1.61E+02	BMDL	BMDL	4.78E+02	2.77E+02	4.99E+02	BMDL	1.29E+04	1.40E+04
YELL - average values after blank correction	4.42E+03	3.72E+03	BMDL	BMDL	2.39E+02	6.64E+01	7.55E+02	BMDL	4.31E+03	1.35E+04
Whitehorse, Yukon										
WEP	ND	3.38E+02	7.09E+03	2.41E+03	4.97E+02	1.19E+03	1.88E+03	7.01E+03	1.49E+05	1.69E+05
Procedural blank	ND	1.10E+01	3.21E+02	1.91E+02	2.66E+01	1.89E+02	1.43E+03	1.83E+03	2.24E+04	N/A
Value after blank correction	ND	3.16E+02	6.45E+03	2.03E+03	4.44E+02	8.08E+02	BMDL	3.35E+03	1.04E+05	1.17E+05
SWE-4B	ND	1.48E+02	5.71E+03	2.79E+03	2.90E+02	3.57E+02	2.49E+03	7.52E+03	1.15E+05	1.35E+05
Procedural blank	ND	1.91E+02	7.92E+03	3.29E+03	1.68E+02	3.87E+02	1.33E+03	3.64E+03	3.19E+04	N/A
Value after blank correction	ND	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	2.32E+02	5.15E+04	5.17E+04

ND - not detected; N/A - not available ; BMDL - below method detection limit

Table D.4 BDE concentrations in effluent samples collected in the Canadian North, summer 2006 (pg/L). Analyzed by DFO-IOS.

Sample ID	di-BDEs	tri-BDEs	tetra-BDEs	penta-BDEs	hexa-BDEs	hepta-BDEs	octa-BDEs	nona-BDEs	deca-BDEs	Total PBDEs
Pangnirtung, Nunavut										
PANG1	ND	3.89E+02	2.58E+04	3.52E+04	6.41E+03	1.16E+03	2.60E+03	1.57E+04	3.43E+05	4.30E+05
Procedural blank	ND	191	7,923	3,290	168	387	1,331	3,645	31,910	N/A
Value after blank correction	ND	1.98E+02	1.79E+04	3.19E+04	6.41E+03	1.16E+03	1.27E+03	1.20E+04	3.11E+05	3.82E+05
PANG2 - 1st analysis	ND	3.58E+02	1.99E+04	3.02E+04	5.53E+03	8.99E+02	2.29E+03	1.26E+04	1.73E+05	2.45E+05
Procedural blank	ND	191	7,923	3,290	168	387	1,331	3,645	31,910	N/A
Value after blank correction	ND	3.58E+02	1.20E+04	2.69E+04	5.36E+03	5.13E+02	9.62E+02	8.95E+03	1.41E+05	1.97E+05
PANG2 - 2nd analysis (rep 2)	425	692	28,477	43,078	6,262	1,348	4,411	26,154	264,361	375,208
Procedural blank	76	142	2,539	1,425	131	170	422	2,097	18,979	N/A
Value after blank correction	273	408	23,399	40,227	6,001	1,009	3,566	21,961	226,404	323,248
PANG2 - 2nd analysis (rep 3)	425	705	27,153	43,845	6,797	1,509	5,448	36,429	387,013	509,325
Procedural blank	76	142	2,539	1,425	131	170	422	2,097	18,979	N/A
Value after blank correction	273	421	22,075	40,995	6,536	1,169	4,604	32,236	349,055	457,365
PANG2 avg before blk correction	425	698	27,815	43,462	6,530	1,429	4,929	31,292	325,687	
Cape Dorset, Nunavut										
CD3 - 1st analysis (rep 1)	BMDL	1.88E+02	7.69E+03	1.02E+04	1.68E+03	5.15E+02	2.83E+03	6.63E+03	3.59E+04	6.57E+04
Procedural blank	ND	191	7,923	3,290	168	387	1,331	3,645	31,910	N/A
Value after blank correction	ND	1.88E+02	BMDL	6.92E+03	1.51E+03	1.28E+02	1.50E+03	2.99E+03	4.03E+03	8.62E+03
CD3 - 1st analysis (rep 2)	BMDL	2.47E+02	7.08E+03	8.28E+03	1.40E+03	6.84E+02	2.67E+03	8.36E+03	1.24E+05	1.53E+05
Procedural blank	ND	191	7,923	3,290	168	387	1,331	3,645	31,910	N/A
Value after blank correction	ND	2.47E+02	-8.41E+02	4.99E+03	1.23E+03	2.98E+02	1.33E+03	4.72E+03	9.20E+04	1.04E+05
CD3 - 2nd analysis (rep 3)	227	280	8,012	10,058	1,516	713	3,778	12,701	53,568	90,853
Procedural blank	76	142	2,539	1,425	131	170	422	2,097	18,979	N/A
Value after blank correction	75	(4)	2,934	7,207	1,255	373	2,934	8,508	15,611	38,892
CD3- avg value before blk corr	227	263	7,547	9,170	1,459	699	3,222	10,531	88,750	
Cambridge Bay, Nunavut										
CAMBY 1	ND	6.17E+02	9.50E+03	7.89E+03	2.13E+03	9.91E+02	3.31E+03	7.48E+03	1.08E+05	1.39E+05
Procedural blank	ND	191	7,923	3,290	168	387	1,331	3,645	31,910	N/A
Value after blank correction	ND	4.26E+02	1.57E+03	4.60E+03	2.13E+03	9.91E+02	1.98E+03	3.84E+03	7.56E+04	9.11E+04

ND - not detected; N/A - not available ; BMDL - below method detection limit

Pangnirtung, NU (PANG1 :Outflow from secondary treatment plant); PANG2 (Further down from WWTP outflow- before discharge to ocean); Cape Dorset, NU

(CD3: Sewage outfall prior to entering Arctic Ocean - Telik Inlet)

Cambridge Bay, NU (CAMBY1: Entrance to effluent drainage area (CAM03-Arctic 2004 samples))

Table D.5 BDE concentrations in background water samples collected in the Canadian North, summer 2006 (pg/L). Analyzed by DFO-IOS

Sample ID	di-BDEs	tri-BDEs	tetra-BDEs	penta-BDEs	hexa-BDEs	hepta-BDEs	octa-BDEs	nona-BDEs	deca-BDEs	Total PBDEs
Iqaluit, Nunavut										
Apex - IQAX-3	ND	ND	3.15E+03	1.20E+03	1.05E+02	3.88E+02	1.31E+03	3.08E+03	7.02E+04	7.94E+04
Procedural blank	ND	191	7.92E+03	3.29E+03	1.68E+02	3.87E+02	1.33E+03	3.64E+03	3.19E+04	N/A
Value after blank correction	ND	ND	BMDL	BMDL	BMDL	1.25E+00	-1.67E+01	-5.62E+02	3.83E+04	3.77E+04
IQ5W40										
Procedural blank	ND	1.14E+02	3.64E+03	1.56E+03	8.00E+01	1.95E+02	ND	1.59E+03	2.43E+04	3.15E+04
Value after blank correction	ND	1.91E+02	7.92E+03	3.29E+03	1.68E+02	3.87E+02	1.33E+03	3.64E+03	3.19E+04	5.18E+04
Pangnirtung, Nunavut										
PANG3	1.14E+02	1.46E+02	3.28E+03	1.26E+03	1.33E+02	2.50E+02	ND	9.76E+02	1.79E+04	2.41E+04
Procedural blank	ND	1.91E+02	7.92E+03	3.29E+03	1.68E+02	3.87E+02	1.33E+03	3.64E+03	3.19E+04	N/A
Value after blank correction	1.14E+02	1.46E+02	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	-1.40E+04	-1.37E+04
Cape Dorset, Nunavut										
CD1	ND	1.45E+02	3.65E+03	1.49E+03	1.30E+02	3.26E+02	6.34E+02	4.40E+03	6.24E+04	7.32E+04
Procedural blank	ND	1.91E+02	7.92E+03	3.29E+03	1.68E+02	3.87E+02	1.33E+03	3.64E+03	3.19E+04	N/A
Value after blank correction	ND	1.45E+02	BMDL	BMDL	BMDL	BMDL	BMDL	7.59E+02	3.05E+04	#VALUE!
Hall Beach, Nunavut										
HB-02	2.22E+02	2.63E+02	5.38E+03	2.07E+03	3.79E+02	5.04E+02	5.07E+02	2.70E+03	3.59E+04	4.79E+04
Procedural blank	ND	1.91E+02	7.92E+03	3.29E+03	1.68E+02	3.87E+02	1.33E+03	3.64E+03	3.19E+04	N/A
Value after blank correction	2.22E+02	2.63E+02	BMDL	BMDL	2.10E+02	1.17E+02	BMDL	-9.47E+02	3.98E+03	3.84E+03
Pond Inlet, Nunavut										
Pond Inlet - P1-1	ND	1.89E+02	4.80E+03	1.92E+03	1.37E+02	2.74E+02	4.25E+02	9.38E+02	1.01E+04	1.88E+04
Procedural blank	ND	1.91E+02	7.92E+03	3.29E+03	1.68E+02	3.87E+02	1.33E+03	3.64E+03	3.19E+04	N/A
Value after blank correction	ND	BMDL	BMDL	BMDL	1.37E+02	2.74E+02	BMDL	BMDL	BMDL	4.11E+02
Cambridge Bay, Nunavut										
CAMBY 7	2.62E+02	1.95E+02	5.39E+03	1.77E+03	1.21E+02	5.33E+02	5.33E+02	1.16E+03	1.04E+04	2.04E+04
Procedural blank	ND	1.91E+02	7.92E+03	3.29E+03	1.68E+02	3.87E+02	1.33E+03	3.64E+03	3.19E+04	N/A
Value after blank correction	2.62E+02	1.95E+02	BMDL	BMDL	BMDL	1.46E+02	BMDL	BMDL	BMDL	4.57E+02
CAMBY 8 - dup1	ND	ND	3.68E+03	2.03E+03	ND	5.80E+02	ND	5.47E+02	9.06E+03	1.59E+04
Procedural blank	ND	1.91E+02	7.92E+03	3.29E+03	1.68E+02	3.87E+02	1.33E+03	3.64E+03	3.19E+04	N/A
Value after blank correction	ND	ND	BMDL	BMDL	ND	1.93E+02	ND	BMDL	BMDL	1.93E+02
CAMBY 8 - dup2	ND	1.34E+02	3.53E+03	1.71E+03	3.25E+02	5.09E+02	ND	5.72E+02	1.66E+04	2.34E+04
Procedural blank	ND	1.91E+02	7.92E+03	3.29E+03	1.68E+02	3.87E+02	1.33E+03	3.64E+03	3.19E+04	N/A
Value after blank correction	ND	1.34E+02	BMDL	BMDL	1.57E+02	1.22E+02	ND	BMDL	BMDL	4.14E+02
CAMBY8 avg value after blk corr	ND	67	BMDL	BMDL	78	158	BMDL	BMDL	BMDL	304
Inuvik, Northwest Territories										
INUVIK1	2.28E+02	2.17E+02	6.76E+03	2.45E+03	2.03E+02	2.45E+02	1.25E+03	2.83E+03	4.53E+04	5.95E+04
Procedural blank	ND	1.91E+02	7.92E+03	3.29E+03	1.68E+02	3.87E+02	1.33E+03	3.64E+03	3.19E+04	N/A
Value after blank correction	2.28E+02	2.17E+02	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	1.34E+04	1.39E+04
INUVIK 3	ND	1.51E+02	4.80E+03	1.58E+03	ND	2.25E+02	4.57E+02	1.93E+03	2.63E+04	3.54E+04
Procedural blank	ND	1.91E+02	7.92E+03	3.29E+03	1.68E+02	3.87E+02	1.33E+03	3.64E+03	3.19E+04	N/A
Value after blank correction	ND	1.51E+02	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	-5.63E+03	-5.48E+03
Tuktoyaktuk, Northwest Territories										
TUK-1	ND	2.77E+02	5.54E+03	2.47E+03	2.88E+02	1.51E+03	1.71E+03	3.86E+03	1.96E+04	3.53E+04
Procedural blank	ND	1.91E+02	7.92E+03	3.29E+03	1.68E+02	3.87E+02	1.33E+03	3.64E+03	3.19E+04	N/A
Value after blank correction	ND	2.77E+02	BMDL	BMDL	1.20E+02	1.13E+03	3.83E+02	2.16E+02	-1.23E+04	-1.02E+04
Rankin Inlet, Nunavut										
Nipissar Lake	ND	2.16E+02	5.56E+03	1.87E+03	1.77E+02	1.72E+02	5.19E+01	1.91E+02	2.63E+03	1.09E+04
Procedural blank	ND	1.91E+02	7.92E+03	3.29E+03	1.68E+02	3.87E+02	1.33E+03	3.64E+03	3.19E+04	N/A
Value after blank correction	ND	2.16E+02	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	2.16E+02
Whitehorse, Yukon										
WHT-PC	ND	3.88E+02	5.48E+03	2.40E+03	3.45E+02	1.10E+03	1.72E+03	7.05E+03	2.27E+05	2.45E+05
Procedural blank	ND	1.10E+01	3.21E+02	1.91E+02	2.66E+01	1.89E+02	1.43E+03	1.83E+03	2.24E+04	N/A
Value after blank correction	ND	3.66E+02	4.84E+03	2.02E+03	2.92E+02	7.25E+02	BMDL	3.40E+03	1.82E+05	1.94E+05

Table D.5 (continued)

Sample code	Sample type: background water
<i>Iqaluit, Nunavut</i>	
Apex - IQAX-3 IQ5W40	Apex flats Background sample upgradient from W40 landfill
<i>Pangnirtung, Nunavut</i>	
PANG3	Background sample upstream river-drinking H2O source
<i>Cape Dorset, Nunavut</i>	
CD1	Cape Dorset-background sample at Tellik Inlet (Arctic Ocean)
<i>Hall Beach, Nunavut</i>	
HB-02	Drinking water source for town
<i>Pond Inlet, Nunavut</i>	
Pond Inlet - P1-1	Primary water source NE of town, approx 5 km away
<i>Cambridge Bay, Nunavut</i>	
CAMBY 7 CAMBY 8	Background sample (was CAM07-Arctic samples 2004) Cambridge Bay-background sample - towards Mt. Pelly (CAM08 sample in 2004 research season)
<i>Inuvik, Northwest Territories</i>	
INUVIK1 INUVIK 3	Background sample located- "Roads End" golf course Boot Lake background sample
<i>Tuktoyaktuk, Northwest Territories</i>	
TUK-1	Former drinking water source for town (i.e. Water Lake)
<i>Rankin Inlet, Nunavut</i>	
Nipissar Lake	Background source
<i>Whitehorse, Yukon</i>	
WHT-PC	Upstream at Porter Creek, background prior to entering landfill

Table D.6 BDE concentrations in soil samples collected in the Canadian North, summer 2006 (pg/L)

Sample ID	di-BDEs	tri-BDEs	tetra-BDEs	penta-BDEs	hexa-BDEs	hepta-BDEs	octa-BDEs	nona-BDEs	deca-BDEs	Total PBDEs
Yellowknife, NWT										
YELL01	ND	2.02E+01	5.97E+02	1.15E+03	2.50E+02	1.29E+02	3.21E+02	1.29E+03	1.93E+04	2.31E+04
YELL01	ND	2.36E+01	6.10E+02	1.08E+03	2.19E+02	1.19E+02	2.84E+02	1.05E+03	2.20E+04	2.54E+04
Avg YELL01 before blank correction	ND	2.21E+01	6.08E+02	1.12E+03	2.36E+02	1.25E+02	3.05E+02	1.18E+03	2.08E+04	2.44E+04
Procedural blank	ND	6.04E+00	8.10E+01	3.77E+01	3.74E+00	ND	3.05E+01	3.30E+02	4.51E+03	N/A
Avg YELL01 after blank correction	ND	9.99E+00	4.46E+02	1.05E+03	2.29E+02	1.25E+02	2.44E+02	5.21E+02	1.18E+04	1.44E+04
YELL02	ND	5.88E+00	1.25E+02	2.23E+02	4.10E+01	1.76E+01	1.73E+02	1.65E+02	1.69E+03	2.44E+03
YELL02	ND	6.03E+00	1.65E+02	2.44E+02	5.64E+01	5.17E+01	3.14E+01	6.11E+01	9.37E+02	1.55E+03
Avg YELL02 before blank correction	ND	5.99E+00	1.46E+02	2.35E+02	4.90E+01	3.49E+01	1.03E+02	1.14E+02	1.32E+03	2.01E+03
Procedural blank	ND	ND	3.56E+01	1.48E+01	ND	ND	3.64E+00	9.44E+00	1.78E+02	N/A
Avg YELL02 after blank correction	ND	5.99E+00	7.49E+01	2.06E+02	4.90E+01	3.49E+01	9.57E+01	9.51E+01	9.66E+02	1.52E+03
YELL03	6.46E+00	1.29E+01	1.79E+02	1.81E+02	2.04E+01	6.90E+00	8.08E+00	2.50E+01	4.49E+02	8.88E+02
Procedural blank	ND	ND	3.56E+01	1.48E+01	ND	ND	3.64E+00	9.44E+00	1.78E+02	N/A
Value after blank correction	6.46E+00	1.29E+01	1.07E+02	1.52E+02	2.04E+01	6.90E+00	8.05E+01	6.15E+00	9.29E+01	4.06E+02
YELL04	ND	2.80E+00	1.05E+02	7.69E+01	7.95E+00	7.99E+00	1.14E+01	2.42E+01	6.66E+02	9.03E+02
Procedural blank	ND	6.04E+00	8.10E+01	3.77E+01	3.74E+00	ND	3.05E+01	3.30E+02	4.51E+03	N/A
Value after blank correction	BMDL	BMDL	BMDL	1.50E+00	4.69E-01	7.99E+00	BMDL	BMDL	BMDL	9.96E+00
Iqaluit, Nunavut										
IQ2W40	7.63E+02	2.11E+03	3.91E+04	7.33E+04	1.38E+04	5.21E+03	7.63E+03	2.73E+04	5.97E+05	7.66E+05
Procedural blank	BMDL	BMDL	BMDL	3.56E+01	1.48E+01	BMDL	BMDL	3.64E+00	9.44E+00	N/A
Value after blank correction	7.63E+02	2.11E+03	3.91E+04	7.32E+04	1.37E+04	5.21E+03	7.63E+03	2.73E+04	5.97E+05	7.66E+05
IQ3W40	5.63E+02	1.97E+03	3.23E+04	4.75E+04	7.88E+03	1.10E+03	1.06E+03	2.30E+03	5.40E+04	1.49E+05
Procedural blank	BMDL	BMDL	BMDL	3.56E+01	1.48E+01	BMDL	BMDL	3.64E+00	9.44E+00	N/A
Value after blank correction	5.63E+02	1.97E+03	3.23E+04	4.75E+04	7.85E+03	1.10E+03	1.06E+03	2.29E+03	5.39E+04	1.48E+05
IQ4W40	3.19E+00	ND	5.78E+01	3.03E+01	2.42E+00	2.27E+00	1.03E+01	BMDL	2.21E+03	2.31E+03
Procedural blank	BMDL	BMDL	BMDL	3.56E+01	1.48E+01	BMDL	BMDL	3.64E+00	9.44E+00	N/A
Value after blank correction	3.19E+00	BMDL	5.78E+01	BMDL	BMDL	2.27E+00	1.03E+01	BMDL	2.19E+03	2.26E+03
IQ6	ND	5.65E+00	7.41E+01	3.55E+01	2.98E+00	5.16E+00	5.04E+00	7.87E+01	2.29E+03	2.50E+03
Procedural blank	BMDL	6.04E+00	8.10E+01	3.77E+01	BMDL	BMDL	3.05E+01	3.30E+02	4.51E+03	N/A
Value after blank correction	BMDL	BMDL	BMDL	BMDL	BMDL	5.16E+00	BMDL	BMDL	BMDL	5.16E+00
IQ7	ND	5.46E+00	2.19E+02	3.94E+02	7.15E+01	3.50E+01	4.14E+01	8.37E+01	9.60E+02	1.81E+03
Procedural blank	BMDL	BMDL	BMDL	3.56E+01	1.48E+01	BMDL	BMDL	3.64E+00	9.44E+00	N/A
Value after blank correction	ND	5.46E+00	2.19E+02	3.26E+02	4.23E+01	3.50E+01	4.14E+01	7.70E+01	9.49E+02	1.70E+03
IQ-2	1.78E+00	3.79E+00	1.16E+02	4.94E+01	4.69E+00	3.60E+00	1.65E+00	3.10E+01	8.90E+02	1.10E+03
Procedural blank	BMDL	BMDL	BMDL	3.56E+01	1.48E+01	BMDL	BMDL	3.64E+00	9.44E+00	N/A
Value after blank correction	1.78E+00	3.79E+00	1.16E+02	BMDL	BMDL	3.60E+00	1.65E+00	2.37E+01	8.71E+02	1.02E+03

ND - not detected; N/A - not available ; BMDL - below method detection limit

Table D.6 (continued)

Sample ID	di-BDEs	tri-BDEs	tetra-BDEs	penta-BDEs	hexa-BDEs	hepta-BDEs	octa-BDEs	nona-BDEs	deca-BDEs	Total PBDEs
Rankin Inlet, Nunavut										
Downtown Rankin Inlet	ND	4.64E+00	1.38E+02	1.38E+02	1.65E+01	4.66E+00	1.48E+01	1.15E+02	3.99E+03	4.42E+03
Procedural blank	ND	3.00E+01	8.34E+02	3.35E+02	ND	ND	1.33E+02	5.26E+02	6.11E+03	N/A
Value after blank correction	ND	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL	BMDL
Cambridge Bay, Nunavut										
CAMBY 2	1.20E+03	2.86E+03	8.43E+03	9.19E+03	2.72E+03	9.02E+02	1.06E+03	2.21E+03	2.59E+04	5.45E+04
Procedural blank	BMDL	BMDL	3.56E+01	1.48E+01	BMDL	BMDL	3.64E+00	9.44E+00	1.78E+02	N/A
Value after blank correction	1.20E+03	2.86E+03	8.36E+03	9.16E+03	2.72E+03	9.02E+02	1.05E+03	2.20E+03	2.55E+04	5.40E+04
CAMBY 3	7.64E+02	2.26E+03	3.08E+04	5.60E+04	9.79E+03	1.59E+03	1.61E+03	1.87E+03	2.91E+04	1.34E+05
Procedural blank	BMDL	6.04E+00	8.10E+01	3.77E+01	3.74E+00	BMDL	3.05E+01	3.30E+02	4.51E+03	N/A
Value after blank correction	7.64E+02	2.25E+03	3.06E+04	5.59E+04	9.78E+03	1.59E+03	1.55E+03	1.21E+03	2.00E+04	1.24E+05
CAMBY 5	1.75E+01	6.40E+02	3.05E+03	3.35E+03	7.90E+02	3.21E+02	1.13E+03	1.23E+03	1.43E+04	2.48E+04
Procedural blank	BMDL	6.04E+00	8.10E+01	3.77E+01	3.74E+00	BMDL	3.05E+01	3.30E+02	4.51E+03	N/A
Value after blank correction	1.75E+01	6.28E+02	2.89E+03	3.28E+03	7.82E+02	3.21E+02	1.07E+03	BMDL	5.29E+03	1.43E+04
CAMBY 6	6.41E+03	4.75E+03	1.37E+04	2.83E+04	7.15E+04	2.09E+05	1.32E+05	3.50E+04	1.43E+04	5.15E+05
Procedural blank	BMDL	BMDL	3.56E+01	1.48E+01	BMDL	BMDL	3.64E+00	9.44E+00	1.78E+02	N/A
Value after blank correction	6.41E+03	4.75E+03	1.36E+04	2.83E+04	7.15E+04	2.09E+05	1.32E+05	3.50E+04	1.39E+04	5.14E+05
CAMBY 7	ND	1.65E+01	4.70E+02	6.83E+02	1.65E+02	9.30E+01	4.32E+02	1.65E+03	5.83E+04	6.18E+04
Procedural blank	BMDL	6.00E+00	8.10E+01	3.77E+01	3.74E+00	BMDL	3.05E+01	3.30E+02	4.51E+03	N/A
Value after blank correction	ND	4.51E+00	3.08E+02	6.08E+02	1.58E+02	9.30E+01	3.71E+02	9.90E+02	4.93E+04	5.18E+04
CAMBY 8	ND	6.49E+00	1.11E+02	8.46E+01	1.58E+01	3.31E+01	7.27E+01	1.89E+02	4.03E+03	4.54E+03
Procedural blank	ND	6.04E+00	8.10E+01	3.77E+01	3.74E+00	ND	3.05E+01	3.30E+02	4.51E+03	N/A
Value after blank correction	ND	BMDL	BMDL	9.20E+00	8.29E+00	3.31E+01	1.17E+01	BMDL	BMDL	6.23E+01

ND - not detected; N/A - not available ; BMDL - below method detection limit

Table D.6 (concluded)

Key	Sample type: soil
<i>Yellowknife, Northwest Territories</i>	
YELL01	Old dumping area Yellowknife landfill (average of 2 samples)
YELL02	White goods area-Yellowknife landfill (average of 2 samples)
YELL03	Current working area-Yellowknife landfill
YELL04	Background sample
<i>Iqaluit, Nunavut</i>	
IQ2W40	West 40 landfill (IQA06 sample ID, 2004)
IQ3W40	West 40 landfill (IQA05 sample ID, 2004)
IQ4W40	West 40 landfill
IQ6	former military dump (IQA14 sample ID, 2004)
IQ7	North 40 metal dump
IQ-2	Apex flats (IQ2-original ID; IQA02 sample ID, 2004)
<i>Cambridge Bay, Nunavut</i>	
CAMBY 2	Close to effluent drainage area (CAMO4 sample ID, 2004)
CAMBY 3	Garbage dump (CAMO1 sample ID, 2004)
CAMBY 5	Effluent discharge to ocean (CAMO6 sample ID, 2004)
CAMBY 6	Metal waste dump (CAMO2 sample ID, 2004)
CAMBY 7	Background (CAMO7 sample ID, 2004)
CAMBY 8	Background-toward Mt Pelly (CAMO8 sample ID, 2004)
<i>Rankin Inlet</i>	
Rankin Inlet	Downtown area where former slimes were accumulated

Appendix D – Experimental Results: Investigation of PBDEs, Distribution in Landfills and Sewage Treatment in Northern Canada

Table D.7 BDE concentrations in raw aqueous data from the Canadian North, summer 2006 (pg/L). Analyzed by DFO-IOS.

SAMPLE #	QDOS FILE #	SPECIES	SITE	2-BDE-1	3-BDE-2	4-BDE-3	26-BDE-10	24-BDE-7	24/33-BDE-8/11	34-BDE-12	34-BDE-13	44-BDE-15	D(1)	246-BDE-30	246-BDE-32	224-BDE-17
7416Aq 31oct06 pcb	pg/100ml	Arctic Project Aqueous	Iqaluit-Apex - IQAX-3	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7432Aq 08no06 pcb	pg/100ml	Arctic Project Aqueous	Iqaluit Landfill - IQSW40	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7441Aq 17no06 pcb	pg/100ml	Arctic Project Aqueous	Iqaluit Landfill - IQ1	N/A	N/A	N/A	ND	ND	8.7	ND	ND	11.7	ND	ND	ND	ND
7441Aqrep 17no06 pcb	pg/100ml	Arctic Project Aqueous	Iqaluit Landfill - IQ1	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7440Aq 17no06 pcb	pg/100ml	Arctic Project Aqueous	Pangnirtung - PANG1	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	NDR(10.7)
7430Aq 08no06 pcb	pg/100ml	Arctic Project Aqueous	Pangnirtung - PANG2	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7417Aq 31oct06 pcb	pg/100ml	Arctic Project Aqueous	Pangnirtung - PANG3	N/A	N/A	N/A	ND	ND	11.4	ND	ND	ND	ND	ND	ND	ND
7418Aq 31oct06 pcb	pg/100ml	Arctic Project Aqueous	Cape Dorset - CD1	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7437Aq+sed 17no06 pcpg/100ml	pg/100ml	Arctic Project Aqueous	Cape Dorset - CD2	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7431Aq 08no06 pcb	pg/100ml	Arctic Project Aqueous	Cape Dorset - CD3	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7431Aqrep 08no06 pcb	pg/100ml	Arctic Project Aqueous	Cape Dorset - CD3	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	7.6
7438Aq 17no06 pcb	pg/100ml	Arctic Project Aqueous	Hall Beach - HB-01	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	13.2
7419Aq 31oct06 pcb de	pg/100ml	Arctic Project Aqueous	Hall Beach - HB-02	N/A	N/A	N/A	ND	ND	7.6	ND	8.6	5.9	ND	ND	ND	7.6
7439Aq 17no06 pcb	pg/100ml	Arctic Project Aqueous	Pond Inlet - P1-1	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7442Aq 17no06 pcb	pg/100ml	Arctic Project Aqueous	Cambridge Bay - CAMBY 1	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	39.4
7433Aq 08no06 pcb	pg/100ml	Arctic Project Aqueous	Cambridge Bay - CAMBY 4	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7414Aq 31oct06 pcb	pg/100ml	Arctic Project Aqueous	Cambridge Bay - CAMBY 7(background sample)	N/A	N/A	N/A	ND	ND	ND	ND	ND	26.2	ND	ND	ND	ND
7415Aq 31oct06 pcb	pg/100ml	Arctic Project Aqueous	Cambridge Bay - CAMBY 8(background sample headed to Mt Pelly out of town)	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7415Aqrep 31oct06 pcb	pg/100ml	Arctic Project Aqueous	Cambridge Bay - CAMBY 8(background sample headed to Mt Pelly out of town)	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7428Aq 08no06 pcb	pg/100ml	Arctic Project Aqueous	Inuvik - Inuvik1 (Roads End golf course, close to landfill)	N/A	N/A	N/A	ND	ND	ND	ND	ND	22.8	ND	ND	ND	ND
7434Aq 08no06 pcb	pg/100ml	Arctic Project Aqueous	Inuvik - Inuvik2 (down from dump, @ Finning Lake)	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7420Aq 31oct06 pcb	pg/100ml	Arctic Project Aqueous	Inuvik - Boot Lake - INUVIK 3 (background)	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7413Aq 31oct06 pcb	pg/100ml	Arctic Project Aqueous	Tuktoyaktuk - TUK-1 (background sample)	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7371Aq 20oct06 pcb	pg/100ml	Arctic Project Aqueous	Tuktoyaktuk - TUK-2 (runoff after berm straight to ocean)	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7443Aq 17no06 pcb	pg/100ml	Arctic Project Aqueous	Tuktoyaktuk - TUK-3 (ponded leachate at dumpsite)	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7435Aq 08no06 pcb	pg/100ml	Arctic Project Aqueous	Rankin Inlet - Nipissar Lake	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7429Aq+sed 08no06 pcpg/100ml	pg/100ml	Arctic Project Aqueous	Yellowknife Landfill - YE-1	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	8.4
pb2 31oct06 pcb	pg/100ml	background samples	TUK1, CAMBY 7+8, IQAX 3, PANG 3, CD1, HB02, INUV3	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
pb 08no06 pcb	pg/100ml	Procedural Blank	YE1,INUVIK1+2, PANG2, CD3, IQ540, CAMBY4, RANKIN	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
pb 17no06 pcb	pg/100ml	Procedural Blank	CD2,HB1,PH1,PANG1,IQ1,CAMBY1,TUK3,RANKINsoil	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SAMPLE #	QDOS FILE #	SPECIES	SITE	234-BDE-244/234-BDE-28/33	334-BDE-35	Tr(1)	Tr(2)	344-BDE-37	2446-BDE-75	2245-BDE-49	2346-BDE-71	2244-BDE-47	2344-BDE-66	3344-BDE-77	22446-BDE-100	
7416Aq 31oct06 pcb	pg/100ml	Arctic Project Aqueous	Iqaluit-Apex - IQAX-3	ND	ND	ND	ND	ND	ND	10.3	ND	304.8	ND	ND	30.1	
7432Aq 08no06 pcb	pg/100ml	Arctic Project Aqueous	Iqaluit Landfill - IQSW40	ND	11.4	ND	ND	ND	ND	10.6	ND	353.4	ND	ND	26.6	
7441Aq 17no06 pcb	pg/100ml	Arctic Project Aqueous	Iqaluit Landfill - IQ1	ND	27.2	ND	ND	ND	ND	28.2	ND	854.0	18.1	ND	82.1	
7441Aqrep 17no06 pcb	pg/100ml	Arctic Project Aqueous	Iqaluit Landfill - IQ1	ND	24.0	ND	ND	ND	ND	26.4	ND	753.4	16.0	ND	78.6	
7440Aq 17no06 pcb	pg/100ml	Arctic Project Aqueous	Pangnirtung - PANG1	ND	38.9	ND	ND	ND	ND	119.1	6.1	2406.6	52.1	ND	616.8	
7430Aq 08no06 pcb	pg/100ml	Arctic Project Aqueous	Pangnirtung - PANG2	ND	35.8	ND	ND	ND	ND	59.3	ND	1888.0	47.5	ND	490.4	
7417Aq 31oct06 pcb	pg/100ml	Arctic Project Aqueous	Pangnirtung - PANG3	ND	14.6	ND	ND	ND	ND	9.1	ND	313.3	6.0	ND	30.3	
7418Aq 31oct06 pcb	pg/100ml	Arctic Project Aqueous	Cape Dorset - CD1	ND	14.5	ND	ND	ND	ND	10.5	ND	354.8	ND	ND	40.8	
7437Aq+sed 17no06 pcpg/100ml	pg/100ml	Arctic Project Aqueous	Cape Dorset - CD2	ND	40.1	ND	ND	ND	ND	38.7	ND	1222.4	ND	ND	139.9	
7431Aq 08no06 pcb	pg/100ml	Arctic Project Aqueous	Cape Dorset - CD3	ND	18.8	ND	ND	ND	ND	22.5	ND	726.6	20.2	ND	182.6	
7431Aqrep 08no06 pcb	pg/100ml	Arctic Project Aqueous	Cape Dorset - CD3	ND	17.1	ND	ND	ND	ND	25.8	ND	672.5	9.9	ND	133.9	
7438Aq 17no06 pcb	pg/100ml	Arctic Project Aqueous	Hall Beach - HB-01	ND	23.9	ND	ND	ND	ND	35.0	4.4	683.4	24.1	ND	127.2	
7419Aq 31oct06 pcb de	pg/100ml	Arctic Project Aqueous	Hall Beach - HB-02	ND	18.7	ND	ND	ND	ND	16.1	ND	514.0	7.8	ND	51.7	
7439Aq 17no06 pcb	pg/100ml	Arctic Project Aqueous	Pond Inlet - P1-1	ND	18.9	ND	ND	ND	ND	14.8	ND	452.9	12.8	ND	45.0	
7442Aq 17no06 pcb	pg/100ml	Arctic Project Aqueous	Cambridge Bay - CAMBY 1	ND	22.3	ND	ND	ND	15.8	119.5	26.5	766.2	21.7	ND	155.2	
7433Aq 08no06 pcb	pg/100ml	Arctic Project Aqueous	Cambridge Bay - CAMBY 4	ND	18.2	ND	ND	ND	ND	19.3	ND	568.6	6.7	ND	59.2	
7414Aq 31oct06 pcb	pg/100ml	Arctic Project Aqueous	Cambridge Bay - CAMBY 7(background sample)	ND	19.5	ND	ND	ND	ND	13.3	ND	515.3	10.4	ND	43.7	
7415Aq 31oct06 pcb	pg/100ml	Arctic Project Aqueous	Cambridge Bay - CAMBY 8(background sample headed to Mt Pelly out of town)	ND	ND	ND	ND	ND	ND	8.6	ND	399.7	ND	ND	45.2	
7415Aqrep 31oct06 pcb	pg/100ml	Arctic Project Aqueous	Cambridge Bay - CAMBY 8(background sample headed to Mt Pelly out of town)	ND	13.4	ND	ND	ND	ND	12.5	ND	334.2	6.8	ND	43.4	
7428Aq 08no06 pcb	pg/100ml	Arctic Project Aqueous	Inuvik - Inuvik1 (Roads End golf course, close to landfill)	ND	21.7	ND	ND	ND	ND	17.9	ND	644.8	13.7	ND	62.3	
7434Aq 08no06 pcb	pg/100ml	Arctic Project Aqueous	Inuvik - Inuvik2 (down from dump, @ Finning Lake)	ND	17.7	ND	ND	ND	ND	16.7	ND	541.3	7.6	ND	64.9	
7420Aq 31oct06 pcb	pg/100ml	Arctic Project Aqueous	Inuvik - Boot Lake - INUVIK 3 (background)	ND	15.1	ND	ND	ND	ND	13.4	ND	459.6	7.0	ND	48.6	
7413Aq 31oct06 pcb	pg/100ml	Arctic Project Aqueous	Tuktoyaktuk - TUK-1 (background sample)	ND	27.7	ND	ND	ND	ND	12.8	ND	530.3	10.6	ND	63.4	
7371Aq 20oct06 pcb	pg/100ml	Arctic Project Aqueous	Tuktoyaktuk - TUK-2 (runoff after berm straight to ocean)	ND	16.0	ND	ND	ND	ND	17.0	ND	511.0	9.4	ND	52.1	
7443Aq 17no06 pcb	pg/100ml	Arctic Project Aqueous	Tuktoyaktuk - TUK-3 (ponded leachate at dumpsite)	ND	ND	ND	ND	ND	ND	10.4	ND	334.4	5.7	ND	37.1	
7435Aq 08no06 pcb	pg/100ml	Arctic Project Aqueous	Rankin Inlet - Nipissar Lake	ND	21.6	ND	ND	ND	ND	16.6	ND	529.1	10.3	ND	48.3	
7429Aq+sed 08no06 pcpg/100ml	pg/100ml	Arctic Project Aqueous	Yellowknife Landfill - YE-1	ND	21.9	ND	ND	ND	ND	60.4	ND	1266.5	42.6	ND	223.7	
pb2 31oct06 pcb	pg/100ml	background samples	TUK1, CAMBY 7+8, IQAX 3, PANG 3, CD1, HB02, INUV3	ND	ND	ND	ND	ND	ND	18.1	ND	603.7	ND	ND	59.5	
pb 08no06 pcb	pg/100ml	Procedural Blank	YE1,INUVIK1+2, PANG2, CD3, IQ540, CAMBY4, RANKIN	ND	ND	ND	ND	ND	ND	29.9	ND	1032.2	11.3	ND	120.5	
pb 17no06 pcb	pg/100ml	Procedural Blank	CD2,HB1,PH1,PANG1,IQ1,CAMBY1,TUK3,RANKINsoil	ND	30.3	ND	ND	ND	ND	21.3	ND	797.8	14.6	ND	86.0	

Appendix D – Experimental Results: Investigation of PBDEs, Distribution in Landfills and Sewage Treatment in Northern Canada

**Table D.7 (continued) BDE concentrations in raw aqueous data from the Canadian North, summer 2006 (pg/L). Analyzed by DFO-
IOS.**

SAMPLE #	DOS FILE #	SPECIES	SITE	23446-BL/22445-BDE-99	23466-BDE-116	22445-BDE-85	23344-BDE-105#	33445-BDE-126	Pe(1)	Pe(2)	Pe(3)	Pe(4)	Pe(5)	Pe(6)	22455-BDE-101*
7416Aq 310c06 pcb	pg/100ml	Arctic Project Aqueous	Iqaluit-Apex - IQAX-3	ND	89.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7432Aq 08n06 pcb	pg/100ml	Arctic Project Aqueous	Iqaluit Landfill - IQSW40	ND	127.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7441Aq 17n06 pcb	pg/100ml	Arctic Project Aqueous	Iqaluit Landfill - IQ1	ND	233.7	ND	NDR(5.5)	ND	ND	ND	ND	ND	ND	ND	ND
7441Aqrep 17n06 pcb	pg/100ml	Arctic Project Aqueous	Iqaluit Landfill - IQ1	ND	215.0	ND	6.7	ND	ND	ND	ND	ND	ND	ND	ND
7440Aq 17n06 pcb	pg/100ml	Arctic Project Aqueous	Pangnirtung - PANG1	15.5	2753.4	ND	128.0	ND	ND	ND	ND	ND	ND	ND	ND
7430Aq 08n06 pcb	pg/100ml	Arctic Project Aqueous	Pangnirtung - PANG2	13.5	2418.9	ND	89.8	ND	ND	ND	ND	ND	ND	7.4	ND
7417Aq 310c06 pcb	pg/100ml	Arctic Project Aqueous	Pangnirtung - PANG3	ND	95.4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7418Aq 310c06 pcb	pg/100ml	Arctic Project Aqueous	Cape Dorset - CD1	ND	108.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7437Aq+sed 17n06 pcb	pg/100ml	Arctic Project Aqueous	Cape Dorset - CD2	ND	371.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7431Aq 08n06 pcb	pg/100ml	Arctic Project Aqueous	Cape Dorset - CD3	ND	817.0	ND	21.2	ND	ND	ND	ND	ND	ND	ND	ND
7431Aqrep 08n06 pcb	pg/100ml	Arctic Project Aqueous	Cape Dorset - CD3	8.4	660.9	ND	24.9	ND	ND	ND	ND	ND	ND	ND	ND
7438Aq 17n06 pcb	pg/100ml	Arctic Project Aqueous	Hall Beach - HB-01	9.6	497.8	ND	NDR(18.4)	ND	ND	ND	ND	ND	ND	ND	ND
7419Aq 310c06 pcb de	pg/100ml	Arctic Project Aqueous	Hall Beach - HB-02	ND	148.3	ND	6.9	ND	ND	ND	ND	ND	ND	ND	ND
7439Aq 17n06 pcb	pg/100ml	Arctic Project Aqueous	Pond Inlet - P1-1	ND	142.1	ND	5.2	ND	ND	ND	ND	ND	ND	ND	ND
7442Aq 17n06 pcb	pg/100ml	Arctic Project Aqueous	Cambridge Bay - CAMBY 1	20.5	601.0	ND	NDR(20.7)	ND	ND	6.9	ND	ND	ND	NDR(8.7)	ND
7433Aq 08n06 pcb	pg/100ml	Arctic Project Aqueous	Cambridge Bay - CAMBY 4	ND	195.9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7414Aq 310c06 pcb	pg/100ml	Arctic Project Aqueous	Cambridge Bay - CAMBY 7(background sample)	ND	133.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7415Aq 310c06 pcb	pg/100ml	Arctic Project Aqueous	Cambridge Bay - CAMBY 8(background sample headed to Mt Pelly out of town)	ND	157.8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7415Aqrep 310c06 pcb	pg/100ml	Arctic Project Aqueous	Cambridge Bay - CAMBY 8(background sample headed to Mt Pelly out of town)	ND	127.8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7428Aq 08n06 pcb	pg/100ml	Arctic Project Aqueous	Inuvik - Inuvik1 (Roads End golf course, close to landfill)	ND	182.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7434Aq 08n06 pcb	pg/100ml	Arctic Project Aqueous	Inuvik - Inuvik2 (down from dump, @ Finning Lake)	ND	174.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7420Aq 310c06 pcb	pg/100ml	Arctic Project Aqueous	Inuvik - Boot Lake - INUVIK 3 (background)	ND	109.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7413Aq 310c06 pcb	pg/100ml	Arctic Project Aqueous	Tuktoyaktuk - TUK-1 (background sample)	ND	183.9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7371Aq 20c06 pcb	pg/100ml	Arctic Project Aqueous	Tuktoyaktuk - TUK-2 (runoff after berm straight to ocean)	ND	153.2	ND	4.5	ND	ND	ND	ND	ND	ND	ND	ND
7443Aq 17n06 pcb	pg/100ml	Arctic Project Aqueous	Tuktoyaktuk - TUK-3 (ponded leachate at dumpsite)	ND	103.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7435Aq 08n06 pcb	pg/100ml	Arctic Project Aqueous	Rankin Inlet - Nipissar Lake	ND	138.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7429Aq+sed 08n06 pcb	pg/100ml	Arctic Project Aqueous	Yellowknife Landfill - YE-1	ND	819.6	ND	45.7	ND	ND	ND	ND	ND	ND	ND	10.2
pb2 310c06 pcb	pg/100ml	background samples	TUK1, CAMBY 7+8, IQAX 3, PANG 3, CD1, HB02, INUV3	ND	206.4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
pb 08n06 pcb	pg/100ml	Procedural Blank	YE1, INUVIK1+2, PANG2, CD3, IQS40, CAMBY4, RANKIN	ND	322.5	ND	4.9	ND	ND	ND	ND	ND	ND	ND	ND
pb 17n06 pcb	pg/100ml	Procedural Blank	CD2, HB1, P1, PANG1, IQ1, CAMBY1, TUK3, RANKIN	ND	249.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SAMPLE #	DOS FILE #	SPECIES	SITE	Pe(7)	Pe(8)	23445-BDE-118	22446-BDE-155	224455-BDE-153	223445-BDE-140W	223445/234456-BDE-HK(1)	Hk(2)	2234456-BDE-183	2234456-BDE-181	2234456-BDE-183	2234456-BDE-183
7416Aq 310c06 pcb	pg/100ml	Arctic Project Aqueous	Iqaluit-Apex - IQAX-3	ND	ND	ND	ND	10.5	ND	ND	ND	38.5	ND	ND	ND
7432Aq 08n06 pcb	pg/100ml	Arctic Project Aqueous	Iqaluit Landfill - IQSW40	ND	ND	ND	ND	8.0	ND	ND	ND	19.5	ND	ND	ND
7441Aq 17n06 pcb	pg/100ml	Arctic Project Aqueous	Iqaluit Landfill - IQ1	ND	ND	ND	9.7	15.8	ND	ND	ND	33.0	ND	ND	ND
7441Aqrep 17n06 pcb	pg/100ml	Arctic Project Aqueous	Iqaluit Landfill - IQ1	ND	ND	ND	NDR(8.0)	NDR(12.3)	ND	ND	ND	28.8	ND	ND	ND
7440Aq 17n06 pcb	pg/100ml	Arctic Project Aqueous	Pangnirtung - PANG1	ND	7.2	ND	15.9	257.2	319.0	6.5	42.0	ND	116.1	ND	ND
7430Aq 08n06 pcb	pg/100ml	Arctic Project Aqueous	Pangnirtung - PANG2	ND	ND	ND	15.6	218.1	289.9	ND	29.4	ND	89.9	ND	ND
7417Aq 310c06 pcb	pg/100ml	Arctic Project Aqueous	Pangnirtung - PANG3	ND	ND	ND	ND	13.3	ND	ND	ND	25.0	ND	ND	ND
7418Aq 310c06 pcb	pg/100ml	Arctic Project Aqueous	Cape Dorset - CD1	ND	ND	ND	ND	ND	13.0	ND	ND	ND	32.6	ND	ND
7437Aq+sed 17n06 pcb	pg/100ml	Arctic Project Aqueous	Cape Dorset - CD2	ND	ND	ND	ND	34.1	ND	ND	ND	62.8	ND	ND	ND
7431Aq 08n06 pcb	pg/100ml	Arctic Project Aqueous	Cape Dorset - CD3	ND	ND	ND	ND	70.8	97.4	ND	ND	ND	51.5	ND	ND
7431Aqrep 08n06 pcb	pg/100ml	Arctic Project Aqueous	Cape Dorset - CD3	ND	ND	ND	ND	62.3	77.8	ND	ND	ND	68.4	ND	ND
7438Aq 17n06 pcb	pg/100ml	Arctic Project Aqueous	Hall Beach - HB-01	ND	ND	ND	ND	98.9	340.1	8.5	34.0	16.6	34.7	1837.9	ND
7419Aq 310c06 pcb de	pg/100ml	Arctic Project Aqueous	Hall Beach - HB-02	ND	ND	ND	ND	10.6	15.4	ND	11.9	ND	29.9	10.9	9.6
7439Aq 17n06 pcb	pg/100ml	Arctic Project Aqueous	Pond Inlet - P1-1	ND	ND	ND	ND	4.9	8.8	ND	ND	ND	27.4	ND	ND
7442Aq 17n06 pcb	pg/100ml	Arctic Project Aqueous	Cambridge Bay - CAMBY 1	ND	ND	5.1	6.2	83.9	97.9	9.4	7.8	7.4	99.1	ND	ND
7433Aq 08n06 pcb	pg/100ml	Arctic Project Aqueous	Cambridge Bay - CAMBY 4	ND	ND	ND	ND	11.3	11.0	ND	ND	ND	31.4	ND	ND
7414Aq 310c06 pcb	pg/100ml	Arctic Project Aqueous	Cambridge Bay - CAMBY 7(background sample)	ND	ND	ND	ND	NDR(7.3)	12.1	ND	ND	53.3	ND	ND	ND
7415Aq 310c06 pcb	pg/100ml	Arctic Project Aqueous	Cambridge Bay - CAMBY 8(background sample headed to Mt Pelly out of town)	ND	ND	ND	ND	ND	NDR(15.9)	ND	ND	58.0	ND	ND	ND
7415Aqrep 310c06 pcb	pg/100ml	Arctic Project Aqueous	Cambridge Bay - CAMBY 8(background sample headed to Mt Pelly out of town)	ND	ND	ND	ND	9.1	23.5	ND	ND	50.9	ND	ND	ND
7428Aq 08n06 pcb	pg/100ml	Arctic Project Aqueous	Inuvik - Inuvik1 (Roads End golf course, close to landfill)	ND	ND	ND	ND	6.8	13.5	ND	ND	ND	24.5	ND	ND
7434Aq 08n06 pcb	pg/100ml	Arctic Project Aqueous	Inuvik - Inuvik2 (down from dump, @ Finning Lake)	ND	ND	ND	ND	13.9	ND	ND	ND	ND	25.2	ND	ND
7420Aq 310c06 pcb	pg/100ml	Arctic Project Aqueous	Inuvik - Boot Lake - INUVIK 3 (background)	ND	ND	ND	ND	ND	ND	ND	ND	22.5	ND	ND	ND
7413Aq 310c06 pcb	pg/100ml	Arctic Project Aqueous	Tuktoyaktuk - TUK-1 (background sample)	ND	ND	ND	ND	NDR(13.8)	28.8	ND	ND	ND	151.4	ND	ND
7371Aq 20c06 pcb	pg/100ml	Arctic Project Aqueous	Tuktoyaktuk - TUK-2 (runoff after berm straight to ocean)	ND	ND	ND	ND	8.6	13.3	ND	ND	ND	25.1	ND	ND
7443Aq 17n06 pcb	pg/100ml	Arctic Project Aqueous	Tuktoyaktuk - TUK-3 (ponded leachate at dumpsite)	ND	ND	ND	ND	5.7	ND	ND	ND	ND	9.4	ND	ND
7435Aq 08n06 pcb	pg/100ml	Arctic Project Aqueous	Rankin Inlet - Nipissar Lake	ND	ND	ND	ND	8.9	8.8	ND	ND	ND	17.2	ND	ND
7429Aq+sed 08n06 pcb	pg/100ml	Arctic Project Aqueous	Yellowknife Landfill - YE-1	ND	ND	ND	ND	71.6	117.3	ND	16.6	ND	238.1	ND	10.1
pb2 310c06 pcb	pg/100ml	background samples	TUK1, CAMBY 7+8, IQAX 3, PANG 3, CD1, HB02, INUV3	ND	ND	ND	ND	16.6	ND	ND	ND	ND	30.6	ND	ND
pb 08n06 pcb	pg/100ml	Procedural Blank	YE1, INUVIK1+2, PANG2, CD3, IQS40, CAMBY4, RANKIN	ND	ND	ND	ND	14.5	22.3	ND	ND	ND	49.7	ND	ND
pb 17n06 pcb	pg/100ml	Procedural Blank	CD2, HB1, P1, PANG1, IQ1, CAMBY1, TUK3, RANKIN	ND	ND	ND	ND	NDR(11.4)	NDR(19.2)	ND	ND	ND	NDR(49.5)	ND	ND

Appendix D – Experimental Results: Investigation of PBDEs, Distribution in Landfills and Sewage Treatment in Northern Canada

Table D.7 (continued) BDEs concentrations in raw aqueous data from the Canadian North, summer 2006 (pg/L). Analyzed by DFO-IOS.

SAMPLE #	DIOS FILE #	SPECIES	SITE	OC(1)	22334566-BDE-201	22344566/22334466-BDE-204/19/22344556-BDE-203	22334456-BDE-196	22334556-BDE-208	223344566-BDE-207	223344556-BDE-206	2233445566-BDE-209	
7416Aq 31oc06 pcb	pg/100ml	Arctic Project Aqueous	Iqaluit-Apex - IQAX-3	15.2	34.9	32.2	29.5	19.7	N/A	161.7	146.5	7,019.0
7432Aq 08no06 pcb	pg/100ml	Arctic Project Aqueous	Iqaluit Landfill - IQ5W40	ND	ND	ND	ND	ND	N/A	117.6	41.6	2,434.1
7441Aq 17no06 pcb	pg/100ml	Arctic Project Aqueous	Iqaluit Landfill - IQ1	ND	ND	17.7	17.5	20.0	N/A	65.9	396.9	17,773.3
7441Aqrep 17no06 pcb	pg/100ml	Arctic Project Aqueous	Iqaluit Landfill - IQ1	5.1	6.8	17.7	18.1	13.6	N/A	93.5	188.4	6,467.1
7440Aq 17no06 pcb	pg/100ml	Arctic Project Aqueous	Pangnirtung - PANG1	18.6	30.6	73.6	83.1	54.2	N/A	608.4	958.5	34,262.1
7430Aq 08no06 pcb	pg/100ml	Arctic Project Aqueous	Pangnirtung - PANG2	19.7	24.9	57.1	77.6	49.9	N/A	598.5	661.2	17,333.5
7417Aq 31oc06 pcb	pg/100ml	Arctic Project Aqueous	Pangnirtung - PANG3	ND	ND	ND	ND	ND	N/A	55.1	42.6	1,792.0
7418Aq 31oc06 pcb	pg/100ml	Arctic Project Aqueous	Cape Dorset - CD1	ND	9.6	25.8	14.6	13.4	N/A	259.7	180.7	6,242.4
7437Aq+sed 17no06 pc	pg/100ml	Arctic Project Aqueous	Cape Dorset - CD2	8.7	25.7	45.5	34.4	39.5	N/A	282.4	296.5	8,167.4
7431Aq 08no06 pcb	pg/100ml	Arctic Project Aqueous	Cape Dorset - CD3	31.1	50.1	47.1	100.7	53.9	N/A	312.2	351.0	3,594.3
7431Aqrep 08no06 pcb	pg/100ml	Arctic Project Aqueous	Cape Dorset - CD3	22.4	46.3	45.2	92.5	60.2	N/A	396.6	439.6	12,393.1
7438Aq 17no06 pcb	pg/100ml	Arctic Project Aqueous	Hall Beach - HB-01	9.6	52.8	691.1	218.1	280.3	N/A	1016.6	429.4	12,862.0
7419Aq 31oc06 pcb de	pg/100ml	Arctic Project Aqueous	Hall Beach - HB-02	5.2	8.2	11.7	15.2	10.4	N/A	157.5	112.3	3,588.6
7439Aq 17no06 pcb	pg/100ml	Arctic Project Aqueous	Pond Inlet - P1-1	NDR(2.8)	7.0	14.7	10.3	10.4	N/A	62.3	31.5	1,009.2
7442Aq 17no06 pcb	pg/100ml	Arctic Project Aqueous	Cambridge Bay - CAMBY 1	25.7	39.3	113.5	86.8	65.5	N/A	391.3	356.9	10,752.6
7433Aq 08no06 pcb	pg/100ml	Arctic Project Aqueous	Cambridge Bay - CAMBY 4	13.2	21.2	27.6	24.9	21.1	N/A	193.8	186.9	4,312.3
7414Aq 31oc06 pcb	pg/100ml	Arctic Project Aqueous	Cambridge Bay - CAMBY 7(background sample)	ND	ND	15.6	19.8	17.9	N/A	77.1	39.1	1,044.7
7415Aq 31oc06 pcb	pg/100ml	Arctic Project Aqueous	Cambridge Bay - CAMBY 8(background sample headed to Mt Pelly out of town)	ND	ND	ND	ND	ND	N/A	42.5	12.2	906.0
7415Aqrep 31oc06 pcb	pg/100ml	Arctic Project Aqueous	Cambridge Bay - CAMBY 8(background sample headed to Mt Pelly out of town)	ND	ND	ND	ND	ND	N/A	45.2	11.9	1,658.5
7428Aq 08no06 pcb	pg/100ml	Arctic Project Aqueous	Inuvik - Inuvik1 (Roads End golf course, close to landfill)	11.3	13.7	38.4	35.5	26.4	N/A	227.2	55.7	4,533.8
7434Aq 08no06 pcb	pg/100ml	Arctic Project Aqueous	Inuvik - Inuvik2 (down from dump, @ Finning Lake)	6.5	10.0	17.7	15.2	12.8	N/A	64.0	69.6	1,889.9
7420Aq 31oc06 pcb	pg/100ml	Arctic Project Aqueous	Inuvik - Boot Lake - INUVIK 3 (background)	ND	8.4	14.1	12.0	11.2	N/A	132.0	61.2	2,627.7
7413Aq 31oc06 pcb	pg/100ml	Arctic Project Aqueous	Tuktoyaktuk - TUK-1 (background sample)	ND	34.0	46.8	54.7	35.8	N/A	235.9	150.2	1,959.0
7371Aq 20oc06 pcb	pg/100ml	Arctic Project Aqueous	Tuktoyaktuk - TUK-2 (runoff after berm straight to ocean)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
7443Aq 17no06 pcb	pg/100ml	Arctic Project Aqueous	Tuktoyaktuk - TUK-3 (ponded leachate at dumpsite)	3.2	5.6	8.7	7.9	7.2	N/A	29.1	14.0	824.2
7435Aq 08no06 pcb	pg/100ml	Arctic Project Aqueous	Rankin Inlet - Nipissar Lake	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
7429Aq+sed 08no06 pc	pg/100ml	Arctic Project Aqueous	Yellowknife Landfill - YE-1	ND	28.2	26.3	ND	ND	N/A	103.7	118.6	5266.2
pb2 31oc06 pcb	pg/100ml	background samples	TUK1, CAMBY 7+8, IQAX 3, PANG 3, CD1, HB02, INUV3	ND	15.7	25.7	23.3	19.8	N/A	131.1	78.1	1532.7
pb 08no06 pcb	pg/100ml	Procedural Blank	YE1,INUVIK1+2, PANG2, CD3, IQ540, CAMBY4, RANKIN	ND	42.0	70.3	55.7	43.2	N/A	362.1	150.6	2,886.3
pb 17no06 pcb	pg/100ml	Procedural Blank	CD2,HB1,P11,PANG1,IQ1,CAMBY1,TUK3,RANKINsoil	11.2	20.7	35.3	36.9	29.0	N/A	260.6	265.8	6,109.0
Note:												
(1)	Results are corrected for surrogate recovery ND = not detected											
(3)	NDR = not detected due to incorrect isotop DL = detection limit (pg/sample/analyte peak)											
(5)	N/A = not applicable											
(7)	* relative retention time (rtt) relative to recovery standard											
(9)	(Mo-Hp) = MoBDE to HpBDE analysis (Oc-De) = OcBDE to DeBDE analysis											
(11)	** Lockmass indicates interferences that may affect the accuracy of the concentration											

Appendix D – Experimental Results: Investigation of PBDEs, Distribution in Landfills and Sewage Treatment in Northern Canada

Table D.8 Raw soil data from the Canadian North, summer 2006 (pg/g)

SAMPLE #	DIOS FILE #	SPECIES	SITE	2-BDE-1	3-BDE-2	4-BDE-3	26-BDE-10	24-BDE-7	24/33'-BDE-8/11	34-BDE-12	34'-BDE-13	44'-BDE-15	Di(1)	246-BDE-30	246-BDE-32	224-BDE-17
7334S 06oc06 pcb	pg/g	Arctic Project Soil	YELL01	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	5.1
7334Srep 06oc06 pcb	pg/g	Arctic Project Soil	YELL01	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	5.9
7335S 13oc06 pcb RR	pg/g	Arctic Project Soil	YELL02	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.1
7335Srep 13oc06 pcb	pg/g	Arctic Project Soil	YELL02	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.5
7336S 13oc06 pcb	pg/g	Arctic Project Soil	YELL03	N/A	N/A	N/A	ND	ND	3.5	ND	ND	2.8	ND	ND	ND	3.1
7337S 06oc06 pcb	pg/g	Arctic Project Soil	YELL04	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7338S 13oc06 pcb	pg/g	Arctic Project Soil	Iqaluit Landfill - IQ2W40	N/A	N/A	N/A	ND	122.6	346.6	ND	143.2	121.1	ND	ND	17.1	459.6
7339S 13oc06 pcb	pg/g	Arctic Project Soil	Iqaluit Landfill - IQ3W40	N/A	N/A	N/A	ND	71.7	211.4	ND	58.9	101.3	ND	ND	5.4	355.7
7340S 13oc06 pcb RR	pg/g	Arctic Project Soil	Iqaluit Landfill - IQ4W40	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7342S 06oc06 pcb RR	pg/g	Arctic Project Soil	Iqaluit former Military dump - IQc	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.2
7343S 13oc06 pcb	pg/g	Arctic Project Soil	Iqaluit North 40 metal dump - IQ	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.5
7345S 13oc06 pcb	pg/g	Arctic Project Soil	Iqaluit - Apex - IQAX-2	N/A	N/A	N/A	ND	ND	ND	ND	ND	1.5	ND	ND	ND	ND
7445S 17no06 pcb	pg/g	Soil	Rankin Inlet (Slimes)	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.1
7346S 13oc06 pcb	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 2	N/A	N/A	N/A	ND	125.5	329.0	ND	123.5	82.2	ND	ND	317.5	577.2
7347S 06oc06 pcb	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 3	N/A	N/A	N/A	ND	83.2	265.3	14.9	223.9	173.9	ND	10.4	15.5	463.2
7348S 06oc06 pcb	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 5	N/A	N/A	N/A	ND	ND	2.3	ND	1.8	4.4	ND	ND	ND	231.9
7349S 13oc06 pcb dl	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 6	N/A	N/A	N/A	ND	1708.5	2690.2	18.0	913.6	547.1	ND	ND	104.8	643.1
7350S 06oc06 pcb	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 7	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.9
7351S 06oc06 pcb	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 8	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.3
pb 13oc06 pcb	pg/g	Procedural Blank	YELL2	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
pb 06oc06 pcb	pg/g	Procedural Blank	YELL1	N/A	N/A	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.8
SAMPLE #	DIOS FILE #	SPECIES	SITE	234-BDE-25	244/234-BDE-28/33	334-BDE-35	Tri(1)	Tri(2)	Tri	2446-BDE-75	2245'-BDE-49	2346-BDE-71	2244'-BDE-47	2344'-BDE-66	3344'-BDE-77	Tetra
7334S 06oc06 pcb	pg/g	Arctic Project Soil	YELL01	ND	15.2	ND	ND	ND	15.2 ND	47.5	5.9	514.4	28.3	1.2	597.2	597.2
7334Srep 06oc06 pcb	pg/g	Arctic Project Soil	YELL01	1.3	14.5	ND	ND	1.9	17.7 2.1	41.8	4.3	532.8	28.0	1.1	610.2	610.2
7335S 13oc06 pcb RR	pg/g	Arctic Project Soil	YELL02	ND	3.8	ND	ND	ND	3.8 ND	7.6	1.1	111.9	4.7	ND	125.3	125.3
7335Srep 13oc06 pcb	pg/g	Arctic Project Soil	YELL02	ND	4.5	ND	ND	ND	4.5 ND	7.9	ND	151.8	5.7	ND	165.3	165.3
7336S 13oc06 pcb	pg/g	Arctic Project Soil	YELL03	1.0	7.3	ND	ND	1.2	9.5 ND	10.3	1.1	155.9	6.3	0.4	174.1	174.1
7337S 06oc06 pcb	pg/g	Arctic Project Soil	YELL04	ND	2.8	ND	ND	ND	2.8 ND	3.9	0.4	98.5	2.4	ND	105.1	105.1
7338S 13oc06 pcb	pg/g	Arctic Project Soil	Iqaluit Landfill - IQ2W40	126.4	1009.1	107.1	ND	187.5	1430.1 122.7	1914.4	164.1	34075.9	1302.4	51.8	37631.3	37631.3
7339S 13oc06 pcb	pg/g	Arctic Project Soil	Iqaluit Landfill - IQ3W40	70.6	943.0	20.5	ND	107.6	1141.6 79.3	1949.0	125.9	21850.0	1388.2	17.0	25409.3	25409.3
7340S 13oc06 pcb RR	pg/g	Arctic Project Soil	Iqaluit Landfill - IQ4W40	ND	1.2	ND	ND	ND	1.2 ND	2.0	ND	53.1	1.1	ND	56.1	56.1
7342S 06oc06 pcb RR	pg/g	Arctic Project Soil	Iqaluit former Military dump - IQc	ND	3.4	ND	ND	ND	3.4 ND	ND	1.3	58.6	1.1	ND	61.0	61.0
7343S 13oc06 pcb	pg/g	Arctic Project Soil	Iqaluit North 40 metal dump - IQ	ND	4.0	ND	ND	ND	4.0 ND	16.1	ND	189.2	11.9	ND	217.1	217.1
7345S 13oc06 pcb	pg/g	Arctic Project Soil	Iqaluit - Apex - IQAX-2	ND	3.1	ND	ND	ND	3.1 ND	3.6	ND	88.1	2.1	ND	94.8	94.8
7445S 17no06 pcb	pg/g	Soil	Rankin Inlet (Slimes)	ND	3.5	ND	ND	ND	3.5 ND	8.8	0.5	122.6	6.5	ND	138.4	138.4
7346S 13oc06 pcb	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 2	115.5	332.6	40.1	ND	108.0	596.2 37.2	1343.0	140.4	2817.9	257.9	24.7	4621.1	4621.1
7347S 06oc06 pcb	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 3	155.7	979.2	191.1	5.6	220.8	1552.3 147.1	2109.5	212.6	28557.4	1542.9	85.5	30655.0	30655.0
7348S 06oc06 pcb	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 5	9.1	57.3	ND	ND	13.1	79.5 3.5	266.1	70.4	1084.6	57.4	ND	1481.9	1481.9
7349S 13oc06 pcb dl	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 6	502.2	1289.3	516.6	ND	680.8	2988.8 427.0	1718.1	545.8	7862.0	1506.5	472.0	12531.4	12531.4
7350S 06oc06 pcb	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 7	1.1	10.5	ND	ND	ND	11.6 ND	NDR(41.0)	11.2	368.7	32.3	1.1	413.3	413.3
7351S 06oc06 pcb	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 8	ND	4.2	ND	ND	ND	4.2 ND	7.1	ND	99.2	3.8	0.6	110.7	110.7
pb 13oc06 pcb	pg/g	Procedural Blank	YELL2	ND	ND	ND	ND	ND	0.0 ND	1.9	ND	33.7	ND	ND	35.6	35.6
pb 06oc06 pcb	pg/g	Procedural Blank	YELL1	ND	4.3	ND	ND	ND	4.3 ND	4.0	ND	74.5	2.6	ND	81.0	81.0
SAMPLE #	DIOS FILE #	SPECIES	SITE	22446-BDE-100	23456-BDE-116	22445-BDE-85	23344'-BDE-105#	33445-BDE-126	Pe(1)	Pe(2)	Pe(3)	Pe(4)	Pe(5)	Pe(6)	22455'-BDE-1	Penta
7334S 06oc06 pcb	pg/g	Arctic Project Soil	YELL01	179.3	ND	52.5	ND	ND	ND	4.8	ND	ND	4.0	10.2	ND	71.5
7334Srep 06oc06 pcb	pg/g	Arctic Project Soil	YELL01	168.1	ND	48.8	ND	ND	ND	6.4	ND	ND	4.1	10.6	ND	69.9
7335S 13oc06 pcb RR	pg/g	Arctic Project Soil	YELL02	33.9	ND	9.5	ND	ND	ND	0.5	ND	ND	ND	0.7	2.2	12.8
7335Srep 13oc06 pcb	pg/g	Arctic Project Soil	YELL02	39.5	ND	12.0	ND	ND	ND	ND	ND	ND	ND	ND	2.2	14.2
7336S 13oc06 pcb	pg/g	Arctic Project Soil	YELL03	32.6	ND	6.6	ND	ND	ND	ND	ND	ND	0.8	ND	1.1	8.4
7337S 06oc06 pcb	pg/g	Arctic Project Soil	YELL04	14.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.0
7338S 13oc06 pcb	pg/g	Arctic Project Soil	Iqaluit Landfill - IQ2W40	10627.8	28.0	3528.0	35.1	ND	14.1	171.5	20.1	18.7	104.1	349.2	515.9	4784.8
7339S 13oc06 pcb	pg/g	Arctic Project Soil	Iqaluit Landfill - IQ3W40	6230.2	ND	1581.6	15.1	ND	6.1	168.0	4.9	ND	25.2	176.4	473.7	2451.0
7340S 13oc06 pcb RR	pg/g	Arctic Project Soil	Iqaluit Landfill - IQ4W40	7.5	ND	0.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.7
7342S 06oc06 pcb RR	pg/g	Arctic Project Soil	Iqaluit former Military dump - IQc	6.9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.0
7343S 13oc06 pcb	pg/g	Arctic Project Soil	Iqaluit North 40 metal dump - IQ	72.6	ND	17.9	ND	ND	ND	2.2	ND	ND	ND	2.0	4.2	26.3
7345S 13oc06 pcb	pg/g	Arctic Project Soil	Iqaluit - Apex - IQAX-2	9.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.0
7445S 17no06 pcb	pg/g	Soil	Rankin Inlet (Slimes)	24.4	ND	6.3	ND	ND	ND	1.0	ND	ND	ND	ND	1.9	9.2
7346S 13oc06 pcb	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 2	801.9	ND	131.8	4.4	ND	6.7	122.8	5.6	ND	52.3	66.0	242.6	632.2
7347S 06oc06 pcb	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 3	8096.2	35.6	3125.0	41.5	ND	18.2	207.5	ND	54.7	114.7	400.3	97.5	4095.0
7348S 06oc06 pcb	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 5	258.3	ND	53.9	1.6	ND	1.3	16.4	ND	3.3	8.2	17.1	35.3	137.1
7349S 13oc06 pcb dl	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 6	3057.2	86.4	939.4	347.0	ND	32.5	684.6	40.2	149.2	530.2	915.2	2882.5	6607.0
7350S 06oc06 pcb	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 7	106.1	ND	NDR(21.5)	ND	ND	ND	6.4	2.2	ND	4.2	6.3	ND	19.1
7351S 06oc06 pcb	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 8	15.7	ND	3.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	3.5
pb 13oc06 pcb	pg/g	Procedural Blank	YELL2	3.3	ND	3.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.0
pb 06oc06 pcb	pg/g	Procedural Blank	YELL1	7.9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.0

Appendix D – Experimental Results: Investigation of PBDEs, Distribution in Landfills and Sewage Treatment in Northern Canada

Table D.8 (continued) Raw soil data from the Canadian North, summer 2006 (pg/g)

SAMPLE #	DIOS FILE #	SPECIES	SITE	22'44'66"-BDE-155	22'44'56"-BDE-154	22'44'55"-BDE-153	22'344'6"-BDE-140#	22'344'5/2344'56-BDE Hx(1)	Hx(2)	Hexa	22'344'5'6-BDE-183	22'344'56-BDE-18	233'44'56-BDE-19f	Hepta	Oct(1)
7334S 06oc06 pcb	pg/g	Arctic Project Soil	YELL01	3.8	77.3	116.7	5.1	24.8	ND	22.5	250.2 103.9	11.1	14.4	14.4	20.7
7334Srep 06oc06 pcb	pg/g	Arctic Project Soil	YELL01	3.6	65.2	101.6	5.1	20.7	3.1	19.4	218.7 96.5	9.0	13.9	13.9	19.0
7335S 13oc06 pcb RR	pg/g	Arctic Project Soil	YELL02	0.8	13.9	21.5	0.7	2.8	ND	1.3	41.0 16.6	ND	1.0	1.0	1.6
7335Srep 13oc06 pcb	pg/g	Arctic Project Soil	YELL02	1.0	17.3	32.5	ND	3.6	ND	2.2	56.4 49.1	ND	2.6	2.6	0.9
7336S 13oc06 pcb	pg/g	Arctic Project Soil	YELL03	ND	9.0	9.8	ND	ND(1.6)	ND	1.1	19.9 6.7	ND	ND	0.0	0.9
7337S 06oc06 pcb	pg/g	Arctic Project Soil	YELL04	ND	3.2	4.7	ND	ND	ND	ND	7.9 8.0	ND	ND	0.0	N/A
7339S 13oc06 pcb	pg/g	Arctic Project Soil	Iqaluit Landfill - IQ2W40	244.0	4874.2	6352.0	205.6	991.8	90.7	478.6	13236.9 4556.6	109.4	338.0	338.0	423.3
7339S 13oc06 pcb	pg/g	Arctic Project Soil	Iqaluit Landfill - IQ3W40	128.0	2549.9	2957.6	70.1	361.7	15.7	122.8	6205.9 786.7	18.7	58.7	58.7	48.6
7340S 13oc06 pcb RR	pg/g	Arctic Project Soil	Iqaluit Landfill - IQ4W40	ND	0.8	1.6	ND	ND	ND	ND	2.4 2.2	ND	ND	0.0	0.8
7342S 06oc06 pcb RR	pg/g	Arctic Project Soil	Iqaluit former Military dump - IQt ND	ND	0.9	1.5	ND	ND	ND	ND	2.5 5.2	ND	ND	0.0	ND
7343S 13oc06 pcb	pg/g	Arctic Project Soil	Iqaluit North 40 metal dump - IQ 1.7	29.1	33.9	ND	4.4	ND	ND	1.8	70.9 32.3	ND	2.4	2.4	1.9
7345S 13oc06 pcb	pg/g	Arctic Project Soil	Iqaluit - Apex - IQAX-2	2.0	1.9	ND	ND	ND	ND	ND	3.9 3.0	ND	ND	0.0	ND
7445S 17no06 pcb	pg/g	Soil	Rankin Inlet (Slimes)	ND	5.9	8.3	0.3	1.0	ND	1.0	16.5 3.7	ND	0.9	0.9	1.3
7346S 13oc06 pcb	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 2	31.0	561.0	641.0	17.4	69.2	72.6	101.9	1494.1 445.9	17.9	30.6	30.6	48.4
7347S 06oc06 pcb	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 3	154.1	3417.5	4841.6	140.6	785.7	80.9	337.3	9757.6 1356.2	85.9	144.1	144.1	99.9
7348S 06oc06 pcb	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 5	7.6	144.2	152.3	5.7	19.0	16.3	39.0	383.9 117.2	19.2	19.5	19.5	65.5
7349S 13oc06 pcb dl	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 6	168.4	10983.2	43445.2	973.1	4912.2	1111.0	4010.5	65603.7 182904.2	242.4	8988.0	8988.0	47.5
7350S 06oc06 pcb	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 7	3.1	49.9	51.0	3.8	15.1	2.4	20.2	145.4 53.7	13.5	14.6	14.6	45.0
7351S 06oc06 pcb	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 8	ND	5.0	7.1	ND	ND	ND	3.6	15.7 33.0	ND	ND	0.0	6.0
pb 13oc06 pcb	pg/g	Procedural Blank	YELL2	ND	ND	ND	ND	ND	ND	ND	0.0 NDR(1.7)	ND	ND	0.0	ND
pb 06oc06 pcb	pg/g	Procedural Blank	YELL1	ND	1.5	2.3	ND	ND	ND	ND	3.7 NDR(3.2)	ND	ND	0.0	2.3
SAMPLE #	DIOS FILE #	SPECIES	SITE	22'33'45'66"-BDE-201	22'344'566/22'33'44'66"-BDE-202	22'344'55'6"-BDE-203	22'33'44'56"-BDE-196	22'33'45'566"-BDE-208	22'33'44'566"-BDE-22'33'44'55'6"-E	Nona	22'33'44'55'66"-BDE-209	Deca	Total PBDEs		
7334S 06oc06 pcb	pg/g	Arctic Project Soil	YELL01	50.5	78.7	91.1	80.0	710.0	583.4	1293.4	19305.3	19305.25			
7334Srep 06oc06 pcb	pg/g	Arctic Project Soil	YELL01	44.5	71.8	78.8	70.1	505.3	544.3	1049.6	22008.9	22008.85			
7335S 13oc06 pcb RR	pg/g	Arctic Project Soil	YELL02	7.9	97.4	24.7	41.7	108.2	57.3	165.5	1690.5	1690.51			
7335Srep 13oc06 pcb	pg/g	Arctic Project Soil	YELL02	2.5	15.6	4.9	7.5	32.7	28.3	61.1	937.4	937.38			
7336S 13oc06 pcb	pg/g	Arctic Project Soil	YELL03	1.3	1.5	2.5	1.7	11.7	12.7	24.4	437.5	437.46			
7337S 06oc06 pcb	pg/g	Arctic Project Soil	YELL04	N/A	N/A	N/A	N/A	N/A	N/A	0.0	N/A	N/A			
7338S 13oc06 pcb	pg/g	Arctic Project Soil	Iqaluit Landfill - IQ2W40	980.4	2421.3	1858.2	1649.6	N/A	7257.4	18999.4	26256.7	574148.6	574148.6		
7339S 13oc06 pcb	pg/g	Arctic Project Soil	Iqaluit Landfill - IQ3W40	107.3	285.9	215.3	175.0	N/A	794.7	1015.3	1810.1	42499.0	42499.02		
7340S 13oc06 pcb RR	pg/g	Arctic Project Soil	Iqaluit Landfill - IQ4W40	1.3	2.6	3.1	2.3	N/A	ND	ND	0.0	2143.2	2143.2		
7342S 06oc06 pcb RR	pg/g	Arctic Project Soil	Iqaluit former Military dump - IQt 0.7	ND	ND(2.2)	1.6	1.9	N/A	26.1	38.7	64.8	1888.6	1888.57		
7343S 13oc06 pcb	pg/g	Arctic Project Soil	Iqaluit North 40 metal dump - IQ 4.3	15.0	6.3	6.4	N/A	N/A	49.7	33.3	83.0	951.9	951.87		
7345S 13oc06 pcb	pg/g	Arctic Project Soil	Iqaluit - Apex - IQAX-2	ND	ND	1.4	N/A	N/A	8.0	17.4	25.4	730.0	730.02		
7445S 17no06 pcb	pg/g	Soil	Rankin Inlet (Slimes)	2.0	3.3	4.7	3.5	N/A	19.4	96.0	115.4	3986.8	3986.77		
7346S 13oc06 pcb	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 2	84.4	210.6	130.6	107.6	N/A	694.8	519.3	1214.2	14202.9	14202.94		
7347S 06oc06 pcb	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 3	278.0	535.5	347.6	341.8	N/A	1036.6	822.3	1858.9	28963.6	28963.64		
7348S 06oc06 pcb	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 5	114.4	88.7	185.1	97.2	N/A	277.6	322.6	600.2	6960.0	6960.01		
7349S 13oc06 pcb dl	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 6	2812.2	74839.6	15552.2	27488.8	N/A	25780.5	2322.3	32102.8	13097.3	13097.34		
7350S 06oc06 pcb	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 7	78.3	65.4	110.3	80.8	N/A	516.4	933.1	1449.5	51212.2	51212.21		
7351S 06oc06 pcb	pg/g	Arctic Project Soil	Cambridge Bay - CAMBY 8	10.9	21.9	19.4	14.2	N/A	89.3	98.6	187.9	4010.6	4010.64		
pb 13oc06 pcb	pg/g	Procedural Blank	YELL2	ND	1.6	1.1	0.9	N/A	5.0	4.4	9.4	178.0	177.98	241	
pb 06oc06 pcb	pg/g	Procedural Blank	YELL1	5.7	7.6	8.2	6.7	N/A	205.4	124.2	329.7	4511.7	4511.7	5,000	

Note:
 (1) Results are corrected for surrogate r ND = not detected
 (3) NDR = not detected due to incorrect DL = detection limit (pg/sample/analyte peak)
 (5) N/A = not applicable * relative retention time (rt) relative to recovery standard
 (7) (Mo-Hp) = MoBDE to HpBDE analysis (Oc-De) = OcBDE to DeBDE analysis
 (9) **Lockmass indicates interferences that may affect the accuracy of the concentration.

**Table D.9 BDE concentrations in re-extracted leachate samples from the 2006 field sampling program (pg/L). Analyzed by DFO-
IOS**

blk642 ase 26jn07	Cluster E	BDE-47	BDE-100	BDE-99	BDE-154	BDE-153	BDE-183	blk642 ase 26jn07	Cluster K	BDE-207	BDE-206	BDE-209
PRO BLANK avg value	2x blk	2,355	310	1,053	50	81	170	PRO BLANK avg value	1x blk	489	928	18,979
7431Aqrex 26jn07	Cape Dorset - CD3	7,395	1,688	7,891	527	748	582	7431Aqrex 26jn07	Cape Dorset - CD3	3,654	5,292	53,568
7431Aqrex 26jn07	CD3- blk corr	2,686	1,068	5,786	427	587	242	7431Aqrex 26jn07	CD3- blk corr	3,165	4,364	34,590
7438Aqrex 26jn07	Hall Beach - HB-01	6,284	1,740	7,006	1,629	7,080	39,651	7438Aqrex 26jn07	Hall Beach - HB-01	16,676	5,907	101,542
7438Aqrex 26jn07	HB-01 - blk corr	1,575	1,120	4,901	1,530	6,918	39,311	7438Aqrex 26jn07	HB-01 - blk corr	16,187	4,979	82,563
7441Aqrex 26jn07 RR1	Iqaluit Landfill - IQ1	4,081	703	2,350	145	204	354	7441Aqrex 26jn07 RR1	Iqaluit Landfill - IQ1	1,356	2,618	76,236
7441Aqrex 26jn07 RR1	IQ1- blk corr	BMDL	83	245	45	42	14	7441Aqrex 26jn07 RR1	IQ1- blk corr	867	1,689	57,257
7430Aqrex 26jn07	Pangnirtung - PANG2	26,584	6,335	34,378	2,276	3,358	1,231	7430Aqrex 26jn07	Pangnirtung - PANG2	6,405	11,155	264,361
7430Aqrex 26jn07	PANG2- rep 1 blk corr	21,875	5,715	32,273	2,177	3,196	891	7430Aqrex 26jn07	PANG2- rep 1 blk corr	5,916	10,227	245,382
7430Aqrexrep 26jn07	Pangnirtung - PANG2	25,313	6,645	34,750	2,416	3,660	1,282	7430Aqrexrep 26jn07	Pangnirtung - PANG2	8,460	15,718	387,013
7430Aqrexrep 26jn07	PANG2- rep 2 blk corr	20,603	6,025	32,645	2,316	3,499	943	7430Aqrexrep 26jn07	PANG2- rep 2 blk corr	7,971	14,789	368,034
7370Aqrex 26jn07	Iqaluit Landfill - Iqaluit X-Can	4,214	568	2,163	101	149	271	7370Aqrex 26jn07	Iqaluit Landfill - Iqaluit X-	1,431	4,221	72,790
7370Aqrex 26jn07	IqaX-Can - rep 1 blk corr	BMDL	BMDL	57	2	BMDL	BMDL	7370Aqrex 26jn07	IqaX-Can - rep 1 blk corr	942	3,293	53,811
7370Aqrexrep 26jn07	Iqaluit Landfill - Iqaluit X-Can	3,472	506	1,827	109	155	239	7370Aqrexrep 26jn07	Iqaluit Landfill - Iqaluit X-	2,393	3,211	23,519
7370Aqrexrep 26jn07	IqaX-Can - rep 2 blk corr	BMDL	BMDL	BMDL	9	BMDL	BMDL	7370Aqrexrep 26jn07	IqaX-Can - rep 2 blk corr	1,904	2,283	4,540

**Table D.10 BDE concentrations in soil samples collected in the Canadian North, summer 2004 and 2006 (pg/g). Analyzed by DFO-
IOS**

Sample ID	di-BDEs		tri-BDEs		tetra-BDEs		penta-BDEs		hexa-BDEs		hepta-BDEs		octa-BDEs		nona-BDEs		deca-BDEs		Total PBDEs	
Yellowknife, NWT	2004	2006	2004	2006	2004	2006	2004	2006	2004	2006	2004	2006	2004	2006	2004	2006	2004	2006	2004	2006
YELL01	1.03E+00	ND	5.91E+00	2.21E+01	9.61E+01	6.08E+02	1.22E+02	1.12E+03	2.11E+01	2.36E+02	3.75E+00	1.25E+02	3.11E+01	3.05E+02	2.53E+01	1.18E+03	4.35E+02	2.08E+04	7.41E+02	2.44E+04
Procedural blank	1.41E+00	ND	2.13E+00	6.04E+00	1.96E+01	8.10E+01	1.09E+01	3.77E+01	1.83E+00	3.74E+00	1.83E+00	0.00E+00	ND	3.05E+01	8.10E+00	3.30E+02	1.85E+02	4.51E+03	N/A	N/A
Value after blank correction	BMDL	ND	3.78E+00	9.99E+00	7.65E+01	4.46E+02	1.11E+02	1.05E+03	1.93E+01	2.29E+02	1.92E+00	1.25E+02	3.11E+01	2.44E+02	1.72E+01	5.21E+02	2.50E+02	1.18E+04	5.11E+02	1.44E+04
YELL02	2.10E+01	ND	1.87E+02	5.99E+00	5.41E+03	1.46E+02	8.11E+03	2.35E+02	3.09E+03	4.90E+01	7.08E+03	3.49E+01	2.89E+03	1.03E+02	1.61E+03	1.14E+02	2.85E+04	1.32E+03	5.69E+04	2.01E+03
Procedural blank	1.41E+00	ND	2.13E+00	ND	1.96E+01	3.56E+01	1.09E+01	1.48E+01	1.83E+00	ND	1.83E+00	ND	ND	3.64E+00	8.10E+00	9.44E+00	1.85E+02	1.78E+02	N/A	N/A
Value after blank correction	1.95E+01	ND	1.85E+02	5.99E+00	5.39E+03	1.11E+02	8.10E+03	2.20E+02	3.09E+03	4.90E+01	7.07E+03	3.49E+01	2.89E+03	9.93E+01	1.60E+03	1.05E+02	2.83E+04	1.14E+03	5.67E+04	1.77E+03
YELL03	N/A	6.46E+00	N/A	1.29E+01	N/A	1.79E+02	N/A	1.81E+02	N/A	2.04E+01	N/A	6.90E+00	N/A	8.08E+00	N/A	2.50E+01	N/A	4.49E+02	N/A	8.88E+02
Procedural blank	N/A	ND	N/A	ND	N/A	3.56E+01	N/A	1.48E+01	N/A	ND	N/A	ND	N/A	3.64E+00	N/A	9.44E+00	N/A	1.78E+02	N/A	N/A
Value after blank correction	N/A	6.46E+00	N/A	1.29E+01	N/A	1.43E+02	N/A	1.66E+02	N/A	2.04E+01	N/A	6.90E+00	N/A	4.44E+00	N/A	1.56E+01	N/A	2.71E+02	N/A	6.47E+02
YELL04	1.71E+00	ND	2.26E+00	2.80E+00	4.03E+01	1.05E+02	3.19E+01	7.69E+01	4.69E+00	7.95E+00	4.27E+00	7.99E+00	ND	1.14E+01	1.90E+01	2.42E+01	4.16E+02	6.66E+02	5.21E+02	9.03E+02
Procedural blank	3.10E+00	ND	5.31E+00	6.04E+00	4.50E+01	8.10E+01	2.32E+01	3.77E+01	5.73E+00	3.74E+00	4.39E+00	ND	ND	3.05E+01	ND	3.30E+02	5.92E+00	4.51E+03	N/A	N/A
Value after blank correction	BMDL	ND	BMDL	BMDL	BMDL	BMDL	8.78E+00	1.50E+00	BMDL	BMDL	BMDL	7.99E+00	ND	BMDL	1.90E+01	BMDL	4.10E+02	BMDL	4.38E+02	9.49E+00
Iqaluit, Nunavut																				
IQ2W40	4.62E+01	7.63E+02	1.34E+02	2.11E+03	1.49E+03	3.91E+04	2.23E+03	7.33E+04	4.12E+02	1.38E+04	7.58E+01	5.21E+03	3.58E+01	7.63E+03	5.31E+01	2.73E+04	6.56E+02	5.97E+05	5.13E+03	7.66E+05
Procedural blank	1.41E+00	ND	2.13E+00	ND	1.96E+01	3.56E+01	1.09E+01	1.48E+01	1.83E+00	ND	1.83E+00	ND	ND	3.64E+00	8.10E+00	9.44E+00	1.85E+02	1.78E+02	ND	N/A
Value after blank correction	4.48E+01	7.63E+02	1.32E+02	2.11E+03	1.47E+03	3.91E+04	2.22E+03	7.33E+04	4.10E+02	1.38E+04	7.40E+01	5.21E+03	3.58E+01	7.62E+03	4.50E+01	2.73E+04	6.56E+02	5.97E+05	4.90E+03	7.66E+05
IQ3W40	4.47E+00	5.63E+02	1.23E+01	1.97E+03	1.37E+02	3.23E+04	1.91E+02	4.75E+04	4.24E+01	7.88E+03	8.03E+00	1.10E+03	1.48E+01	1.06E+03	1.40E+01	2.30E+03	5.22E+02	5.40E+04	9.46E+02	1.49E+05
Procedural blank	1.41E+00	ND	2.13E+00	ND	1.96E+01	3.56E+01	1.09E+01	1.48E+01	1.83E+00	1.50E+01	1.83E+00	ND	ND	3.64E+00	8.10E+00	9.44E+00	1.85E+02	1.78E+02	N/A	N/A
Value after blank correction	3.06E+00	5.63E+02	1.01E+01	1.97E+03	1.17E+02	3.22E+04	1.80E+02	4.75E+04	4.06E+01	7.86E+03	6.20E+00	1.10E+03	1.48E+01	1.05E+03	5.89E+00	2.29E+03	3.37E+02	5.38E+04	7.15E+02	1.48E+05
IQ4W40	N/A	3.19E+00	N/A	ND	N/A	5.78E+01	N/A	3.03E+01	N/A	2.42E+00	N/A	2.27E+00	N/A	1.00E+01	N/A	BMDL	N/A	2.21E+03	N/A	2.31E+03
Procedural blank	N/A	BMDL	N/A	BMDL	N/A	3.56E+01	N/A	1.48E+01	N/A	BMDL	N/A	BMDL	N/A	3.64E+00	N/A	9.44E+00	N/A	1.78E+02	N/A	N/A
Value after blank correction	N/A	3.19E+00	N/A	ND	N/A	2.22E+01	N/A	1.55E+01	N/A	2.42E+00	N/A	2.27E+00	N/A	6.40E+00	N/A	BMDL	N/A	2.03E+03	N/A	2.08E+03
IQ6	ND	ND	6.35E+00	5.65E+00	ND	7.41E+01	5.51E+01	3.55E+01	1.47E+01	2.98E+00	8.49E+00	5.16E+00	ND	5.04E+00	4.65E+01	7.87E+01	8.21E+02	2.29E+03	9.52E+02	2.50E+03
Procedural blank	1.41E+00	ND	2.13E+00	6.04E+00	1.96E+01	8.10E+01	1.09E+01	3.77E+01	1.83E+00	3.74E+00	1.83E+00	ND	ND	3.05E+01	8.10E+00	3.30E+02	1.85E+02	4.51E+03	N/A	N/A
Value after blank correction	BMDL	ND	4.22E+00	BMDL	BMDL	BMDL	4.42E+01	BMDL	1.29E+01	BMDL	6.66E+00	5.16E+00	ND	BMDL	3.84E+01	BMDL	6.36E+02	BMDL	7.43E+02	5.16E+00
IQ7	N/A	ND	N/A	5.46E+00	N/A	2.19E+02	N/A	3.94E+02	N/A	7.15E+01	N/A	3.50E+01	N/A	4.14E+01	N/A	8.37E+01	N/A	9.60E+02	N/A	1.81E+03
Procedural blank	N/A	ND	N/A	ND	N/A	3.56E+01	N/A	1.48E+01	N/A	ND	N/A	ND	N/A	3.64E+00	N/A	9.44E+00	N/A	1.78E+02	N/A	N/A
Value after blank correction	N/A	BMDL	N/A	5.46E+00	N/A	1.83E+02	N/A	3.80E+02	N/A	7.15E+01	N/A	3.50E+01	N/A	3.78E+01	N/A	7.42E+01	N/A	7.82E+02	N/A	1.57E+03
IQ-2	1.44E+00	1.78E+00	2.70E+00	3.79E+00	3.89E+01	1.16E+02	2.39E+01	4.94E+01	2.41E+00	4.69E+00	N/A	3.60E+00	N/A	1.65E+00	1.47E+01	3.10E+01	3.47E+02	8.90E+02	4.31E+02	1.10E+03
Procedural blank	3.10E+00	ND	5.31E+00	ND	4.50E+01	3.56E+01	2.32E+01	1.48E+01	5.73E+00	0.00E+00	4.39E+00	ND	ND	3.64E+00	2.20E-01	9.44E+00	5.92E+00	1.78E+02	N/A	N/A
Value after blank correction	BMDL	1.78E+00	BMDL	3.79E+00	BMDL	8.00E+01	7.05E-01	3.46E+01	BMDL	4.69E+00	BMDL	3.60E+00	BMDL	BMDL	1.42E+01	2.16E+01	3.41E+02	7.12E+02	3.56E+02	8.62E+02
Cambridge Bay, Nunavut																				
CAMBY 2	1.35E+02	1.20E+03	3.18E+02	2.86E+03	1.93E+03	8.43E+03	2.47E+03	9.19E+03	5.26E+02	2.72E+03	1.78E+02	9.02E+02	2.69E+02	1.06E+03	1.79E+03	2.21E+03	2.06E+04	2.59E+04	2.82E+04	5.45E+04
Procedural blank	1.41E+00	ND	2.13E+00	ND	1.96E+01	3.56E+01	1.09E+01	1.48E+01	1.83E+00	0.00E+00	1.83E+00	ND	ND	3.64E+00	8.10E+00	9.44E+00	1.85E+02	1.78E+02	N/A	N/A
Value after blank correction	1.32E+02	1.20E+03	3.13E+02	2.86E+03	1.89E+03	8.39E+03	2.45E+03	9.17E+03	5.22E+02	2.72E+03	1.74E+02	9.02E+02	2.69E+02	1.06E+03	1.77E+03	2.20E+03	2.02E+04	2.57E+04	2.77E+04	5.42E+04
CAMBY 3	2.18E+02	7.64E+02	4.70E+02	2.26E+03	1.86E+03	3.08E+04	3.75E+03	5.60E+04	1.09E+03	9.79E+03	2.61E+02	1.59E+03	6.69E+02	1.61E+03	4.29E+02	1.87E+03	5.52E+03	2.91E+04	1.43E+04	1.34E+05
Procedural blank	1.41E+00	ND	2.13E+00	6.04E+00	1.96E+01	8.10E+01	1.09E+01	3.77E+01	1.83E+00	3.74E+00	1.83E+00	0.00E+00	ND	3.05E+01	8.10E+00	3.30E+02	1.85E+02	4.51E+03	N/A	N/A
Value after blank correction	2.16E+02	7.64E+02	4.66E+02	2.25E+03	1.82E+03	3.06E+04	3.73E+03	5.59E+04	1.08E+03	9.78E+03	2.57E+02	1.59E+03	6.69E+02	1.55E+03	4.13E+02	1.21E+03	5.15E+03	2.00E+04	1.38E+04	1.24E+05
CAMBY 5	1.20E+02	1.75E+01	1.48E+02	6.40E+02	4.35E+02	3.05E+03	5.43E+02	3.35E+03	1.35E+02	7.90E+02	6.91E+01	3.21E+02	2.01E+02	1.13E+03	3.29E+02	1.23E+03	2.05E+03	1.43E+04	4.03E+03	2.48E+04
Procedural blank	3.10E+00	ND	5.31E+00	6.04E+00	4.50E+01	8.10E+01	2.32E+01	3.77E+01	5.73E+00	3.74E+00	4.39E+00	0.00E+00	ND	3.05E+01	2.20E-01	3.30E+02	5.92E+00	4.51E+03	N/A	N/A
Value after blank correction	1.14E+02	1.75E+01	1.38E+02	6.28E+02	3.45E+02	2.89E+03	4.97E+02	3.28E+03	1.24E+02	7.82E+02	6.03E+01	3.21E+02	2.01E+02	1.07E+03	3.29E+02	5.75E+02	2.04E+03	5.29E+03	3.85E+03	1.48E+04
CAMBY 6	7.99E+01	6.41E+03	3.28E+02	4.75E+03	2.25E+03	1.37E+04	3.57E+03	2.83E+04	1.39E+03	7.15E+04	7.95E+02	2.09E+05	1.47E+03	1.32E+05	7.83E+02	3.50E+04	1.88E+04	1.43E+04	2.94E+04	5.15E+05
Procedural blank	1.41E+00	ND	2.13E+00	ND	1.96E+01	3.56E+01	1.09E+01	1.48E+01	1.83E+00	0.00E+00	1.83E+00	ND	ND	3.64E+00	8.10E+00	9.44E+00	1.85E+02	1.78E+02	N/A	N/A
Value after blank correction	7.85E+01	6.41E+03	3.25E+02	4.75E+03	2.23E+03	1.36E+04	3.56E+03	2.83E+04	1.39E+03	7.15E+04	7.93E+02	2.09E+05	1.47E+03	1.32E+05	7.75E+02	3.50E+04	1.86E+04	1.41E+04	2.92E+04	5.15E+05
CAMBY 7	2.43E+00	ND	5.05E+00	1.65E+01	4.99E+01	4.70E+02	3.58E+01	6.83E+02	7.31E+00	1.65E+02	5.25E+00	9.30E+01	2.81E+01	4.32E+02	4.33E+01	1.65E+03	1.02E+03	5.83E+04	1.20E+03	6.18E+04
Procedural blank	3.10E+00	ND	5.31E+00	6.04E+00	4.50E+01	8.10E+01	2.32E+01	3.77E+01	5.73E+00	3.74E+00	4.39E+00	0.00E+00	ND	3.05E+01	2.20E-01	3.30E+02	5.92E+00	4.51E+03	N/A	N/A
Value after blank correction	BMDL	BMDL	BMDL	4.43E+00	BMDL	3.08E+02	BMDL	6.08E+02	BMDL	1.58E+02	BMDL	9.30E+01	2.81E+01	3.71E+02	42.81	9.90E+02	1009.45			

Table D.10 (concluded)

Key	Sample type: soil
<i>Yellowknife, NWT</i>	
YELL01	Old dumping area Yellowknife landfill (average of 2 samples)
YELL02	White goods area-Yellowknife landfill (average of 2 samples)
YELL03	Current working area-Yellowknife landfill
YELL04	Background sample
<i>Iqaluit, Nunavut</i>	
IQ2W40	West 40 landfill (IQA06 sample ID in 2004 research season)
IQ3W40	West 40 landfill (IQA05 sample ID in 2004 research season)
IQ4W40	West 40 landfill
IQ6	former military dump (IQA14 sample ID in 2004 research season)
IQ7	North 40 metal dump
IQ-2	Apex flats (IQ2-original ID; IQA02 sample ID in 2004 research season)
<i>Cambridge Bay, Nunavut</i>	
CAMBY 2	Close to effluent drainage area (CAMO4 sample ID in 2004 research season)
CAMBY 3	Garbage dump (CAMO1 sample ID in 2004 research season)
CAMBY 5	Effluent discharge to ocean (CAMO6 sample ID in 2004 research season)
CAMBY 6	Metal waste dump (CAMO2 sample ID in 2004 research season)
CAMBY 7	Background (CAMO7 sample ID in 2004 research season)
CAMBY 8	Background-toward Mt Pelly (CAMO8 sample ID in 2004 research season)

Table D.11 BDE concentrations in aqueous samples collected in the Canadian North, summer 2004 and 2006 (pg/L)

Canadian North Aqueous samples - 2004 and 2006 (pg/L)																				
Sample ID	di-BDEs		tri-BDEs		tetra-BDEs		penta-BDEs		hexa-BDEs		hepta-BDEs		octa-BDEs		nona-BDEs		deca-BDEs		Total PBDEs	
Cambridge Bay, Nunavut	2004	2006	2004	2006	2004	2006	2004	2006	2004	2006	2004	2006	2004	2006	2004	2006	2004	2006	2004	2006
CAMBY 1	2.09E+02	ND	8.81E+02	6.17E+02	2.08E+04	9.50E+03	2.84E+04	7.89E+03	4.52E+03	2.13E+03	1.02E+03	9.91E+02	2.60E+03	3.31E+03	1.18E+04	7.48E+03	1.94E+05	1.08E+05	2.64E+05	1.39E+05
Procedural blank	2.31E+00	ND	1.29E+01	3.03E+02	2.59E+02	8.34E+03	1.44E+02	3.35E+03	1.70E+01	ND	1.45E+01	ND	3.96E+01	1.33E+03	3.57E+01	5.26E+03	5.49E+02	6.11E+04	N/A	N/A
Value after blank correction	2.05E+02	ND	8.55E+02	9.80E+00	2.03E+04	BMDL	2.81E+04	1.18E+03	4.49E+03	2.13E+03	9.94E+02	9.91E+02	2.52E+03	6.47E+02	1.17E+04	BMDL	1.93E+05	BMDL	2.62E+05	4.95E+03
CAMBY 4	1.06E+02	ND	2.96E+02	1.82E+02	1.77E+03	5.95E+03	1.47E+03	2.55E+03	2.45E+02	2.23E+02	1.31E+02	3.14E+02	3.55E+02	1.08E+03	3.45E+02	3.81E+03	1.67E+03	4.31E+04	6.38E+03	5.72E+04
Procedural blank	2.31E+00	ND	1.29E+01	ND	2.59E+02	1.07E+04	1.44E+02	4.48E+03	1.70E+01	3.68E+02	1.45E+01	4.97E+02	3.96E+01	2.11E+03	3.57E+01	5.13E+03	5.49E+02	2.89E+04	N/A	N/A
Value after blank correction	1.02E+02	ND	2.70E+02	1.82E+02	1.25E+03	BMDL	1.18E+03	BMDL	2.11E+02	BMDL	1.02E+02	BMDL	2.76E+02	BMDL	2.74E+02	BMDL	5.67E+02	BMDL	4.23E+03	1.82E+02

ND - not detected; N/A - not available ; BMDL - below method detection limit

Key	
Cambridge Bay, Nunavut	aqueous samples
CAMBY 1	Entrance to effluent drainage area (CAMO3 sample ID in 2004 research season)
CAMBY 4	Effluent discharge to ocean (CAMO5 sample ID in 2004 research season)

Table E.2 BDE concentrations including re-extractions of March 2008 (pg/L). Analyzed by DFO-IOS

Sample ID	tot di	tot tri	tot tetra	tot penta	tot hexa	tot hepta	tot octa	tot nona	tot deca	tot PBDEs	BDE-47	BDE-100	BDE-99	BDE-154	BDE-153	BDE-183	BDE-207	BDE-206	BDE-209
Z	114	241	4,703	3,938	970	1,395	BMDL	526	4,756	16,643	4,236	784	2,843	385	488	1,395	26	501	4,756
W	ND	ND	6,716	9,842	2,982	824	BMDL	BMDL	5,116	25,480	6,255	2,149	7,692	1,241	1,741	824	BMDL	55	5,116
N	30	364	6,199	2,423	267	413	BMDL	3,964	157,115	170,775	5,885	609	1,814	119	148	413	2,720	1,245	157,115
J	ND	520	6,731	5,372	2,615	606	BMDL	3,375	124,568	143,788	5,971	1,076	4,138	1,201	1,414	606	2,116	1,259	124,568
S	ND	385	6,629	2,317	239	ND	BMDL	4,229	134,445	148,244	6,302	569	1,748	89	150	BMDL	2,752	1,476	134,445
H	ND	548	8,883	11,191	8,170	7,205	2,596	2,550	16,094	57,237	6,863	2,305	7,958	2,965	4,008	6,862	1,876	674	16,094
X	580	770	1,980	6,637	3,442	BMDL	BMDL	781	13,565	27,755	BMDL	1,412	4,677	1,784	1,677	BMDL	345	436	13,565
U	ND	ND	BMDL	315	221	BMDL	BMDL	424	22,759	23,719	BMDL	BMDL	388	354	BMDL	BMDL	BMDL	424	22,759
AA	ND	10	BMDL	BMDL	138	137	BMDL	711	29,852	30,848	BMDL	BMDL	BMDL	19	BMDL	BMDL	326	731	29,852
Y	ND	BMDL	BMDL	61	176	BMDL	BMDL	BMDL	BMDL	237	BMDL	BMDL	BMDL	BMDL	25	BMDL	BMDL	BMDL	BMDL
T	1,890	5,524	251,982	614,200	189,602	21,008	16,928	8,641	29,757	1,139,532	194,108	105,224	489,426	81,675	89,640	20,279	6,521	2,468	29,757
M	ND	24	BMDL	BMDL	223	515	6,685	27,265	461,204	495,916	BMDL	BMDL	BMDL	18	48	236	14,640	12,973	461,204
I	383	1,389	16,124	28,904	9,948	841	1,752	4,233	45,468	108,165	11,197	6,252	20,873	4,878	4,642	939	1,691	1,845	45,468
V	1,083	1,174	19,529	29,612	12,726	2,522	3,219	5,792	72,092	147,749	14,567	5,971	21,560	5,613	6,405	2,544	1,859	2,465	72,092
G	15	74	2,597	4,800	718	617	1,336	6,854	134,381	151,082	2,633	883	4,223	488	467	413	2,988	2,816	134,381
A	1,369	4,240	227,660	400,973	141,993	9,594	9,832	22,850	35,057	853,568	143,062	73,058	302,126	68,028	59,197	7,178	8,788	8,619	35,057
F	662	28	8,358	5,072	2,113	1,689	1,215	2,689	47,185	69,011	5,655	2,403	2,781	1,045	1,096	1,745	1,298	1,336	47,185
B	37	64	3,114	1,883	178	263	103	3,686	108,532	119,796	4,326	568	2,039	93	154	317	1,467	2,300	108,532
D	845	2,684	61,471	43,764	26,275	8,345	6,665	31,445	287,069	468,563	27,105	13,772	21,739	11,606	10,857	6,689	12,043	14,241	287,069
C	47	138	7,594	26,232	8,639	13,298	18,984	56,190	305,031	436,154	4,978	3,549	19,701	2,771	4,296	11,202	21,308	19,445	305,031
average:	588	1,069	40,017	66,530	20,582	4,330	6,301	10,345	107,055	231,713	29,543	13,786	53,866	9,704	10,358	4,109	4,869	3,964	107,055

Table E.3 PBDE concentrations from leachate collected from landfills from across Canada (pg/L). Analyzed by DFO-IOS

Locations		BDE-47	BDE-99	BDE-100	BDE-153	BDE-154	BDE-183	BDE-206	BDE-207	BDE-209	Total PBDEs
▲	U	BMDL	388	BMDL	BMDL	354	BMDL	424	BMDL	22,759	23,719
▲	T	194,108	489,426	105,224	89,640	81,675	20,279	2,468	6,521	29,757	1,139,532
▲	AA	BMDL	BMDL	BMDL	BMDL	19	BMDL	731	326	29,852	30,848
▲	Y	BMDL	BMDL	BMDL	25	BMDL	BMDL	BMDL	BMDL	BMDL	237
▲	B	4,326	2,039	568	154	93	317	2,300	1,467	108,532	134,182
▲	C	4,978	19,701	3,549	4,296	2,771	11,202	19,445	21,308	305,031	400,523
•	X	BMDL	4,677	1,412	1,677	1,784	BMDL	436	345	13,565	27,755
•	I	11,197	20,873	6,252	4,642	4,878	939	1,845	1,691	45,468	108,165
•	V	14,567	21,560	5,971	6,405	5,613	2,544	2,465	1,859	72,092	147,749
•	G	2,633	4,223	883	467	488	413	2,816	2,988	134,381	151,082
•	A	143,062	302,126	73,058	59,197	68,028	7,178	8,619	8,788	35,057	853,568
•	F	5,655	2,781	2,403	1,096	1,045	1,745	1,336	1,298	47,185	69,011
•	H	6,863	7,958	2,305	4,008	2,965	6,862	674	1,876	16,094	57,237
•	S	6,302	1,748	569	150	89	BMDL	1,476	2,752	134,445	148,244
•	N	5,885	1,814	609	148	119	413	1,245	2,720	157,115	170,775
•	J	5,971	4,138	1,076	1,414	1,201	606	1,259	2,116	124,568	143,788
•	D	27,105	21,739	13,772	10,857	11,606	6,689	14,241	12,043	287,069	457,050
•	M	BMDL	BMDL	BMDL	48	18	236	12,973	14,640	461,204	495,916
•	W	6,255	7,692	2,149	1,741	1,241	824	55	BMDL	5,116	25,480
•	Z	4,236	2,843	784	488	385	1,395	501	26	4,756	16,643

Appendix F – E-Waste Contacting Experiments

Table F.1 Raw data for crushed e-waste analysis (pg/g). Analyzed by Vista Analytical

Alta Project	Sample ID	Date Sampled	Matrix	Method	Date Extracted	Sample Size	Analyte	Concentration	Report Units	Detection	EMPC	%Recovery	Qualifiers
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-1	-	pg/g	315	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-2	-	pg/g	222	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-3	-	pg/g	197	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-7	-	pg/g	20.6	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-8/11	37	pg/g	0	0	0	J
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-10	-	pg/g	19.2	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-12/13	-	pg/g	11.9	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-15	299	pg/g	0	0	0	J,B
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-17	61	pg/g	0	0	0	J
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-25	-	pg/g	58.4	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-28/33	198	pg/g	0	0	0	J
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-32	-	pg/g	37.3	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-35	-	pg/g	28.2	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-37	-	pg/g	26.4	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-30	-	pg/g	42.6	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-47	5,580	pg/g	0	0	0	B
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-49	328	pg/g	0	0	0	J
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-66	-	pg/g	37.8	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-71	-	pg/g	32.2	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-75	-	pg/g	24.6	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-77	-	pg/g	21.9	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-85	325	pg/g	0	0	0	J
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-99	8,930	pg/g	0	0	0	B
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-100	1,530	pg/g	0	0	0	B
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-116	-	pg/g	121	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-119	888	pg/g	0	0	0	J
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-126	-	pg/g	51.4	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-138	15,300	pg/g	0	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-153	319,000	pg/g	0	0	0	B
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-154	40,900	pg/g	0	0	0	B
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-155	-	pg/g	159	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-156	-	pg/g	586	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-166	-	pg/g	442	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-181	-	pg/g	1120	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-183	1,510,000	pg/g	0	0	0	B
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-190	68,100	pg/g	0	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-197	827,000	pg/g	0	0	0	B
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-203	307,000	pg/g	0	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-207	620,000	pg/g	0	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	BDE-209	7,530,000	pg/g	0	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	Total Monc	-	pg/g	235	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	Total Di-BI	382	pg/g	0	0	0	B
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	Total Tri-B	259	pg/g	0	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	Total Tetra	5,910	pg/g	0	0	0	B
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	Total Penta	14,000	pg/g	0	0	0	B
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	Total Hexa	387,000	pg/g	0	0	0	B
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	Total Hepta	1,670,000	pg/g	0	0	0	B
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	Total Octa	1,540,000	pg/g	0	0	0	B
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	Total Nona	801,000	pg/g	0	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	Total Deca	7,530,000	pg/g	0	0	0	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	13C-BDE-3	19,500	pg/g	0		56.1	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	13C-BDE-1	26,800	pg/g	0		77.2	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	13C-BDE-2	27,900	pg/g	0		80.3	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	13C-BDE-7	33,300	pg/g	0		95.8	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	13C-BDE-5	32,500	pg/g	0		93.6	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	13C-BDE-1	33,100	pg/g	0		95.4	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	13C-BDE-1	37,800	pg/g	0		109	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	13C-BDE-1	42,800	pg/g	0		123	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	13C-BDE-1	43,900	pg/g	0		126	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	13C-BDE-1	45,600	pg/g	0		131	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	13C-BDE-1	95,000	pg/g	0		137	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	13C-BDE-2	128,000	pg/g	0		184	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	13C-BDE-2	698,000	pg/g	0		402	
27342	1980-1984	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.72 L	13C-BDE-1	33,500	pg/g	0		96.5	

Appendix F – E-Waste Contacting Experiments

Table F.1 (continued) Raw data for crushed e-waste analysis (pg/g). Analyzed by Vista Analytical

Alta Project	Sample ID	Date Sampled	Matrix	Method	Date Extracted	Sample Size	Analyte	Concentration	Report Units	Detection	EMPC	%Recovery	Qualifiers
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-1	13,900	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-2	7,570	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-3	30,800	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-7	31,400	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-8/11	24,200	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-10	357	pg/g	0	0	0	J
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-12/13	8,780	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-15	31,900	pg/g	0	0	0	B
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-17	64,500	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-25	21,200	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-28/33	103,000	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-32	4,830	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-35	9,190	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-37	7,860	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-30	1,090	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-47	681,000	pg/g	0	0	0	B
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-49	68,300	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-66	93,600	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-71	133,000	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-75	3,190	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-77	15,600	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-85	433,000	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-99	13,400,000	pg/g	0	0	0	B
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-100	736,000	pg/g	0	0	0	B
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-116	33,300	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-119	798,000	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-126	20,200	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-138	67,600,000	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-153	1,260,000,000	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-154	143,000,000	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-155	480,000	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-156	716,000	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-166	-	pg/g	92700	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-181	1,160,000,000	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-183	1,870,000,000	pg/g	0	0	0	B
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-190	55,200,000	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-197	2,550,000,000	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-203	1,230,000,000	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-207	1,790,000,000	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	BDE-209	1,670,000,000	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	Total Monoc	52,200	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	Total Di-BI	119,000	pg/g	0	0	0	B
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	Total Tri-B	253,000	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	Total Tetra-	1,110,000	pg/g	0	0	0	B
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	Total Penta	36,100,000	pg/g	0	0	0	B
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	Total Hexa-	1,530,000,000	pg/g	0	0	0	B
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	Total Hepta	2,050,000,000	pg/g	0	0	0	B
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	Total Octa-	5,190,000,000	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	Total Nona-	1,910,000,000	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	Total Deca-	1,670,000,000	pg/g	0	0	0	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	13C-BDE-3	32,900	pg/g	0		67.2	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	13C-BDE-1	40,100	pg/g	0		81.8	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	13C-BDE-2	38,300	pg/g	0		78.1	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	13C-BDE-7	58,600	pg/g	0		120	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	13C-BDE-5	80,600	pg/g	0		164	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	13C-BDE-1	58,100	pg/g	0		119	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	13C-BDE-1 NA		pg/g	0		NA	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	13C-BDE-1 NA		pg/g	0		NA	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	13C-BDE-1 NA		pg/g	0		NA	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	13C-BDE-1 NA		pg/g	0		NA	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	13C-BDE-1 NA		pg/g	0		NA	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	13C-BDE-2 NA		pg/g	0		NA	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	13C-BDE-2 NA		pg/g	0		NA	
27342	1985-1989	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.51 L	13C-BDE-1 NA		pg/g	0		NA	

Appendix F – E-Waste Contacting Experiments

Table F.1 (continued) Raw data for crushed e-waste analysis (pg/g). Analyzed by Vista Analytical

Alta Project	Sample ID	Date Sampled	Matrix	Method	Date Extracted	Sample Size	Analyte	Concentration	Report Units	Detection	EMPC	%Recovery	Qualifiers
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-1	-	pg/g	174	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-2	-	pg/g	122	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-3	-	pg/g	109	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-7	-	pg/g	8.37	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-8/11	28	pg/g	0	0	0	J
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-10	-	pg/g	7.83	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-12/13	-	pg/g	4.86	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-15	277	pg/g	0	0	0	J,B
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-17	-	pg/g	6.24	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-25	-	pg/g	11.3	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-28/33	220	pg/g	0	0	0	J
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-32	-	pg/g	7.2	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-35	-	pg/g	5.44	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-37	-	pg/g	5.09	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-30	-	pg/g	8.23	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-47	1,290	pg/g	0	0	0	B
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-49	-	pg/g	19.9	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-66	-	pg/g	23.1	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-71	-	pg/g	19.7	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-75	-	pg/g	15	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-77	-	pg/g	13.4	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-85	-	pg/g	55.7	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-99	1,420	pg/g	0	0	0	B
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-100	337	pg/g	0	0	0	J,B
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-116	-	pg/g	102	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-119	-	pg/g	49.1	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-126	-	pg/g	40.5	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-138	-	pg/g	110	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-153	2,280	pg/g	0	0	0	B
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-154	433	pg/g	0	0	0	J,B
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-155	-	pg/g	51.5	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-156	-	pg/g	177	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-166	-	pg/g	162	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-181	-	pg/g	619	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-183	19,800	pg/g	0	0	0	B
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-190	-	pg/g	814	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-197	9,760	pg/g	0	0	0	B
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-203	3,890	pg/g	0	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-207	21,200	pg/g	0	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	BDE-209	268,000	pg/g	0	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	Total Monoc	-	pg/g	130	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	Total Di-BI	304	pg/g	0	0	0	B
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	Total Tri-B	220	pg/g	0	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	Total Tetra-	1,290	pg/g	0	0	0	B
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	Total Penta	1,760	pg/g	0	0	0	B
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	Total Hexa-	2,710	pg/g	0	0	0	B
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	Total Hepta	19,800	pg/g	0	0	0	B
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	Total Octa-	18,000	pg/g	0	0	0	B
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	Total Nona-	40,600	pg/g	0	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	Total Deca-	268,000	pg/g	0	0	0	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	13C-BDE-2	14,400	pg/g	0		62.3	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	13C-BDE-1	17,400	pg/g	0		75.3	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	13C-BDE-2	17,400	pg/g	0		75.3	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	13C-BDE-7	21,600	pg/g	0		93.4	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	13C-BDE-5	19,100	pg/g	0		82.4	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	13C-BDE-1	17,900	pg/g	0		77.3	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	13C-BDE-1	21,600	pg/g	0		93.1	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	13C-BDE-1	21,600	pg/g	0		93.1	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	13C-BDE-1	23,500	pg/g	0		101	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	13C-BDE-1	18,600	pg/g	0		80.5	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	13C-BDE-1	25,200	pg/g	0		54.5	
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	13C-BDE-2	7,950	pg/g	0		17.2	H
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	13C-BDE-2	11,800	pg/g	0		10.2	H
27342	1990-1994	24/02/2006	Solid	EPA Method 1614	07/03/2006	1.08 L	13C-BDE-1	22,900	pg/g	0		99	

Appendix F – E-Waste Contacting Experiments

Table F.1 (continued) Raw data for crushed e-waste analysis (pg/g). Analyzed by Vista Analytical

Alta Project	Sample ID	Date Sampled	Matrix	Method	Date Extracted	Sample Size	Analyte	Concentration	Report Units	Detection	EMPC	%Recovery	Qualifiers
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-1	-	pg/g	228	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-2	-	pg/g	160	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-3	-	pg/g	143	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-7	-	pg/g	15.1	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-8/11	-	pg/g	11.3	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-10	-	pg/g	14.2	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-12/13	-	pg/g	8.78	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-15	44	pg/g	0	0	0	J,B
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-17	-	pg/g	31.9	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-25	-	pg/g	57.6	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-28/33	80	pg/g	0	0	0	J
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-32	-	pg/g	36.8	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-35	-	pg/g	27.8	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-37	-	pg/g	26	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-30	-	pg/g	42.1	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-47	3,030	pg/g	0	0	0	B
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-49	-	pg/g	23.5	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-66	-	pg/g	27.3	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-71	-	pg/g	23.2	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-75	-	pg/g	17.7	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-77	-	pg/g	15.8	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-85	156	pg/g	0	0	0	J
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-99	4,700	pg/g	0	0	0	B
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-100	1,040	pg/g	0	0	0	B
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-116	-	pg/g	163	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-119	-	pg/g	78.8	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-126	-	pg/g	85.5	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-138	698	pg/g	0	0	0	J
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-153	6,170	pg/g	0	0	0	B
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-154	1,920	pg/g	0	0	0	B
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-155	-	pg/g	94.8	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-156	-	pg/g	500	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-166	-	pg/g	368	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-181	-	pg/g	1240	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-183	26,700	pg/g	0	0	0	B
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-190	-	pg/g	1630	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-197	15,500	pg/g	0	0	0	B
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-203	-	pg/g	269	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-207	-	pg/g	8770	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	BDE-209	41,200	pg/g	0	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	Total Monoc	-	pg/g	170	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	Total Di-BI	44	pg/g	0	0	0	B
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	Total Tri-B	80	pg/g	0	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	Total Tetra-	3,030	pg/g	0	0	0	B
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	Total Penta	5,900	pg/g	0	0	0	B
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	Total Hexa-	8,780	pg/g	0	0	0	B
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	Total Hepta	26,700	pg/g	0	0	0	B
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	Total Octa-	19,600	pg/g	0	0	0	B
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	Total Nona-	-	pg/g	8770	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	Total Deca-	41,200	pg/g	0	0	0	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	13C-BDE-2	19,700	pg/g	0		78.8	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	13C-BDE-1	24,000	pg/g	0		96	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	13C-BDE-2	23,000	pg/g	0		92.1	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	13C-BDE-7	27,200	pg/g	0		109	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	13C-BDE-5	19,600	pg/g	0		78.2	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	13C-BDE-1	21,300	pg/g	0		85.2	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	13C-BDE-1	22,500	pg/g	0		89.9	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	13C-BDE-1	26,500	pg/g	0		106	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	13C-BDE-1	36,700	pg/g	0		147	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	13C-BDE-1	21,400	pg/g	0		85.5	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	13C-BDE-1	32,000	pg/g	0		63.9	
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	13C-BDE-2	2,040	pg/g	0		4.08	H
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	13C-BDE-2	17,100	pg/g	0		13.7	H
27342	1995-1999	24/02/2006	Solid	EPA Method 1614	07/03/2006	1 L	13C-BDE-1	29,500	pg/g	0		118	

Appendix F – E-Waste Contacting Experiments

Table F.1 (continued) Raw data for crushed e-waste analysis (pg/g). Analyzed by Vista Analytical

Alta Project	Sample ID	Date Sampled	Matrix	Method	Date Extracted	Sample Size	Analyte	Concentration	Report Units	Detection	EMPC	%Recovery	Qualifiers
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-1	-	pg/g	424	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-2	-	pg/g	297	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-3	-	pg/g	265	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-7	-	pg/g	29.7	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-8/11	-	pg/g	22.3	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-10	-	pg/g	27.8	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-12/13	-	pg/g	17.3	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-15	91	pg/g	0	0	0	J,B
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-17	-	pg/g	30.4	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-25	-	pg/g	55	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-28/33	89	pg/g	0	0	0	J
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-32	-	pg/g	35.1	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-35	-	pg/g	26.5	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-37	-	pg/g	24.8	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-30	-	pg/g	40.1	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-47	1,550	pg/g	0	0	0	B
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-49	-	pg/g	65.4	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-66	-	pg/g	75.8	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-71	-	pg/g	64.6	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-75	-	pg/g	49.2	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-77	-	pg/g	43.9	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-85	-	pg/g	118	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-99	2,140	pg/g	0	0	0	J,B
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-100	551	pg/g	0	0	0	J,B
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-116	-	pg/g	216	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-119	-	pg/g	104	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-126	-	pg/g	96	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-138	-	pg/g	441	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-153	1,210	pg/g	0	0	0	J,B
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-154	492	pg/g	0	0	0	J,B
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-155	-	pg/g	188	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-156	-	pg/g	624	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-166	-	pg/g	650	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-181	-	pg/g	773	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-183	5,040	pg/g	0	0	0	B
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-190	-	pg/g	1020	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-197	3,210	pg/g	0	0	0	J,B
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-203	-	pg/g	728	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-207	-	pg/g	2420	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	BDE-209	-	pg/g	32000	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	Total Monoc	-	pg/g	316	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	Total Di-BI	91	pg/g	0	0	0	B
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	Total Tri-B	89	pg/g	0	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	Total Tetra-	1,550	pg/g	0	0	0	B
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	Total Penta	2,690	pg/g	0	0	0	B
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	Total Hexa-	1,710	pg/g	0	0	0	B
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	Total Hepta	5,040	pg/g	0	0	0	B
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	Total Octa-	3,210	pg/g	0	0	0	B
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	Total Nona-	-	pg/g	2420	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	Total Deca-	-	pg/g	32000	0	0	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	13C-BDE-2	35,500	pg/g	0		63.8	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	13C-BDE-1	39,500	pg/g	0		71.1	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	13C-BDE-2	39,700	pg/g	0		71.4	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	13C-BDE-7	46,600	pg/g	0		84	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	13C-BDE-5	37,000	pg/g	0		66.5	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	13C-BDE-1	39,700	pg/g	0		71.5	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	13C-BDE-1	57,000	pg/g	0		103	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	13C-BDE-1	53,000	pg/g	0		95.5	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	13C-BDE-1	68,000	pg/g	0		122	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	13C-BDE-1	56,600	pg/g	0		102	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	13C-BDE-1	83,800	pg/g	0		75.4	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	13C-BDE-2	23,000	pg/g	0		20.7	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	13C-BDE-2	11,400	pg/g	0		4.11 H	
27342	2000-2005	24/02/2006	Solid	EPA Method 1614	07/03/2006	0.45 L	13C-BDE-1	62,300	pg/g	0		112	

Appendix F – E-Waste Contacting Experiments

Table F.1 (continued) Raw data for crushed e-waste analysis (pg/g). Analyzed by Vista Analytical

Alta Project	Sample ID	Date Sampled	Matrix	Method	Date Extracted	Sample Size	Analyte	Concentration	Report Units	Detection	EMPC	%Recovery	Qualifiers
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-1	1,570	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-2	881	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-3	4,080	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-7	3,600	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-8/11	2,710	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-10	41	pg/g	0	0	0	J
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-12/13	1,870	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-15	3,660	pg/g	0	0	0	B
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-17	7,680	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-25	2,040	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-28/33	11,800	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-32	523	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-35	1,110	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-37	937	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-30	120	pg/g	0	0	0	J
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-47	104,000	pg/g	0	0	0	B
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-49	13,100	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-66	1,000	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-71	16,500	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-75	519	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-77	1,750	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-85	3,600,000	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-99	5,360,000	pg/g	0	0	0	B
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-100	413,000,000	pg/g	0	0	0	B
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-116	71,900,000	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-119	5,440,000	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-126	4,210	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-138	17,800,000	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-153	367,000,000	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-154	37,400,000	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-155	89,100	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-156	-	pg/g	178000	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-166	-	pg/g	268000	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-181	192,000	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-183	464,000,000	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-190	24,800,000	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-197	909,000,000	pg/g	0	0	0	B
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-203	361,000,000	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-207	608,000,000	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	BDE-209	214,000,000	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	Total Monc	6,530	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	Total Di-BI	13,200	pg/g	0	0	0	B
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	Total Tri-B	29,000	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	Total Tetra-	154,000	pg/g	0	0	0	B
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	Total Penta	515,000,000	pg/g	0	0	0	B
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	Total Hexa-	435,000,000	pg/g	0	0	0	B
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	Total Hepta	520,000,000	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	Total Octa-	1,710,000,000	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	Total Nona-	638,000,000	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	Total Deca-	214,000,000	pg/g	0	0	0	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	13C-BDE-3	15,100	pg/g	0		62.7	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	13C-BDE-1	22,000	pg/g	0		91.5	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	13C-BDE-2	20,800	pg/g	0		86.3	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	13C-BDE-7	22,900	pg/g	0		95.2	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	13C-BDE-5	26,000	pg/g	0		108	
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	13C-BDE-1 NA		pg/g	0	NA		
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	13C-BDE-1 NA		pg/g	0	NA		
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	13C-BDE-1 NA		pg/g	0	NA		
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	13C-BDE-1 NA		pg/g	0	NA		
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	13C-BDE-1 NA		pg/g	0	NA		
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	13C-BDE-1 NA		pg/g	0	NA		
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	13C-BDE-2 NA		pg/g	0	NA		
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	13C-BDE-2 NA		pg/g	0	NA		
27342	COMPOSITE		Solid	EPA Method 1614	07/03/2006	1.04 L	13C-BDE-1 NA		pg/g	0	NA		H

Appendix F – E-Waste Contacting Experiments

Table F.1 (concluded) Raw data for crushed e-waste analysis (pg/g). Analyzed by Vista Analytical

Alta Project	Sample ID	Date Sampled	Matrix	Method	Date Extracted	Sample Size	Analyte	Concentration	Report Units	Detection	EMPC	%Recovery	Qualifiers
27342	EPA Method 1614	07/03/2006	1.L	BDE-1	0 pg/g	168	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-2	0 pg/g	118	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-3	0 pg/g	105	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-7	0 pg/g	10.9	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-8/11	0 pg/g	8.16	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-10	0 pg/g	10.2	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-12/13	0 pg/g	6.33	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-15	24.6 pg/g	0	0	0	J				
27342	EPA Method 1614	07/03/2006	1.L	BDE-17	0 pg/g	17.4	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-25	0 pg/g	31.4	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-28/33	0 pg/g	20.3	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-32	0 pg/g	20.1	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-35	0 pg/g	15.2	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-37	0 pg/g	14.2	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-30	0 pg/g	22.9	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-47	395 pg/g	0	0	0	J				
27342	EPA Method 1614	07/03/2006	1.L	BDE-49	0 pg/g	25.2	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-66	0 pg/g	29.2	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-71	0 pg/g	24.9	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-75	0 pg/g	19	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-77	0 pg/g	16.9	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-85	0 pg/g	41.8	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-99	837 pg/g	0	0	0	J				
27342	EPA Method 1614	07/03/2006	1.L	BDE-100	192 pg/g	0	0	0	J				
27342	EPA Method 1614	07/03/2006	1.L	BDE-116	0 pg/g	76.3	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-119	0 pg/g	36.9	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-126	0 pg/g	34.1	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-138	0 pg/g	48.1	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-153	177 pg/g	0	0	0	J				
27342	EPA Method 1614	07/03/2006	1.L	BDE-154	90.2 pg/g	0	0	0	J				
27342	EPA Method 1614	07/03/2006	1.L	BDE-155	0 pg/g	22.5	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-156	0 pg/g	82.5	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-166	0 pg/g	70.9	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-181	0 pg/g	91.6	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-183	414 pg/g	0	0	0	J				
27342	EPA Method 1614	07/03/2006	1.L	BDE-190	0 pg/g	121	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-197	219 pg/g	0	0	0	J				
27342	EPA Method 1614	07/03/2006	1.L	BDE-203	0 pg/g	108	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-207	0 pg/g	455	0	0					
27342	EPA Method 1614	07/03/2006	1.L	BDE-209	0 pg/g	2720	0	0					
27342	EPA Method 1614	07/03/2006	1.L	Total Mono-BD	0 pg/g	125	0	0					
27342	EPA Method 1614	07/03/2006	1.L	Total Di-BDE	24.6 pg/g	0	0	0					
27342	EPA Method 1614	07/03/2006	1.L	Total Tri-BDE	0 pg/g	19.1	0	0					
27342	EPA Method 1614	07/03/2006	1.L	Total Tetra-BD	395 pg/g	0	0	0					
27342	EPA Method 1614	07/03/2006	1.L	Total Penta-BD	1030 pg/g	0	0	0					
27342	EPA Method 1614	07/03/2006	1.L	Total Hexa-BD	268 pg/g	0	0	0					
27342	EPA Method 1614	07/03/2006	1.L	Total Hepta-BD	414 pg/g	0	0	0					
27342	EPA Method 1614	07/03/2006	1.L	Total Octa-BD	219 pg/g	0	0	0					
27342	EPA Method 1614	07/03/2006	1.L	Total Nona-BD	0 pg/g	455	0	0					
27342	EPA Method 1614	07/03/2006	1.L	Total Deca-BD	0 pg/g	2720	0	0					
27342	EPA Method 1614	07/03/2006	1.L	13C-BDE-3	23900 pg/g	0	95.7						
27342	EPA Method 1614	07/03/2006	1.L	13C-BDE-15	29900 pg/g	0	120						
27342	EPA Method 1614	07/03/2006	1.L	13C-BDE-28	29500 pg/g	0	118						
27342	EPA Method 1614	07/03/2006	1.L	13C-BDE-77	24400 pg/g	0	97.6						
27342	EPA Method 1614	07/03/2006	1.L	13C-BDE-99	25800 pg/g	0	103						
27342	EPA Method 1614	07/03/2006	1.L	13C-BDE-100	27500 pg/g	0	110						
27342	EPA Method 1614	07/03/2006	1.L	13C-BDE-138	25400 pg/g	0	102						
27342	EPA Method 1614	07/03/2006	1.L	13C-BDE-153	26500 pg/g	0	106						
27342	EPA Method 1614	07/03/2006	1.L	13C-BDE-154	29100 pg/g	0	116						
27342	EPA Method 1614	07/03/2006	1.L	13C-BDE-183	25000 pg/g	0	100						
27342	EPA Method 1614	07/03/2006	1.L	13C-BDE-197	45000 pg/g	0	90						
27342	EPA Method 1614	07/03/2006	1.L	13C-BDE-207	35800 pg/g	0	71.5						
27342	EPA Method 1614	07/03/2006	1.L	13C-BDE-209	53700 pg/g	0	42.9						
27342	EPA Method 1614	07/03/2006	1.L	13C-BDE-126	26800 pg/g	0	107						
27342	EPA Method 1614	07/03/2006	1.L	BDE-1	9.72 ng/mL	0	97.2						
27342	EPA Method 1614	07/03/2006	1.L	BDE-2	9.94 ng/mL	0	99.4						
27342	EPA Method 1614	07/03/2006	1.L	BDE-3	10 ng/mL	0	100						
27342	EPA Method 1614	07/03/2006	1.L	BDE-7	8.76 ng/mL	0	87.6						
27342	EPA Method 1614	07/03/2006	1.L	BDE-8/11	20.3 ng/mL	0	101.5						
27342	EPA Method 1614	07/03/2006	1.L	BDE-10	8.56 ng/mL	0	85.6						
27342	EPA Method 1614	07/03/2006	1.L	BDE-12/13	21 ng/mL	0	105						
27342	EPA Method 1614	07/03/2006	1.L	BDE-15	10.1 ng/mL	0	101						
27342	EPA Method 1614	07/03/2006	1.L	BDE-17	8.36 ng/mL	0	83.6						
27342	EPA Method 1614	07/03/2006	1.L	BDE-25	13.2 ng/mL	0	132						
27342	EPA Method 1614	07/03/2006	1.L	BDE-28/33	19.6 ng/mL	0	98						
27342	EPA Method 1614	07/03/2006	1.L	BDE-32	10.6 ng/mL	0	106						
27342	EPA Method 1614	07/03/2006	1.L	BDE-35	10 ng/mL	0	100						
27342	EPA Method 1614	07/03/2006	1.L	BDE-37	9.63 ng/mL	0	96.3						
27342	EPA Method 1614	07/03/2006	1.L	BDE-30	9.5 ng/mL	0	95						
27342	EPA Method 1614	07/03/2006	1.L	BDE-47	11.7 ng/mL	0	117						
27342	EPA Method 1614	07/03/2006	1.L	BDE-49	10.6 ng/mL	0	106						
27342	EPA Method 1614	07/03/2006	1.L	BDE-66	10.4 ng/mL	0	104						
27342	EPA Method 1614	07/03/2006	1.L	BDE-71	11.4 ng/mL	0	114						
27342	EPA Method 1614	07/03/2006	1.L	BDE-75	10.9 ng/mL	0	109						
27342	EPA Method 1614	07/03/2006	1.L	BDE-77	10.1 ng/mL	0	101						
27342	EPA Method 1614	07/03/2006	1.L	BDE-85	18.3 ng/mL	0	183						
27342	EPA Method 1614	07/03/2006	1.L	BDE-99	20.9 ng/mL	0	209						
27342	EPA Method 1614	07/03/2006	1.L	BDE-100	20.4 ng/mL	0	102						
27342	EPA Method 1614	07/03/2006	1.L	BDE-116	18.2 ng/mL	0	91						
27342	EPA Method 1614	07/03/2006	1.L	BDE-119	19.7 ng/mL	0	98.5						
27342	EPA Method 1614	07/03/2006	1.L	BDE-126	18.9 ng/mL	0	94.5						
27342	EPA Method 1614	07/03/2006	1.L	BDE-138	17.9 ng/mL	0	89.5						
27342	EPA Method 1614	07/03/2006	1.L	BDE-153	20.4 ng/mL	0	102						
27342	EPA Method 1614	07/03/2006	1.L	BDE-154	20.7 ng/mL	0	103.5						
27342	EPA Method 1614	07/03/2006	1.L	BDE-155	19.1 ng/mL	0	95.5						
27342	EPA Method 1614	07/03/2006	1.L	BDE-156	18.7 ng/mL	0	93.5						
27342	EPA Method 1614	07/03/2006	1.L	BDE-166	22.2 ng/mL	0	111						
27342	EPA Method 1614	07/03/2006	1.L	BDE-181	19 ng/mL	0	95						
27342	EPA Method 1614	07/03/2006	1.L	BDE-183	20.7 ng/mL	0	103.5						
27342	EPA Method 1614	07/03/2006	1.L	BDE-197	39.9 ng/mL	0	99.75						
27342	EPA Method 1614	07/03/2006	1.L	BDE-203	37.1 ng/mL	0	92.75						
27342	EPA Method 1614	07/03/2006	1.L	BDE-207	41.4 ng/mL	0	103.5						
27342	EPA Method 1614	07/03/2006	1.L	BDE-209	205 ng/mL	0	102.5						
27342	EPA Method 1614	07/03/2006	1.L	13C-BDE-3	93.7 ng/mL	0	93.7						
27342	EPA Method 1614	07/03/2006	1.L	13C-BDE-15	115 ng/mL	0	115						
27342	EPA Method 1614	07/03/2006	1.L	13C-BDE-28	118 ng/mL	0	118						
27342	EPA Method 1614	07/03/2006	1.L	13C-BDE-77	99.8 ng/mL	0	99.8						
27342	EPA Method 1614	07/03/2006	1.L	13C-BDE-99	113 ng/mL	0	113						
27342	EPA Method 1614	07/03/2006	1.L	13C-BDE-100	116 ng/mL	0	116						
27342	EPA Method 1614	07/03/2006	1.L	13C-BDE-138	103 ng/mL	0	103						
27342	EPA Method 1614	07/03/2006	1.L	13C-BDE-153	106 ng/mL	0	106						
27342	EPA Method 1614	07/03/2006	1.L	13C-BDE-154	111 ng/mL	0	111						

Appendix F – E-Waste Contacting Experiments

Table F.2 Raw data for the 1-24-168 h experiment (pg/L). Analyzed by Vista Analytical

Alta Project	Sample ID	Matrix	Date Extracted	Sample Size	Sample Size	Date Analyzed	CAS Number	Analyte	Concentration	Units	Qualifiers
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-1	BDE-1	-	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-2	BDE-2	-	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-3	BDE-3	-	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-7	BDE-7	135	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-8/11	BDE-8/11	74	pg/L	J
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-10	BDE-10	-	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-12/13	BDE-12/13	58	pg/L	J
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-15	BDE-15	119	pg/L	B
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-17	BDE-17	39	pg/L	J,B
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-25	BDE-25	290	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	41318-75-6	BDE-28/33	297	pg/L	B
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-32	BDE-32	-	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-35	BDE-35	-	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-37	BDE-37	31	pg/L	J
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-30	BDE-30	-	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	5436-43-1	BDE-47	3,040	pg/L	B
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-49	BDE-49	388	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-66	BDE-66	529	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-71	BDE-71	336	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-75	BDE-75	52	pg/L	J
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	93703-48-1	BDE-77	122	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	182346-21-0	BDE-85	1,420	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-99	BDE-99	36,500	pg/L	B
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-100	BDE-100	4,410	pg/L	B
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-116	BDE-116	-	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-119	BDE-119	2,390	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-126	BDE-126	-	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-138	BDE-138	608,000	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		26/03/2006	68631-49-2	BDE-153	10,400,000	pg/L	B,*
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-154	BDE-154	1,090,000	pg/L	B
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-155	BDE-155	-	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-156	BDE-156	2,580	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-166	BDE-166	-	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-181	BDE-181	14,000	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		26/03/2006	BDE-183	BDE-183	31,200,000	pg/L	*
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-190	BDE-190	2,390,000	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		26/03/2006	BDE-197	BDE-197	24,900,000	pg/L	B,*
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	337513-72-1	BDE-203	12,500,000	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		26/03/2006	BDE-207	BDE-207	15,100,000	pg/L	B,*
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	1163-19-5	BDE-209	13,200,000	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	101-55-3	Total Mono-BDE	-	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	2050-47-7	Total Di-BDE	386	pg/L	B
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	49690-940	Total Tri-BDE	657	pg/L	B
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	40088-47-9	Total Tetra-BDE	4,460	pg/L	B
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	32534-81-9	Total Penta-BDE	97,900	pg/L	B
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	36483-60-0	Total Hexa-BDE	12,600,000	pg/L	B,*
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	68928-80-3	Total Hepta-BDE	36,000,000	pg/L	B,*
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	32536-52-0	Total Octa-BDE	51,200,000	pg/L	B,*
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	63936-56-1	Total Nona-BDE	15,100,000	pg/L	B,*
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	Total Deca-BDE	Total Deca-BDE	13,200,000	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	13C-BDE-3	13C-BDE-3	6,640	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	13C-BDE-15	13C-BDE-15	10,400	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	13C-BDE-28	13C-BDE-28	9,300	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	13C-BDE-77	13C-BDE-77	10,600	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	13C-BDE-99	13C-BDE-99	13,200	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	13C-BDE-100	13C-BDE-100	11,500	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	13C-BDE-138	13C-BDE-138	9,620	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		26/03/2006	13C-BDE-153	13C-BDE-153	12,500	pg/L	*
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	13C-BDE-154	13C-BDE-154	8,210	pg/L	
	27306 33A-1	Aqueous	23/03/2006	0.5 L		26/03/2006	13C-BDE-183	13C-BDE-183	20,700	pg/L	*
	27306 33A-1	Aqueous	23/03/2006	0.5 L		26/03/2006	13C-BDE-197	13C-BDE-197	31,100	pg/L	*
	27306 33A-1	Aqueous	23/03/2006	0.5 L		26/03/2006	13C-BDE-207	13C-BDE-207	36,100	pg/L	*
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	13C-BDE-209	13C-BDE-209	115,000	pg/L	*
	27306 33A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	13C-BDE-126	13C-BDE-126	11,400	pg/L	

Appendix F – E-Waste Contacting Experiments

Table F.2 (continued) Raw data for the 1-24-168 h experiment (pg/L). Analyzed by Vista Analytical

Alta Project	Sample ID	Matrix	Date Extracted	Sample Size	Sample Size	Date Analyzed	CAS Number	Analyte	Concentration	Units	Qualifiers
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-1	BDE-1	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-2	BDE-2	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-3	BDE-3	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-7	BDE-7	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-8/11	BDE-8/11	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-10	BDE-10	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-12/13	BDE-12/13	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-15	BDE-15	20	pg/L	J,B
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-17	BDE-17	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-25	BDE-25	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	41318-75-6	BDE-28/33	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-32	BDE-32	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-35	BDE-35	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-37	BDE-37	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-30	BDE-30	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	5436-43-1	BDE-47	274	pg/L	B
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-49	BDE-49	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-66	BDE-66	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-71	BDE-71	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-75	BDE-75	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	93703-48-1	BDE-77	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	182346-21-0	BDE-85	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-99	BDE-99	429	pg/L	B
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-100	BDE-100	73	pg/L	J,B
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-116	BDE-116	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-119	BDE-119	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-126	BDE-126	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-138	BDE-138	269	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	68631-49-2	BDE-153	3,270	pg/L	B
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-154	BDE-154	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-155	BDE-155	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-156	BDE-156	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-166	BDE-166	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-181	BDE-181	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-183	BDE-183	20,500	pg/L	B
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-190	BDE-190	1,500	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-197	BDE-197	16,200	pg/L	B
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	337513-72-1	BDE-203	6,160	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	BDE-207	BDE-207	14,200	pg/L	B
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	1163-19-5	BDE-209	17,500	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	101-55-3	Total Mono- <i>i</i>	-	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	2050-47-7	Total Di-BD <i>i</i>	20	pg/L	B
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	49690-940	Total Tri-BD	33	pg/L	B
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	40088-47-9	Total Tetra-F	274	pg/L	B
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	32534-81-9	Total Penta-F	502	pg/L	B
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	36483-60-0	Total Hexa-F	4,290	pg/L	B
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	68928-80-3	Total Hepta- <i>i</i>	23,300	pg/L	B
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	32536-52-0	Total Octa-B	30,000	pg/L	B
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	63936-56-1	Total Nona-F	15,100	pg/L	B
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	Total Deca-BDE	Total Deca-F	17,500	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	13C-BDE-3	13C-BDE-3	6,670	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	13C-BDE-15	13C-BDE-15	10,400	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	13C-BDE-28	13C-BDE-28	12,200	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	13C-BDE-77	13C-BDE-77	10,400	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	13C-BDE-99	13C-BDE-99	14,000	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	13C-BDE-100	13C-BDE-10	12,700	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	13C-BDE-138	13C-BDE-13	8,600	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	13C-BDE-153	13C-BDE-15	8,880	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	13C-BDE-154	13C-BDE-15	8,760	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	13C-BDE-183	13C-BDE-18	7,990	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	13C-BDE-197	13C-BDE-19	11,800	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	13C-BDE-207	13C-BDE-20	12,700	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	13C-BDE-209	13C-BDE-20	22,700	pg/L	
	27306 34A-1	Aqueous	23/03/2006	0.495 L		25/03/2006	13C-BDE-126	13C-BDE-12	12,400	pg/L	

Appendix F – E-Waste Contacting Experiments

Table F.2 (continued) Raw data for the 1-24-168 h experiment (pg/L). Analyzed by Vista Analytical

Alta Project	Sample ID	Matrix	Date Extracted	Sample Size	Sample Size	Date Analyzed	CAS Number	Analyte	Concentration	Units	Qualifiers
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-1	BDE-1	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-2	BDE-2	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-3	BDE-3	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-7	BDE-7	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-8/11	BDE-8/11	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-10	BDE-10	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-12/13	BDE-12/13	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-15	BDE-15	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-17	BDE-17	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-25	BDE-25	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	41318-75-6	BDE-28/33	44	pg/L	J,B
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-32	BDE-32	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-35	BDE-35	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-37	BDE-37	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-30	BDE-30	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	5436-43-1	BDE-47	344	pg/L	B
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-49	BDE-49	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-66	BDE-66	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-71	BDE-71	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-75	BDE-75	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	93703-48-1	BDE-77	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	182346-21-0	BDE-85	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-99	BDE-99	593	pg/L	B
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-100	BDE-100	95	pg/L	J,B
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-116	BDE-116	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-119	BDE-119	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-126	BDE-126	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-138	BDE-138	50	pg/L	J
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	68631-49-2	BDE-153	666	pg/L	B
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-154	BDE-154	126	pg/L	J,B
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-155	BDE-155	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-156	BDE-156	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-166	BDE-166	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-181	BDE-181	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-183	BDE-183	2,620	pg/L	B
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-190	BDE-190	161	pg/L	J
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-197	BDE-197	1,720	pg/L	B

Alta Project	Sample ID	Matrix	Date Extracted	Sample Size	Sample Size	Date Analyzed	CAS Number	Analyte	Concentration	Units	Qualifiers
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	337513-72-1	BDE-203	666	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	BDE-207	BDE-207	2,140	pg/L	B
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	1163-19-5	BDE-209	13,600	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	101-55-3	Total Mono-BD	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	2050-47-7	Total Di-BD	-	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	49690-940	Total Tri-BD	44	pg/L	B
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	40088-47-9	Total Tetra-F	344	pg/L	B
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	32534-81-9	Total Penta-I	688	pg/L	B
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	36483-60-0	Total Hexa-F	792	pg/L	B
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	68928-80-3	Total Hepta-I	2,950	pg/L	B
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	32536-52-0	Total Octa-B	3,260	pg/L	B
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	63936-56-1	Total Nona-I	2,410	pg/L	B
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	Total Deca-BDE	Total Deca-F	13,600	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	13C-BDE-3	13C-BDE-3	5,970	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	13C-BDE-15	13C-BDE-15	9,330	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	13C-BDE-28	13C-BDE-28	11,100	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	13C-BDE-77	13C-BDE-77	11,500	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	13C-BDE-99	13C-BDE-99	14,500	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	13C-BDE-100	13C-BDE-10	12,400	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	13C-BDE-138	13C-BDE-13	9,410	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	13C-BDE-153	13C-BDE-15	9,220	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	13C-BDE-154	13C-BDE-15	9,240	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	13C-BDE-183	13C-BDE-18	8,940	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	13C-BDE-197	13C-BDE-19	12,800	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	13C-BDE-207	13C-BDE-20	13,800	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	13C-BDE-209	13C-BDE-20	26,400	pg/L	
	27306 35A-1	Aqueous	23/03/2006	0.5 L		25/03/2006	13C-BDE-126	13C-BDE-12	12,300	pg/L	

Appendix F – E-Waste Contacting Experiments

Table F.2 (continued) Raw data for the 1-24-168 h experiment (pg/L). Analyzed by Vista Analytical

Alta Project	Sample ID	Matrix	Date Extracted	Sample Size	Sample Size	Date Analyzed	CAS Number	Analyte	Concentration	Units	Qualifiers
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-1	BDE-1	286	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-2	BDE-2	-	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-3	BDE-3	358	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-7	BDE-7	279	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-8/11	BDE-8/11	183	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-10	BDE-10	-	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-12/13	BDE-12/13	143	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-15	BDE-15	263	pg/L	B
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-17	BDE-17	72	pg/L	J,B
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-25	BDE-25	622	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	41318-75-6	BDE-28/33	566	pg/L	B
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-32	BDE-32	94	pg/L	J
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-35	BDE-35	44	pg/L	J
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-37	BDE-37	-	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-30	BDE-30	-	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	5436-43-1	BDE-47	96	pg/L	J,B
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-49	BDE-49	535	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-66	BDE-66	-	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-71	BDE-71	-	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-75	BDE-75	83	pg/L	J
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	93703-48-1	BDE-77	-	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	182346-21-0	BDE-85	1,370	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-99	BDE-99	46,700	pg/L	B
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-100	BDE-100	22,300	pg/L	B
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-116	BDE-116	3,490	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-119	BDE-119	-	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-126	BDE-126	-	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-138	BDE-138	872,000	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		26/03/2006	68631-49-2	BDE-153	16,400,000	pg/L	*
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-154	BDE-154	1,600,000	pg/L	B
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-155	BDE-155	-	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-156	BDE-156	-	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-166	BDE-166	-	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-181	BDE-181	2,430,000	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		26/03/2006	BDE-183	BDE-183	37,200,000	pg/L	*
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	BDE-190	BDE-190	3,200,000	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		26/03/2006	BDE-197	BDE-197	29,500,000	pg/L	*
	27306 36A-24	Aqueous	23/03/2006	0.462 L		26/03/2006	337513-72-1	BDE-203	11,800,000	pg/L	*
	27306 36A-24	Aqueous	23/03/2006	0.462 L		26/03/2006	BDE-207	BDE-207	18,900,000	pg/L	*
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	1163-19-5	BDE-209	9,800,000	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	101-55-3	Total Mono-BDE	286	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	2050-47-7	Total Di-BDE	941	pg/L	B
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	49690-940	Total Tri-BDE	1,580	pg/L	B
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	40088-47-9	Total Tetra-BDE	7,460	pg/L	B
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	32534-81-9	Total Penta-BDE	111,000	pg/L	B
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	36483-60-0	Total Hexa-BDE	19,400,000	pg/L	B,*
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	68928-80-3	Total Hepta-BDE	43,600,000	pg/L	B,*
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	32536-52-0	Total Octa-BDE	56,800,000	pg/L	B,*
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	63936-56-1	Total Nona-BDE	20,800,000	pg/L	B,*
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	Total Deca-BDE	Total Deca-BDE	9,800,000	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	13C-BDE-3	13C-BDE-3	4,970	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	13C-BDE-15	13C-BDE-15	6,890	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	13C-BDE-28	13C-BDE-28	8,550	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	13C-BDE-77	13C-BDE-77	10,400	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	13C-BDE-99	13C-BDE-99	11,600	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	13C-BDE-100	13C-BDE-100	10,400	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	13C-BDE-138	13C-BDE-138	11,300	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		26/03/2006	13C-BDE-153	13C-BDE-153	12,400	pg/L	*
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	13C-BDE-154	13C-BDE-154	9,790	pg/L	
	27306 36A-24	Aqueous	23/03/2006	0.462 L		26/03/2006	13C-BDE-183	13C-BDE-183	25,100	pg/L	*
	27306 36A-24	Aqueous	23/03/2006	0.462 L		26/03/2006	13C-BDE-197	13C-BDE-197	36,000	pg/L	*
	27306 36A-24	Aqueous	23/03/2006	0.462 L		26/03/2006	13C-BDE-207	13C-BDE-207	41,200	pg/L	*
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	13C-BDE-209	13C-BDE-209	182,000	pg/L	*
	27306 36A-24	Aqueous	23/03/2006	0.462 L		25/03/2006	13C-BDE-126	13C-BDE-126	14,100	pg/L	

Appendix F – E-Waste Contacting Experiments

Table F.2 (continued) Raw data for the 1-24-168 h experiment (pg/L). Analyzed by Vista Analytical

Alta Project	Sample ID	Matrix	Date Extracted	Sample Size	Sample Size	Date Analyzed	CAS Number	Analyte	Concentration	Units	Qualifiers
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-1	BDE-1	-	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-2	BDE-2	-	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-3	BDE-3	-	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-7	BDE-7	-	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-8/11	BDE-8/11	-	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-10	BDE-10	-	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-12/13	BDE-12/13	-	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-15	BDE-15	15	pg/L	J,B
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-17	BDE-17	-	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-25	BDE-25	-	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	41318-75-6	BDE-28/33	46	pg/L	J,B
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-32	BDE-32	-	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-35	BDE-35	-	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-37	BDE-37	-	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-30	BDE-30	-	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	5436-43-1	BDE-47	376	pg/L	B
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-49	BDE-49	-	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-66	BDE-66	-	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-71	BDE-71	-	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-75	BDE-75	-	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	93703-48-1	BDE-77	-	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	182346-21-0	BDE-85	-	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-99	BDE-99	631	pg/L	B
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-100	BDE-100	108	pg/L	J,B
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-116	BDE-116	-	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-119	BDE-119	-	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-126	BDE-126	-	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-138	BDE-138	637	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	68631-49-2	BDE-153	7,010	pg/L	B
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-154	BDE-154	761	pg/L	B
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-155	BDE-155	-	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-156	BDE-156	-	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-166	BDE-166	-	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-181	BDE-181	-	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-183	BDE-183	48,800	pg/L	B
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-190	BDE-190	3,470	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-197	BDE-197	39,700	pg/L	B
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	337513-72-1	BDE-203	16,700	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	BDE-207	BDE-207	36,000	pg/L	B
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	1163-19-5	BDE-209	29,000	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	101-55-3	Total Mono- <i>i</i>	-	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	2050-47-7	Total Di-BD <i>i</i>	15	pg/L	B
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	49690-940	Total Tri-BD	46	pg/L	B
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	40088-47-9	Total Tetra-F	447	pg/L	B
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	32534-81-9	Total Penta-I	739	pg/L	B
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	36483-60-0	Total Hexa-F	8,670	pg/L	B
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	68928-80-3	Total Hepta- <i>i</i>	56,400	pg/L	B
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	32536-52-0	Total Octa-B	76,700	pg/L	B
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	63936-56-1	Total Nona-F	38,800	pg/L	B
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	Total Deca-BDE	Total Deca-F	29,000	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	13C-BDE-3	13C-BDE-3	5,940	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	13C-BDE-15	13C-BDE-15	10,000	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	13C-BDE-28	13C-BDE-28	9,460	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	13C-BDE-77	13C-BDE-77	10,000	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	13C-BDE-99	13C-BDE-99	13,000	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	13C-BDE-100	13C-BDE-10	11,400	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	13C-BDE-138	13C-BDE-13	8,180	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	13C-BDE-153	13C-BDE-15	7,750	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	13C-BDE-154	13C-BDE-15	7,570	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	13C-BDE-183	13C-BDE-18	8,080	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	13C-BDE-197	13C-BDE-19	11,400	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	13C-BDE-207	13C-BDE-20	13,100	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	13C-BDE-209	13C-BDE-20	25,400	pg/L	
	27306 37A-24	Aqueous	23/03/2006	0.499 L		25/03/2006	13C-BDE-126	13C-BDE-12	10,200	pg/L	

Appendix F – E-Waste Contacting Experiments

Table F.2 (continued) Raw data for the 1-24-168 h experiment (pg/L). Analyzed by Vista Analytical

Alta Project	Sample ID	Matrix	Date Extracted	Sample Size	Sample Size	Date Analyzed	CAS Number	Analyte	Concentration	Units	Qualifiers
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-1	BDE-1	-	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-2	BDE-2	-	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-3	BDE-3	-	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-7	BDE-7	-	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-8/11	BDE-8/11	-	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-10	BDE-10	-	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-12/13	BDE-12/13	-	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-15	BDE-15	19	pg/L	J,B
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-17	BDE-17	-	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-25	BDE-25	22	pg/L	J
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	41318-75-6	BDE-28/33	-	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-32	BDE-32	-	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-35	BDE-35	-	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-37	BDE-37	-	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-30	BDE-30	-	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	5436-43-1	BDE-47	911	pg/L	B
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-49	BDE-49	-	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-66	BDE-66	-	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-71	BDE-71	-	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-75	BDE-75	-	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	93703-48-1	BDE-77	-	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	182346-21-0	BDE-85	62	pg/L	J
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-99	BDE-99	1,330	pg/L	B
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-100	BDE-100	233	pg/L	B
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-116	BDE-116	-	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-119	BDE-119	-	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-126	BDE-126	-	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-138	BDE-138	160	pg/L	J
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	68631-49-2	BDE-153	2,010	pg/L	B
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-154	BDE-154	344	pg/L	B
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-155	BDE-155	-	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-156	BDE-156	-	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-166	BDE-166	-	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-181	BDE-181	-	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-183	BDE-183	8,510	pg/L	B
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-190	BDE-190	539	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-197	BDE-197	-	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	337513-72-1	BDE-203	1,990	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	BDE-207	BDE-207	4,560	pg/L	B
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	1163-19-5	BDE-209	27,100	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	101-55-3	Total Mono- <i>i</i>	-	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	2050-47-7	Total Di-BD _i	19	pg/L	B
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	49690-940	Total Tri-BD	99	pg/L	B
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	40088-47-9	Total Tetra-F	1,100	pg/L	B
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	32534-81-9	Total Penta-I	1,650	pg/L	B
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	36483-60-0	Total Hexa-F	2,580	pg/L	B
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	68928-80-3	Total Hepta- <i>i</i>	9,500	pg/L	B
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	32536-52-0	Total Octa-B	4,420	pg/L	B
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	63936-56-1	Total Nona-F	5,290	pg/L	B
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	Total Deca-BDE	Total Deca-F	27,100	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	13C-BDE-3	13C-BDE-3	6,810	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	13C-BDE-15	13C-BDE-15	10,700	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	13C-BDE-28	13C-BDE-28	12,800	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	13C-BDE-77	13C-BDE-77	13,200	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	13C-BDE-99	13C-BDE-99	16,600	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	13C-BDE-100	13C-BDE-100	13,800	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	13C-BDE-138	13C-BDE-138	10,500	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	13C-BDE-153	13C-BDE-153	10,300	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	13C-BDE-154	13C-BDE-154	10,200	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	13C-BDE-183	13C-BDE-183	10,600	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	13C-BDE-197	13C-BDE-197	14,800	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	13C-BDE-207	13C-BDE-207	16,700	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	13C-BDE-209	13C-BDE-209	37,600	pg/L	
	27306 38A-24	Aqueous	23/03/2006	0.45 L		25/03/2006	13C-BDE-126	13C-BDE-126	13,000	pg/L	

Appendix F – E-Waste Contacting Experiments

Table F.2 (continued) Raw data for the 1-24-168 h experiment (pg/L). Analyzed by Vista Analytical

Alta Project	Sample ID	Matrix	Date Extracted	Sample Size	Sample Size	Date Analyzed	CAS Number	Analyte	Concentration	Units	Qualifiers
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-1	BDE-1	-	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-2	BDE-2	-	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-3	BDE-3	-	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-7	BDE-7	1,010	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-8/11	BDE-8/11	635	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-10	BDE-10	17	pg/L	J
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-12/13	BDE-12/13	491	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-15	BDE-15	850	pg/L	B
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-17	BDE-17	-	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-25	BDE-25	351	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	41318-75-6	BDE-28/33	1,600	pg/L	B
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-32	BDE-32	93	pg/L	J
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-35	BDE-35	169	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-37	BDE-37	166	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-30	BDE-30	27	pg/L	J
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	5436-43-1	BDE-47	6,370	pg/L	B
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-49	BDE-49	-	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-66	BDE-66	-	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-71	BDE-71	203	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-75	BDE-75	81	pg/L	J
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	93703-48-1	BDE-77	253	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	182346-21-0	BDE-85	1,300	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-99	BDE-99	45,000	pg/L	B
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-100	BDE-100	4,590	pg/L	B
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-116	BDE-116	188	pg/L	J
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-119	BDE-119	35,400	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-126	BDE-126	118	pg/L	J
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-138	BDE-138	486,000	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		26/03/2006	68631-49-2	BDE-153	9,040,000	pg/L	B,*
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-154	BDE-154	1,110,000	pg/L	B
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-155	BDE-155	-	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-156	BDE-156	1,800	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-166	BDE-166	-	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-181	BDE-181	9,840	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		26/03/2006	BDE-183	BDE-183	21,700,000	pg/L	*
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-190	BDE-190	1,510,000	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-197	BDE-197	7,890,000	pg/L	B
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	337513-72-1	BDE-203	4,340,000	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	BDE-207	BDE-207	3,980,000	pg/L	B
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	1163-19-5	BDE-209	1,740,000	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	101-55-3	Total Mono-BDE	-	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	2050-47-7	Total Di-BDE	3,380	pg/L	B
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	49690-940	Total Tri-BDE	4,290	pg/L	B
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	40088-47-9	Total Tetra-BDE	10,700	pg/L	B
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	32534-81-9	Total Penta-BDE	121,000	pg/L	B
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	36483-60-0	Total Hexa-BDE	10,900,000	pg/L	B,*
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	68928-80-3	Total Hepta-BDE	25,000,000	pg/L	B,*
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	32536-52-0	Total Octa-BDE	17,000,000	pg/L	B
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	63936-56-1	Total Nona-BDE	4,240,000	pg/L	B
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	Total Deca-BDE	Total Deca-BDE	1,740,000	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	13C-BDE-3	13C-BDE-3	3,720	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	13C-BDE-15	13C-BDE-15	6,570	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	13C-BDE-28	13C-BDE-28	7,770	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	13C-BDE-77	13C-BDE-77	9,330	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	13C-BDE-99	13C-BDE-99	9,880	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	13C-BDE-100	13C-BDE-100	9,400	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	13C-BDE-138	13C-BDE-138	10,900	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		26/03/2006	13C-BDE-153	13C-BDE-153	13,100	pg/L	*
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	13C-BDE-154	13C-BDE-154	10,800	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		26/03/2006	13C-BDE-183	13C-BDE-183	19,800	pg/L	*
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	13C-BDE-197	13C-BDE-197	28,900	pg/L	
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	13C-BDE-207	13C-BDE-207	54,700	pg/L	*
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	13C-BDE-209	13C-BDE-209	112,000	pg/L	*
	27306 39A-168	Aqueous	23/03/2006	0.496 L		25/03/2006	13C-BDE-126	13C-BDE-126	12,100	pg/L	

Appendix F – E-Waste Contacting Experiments

Table F.2 (continued) Raw data for the 1-24-168 h experiment (pg/L). Analyzed by Vista Analytical

Alta Project	Sample ID	Matrix	Date Extracted	Sample Size	Sample Size	Date Analyzed	CAS Number	Analyte	Concentration	Units	Qualifiers
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-1	BDE-1	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-2	BDE-2	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-3	BDE-3	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-7	BDE-7	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-8/11	BDE-8/11	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-10	BDE-10	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-12/13	BDE-12/13	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-15	BDE-15	14	pg/L	J,B
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-17	BDE-17	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-25	BDE-25	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	41318-75-6	BDE-28/33	53	pg/L	J,B
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-32	BDE-32	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-35	BDE-35	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-37	BDE-37	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-30	BDE-30	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	5436-43-1	BDE-47	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-49	BDE-49	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-66	BDE-66	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-71	BDE-71	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-75	BDE-75	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	93703-48-1	BDE-77	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	182346-21-0	BDE-85	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-99	BDE-99	356	pg/L	B
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-100	BDE-100	74	pg/L	J,B
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-116	BDE-116	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-119	BDE-119	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-126	BDE-126	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-138	BDE-138	749	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	68631-49-2	BDE-153	8,570	pg/L	B
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-154	BDE-154	1,060	pg/L	B
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-155	BDE-155	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-156	BDE-156	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-166	BDE-166	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-181	BDE-181	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-183	BDE-183	43,800	pg/L	B
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-190	BDE-190	2,860	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-197	BDE-197	21,100	pg/L	B
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	337513-72-1	BDE-203	8,890	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	BDE-207	BDE-207	15,700	pg/L	B
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	1163-19-5	BDE-209	9,240	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	101-55-3	Total Mono- ^l	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	2050-47-7	Total Di-BD ^l	-	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	49690-940	Total Tri-BD	53	pg/L	B
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	40088-47-9	Total Tetra-E	374	pg/L	B
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	32534-81-9	Total Penta-I	471	pg/L	B
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	36483-60-0	Total Hexa-E	10,800	pg/L	B
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	68928-80-3	Total Hepta- ^l	49,400	pg/L	B
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	32536-52-0	Total Octa-B	40,700	pg/L	B
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	63936-56-1	Total Nona-I	16,700	pg/L	B
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	Total Deca-BDE	Total Deca-E	9,240	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	13C-BDE-3	13C-BDE-3	4,910	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	13C-BDE-15	13C-BDE-15	6,460	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	13C-BDE-28	13C-BDE-28	8,330	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	13C-BDE-77	13C-BDE-77	10,200	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	13C-BDE-99	13C-BDE-99	11,400	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	13C-BDE-100	13C-BDE-10	10,700	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	13C-BDE-138	13C-BDE-13	8,820	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	13C-BDE-153	13C-BDE-15	8,710	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	13C-BDE-154	13C-BDE-15	9,020	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	13C-BDE-183	13C-BDE-18	10,200	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	13C-BDE-197	13C-BDE-19	15,700	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	13C-BDE-207	13C-BDE-20	18,600	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	13C-BDE-209	13C-BDE-20	35,300	pg/L	
	27306 40A-168	Aqueous	23/03/2006	0.497 L		25/03/2006	13C-BDE-126	13C-BDE-12	12,300	pg/L	

Appendix F – E-Waste Contacting Experiments

Table F.2 (concluded) Raw data for the 1-24-168 h experiment (pg/L). Analyzed by Vista Analytical

Alta Project	Sample ID	Matrix	Date Extracted	Sample Size	Sample Size	Date Analyzed	CAS Number	Analyte	Concentration	Units	Qualifiers
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-1	BDE-1	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-2	BDE-2	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-3	BDE-3	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-7	BDE-7	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-8/11	BDE-8/11	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-10	BDE-10	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-12/13	BDE-12/13	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-15	BDE-15	18	pg/L	J,B
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-17	BDE-17	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-25	BDE-25	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	41318-75-6	BDE-28/33	65	pg/L	J,B
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-32	BDE-32	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-35	BDE-35	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-37	BDE-37	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-30	BDE-30	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	5436-43-1	BDE-47	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-49	BDE-49	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-66	BDE-66	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-71	BDE-71	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-75	BDE-75	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	93703-48-1	BDE-77	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	182346-21-0	BDE-85	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-99	BDE-99	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-100	BDE-100	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-116	BDE-116	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-119	BDE-119	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-126	BDE-126	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-138	BDE-138	110	pg/L	J
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	68631-49-2	BDE-153	1,840	pg/L	B
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-154	BDE-154	312	pg/L	B
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-155	BDE-155	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-156	BDE-156	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-166	BDE-166	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-181	BDE-181	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-183	BDE-183	6,720	pg/L	B
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-190	BDE-190	441	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-197	BDE-197	2,990	pg/L	B
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	337513-72-1	BDE-203	1,280	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	BDE-207	BDE-207	2,810	pg/L	B
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	1163-19-5	BDE-209	7,010	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	101-55-3	Total Mono-l	-	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	2050-47-7	Total Di-BDl	18	pg/L	B
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	49690-940	Total Tri-BD	90	pg/L	B
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	40088-47-9	Total Tetra-F	416	pg/L	B
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	32534-81-9	Total Penta-I	461	pg/L	B
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	36483-60-0	Total Hexa-F	2,260	pg/L	B
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	68928-80-3	Total Hepta-l	7,060	pg/L	B
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	32536-52-0	Total Octa-B	5,660	pg/L	B
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	63936-56-1	Total Nona-F	3,030	pg/L	B
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	Total Deca-BDE	Total Deca-F	7,010	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	13C-BDE-3	13C-BDE-3	4,750	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	13C-BDE-15	13C-BDE-15	6,840	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	13C-BDE-28	13C-BDE-28	8,650	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	13C-BDE-77	13C-BDE-77	9,070	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	13C-BDE-99	13C-BDE-99	9,550	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	13C-BDE-100	13C-BDE-10	9,670	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	13C-BDE-138	13C-BDE-13	8,470	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	13C-BDE-153	13C-BDE-15	8,590	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	13C-BDE-154	13C-BDE-15	8,850	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	13C-BDE-183	13C-BDE-18	10,300	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	13C-BDE-197	13C-BDE-19	17,500	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	13C-BDE-207	13C-BDE-20	19,900	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	13C-BDE-209	13C-BDE-20	32,700	pg/L	
27306 41A-168	41A-168	Aqueous	23/03/2006	0.506 L		25/03/2006	13C-BDE-126	13C-BDE-12	11,900	pg/L	

Appendix F – E-Waste Contacting Experiments

Table F.3 Raw data for the 1-24-96 h experiment (pg/L). Analyzed by Vista Analytical

Alta Project	Sample ID	Date Sampled	Sample Size	Date Analyzed	CAS Number	Concentration	Units	Detection Limit	EMPC	%Recovery	Qualifiers
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-1	0	pg/L	42	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-2	0	pg/L	29.5	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-3	71	pg/L	0	0	0	0 J,B
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-7	0	pg/L	11.1	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-8/11	0	pg/L	8.33	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-10	0	pg/L	10.4	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-12/13	0	pg/L	6.46	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-15	19	pg/L	0	0	0	0 J,B
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-17	21.8	pg/L	0	0	0	0 J,B
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-25	0	pg/L	12.3	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	41318-75-6	50.5	pg/L	0	0	0	0 J,B
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-32	0	pg/L	7.82	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-35	0	pg/L	5.91	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-37	0	pg/L	5.53	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-30	0	pg/L	8.94	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	5436-43-1	413	pg/L	0	0	0	0 B
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-49	35.4	pg/L	0	0	0	0 J
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-66	41.3	pg/L	0	0	0	0 J
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-71	0	pg/L	16.8	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-75	0	pg/L	12.8	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	93703-48-1	0	pg/L	11.4	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	182346-21-0	0	pg/L	21.7	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-99	1040	pg/L	0	0	0	0 B
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-100	176	pg/L	0	0	0	0 J,B
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-116	0	pg/L	39.6	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-119	514	pg/L	0	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-126	0	pg/L	16.8	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-138	6160	pg/L	0	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	68631-49-2	130000	pg/L	0	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-154	16700	pg/L	0	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-155	62.8	pg/L	0	0	0	0 J
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-156	0	pg/L	153	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-166	0	pg/L	119	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-181	0	pg/L	85.2	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-183	534000	pg/L	0	0	0	0 B
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-190	22700	pg/L	0	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-197	298000	pg/L	0	0	0	0 B
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	337513-72-1	85300	pg/L	0	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	BDE-207	160000	pg/L	0	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	1163-19-5	421000	pg/L	0	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	101-55-3	71	pg/L	0	0	0	0 B
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	2050-47-7	19	pg/L	0	0	0	0 B
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	49690-940	72.3	pg/L	0	0	0	0 B
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	40088-47-9	490	pg/L	0	0	0	0 B
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	32534-81-9	2540	pg/L	0	0	0	0 B
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	36483-60-0	158000	pg/L	0	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	68928-80-3	586000	pg/L	0	0	0	0 B
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	32536-52-0	492000	pg/L	0	0	0	0 B
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	63936-56-1	169000	pg/L	0	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	Total Deca-BDE	421000	pg/L	0	0	0	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	13C-BDE-3	7350	pg/L	0		73.5	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	13C-BDE-15	8330	pg/L	0		83.3	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	13C-BDE-28	7970	pg/L	0		79.7	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	13C-BDE-77	7500	pg/L	0		75	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	13C-BDE-99	6860	pg/L	0		68.6	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	13C-BDE-100	6970	pg/L	0		69.7	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	13C-BDE-138	7210	pg/L	0		72.1	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	13C-BDE-153	8270	pg/L	0		82.7	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	13C-BDE-154	7700	pg/L	0		77	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	13C-BDE-183	9320	pg/L	0		93.2	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	13C-BDE-197	19500	pg/L	0		97.3	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	13C-BDE-207	21000	pg/L	0		105	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	13C-BDE-209	41900	pg/L	0		83.7	
	27306 42A-C1	17/02/2006	0.5 L	10/03/2006	13C-BDE-126	9290	pg/L	0		92.9	

Appendix F – E-Waste Contacting Experiments

Table F.3 Raw data for the 1-24-96 h experiment (pg/L). Analyzed by Vista Analytical

Alta Project	Sample ID	Date Sampled	Sample Size	Date Analyzed	CAS Number	Concentration	Units	Detection Limit	EMPC	%Recovery	Qualifiers
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-1	0	pg/L	71.9	0	0	
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-2	0	pg/L	50.5	0	0	
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-3	103	pg/L	0	0	0	0 B
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-7	55.3	pg/L	0	0	0	0 J
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-8/11	31	pg/L	0	0	0	0 J
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-10	0	pg/L	4.81	0	0	0
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-12/13	0	pg/L	2.98	0	0	0
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-15	60.8	pg/L	0	0	0	0 J,B
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-17	119	pg/L	0	0	0	0 B
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-25	0	pg/L	37.7	0	0	0
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	41318-75-6	219	pg/L	0	0	0	0 B
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-32	0	pg/L	24	0	0	0
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-35	0	pg/L	18.2	0	0	0
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-37	0	pg/L	17	0	0	0
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-30	0	pg/L	27.5	0	0	0
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	5436-43-1	2740	pg/L	0	0	0	0 B
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-49	330	pg/L	0	0	0	0
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-66	367	pg/L	0	0	0	0
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-71	0	pg/L	29.5	0	0	0
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-75	44	pg/L	0	0	0	0 J
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	93703-48-1	78.7	pg/L	0	0	0	0 J
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	182346-21-0	0	pg/L	241	0	0	0
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-99	13800	pg/L	0	0	0	0 B
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-100	1750	pg/L	0	0	0	0 B
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-116	0	pg/L	441	0	0	0
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-119	1150	pg/L	0	0	0	0
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-126	0	pg/L	182	0	0	0
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-138	131000	pg/L	0	0	0	0
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	68631-49-2	2960000	pg/L	0	0	0	0
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-154	353000	pg/L	0	0	0	0
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-155	0	pg/L	362	0	0	0
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-156	0	pg/L	1100	0	0	0
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-166	0	pg/L	835	0	0	0
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-181	0	pg/L	319	0	0	0
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-183	7530000	pg/L	0	0	0	0 B
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-190	357000	pg/L	0	0	0	0
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-197	2270000	pg/L	0	0	0	0 B
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	337513-72-1	888000	pg/L	0	0	0	0
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	BDE-207	963000	pg/L	0	0	0	0
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	1163-19-5	2340000	pg/L	0	0	0	0
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	101-55-3	103	pg/L	0	0	0	0 B
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	2050-47-7	147	pg/L	0	0	0	0 B
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	49690-940	339	pg/L	0	0	0	0 B
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	40088-47-9	3830	pg/L	0	0	0	0 B
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	32534-81-9	42100	pg/L	0	0	0	0 B
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	36483-60-0	3540000	pg/L	0	0	0	0
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	68928-80-3	8340000	pg/L	0	0	0	0 B
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	32536-52-0	4260000	pg/L	0	0	0	0 B
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	63936-56-1	1030000	pg/L	0	0	0	0
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	Total Deca-BDE	2340000	pg/L	0	0	0	0
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	13C-BDE-3	6020	pg/L	0		60.2	
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	13C-BDE-15	7290	pg/L	0		72.9	
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	13C-BDE-28	5620	pg/L	0		56.2	
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	13C-BDE-77	3780	pg/L	0		37.8	
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	13C-BDE-99	2780	pg/L	0		27.8	
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	13C-BDE-100	2890	pg/L	0		28.9	
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	13C-BDE-138	3020	pg/L	0		30.2	
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	13C-BDE-153	3830	pg/L	0		38.3	
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	13C-BDE-154	3120	pg/L	0		31.2	
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	13C-BDE-183	5950	pg/L	0		59.5	
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	13C-BDE-197	17800	pg/L	0		88.9	
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	13C-BDE-207	28400	pg/L	0		142	
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	13C-BDE-209	78300	pg/L	0		157	
	27306 43A-C24	18/02/2006	0.5 L	10/03/2006	13C-BDE-126	9520	pg/L	0		95.2	

Appendix F – E-Waste Contacting Experiments

Table F.3 Raw data for the 1-24-96 h experiment (pg/L). Analyzed by Vista Analytical

Alta Project	Sample ID	Date Sampled	Sample Size	Date Analyzed	CAS Number	Concentration	Units	Detection Limit	EMPC	%Recovery	Qualifiers
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-1	0	pg/L	88.2	0	0	
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-2	0	pg/L	61.9	0	0	
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-3	148	pg/L	0	0	0	0 B
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-7	91.1	pg/L	0	0	0	0 J
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-8/11	63.7	pg/L	0	0	0	0 J
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-10	0	pg/L	7.62	0	0	0
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-12/13	48.5	pg/L	0	0	0	0 J
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-15	129	pg/L	0	0	0	0 B
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-17	201	pg/L	0	0	0	0 B
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-25	0	pg/L	10.5	0	0	0
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	41318-75-6	389	pg/L	0	0	0	0 B
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-32	0	pg/L	6.72	0	0	0
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-35	31.2	pg/L	0	0	0	0 J
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-37	34	pg/L	0	0	0	0 J
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-30	0	pg/L	7.69	0	0	0
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	5436-43-1	4500	pg/L	0	0	0	0 B
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-49	560	pg/L	0	0	0	0
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-66	632	pg/L	0	0	0	0
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-71	0	pg/L	28.9	0	0	0
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-75	0	pg/L	22	0	0	0
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	93703-48-1	141	pg/L	0	0	0	0
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	182346-21-0	586	pg/L	0	0	0	0
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-99	27400	pg/L	0	0	0	0 B
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-100	3070	pg/L	0	0	0	0 B
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-116	0	pg/L	280	0	0	0
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-119	1960	pg/L	0	0	0	0
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-126	0	pg/L	116	0	0	0
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-138	312000	pg/L	0	0	0	0
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	68631-49-2	6700000	pg/L	0	0	0	0
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-154	864000	pg/L	0	0	0	0
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-155	1670	pg/L	0	0	0	0
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-156	0	pg/L	64.5	0	0	0
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-166	0	pg/L	53.1	0	0	0
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-181	7610	pg/L	0	0	0	0
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-183	15000000	pg/L	0	0	0	0 B
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-190	738000	pg/L	0	0	0	0
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-197	4770000	pg/L	0	0	0	0 B
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	337513-72-1	1910000	pg/L	0	0	0	0
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	BDE-207	1690000	pg/L	0	0	0	0
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	1163-19-5	2740000	pg/L	0	0	0	0
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	101-55-3	148	pg/L	0	0	0	0 B
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	2050-47-7	349	pg/L	0	0	0	0 B
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	49690-940	784	pg/L	0	0	0	0 B
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	40088-47-9	6720	pg/L	0	0	0	0 B
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	32534-81-9	89500	pg/L	0	0	0	0 B
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	36483-60-0	8110000	pg/L	0	0	0	0
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	68928-80-3	16700000	pg/L	0	0	0	0 B
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	32536-52-0	8950000	pg/L	0	0	0	0 B
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	63936-56-1	1790000	pg/L	0	0	0	0
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	Total Deca-BDE	2740000	pg/L	0	0	0	0
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	13C-BDE-3	6770	pg/L	0		67.7	
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	13C-BDE-15	7680	pg/L	0		76.8	
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	13C-BDE-28	7420	pg/L	0		74.2	
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	13C-BDE-77	6250	pg/L	0		62.5	
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	13C-BDE-99	4120	pg/L	0		41.2	
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	13C-BDE-100	4310	pg/L	0		43.1	
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	13C-BDE-138	3490	pg/L	0		34.9	
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	13C-BDE-153	4580	pg/L	0		45.8	
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	13C-BDE-154	3890	pg/L	0		38.9	
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	13C-BDE-183	5600	pg/L	0		56	
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	13C-BDE-197	12200	pg/L	0		61.2	
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	13C-BDE-207	19900	pg/L	0		99.7	
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	13C-BDE-209	49000	pg/L	0		98	
	27306 44A-C96	20/02/2006	0.5 L	10/03/2006	13C-BDE-126	7810	pg/L	0		78.1	

Table G.1 BDE concentrations in bottom ash, fly ash and waste residue samples collected from a waste-to-energy facility (pg/g) (Lab: MOE)

Algonquin ash results for PBDEs		Bottom	Bottom	Flyash	Flyash	Waste	Waste
		acid wash	no acid	acid wash	no acid	acid wash	no acid
		pg/g					
tri	BDE 17	1,600	2,700	<40	<30	120	130
tri	BDE 28	2,400	4,400	<160	<100	290	210
tot tri		4,000	7,100			410	340
tetra	BDE 49	2,500	4,200	<120	<100	190	<200
tetra	BDE 71	370	570	<40	<30	94	56
tetra	BDE 47	20,000	28,000	<4000	<3000	<2000	<2000
tetra	BDE 66	2,000	3,100	<120	<80	180	130
tetra	BDE 77	760	300	<8	<20	51	53
tot tetra		25,630	36,170			515	239
penta	BDE 100	4,700	5,900	800	<700	<500	<500
penta	BDE 119	850	960	<23	<40	<50	<50
penta	BDE 99	24,000	30,000	<4000	<3000	<2000	<3000
penta	BDE 85	1,100	1,400	<140	<90	<100	<100
penta	BDE 126	240	240	<110	<40	<50	<30
tot penta		30,890	38,500				
hexa	BDE 154	2,900	3,200	<180	<200	<200	<200
hexa	BDE 153	3,300	4,100	<200	<200	<300	<200
tot hexa		6,200	7,300				
hepta	BDE 138	610	600	<70	<70	<80	<50
hepta	BDE 183	2,000	2,200	<40	99	110	66
tot hepta		2,610	2,800		99	110	66
deca	BDE 209	9,300	11,000	2,500	1,900	3,500	<500
tot deca		9,300	11,000	2,500	1,900	3,500	<500

H.1 Estimation of mass (kg) of BFRs in plastics

Calcs for mass (kg) of BFRs in plastics (justification)

- » Literature values reported between 6-25% (see worksheet for % table)
- » values from crushed e-waste analysed by Vista Analytical (March 2006) for the 1985-89 time interval
- » crushed e-waste is basically e-plastics (monitor casings + peripherals, e.g. keyboards etc)

volume of total PBDEs:

$$(1.24 \times 10^{10} \text{ pg/g}) \times (1.075 \text{ g/cm}^3) \times (100 \text{ cm/m})^3 \times (1 \text{E-15 kg/1 pg}) = 13.3 \text{ kg/m}^3$$

where:

1.24E10 pg/g is total PBDE concentration from the 1985-1989 time interval
 1.075 g/cm³ is the density for plastics (Ref: Handbook of Chemistry & Physics)
 (100 cm/m)³ is the conversion factor
 1E-15 kg/1pg is the conversion factor

density for monitor casings + keyboards (i.e. peripherals):

$$\rho = \frac{\text{mass of monitor casings + keyboards}}{\text{monitor volume + keyboards}} = \frac{3.24 \text{ kg}}{7.45 \times 10^{-2}} = 43.47 \text{ kg/m}^3$$

where:

3.24 kg = 2.44 kg of monitor casings (avg of 59 monitors weighed) + 0.8 kg (typical keyboard weight)
 7.45E-02 = 0.07056 m³ (monitor volume) + 0.00396 m³ (peripheral volume)

volume of total PBDEs:

$$(1.24 \times 10^{10} \text{ pg/g}) \times (1.075 \text{ g/cm}^3) \times (100 \text{ cm/m})^3 \times (1 \text{E-15 kg/1 pg}) = 13.3 \text{ kg/m}^3$$

volume of total deca-BDEs:

$$(1.6 \times 10^9 \text{ pg/g}) \times (1.075 \text{ g/cm}^3) \times (100 \text{ cm/m})^3 \times (1 \text{E-15 kg/1 pg}) = 1.79 \text{ kg/m}^3$$

volume of total octa-BDEs:

$$(5.19 \times 10^9 \text{ pg/g}) \times (1.075 \text{ g/cm}^3) \times (100 \text{ cm/m})^3 \times (1 \text{E-15 kg/1 pg}) = 5.57 \text{ kg/m}^3$$

Therefore, the % of BDEs in the ewaste is:

a) **Total PBDEs**, % in e-plastics, according to our experimental results:

43.47 kg/m³ is taken as a base for 100%

13.3 kg/m³ of total PBDEs = x, where **x = 30.59%**

b) **deca-BDEs**, % in e-plastics, according to our experimental results:

43.47 kg/m³ is taken as a base for 100%

1.79 kg/m³ of deca-BDEs = x, where **x = 4.11%**

c) **octa-BDEs**, % in e-plastics, according to our experimental results:

43.47 kg/m³ is taken as a base for 100%

5.57 kg/m³ of octa-BDEs = x, where **x = 12.81%**

H.2 Mass transfer coefficient calculations

The following diffusivity equations were used to estimate the mass transfer coefficient, k_c . First estimate the molecular diffusivity, \mathcal{D}_i (m²/s – Treybal, 1980, and cm²/s – Reid *et al.* 1976), from the correlation of Wilke and Chang (1955):

$$\mathcal{D} = ((117.3E-18) \times (\varphi \times M)^{0.5} T) / \mu v^{0.6} \quad \begin{array}{l} \text{(Treybal, 1980)} \\ \text{(m}^2\text{/s)} \end{array} \quad (1)$$

$$\mathcal{D} = ((7.4E-8) \times (\varphi \times M)^{0.5} T) / \mu v^{0.6} \quad \begin{array}{l} \text{(Reid et al., 1976; Treybal,} \\ \text{1980)} \\ \text{(cm}^2\text{/s)} \end{array} \quad (2)$$

where

φ = association factor for solvent (water in our case) = 2.26

M = molecular weight of the solvent (water in our case) = 18.02 g/mole

T = ambient temperature in degrees Kelvin, taken as 293°K

μ = viscosity of the solution (kg/ m s) (water in our case) = 1.005 E-3 kg/m s

v = molal volume of the solute (m³/kmol) (of each BDE congener group)

Next, the dimensionless Peclet number, Pe , is obtained:

$$Pe = d \times U / \mathcal{D} \quad (2)$$

where

d = diameter of e-waste particle, 0.0024 m

U = fluid velocity (m/s) but will use instead hindered velocity $v_T = 0.0122$ m/s, taking the void fraction $\varepsilon = 0.44$ into account

Then, the Schmidt number, which is used to characterize fluid flows where simultaneous momentum and mass diffusion convection processes take place:

$$Sc = v / \mathcal{D} \quad (3)$$

where

Sc = Schmidt dimensionless number

Appendix H – Mass Balance Model Formulation

ν = kinematic viscosity, for water = $1 \times 10^{-6} \text{ m}^2/\text{s}$

Afterwards, calculate the Reynolds dimensionless number, which is a ratio of inertial forces to viscous forces and is used to quantify flow regimes:

$$\text{Re} = \rho u / \mu$$

Then estimate the Sherwood number, which is the dimensionless mass transfer coefficient from the empirical correlation of Frossling for flow past single sphere:

$$\text{Sh} = 0.43 + 0.532 \times \text{Re}^{0.5} \times \text{Sc}^{0.31} \quad (5)$$

Finally, the mass transfer coefficient, K_c is estimated, and by definition is:

$$K_c = (\text{Sh} \times D) / d$$

H.3.

Part I. Mass transfer to aqueous phase

The calculations were based on a well-stirred batch reactor

$$\frac{dN_A}{dt} = k_A A (C_{A_e} - C_A)$$

$$= V \frac{dC_A}{dt}$$

$$\therefore \int_{C_{A_0}=0}^{C_A} \frac{dC_A}{C_A - C_{A_e}} = - \int_0^t \frac{k_A A}{V} dt = - \int_0^t k_A a dt$$

$$\ln \left\{ \frac{C_A - C_{A_e}}{-C_{A_e}} \right\} = -k_A a t;$$

$$C_A - C_{A_e} = -C_{A_e} e^{-k_A a t}$$

$$i.e. \Rightarrow C_A = C_{A_e} (1 - e^{-k_A a t})$$

where

$$a = \frac{A}{V} = \frac{\text{surface area of particles}}{\text{volume of liquid}}$$

Correlate mass transfer coefficient, k_A , in terms of

$$Sh = \frac{k_A d}{D_{AB}} = f(Re, Sc)$$

where

$$Re = \frac{\rho d U}{\mu};$$

$$Sc = \frac{\mu}{\rho D_{AB}}$$

e.g. Thoenes & Kramers correlation:

Appendix H – Mass Balance Model Formulation

$Sh'=1.0(Re')^{0.5} Sc^{1/3}$ for a packed bed.

where

$$Sh' = \frac{k_A d_p}{D_{AB}} \left(\frac{\varepsilon}{1-\varepsilon} \right) \frac{1}{\gamma}$$

where

ε =voidage

γ =sphericity

$$Re' = \frac{\rho d_p U}{\mu(1-\varepsilon)\gamma}$$

Assume: $\rho = 997 \text{ kg/m}^3$; $\mu = 1.05 \times 10^{-3} \text{ Pa}\cdot\text{s}$; $\varepsilon = 0.50$

$d_p = 0.0024 \text{ m}$; $U = 0.0122 \text{ m/s}$

$D_{AB} \cong 6 \times 10^{-10} \frac{\text{m}^2}{\text{s}}$; take $\gamma = 1.0$

Therefore,

$Sc = 1755$;

$$Re' = \frac{997 \times 0.0024 \times 0.0122}{1.05 \times 10^{-3} \times 0.5} = 55.6$$

$$Sh' = \frac{k_A d_p}{D_{AB}} \left(\frac{\varepsilon}{1-\varepsilon} \right) = 1.0 \times (55.6)^{0.5} \times (1755)^{1/3} = 89.9$$

$$k_A = \frac{89.9 \times 6E-10 \frac{\text{m}^2}{\text{s}} \times 0.5}{0.0024 \times 0.5} = 2.25 \times 10^{-5} \text{ m/s}$$

This is approximately one order of magnitude greater than the values reported in Table 8.10, which are based on single particle at its hindered terminal settling velocity.

Part II. Experimental mass transfer coefficients

$$1 - \frac{C_A}{C_{A_e}} = e^{-k_A at}; \frac{C_{A_e} - C_A}{C_{A_e}} = e^{-k_A at} = \frac{1}{e^{k_A at}}$$

$$\therefore e^{k_A at} = \frac{C_{A_e}}{C_{A_e} - C_A};$$

$$k_A = \frac{1}{at} \ln \left(\frac{C_{A_e}}{C_{A_e} - C_A} \right)$$

Total volume:

$$1m^3 \rightarrow \frac{0.5m^3 \text{ particles} \rightarrow 0.5m^3 \times (0.0024)^2 m^2}{\frac{\pi}{6} \times (0.0024)^3 m^3} = 1250 \frac{m^2}{m^3 \text{ suspended} \cdot \text{particle}}$$

$$k_A at: 2.25 \times 10^{-5} \frac{m}{s} \times 1250 \frac{1}{m} \times 3600s = 101.25$$

$$\therefore \dot{C}_A = C_{A_e} (1 - e^{-k_A at}) \rightarrow C_A \rightarrow C_{A_e}$$

We could have had

$$C_A = \underbrace{C_{A_e} (1 - e^{-k_A at})}_{\text{dissolution}} + \underbrace{C_{A_s} (1 - e^{-k_{\text{effective}} at})}_{\text{dislodgement}}$$

For the long time periods of interest in this thesis, the dissolution term is ignored in deriving the mass transfer coefficients, with dislodgement assumed to be the dominant term.