DALHOUSIE UNIVERSITY

# Honours Thesis

## Examining The Effects of Waste Diversion on Leachate Quality

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# 1.0 Introduction

## 1.1 Statement of Problem

The disposal of Municipal Solid Waste has traditionally been a concern to society due to environmental liability and availability of land (Fan, Shu, Yang, & Chen, 2006). Waste management usually incorporates several types of processes: recycling, composting, incinerating and ultimately disposal of waste in a landfill. To minimize the impact of these processes on society, waste reduction is a very useful waste management strategy. Unfortunately, "modern" society is not yet ready to produce "zero waste" and hence landfilling will be required for some time. This is why landfilling is one of the most commonly used waste management techniques in the world (Read, Hudgins, & Phillips, 2001). Landfills offer economic benefits, such as, relatively low capital investment costs (Lema, Mendez, & Blazquez, 1988; Reinhart & Grosh, 1998) and the ability to decompose waste in a controlled environment (Robinson & Maris, 1983). One perceived problem with landfills, is that leachate will eventually seep out into the surrounding environment, even with a containment barrier in place (Koshy, Paris, Ling, Jones, & BeruBe, 2007; Pivato & Gaspari, 2006; Read, et al., 2001). However, many advances in landfill engineering have been made over the past 20 years and it is known that well designed landfills can offer environmental protection in perpetuity (Rowe, 2006).

Most of the available information on leachate quality from landfills has been taken from studies in which landfills consist of "waste" that has not been subject to any sort of diversion or separation measures. Published leachate data (e.g. Rowe, Quigley, Brachman & Booker, 2004) shows high amounts of variability in terms of concentration but often exhibits similar constituents. Leachate quality investigations are very complicated because leachate quality is

affected by several factors such as initial composition, volume of waste, particle size and density of waste, as well as, climate, age of landfill, landfill design and operation and interactions of leachate with the surrounding environment (Yildiz, Unlu, & Rowe, 2004; Qasim & Chiang, 1994). Leachate research has increased in the past 25 years (Renou, Givaudan, Poulain, Dirassouyan, & Moulin, 2008); however, little research can be found relating to the influence of waste diversion on leachate quality. Collins (1991) is one of the few studies that has examined this topic is some detail. Collins (1991) studies have shown that recycling of paper and other inorganic constituents can promote lower COD and iron concentrations.

Other previous studies have compared leachate quality with aspects of waste management (Christensen et al., 2001; Lema, et al., 1988; Lo, 1996; Reinhart & Grosh, 1998; Renou, et al., 2008). Studies like Reinhart and Grosh (1998) have compared Florida leachate quality to other landfills through literature review and found Florida landfills produced diluted leachate compared to other landfills found in the Browning-Ferris Industries landfill data (Reinhart & Grosh, 1998). In addition, shredded waste had significantly higher concentrations of organic pollutants in the leachate compared to that of unshredded waste. As well, co-disposal of ash with municipal solid waste did not appear to adversely impact leachate quality (Reinhart & Grosh, 1998). The above mentioned studies show that comparisons can be completed on leachate and other aspects of waste management.

A possible solution to lowering costs and potential risks associated with leachate would be to improve the quality of leachate (i.e. lower concentrations). Waste diversion is a technique that could possibly improve leachate quality by lowering certain hazardous constituents found in leachate. Possible techniques a municipality can use for waste diversion is through an active recycling, composting or a hazardous waste collection program. This project will look at the

effects recycling, composting and hazardous waste diversion have on leachate quality. It is hypothesized in the research that although waste diversion programs may have limited influence on the quality of municipal solid waste leachate, it may significantly reduce hazardous waste leachate constituents.

## 1.2 Purpose

Lower concentrations of constituents in municipal solid waste landfills could have a dramatic impact on the design of landfill barrier systems and collection systems. It has been discussed by Rowe et al. (2004) that high levels of BOD and calcium in leachate can cause premature failure of leachate collection systems in landfills. The rate of clogging in a collection system is related to leachate strength (Rowe et al., 2004). High concentrations of non-degradable inorganic constituents such as chloride result in the need for liner systems to last for hundreds of years. High concentrations of volatile organic compounds in municipal solid waste leachate result in thick barrier systems to mitigate against diffusive migration through the barrier system (Lake, MacNeill & Rowe, 2004). Improved leachate quality can potentially lower construction costs of landfill development, while at the same time maintaining adequate environmental controls against groundwater contamination.

## 1.3 Agenda

This research project is presented as several sections. A literature review (section 2.0) is provided to give the reader some knowledge of leachate quality and landfill systems, as well as, some information on related research that has been completed in this area. The method section (section 3.0) explains the methods used to collect and analyze the data. The results (section 4.0) and discussion (section 5.0) provide information on the data collected, as well as, some inference on their significance, in the context of this project. Conclusions are provided at the end of this

thesis to provide a summary of the work that has been presented, as well as, to suggest future work that could be pursued.

# 2.0 Literature Review

## 2.1 Waste Disposal

To understand leachate quality and recycling, some key terms need to be defined, as well, an overview of what methods are used when disposing of municipal solid waste. Tam & Tam (2006) define waste as any by-product from human and industrial activity, which has little current residual value. Municipal solid wastes are produced by the public of a municipality, such as a city and usually do not include municipal sludge, industrial, agriculture, mining or animal waste (Qasim & Chiang, 1994). The hierarchy of disposal options deduced by Peng, Scorpio, and Kibert, (1997) is used by many municipalities to determine a municipality's environmental impact when disposing of waste. This hierarchy identifies six categories of environmental impacts from low to high: reduce, reuse, recycle, compost, incineration and use of a landfill (Peng, et al., 1997). Of these six categories, landfilling is globally the most commonly used technique in disposing of solid waste (Lema, Mendez, & Blazquez, 1988; Peng, et al., 1997). It is not the most preferred technique in some countries like the European Union nations (Tatsi & Zouboulis, 2002) but is still used because any waste treatment process will have residues that cannot be further recovered or reused; therefore must be landfilled (Komilis, Ham & Stegmann, 1999). In addition, landfills minimize environmental effects and risks because the waste decomposes in controlled conditions until the materials become relatively stabilized (Robinson & Maris, 1983).

## 2.2 Landfill Types

There are several different types of landfills used in different countries. Globally the most commonly used today are an open dump, sanitary landfill and secure or controlled landfill (Cho, Tameda, Hanashima, Yamada, & Higuchi, 2008; Slimak, 1978). Open dumping is where waste is pilled on the existing ground with direct contact to precipitation and air. This type of dumping is being phased out in most developed nations due to its potential environmental effects on surrounding environments (Slimak, 1978). The second type of landfill is a sanitary landfill, which uses engineering methods to confine the waste into the smallest practical area. The top of the waste is covered with soil at certain intervals of time to minimize public nuisances like smell (Slimak, 1978). The third option is the secure or controlled landfill, which takes all aspects of waste and decomposition into account. Different types of engineering techniques are used in this type of landfill (Slimak, 1978). The techniques used, usually include a bottom liner, leachate collection system, cover and a natural hydrogeologic setting (Pennsylvania Action Center, 2003). This type of landfill is used to protect the surrounding environment from various hazardous components like leachate.

## 2.3 Landfill Process

Before moving on to leachate quality, a description of what occurs in a landfill is warranted. A typical landfill has three phases of biodegradation that occur within a time span of approximately 15 years (Lo, 1996). The first phase is aerobic decomposition, where oxygen is used up rapidly by bacteria, which begin to decompose and biodegrade the waste. The second phase is the acetogenic stage. This phase has anaerobic and facultative organisms, which hydrolyze and ferment cellulose and other putresible materials (Lo, 1996). This phase produces high concentrations of ammonia nitrogen ($NH_3^-N$) and volatile fatty acids, which contribute to

high BOD and COD levels (Kulikowska & Klimiuk, 2008; Reinhart & Grosh, 1998; Lo, 1996). The third and final stage is a slower methanogenic phase. In this stage, the organics are consumed (Lo, 1996). This stage has low levels of BOD with high concentrations of $NH_3$-N (Lo, 1996).

## 2.4 Leachate Collection System and Landfill Liner System

In the landfill phases mentioned above, there are three physical phases that are produced. These stages are the solid phase (waste), liquid phase (leachate) and the gas phase (landfill gas) (Christensen, Cossu, & Stegmann, 1992). Leachate that is produced in the liquid phase is a huge concern with landfill plans and operations, as well as, the surrounding environment (Christensen, et al., 1992; Yildiz, et al., 2004). The major problem in landfills with leachate is the leachate collection system. The rate of clogging in a leachate collection system is dependent on the leachate strength (Rowe, et. al., 2004). A clog in the leachate collection system results in a mound accumulation of leachate at the base of the landfill. This mound can result in an increase in temperature on the underlying liner system (Rowe et. al., 2004). This temperature increase has the potential to increase advective-diffusive contaminant transport, which can decrease the service life of some of the engineering components in the barrier system (Rowe, et. al., 2004).

The landfill liner system is one of the most important parts of the landfill for minimizing impact on the environment. High leachate concentrations do not affect hydraulic movements through liner systems but the potential impact on the environment could be more. High leachate mounds due to leachate collection system clogging can potentially impact hydraulic leachate migration. Also, higher leachate concentrations can increase the diffusive migration through liner systems. Hence there is some benefit to examining waste diversion effects on leachate quality.

## 2.5 Factors Affecting Leachate Quality

Leachate production from municipal solid waste is one of the most important environmental issues that arise with landfills (Touraud, Roussy, Domeizel, Junqua, & Thomas, 2007). In a landfill there are physical, chemical and biological processes that occur, which transform or degrade the waste to more stabilized materials (Fan, et al., 2006; Kulikowska & Klimiuk, 2008; Reinhart & Grosh, 1998). As water percolates through the waste, contaminants will react and then leach into the water forming leachate (Reinhart & Grosh, 1998). The characteristics of leachates can vary greatly (Kulikowska & Klimiuk, 2008; Touraud, et al., 2007) due to the composition of the solid waste, precipitation rates, site hydrology, compaction, waste age, sampling procedure, interaction of leachate with the environment and landfill design and operation (Reinhart & Grosh, 1998).

### *2.5.1 Waste composition*

There is great deal of variation in the composition and characteristics of solid waste in a landfill (Reinhart & Grosh, 1998; Al-Yaqout & Hamoda, 2003). The composition of waste determines the extent of biological activity of a landfill (Reinhart & Grosh, 1998). Rubbish, food and garden waste, along with animal residues, contribute to the organic material found in leachate. Usually high BOD and COD levels indicate biodegradation of this putrescible material within the landfill. The inorganic constituents found in leachate come from ash wastes and construction and demolition waste (Reinhart & Grosh, 1998).

Several interesting facts were found while conducting this literature review on waste composition in a landfill. Komilis et al. (1999) state that shredding of putrescible waste enhances decomposition in a landfill. It was found that long term composting is effective for the biological stabilisation of already source-seperated putrescible fraction of municipal solid waste (Jokela,

Kettunen & Rintala, 2002). This results in lower pollution potential of methane and ammonium nitrate. The most interesting and related to this research was from Collins (1991). Collins investigated the effect of recycling paper and inorganic components on municipal solid waste. It was found that recycling of paper and inorganic components reduced leachable COD by 25% and iron loadings by 80% compared to that of unsorted waste (Collins, 1991).

### *2.5.2 Moisture and Temperature*

The most significant factor affecting waste stabilisation and leachate quality is water (Reinhart & Grosh, 1998). The quantity of water found in the landfill contributes to how fast and slow the decomposition process occurs (Qasim & Chiang, 1994). Within dry seasons or dry areas, biological degradation will take longer or even cease due to lack of moisture, while in wet conditions the stabilisation rate increases (Klinck & Stuart, 1999; Reinhart & Grosh, 1998; Trankler, Visvanathan, Kuruparan & Tubtimthai, 2005). Temperature also can influence leachate quality by increasing bacteria growth and chemical reactions in hot climates. This produces faster biodegradation of waste within the landfill (Reinhart & Grosh, 1998).

### *2.5.3 Age of Landfill*

The length of time which has elapsed since the waste was placed in the landfill will influence leachate quality (Lo, 1996; Reinhart & Grosh, 1998). Most of the studies that have been found (Fan, et al., 2006; Kulikowska & Klimiuk, 2008; Lo, 1996; Pivato & Gaspari, 2006; Qasim & Chiang, 1994), state that as the waste biodegrades, the leachate quality will improve. Leachate will have high levels of contaminants at the beginning of disposal and slowly taper off until the waste has become stabilized (Lo, 1996). During early stages in the above mentioned acetogenic stage of a landfill, there will be high decomposition of materials, which cause high levels of BOD and COD. After these stages comes the methanogenic phase were most organics

have biodegraded and what is left is carbon dioxide ($CO^2$) and methane ($CH_4$) being produced with low BOD levels. This can cause problems in comparing or characterizing leachate quality between different landfills. It also causes problems at certain depths within the same landfill because there can be different lengths of time for each particular waste deposited in each cell. It can also be difficult to characterize individual wastes, due to operation styles of different landfills (Qasim & Chiang, 1994). For example, one landfill might allow certain materials into the landfill while another landfill may not.

## 2.6 Leachate Toxicity

It was found that a majority of the studies used physicochemical analyses that use parameters like BOD, COD, $NH_3^-N$, TOC, pH and heavy metals to determine leachate hazard (toxicity). Reinhart & Grosh (1998) stated that these parameters were the most applicable to leachate studies due to the fact they are used primarily by all landfill operations. Leachate toxicity is a consequence of the numerous contaminants found within leachate and the interaction between them (Marttinen, Kettunen, Sormunen, Soimasuo, and Rintala, 2002). To provide some baseline of concentrations used to model landfill design, Table 1 lists several parameters and their overall concentrations that should be used in modelling applications for landfill operations and structures (Ministry of the Environment, 1998).

**Table 1: Concentrations in Landfill Modelling Applications**

| Contaminant | Initial Source Concentration |
|---|---|
| Chloride<br>150,000 t/ha<br><br>increasing to<br>250,000 t/ha | 1,500 mg/L<br><br><br>increasing to<br>2,500 mg/L |
| Benzene | 0.02 mg/L |
| Toluene | 1 mg/L |

Table 2 shows a range of concentrations for the remaining parameters used in this project. This table represents a reasonable fraction of what concentrations are to be expected in an average landfill found in Ontario (Rowe et al., 2004). The ranges were collected through three separate landfills. This table is only a typical representation of municipal solid waste. It should not be taken as standards for leachate toxicity but as a comparison for the leachate concentrations found in this project.

**Table 2: Typical Leachate Concentrations of Municipal Solid Waste**

| Parameter | Concentration (mg/L) |
|---|---|
| BOD | 30 – 3875 |
| COD | 53 – 21,200 |
| Calcium | 60 - 2500 |
| Zinc | 0.3 – 3.8 |
| Lead | 0.03 – 0.22 |
| Copper | 0.04 – 0.1 |
| Chromium | 0.02 – 0.06 |

## 2.7 Review

Through the literature review it was found that BOD and iron concentrations can be lowered through recycling certain products (Collins, 1991), as well, improvements on the leachate toxicity could be attained if heavy metals were prevented from entering landfills (Olivero-Verbel, Padilla-Bottet, and De la Rosa, 2008). These former results show there is potential to improve leachate quality. However, throughout most of the research, it has been found that the components of leachate vary too much to make any definitive correlation between leachate quality and other components of a landfill. This research may not be able to conclude a definitive answer on leachate quality, just like other past projects in this field. However, it is still an important first step in furthering an understanding of leachate quality and how it relates to waste diversion programs in cities.

# 3.0 Methods

The following sections include a description of the sample design, research tools and procedures used in collecting and compiling data. The methods used in gathering data are discussed and justified, as well as, an explanation of the delimitations and limitations put on the research. This research will use a comparison design, that will use existing collected leachate quality and waste diversion data from several Canadian cities. The purpose of the design is to find similarities and differences between the quality of leachate and waste diversion by comparing several leachate components and waste diversion stats between different landfills in cities.

## 3.1 Sample Design

For this project the following information was collected from landfills across Canada:

- landfill operational information (if available)
- waste diversion statistics through recycling, composting and household hazardous waste collection
- leachate quality (concentrations and sampling rates)

In total 12 cities were contacted. As shown in this report, 5 cities responded. Time constraints limited some of the data gathering; therefore more research could be conducted in this field if desired.

## 3.2 Research Tools

The specific parameters of the leachate that were collected, included, where possible:

- tonnage of waste going into the landfill

- tonnage of waste diverted from the landfill (including details of the diversion program where possible), and,
- leachate concentrations, such as, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), chloride (Cl), calcium (Ca), lead (Pb), zinc (Zn), lead (Pb), chromium (Cr), copper (Cu), Benzene, Toluene, Ethyl Benzene, and Xylenes, (BTEX).

These leachate parameters are used because they provide ways to determine the organic, heavy metals and hazardous waste components of leachate. As well, these parameters can be compared to previous historical studies.

## 3.3 Sampling Procedure and Data Analysis

The procedure of data collection began with internet research to find the appropriate people to contact for landfill and leachate information. These people were then contacted by phone or email, and asked to send the appropriate data. Table 3 shows the landfills that were collected for this project along with the year the operations began. For various reasons the names of the landfills or cities were not used in this project. For this project all designations of the five cities and landfills used will be expressed by the symbols given in Table 3.

**Table 3: Landfills used in thesis**

| Landfill | Year Operations Started |
|---|---|
| A1 | 1999 |
| B2 | 1980 |
| C3 | 1973 |
| D4 | 1966 Initially Operation Started<br>1980 Current cell used for waste diversion |
| E5 | 1955 |

The accompanying population size and precipitation rates through Census Canada and The Weather Network were also collected and compiled into a Microsoft excel spreadsheet. This was done to give the reader a perspective of each landfill and city.

To begin analysing the data, the landfill tonnage and waste diversion information was gathered and compared. The data was put in an excel spreadsheet and then placed into bar graphs to visualize similarities and differences between the landfills and waste diversion. The different types of figures and graphs produced can be found in the Results and Discussion sections, as well as, the Appendices. They include:

- Figure 1: Yearly Landfill Tonnage for Cities
- Figure 2: Total Diversion of Material from Landfills
- Appendix A: Population of Cities
- Appendix B: Yearly Total Precipitation of Cities
- Appendix C: Leachate Parameter Concentration versus Time, for each individual landfill.

The next step in data collection was to compile the different leachate parameters into a Microsoft Excel spreadsheet. Through the literature review and the variability of leachate, comparative studies between the leachate parameters were used. It was determined from other literature (Lema, et al., 1988) that this would be the best way to interpret results for this type of data. The following table below illustrates, which leachate parameters were available from the collected data.

**Table 4: Matrix of Parameters Available**

| | A1 | B2 | C3 | D4 | E5 |
|---|---|---|---|---|---|
| BOD | X | X | | | |
| COD | X | X | | | |
| Chloride | X | X | | | X |
| Calcium | X | X | X | X | X |
| Lead | X | X | X | X | X |
| Zinc | X | X | X | X | X |
| Chromium | X | X | X | X | X |
| Copper | X | X | X | X | X |
| Benzene | X | X | X | X | |
| Toluene | X | X | X | X | |
| Ethyl Benzene | X | X | X | X | |
| Xylenes | X | X | X | X | |
| Dichloromethane | X | X | | | |
| 1,4 Dichlorobenzene | X | X | X | X | |

Note: "X" denotes available for study

Individual graphs were made of leachate parameters over to time. This was done for each landfill. The purpose of this was to visually interpret significant similarities and differences in landfill concentration over time. The next step in analysing the data was to calculate the mean and standard deviation of the leachate parameters. These statistical measurements were calculated through Microsoft Excel and then placed into a table for further analysis. To determine if any similarities or differences were through waste diversion, research was conducted on each city's waste diversion program. This research was completed by searching through city websites. Using this research and the previous waste diversion data, a table was created with a set of four key points in an active waste diversion program. This was to illustrate and explain how some city programs may influence waste diversion rates.

At the start of this project, visual interpretation was the main tool used to find results. Through further discussion, a statistical measurement was chosen to further understand the data. This statistical measurement was a one-way ANOVA test. This one-way ANOVA test was

completed using the SPSS 16.0 program (SPSS, 2007). The different sampled landfill leachate concentrations were placed into this program to determine, which mean concentrations in the leachate parameters were significantly different from one another. The ANOVA test was used because it has no restriction on the number of means (Howell, 2007).

The above mentioned data can be found in the results section of this project and include:

- Table 5: Matrix of four key points in an active waste diversion program for a city
- Table 6: Mean and standard deviation for leachate parameters from landfills
- Table 7: One-Way Anova and Tukey Post Hoc test on Significant Parameters, for each landfill

## 3.5 Limitations and Delimitations

Landfill age, climate, leachate collection and landfill operation are all factors that limit this research. The literature review has found that as waste biodegrades, the leachate quality will change (Fan, et al., 2006; Kulikowska & Klimiuk, 2008; Lo, 1996; Pivato & Gaspari, 2006; Qasim & Chiang, 1994). The collection system for leachate may have errors due to dilution or inaccurate sampling (Slimak, 1978). It has also been found that waste composition can alter leachate quality (Reinhart & Grosh, 1998; Al-Yaqout & Hamoda, 2003). Different landfill operations can result in different waste composition (Qasim & Chiang, 1994). Operations that allow industrial, construction and shredded waste in landfills can alter leachate quality (Bakare, Mosuro, & Osibanjo, 2005; Qasim & Chiang, 1994). It can be seen that there are many variables in leachate and is the reason there has been no standard method in comparing leachate quality. For these reasons no technique can control these limitations for this project.

Even with the high variability in leachate, there was one delimitation that this project used to lower error. The delimitation placed on this project is to only include cities in Canada.

This was to keep similar climates; therefore to minimize differences in leachates throughout the samples. As mentioned earlier, leachate quality volume can vary due to certain climate factors (Qasim & Chiang, 1994; Reinhart & Grosh, 1998). It was found that there was one notable differences, the difference in precipitation rates. The only way to limit this error, was to show the different precipitation rates between the different cities.

# 4.0 Results

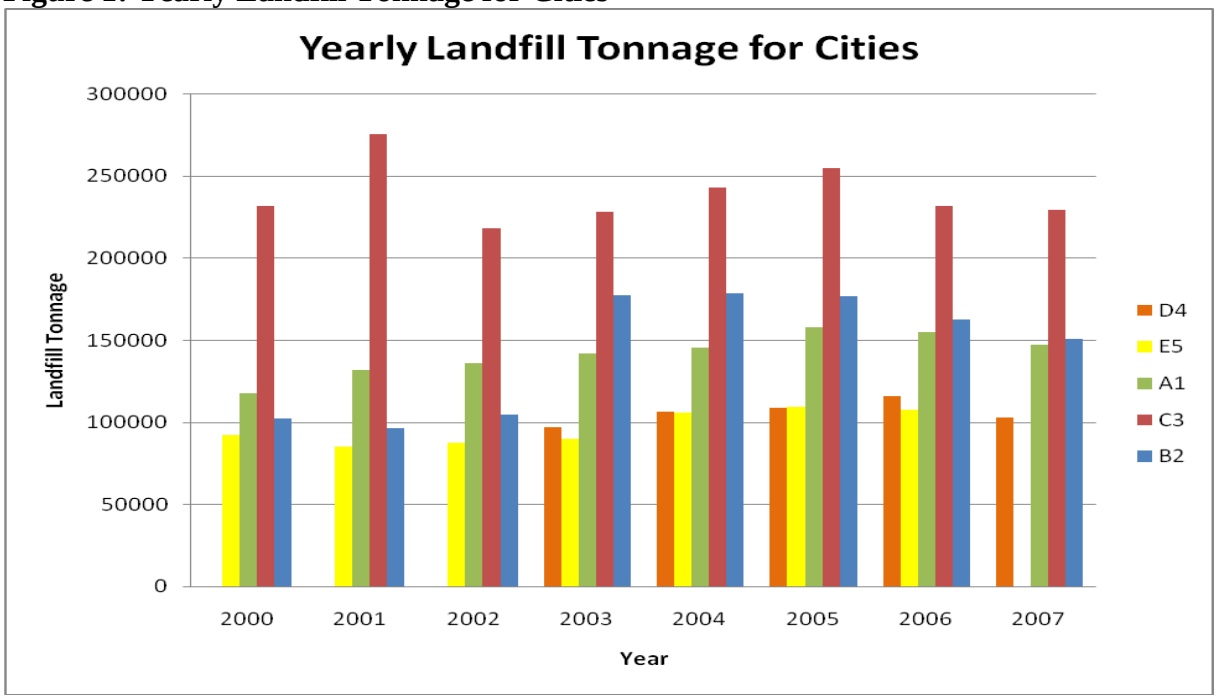
## 4.1 City and Landfill Information

To gain some perspective of the different cities and landfills, one can refer to the population size and yearly precipitation rate found in Appendix A and B. It was found that each city has had a positive increase in population since 2003. Looking at the yearly precipitation rates it can be seen that A1 and B2 were significantly higher. If these cities do not have a proper cap system on the landfill, higher amounts of water will enter the landfill causing increased volume and dilution of the leachate.

Figure 1 shows the landfill tonnage for each city. The yearly tonnage represents all the tonnage of waste going into landfills within the cities. Most of the cities have used or are currently using more than one landfill to dispose of waste. Therefore it should be kept in mind that each individual landfill studied in this project may not represent the entire waste fraction for the cities. There is one key discrepancy in Figure 1. The discrepancy is for B2 during 2003 where it makes a significant increase in tonnage of waste going into the landfill. This occurred because B2 was diverting a portion of waste from the landfill into an energy for waste (efw) program, which created electricity or heat through the incineration of certain waste products. In 2003, this program was no longer being implemented, which resulted in an increase in tonnage of waste going to the landfill.

By looking at the data in Figure 1, the cities can be grouped into three categories. The first grouping is D4 and E5, which have a smaller yearly tonnage. The second group is A1 and B2, which have moderate landfill tonnage since 2003. The final group would be C3, which has significantly higher yearly tonnage rate than the other landfills.

**Figure 1: Yearly Landfill Tonnage for Cities**

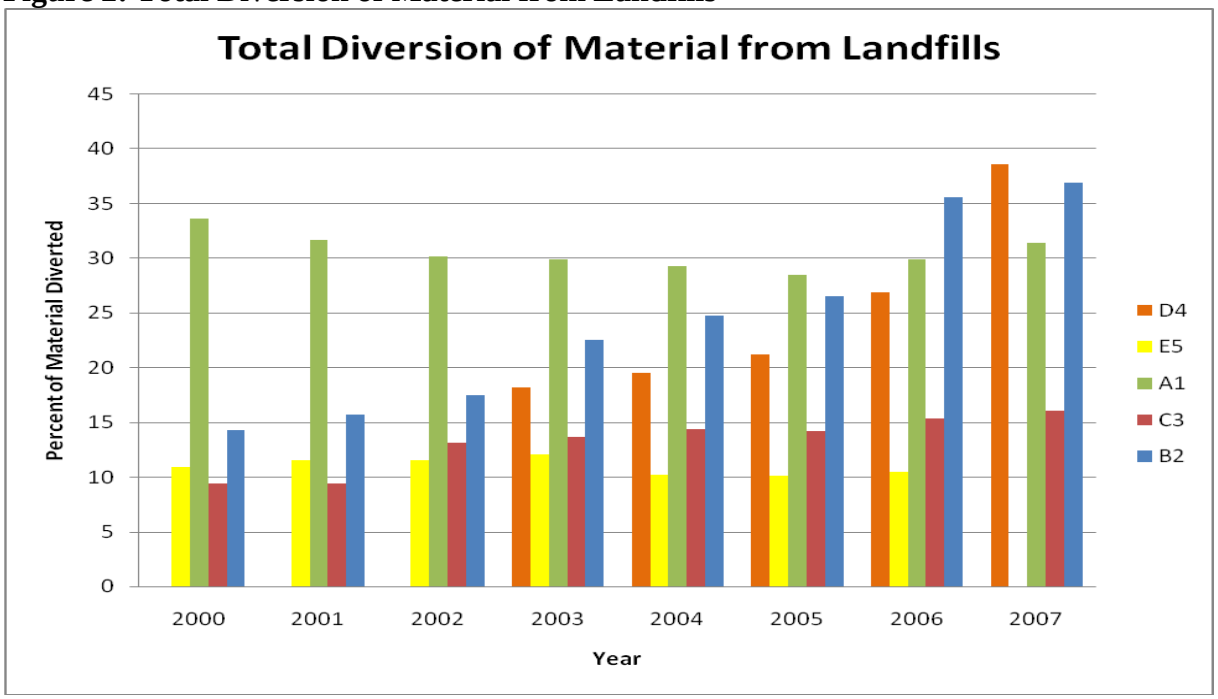



The total percent diversion of material from landfills for each particular city is found in Figure 2. An important factor to mention for this graph is that A1 and B2 waste diversion percentages may be slightly misleading. The data used to calculate Figure 2 was collected from city records. Both A1 and B2 indicated that the numbers in Figure 2 are waste diversion numbers through municipality resources. Both these cities have businesses that are not part of the municipality but privately owned. These business make profit by taking in recyclable and compostable material for resale. Unfortunately, the municipalities did not have the exact tonnage of waste diverted from the landfill from these privately owned businesses. From talking with a representative from each city, it was found that B2 diversion is approximately 5% greater than

what is seen, while A1 is around 15 to 20% greater. Since there were no exact tonnage numbers for these privately owned businesses, they were not included in this report. However it should be kept in mind that A1 and B2 should have higher percentages of waste diversion then indicated on the figure.

By looking at Figure 2 it was decided that there are two major groupings between the different cities. A1, B2 and D4 can be grouped with relatively high percentages in waste diversion since 2003. The other goruping would be E5 and C3, which have lower percentages of waste diversion. These groupings are important because it has the potential for a comparison to be made with leachate quality and the differences in waste diversion between the two groups.

**Figure 2: Total Diversion of Material from Landfills**




Further examination was conducted on each city's waste diversion program. By looking at the various programs, there was four key points that illustrated the similarities and differences between the waste diversion programs (see table 5). These key points were: 1) weekly or bi-weekly recycling pickup; 2) weekly or bi-weekly composting pickup; 3) weekly household

hazardous recycling option; and 4) mandatory or optional recycling. These waste diversion programs seen in Table 5 are stated to show the possibility for the differences in waste diversion rates between the cities.

**Table 5: Matrix of four key points of waste diversion for each city**

| | A1 | B2 | C3 | D4 | E5 |
|---|---|---|---|---|---|
| weekly or bi-weekly recycling pickup | X | X | X | X | |
| weekly or bi-weekly composting pickup | X | X | | | |
| weekly household hazardous recycling option | X | X | | | |
| mandatory recycling through bylaw | X | X | | X | |

It should be noted that the data gathered for this information came from city websites. Some cities may have other programs in place that are not discussed in this matrix. For instance, the key point of weekly or bi-weekly composting, included diverting a majority of organics from going into the landfill, not just leaf and yard waste. Cities like C3, D4 have pickup of leaf and yard waste during specific times. However, it was found that organics like food or other compostable materials were not part of this diversion. For this reason, C3, D4 and E5 are not considered as having weekly or bi-weekly composting pickup. Other notable information would be that all cities had a household hazardous waste collection option. However, C3, D4 and E5 have a monthly or semi-monthly collection city service at certain times.

## 4.2 Leachate Data for Landfills

Appendix C presents the time varying concentration of the various leachate constituents. It was noticed in the A1 landfill from the year 2000 to 2003 that certain leachate constituents were still raising and lowering in concentration. This was probably due to the fact that this landfill was recently built. It appears that 2004 is the approximate time when the leachate parameters stabilized and became more consistent like the other landfills. For this reason all

calculations for A1 do not include data from 2003 and earlier. The exception for this is the BTEX information, which had limited data; therefore, was used prior to 2003. All the older landfills had relatively consistent stabilized leachate; therefore all data that was supplied for each parameter was used in this project. Since the BTEX had limited data, no detection (nd) monitoring was used in the calculations. Instead of using no detection, some landfills just stated the sample was less than the lowest sampling concentration detection. This lowest concentration detection was also used in the calculations the BTEX information.

Each city had different procedures and ways of sampling. This meant that some cities sampled for certain parameters that other cities did not. A few of the landfills had multiple leachate monitoring stations that collected samples, while others were using a single collection system facility. It was found that the leachate varied from each monitoring station. To simplify matters, only one monitoring stations was used for this project. The station, which had the longest sampling period was chosen. Problems also arose with the number of monitored samples recorded. Some cities collected extensive data, while others had sporadic sampling times. Even with these issues, comparisons were made for certain parameters with the different landfills.

In order to better understand the leachate parameter data from the concentration compared to time graphs found in Appendix C, the mean and standard deviation was calculated for each parameter (see Table 6). The number of samples are also provided in Table 6.

**Table 6: Mean and standard deviation for leachate parameters from landfills**

| | A1 | B2 | C3 | D4 | E5 |
|---|---|---|---|---|---|
| **Biological Oxygen Demand** | | | | | |
| **Number of Samples** | 14 | 10 | | | |
| **Mean mg/L** | 137.4 | 14.3 | | | |
| **Standard Deviation** | 98.1 | 11.6 | | | |
| **Chemical Oxygen Demand** | | | | | |
| **Number of Samples** | 14 | 10 | | | |
| **Mean mg/L** | 1299.4 | 204.0 | | | |
| **Standard Deviation** | 539.4 | 100.9 | | | |
| **Chloride (Cl)** | | | | | |
| **Number of Samples** | 12 | 10 | | | 8 |
| **Mean mg/L** | 1150.0 | 330.8 | | | 332.9 |
| **Standard Deviation** | 425.8 | 182.3 | | | 126.6 |
| **Calcium (Ca)** | | | | | |
| **Number of Samples** | 16 | 10 | 8 | 17 | 8 |
| **Mean mg/L** | 177.2 | 237.5 | 240.0 | 112.8 | 175.8 |
| **Standard Deviation** | 247.7 | 27.2 | 96.1 | 16.8 | 56.0 |
| **Zinc (Zn)** | | | | | |
| **Number of Samples** | 16 | 10 | 6 | 15 | 8 |
| **Mean mg/L** | 5.2E-01 | 2.7E-02 | 2.6E-01 | 3.1E-02 | 1.3E-02 |
| **Standard Deviation** | 4.0E-01 | 2.5E-02 | 2.3E-01 | 2.0E-02 | 9.0E-03 |
| **Lead (Pb)** | | | | | |
| **Number of Samples** | 16 | 10 | 7 | 14 | 8 |
| **Mean mg/L** | 4.3E-02 | 1.9E-03 | 8.6E-02 | 1.1E-02 | 2.0E-03 |
| **Standard Deviation** | 3.4E-02 | 8.7E-04 | 8.4E-02 | 1.4E-02 | 0.0 |
| **Copper (Cu)** | | | | | |
| **Number of Samples** | 16 | 10 | 6 | 17 | 8 |
| **Mean mg/L** | 6.5E-01 | 4.8E-03 | 6.0E-01 | 2.0E-01 | 3.0E-03 |
| **Standard Deviation** | 1.1E+00 | 2.2E-03 | 1.4E+00 | 3.9E-01 | 3.0E-03 |
| **Chromium (Cr)** | | | | | |
| **Number of Samples** | 16 | 10 | 8 | 17 | 8 |
| **Mean mg/L** | 4.9E-01 | 1.8E-01 | 8.1E-02 | 2.0E-02 | 1.0E-03 |
| **Standard Deviation** | 6.3E-01 | 5.3E-01 | 7.1E-02 | 1.6E-02 | 0.0 |
| **Benzene** | | | | | |
| **Number of Samples** | 9 | 4 | 8 | 12 | |
| **Mean µg/L** | 4.4E-01 | 6.9 | 10.7 | 5.6 | |
| **Standard Deviation** | 8.8E-01 | 2.2 | 9.3 | 1.6 | |
| **Toluene** | | | | | |
| **Number of Samples** | 9 | 4 | 8 | 12 | |
| **Mean µg/L** | 10.6 | 11.1 | 565.1 | 5.6 | |
| **Standard Deviation** | 13.6 | 19.3 | 636.6 | 5.8 | |
| **Ethyl Benzene** | | | | | |
| **Number of Samples** | 9 | 4 | 8 | 12 | |
| **Mean µg/L** | 3.1 | 17.0 | 109.8 | 38.7 | |
| **Standard Deviation** | 5.3 | 17.5 | 85.6 | 25.8 | |
| **Xylenes** | | | | | |
| **Number of Samples** | 9 | 3 | 2 | 12 | |
| **Mean µg/L** | 12.3 | 25.0 | 308.5 | 17.5 | |
| **Standard Deviation** | 19.0 | 17.1 | 341.5 | 7.6 | |

By visual inspection, it was found that for certain parameters there was differences between the landfills. Before stating which parameters had differences, it had to be determined if these differences were actually significant or just apparent. As previously discussed, a one-way ANOVA was conducted on each individual parameter, except for BOD and COD. The assumptions used in the one-way ANOVA were:

- each landfill was independent of one another
- the data scores have the same variance; they were all similar in shape (e.g. all positively skewed)

There was a violation on the analysis of variance assumption when using the one-way ANOVA. Research was completed to determine if these violations were minimal, which would allow the results from the test to still be valid. The violation was that the data scores were not normally distributed around their mean. However it was found that a one-way ANOVA can still be done under certain circumstances. Howell (2007), states that an analysis of variance can be a robust procedure, which can be frequently violated with relatively minor effect (Howell, 2007). If the data can be assumed similar in shape (e.g., all positively or negatively skewed) and if the largest variance is no more than four or five times that of the smallest, then the analysis of variance is likely to be valid (Howell, 2007). The data collected were all positively skewed and none of the largest scores were five times greater than that of the smallest, which makes the analysis of variance assumption valid in this case.

After completing the one-way ANOVA, a Tukey's Post Hoc test was conducted on the significantly different parameters. The Tukey's test was conducted because it is the most commonly used Post Hoc analysis test used. The results are summarized in Table 7 and can be found in its entirety on Appendix D along with the one-way ANOVA results. Only the

parameters that were significantly different at $p<0.05$ were mentioned in Table 7. When it is said that a difference is statistically significant at $p<0.05$ level, what is meant is that a difference this large between the groups would occur less than 5% of the time if the null were true. The null hypothesis being that the groups are the same (Howell, 2007).

**Table 7: Tukey Post Hoc Test on Significant Parameters**

| | Post Hoc Test | F | df |
|---|---|---|---|
| Chloride (A1, B2, E5) | A1 ≠ B2, E5 | 28.081 | 2,31 |
| Zinc (A1, B2, C3, D4, E5) | A1 ≠ B2, D4, E5 | 12.627 | 4,50 |
| Lead (A1, B2, C3, D4, E5) | A1 ≠B2<br>C3 ≠ B2, D4, E5 | 8.728 | 4,50 |
| Chromium (A1, B2, C3, D4, E5) | A1 ≠ D4, E5 | 3.629 | 4,54 |
| Benzene (A1, B2, C3, D4) | C3 ≠ A1 | 6.568 | 3,29 |
| Toluene (A1, B2, C3, D4) | C3 ≠ A1, B2, D4 | 6.405 | 3,29 |
| Ethyl Benzene (A1, B2, C3, D4) | C3 ≠ A1, B2, D4 | 8.574 | 3,29 |
| Xylenes (A1, B2, C3, D4) | C3 ≠A1, B2, D4 | 9.582 | 3,22 |

To explain the symbols and terms presented in Table 7, an example is provided below:

1st column: Represents the parameter and which landfills had data for that parameter
2nd column: The Tukey Post Hoc test shows which cities are significantly different at $p<0.05$ from each other
A1≠B2: A1 is significantly different than B2
C3≠B2: C3 is significantly different than B2
C3≠D4: C3 is significantly different than D4
C3≠E5: C3 is significantly different than E5
3rd column: F Test (shows significance, e.g. the higher the F test number, the higher the significance)
4th column: Degrees of freedom (shows how many samples can vary between and within the data)

## 4.3 Organic and Inorganic Constituents

### *4.3.1 BOD and COD*

Unfortunately for BOD and COD there was only A1 and B2 landfills that supplied data for these parameters. Due to the fact that A1 and B2 were similar in the four key point waste diversion program and percent of waste diverted from the landfill; there can be no correlation discovered between BOD and COD concentration and waste diversion between the cities. However, it still is important to see that the BOD and COD concentrations are within the range of other typical landfills found in Table 2. It can also be noted that A1 is higher than B2.

### *4.3.2. Chloride*

Referring to Table 1, the overall concentrations of chloride for landfill design in Ontario can range between 1,500 - 2,500 mg/L. Visual interpretation can see that A1 is lower than this range but significantly higher than that of B2 and E5, as well, B2 and E5 are extremely similar in concentration. Upon conducting the one-way ANOVA, it was found that the visual interpretation was correct in saying there was a difference in chloride between the different landfills. The Post Hoc test indicated that there was a high difference between A1 and that of B2 and E5 landfills. This difference is most likely due to differences in age of the landfill (see Table 3).

## 4.4 Metals

### *4.4.1 Calcium and Copper*

Completing a one-way ANOVA on calcium and copper indicated that there was no significant difference between the five landfills for these parameters. It was found that C3 and A1 were among the highest concentrations for these parameters followed by B2. The lowest of all the concentrations was D4. All landfills fell within the typical concentration for calcium in

Table 2. However, for copper the numbers were higher than what is found in Table 2. This could be due to the sporadic nature of the data. Looking at the concentration compared to time graphs, it can be seen that there was not much consistency between the samples. This tends to occur when sampling for metals due to precipitation.

### *4.4.2 Zinc*

A1 and C3 were found to have higher concentrations of zinc than that of B2, D4 and E5. It was found through the one-way ANOVA that there was a significantly high difference with zinc between the landfills. Using the Post Hoc test, it showed that A1 was significantly different from B2, D4 and E5. Even though C3 had a high concentration, there was no significant difference between B2, D4 and E5 landfills. Looking at Table 2 it can be said that most of the landfills are at the low end of typical concentrations for zinc.

### *4.4.3 Lead*

It was found that C3 and A1 had the highest concentration of lead between all the different landfills. However, these concentration fall within the typical range of concentrations found in Table 2. B2 and E5 were found to be lower than the other three landfills. The Post Hoc test revealed that A1 was significantly different than B2. C3 was also significantly different from B2, D4 and E5. There was no significant difference between A1 and C3.

### *4.4.4 Chromium*

All the landfills were found to have typical concentrations of chromium compared to Table 2. By looking at the five individual landfills, it was found that A1 and B2 had the highest concentrations among the landfills. Through the Post Hoc test, it was found that A1 was moderately significant to that of D4 and E5.

### 4.5 Volatile Organic Compounds

#### *4.5.1 BTEX*

For the BTEX's, only four of the five landfills had data. E5 data did not include any BTEX compounds that were looked at in this project. Looking at the four landfills that did sample for the BTEX compounds, it was found that C3 has the highest concentrations for all the BTEX's. Some of these numbers for C3, like toluene were extremely skewed due to sampling points that reached very high concentrations. It was seen for benzene that C3 was higher than the other landfills; however the one-way ANOVA test found that C3 was only significantly different than A1. For toluene it was found that C3 had a higher mean concentration than the other landfills. The one-way ANOVA test also found there to be a significant difference between the landfills for toluene. Ethyl benzene had C3 being different than A1, B2 and D4. The xylenes indicated C3 was different than A1, B2 and D4. This Post Hoc test affirms visual interpretations that C3 has high concentrations for BTEX's.

## 5.0 Discussion

### 5.1 Landfill Tonnage and Waste Diversion

As shown in Figure 1, the five cities were grouped into three separate categories for landfill tonnage rate. E5 and D4 were the lowest while A1 and B2 had moderate tonnage going into the landfill. C3 had a significantly higher tonnage rate than that of the other landfills. Possible reasons for this high tonnage rate could be due to the high population and number of landfills in operation. Another reason could be that this particular landfill is from a particular location where waste demand is high or maybe another landfill has just recently closed causing waste disposal to increase. This high landfill tonnage rate could also be caused by low waste

diversion. As seen in Figure 2, C3 is grouped along with E5 as the cities having the lowest waste diversion rates with approximately 10 -16% diversion of waste. A1, B2 and D4 were the cities that had significantly higher waste diversion rates.

## 5.2 Correlation between Leachate Parameters and Waste Diversion

To examine the influence of diversion rates on specific leachate parameters, these diversion rates will have to be combined with the leachate parameter concentrations found in Table 6. The results from Table 6 show the general characterization of the leachate samples throughout the different landfills. The leachate samples can been grouped into three parameters, which include:

- organic and inorganic constituents (BOD, COD and Chloride)
- metals (Calcium, Zinc, Lead, Copper and Chromium)
- volatile organic compounds (BTEX's)

### *5.2.1 BOD, COD and Chloride*

Unfortunately, not all the cities sampled for BOD, COD and chloride. A1 was the highest, probably due to it being the "youngest" of these landfills. It has been found that inorganic constituents are higher at earlier stages of a landfill and decrease with age (Lo, 1996). As mentioned above due to the limited landfill data for these parameters, it can not be determined if there are any trends present. Only observations can be made with the organic and inorganic parameters.

### *5.2.2 Calcium, Zinc, Lead, Copper and Chromium*

The next group of leachate parameters considered were the metals: calcium, zinc, lead, copper and chromium. It can be seen that for these metals A1 and C3 were usually the highest. Using the Post Hoc test it was found that A1 was primarly always different than the other

landfills except when compared to C3. This could be due to that heavy metals tend to have high concentrations at the early stages of a landfill operations (Kulikowska & Klimiuk, 2008; Lo, 1996) due to high acidity. There are many possibilities for the high metals in C3. One possibility would be the low diversion rate. Not having mandatory recycling could result excess metals and heavy metal material going to the landfill. However, E5's landfill contradicts this theory because it contains the lowest concentrations of metals for all the landfills. E5 concentrations seem to be consistently low probably due to the landfill being over 50 years old. The E5 landfill may be monitoring already biodegraded waste, which would have lower leachate concentrations; therefore may not accurately represent the city's waste composition.

There are other possibilities that C3 has high concentrations in metals. One reason could be due to waste composition and landfill operations. New waste can be mixed in with old waste, which could cause these high metals. The sporadic nature of the metals concentration is probably one of the reasons for the variability in the leachate between the different landfills. Referring back to the Post Hoc test it was determined that for C3, only lead had a significant difference between the different landfills. For the rest of the metal parameters, there was no difference. This could mean that even though C3 may visually be high in metals, they are still similar in concentration to the other landfills. All these reasons indicate that there can be no prediction on relationship between high waste diversion and lower concentrations of hazardous components like metals, based on the present data set.

### *5.2.3 BTEX*

The final group is the volatile organic compounds, that include benzene, toluene, ethyl benzene and xylene (BTEX). There were two trends found between the different landfills and the BTEX parameters. The first is that C3 has the highest concentration out of all the landfills. The

second trend is that A1 is significantly different than C3 for all four parameters, as well, A1 has the lowest concentration for three out of the four BTEX parameters. There is a significant difference between A1's and C3's waste diversion, which could mean there is a correlation between waste diversion and BTEX compounds. However, both A1 and C3 BTEX mean concentrations come with large standard deviations. This large standard deviation could mean possible error, which is probably caused by sampling error and the limited number of samples. Using the zero as no detection for certain parameters could also cause some error; however, when just omitting the no detection samples, A1 was still found to be low in the BTEX parameters.

It is interesting to see that for the BTEX parameters the A1, B2 and D4 with their high waste diversion rates have lower concentrations for these parameters compared to C3. As well, C3 is significantly different than the other landfills for three out of four parameters, while A1, B2 and C3 landfills have no difference between each other. These findings show a trend that high waste diversion could influence BTEX concentration. Unfortunately for the BTEX compounds, limited samples and the standard deviation was high for the parameters, which means the trend between waste diversion and BTEX could be skewed. Further data would be needed to better understand the exact reason for the concentrations found in the BTEX parameters.

## 5.3 Findings

After analysing all of the data, there was one trend that was significant throughout the metals and BTEX compounds. This was that C3 was high in a majority of these leachate parameters. This was especially evident in the BTEX compounds, where C3's parameters had significant differences from the other landfills. It was also found that for the BTEX parameters the cities with the higher waste diversion were always lower than C3. Referring back to Table 5,

C3 does not have mandatory recycling. This, plus one of the largest populations is one possible cause for C3 to have the most tonnage of material going into the landfill. This high tonnage rate of material going into the landfill, along with low percentages of material being diverted from the landfill, could be a possible reason why C3 landfill leachate concentrations are among the highest of all cities.

Reasoning would have you to believe that E5's landfill should be similar to C3 in parameter concentrations because it also has low waste diversion rates. However, E5 landfill leachate concentration is actually the opposite of C3's. It is even lower than A1, B2 and D4 landfills, which have high diversion rates and an active waste diversion program. This difference in data could be due to a number of factors, such as age of landfill (E5 landfill is over 50 years old), different landfill operation and what location and how the leachate was sampled. It could also mean that waste diversion does not affect leachate quality, which then disproves the trend found in C3. What ever the case, this report shows that leachate quality is extremly variable and is hard to determine any quantifiable conclusions; therefore continued research is needed to understand the effects on leachate quality.

## 6.0 Conclusion

This project has looked at the various aspects of an active waste diversion program. Recycling, composting and household hazardous waste collections have all been looked at to determine if they affect leachate quality. Using visual interpretation and statistical methods, there were two findings in this research. Through this study it was found that potentially there is a trend between waste diversion and the combination of proper waste management, to improve the quality of leachate within a landfill. However, the overall conclusion in this project would be that further research is needed on this topic in order to determine if waste diversion actually affects

leachate quality. From the results in this project it was shown that the prediction of landfill behavior is still uncertain, therefore the effects of waste diversion are more descriptive than predictive. The data was insufficient and appeared to have errors due to sampling and other landfill and waste components. There needs to be more data collected on each cities waste program and landfill operations in order to determine the reasons for the overall leachate concentration. It is believed that this report is a starting point and with sufficient data, further research will be conducted on this topic.

## 6.1 Recommendations

Due to the descriptive nature of the results, it is recommended that there should be more studies on the effects of waste diversion and leachate quality. There was a large amount of variability between the leachate parameters and the different landfills from the cities. To limit the variability of the leachate concentrations, increased monitoring should be done. It was found that certain parameters were only sampled two to four times in the provided data for this project. This limited the data and even skewed some parameters because one sample would be extremely high. Cities should monitor three to four times a year for certain parameters to have sufficient data for future projects. It would also give them more sufficient data to see what is occurring to the leachate concentrations with time.

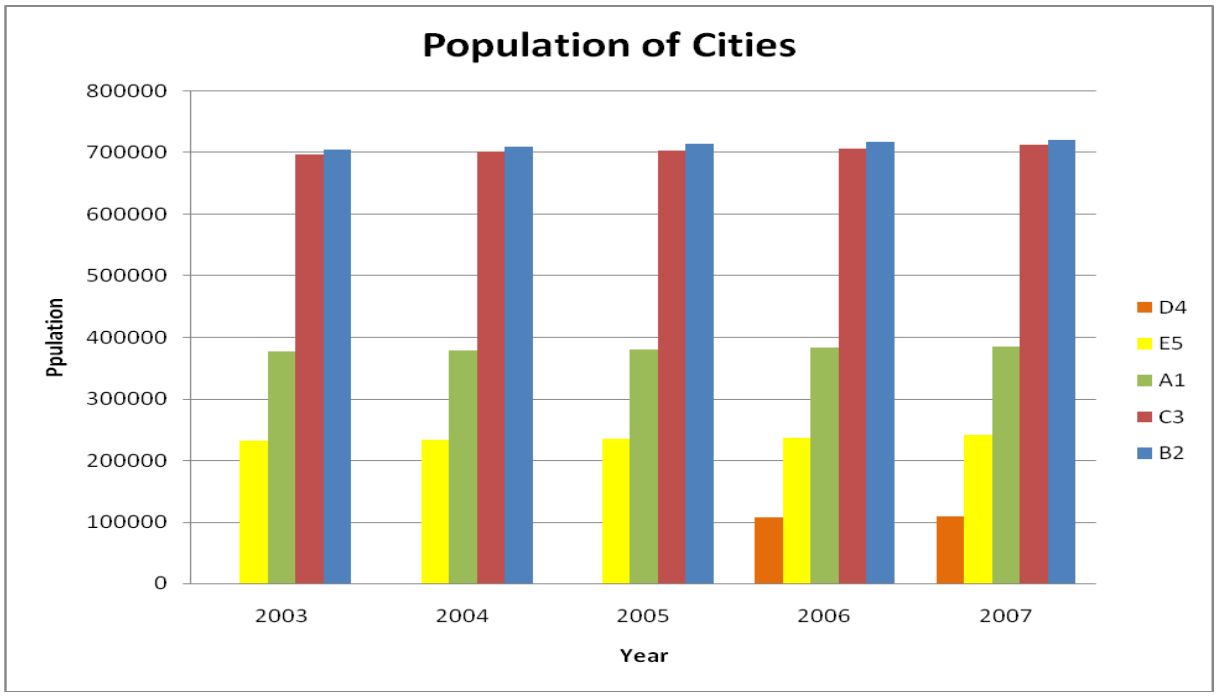
Another recommendation would be for cities to sample for specific parameters. In this project BOD, COD and chloride were not monitored by all landfills. These parameters show the biodegradability of the waste in the landfill along with the toxicity. Another set of parameters that should be monitored is volatile organic compounds like the BTEX's. These parameters were very limited with even one city not having data for them. As mentioned, more monitoring well

help future studies and improve landfill operations by understanding what leachate parameters are being produced and at what concentrations.

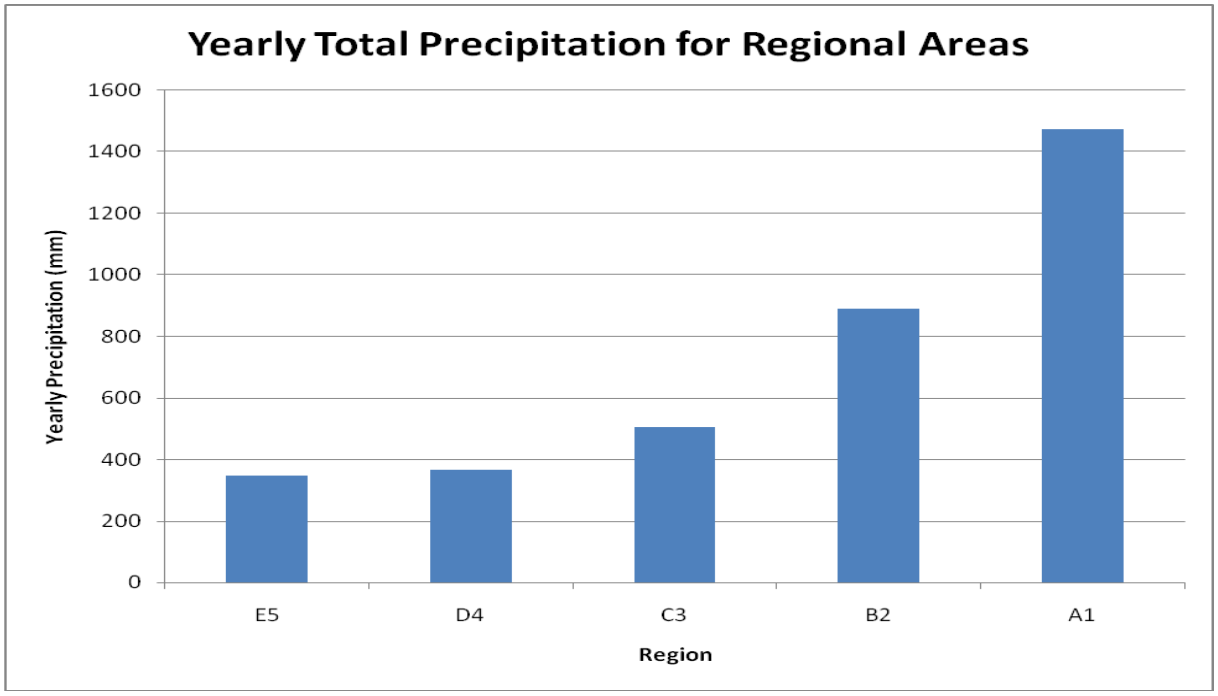
A final recommendation would be to conduct a controlled study. This controlled study would be to separate the waste before dumping it onto the land. This separation could then allow the person conducting the study to better understand what the waste components are. A study could consist of separating three separate piles of wastes and then placing them over top of a leachate monitoring station to find the difference in parameter concentration. Collins (1991) conducted a study like this and was able to find results. The problem with this is that these studies would be time consuming and costly. However, the variability in leachate is still unknown; therefore continued research on this topic is needed, to further our knowledge on leachate quality.

# Appendices

## Appendix A

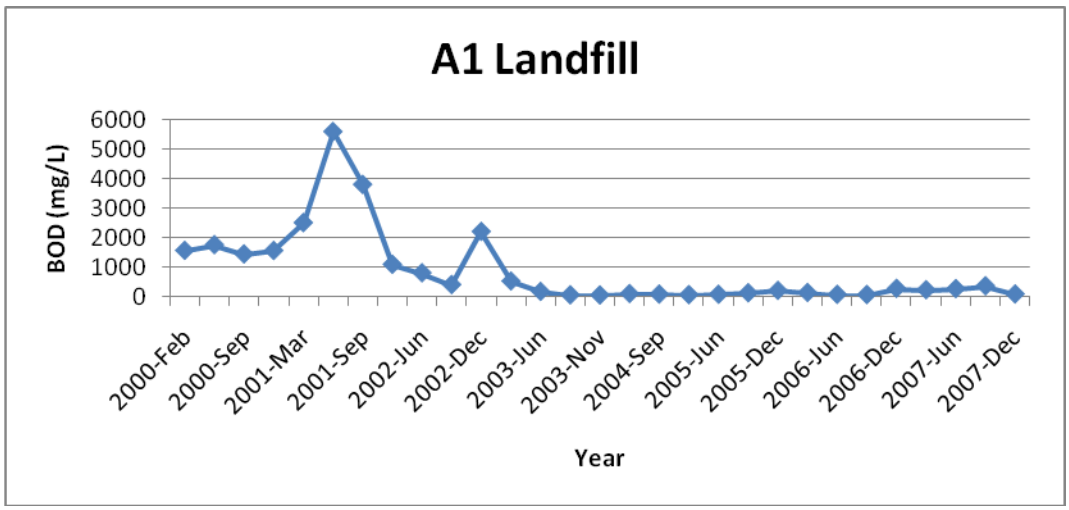


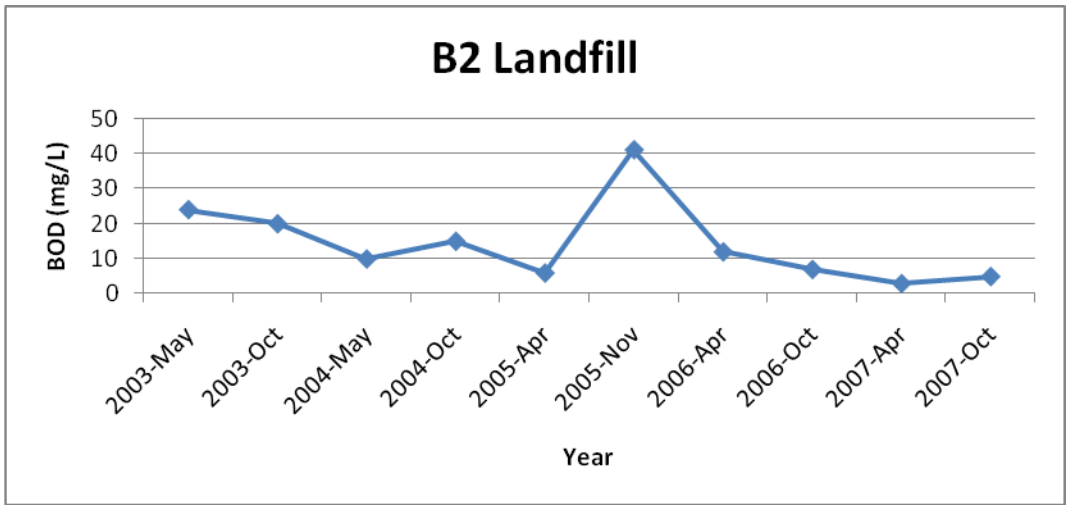
## Appendix B


Yearly Total Precipitation for Regional Areas
1600
1400
1200
1000
800
600
400
200
0
Yearly Precipitation (mm)
E5
D4
C3
B2
A1
Region

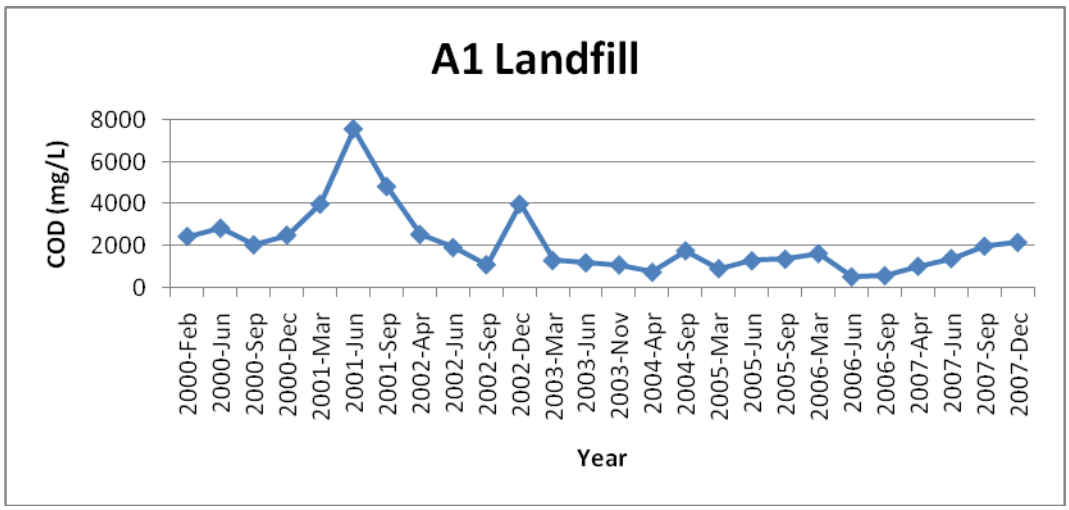
**Appendix C**

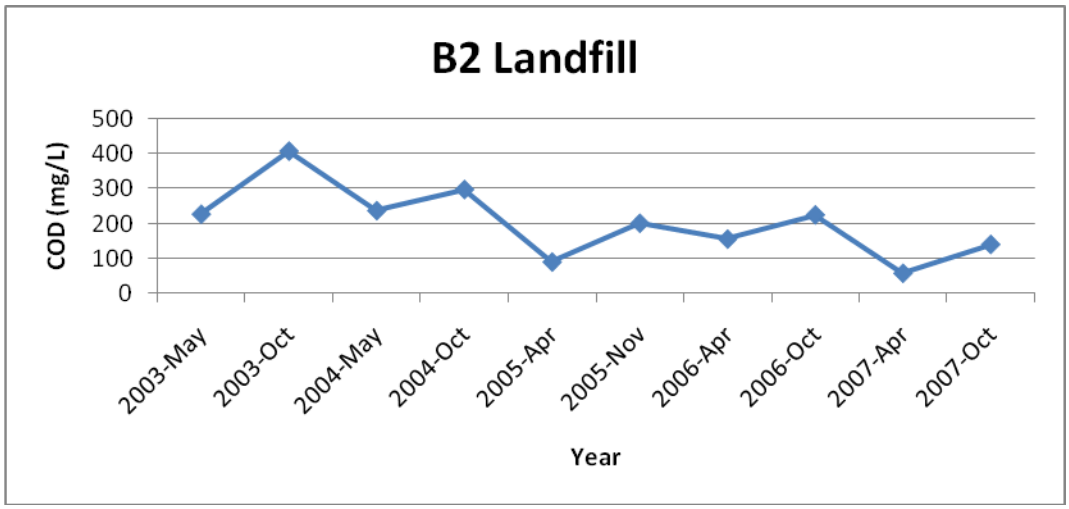
BOD



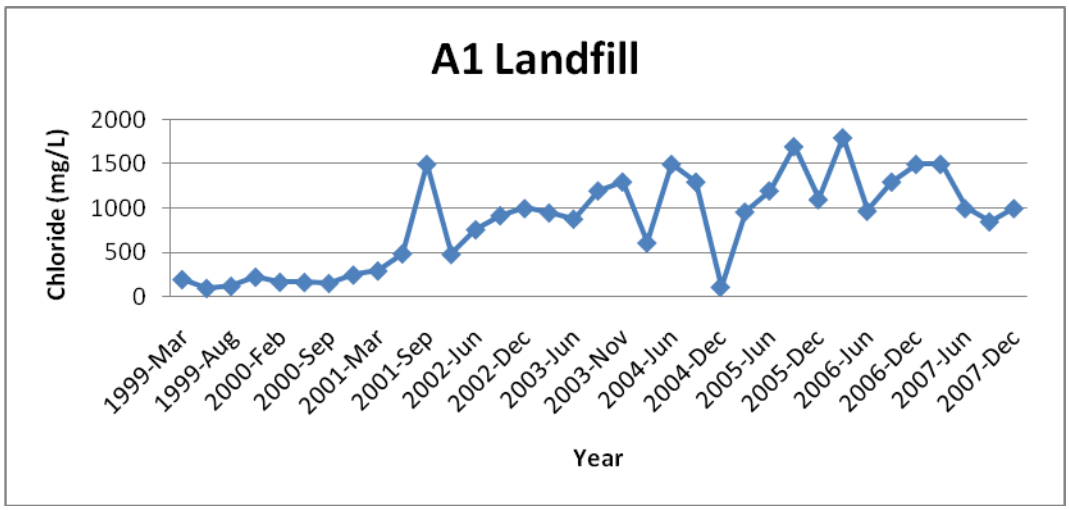



COD


A1 Landfill
COD (mg/L)
8000
6000
4000
2000
0
2000-Feb
2000-Jun
2000-Sep
2000-Dec
2001-Mar
2001-Jun
2001-Sep
2002-Apr
2002-Jun
2002-Sep
2002-Dec
2003-Mar
2003-Jun
2003-Nov
2004-Apr
2004-Sep
2005-Mar
2005-Jun
2005-Sep
2006-Mar
2006-Jun
2006-Sep
2007-Apr
2007-Jun
2007-Sep
2007-Dec
Year


B2 Landfill
COD (mg/L)
500
400
300
200
100
0
2003-May
2003-Oct
2004-May
2004-Oct
2005-Apr
2005-Nov
2006-Apr
2006-Oct
2007-Apr
2007-Oct
Year

Chloride


A1 Landfill
Chloride (mg/L)
2000
1500
1000
500
0
1999-Mar
1999-Aug
2000-Feb
2000-Sep
2001-Mar
2001-Sep
2002-Jun
2002-Dec
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2003-Nov
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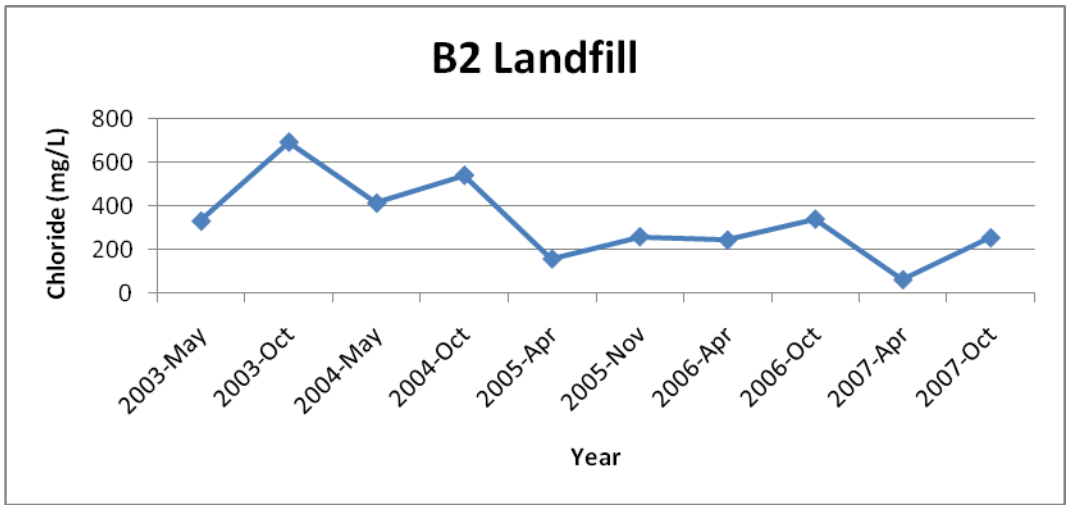
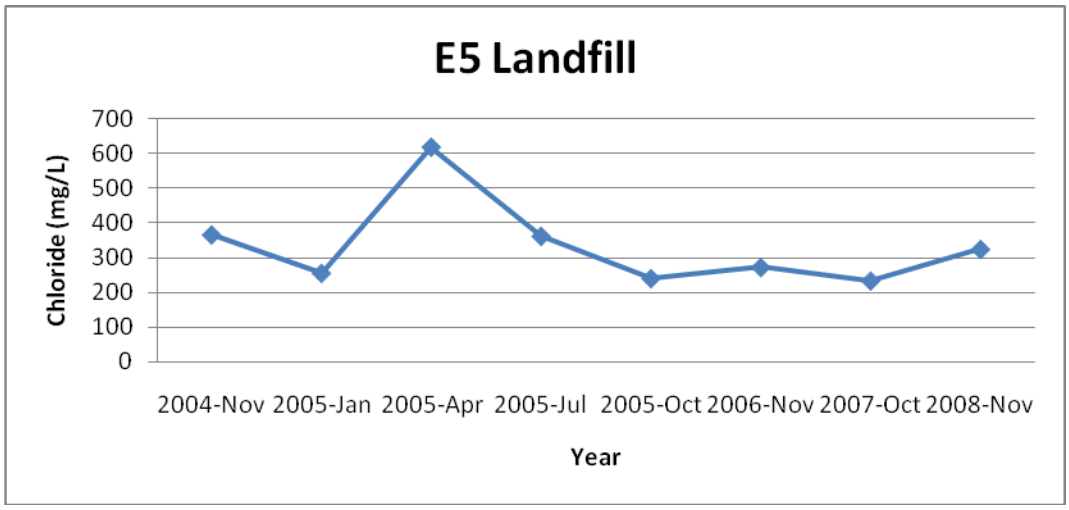
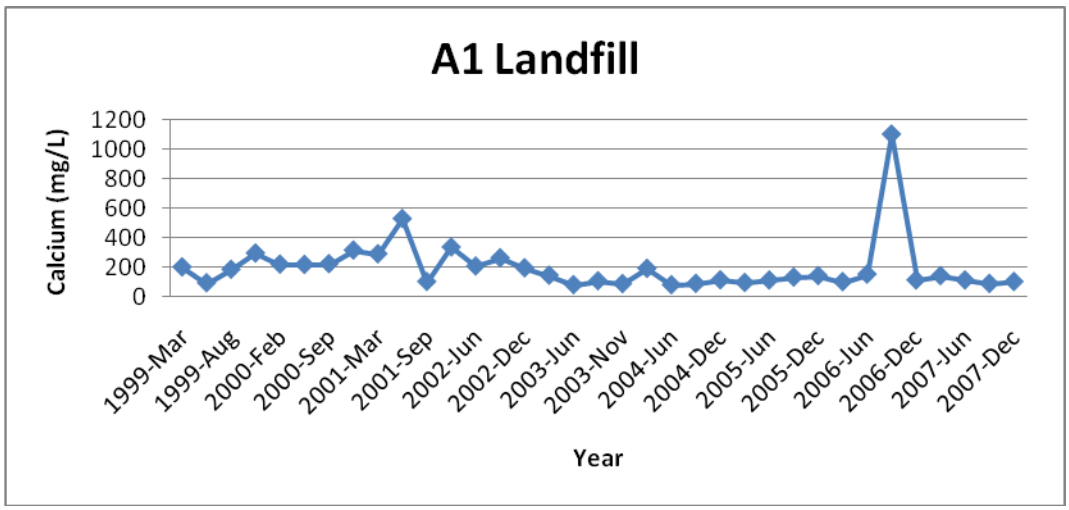
2004-Dec
2005-Jun
2005-Dec
2006-Jun
2006-Dec
2007-Jun
2007-Dec
Year


B2 Landfill
Chloride (mg/L)
800
600
400
200
0
2003-May
2003-Oct
2004-May
2004-Oct
2005-Apr
2005-Nov
2006-Apr
2006-Oct
2007-Apr
2007-Oct
Year


E5 Landfill
Chloride (mg/L)
700
600
500
400
300
200
100
0
2004-Nov
2005-Jan
2005-Apr
2005-Jul
2005-Oct
2006-Nov
2007-Oct
2008-Nov
Year

Calcium


A1 Landfill
Calcium (mg/L)
1200
1000
800
600
400
200
0
1999-Mar
1999-Aug
2000-Feb
2000-Sep
2001-Mar
2001-Sep
2002-Jun
2002-Dec
2003-Jun
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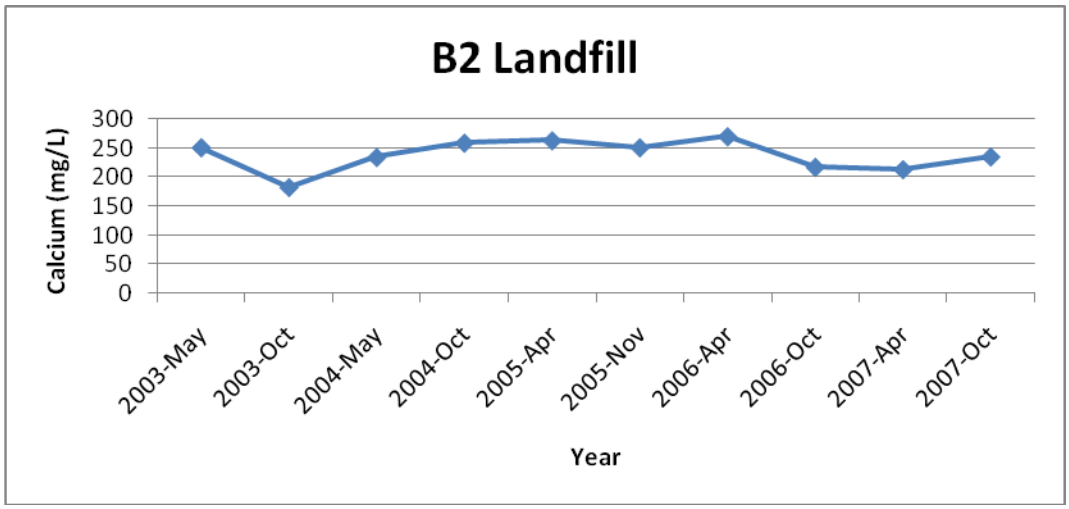
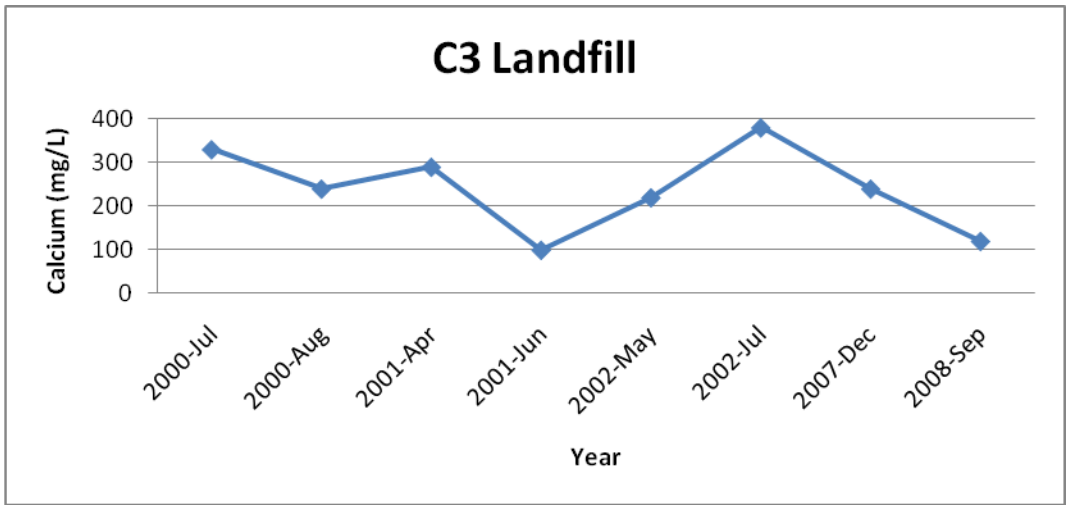
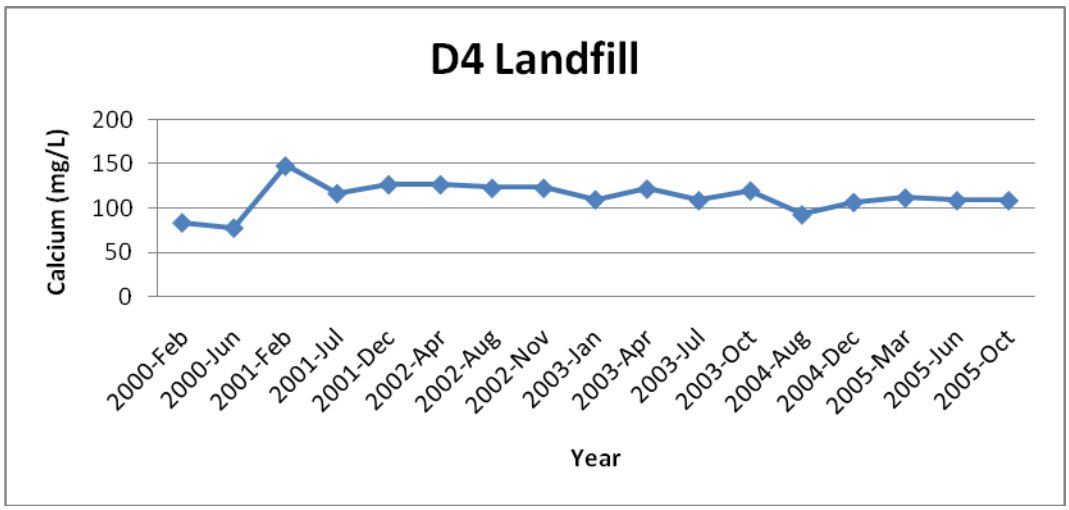
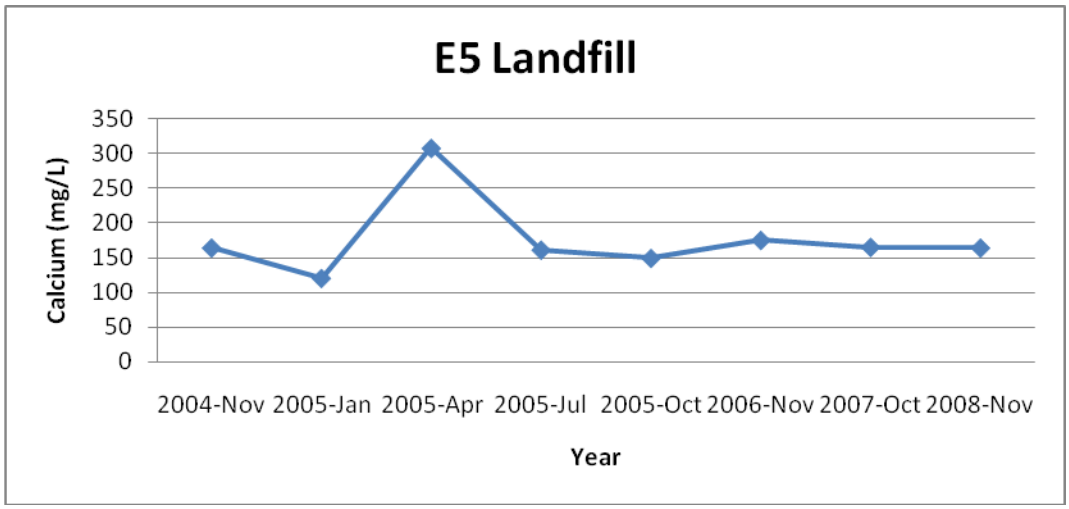
2005-Dec
2006-Jun
2006-Dec
2007-Jun
2007-Dec
Year


B2 Landfill
Calcium (mg/L)
300
250
200
150
100
50
0
2003-May
2003-Oct
2004-May
2004-Oct
2005-Apr
2005-Nov
2006-Apr
2006-Oct
2007-Apr
2007-Oct
Year

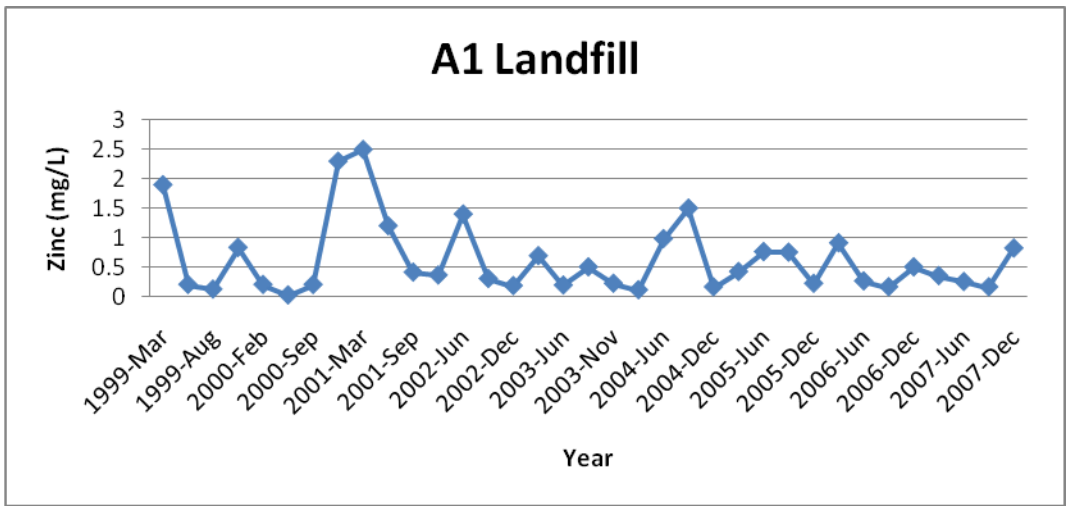

C3 Landfill
Calcium (mg/L)
400
300
200
100
0
2000-Jul
2000-Aug
2001-Apr
2001-Jun
2002-May
2002-Jul
2007-Dec
2008-Sep
Year

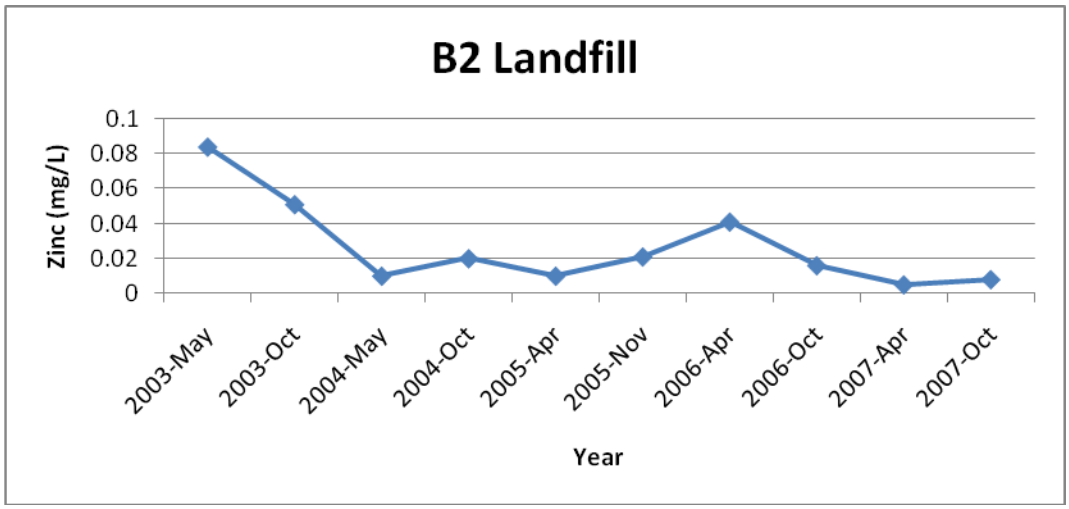
Calcium

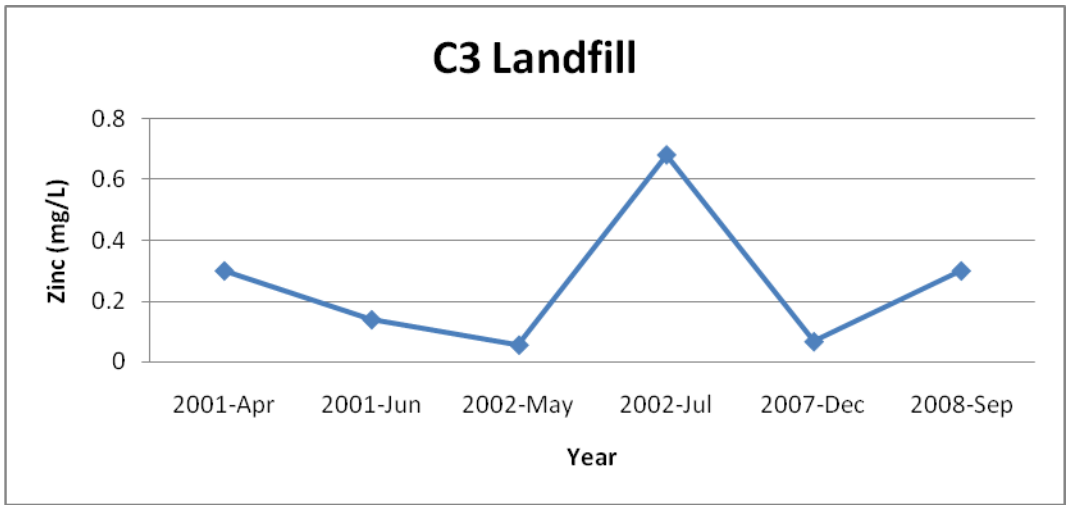

D4 Landfill
Calcium (mg/L)
200
150
100
50
0
2000-Feb
2000-Jun
2001-Feb
2001-Jul
2001-Dec
2002-Apr
2002-Aug
2002-Nov
2003-Jan
2003-Apr
2003-Jul
2003-Oct
2004-Aug
2004-Dec
2005-Mar
2005-Jun
2005-Oct
Year


E5 Landfill
Calcium (mg/L)
350
300
250
200
150
100
50
0
2004-Nov
2005-Jan
2005-Apr
2005-Jul
2005-Oct
2006-Nov
2007-Oct
2008-Nov
Year

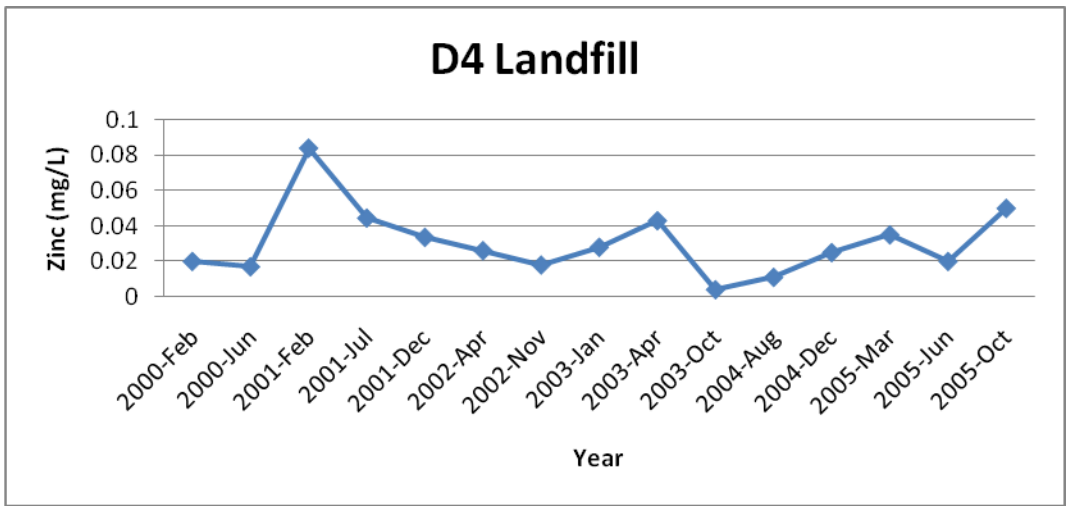
Zinc

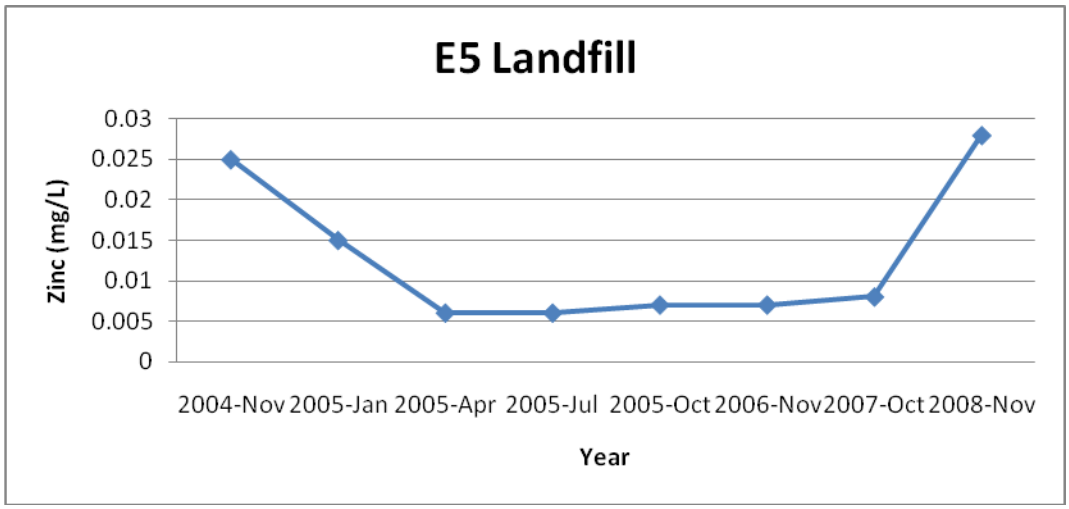

A1 Landfill
Zinc (mg/L)
3
2.5
2
1.5
1
0.5
0
1999-Mar
1999-Aug
2000-Feb
2000-Sep
2001-Mar
2001-Sep
2002-Jun
2002-Dec
2003-Jun
2003-Nov
2004-Jun
2004-Dec
2005-Jun
2005-Dec
2006-Jun
2006-Dec
2007-Jun
2007-Dec
Year


B2 Landfill
Zinc (mg/L)
0.1
0.08
0.06
0.04
0.02
0
2003-May
2003-Oct
2004-May
2004-Oct
2005-Apr
2005-Nov
2006-Apr
2006-Oct
2007-Apr
2007-Oct
Year

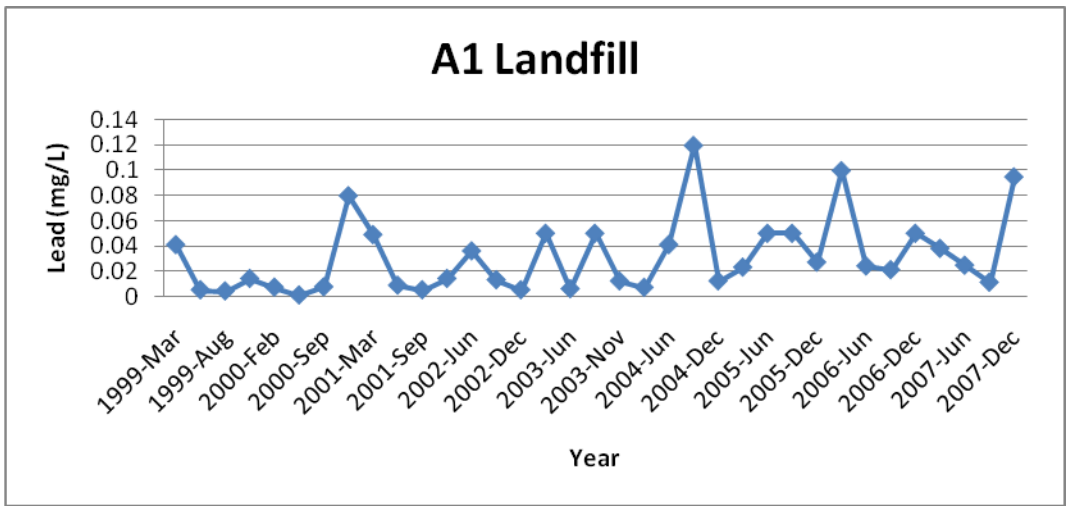

C3 Landfill
Zinc (mg/L)
0.8
0.6
0.4
0.2
0
2001-Apr
2001-Jun
2002-May
2002-Jul
2007-Dec
2008-Sep
Year

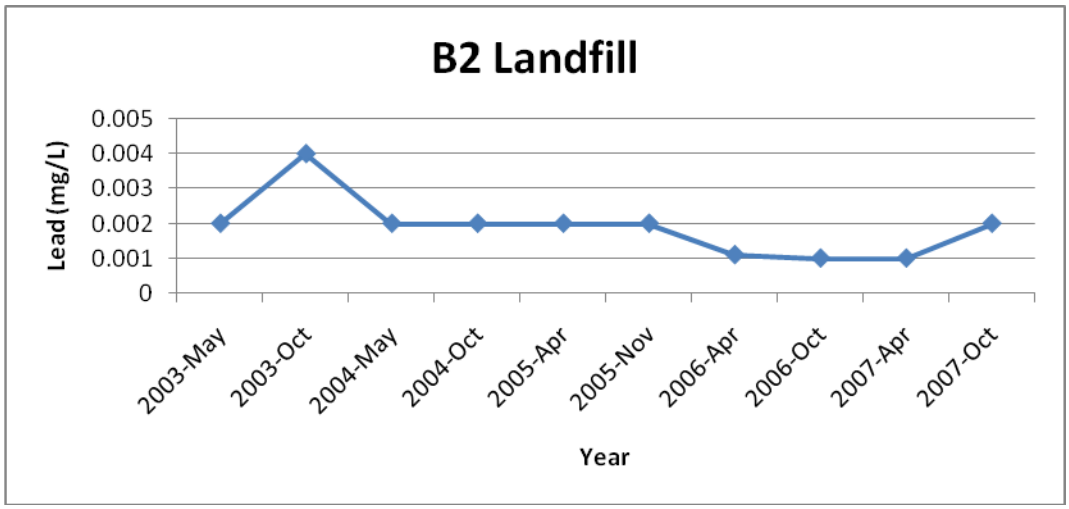
Zinc

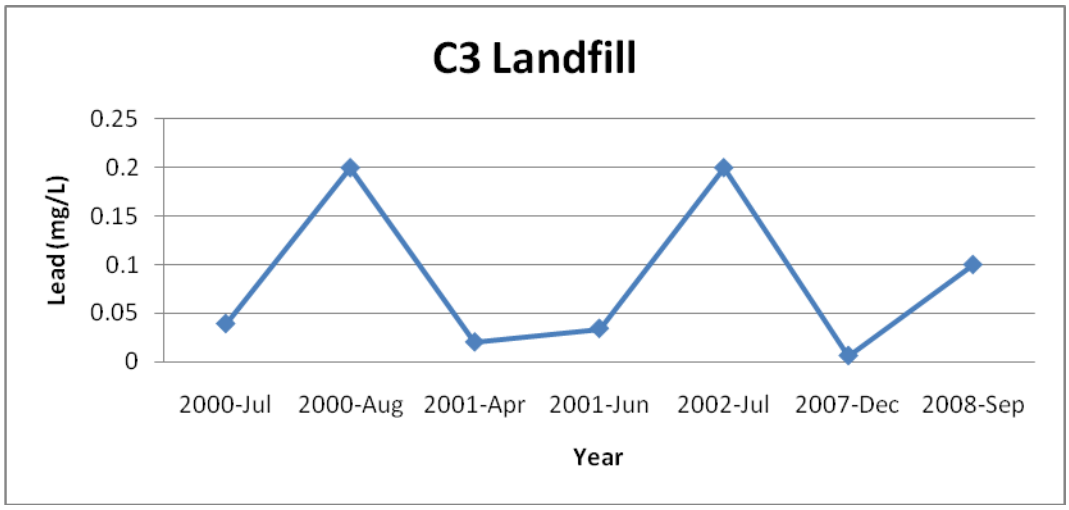

D4 Landfill
Zinc (mg/L)
0.1
0.08
0.06
0.04
0.02
0
2000-Feb
2000-Jun
2001-Feb
2001-Jul
2001-Dec
2002-Apr
2002-Nov
2003-Jan
2003-Apr
2003-Oct
2004-Aug
2004-Dec
2005-Mar
2005-Jun
2005-Oct
Year


E5 Landfill
Zinc (mg/L)
0.03
0.025
0.02
0.015
0.01
0.005
0
2004-Nov
2005-Jan
2005-Apr
2005-Jul
2005-Oct
2006-Nov
2007-Oct
2008-Nov
Year

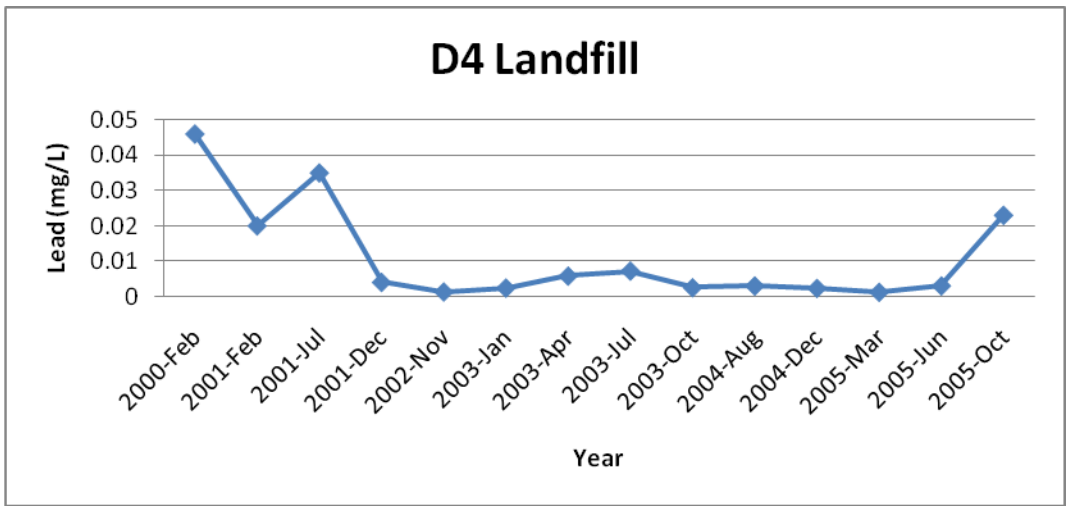
Lead

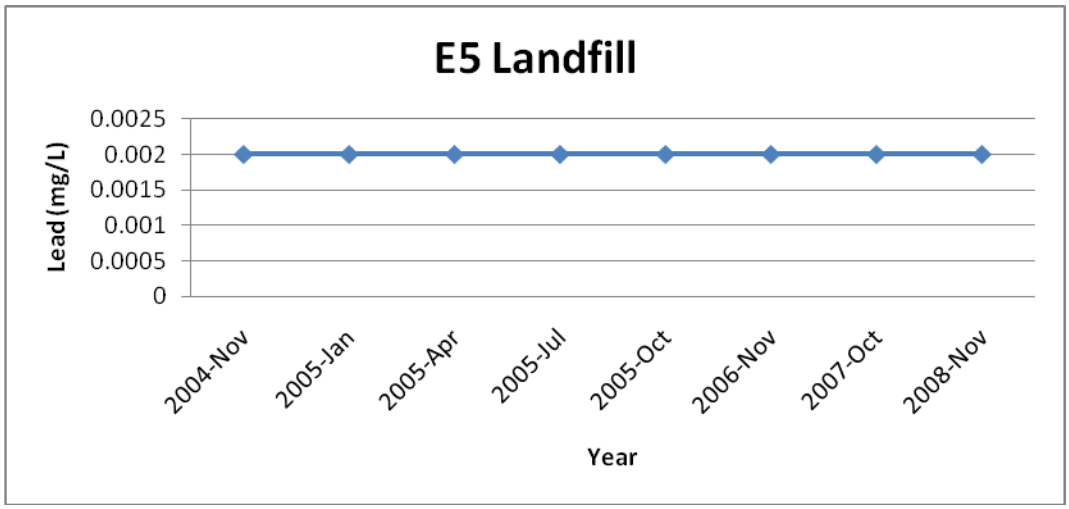

A1 Landfill
Lead (mg/L)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1999-Mar
1999-Aug
2000-Feb
2000-Sep
2001-Mar
2001-Sep
2002-Jun
2002-Dec
2003-Jun
2003-Nov
2004-Jun
2004-Dec
2005-Jun
2005-Dec
2006-Jun
2006-Dec
2007-Jun
2007-Dec
Year


B2 Landfill
Lead (mg/L)
0.005
0.004
0.003
0.002
0.001
0
2003-May
2003-Oct
2004-May
2004-Oct
2005-Apr
2005-Nov
2006-Apr
2006-Oct
2007-Apr
2007-Oct
Year

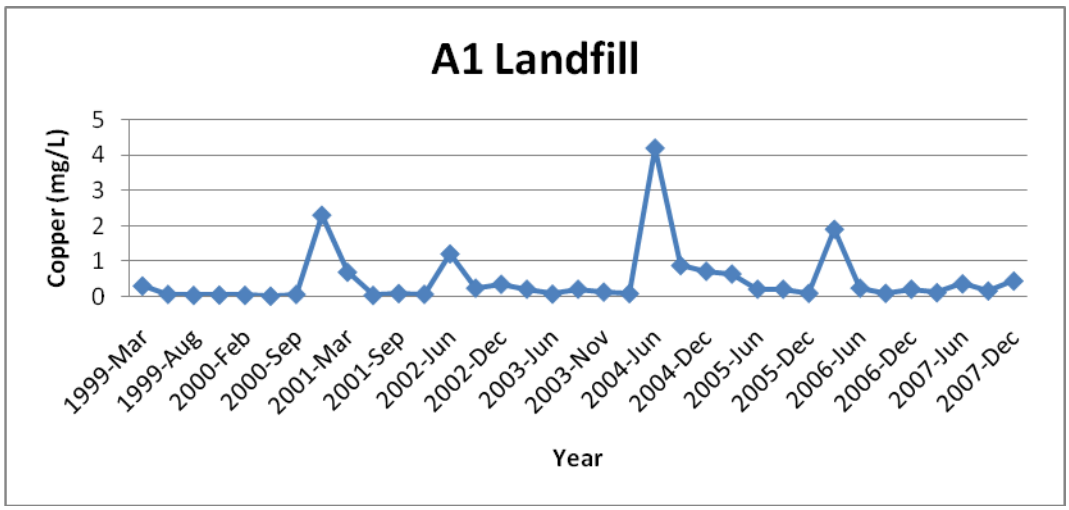

C3 Landfill
Lead (mg/L)
0.25
0.2
0.15
0.1
0.05
0
2000-Jul
2000-Aug
2001-Apr
2001-Jun
2002-Jul
2007-Dec
2008-Sep
Year

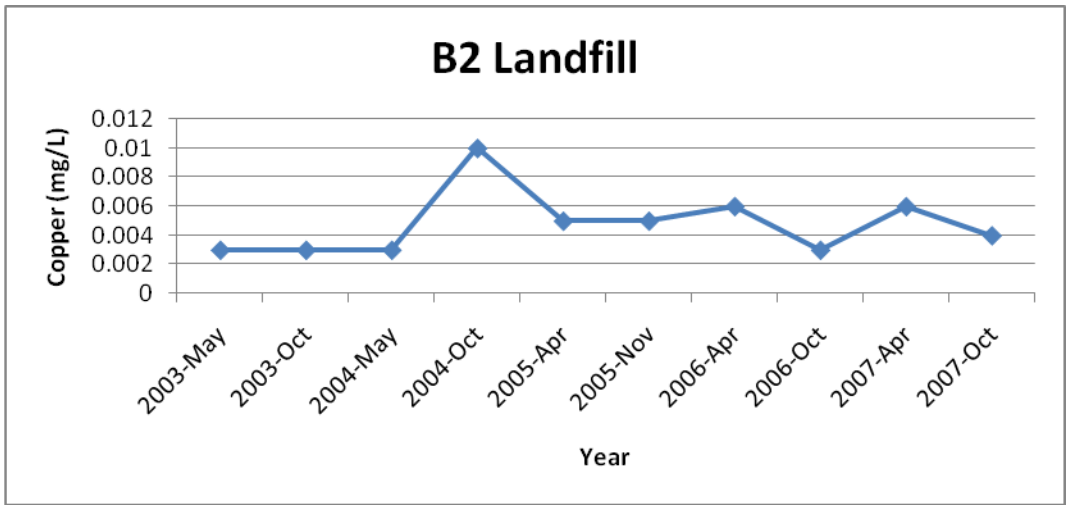
Lead

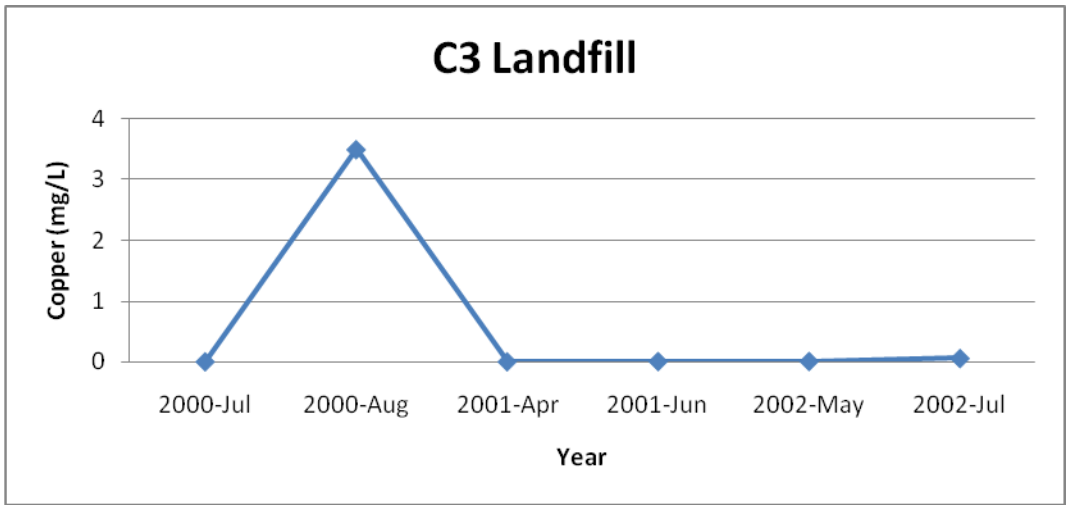

D4 Landfill
Lead (mg/L)
0.05
0.04
0.03
0.02
0.01
0
2000-Feb
2001-Feb
2001-Jul
2001-Dec
2002-Nov
2003-Jan
2003-Apr
2003-Jul
2003-Oct
2004-Aug
2004-Dec
2005-Mar
2005-Jun
2005-Oct
Year


E5 Landfill
Lead (mg/L)
0.0025
0.002
0.0015
0.001
0.0005
0
2004-Nov
2005-Jan
2005-Apr
2005-Jul
2005-Oct
2006-Nov
2007-Oct
2008-Nov
Year

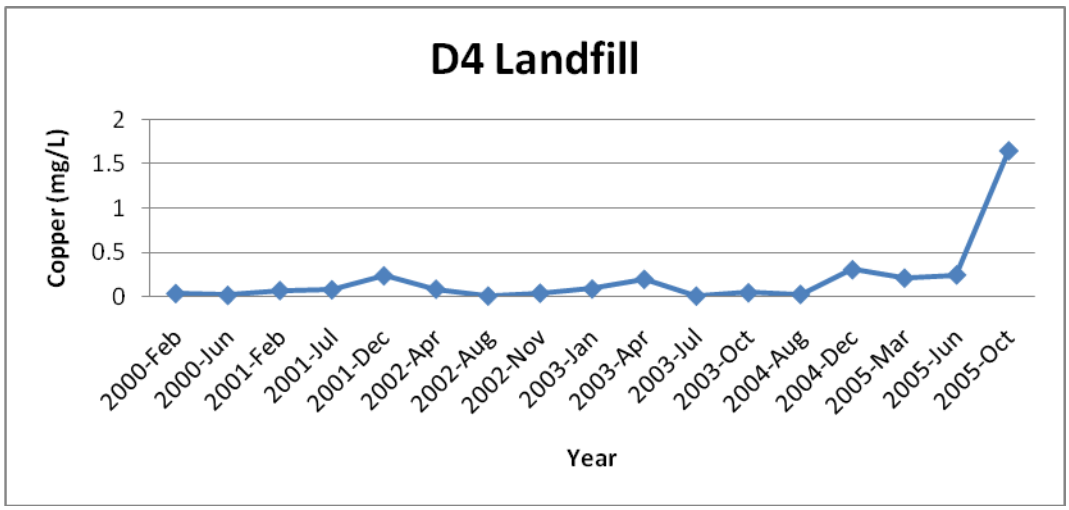
Copper

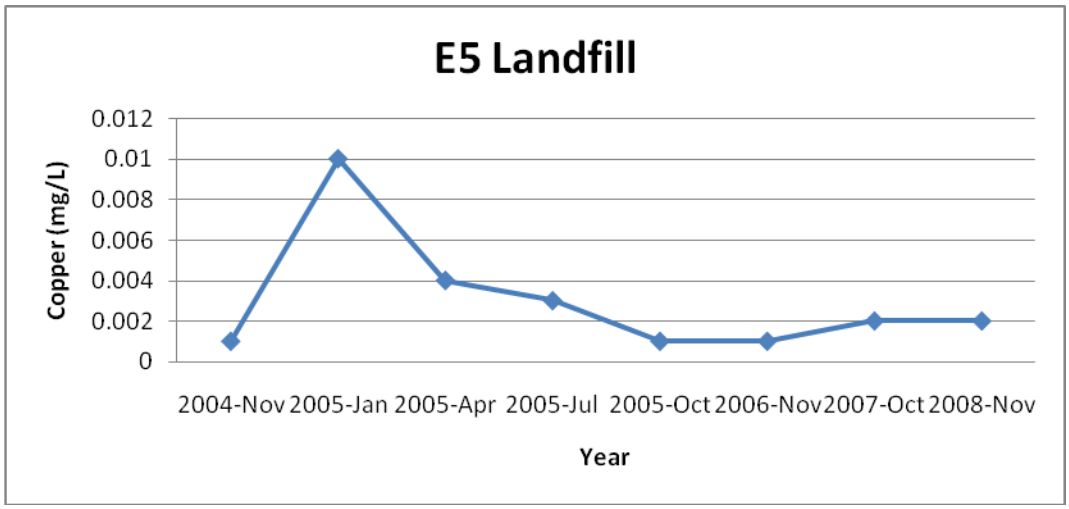

A1 Landfill
Copper (mg/L)
5
4
3
2
1
0
1999-Mar
1999-Aug
2000-Feb
2000-Sep
2001-Mar
2001-Sep
2002-Jun
2002-Dec
2003-Jun
2003-Nov
2004-Jun
2004-Dec
2005-Jun
2005-Dec
2006-Jun
2006-Dec
2007-Jun
2007-Dec
Year


B2 Landfill
Copper (mg/L)
0.012
0.01
0.008
0.006
0.004
0.002
0
2003-May
2003-Oct
2004-May
2004-Oct
2005-Apr
2005-Nov
2006-Apr
2006-Oct
2007-Apr
2007-Oct
Year

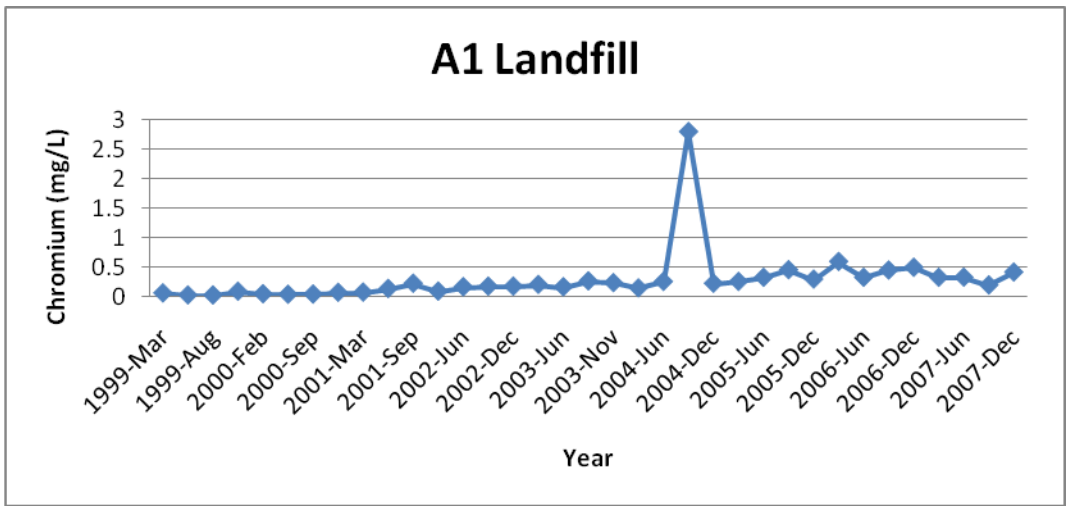

C3 Landfill
Copper (mg/L)
4
3
2
1
0
2000-Jul
2000-Aug
2001-Apr
2001-Jun
2002-May
2002-Jul
Year

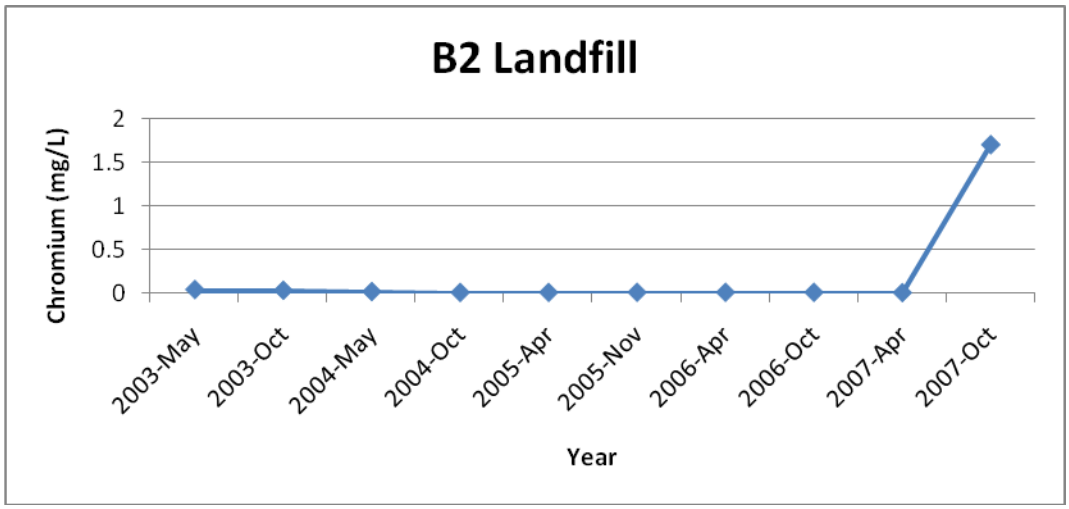
Copper

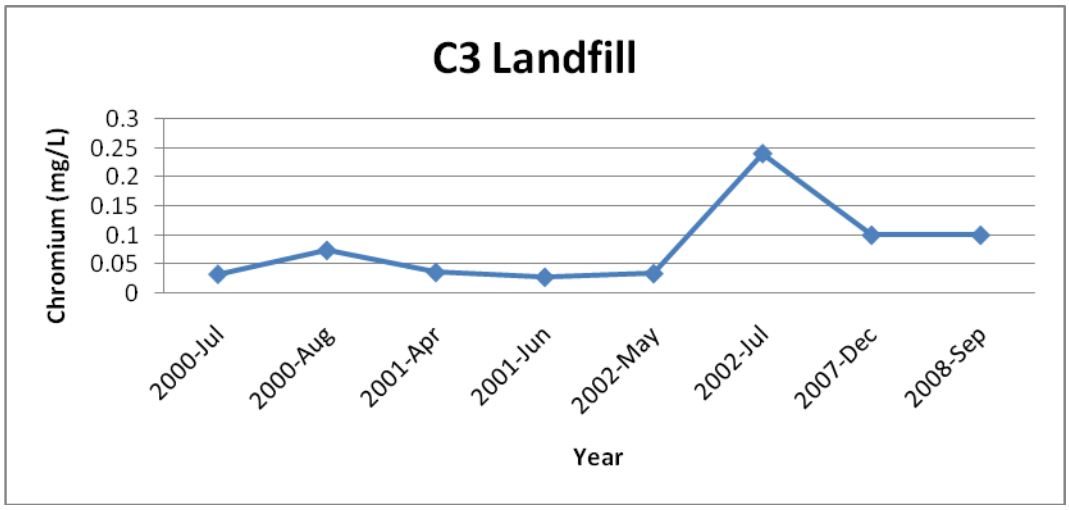

D4 Landfill
Copper (mg/L)
2
1.5
1
0.5
0
2000-Feb
2000-Jun
2001-Feb
2001-Jul
2001-Dec
2002-Apr
2002-Aug
2002-Nov
2003-Jan
2003-Apr
2003-Jul
2003-Oct
2004-Aug
2004-Dec
2005-Mar
2005-Jun
2005-Oct
Year


E5 Landfill
Copper (mg/L)
0.012
0.01
0.008
0.006
0.004
0.002
0
2004-Nov
2005-Jan
2005-Apr
2005-Jul
2005-Oct
2006-Nov
2007-Oct
2008-Nov
Year

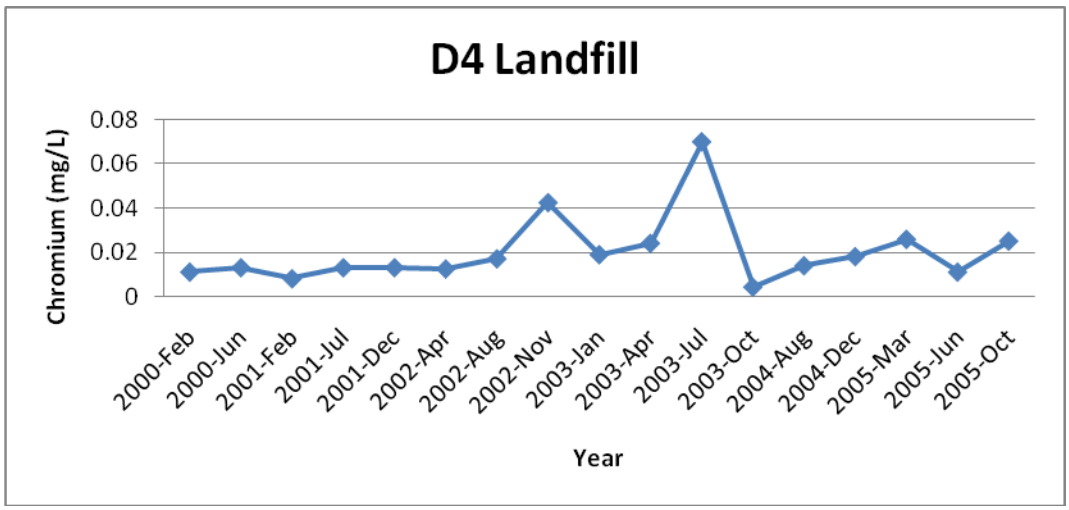
Chromium

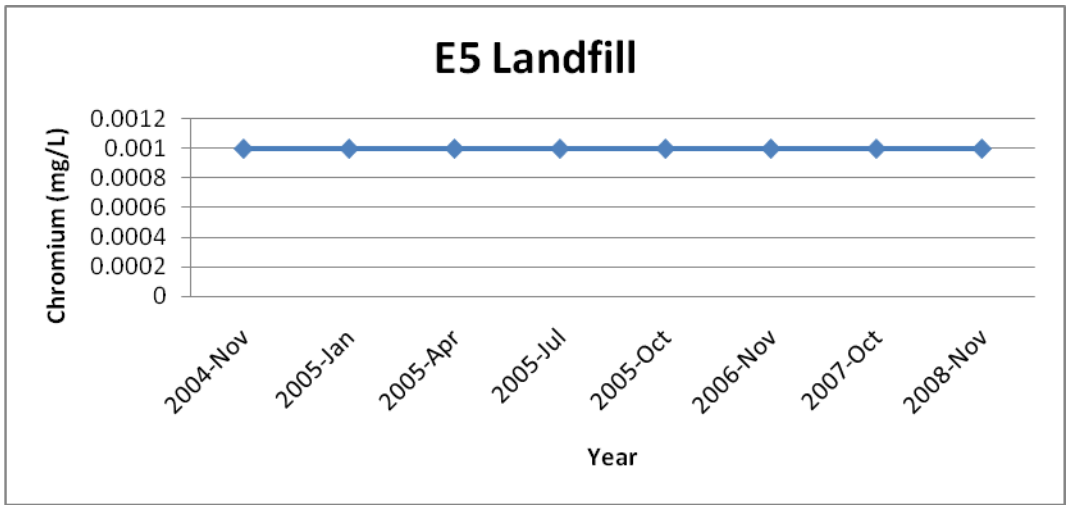

A1 Landfill
Chromium (mg/L)
3
2.5
2
1.5
1
0.5
0
1999-Mar
1999-Aug
2000-Feb
2000-Sep
2001-Mar
2001-Sep
2002-Jun
2002-Dec
2003-Jun
2003-Nov
2004-Jun
2004-Dec
2005-Jun
2005-Dec
2006-Jun
2006-Dec
2007-Jun
2007-Dec
Year


B2 Landfill
Chromium (mg/L)
2
1.5
1
0.5
0
2003-May
2003-Oct
2004-May
2004-Oct
2005-Apr
2005-Nov
2006-Apr
2006-Oct
2007-Apr
2007-Oct
Year

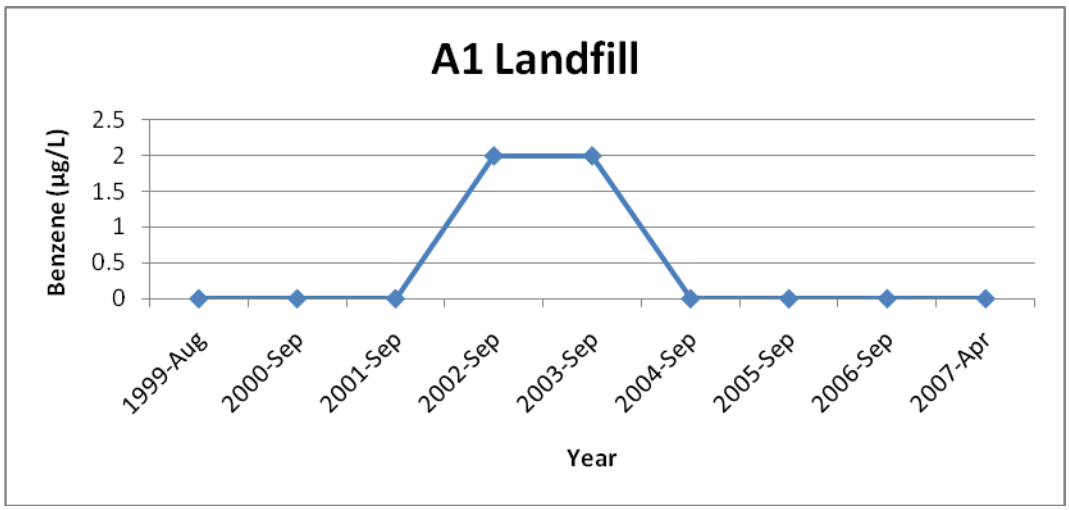

C3 Landfill
Chromium (mg/L)
0.3
0.25
0.2
0.15
0.1
0.05
0
2000-Jul
2000-Aug
2001-Apr
2001-Jun
2002-May
2002-Jul
2007-Dec
2008-Sep
Year

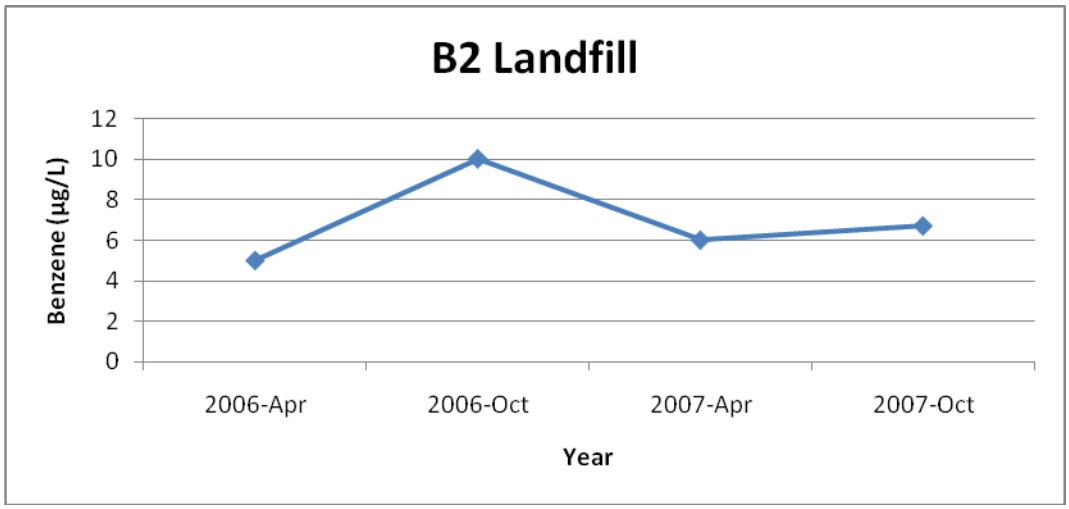
Chromium


D4 Landfill
Chromium (mg/L)
0.08
0.06
0.04
0.02
0
2000-Feb
2000-Jun
2001-Feb
2001-Jul
2001-Dec
2002-Apr
2002-Aug
2002-Nov
2003-Jan
2003-Apr
2003-Jul
2003-Oct
2004-Aug
2004-Dec
2005-Mar
2005-Jun
2005-Oct
Year

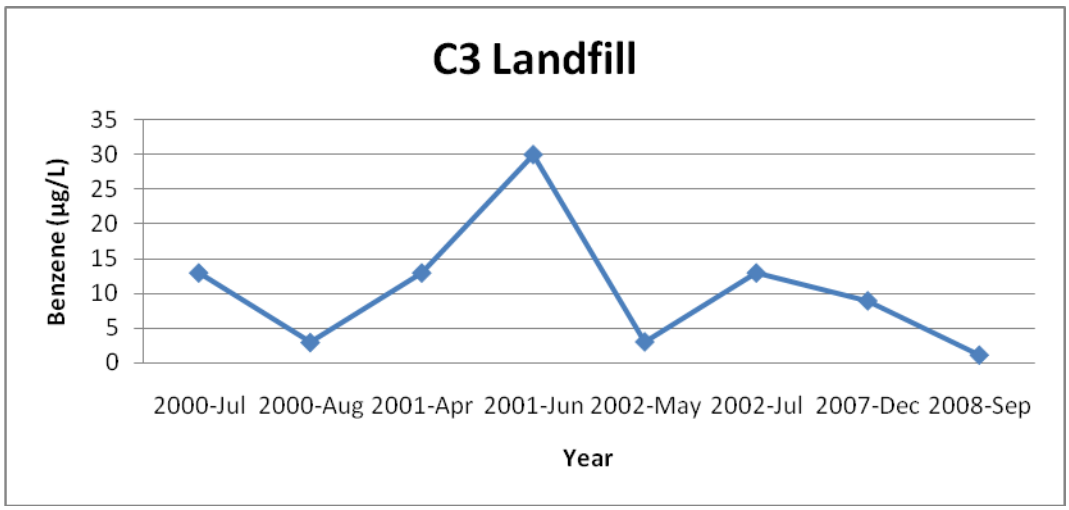

E5 Landfill
Chromium (mg/L)
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
0
2004-Nov
2005-Jan
2005-Apr
2005-Jul
2005-Oct
2006-Nov
2007-Oct
2008-Nov
Year

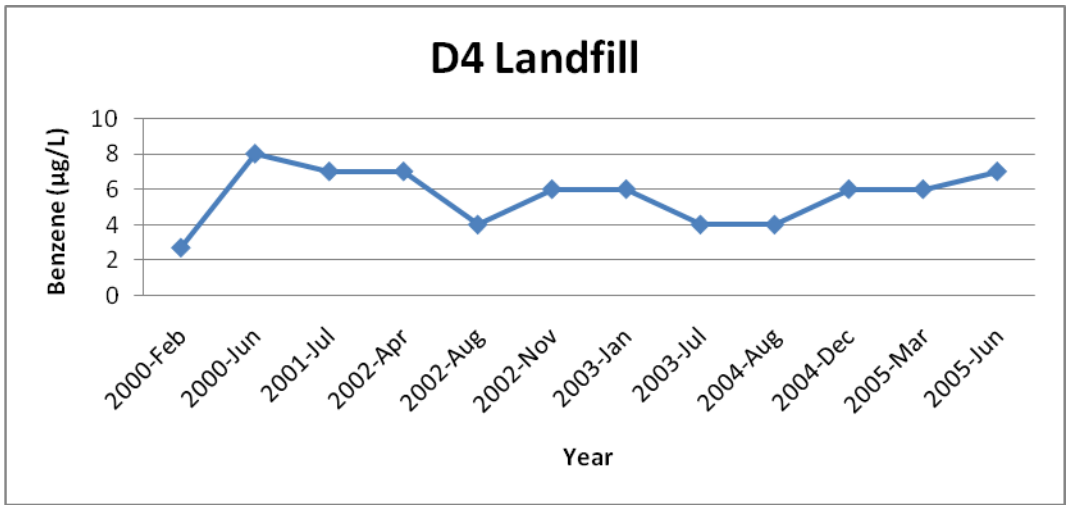
Benzene


A1 Landfill
Benzene (µg/L)
2.5
2
1.5
1
0.5
0
1999-Aug
2000-Sep
2001-Sep
2002-Sep
2003-Sep
2004-Sep
2005-Sep
2006-Sep
2007-Apr
Year

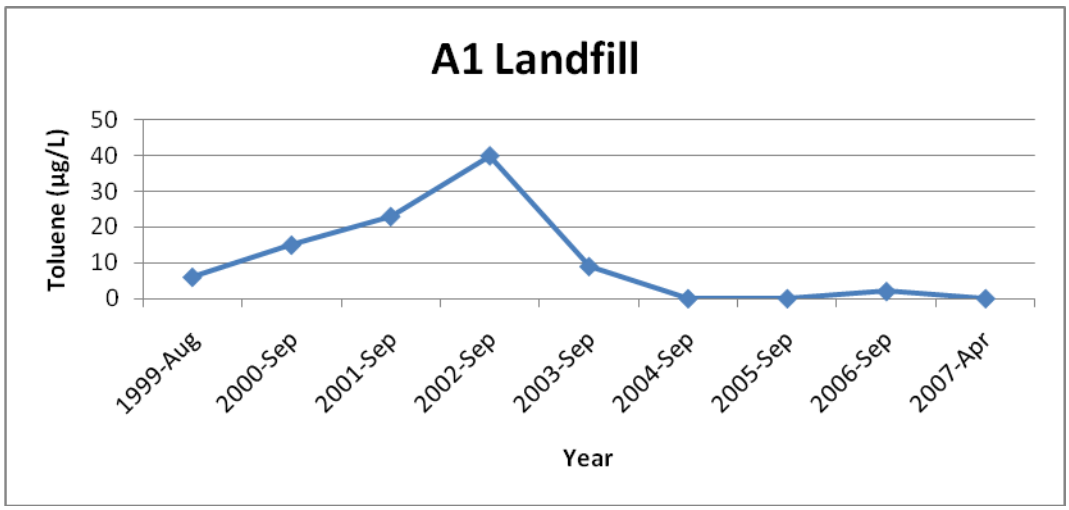

B2 Landfill
Benzene (µg/L)
12
10
8
6
4
2
0
2006-Apr
2006-Oct
2007-Apr
2007-Oct
Year

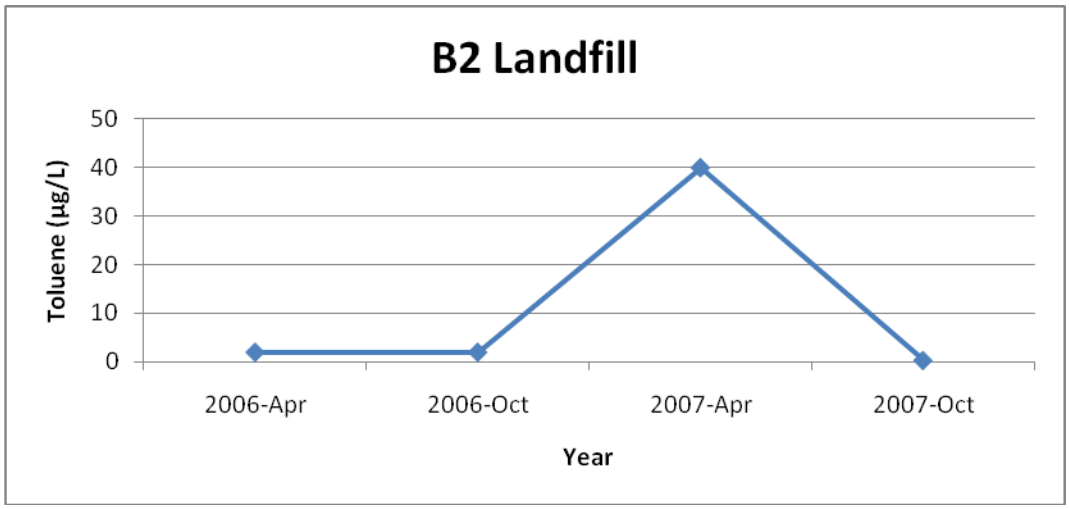
Benzene


C3 Landfill
Benzene (µg/L)
35
30
25
20
15
10
5
0
2000-Jul
2000-Aug
2001-Apr
2001-Jun
2002-May
2002-Jul
2007-Dec
2008-Sep
Year

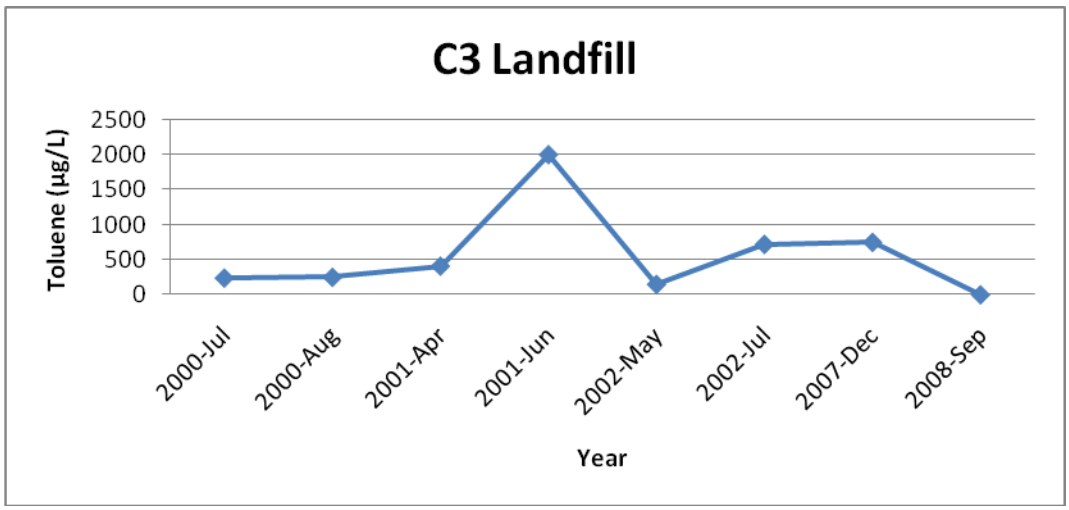

D4 Landfill
Benzene (µg/L)
10
8
6
4
2
0
2000-Feb
2000-Jun
2001-Jul
2002-Apr
2002-Aug
2002-Nov
2003-Jan
2003-Jul
2004-Aug
2004-Dec
2005-Mar
2005-Jun
Year

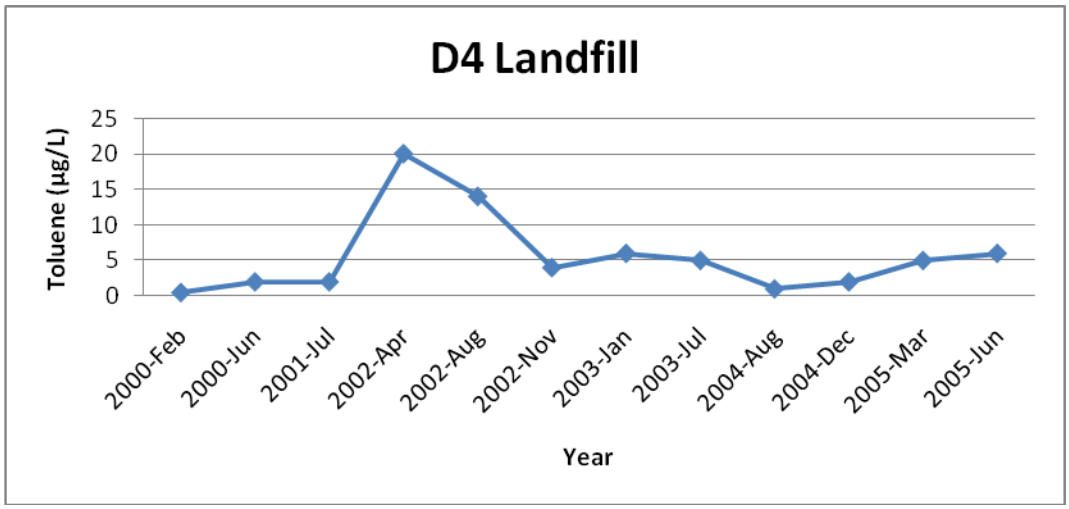
Toluene


A1 Landfill
Toluene (µg/L)
50
40
30
20
10
0
1999-Aug
2000-Sep
2001-Sep
2002-Sep
2003-Sep
2004-Sep
2005-Sep
2006-Sep
2007-Apr
Year

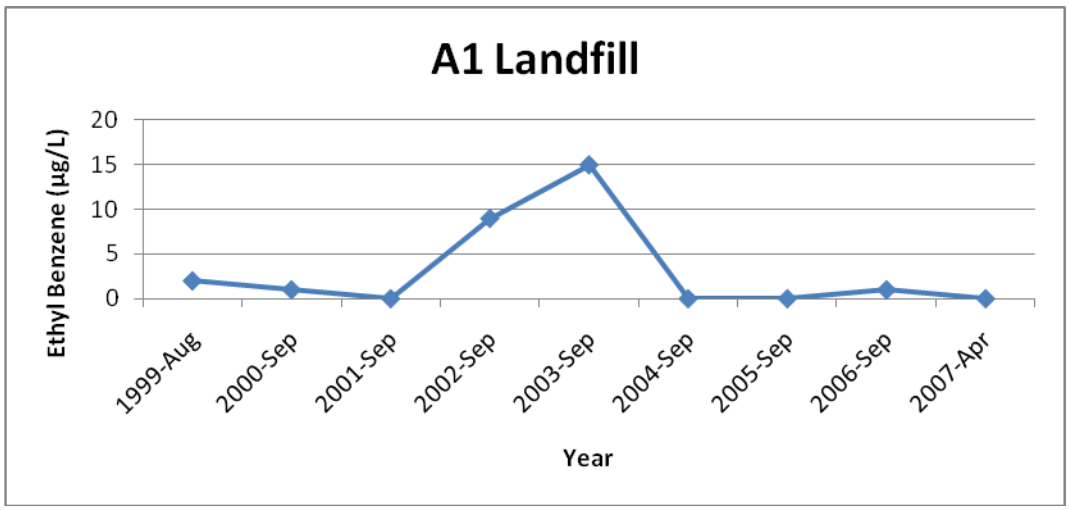

B2 Landfill
Toluene (µg/L)
50
40
30
20
10
0
2006-Apr
2006-Oct
2007-Apr
2007-Oct
Year

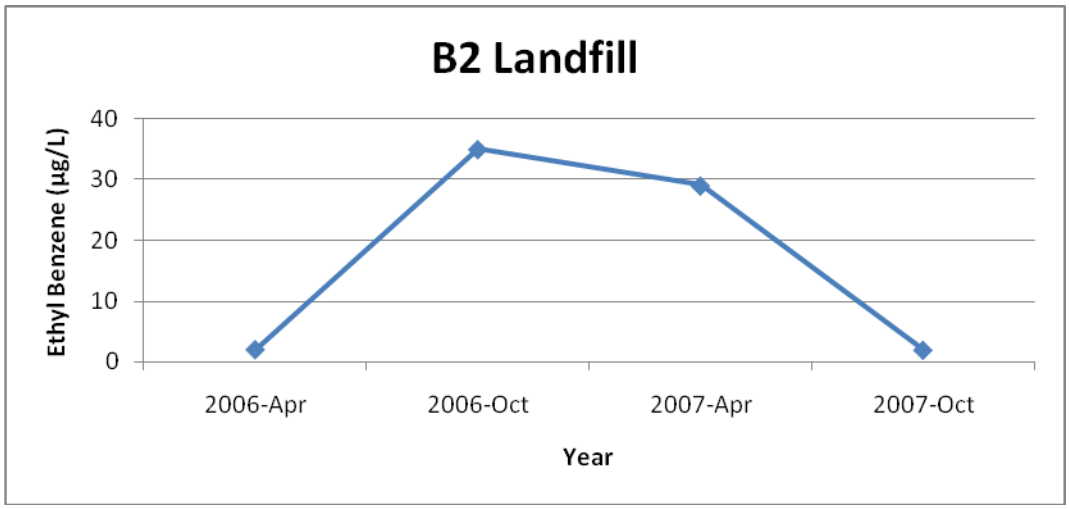
Toluene


C3 Landfill
Toluene (µg/L)
2500
2000
1500
1000
500
0
2000-Jul
2000-Aug
2001-Apr
2001-Jun
2002-May
2002-Jul
2007-Dec
2008-Sep
Year

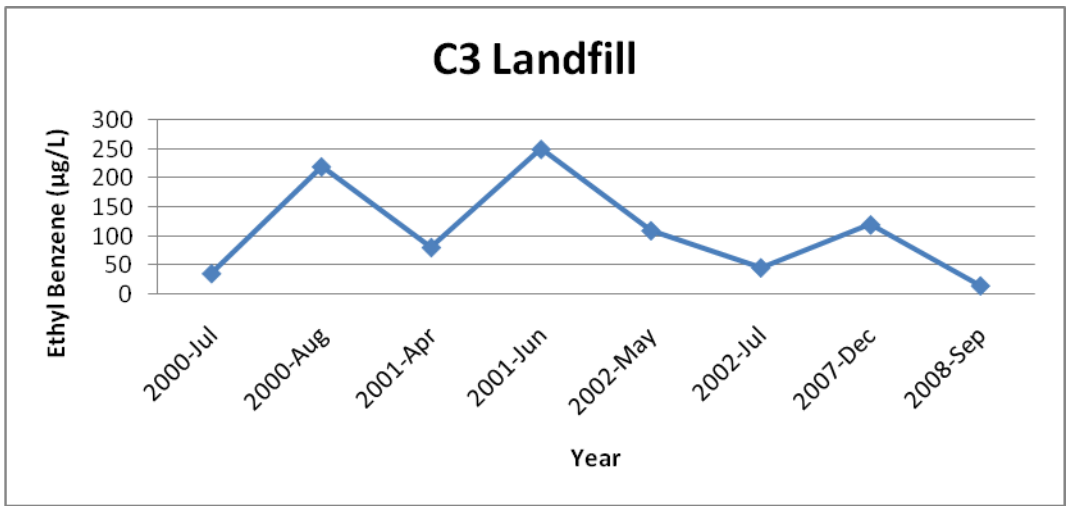

D4 Landfill
Toluene (µg/L)
25
20
15
10
5
0
2000-Feb
2000-Jun
2001-Jul
2002-Apr
2002-Aug
2002-Nov
2003-Jan
2003-Jul
2004-Aug
2004-Dec
2005-Mar
2005-Jun
Year

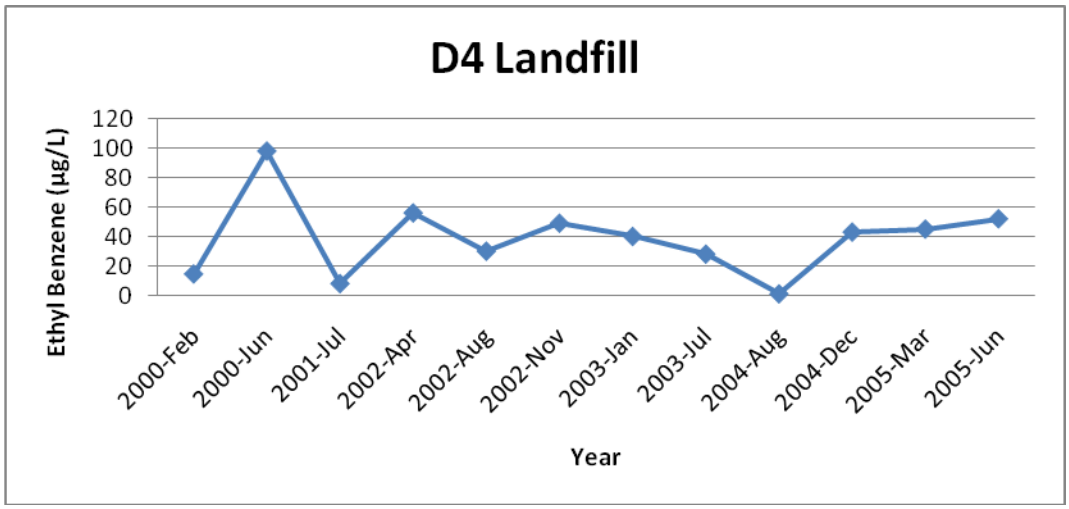
Ethyl Benzene



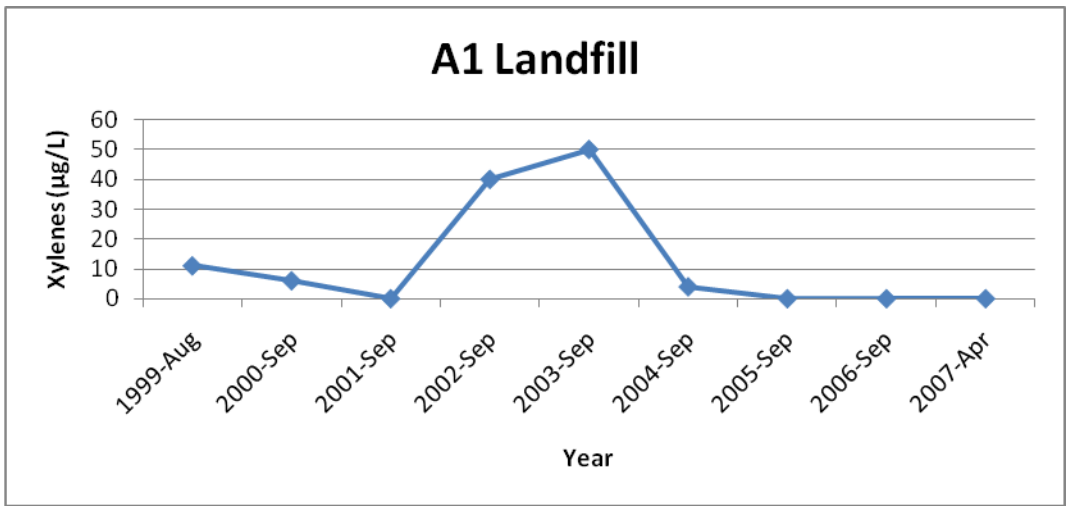



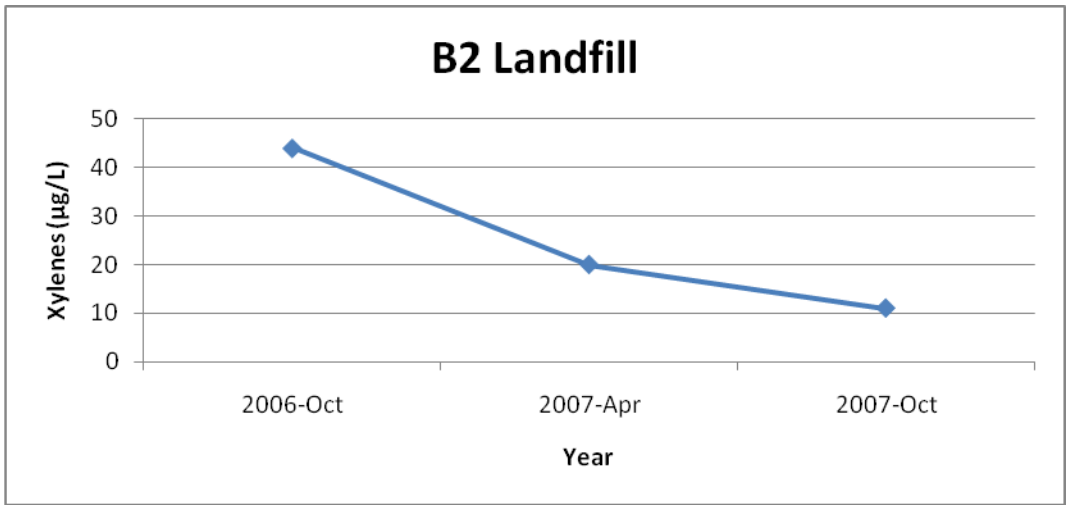
Ethyl Benzene



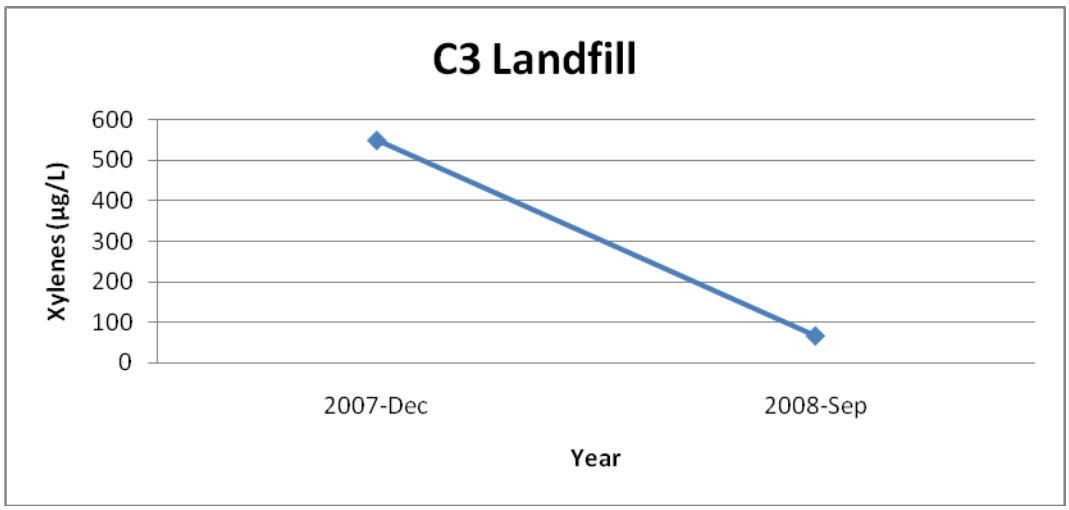



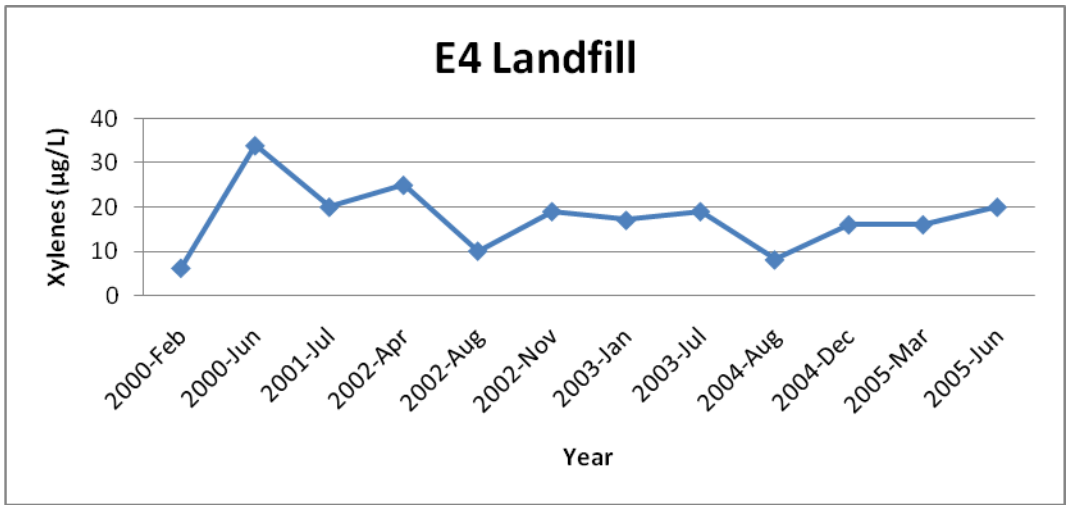
Xylenes


A1 Landfill
Xylenes (µg/L)
60
50
40
30
20
10
0
1999-Aug
2000-Sep
2001-Sep
2002-Sep
2003-Sep
2004-Sep
2005-Sep
2006-Sep
2007-Apr
Year


B2 Landfill
Xylenes (µg/L)
50
40
30
20
10
0
2006-Oct
2007-Apr
2007-Oct
Year

Xylenes


C3 Landfill
Xylenes (µg/L)
600
500
400
300
200
100
0
2007-Dec
2008-Sep
Year


E4 Landfill
Xylenes (µg/L)
40
30
20
10
0
2000-Feb
2000-Jun
2001-Jul
2002-Apr
2002-Aug
2002-Nov
2003-Jan
2003-Jul
2004-Aug
2004-Dec
2005-Mar
2005-Jun
Year

## Appendix D

**ANOVA**

Chloride (Cl)

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 5671743.084 | 2 | 2835871.542 | 28.081 | .000 |
| Within Groups | 3130612.475 | 31 | 100987.499 | | |
| Total | 8802355.559 | 33 | | | |

**Multiple Comparisons**

Chloride (Cl)

Tukey HSD

| (I) Group | (J) Group | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| A1 | B2 | 819.200* | 128.103 | .000 | 503.91 | 1134.49 |
| | E5 | 817.125* | 137.605 | .000 | 478.45 | 1155.80 |
| B2 | A1 | -819.200* | 128.103 | .000 | -1134.49 | -503.91 |
| | E5 | -2.075 | 150.739 | 1.000 | -373.07 | 368.92 |
| E5 | A1 | -817.125* | 137.605 | .000 | -1155.80 | -478.45 |
| | B2 | 2.075 | 150.739 | 1.000 | -368.92 | 373.07 |

*. The mean difference is significant at the 0.05 level.

**ANOVA**

Copper (Cu)

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 4.249 | 4 | 1.062 | 1.895 | .125 |
| Within Groups | 29.143 | 52 | .560 | | |
| Total | 33.392 | 56 | | | |

**ANOVA**

Calcium

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 138369.169 | 4 | 34592.292 | 1.835 | .136 |
| Within Groups | 1018131.365 | 54 | 18854.285 | | |
| Total | 1156500.534 | 58 | | | |

**ANOVA**

Zinc (Zn)

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 2.662 | 4 | .665 | 12.627 | .000 |
| Within Groups | 2.635 | 50 | .053 | | |
| Total | 5.296 | 54 | | | |

**Multiple Comparisons**

Zinc (Zn)

Tukey HSD

| (I) Group | (J) Group | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| A1 | B2 | .493* | .093 | .000 | .23 | .75 |
| | C3 | .262 | .110 | .137 | -.05 | .57 |
| | D4 | .489* | .083 | .000 | .26 | .72 |
| | E5 | .507* | .099 | .000 | .23 | .79 |
| B2 | A1 | -.493* | .093 | .000 | -.75 | -.23 |
| | C3 | -.231 | .119 | .306 | -.57 | .10 |
| | D4 | -.004 | .094 | 1.000 | -.27 | .26 |
| | E5 | .014 | .109 | 1.000 | -.29 | .32 |
| C3 | A1 | -.262 | .110 | .137 | -.57 | .05 |
| | B2 | .231 | .119 | .306 | -.10 | .57 |
| | D4 | .227 | .111 | .260 | -.09 | .54 |
| | E5 | .245 | .124 | .293 | -.11 | .60 |
| D4 | A1 | -.489* | .083 | .000 | -.72 | -.26 |
| | B2 | .004 | .094 | 1.000 | -.26 | .27 |
| | C3 | -.227 | .111 | .260 | -.54 | .09 |
| | E5 | .018 | .100 | 1.000 | -.27 | .30 |
| E5 | A1 | -.507* | .099 | .000 | -.79 | -.23 |
| | B2 | -.014 | .109 | 1.000 | -.32 | .29 |
| | C3 | -.245 | .124 | .293 | -.60 | .11 |
| | D4 | -.018 | .100 | 1.000 | -.30 | .27 |

*. The mean difference is significant at the 0.05 level.

**ANOVA**

Lead (Pb)

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | .043 | 4 | .011 | 8.728 | .000 |
| Within Groups | .062 | 50 | .001 | | |
| Total | .105 | 54 | | | |

**Multiple Comparisons**

Lead (Pb)

Tukey HSD

| (I) Group | (J) Group | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| A1 | B2 | .041* | .014 | .039 | .00 | .08 |
| | C3 | -.042 | .016 | .076 | -.09 | .00 |
| | D4 | .032 | .013 | .107 | .00 | .07 |
| | E5 | .041 | .015 | .065 | .00 | .08 |
| B2 | A1 | -.041* | .014 | .039 | -.08 | .00 |
| | C3 | -.084* | .017 | .000 | -.13 | -.03 |
| | D4 | -.009 | .015 | .968 | -.05 | .03 |
| | E5 | .000 | .017 | 1.000 | -.05 | .05 |
| C3 | A1 | .042 | .016 | .076 | .00 | .09 |
| | B2 | .084* | .017 | .000 | .03 | .13 |
| | D4 | .074* | .016 | .000 | .03 | .12 |
| | E5 | .084* | .018 | .000 | .03 | .14 |
| D4 | A1 | -.032 | .013 | .107 | -.07 | .00 |
| | B2 | .009 | .015 | .968 | -.03 | .05 |
| | C3 | -.074* | .016 | .000 | -.12 | -.03 |
| | E5 | .009 | .016 | .976 | -.03 | .05 |
| E5 | A1 | -.041 | .015 | .065 | -.08 | .00 |
| | B2 | .000 | .017 | 1.000 | -.05 | .05 |
| | C3 | -.084* | .018 | .000 | -.14 | -.03 |
| | D4 | -.009 | .016 | .976 | -.05 | .03 |

**ANOVA**

Chromium (Cr)

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 2.288 | 4 | .572 | 3.629 | .011 |
| Within Groups | 8.509 | 54 | .158 | | |
| Total | 10.797 | 58 | | | |

**Multiple Comparisons**

Chromium (Cr)

Tukey HSD

| (I) Group | (J) Group | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| A1 | B2 | .305 | .160 | .327 | -.15 | .76 |
| | C3 | .407 | .172 | .140 | -.08 | .89 |
| | D4 | .468* | .138 | .011 | .08 | .86 |
| | E5 | .487* | .172 | .049 | .00 | .97 |
| B2 | A1 | -.305 | .160 | .327 | -.76 | .15 |
| | C3 | .102 | .188 | .982 | -.43 | .63 |
| | D4 | .163 | .158 | .841 | -.28 | .61 |
| | E5 | .182 | .188 | .869 | -.35 | .71 |
| C3 | A1 | -.407 | .172 | .140 | -.89 | .08 |
| | B2 | -.102 | .188 | .982 | -.63 | .43 |
| | D4 | .061 | .170 | .996 | -.42 | .54 |
| | E5 | .080 | .198 | .994 | -.48 | .64 |
| D4 | A1 | -.468* | .138 | .011 | -.86 | -.08 |
| | B2 | -.163 | .158 | .841 | -.61 | .28 |
| | C3 | -.061 | .170 | .996 | -.54 | .42 |
| | E5 | .019 | .170 | 1.000 | -.46 | .50 |
| E5 | A1 | -.487* | .172 | .049 | -.97 | .00 |
| | B2 | -.182 | .188 | .869 | -.71 | .35 |
| | C3 | -.080 | .198 | .994 | -.64 | .48 |
| | D4 | -.019 | .170 | 1.000 | -.50 | .46 |

**ANOVA**

Benzene

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 442.083 | 3 | 147.361 | 6.568 | .002 |
| Within Groups | 650.698 | 29 | 22.438 | | |
| Total | 1092.781 | 32 | | | |

**Multiple Comparisons**

Benzene

Tukey HSD

| (I) Group | (J) Group | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| A1 | B2 | -6.381 | 2.846 | .136 | -14.14 | 1.37 |
| | C3 | -10.118* | 2.302 | .001 | -16.39 | -3.85 |
| | D4 | -5.097 | 2.089 | .092 | -10.79 | .59 |
| B2 | A1 | 6.381 | 2.846 | .136 | -1.37 | 14.14 |
| | C3 | -3.738 | 2.901 | .577 | -11.64 | 4.17 |
| | D4 | 1.283 | 2.735 | .965 | -6.17 | 8.73 |
| C3 | A1 | 10.118* | 2.302 | .001 | 3.85 | 16.39 |
| | B2 | 3.738 | 2.901 | .577 | -4.17 | 11.64 |
| | D4 | 5.021 | 2.162 | .116 | -.87 | 10.91 |
| D4 | A1 | 5.097 | 2.089 | .092 | -.59 | 10.79 |
| | B2 | -1.283 | 2.735 | .965 | -8.73 | 6.17 |
| | C3 | -5.021 | 2.162 | .116 | -10.91 | .87 |

*. The mean difference is significant at the 0.05 level.

**ANOVA**

Toluene

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 1881435.616 | 3 | 627145.205 | 6.405 | .002 |
| Within Groups | 2839694.645 | 29 | 97920.505 | | |
| Total | 4721130.261 | 32 | | | |

**Multiple Comparisons**

Toluene

Tukey HSD

| (I) Group | (J) Group | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| A1 | B2 | -1.342 | 188.043 | 1.000 | -513.67 | 510.98 |
| | C3 | -555.392* | 152.053 | .005 | -969.66 | -141.12 |
| | D4 | 4.108 | 137.986 | 1.000 | -371.84 | 380.05 |
| B2 | A1 | 1.342 | 188.043 | 1.000 | -510.98 | 513.67 |
| | C3 | -554.050* | 191.625 | .034 | -1076.13 | -31.97 |
| | D4 | 5.450 | 180.666 | 1.000 | -486.78 | 497.68 |
| C3 | A1 | 555.392* | 152.053 | .005 | 141.12 | 969.66 |
| | B2 | 554.050* | 191.625 | .034 | 31.97 | 1076.13 |
| | D4 | 559.500* | 142.829 | .003 | 170.36 | 948.64 |
| D4 | A1 | -4.108 | 137.986 | 1.000 | -380.05 | 371.84 |
| | B2 | -5.450 | 180.666 | 1.000 | -497.68 | 486.78 |
| | C3 | -559.500* | 142.829 | .003 | -948.64 | -170.36 |

*. The mean difference is significant at the 0.05 level.

**ANOVA**

Ethyl Benzene

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 52940.137 | 3 | 17646.712 | 8.574 | .000 |
| Within Groups | 59683.617 | 29 | 2058.056 | | |
| Total | 112623.753 | 32 | | | |

**Multiple Comparisons**

Ethyl Benzene

Tukey HSD

| (I) Group | (J) Group | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| A1 | B2 | -13.942 | 27.261 | .956 | -88.22 | 60.33 |
| | C3 | -106.717* | 22.044 | .000 | -166.78 | -46.66 |
| | D4 | -35.675 | 20.004 | .302 | -90.18 | 18.83 |
| B2 | A1 | 13.942 | 27.261 | .956 | -60.33 | 88.22 |
| | C3 | -92.775* | 27.781 | .012 | -168.46 | -17.09 |
| | D4 | -21.733 | 26.192 | .840 | -93.09 | 49.63 |
| C3 | A1 | 106.717* | 22.044 | .000 | 46.66 | 166.78 |
| | B2 | 92.775* | 27.781 | .012 | 17.09 | 168.46 |
| | D4 | 71.042* | 20.707 | .009 | 14.63 | 127.46 |
| D4 | A1 | 35.675 | 20.004 | .302 | -18.83 | 90.18 |
| | B2 | 21.733 | 26.192 | .840 | -49.63 | 93.09 |
| | C3 | -71.042* | 20.707 | .009 | -127.46 | -14.63 |

*. The mean difference is significant at the 0.05 level.

**ANOVA**

Xylenes

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 157791.170 | 3 | 52597.057 | 9.582 | .000 |
| Within Groups | 120757.209 | 22 | 5488.964 | | |
| Total | 278548.379 | 25 | | | |

**Multiple Comparisons**

Xylenes

Tukey HSD

| (I) Group | (J) Group | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| A1 | B2 | -12.667 | 49.392 | .994 | -149.82 | 124.49 |
| | C3 | -296.167* | 57.917 | .000 | -456.99 | -135.34 |
| | D4 | -5.175 | 32.670 | .999 | -95.89 | 85.54 |
| B2 | A1 | 12.667 | 49.392 | .994 | -124.49 | 149.82 |
| | C3 | -283.500* | 67.632 | .002 | -471.30 | -95.70 |
| | D4 | 7.492 | 47.823 | .999 | -125.31 | 140.29 |
| C3 | A1 | 296.167* | 57.917 | .000 | 135.34 | 456.99 |
| | B2 | 283.500* | 67.632 | .002 | 95.70 | 471.30 |
| | D4 | 290.992* | 56.585 | .000 | 133.86 | 448.12 |
| D4 | A1 | 5.175 | 32.670 | .999 | -85.54 | 95.89 |
| | B2 | -7.492 | 47.823 | .999 | -140.29 | 125.31 |
| | C3 | -290.992* | 56.585 | .000 | -448.12 | -133.86 |

*. The mean difference is significant at the 0.05 level.

# Bibliography


Al-Yaqout, A. F., & Hamoda, M. F. (2003). Evaluation of landfill leachate in arid climate- A case study. *Environment International*, *29*, 593-600.

Bakare, A. A., Mosuro, A. A., & Osibanjo, O. (2005). An in vivo evaluation of induction of abnormal sperm morphology in mice by landfill leachates. *Genetic Toxicology and Environmental Mutagenesis*, *582*, 28-34.

Census Canada. (2009). *Statistics Canada*. Retrieved March 4, 2009, from http://www12.statcan.gc.ca/census-recensement/index-eng.cfm

Cho, E., Tameda, K., Hanashima, M., Yamada, T., & Higuchi, S. (2008). Toxicological evaluation of the chemical oxidation methods for landfill stabilization. *Waste Management*, 1-6.

Christensen, T. H., et al., (2001). Biogeochemistry of landfill leachate plumes. *Applied Geochemistry*, *16*, 659-718.

Christensen, T. H., Cossu, R., & Stegmann, R. (1992). *Landfilling of waste: Leachate.* London: E & FN Spon.

City of Hamilton. (2009). *Hamilton*. Retrieved March 15, 2009, from http://www.myhamilton.ca/myhamilton/CityandGovernment/

City of Kelowna. (2009). *City of Kelowna*. Retrieved March 15, 2009, from http://www.kelowna.ca/cm/site3.aspx

City of Saskatoon. (2009). *City of Saskatoon*. Retrieved March 15, 2009, from http://www.saskatoon.ca/org/policy/privacy.asp

City of Winnipeg. (2009). *Winnipeg*. Retrieved March 15, 2009, from http://www.winnipeg.ca/interhom/

Collins, H. J. (1991) Influences of recycling household refuse upon sanitary landfills. In: Christensen, T. H., Cossu, R. & Stegmann, R. (eds). *Proceedings Sardinia 91, Third International Landfill Symposium Cagliari, Italy: CISA.*

Fan, H., Shu, H., Yang, H., & Chen, W. (2006). Characteristics of landfill leachates in central Taiwan. *Science of the Total Environment*, *361*, 25-37.

Halifax Regional Municipality. (2009). *Halifax Regional Municipality*. Retrieved March 15, 2009, from http://www.halifax.ca/

Howell, D. C. (2007). *Statistical methods for Psychology* (6th Edition ed.). Canada: Thomson Wadsworth.

Jokela, J. P., Kettunen, R. H., & Rintala, J. A. (2002). Methane and leachate pollutant emission potential from various fractions of municipal solid waste (MSW): Effects of source seperation and aerobic treatment. *Waste Management % Research, 20*, 424-433.

Klinck, B. A., & Stuart, M. E. (1999). *Human health risk in relation to landfill leachate quality.* Nottingham: Natural Environment Research Council.

Komilis, D. P., & Ham, R. K. (1999). The effect of municipal solid waste pretreatment on landfill behavior: a literature review. *Waste Management & Research, 17*, 10-19.

Koshy, L., Paris, E., Ling, S., Jones, T., & BeruBe, K. (2007). Bioreactivity of leachate from municipal solid waste landfills - assessment of toxicity. *Science of the Total Environment, 384*, 171-181.

Kulikowska, D., & Klimiuk, E. (2008). The effect of landfill age on municipal leachate composition. *Bioresource Technology, 99*, 5981-5985.

Lake, C.B., MacNeill, S.G., and Rowe, R.K., 2004. A GCL equivalency assessment for a proposed municipal solid waste landfill. *Proceedings of the 57th Canadian Geotechnical Conference,* Quebec City, Session 3D:7-14.

Lema, J. M., Mendez, R., & Blazquez, R. (1988). Characteristics of landfill leachates and alternatives for their treatment: A review. *Water, Air, and Soil Pollution, 40*, 223-250.

Lo, I. M. (1996). Characteristics and treatment of leachates from domestic landfills. *Environment International, 22* (4), 433-442.

Marttinen, S. K., Kettunen, R. H., Sormunen, K. M., Soimasuo, R. M., & Rintala, J. A. (2002). Screening of physical-chemical methods for removal of organic material, nitrogen and toxicity from low strength landfill leachates. *Chemosphere, 46*, 851-858.

Ministry of the Environment. (1998). Landfill standards-a guideline on the regulatory and approval requirements for new or expanding landfilling sites. Ontario, Canada: Queens Printer for Ontario.

Olivero-Verbel, J., Padilla-Bottet, C., & De la Rosa, O. (2008). Relationships between physicochemical parameters and the toxicity of leachates from a municipal solid waste landfill. *Ecotoxicology and Environmental Safety, 70*, 294-299.

Peng, C., Scorpio, D. E., & Kibert, C. J. (1997). Strategies for successful construction and demolition waste recycling operations. *Journal of Construction Management and Economics, 15* (1), 49-58.

Pennsylvania Action Center. (2003, March 26). Retrieved October 30, 2008, from ejnet.org: http://www.ejnet.org/landfills/

Pivato, A., & Gaspari, L. (2006). Acute toxicity test of leachates from traditional and sustainable landfills using luminescent bacteria. *Waste Management, 26*, 1148-1155.

Qasim, S. R., & Chiang, W. (1994). *Sanitary landfill leachate: Generation, control and treatment.* Florida: CRC Press.

Read, A. D., Hudgins, M., & Phillips, P. (2001). Aerobic landfill test cells and their implication for sustainable waste disposal. *The Geographical Journal, 167* (3), 235-247.

Reinhart, D. R., & Grosh, C. J. (1998). *Analysis of Florida MSW Landfill Leachate Quality.* Florida: Florida Center for Solid and Hazardous Waste Management.

Renou, S., Givaudan, J. G., Poulain, S., Dirassouyan, F., & Moulin, P. (2008). Landfill leachate treatment: Review and opportunity. *Journal of Hazardous Materials, 150*, 468-493.

Robinson, H. D., & Maris, P. J. (1983). The treatment of leachates from domestic wastes in landfills- I; Aerobic biological treatment of a medium-strength leachate. *Water Research, 17* (11), 1537-1548.

Rowe, R.K., Quigley, R.M., Brachman, R.W.I., Booker, J.R. (2004). *Barrier Systems for Waste Disposal Facilities*, Taylor & Francis Books Ltd (E & FN Spon) London, p. 587.

Rowe, R.K. (2006). Long-Term Performance of Contaminant Barrier Systems, 45th Rankine Lecture, *Geotechnique*, 55 (9), 631-678.

Slimak, K. M. (1978). Landfill disposal systems. *Environmental Health Perspectives, 27*, 309-316.

SPSS Inc. (1998). *SPSS Base 8.0 for Windows User's Guide*. SPSS Inc., Chicago IL.

Tam, V. W., & Tam, C. M. (2006). Evaluations of existing waste recycling methods: A Hong Kong study. *Building and Environment, 41*, 1649-1660.

Tatsi, A. A., & Zouboulis, A. I. (2002). A field investigation of the quantity and quality of leachate from a municipal solid waste landfill in a Mediterranean climate (Thessaloniki, Greece). *Advances in Environmental Research, 6*, 207-219.

Touraud, E., Roussy, J., Domeizel, M., Junqua, G., & Thomas, O. (2007). Leachates and organic extracts from solids. In O. Thomas, C. Burgess, & (Eds.), *UV- Visible spectrophotometry of water and wastewater* (pp. 243-265). Quebec: Elsevier.

Trankler, J., Visvanathan, C., Kuruparan, P., & Tubtimthai, O. (2005). Influence of tropical seasonal variations on landfill leachate chracteristics-Results from lysimeter studies. *Waste Management, 25*, 1012-1020.

The Weather Network. (2009). *The Weather Network*. Retrieved March 4, 2009, from http://www.theweathernetwork.com/

Yildiz, E. D., Unlu, K., & Rowe, R. K. (2004). Modelling leachate quality and quantity in municipal solid waste landfills. *Waste Management &Research, 22 (2), 78-92*.