URBAN INFILLING IMPACTS ON FLORIDA SOLID WASTE FACILITIES

by

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ABSTRACT

Increasing urbanization in the US is leading to development or re-development of lands adjacent to solid waste facilities and these lands are being considered for residential communities and commercial projects. Thus, the potential for nuisance complaints against the pre-existing solid waste facility operations has become an increasing reality. The objective of this study was to develop a methodology to gather scientific and quantifiable data related to potential nuisances caused by landfills to determine setbacks and buffer zones near landfill and transfer station operations. Appropriate recommendations for these setbacks were made from case studies conducted at two landfills in Florida. The study involved making measurements related to odor, noise, litter and dust. Impact on housing prices was also evaluated by analyzing publicly available house price data. In this study volatile organic compound (VOC) concentration was used as a surrogate measure for gaseous impacts.

The mass flux of VOCs was measured on the landfills using the dynamic flux chamber method. The ultimate purpose of flux measurements was to provide input data for dispersion modeling to analyze the extent of odor impact around the landfills, which is outside the scope of this study. Ambient measurements were also made around Landfill A for validating the dispersion model. Although there are no significant health and odor impacts caused by the landfill, higher background concentration extend 1.2-1.5 km from the landfill center on the Southeast side of the landfill. Litter from the road sides around the landfills was collected and catalogued based on size and material type. Litter count per site obtained for both landfills was less than the 2001 and 2002 state-wide counts. The difference was statistically significant. Noise measurements were made at landfills during incineration and landfilling. Based on average measurements (L_{eq}) obtained at various distances from WTE facility and landfilling activity, and considering EPA recommended noise level of 55 dB(A) for a quiet neighborhood, a set back distance of 1.6-1.9 km was recommended. Impact on house prices near the landfills was done for four landfills in Florida. Analysis showed that three out of four landfills had significantly impacted the house price within 0.6-0.8 km from the edge of the landfill. Dust measurements were made at Landfill B using particulate samplers, quantifying the dust associated with landfilling. Measured values were below National Ambient Air quality Standard (NAAQ) for PM_{10}. Finally, recommendations were developed to mitigate some of these nuisances.

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1. INTRODUCTION

Increased urbanization and expanded use of disposable products in the past decade have generated greater demand for landfill space. As the U.S. becomes more urbanized, sites once considered remote are now located in areas increasingly ripe for development or re-development. Figure 1 illustrates the increase in the urban population in U.S from 1950 to 2000.

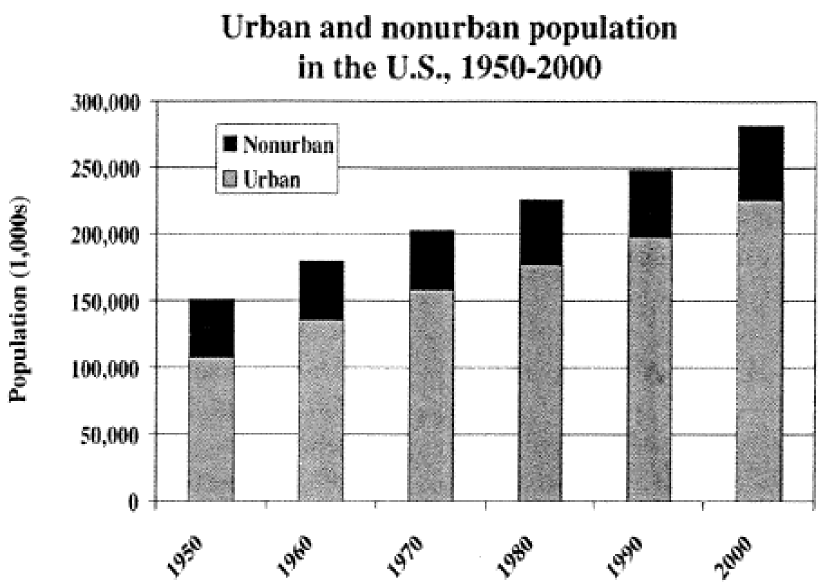

Figure 1. U.S. Population by Urban and Nonurban Components, (USDC Census Bureau, 2001)

As a result of this urban population increase, properties adjacent to the landfills are being considered for commercial and residential development. This development around the landfill is leading to increased nuisance complaints against the pre-existing solid waste facilities. There have been some instances in recent years where public and private owners/operators of solid waste facilities have been forced to close their facilities prematurely (Table 1), resulting in a loss of valuable solid waste capacity and increased cost for solid waste disposal.

Table 1. Examples of Premature Closure of Solid Waste Facilities (Rogoff et al, 2006)

Landfill	**Reason**
Live Oak Landfill Dekalb County, Georgia	Neighborhood groups surrounding the landfill embroiled in disputes regarding landfill operations
Bee Ridge Landfill Sarasota County, FL	Residential Neighborhood complaints
Martin County Landfill, FL	Residential Neighborhood complaints
Osceola County Landfill, FL	Residential Neighborhood complaints

The U.S Environmental Protection Agency and all 50 states have established strict regulations for design, construction and operation of solid waste facilities. Protection of public health and safety as well as the environment is the purpose behind these rules and regulations. These rules and regulations include prohibitions and restrictions regarding landfills cited within certain distances of airports, floodplains, wetlands and groundwater wells, but they do not address the land use issues around the landfill and in proximity to the residential development. Rogoff et al (2006) summarized some of the illustrative ordinances mandating separation distances between the solid waste facilities and residential developments for various counties and states in US. However these ordinances are of little practical help, since these ordinances were based on local experiences rather than established methodology. Hence there is a need to establish rational guidelines for setback distances from the solid waste facilities based on scientific and quantifiable data

1.1. Objectives

The objectives of this research are to:

1) Develop a methodology to gather scientific and quantifiable support to predict acceptable setbacks and buffer zones as a function of activities at solid waste facilities.

2) Recommend setbacks distances for solid waste facilities based on case studies.

1.2. Thesis Organization

This thesis is organized into five chapters. In addition to this introduction chapter, a review of technical literature is presented in Chapter 2 and methodology in Chapter 3. Chapter 4 presents the findings of this research following the ASCE *Journal of Environmental Engineering* paper format. Finally, Chapter 5 provides conclusions and recommendations for future study.

2. LITERATURE REVIEW

In this study, past research related to landfill impacts on the surrounding community is reviewed. Most of the research that has been done is related to evaluating the overall impact caused by the landfill or odor impacts. In many studies overall impact caused by the landfill is evaluated by conducting a community survey in the neighborhood of the landfill and analyzing the results statistically.

2.1. Landfill Impacts

Furuseth (1988) studied the attitudes of people living within 5 km of a sanitary landfill in North Carolina. The primary goal of this study was to assess the role distance to a landfill plays in individual perception and concern. The study involved collecting data from hundreds of residents living near a landfill. The landfill received periodic complaints from the neighborhood regarding operating practices and environmental risks. Various samples of residents were chosen and stratified based on the distance from the landfill. Among the impacts cited, noise, traffic, litter from garbage trucks, appearance of the landfill, and property devaluation raised the greatest concerns. On the other hand, landfill litter, dust, and water contamination were considered minor problems. Other than landfill odor and appearance, the landfill operations produced very few complaints from the neighborhood. Approximately 35% were concerned about the traffic problem, 31% about garbage truck litter, and 21% about traffic noise problem. About one third of the respondents felt that the landfill adversely impacted the value of their property. Further analysis showed that the effects which were sensory related such as landfill noise, odor, litter and dust were strongly influenced by the distance from the landfill. Property devaluation was the only non-sensory effect influenced by the distance from the landfill. Finally, this study recommended better understanding of these effects around the landfill so that buffer distances can be more appropriately defined and efficient local decisions can be made that are fair to citizens and land use planners. In a similar study, Johnson (2002) examined the public attitude towards solid waste facilities in Florida. Analysis of the results showed that only 7.1% of the respondents thought that solid waste facilities were a major environmental issue in their county and less than 10% indicated that problems such as rodents, birds, traffic, and lower property values could be potential problems from the landfill.

Okeke and Armour (2000) conducted a study on post-landfill siting perceptions of residents near the Halton Landfill in Ontario, Canada. They concluded that many of the residents living near the landfill, because of the anticipated fears of various impacts of the landfill, strongly opposed the construction of the landfill in the Halton area. But after construction and operation of the landfill for some years, most of the nearby residents who initially opposed the siting of landfill were only a "little concerned" about the impacts of the landfill. The aim of the study was primarily to consider the issue whether the residents accepted the landfill facility if it was well managed, even if they opposed the construction of the facility initially. A survey of the residents living near the landfill in a radius of 3 km was conducted and results showed that the majority of the residents were either "not concerned" or a "little concerned" about the impacts of landfill. The distance of the residences from the landfill affected the perception of the residents about the impacts and residents living within 800 m of the landfill were the most concerned.

Hence this research proved that the separation distance of residential community from the landfill is a very important parameter.

2.2. Evaluating Odor impact

Bedogni and Resola (2002) developed a methodology to evaluate odor impact of a solid waste landfill in the northern part of Italy. The methodology integrates two different approaches: monitoring data and modeling to simulate the impact of odor emissions. To characterize the actual landfill emissions and the impact outside the landfill fence boundary, the parameters that were monitored were mainly gaseous emissions (CO_2, N_2O, NH_3, CH_4, H_2O) and, at the same time, important meteorological data at ground level (wind speed and direction, temperature). Olfactometric analysis of the emissions released from different parts of the site was carried out to characterize the emissions. A sensory technique known as Olfactometry was used which utilizes human assessors to assess odor. Olfactometric analysis made it possible to express emission and concentration data directly in odor units per cubic meter (ou/m^3) or odor units flux ($ou/(s*m^2)$). Because of the lack of national definitions regarding odor and impact in the Northern part of Italy, some environmental compatibility evaluations were carried out. In that context the environmental site compatibility with residential or industrial areas is defined on the basis of "maximum odor frequency," i.e. the ratio between number of hours during which the odor is discernable and the total hours of the observation period

In this study, the CALPUFF dispersion model was used to carry out the evaluation regarding the odor nuisance. In particular, the probability of odor detection, defined as the exceedance of 1 ou/m^3, was estimated for each point of the study area by means of the long-term (one average year) model simulations on the basis of hourly meteorological data. The validation was carried out comparing the gas and odor concentrations measured in five points outside the landfill with the corresponding values estimated by the model. The results of the validation procedure showed a good agreement with the experimental data concerning methane emissions but overestimated the concentration of odorous gases. Finally, this study focused on methodology used and its importance as a decision tool for odor impact situations.

Sarkar and Hobbs (2002) conducted a study on the analysis of perception of odor from municipal solid waste landfills. The objective of this work was to develop a relationship between odor intensity and odor concentration by using data collected from various areas of the municipal solid waste landfill. In this study, the main focus was on the selection of various psychophysical models, estimation of their parameters with suitable techniques, and evaluation with statistical analysis. Psychophysical models usually employ experimental stimuli that can be objectively measured, such as pure tones varying in intensity, or lights varying in luminance. All the senses including the taste and smell have been studied in psychophysics. In this study various models related to odor are discussed. Model 1 was based on the Weber-Fechner Law, Model 2 on Steven's Psychophysical Power Law, Model 3 on Beidler's model, and Model 4 was based on Laffort's expression. It was concluded that for odor samples from various areas of landfill site, Model 1 could demonstrate the intensity concentration relationship best. In the analysis, Model 1 was ranked first in five out of nine samples and it was found to be more representative of the less intense odor samples. Model 4 could correlate the intensity with odor concentration very well for samples from the horizontal gas wells. Laffort's equation has specifically represented the intensity–concentration relationship better for comparatively more intense odor samples. Hence according to this study, depending on the nature of the odor sample and its range of intensity levels, Model 1 or 4 could be selected to determine the concentration of odor at a particular receptor location and the dispersion modeling results could be validated.

Sarkar et al (2003) developed a quantitative model to predict the annoyance caused by odors from MSW landfills. The overall objective of this research was to develop the major components of the model, namely, assessment of odorous emissions, dispersion, and reception by the surrounding community around the landfill site. This study describes the use of community modeling to link the calculated exposure, from dispersion analysis, with the perception reported by the community surrounding the site. Personnel were recruited to report on a daily basis whether odors were detected from the landfill site. Records reporting odors were then compared with the results from the dispersion model predictions. The first stage of this analysis reduces the reported intensity scales to an odor concentration value (ou/m^3). This value is then incorporated as a value within each of the expressions based on the four psychophysical laws. Human responses to the vast range of odor intensities, from highly intense source odors to less intense dispersed odors at monitoring locations, were found to differ greatly. It was observed that the psychophysical models based on the Weber–Fechner law and Power law fit the data consistently well for the entire range of the intensity scale used. However, the other two models, based on Beidler's law and Laffort's equation showed an inconsistency with the intensity scales higher than a particular value. Community modeling was useful in analyzing the correlation between exposure predictions from dispersion modeling and the analysis of perception of odor from specified sites. This modeling quantitatively integrated two components of a model for the analysis of odor, namely the exposure to odor from a dispersed source and the perceived intensity.

Nicolas et al (2005) studied the estimation of odor emission rates from landfill areas using the sniffing team method. A fundamental assumption in the sniffing team observation method is that it is valid only if odor emission and meteorological conditions do not vary much during the measurement period. The complaints in the surrounding area of the landfill corresponded to the fresh garbage odor during the landfilling and hence the sniffing was mainly concerned with this fresh garbage odor during their process of detection. The odor was detected by the sniffing team at various points around the landfill by moving in a zigzag manner around the plume axis. The meteorological situation was simultaneously recorded. Then a bi-Gaussian model was used to simulate the perception of the odor. The emission rate entered into the model was adjusted until the isopleths fit the measured maximum perception distance. The emission rates obtained were similar to values in the literature. Validation of the procedure was not done because the emission rates varied from day to day.

One of the main errors associated with human nose perception is that it is very subjective as well as the lack of availability of qualified persons since the sniffing team consisted of only one or two people. The bi-Gaussian model chosen neglects the topography and dynamics of pollutant transport. In this study the odor emission rate was adjusted so that 1 ou/m^3 surrounds all the odor points identified in the field. A value of 3 ou/m^3 could have been used, which is considered to be the odor recognition threshold. This study also identified various other errors associated with data collection procedures and modeling of the data.

McGinley (1998) studied the various odor quantification methods and practices at MSW landfills. In this study ten methods were reviewed that were commonly used by MSW landfills and regulatory authorities. Three of the most common methods are described in detail below.

1) Point Source Sampling - Many operations are carried out at landfill facilities that are responsible for emitting odorous compounds. Some of these are point sources like roof exhaust or building side vents. This methodology involves collection of samples at the point sources using Tedlar bags and analyzing the sample in the laboratory for odor concentration.

2) Surface Sampling - Surface sampling of odor emissions is done using the flux chamber method. In this method mass flux rate of odorous gases emitted from the sampling point is obtained by measuring the concentration at the exit port of the flux chamber.

3) On-Site Monitoring - Operators can monitor the odor on site throughout the day. This method can involve monitoring the odor from selected predetermined locations.

The other methods reviewed include random monitoring, scheduled monitoring, citizen survey, odor patrol, plume profiling or dispersion monitoring. In this study, characterization of odors was also reviewed. One of the published standards available is the International Association on Water Pollution Research and Control (IAWPRC) and is called a flavor wheel. In this standard odor descriptors are categorized into 8 groups. Each group consists of a set of similar odor descriptors like woody, earthy or flowery, fragrant, rosy etc. Other standards reviewed include:

1) Word Scale Odor intensity is a measure of relative strength of an odor above the threshold. A common word scale ranges from “no odor” to “very strong” odor.

2) Odor intensity quantification can also be done using the Odor Intensity Referencing Scale (OIRS). This method compares the odor in the ambient air to the odor intensity of a series of concentrations of a reference odorant. The reference odorant that is generally used is n-butanol. The person making the observation refreshes his olfactory sense using the carbon filtered mask between observations. The odor intensity of observed air is expressed in ppm of n-butanol.

3) Dilution ratio is another commonly used estimate and it is the number of dilutions needed so that the odor becomes non-detectable. For this method, a trained odor panel is required. Odor panels use an olfactometer to observe the sample and produce two values known as detection threshold and dilution threshold. Detection threshold is the dilution ratio needed to make the sample "detection free" and dilution threshold is the dilution needed to make the sample "odor free".

Odor Persistence recognizes the fact that odor intensity changes as a function of its concentration. However, the rate of change of intensity versus concentration is different for different odors. This rate of change is called the persistence of the odor (Figure 2). Persistence can be measured in the laboratory from the intensity of an odor at full strength and at various dilution levels above the threshold level.

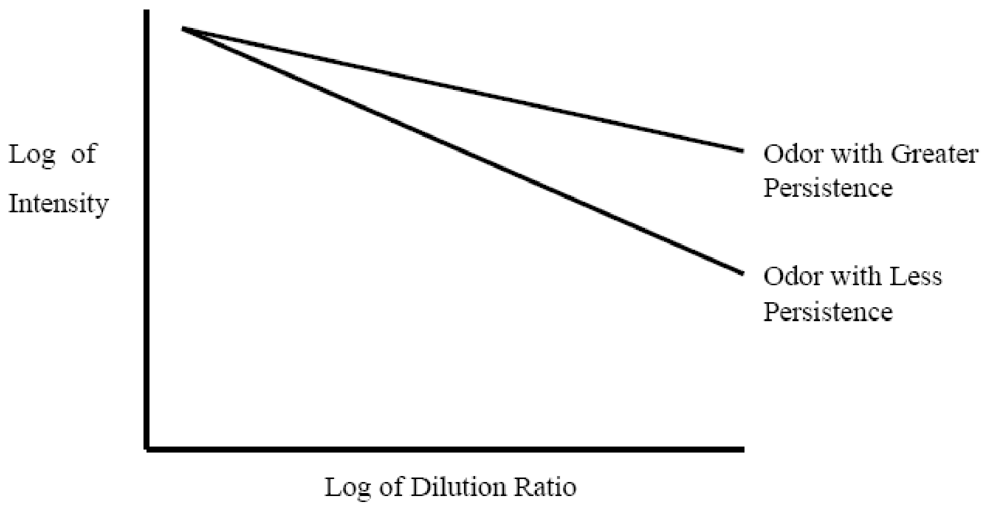

Figure 2. Dose Response Curve for Odor

2.3. Effect on Property Values

From the previous research it can be observed that environmental features can increase land and house value if they are viewed as attractive or desirable, or they can reduce values if they are viewed as nuisances or undesirable (Crecine et al, 1967). This section summarizes a number of recent studies that specifically address the impact of landfills on homeowner attitudes and housing values. Some literature indicates negative effects while other literature indicates positive effects. Reichert et al (1991) studied the impact of five municipal landfills on surrounding residential property values in Cleveland, Ohio. This study specifically examined the following factors:

1) The price-distance relationship to estimate the influence of proximity to the landfill,

2) The impact on market value of a decision to locate or expand a landfill near residential zone, and

3) The effect of landfill on rate of housing price appreciation.

The impact of the landfill on housing prices was estimated using two different approaches. One approach uses multiple regression techniques and the other a survey requesting information regarding landfill nuisance effects and the perceived impact of the landfill on the immediate housing market. The survey results of home owners living near the landfill indicated that the most severe nuisances were odor and unattractiveness which was reported by the 40% of the residents. Also, a strong correlation was found between nuisance and health effects reported and the nuisance respondents estimated market price. In the regression study, a total of 2243 market sales were analyzed; the results were mixed. In a similar study done by Schulze et al (1986) three different California cities housing markets were analyzed for potentially hazardous landfill effects. The study found significant results for one region for houses within 300 meters of the landfill site.

In a study done by Nelson et al (1992) an empirical model was applied to estimate the price effects on 708 homes residential area near a Minnesota landfill during the 1980s. Results indicate that the landfill adversely affected home values by 12 percent at the landfill boundary and 6 percent at about 1.6 kilometers. Beyond about 3-4 kilometers adverse effects were negligible. Gamble et al. (1982) studied the effects of the landfill on nearby home values in Montgomery County, Pennsylvania, during the period 1977-79. The study showed that the landfill had a negative effect on property values, but the results were not statistically significant. Statistical insignificance was attributed to not including a large enough area away from the landfill to adequately measure variation in house prices and most cases were grouped near the outer edge of the 1.6 kilometer zone, which means there was only limited variation in the distance variable.

In a study conducted by Research Planning Consultants Inc. (1983), price and development effects of landfills on residential properties at four sites located in Houston, Texas; Baltimore, Maryland; Minneapolis, Minnesota; and Atlanta, Georgia were evaluated. Results indicated that landfills did not impose negative price effects and, indeed, in some situations they found that landfills actually increased property values and were associated with greater residential development.

2.4. Summary

The literature survey suggests that landfill can have a big impact on nearby residential properties from many perspectives. Required setbacks are highly variable depending on landfill operations, location and development type. Research is needed to develop methods to select defendable setbacks in local ordinances.

3. MATERIALS AND METHODOLOGY

The methodology adopted involved measuring various quantifiable parameters related to potential nuisances caused by landfills. The methodology was carried out at two landfills (Landfills A and B) in Florida. The quantifiable parameters that were measured were volatile organic compounds (VOC) mass flux, noise, litter and dust. Ambient measurements of VOCs were also made around Landfill A, and contours were produced on the base map of the Landfill A using ArcGIS software to depict the concentration levels of VOCs.

3.1. Description of Landfills

The case studies were carried out at two landfills located in the state of Florida. Landfill A is located in one of the most densely populated counties of the state. Approximately 800 to 1000 vehicles arrive at Landfill A each day and in 2006 the landfill received approximately 284,800 Mg of solid waste. This facility consists of a Waste-to-Energy (WTE) facility, an ash processing facility, a municipal solid waste (Class I) landfill and a construction and demolition debris (Class III) landfill. Ash from the processing facility is used as a landfill cover.

When the area was chosen for the construction of a solid waste facility, the surrounding land was undeveloped. The landfill began commercial operation in 1979 and construction of the waste-to-energy plant started in 1980. During this time, over the objection of the county, the City in which landfill is located approved the zoning for construction of a residential community containing several hundred homes directly west of the active landfill. Also during 1980s and 1990s, as permitted by the zoning regulations, the surrounding area developed commercially.

Landfill A started logging complaints related to odor, noise, litter and birds, in 2004, from the residential community west of the landfill. The number declined during later years. All of the complaints were received from the houses nearest to the landfill (100 meters).

Landfill B is located in eastern central part of Florida and started its operations in 1978. It has a total footprint of 0.98 km^2. It is a Class I inward gradient landfill with natural clay liner and has a total design capacity of 34,405,000 m^3. Gas recovery and leachate removal systems were installed. In 2006, the landfill received 308,500 Mg of solid waste and 48,300 Mg of yard waste. Landfill B is surrounded by highly dense trees and the nearest residential housing is at least 600 m away from the landfill. This landfill is surrounded by dense tree growth and never received any complaints related to any of the nuisance issues.

3.2. VOC Flux Measurement

People in communities near landfills are often concerned about odors emitted from landfills. Potential sources of landfill odors include sulfides, ammonia, and certain Non-Methane Organic Compounds (NMOCs) if present at concentrations that are high enough. Hydrogen sulfide, dimethyl sulfide, and mercaptans are the three most common sulfides present in landfill gas and are responsible for landfill odors. These gases produce a rotten-egg smell even at low concentrations. Ammonia, one of the constituent of landfill is also odorous and is produced by the decomposition of organic matter in the landfill. NMOCs also are present in landfill gas and can cause odor problems. Common landfill gas components and their odor thresholds are presented in Table 2.

Table 2. Common Landfill Gas Components and Their Odor Thresholds (ATSDR, 2001)

Component	**Odor Description**	**Odor Threshold (parts per million)**
Hydrogen Sulfide	Strong rotten egg smell	0.0005 to 0.001
Ammonia	Pungent acidic or suffocating odor	1 to 5
Benzene	Paint-thinner-like odor	0.84
Dicholoroethylene	Sweet, ether-like, slightly acrid odor	0.085
Dichloromethane	Sweet, chloroform-like odor	205 to 307
Ethyl benzene	Aromatic odor like benzene	0.09 to 0.6
Toluene	Aromatic odor like benzene	10 to 15
Trichloroethylene	Sweet, chloroform-like odor	21.4
Tetrachloroethylene	Sweet, ether-or-chloroform like odor	50
Vinyl chloride	Faintly sweet odor	10 to 20

In the present study VOC concentration and mass flux were measured (Appendix A) on the landfill using the flux chamber method. The VOC concentration in the flux chamber was measured using a flame ionization detector (FID). The ultimate purpose of flux measurements is to use dispersion modeling to analyze the extent of odor impact around the landfill, which is outside the scope of this study. The following sections provide more details about the methodology used for flux measurements.

3.2.1. Flux Chamber

The flux chamber (Figure 3) used for measuring VOCs on the surface of Landfills A and B was obtained from ODOTECH Inc. (Montreal, Quebec, Canada). Information regarding dimensions of the flux chamber is also shown in Table 3. In this methodology, the dynamic flux chamber method was used since it is the most accurate method for determining emission rates from the landfill (Cooper, et al., 1992). Flux chamber measurements taken at each of the sampling points are measured in terms of concentration ppm of methane. To calculate an emission rate representing the sampling location, the measured concentration was first converted from ppm to µg/L as follows:

$$C(\mu\text{g/L}) = \frac{(\text{C(ppm)} \times \text{P} \times \text{MW})}{T \times R} \qquad (1)$$

Where C (µg/L) is the concentration of VOCs inside the flux chamber in µg/L. C (ppm) is the concentration of VOCs inside the flux chamber in ppm. P is pressure (atm), MW is the molecular weight of species (12g/mole), T is flux chamber air temperature (° K), and R is the Rydberg's gas constant (Liter-atm/mole-K).

The emission rate at the sampling point is then calculated using the converted gas concentration as follows:

$$E = \frac{(C(\mu\text{g/L}) \times \text{Q})}{A} \qquad (2)$$

Where E is the emission rate measured for sampling point (µg/m^2-min), Q is the flux chamber sweep air flow rate (L/min) and A is the enclosed surface area (m^2).

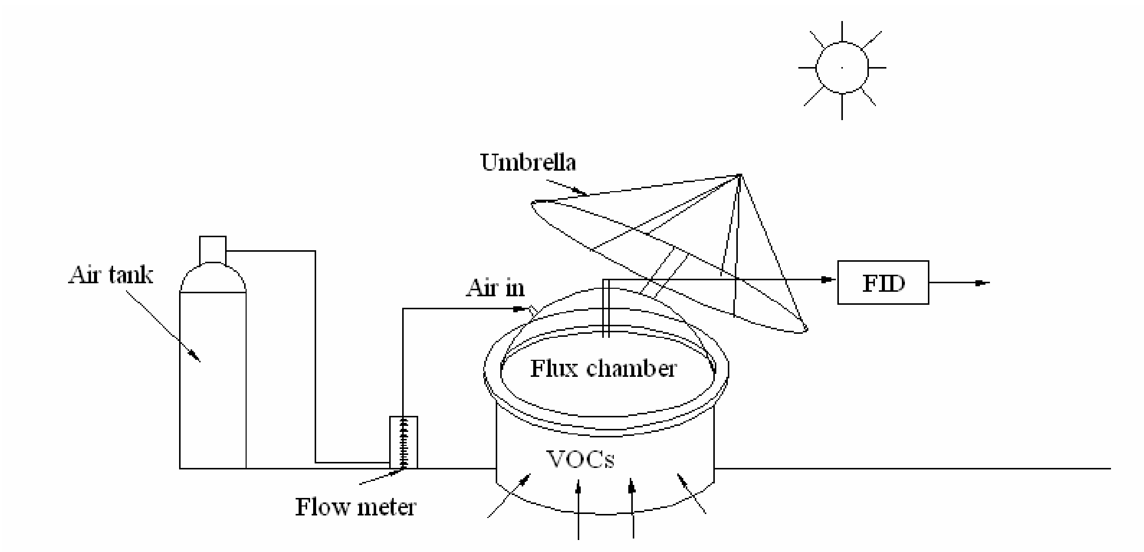

Figure 3. Flux Chamber with Support Equipment

Table 3. Flux Chamber Dimensions

Parameter	**Flux Chamber Dimension**
Geometry	Half-Dome and Skirt
Diameter	0.5 m
Height	0.41m (Skirt: 0.24m+half-dome: 0.17m)
Ground Surface Area	0.19m2
Volume	64.5 L
Sweep Air Flow Rate	5~10 L/min

3.2.2. VOC Measurement

A portable MicroFID from Photovac Inc. (Waltham, Massachusetts, US) was used to measure the concentration of VOCs onsite. The MicroFID uses hydrogen and the necessary oxygen from the sample air to support combustion in the hydrogen-fed flame. When the sample passes through the flame the combustible organic compounds in the sample are ionized. The ions generated move in the electric field, generating a current, which is proportional to the concentration of the ionized molecules. The permanent air gases (argon, carbon dioxide, nitrogen, oxygen, water vapor, etc.) are not ionized by the flame. Figure 4 shows the FID used to measure VOCs.

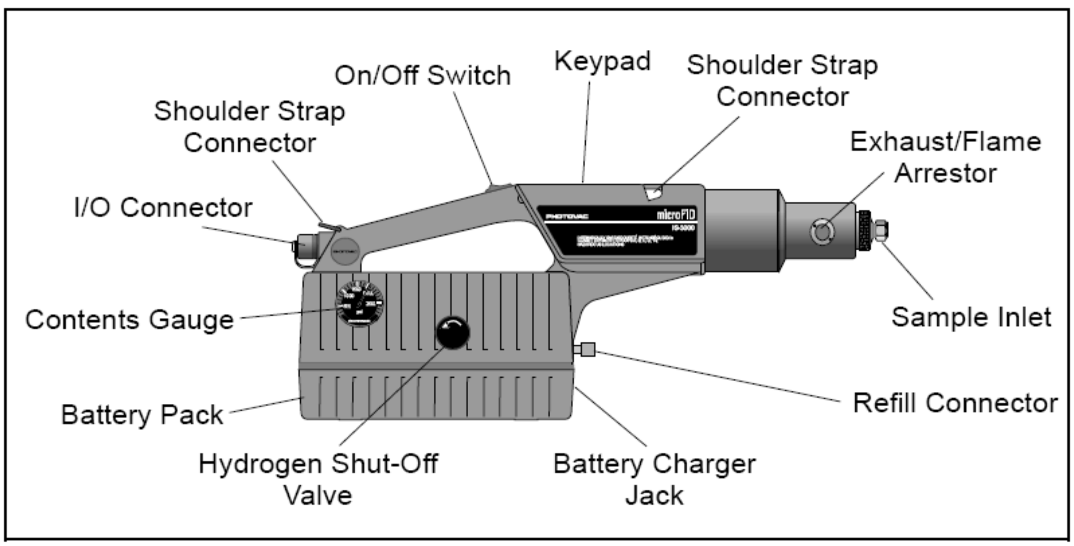

Figure 4. MicroFID Flame Ionization detector (FID) (User's Manual, 2002)

MicroFID must be calibrated in order to display concentration in ppm units equivalent to the calibration gas. First a supply of zero air, which contains no ionizable gases or vapors, is used to set MicroFID's zero point. Then, calibration gas, containing a known concentration of an ionizable gas or vapor, is used to set the sensitivity. The specifications of the MicroFID are shown in Table 4.

Table 4. Specifications of MicroFID (User's manual, 2002)

Characteristic	**Value**
Size	43.5 cm long, 9.8 cm wide 18.8 cm high
Weight	3.7 kg (8.1 lb.)
Inlet Connection	stainless steel compression fitting
Charge/discharge time	8 hr/15 hr
Hydrogen cylinder capacity	9200 cm^3 at 127 kg/cm^2
Hydrogen cylinder discharge time	12 hours
Inlet flow rate	600 mL/min. +/- 10%
Detection range	0.5 ppm-50000 ppm methane

3.2.3 Support Equipment

The support equipment used during flux measurements includes the following:

1) Air tank (Zero Grade Air)

2) Flow meter (0-20L/min)

3) GPS (Explorist 210)

4) Digital thermometer

5) Digital barometer

3.2.4. Field Experiment

The flux chamber has a cylindrical enclosure with a spherical top. The flow meter was placed in-line with the air supply tube as shown in Figure 3. A controlled air flow was supplied to the flux chamber through the perforated tube configured as a loop inside the flux chamber. VOCs that are emitted from the surface mix with the sweep air in the chamber. The sweep air flow rate was varied proportionately to the emission rate of VOCs. Initially the sweep air flow rate was set around 8L/min and concentration was measured after every 2-3 minutes to evaluate the variation in concentration occurring inside the flux chamber. If the concentration was falling rapidly then the flow rate was reduced to 6L/min or less depending on the rate of change in the VOC concentration inside the flux chamber. In this manner if the emission rate of VOCs is high then a high sweep air flow rate was used and vice versa.

3.2.4.1. Flux Chamber Field Operational Procedure

The following procedure was adopted from Walker (1991), Rash (1992) and Eun (2004).

1) Choose a relatively smooth surface to place the flux chamber and other support equipment.

2) Locate the flux chamber at a randomly selected point and connect the flow meter to the flux chamber inlet.

3) In sunny weather, use an umbrella in order to avoid heating of the flux chamber.

4) Seal the flux chamber by applying bentonite slurry to the edges of flux chamber.

5) Start the air supply and monitor the flow rate to ensure that the flow rate does not change during the process.

6) Steady-state conditions will be reached after a residence time of 3-4 times the chamber volume (e.g. At a flow rate of 6.5 L/min, steady state would be achieved in 30-40 mins).

7) When steady-state conditions are achieved, outlet concentration of VOCs was measured using the MicroFID.

8) Measure the temperature inside the flux chamber using the digital thermometer and ambient pressure using the digital barometer.

9) Measure latitude and longitude of the point using the GPS (Explorist 210).

Ambient measurements of VOCs concentration were also made around Landfill A. ArcGIS was used to produce VOC concentration contours around the landfill with different concentrations. This contour map will be helpful in validating the dispersion model that will be used to model the emissions from the landfill and provided a preliminary indication of extent of impact of the landfill from VOCs.

3.3. Litter Survey

Most litter surveys are focused on roadsides because they are easy to access and measurements are straightforward. Also, the methodology adopted for a litter survey is determined by the objectives of the study, such as comparing litter among different geographic areas or documenting the reductions among different categories of items. The Florida Center for Solid and Hazardous Waste Management (FCSHWM) conducted several litter surveys (FCSHWM 2002) to document state-wide litter reduction efforts and hence adopted a methodology of counting roadside litter. The methodology followed for the litter survey around Landfills A and B was similar to the methodology developed by the FCSHWM.

In general there are two approaches for documenting litter. One approach is to document the litter under steady-state conditions without taking into account the length of time during which the litter has accumulated. The second approach involves the removal of litter from a site and returning to the site after a fixed period of time to measure the accumulated litter. In this second approach, rate of littering is determined. The first approach is commonly followed since the second approach is time consuming and not economical and was the approach used by FCSHWM (FCSHWM 2002). The methodology followed in this study was similar to the first approach illustrated by FCSHWM.

At both Landfills A and B, litter is collected five days a week as part of their daily operations. Road segments around the landfills were selected which are accessed daily by trucks and trailers carrying waste to the landfill. Litter is collected on these selected road segments (Figure 5) and the collection procedure is repeated after completing the litter collection on all of these selected roads. Litter is collected on a selected road and when the collection is completed, litter collection on another selected road was started. For Landfill A, litter collection is done on the selected roads around the landfill (Figure 5) in five days and the procedure is repeated every week. Litter collection around Landfill A during third week of April started on 16^{th} April 2007. Litter collected on different roads was stored in different bags with name tags associated with them and collection of litter was completed by 20^{th} April 2007. Overall 40-45 bags of litter were collected and litter was counted and catalogued on 20^{th} April 2007. The procedure was repeated the next week collecting 35-40 bags and collected litter was counted again on 27^{th} April 2007. Landfill B has only one approach road and litter collection on this road is done 3-4 times every week. Each time 4-6 bags of litter are collected on this approach road. Similar to Landfill A collected litter was counted and catalogued. Since litter is removed continuously from the selected roads around each landfill, this approach captures the litter that has accumulated between the scheduled collections.

Similar to the methodology followed by FCSHWM, litter was categorized as small litter (area < 26 cm^2) and large litter (area > 26 cm^2). The purpose of this classification was to compare the litter count values obtained around Landfills A and B, with the values obtained by FCSHWM in state-wide surveys. Figure 5 and Figure 6 show the roads and the numbers designated to them around the landfills on which litter has been collected for litter count. It can be observed from Figure 5 that ten roads were selected around Landfill A for litter survey. Figure 6 shows the approach road near Landfill B used by trucks and trailers carrying waste to the landfill. Similar to FCSHWM state-wide surveys, collected litter was categorized mainly into ten categories (Appendix B). Classification of large litter items was also done based on material type. Large litter was classified as paper, plastic, glass, aluminum, mixed, composite, and steel. Various items collected are categorized based on material type as shown in Table B-14 of Appendix B.

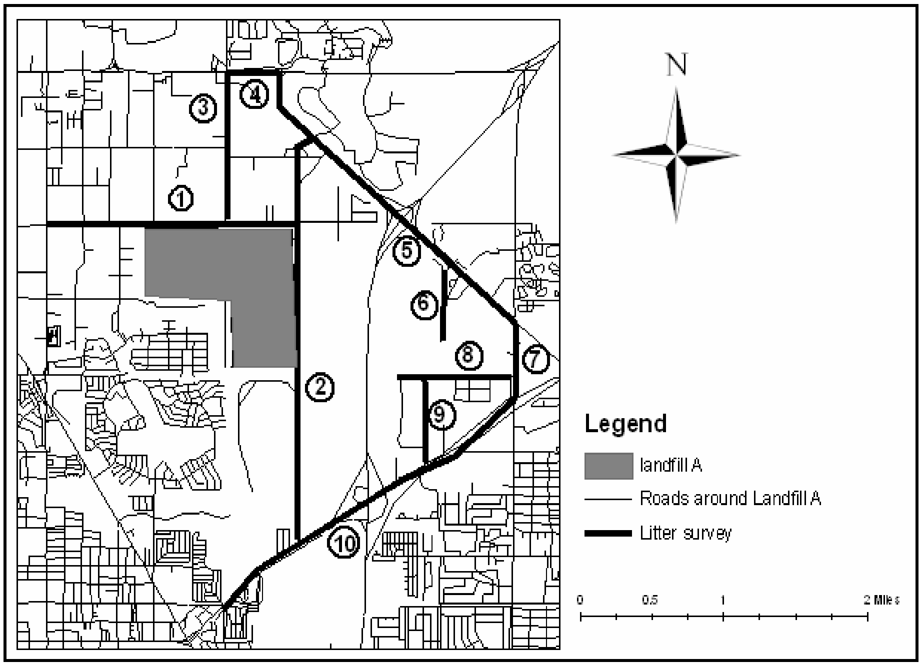

Figure 5. Landfill A Litter Survey

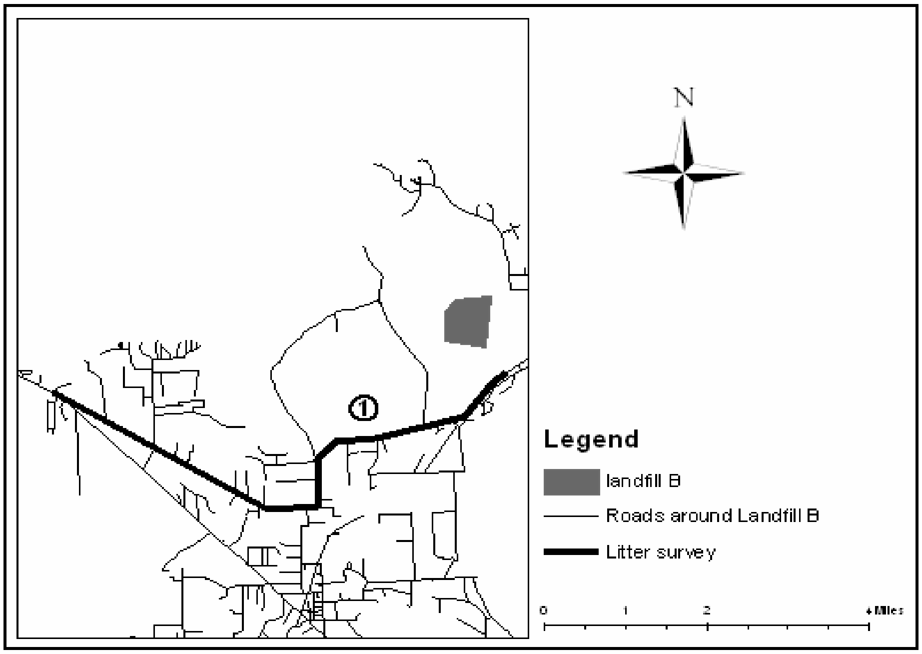

Figure 6. Landfill B Litter Survey

3.4. Impact on House Prices

The effect of certain land uses on residential property values has long been of interest in the public policy arena. In the real estate market, people are willing to pay higher prices for sites that are not affected by nuisances than for sites affected by nuisances (Crecine et al, 1967). Past research showed mixed results regarding impact of landfill on nearby residential property values (Reichert et al, 1991). Statistical approaches were adopted in previous studies to analyze the impact of landfill on house prices.

In this study, impact on house prices near the landfill was evaluated using market price data available from a public website, http://www.zillow.com. In order to evaluate the impact, data regarding 10 year (1997-2007) percentage change in house prices was analyzed.

3.5. Noise Study

The noise study was done by the UCF CEE Community Noise Lab but is included in this study to illustrate its importance as a nuisance issue and in evaluating the setbacks around the landfill. The Noise Control Act of 1972, the Quiet Communities Act of 1978, and the Housing and Urban Development Act of 1965 are some of the federal regulations addressing noise. Although these regulations do not directly address noise from landfills their overall intent was to reduce the noise level in communities.

Everyday, people are subjected to a multitude of sounds in their environment. Sound is mainly described in terms of loudness, frequency and duration. The loudness of the sound pressure level is also referred to as the amplitude or intensity. The amplitude along with the frequency or pitch requires straight-forward measurements utilizing special equipment. The duration of how long a noise lasts and the time of day at which it occurs can be quite variable at some locations but is still an important parameter in a noise test plan and can simply be recorded in units of time.

Noise amplitude is measured in units of decibels (dB) utilizing the logarithm of sound pressure squared, and most typically the A- weighted scale is used. A sound level meter that measures A-weighted decibels has an electrical circuit that allows the meter to have the same sensitivity to sound at different frequencies as the average human ear. There are also B-weighted and C-weighted scales, but the A-weighted scale is the one most commonly used for measuring moderate noise levels. The A-weighted scale extends from 0 dB(A) to 140 dB(A) reflecting the normal sensitivity of the human ear. Typical daily sounds range from 40 dB(A) (very quiet) to

100 dB(A) (very loud). EPA states a goal for community noise levels of 55 dB(A) (EPA, 1974).Table 5 illustrates the noise ranges and their corresponding impacts to normal human beings.

Table 5. Noise ranges and their impacts

Noise Range	**Impacts**
> 60 db(A)	Speech clarity becomes difficult
> 85 db(A)	Physical damage to hearing
90 db(A)	Permanent cell damage
140 db(A)	Threshold of pain occurs
190 db(A)	Eardrum rupture

Noise levels were determined at the landfill and off site. The measurements at the landfill quantified noise levels associated with existing operations and specific equipment, while the off–site measurements focused on ambient noise conditions at nearby sensitive receptors and validation of modeling efforts. Equipment used to measure noise levels included sound level meters Cesva 310 from Scantek Inc. (Columbia, Maryland) and Metrosonic dB308 (Norcross, Georgia). Weather data available from nearby airport were collected.

3.6. Presenting Data in ArcGIS

ArcGIS (ArcInfo, 9.1) software was used for analysis and presentation of field measured VOC data. Data collected in the field were projected on the base map of the landfills obtained from FGDL (Florida Geographic Database Library). GPS (Explorist 210) was used to record the location (Lat/Long) of all measurements.

Contours of ambient VOCs concentrations were obtained by using the Geostatistical Analyst extension of ArcGIS. Inverse Distance Weighted (IDW) interpolation method was used to estimate values by averaging the values of sample data points in the neighborhood. IDW assumes that each input point has a local influence that diminishes with distance. It weights the points closer to the processing points, greater than those farther away.

4. RESULTS AND DISCUSSION

Adapted from a Manuscript to be submitted to ASCE *Journal of Environmental Engineering*

4.1. Introduction

As the nation becomes more urbanized, sites once considered remote are now located in areas increasingly ripe for development or re-development. In order to site solid waste facilities, local governments have installed public works infrastructure such as roads and utilities, reducing the costs for owners of adjacent parcels. Consequently, lands adjacent to solid waste facilities are being considered for developments such as residential communities and commercial and industrial projects. Thus, the potential for nuisance complaints against the existing solid waste facility operations has increased in many areas of the nation. The most widely used measure of the magnitude of a facility's nuisance problem is the number of complaints it receives. Most of the nuisance complaints received by the landfills are related to odor, noise, litter and birds. These issues are a function of distance from the landfill and in reality most of these complaints are received from the people living very near to the landfill. In some cases, people living near the landfill are mainly concerned about the change in their property values compared with the properties farther away from the landfill.

There have been some instances in recent years where public and private owners/operators of solid waste facilities have been forced to close their facilities prematurely, resulting in loss of valuable solid waste capacity and increased cost for solid waste disposal

(Rogoff et al, 2006). Development of properties adjacent to solid waste facilities will become a significant problem for solid waste managers in the years ahead. Therefore the objective of this research was to develop methodology to gather scientific and quantifiable data to support setbacks and buffer zones near landfill and transfer station operations. Appropriate recommendations for these setbacks were made from case studies.

4.2. Background

Most of the research on nuisance issues near the landfill is related to evaluating the overall impact caused by the landfill. In many studies overall impact caused by the landfill was evaluated by conducting a community survey in the neighborhood of the landfill and analyzing the results statistically.

Furuseth and Johnson (1988) studied the attitudes of people living within five kilometers of a sanitary landfill in North Carolina. The primary goal of this study was to assess the role distance to a landfill plays in individual perception and concern. Among the impacts cited, noise, landfill traffic, litter from garbage trucks, appearance of the landfill, and property devaluation raised the greatest concerns. Approximately 35% were concerned about the traffic problem, 31% about garbage truck litter, and 21% about traffic noise problem. About one third of the respondents felt that the landfill adversely impacted the value of their property. Further analysis showed that the effects which were sensory related such as landfill noise, odor, litter and dust were strongly influenced by the distance from the landfill. Property devaluation was the only non-sensory effect influenced by the distance from the landfill. Finally, this study recommended better understanding of these effects around the landfill so that buffer distances can be more appropriately defined and efficient local decisions can be made that are fair to citizens and land use planners.

Odors from landfills are of particular concern for residents living near landfills and have been the subject of several studies. Bedogni and Resola (2002) developed a methodology to evaluate odor impact of a solid waste landfill in the northern part of Italy. The methodology integrates two different approaches: monitoring data and modeling to simulate the impact of odor emissions. In this study, the CALPUFF dispersion model was used to carry out the evaluation regarding the odor nuisance. The validation compared the gas and odor concentrations measured at five points outside the landfill with the corresponding values estimated by the model. The results of the validation procedure showed a good agreement with the experimental data concerning the methane emissions but overestimated the concentration of odorous gases. Finally, this study focused on methodology used and its importance as a decision tool for odor impact situations.

Nicolas et al (2005) studied the estimation of odor emission rates from landfill areas using the sniffing team method. The odor was detected by the sniffing team at various points around the landfill by moving in a zigzag manner around the plume axis. The meteorological situation was simultaneously recorded. Then a bi-Gaussian model was used to simulate the perception of the odor. McGinley (1998) studied the various odor quantification methods and practices at MSW landfills. In this study ten methods were reviewed that were commonly used by MSW landfills and regulatory authorities.

Reichert et al (1991) studied the impact of five municipal landfills on surrounding residential property values in Cleveland, Ohio. In this study, a total of 2243 market sales were analyzed using regression analysis and the results were mixed. In a similar study done by Schulze et al (1986) three different California cities housing markets were analyzed for potentially hazardous landfill effects. The study found significant results for one region for houses within 300 m of the landfill site.

4.3. Materials and Methodology

The methodology adopted involved measuring various quantifiable parameters related to nuisance complaints typically received by landfills at two sites (Landfills A and B) in Florida. The quantifiable parameters that were measured were volatile organic compounds (VOC) mass flux rate, noise, litter, and dust.

Landfill A is located in one of the most densely populated counties of the state. Approximately 800 to 1000 vehicles arrive at Landfill A each day and in 2006 the landfill received approximately 284,800 Mg of solid waste. This facility consists of a Waste-to-Energy (WTE) facility, an ash processing facility, a municipal solid waste (Class I) landfill and a construction and demolition debris (Class III) landfill. Ash from the ash processing facility is used as landfill cover.

When the area was chosen for the construction of solid waste facility, the surrounding land was undeveloped. The landfill began its commercial operation in 1979 and construction of the waste-to-energy plant started in 1980. During this time, over the objection of the county, the city in which landfill is located approved the zoning for construction of a residential community containing several hundred homes directly west of the active landfill. Also during the 1980s and 1990s, as permitted by the zoning regulations, the surrounding area continued to develop commercially.

Landfill A started logging complaints (Figure 7) related to odor, noise, litter and birds, in the year 2004, from the residential community west of the landfill. The number declined during later years. All the complaints were received from the houses which are nearest to the landfill (500 ft due west).

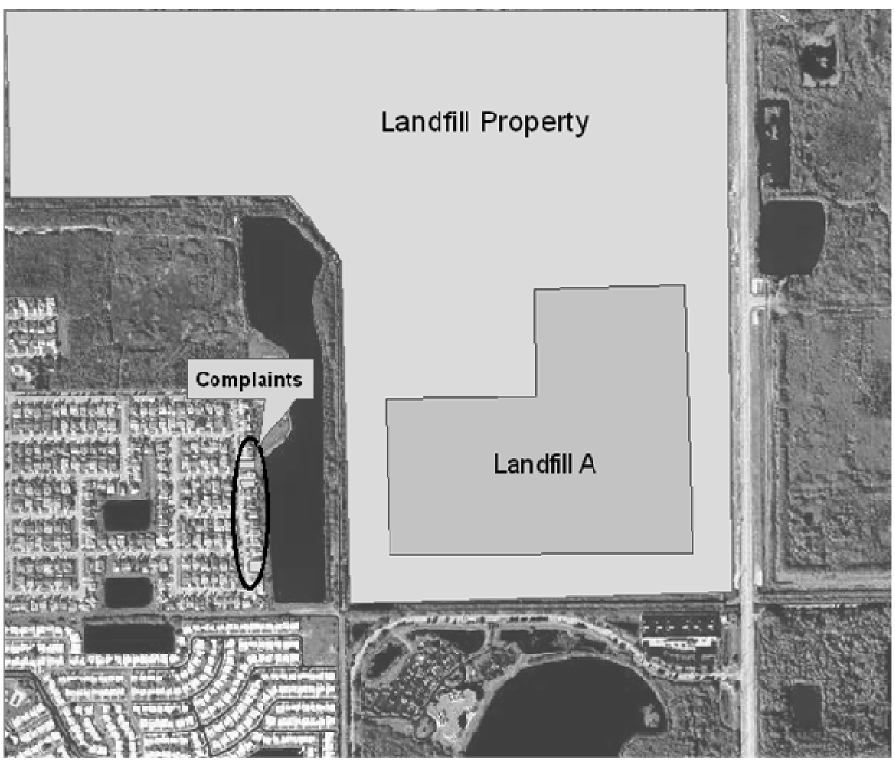

Figure 7. Landfill A complaints

Landfill B is located in the central eastern part of Florida and started its operations in 1978. It has a total footprint of 0.98 km^2. It is a Class I inward-gradient landfill with a natural clay liner and has a total design capacity of 34,405,000 m^3. Gas recovery and leachate removal systems were installed. In 2006, the landfill received 308,500 Mg of solid waste and 48,300 Mg of yard waste. Landfill B is surrounded with highly dense tree growth and the nearest residential housing is at least 600 m away from the landfill. Therefore, they have never received any complaints related to any of the nuisance issues.

4.3.1. VOC Flux Measurement

People in communities near landfills are often concerned about odors emitted from landfills. Potential sources of landfill odors include sulfides, ammonia, and certain Non-Methane Organic Compounds (NMOCs), if present at sufficiently high concentrations. A landfill system has a strong potential to produce and release an excessive amount of organic compounds into the atmosphere (Zou et al., 2003). Also, Kim et al (2005) characterized malodorous sulfur compounds in landfill gas and found that H_2S is the main odor causing component; they found a strong correlation between H_2S and VOCs for several of the landfill sites. VOCs are composed of methane and some non-methane volatile organic compounds (NMOCs) (Kreith, 1995). NMOCs include saturated and unsaturated hydrocarbons, acidic hydrocarbons, organic alcohols, halogenated compounds, aromatic compounds and sulfur compounds (Keller, 1988). Although NMOCs account for less than 1% of total VOCs, they can cause significant health impacts (Zou et al., 2003), and alkyl benzenes, limonene, certain esters and organosulfur compounds are responsible for undesirable odor. Hence, in this study, VOC concentration was used as a surrogate measure for gaseous impacts.

The mass flux of VOCs was measured on the landfill using the flux chamber method. The concentration of VOCs in the exit gas from flux chamber was measured using a flame ionization detector (FID). In this methodology, the dynamic flux chamber method was used since it is the most accurate method for determining emission rates from the landfill (Cooper et al, 1992). The ultimate purpose of flux measurements is to provide input data for dispersion modeling to analyze the extent of odor impact around the landfill, which is outside the scope of this study.

The operational procedure was adopted from Walker (1991), Rash (1992) and Eun (2004). Random sampling points were selected on the landfill to place the flux chamber. The flux chamber was sealed along the edges using bentonite slurry and flow meter was connected to the inlet. Air is supplied at a constant flow rate into the flux chamber. A portable MicroFID from Photovac Inc. (Waltham, Massachusetts, US) was used to measure the concentration of VOCs. The MicroFID uses a hydrogen supply and the oxygen from the sample air to support combustion. Measurements were made at the exit port using MicroFID at constant intervals until steady-state condition is achieved. At steady-state, the concentration of VOCs at the exit port was recorded. The emission rate at the sampling point is calculated using equation 3.

$$F = \frac{(C(mg/\mathrm{L}) \times \mathrm{Q})}{A} \qquad (3)$$

Where: F is the emission flux rate measured for sampling point (mg/m^2-min), C (mg/L) is exit VOC concentration in mg/L as carbon, Q is the flux chamber sweep air flow rate in L/min, and A is the enclosed surface area (0.19 m^2).

4.3.2. Litter Survey

Most litter surveys are focused on roadsides because they are easy to access and measurements are straightforward. The methodology followed for the litter survey around Landfills A and B was similar to that developed by the Florida Center for Solid and Hazardous Waste Management (FCSHWM 2002). The primary goals of the litter survey around Landfills A and B were to quantify the litter and identify the composition of the litter.

At both Landfills A and B, litter is collected five days per week as part of their daily operations. Roads around the landfills were selected which are accessed daily by trucks and trailers carrying waste to the landfill. Litter is collected on these selected roads and the collection procedure is repeated after completing the litter collection on all of these selected roads. Litter is collected on a selected road and when the collection is completed, litter collection on another selected road will be started.

For Landfill A, litter collection is done on the selected roads around the landfill (Figure 5) in five days and the procedure is repeated every week. Litter collection around Landfill A during third week of April started on 16th April 2007. Litter collected on different roads was stored in bags with name tags associated with them. Collection of litter was completed by 20th April 2007. Overall 40-45 bags of litter were collected and litter was counted and catalogued on 20th April 2007. The procedure was repeated next week and 35 to 40 bags were collected. Collected litter was counted again on 27th April 2007.

Landfill B has only one approach road and litter collection on this road is done three to four times every week by the landfill personnel. Each time four to six bags of litter is collected on this approach road. Similar to Landfill A, collected litter near Landfill B was counted and catalogued. Since litter is removed continuously from the selected roads around each landfill, this approach captures the steady-state litter that has accumulated between the scheduled collections.

Litter collected on the roadsides around the landfills was counted and categorized based on material type. Similar to the methodology followed by FCSHWM (FCSHWM 2002), litter was first categorized by size as small litter (area < 26 cm^2) and large litter (area > 26 cm^2) and then based on material type as paper, plastic, glass, aluminum, steel, mixed and composite. This classification allowed comparison of the litter count values obtained around Landfills A and B to the values obtained by the FCSHWM in state-wide surveys, which would represent background litter. FCSHWM state-wide surveys measured litter that had accumulated over relatively long period of time. These surveys capture a steady-state condition balancing litter accumulation and degradation. In this study the amount of litter present on road segments represents a steady-state because of accumulation and regular litter collection by landfill personnel. Therefore it is reasonable to compare data from this study to FCSHWM data to evaluate landfill litter effects.

4.3.3. Impact on House Prices

The effect of certain land uses on residential property values has long been of interest in the public policy arena. In the real estate market, people are willing to pay higher prices for sites that are not affected by nuisances than for sites affected by nuisances (Crecine et al, 1967). Past research showed mixed results regarding impact of landfill on nearby residential property values

(Reichert et al, 1991). Statistical approaches were adopted in previous studies to analyze the impact of landfill on house prices.

In this study, impact on house prices near the landfill was evaluated using market price data available from a public website, http://www.zillow.com. In order to evaluate the impact, data regarding 10-year (1997-2007) percentage change in house prices was analyzed.

4.3.4. Noise and Dust Measurements

These studies were performed by the UCF CEE Community Noise Lab. Typical daily sounds range from 40 dB(A) (very quiet) to 100 dB(A) (very loud). The U.S. EPA states a goal for community noise levels of 55 dB(A). Sound level meters Cesva 310 from Scantek Inc. (Columbia, Maryland) and Metrosonic dB308 (Norcross, Georgia) were used to measure noise. A receiver height of 1.5 meters was used at all microphone locations. All receivers were located at least 3.5 meters from any reflecting source such as a building or wall. Key, or reference, receivers were located as close as possible to avoid unwanted interferences.

At Landfill A, the first set of measurements involved measuring noise levels associated with typical WTE facility activity and the second set of noise levels associated with 100% landfilling of unburned waste were made when the WTE facility was down for maintenance. For both cases, background noise levels were measured by setting up sound level meters far away from the source. Landfill B noise measurements were mainly made to capture the noise levels associated with equipment used on the landfill and then measurements were made to capture the noise levels at various locations on the landfill.

Dust measurements were also made on Landfill B. Dust is generated from the landfill mainly from the landfilling activity and from trucks/trailers traveling around the landfill while moving the waste. Measurements were made by setting up particulate samplers in upwind and downwind locations relative to the landfilling activity. Particulate samplers were designed to collect particulate matter smaller than 10 microns. A 38-elemental break down and analysis of the dust samples collected was done by Chester LabNet (Oregon).

4.4. Results and Discussion

4.4.1. VOCs Mass Flux Results

Flux measurements for Landfills A and B were conducted from December 2006 to June 2007. Most of the trips were made when the forecasted weather was partly cloudy. Occasionally adverse weather conditions were encountered during the measurements, such as rain and heavy wind, and the measurements were stopped. Most of the flux measurements were made between 11 am and 5 pm. The site weather conditions and landfill visit dates are recorded in Table 6. According to EPA users guide (Kienbusch, 1986) the minimum number of samples to be measured is given by equation 4.

$$N_k = 6 + 0.1 \times (Area(m^2))^{0.5} \quad (4)$$

Using the GPS and ArcGIS software, the calculated area available for measuring the gas emissions on Landfill A was 137000m^2. Based on the area available and equation 4, the minimum number of samples required was approximately 40. Calculation of available area on

Landfill B was difficult because of its irregular surface profile, however since the footprint areas were similar; it was assumed that the area available for measurements was also similar. To confirm this similarity, the same distance between the samples was maintained for Landfill B.

Table 6. Landfill Visit Dates and Weather Conditions

Landfill	**Visit Date**	**Weather**
Landfill A	29-Dec-06	79 F, Clear
	4-Jan-07	81 F, Partly Cloudy
	12-Jan-07	75 F, Partly Cloudy
	19-Jan-07	86 F, Partly Cloudy, Heavy winds
	28-Feb-07	81 F, Partly Cloudy
	9-Mar-07	90 F, Clear
	14-Mar-07	79 F, Clear, Heavy winds
	15-Mar-07	81 F, Clear
Landfill A	10-Apr-07	82 F, Partly Cloudy
Landfill B	11-May-07	95 F, Partly Cloudy
	16-May-07	113 F, Clear
	25-May-07	81 F, Partly Cloudy
	30-May-07	86 F, Partly Cloudy, Heavy winds
	7-Jun-07	79 F, rainy
	8-Jun-07	99 F, Partly Cloudy

4.4.1.1. Landfill A

Flux data were collected at Landfill A from December 2006 to April 2007. All the measurements were made using the dynamic flux chamber method. Overall, 38 measurements were made on Landfill A out of which 14 measurements were below detection limit. The facility operates a waste-to-energy plant and destroys more than 85% of the waste received. The ash obtained from the waste-to-energy plant is landfilled in the Class I landfill. Table A-1 (Appendix A) presents the results of flux measurements for Landfill A. Emission rates measured on Landfill A ranged from BDL to 47 mg/m^2-min as carbon and a mean emission rate of 2.37 mg/m^2-min as carbon (Table 7) was obtained.

Figure 8. Landfill A VOC Measurements

4.4.1.2. Landfill B

Flux data was collected at Landfill B from May 2007 to June 2007. Similar to Landfill A, measurements were made using the dynamic flux chamber method. A total of 36 measurements were made on the landfill, out of which 18 measurements were below detection limit. Table A-2 (Appendix A) presents the results of flux measurements for Landfill B. Emission rates measured on Landfill B ranged from BDL to 40 mg/m^2-min as carbon and a mean emission rate of 4.59 mg/m^2-min as carbon (Table 7) was obtained. The flux from most of the locations where measurements were made that had intermediate cover consisting of a mixture of mulch and dirt was BDL. Areas with soil cover only had emissions in the range 15 to 40 mg/m^2-min as carbon.

Figure 9. Landfill B VOC Measurements

4.4.1.3. Summary and Discussion of Emission Rate Results

Table 7 provides a comparison of VOC measurements conducted on Landfills A and B. It can be observed from Table 7 that Landfill B has 94% higher emissions than Landfill A. Table 7 also presents the other characteristics of Landfills A and B.

Table 7. Summary of VOC Mass Flux Measurements at Landfills A and B

Characteristics	Landfill A	Landfill B
# of Flux Measurements	38	36
Area of active landfill (km^2)	0.3	0.38
# of locations Below Detection Limit	14	18
Arithmetic Mean Flux (mg/m^2-min as carbon)	2.37	4.59
Standard Deviation of VOC Flux (mg/m^2-min)	7.79	9.99
Total Emissions (Mg/yr as carbon)	375	933

A number of researchers, Barry (2003); Borjesson et al. (2000); Cardellini (2003); Paladugu (1994); Rash (1992); and Walker (1991) have reported methane flux rates. These rates ranged from 0.253 to 4300 mg/m^2-min. VOCs measured by the MicroFID are composed of methane and NMOCs. In the absence of site-specific data, the value recommended for NMOC concentration by US EPA is 8,000 ppmv as hexane (0.8 % by volume) (EPA, 1999) and for methane it is 50 % as hexane(EPA, 1997). As can be seen, methane concentration is significantly greater than NMOC concentration. Therefore for the purpose of this evaluation methane concentration is assumed to be approximately equal to VOC concentration and the mean flux rates of methane on Landfills A and B are within the range of emission rates reported in the literature.

It is important to note that the flux rates measured were assumed to be constant over time. However in reality, not only the total concentration of VOCs but also the relative composition of various components of VOCs varies with time (Kim et al 2005).

4.4.1.4. Ambient VOC measurements

Ambient measurements (Table 8) were made around Landfill A on February 9, 2007. These measurements will be used to validate dispersion model results by comparing the results from dispersion modeling with ambient data. Weather data were also collected during the same time on the surface of the landfill. Figure 10 shows the contour map with ambient measurements.

The ambient measurements were made around the landfill using the MicroFID. One minute averaging time was used for measuring the concentrations. The prevailing wind direction during the measurements was from northwest. As would be expected highest off-site concentrations were observed southeast of the landfill as shown in Figure 10.

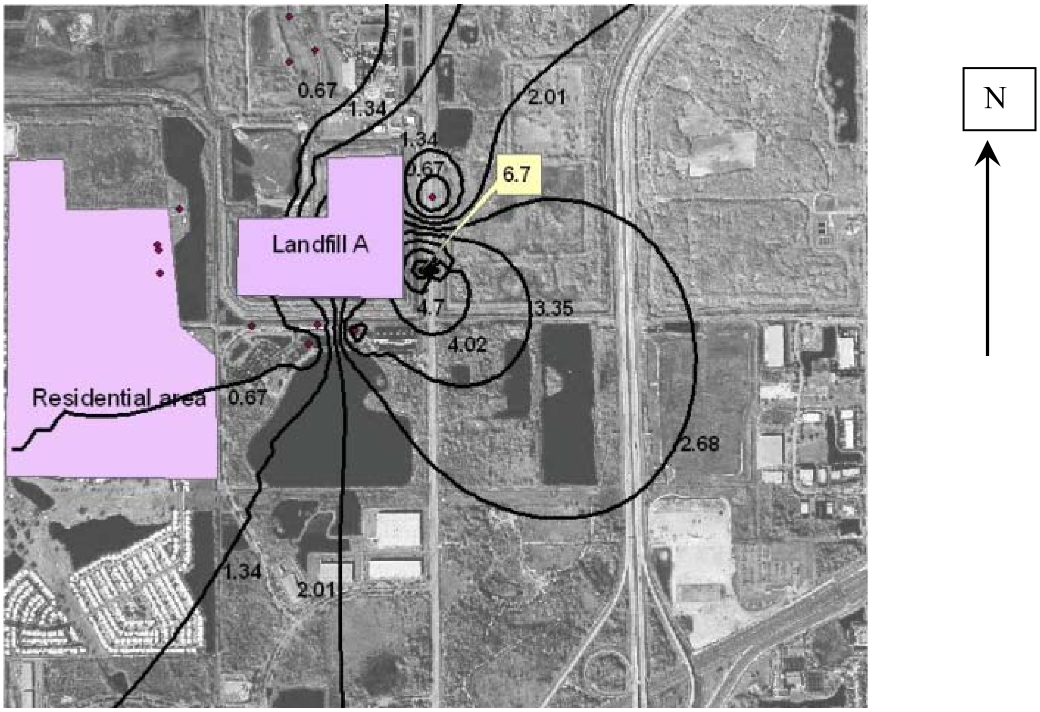

Figure 10. GIS Contour Map with Ambient Measurements (ppm)

Table 8. Ambient Measurements around Landfill A

Location	**Peak Conc. range(ppm)**
Residential neighborhood(West)	0
Commercial neighborhood(south)	0.4-6.7
East side of landfill	0-4.7

Some of the NMOC constituents such as alkylbenzenes and limonene along with H_2S are dominant odor sources (Zou et al, 2003). Although there are negligible health impacts caused by the VOC emissions from the Landfills A and B, the constituents of NMOCs and H_2S can be responsible for causing offsite odors. To evaluate offsite odor impacts, NMOCs and H_2S were estimated from VOC data.

The highest VOC concentration, 6.7 ppm as methane, was observed on the southeast side of the landfill. VOCs measured by the MicroFID are composed of methane and NMOCs. In the absence of site-specific data, the value recommended for NMOC concentration by US EPA is 8,000 ppmv as hexane (0.8 % by volume) (EPA, 1999) and for methane it is 50 % as hexane(EPA, 1997). Methane concentration is significantly greater than NMOC concentration. Hence, in this analysis NMOC to VOC ratio is considered equal to NMOC to methane. Therefore, the ratio of NMOC to VOC concentration in landfill gas is 0.016. Using the ratio of NMOC to VOC determined above, the highest NMOC concentration would be 0.11 ppm as methane. Most of the NMOC gas components have odor detection thresholds higher than 0.11 ppm (ATSDR, 2001) except dicholoroethylene which has an odor threshold of 0.085 ppm. Hence it is unlikely that there were offsite odor impacts due to VOCs.

Using a typical concentration of H_2S of 35.5 ppmv (EPA, 1990); the ratio of H_2S concentration to methane concentration in landfill gas is 8×10^{-5}. Again, since VOCs are mainly composed of methane, H_2S to VOC ratio is assumed to be 8×10^{-5} as well. Therefore, the highest H_2S concentration obtained would be 0.5 ppb which is less than the odor threshold for H_2S (0.5-10 ppb). Hence it is unlikely that offsite odor impacts occur due to H_2S.

Although there are no significant health or odor impacts caused by the emissions from the landfill, it can be observed from Figure 10 that ambient concentrations of VOCs on southeast side of the landfill are higher than the background (northwest) concentration. These higher concentrations extend 1.2 to 1.5 km from the landfill center on southeast side of landfill.

Ambient air measurements could not be made around Landfill B because of the dense tree growth around the landfill.

4.4.2. Litter Survey Results

Litter surveys were performed around Landfills A and B following a procedure similar to Florida Center for Solid and Hazardous Waste Management (FCSHWM) (FCSHWM 2002). Accumulated road side litter was collected around the landfill and counted after sorting was done based on size and material. The length of the roads from which litter was collected was obtained using ArcGIS software. Similar to FCSHWM methodology (FCSHWM 2002), counts per site were obtained by finding the litter count per 100 meters of road length.

4.4.2.1. Landfill A

Litter (Figure 11) was collected on ten selected roads (Figure 5) in five days around Landfill A by the landfill personnel and the procedure is repeated every week. In this study, collected litter on all selected roads was counted and categorized for two collect rounds. Litter count obtained was normalized to road length for the roads around the landfill. Average litter count values were obtained by averaging the values obtained in two collect rounds. Table 9 presents the results of the litter survey around Landfill A.

Figure 11. Litter items collected

Table 9. Litter Survey Results for Landfill A

Roads	**Length (meters)**	**Average Litter count (Large)**	**Average Litter count (Small)**
1	2700	153	24
2	4500	295	62
3	1600	293	68
4	1400	92	31
5	4000	485	73
6	1800	20	0
7	1100	253	28

8	1100	231	58
9	1500	170	29
10	1100	474	88

The average values of litter count normalized to road length for the roads around the landfills are less than the FCSHWM 2001 and 2002 state-wide surveys as shown in Figure 12. The coefficient of variation (COV) for Florida Centers 2001 and 2002 state-wide surveys was in the range of 8.5-9% (Florida Litter Study 2002). The COV for the data collected around landfill A was relatively high (70-90%). In this study, the maximum litter that accumulates around the landfill was measured and was found to be less than the FCSHWM 2001 and 2002 state-wide surveys. Analysis showed that the difference between the litter count values obtained from FCSHWM 2002 state-wide survey and around landfill A was statistically significant at 5% level of significance (Appendix D).

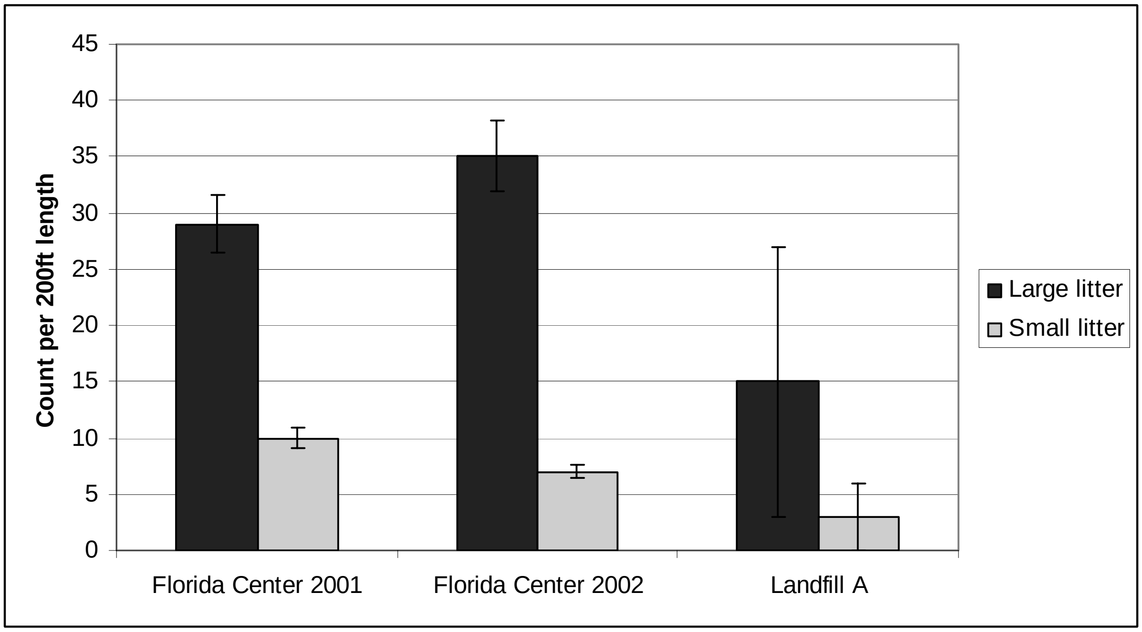

Figure 12. Litter Survey Around Landfill A

Collected litter around Landfill A was also categorized based on material type as shown in Table B-13 of Appendix B. Table B-14 in Appendix B shows various categories of items grouped under different material types. Results are shown in Table 10. From Table 10 it can be observed that paper and plastic constituted more than 80% of the total large litter items. Paper and plastic are the material categories which are relatively less dense compared to other material categories. Hence higher percentage of paper and plastic might be due to litter spillage from the trucks and trailers arriving at the landfill. Occasionally, on some of the roads near the landfill, trash bags filled with household waste were collected which presumably fell from the trucks carrying waste to the landfill.

4.4.2.2. Landfill B

There is only one approach road for landfill B which is accessed by trucks and trailers carrying the waste to the landfill. Collected litter on this approach road by the landfill personnel was counted and categorized. The procedure was repeated two times and average values of large and small litter counts were obtained. It can be seen from Figure 13 that around Landfill B the accumulated litter is negligible compared to FCSHWM 2001 and 2002 state-wide surveys. Statistical analysis has not been done for Landfill B because of small number of counts.

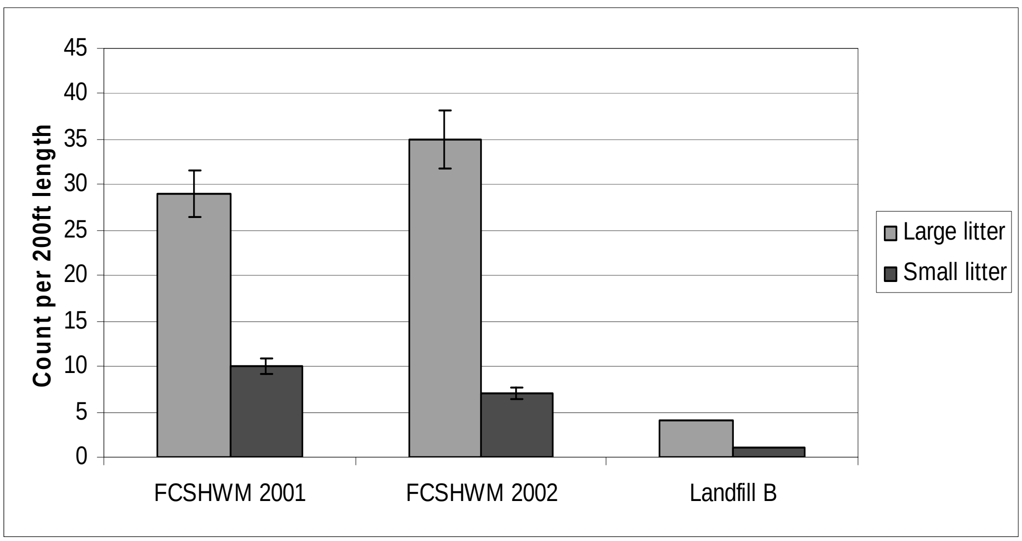

Figure 13. Litter Survey Around Landfill B

Large litter collected on road segments around Landfill B was classified based on material type and compared with the FCSHWM state-wide surveys as shown in Table 10. It can be observed from Table 10 that, in the state-wide litter surveys conducted by FCSHWM, mixed and paper were more than 50% of total large litter. Whereas, in the litter surveys around Landfill B, paper and plastic constituted more than 80% of total large litter. Similar to Landfill A, higher percentage of paper and plastic might be due to litter spillage from the trucks and trailers arriving at the landfill.

Table 10. Classification of Large Litter by Material Type (% of total count)

Material	FCSHWM 2001	FCSHWM 2002	Landfill A	Landfill B
Mixed	35	36	8	2
Paper	25	24	49	27
Plastic	24	24	37	66
Aluminum	11	11	4	3
Glass	5	4	1	3

4.4.3. Property Values Results

Landfill A is located in one of the most densely populated counties in Florida. The area was chosen in 1975 for construction of a solid waste management facility when the surrounding land was vacant. The surrounding land was zoned in the County's comprehensive plan for light industrial and commercial use only. Construction of a waste-to-energy plant began in 1980 and during this time, construction of a residential community directly west of active landfill was approved. The effect of landfill on residential property values was analyzed.

Houses at a particular distance from the edge of the landfill were selected and the 10-year percentage change in the house price was obtained from a public website, http://www.zillow.com. An average value of 10 year percentage change of house prices was obtained for all the houses at a particular distance from the edge of the landfill and this procedure was repeated for various distances from the landfill.

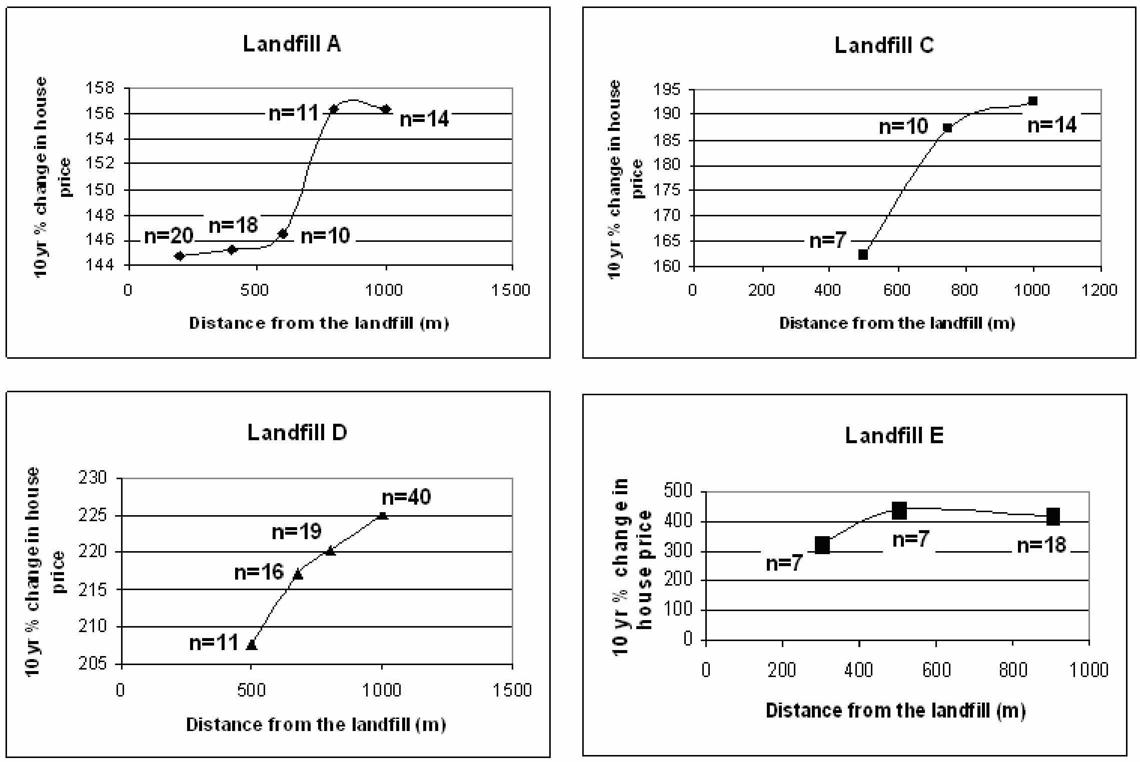

Figure 14. Effect of Landfill on Property Values

Similar analysis was done for three more landfills in Florida which have residential development near the landfill (Figure 14). It can be seen from Figure 14 that the percentage change in house prices increased significantly, 600 m to 800 m (2000 ft to 2600 ft) from the landfill boundaries.

Statistical analysis was done using MS EXCEL to examine the significance in difference of means of percentage change in house prices at various distances. For this purpose, a t-test was done to compare means. Initially an F-test was performed to evaluate whether variances of sample data at various distances are statistically different. For Landfill A, house data at distances below 400 m were combined and compared with the combined data at distances above 800 m. The initial F-test obtained p-value was significantly greater than 0.05. Hence, it can be concluded that the variances of the two samples are statistically the same at 95% confidence interval. Further, a t-test was performed assuming equal variances and a p-value significantly less than 0.05 was obtained. This shows that the mean value of data below 600 m is statistically different than the data above 800 m. Similar analysis for Landfills C and D showed that the mean of the house data below 600 m is statically different from the mean of the house data above 800 m. However, for Landfill E there was no statistical difference in means at distances less than 600 m and greater than 800 m.

Hence, based on this analysis, a setback distance of 800 m to 1200 m from the landfills is recommended to minimize the impact on residential property values. Table 11 compares setback distances recommended in this study and other studies conducted on impact of landfills on housing prices. Since the impact caused by the landfills is a function of many parameters such as operational characteristics, and landfill age, the difference in the spatial impact observed around the landfill is expected.

Table 11. Comparison of setback distances

Source	**State**	**Setback distance from the landfill (km)**
Schulze et al (1986)	California	0.3
Nelson et al (1992)	Minnesota	3-4
Gamble et al. (1982)	Pennsylvania	1.6
Present study	Florida	0.8 to 1.2

4.4.4. Noise measurements

4.4.4.1. Landfill A

Noise measurements at Landfill A were made in July 2006 (during typical WTE activity) and October 2006 (during landfilling of unburned waste). Figure 15 shows the locations of stationary meter measurements during typical WTE activity. A stationary meter located directly in front of the WTE facility Bay 4, Location 4, captured the noise levels associated with the trucks coming and going from the WTE facility, backup beepers, and crane operations. This site recorded a L_{eq} of 64.2 dB(A) and an L_{max} of 76.4 dB(A) and a standard deviation of 2 dB(A). L_{eq} (Equivalent Sound Level) is a steady-state sound which has the same A-weighted sound energy as that contained in the time varying sound in the measurement period and L_{max} is the highest noise level during the measurement period. The L_{eq} and L_{max} values obtained at locations 1, 2, 3 and 4 (Figure 15) are shown in Table 12 along with the standard deviation values.

Figure 15. Noise Measurements during Typical WTE Activity

Table 12. Noise Measurements on Landfill A (dB(A))

Location	L_{eq}	L_{max}	St. dev
Gazebo	58	66.3	4.3
Across from gazebo	58.3	63.7	3.7
28th street	62.4	65.9	3.9
WTE facility	64.2	76.4	2

A roving meter was used to take recordings even closer to the WTE facility and on all four sides of the operations. These sites helped determine a background noise level associated with the landfill during incineration, as well as the sound levels associated with the WTE facility directly.

A second set of measurements were made on Landfill A in October 2006 when the WTE facility was shutdown for maintenance. During this period all incoming waste was diverted to the landfill directly. Measurements were made directly in front of the WTE facility Bay 4 as shown in Figure 16.

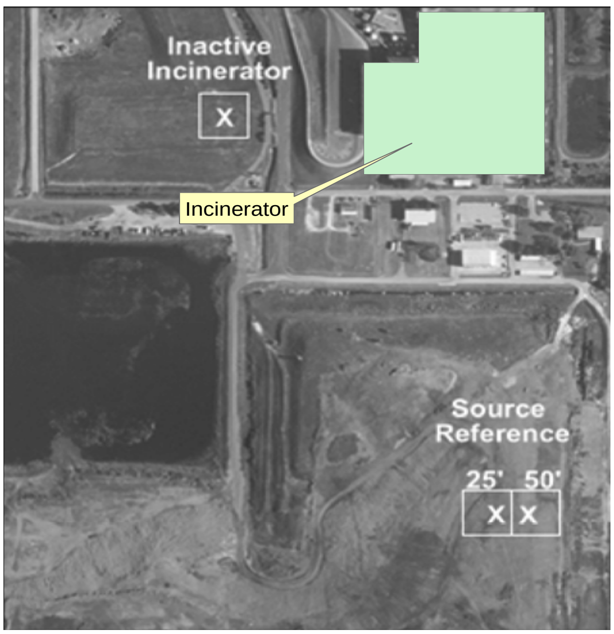

Figure 16. Noise Measurements during WTE Facility Shutdown

In order to record sound levels (Table 13) associated with garbage trucks, dump trucks, and transfer trucks arriving at the landfill, a microphone setup was deployed, 10 meters (25 feet) and 15 meters (50 feet) from the landfill access road.

Table 13. Noise Measurements during WTE Facility Shutdown

Site Description	**L_{eq}**	**L_{max}**	**St. Dev**
Across from Inactive WTE	63.6	81.6	4.1
15 m from access road 90 m from landfill	67.7	76.0	5.6
10 m from access road 85 m from landfill	71.3	84.2	3.4

4.4.4.2. Landfill B

Noise measurements were made on Landfill B during March and April 2007. Landfilling was the only source of noise from this landfill. Hence, measurements were made to capture the noise levels associated with landfilling activity. Figure 17 shows locations of noise measurements on Landfill B. Background measurements were taken 200 meters from the active landfill zone and, similar to Landfill A, measurements were made at 10 and 15 meters from the landfill access road (Table 14).

Figure 17. Noise Measurements on Landfill B

Table 14. Noise Measurements on Landfill B (dB(A))

Site Description	L_{eq}	L_{max}	**St. Dev**
Background Site 200 m from landfill	54	73.7	5.2
15 m from access road 100 m from landfill	59.4	70.0	3.6
10 m from access road 80 m from landfill	60.3	76.8	4.5

Table 15 shows a summary of noise measurements made at Landfills A and B. Based on field measurements at both landfills it can be observed from Table 15 that to achieve EPA recommended values of 55 dB(A) for quiet neighborhood, a setback distance of 1.6 to 1.9 km should be maintained around the landfill if no shielding occurs.

Table 15. Summary of Noise measurements at Landfills A and B

Distance (Meters)	Location	L_{eq} dB(A)	desired L_{eq} dB(A)	d2 for L_{eq} (miles)
100	WTE	64.2	55	0.5
100	Landfill	69.4	55	0.9

It can be observed from Table 13 and Table 14 that Landfill A recorded higher measurements than Landfill B. The distances recommended in Table 15 do not account for ground effects and other topological factors that affect the sound wave propagation between the source and the receptor. Also, it is important to note that the noise measurements recorded may vary when there is a change in the location of landfilling activity.

4.4.5. Dust measurements

Dust measurements have been made at Landfill B over a 48-hour period. Two particulate samplers, known as Mini Vols, were set up on Landfill B as shown in Figure 18. The choice of locations for the Mini Vols was somewhat limited due to sensitivity of the equipment and the layout of the active cell.

Figure 18. Dust Measurements on Landfill B

The first Mini Vol was located about 200 meters off the access road in a inactive area (Figure 18). This site was upwind of the active landfill in a relatively secluded area, and provided background dust levels. The second Mini Vol was located in the active cell area, 50 meters from where the bulldozers were moving waste (Figure 18). This downwind location was selected to collect the particulate matter directly associated with landfilling activity. It is important to note that in an attempt to avoid filter clogging the equipment was located away from traffic that would stir up large amounts of dust. Each location used two 24-hour filters while on location. A 38-elemental break down and analysis of the dust samples collected was done by Chester LabNet (Oregon). Table 16 below gives the net concentration (downwind-upwind) of the ten highest elemental concentrations coming from the landfilling activity. Increase in concentration of all major analytes were observed.

Table 16. Differences in Elemental Concentrations between Downwind and Upwind of Landfill B

Day 1		**Day 2**	
	μg/filter		μg/filter
Ca	3.493	Na	1.2586
Si	1.407	S	0.126
Al	0.793	Si	0.0791
Na	0.675	Sn	0.0735
S	0.299	Ti	0.0475
Fe	0.177	Ni	0.0452
K	0.061	Sb	0.0339
Cl	0.042	Al	0.0249
Cd	0.037	Ag	0.0238
Ti	0.036	Fe	0.0158

Mini Vol located in the upwind location collected a total mass of 110 mg in 24 hours (14.9μg/m^3) and the second Mini Vol located in the downwind direction collected a total of 136 mg in 24 hours (18.4μg/m^3). Both of these values are below National Ambient Air Quality Standards (NAAQS) of 150μg/m^3 for PM_{10} (US EPA 1997).

4.5. Conclusions and Recommendations

This study investigated a methodology to gather scientific and quantifiable data and recommend setback distances from landfills to minimize nuisance impacts. Based on the results obtained, the impact distances recommended for Landfill A are shown in Table 17.

Table 17. Observed Impact Distances

Nuisance	Impact distance (km)
Noise	1.6-1.9
VOCs	1.2-1.5
House prices	0.8-1.2
Complaints/Visual	0.45-0.5
Litter	No Impact

It can be observed from Table 17 that noise is the most significant off-site impact. Since the nuisances caused by the landfill are function of landfill characteristics including landfill age, topography, operating conditions and equipment used, the value of impact distances and the order of importance of nuisances is expected to be site specific.

VOC concentrations were measured and the concentrations of odorous compounds were obtained by using the default concentration ratios of gases present in the landfill gas due to study budget. Better estimation of gaseous impacts can be done by directly measuring the concentration of various odorous gases present in landfill gas. Also, this study did not consider the traffic impact caused by the landfill. Traffic impact can be evaluated by calculating the volume of traffic on the roads near the landfill and comparing with the standard traffic conditions. Visual impacts and bird nuisances can be minimized by maintaining a line of tree growth around the landfill. Also, any operational change such as active gas collection and minimizing exposed active area which would reduce the gas emissions from the landfill are important to reduce offsite impacts.

5. CONCLUSIONS AND RECOMMENDATIONS

The purpose of this research was to investigate a methodology to gather scientific and quantifiable parameters related to nuisance impacts received by the landfills and recommend setback distances for solid waste facilities based on case studies. For this purpose measurements related to odor, noise, litter, house prices and dust have been measured. The following results could be drawn from the results of this study:

1) There were negligible odor impacts caused by VOCs from Landfill A based on ambient measurements. However the VOC concentration in the downwind direction was higher than the background concentration till 1.2 to 1.5 km from the landfill.

2) A setback distance of 1.6 to 1.9 km was recommended around the landfills based on noise study done by UCF CEE Community Noise Lab.

3) Litter study around Landfills A and B showed that there was negligible litter impact caused by the landfills.

4) Analysis of house prices showed a significant impact on pricing of houses closer than 0.8 to 1.2 km.

5) Dust measurements on Landfill B were below the NAAQS of 150µg/m^3 for PM_{10}.

It can be observed from above recommended setbacks, that for Landfill A noise is a significant issue followed by VOCs and house prices. Figure 19 below shows the map with various setback distances around the landfill. Based on this study, a setback distance of at least 1.9 km (1.24 miles) is recommended.

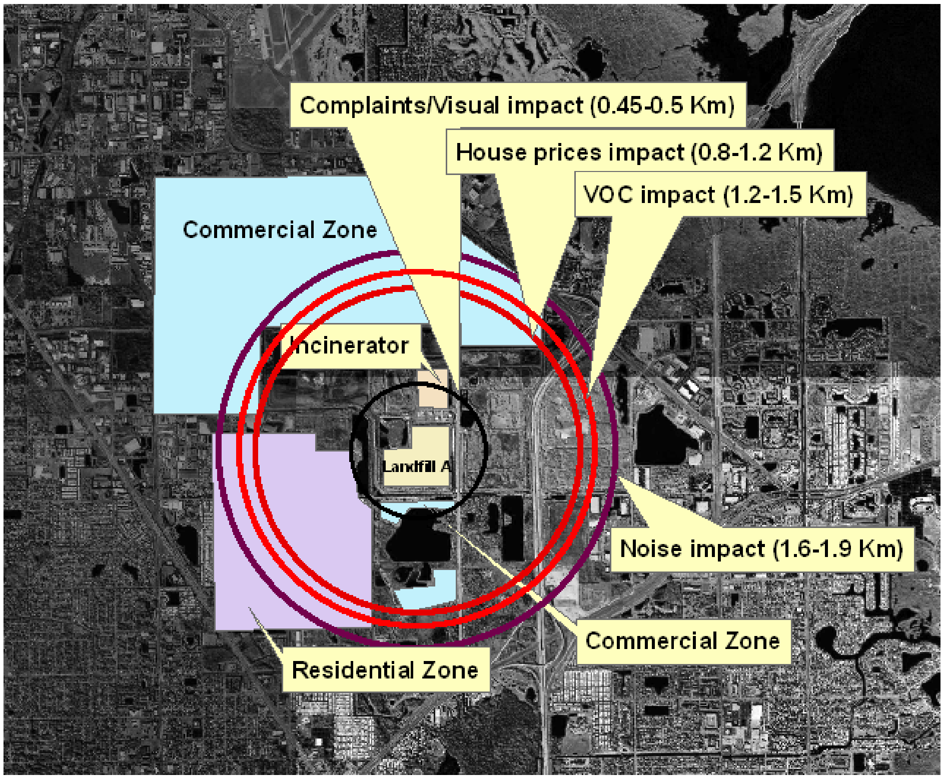

Figure 19. Setback Distances Around Landfill A

Regulations in any industry are made through rational debate, effective consultation and rigorous analysis of the conditions which bring up the need for a regulation. This study illustrates the need for regulations related to nuisance impacts received by the landfills and was an initiative to study the various parameters of concern which determine setback distances around the landfill.

In this study odor impact was assessed quantitatively by measuring the VOC concentrations and using the various gases concentration ratios in landfill gas. Better estimation can be obtained by directly measuring the odorous gases. This research did not address the impact of traffic which can be assessed by calculating the traffic volume and comparing with the standard traffic conditions. Also, according to NAAQS the 24 hour standard for PM_{10} should not be exceeded more than once per year on average over 3 years. Hence, for better estimation of dust impacts, dust measurements have to be carried over a long period of time. For Landfill A, houses directly facing the landfill had considerable visual and bird impacts. They can be minimized by maintaining a line of tree growth around the landfill. Also, any operational change such as active gas collection and minimizing exposed active area which would reduce the gas emissions from the landfill are important to reduce offsite impacts.

APPENDIX A
VOC MEASUREMENTS: PRELIMINARY DATA

Table A-1. Results of Flux Measurements for Landfill A

Location ID	Longitude	Latitude	Date	VOC Conc. (ppm as methane)	Emission Rate (mg/min-m^2) as carbon
1	82.67437	27.86768	29-Dec-06	21	0.42
2	82.67456	27.86748	29-Dec-06	BDL[a]	BDL
3	82.67476	27.86732	29-Dec-06	BDL	BDL
4	82.6746	27.86728	29-Dec-06	45	0.91
5	82.67442	27.86808	29-Dec-06	24	0.48
6	82.67445	27.86703	4-Jan-07	7	0.14
7	82.67478	27.86689	4-Jan-07	8	0.16
8	82.67498	27.86683	4-Jan-07	25	0.5
9	82.67512	27.86665	4-Jan-07	BDL	BDL
10	82.67521	27.86663	12-Jan-07	80	1.63
11	82.67569	27.86661	12-Jan-07	95	1.93
12	82.67629	27.86654	12-Jan-07	BDL	BDL
13	82.67688	27.86706	12-Jan-07	BDL	BDL
14	82.67698	27.86722	12-Jan-07	BDL	BDL
15	82.67766	27.86736	12-Jan-07	BDL	BDL
16	82.67775	27.86735	12-Jan-07	BDL	BDL
17	82.67772	27.86595	19-Jan-07	71	1.41
18	82.67803	27.86587	19-Jan-07	4	0.04
19	82.6779	27.86617	19-Jan-07	360	8.92
20	82.67763	27.86617	19-Jan-07	950	47.1
21	82.67795	27.86728	28-Feb-07	16	0.16
22	82.67788	27.86681	28-Feb-07	BDL	BDL
23	82.67859	27.86685	28-Feb-07	BDL	BDL
24	82.6781	27.86599	28-Feb-07	150	2.99
25	82.67329	27.86944	9-Mar-07	4.8	0.09
26	82.67388	27.86663	9-Mar-07	460	9.04
27	82.67396	27.86614	14-Mar-07	18	0.36
28	82.67437	27.86646	14-Mar-07	156	3.13
29	82.67468	27.86634	14-Mar-07	330	6.62
30	82.67415	27.8667	14-Mar-07	BDL	BDL
31	82.67411	27.86685	15-Mar-07	85	1.28
32	82.6745	27.86676	15-Mar-07	50	0.75
33	82.67483	27.86659	15-Mar-07	29	0.44
34	82.67503	27.86662	15-Mar-07	100	1.5
35	82.67537	27.86664	10-Apr-07	BDL	BDL
36	82.67561	27.86673	10-Apr-07	BDL	BDL
37	82.67578	27.86677	10-Apr-07	BDL	BDL
38	82.67564	27.86692	10-Apr-07	4	0.08

[a]BDL: Below Detection Limit of 0.5 ppm(0.01 mg/min-m^2)

Table A-2. Results of Flux Measurements for Landfill B

Location ID	Longitude	Latitude	Date	VOC Conc.(ppm as methane)	Emission Rate ($mg/min\text{-}m^2$) as carbon
1	81.08818	28.79612	11-May-2007	BDL[a]	BDL
2	81.08776	28.796	11-May-2007	92	1.34
3	81.08801	28.79635	11-May-2007	8.3	0.08
4	81.08649	28.79574	11-May-2007	2	0.03
5	81.08598	28.79563	11-May-2007	BDL	BDL
6	81.0876	28.79656	11-May-2007	26	0.50
7	81.08709	28.79605	11-May-2007	BDL	BDL
8	81.08628	28.79726	16-May-07	8	0.11
9	81.08681	28.7971	16-May-07	BDL	BDL
10	81.08569	28.79729	16-May-07	BDL	BDL
11	81.0851	28.79752	16-May-07	6	0.08
12	81.08645	28.79749	16-May-07	800	15.03
13	81.08481	28.7975	25-May-07	1500	30.03
14	81.08428	28.7975	25-May-07	200	3.00
15	81.08462	28.79718	25-May-07	BDL	BDL
16	81.08384	28.79717	25-May-07	BDL	BDL
17	81.08364	28.79749	25-May-07	70	1.40
18	81.08349	28.79723	30-May-07	BDL	BDL
19	81.08243	28.79620	30-May-07	440	6.53
20	81.08315	28.79708	30-May-07	BDL	BDL
21	81.08271	28.79752	30-May-07	BDL	BDL
22	81.08242	28.79716	30-May-07	BDL	BDL
23	81.08227	28.79674	30-May-07	700	25.96
24	81.08243	28.79619	7-Jun-07	343	6.86
25	81.08241	28.79579	7-Jun-07	12	0.24
26	81.0827	28.79548	7-Jun-07	350	7.00
27	81.08252	28.79521	7-Jun-07	1700	42.51
28	81.08317	28.79509	7-Jun-07	1100	22.01
29	81.08364	28.79504	8-Jun-07	170	2.46
30	81.08387	28.79471	8-Jun-07	BDL	BDL
31	81.08344	28.79571	8-Jun-07	BDL	BDL
32	81.08312	28.79627	8-Jun-07	BDL	BDL
33	81.08389	28.79624	8-Jun-07	BDL	BDL
34	81.08433	28.79635	8-Jun-07	BDL	BDL
35	81.08479	28.79642	8-Jun-07	BDL	BDL
36	81.08534	28.79651	8-Jun-07	BDL	BDL

[a]BDL: Below Detection Limit of 0.5 ppm(0.01 $mg/min\text{-}m^2$)

APPENDIX B
LITTER SURVEY: PRELIMINARY DATA

Table B-1. Large Litter Survey Results for Road 1

Category	Items	Round 1	Round 2
BEVERAGE	Beer cans	6	13
	Beer bottles		1
	Glass bottles	4	
	Soda cans		3
	Soda plastic bottles	3	2
	sports/other plastic bottles		8
	milk jugs/water/ juice HDPE		1
CUPS	Plastic disposable	3	5
	Polystyrene foam	2	10
	Paper	7	3
	Plastic cup lids		7
BAGS	Plastic retail		2
	Zipper/sandwich		2
	Plastic other		2
CONTAINERS	Corrugated cardboard		11
	paperboard boxes	4	2
FOOD WRAPS	Paper		4
	Paper/foil composites		6
TRAYS	Polystyrene foams		1
PLATES	Polystyrene foam	1	
PACKAGING	Plastic	4	
	Paper		2
	Plastic/paper combo		4
PAPER	Towel/Napkin	11	30
	Newspapers/Books/mags/advers		20
OTHER	Misc paper	13	30
	Misc cardboard	7	5
	Misc plastic	2	4
	Misc plastic film		19
	Misc polystyrene foam	1	12
	Const debris		10
	Home items	4	14

Table B-2. Large Litter Survey Results for Road 2

Category	Items	Round 1	Round 2
BEVERAGE	Soda glass bottles	2	
	Soda cans	15	7
	Soda plastic bottles	14	
	sports/other plastic bottles		5
	milk jugs/water/ juice HDPE		1
CUPS	Plastic disposable	8	1
	Plastic reusable	4	2
	Polystyrene foam	13	5
	Paper	10	4
	Plastic cup lids	9	4
BAGS	Plastic retail	40	6
	Zipper/sandwich		1
CONTAINERS	Corrugated cardboard		8
	paperboard boxes	18	
	Paperbeverage casing		1
FOOD WRAPS	Paper		1
	Paper/foil composites		6
PLATES	Polystyrene foam		1
PACKAGING	Plastic	19	
	Paper	20	
	Plastic/paper combo		4
PAPER	Towel/Napkin	40	18
	Lottery	2	1
	Newspapers/Books/mags/advers	22	3
OTHER	Misc paper	18	31
	Misc cardboard	15	3
	Misc plastic	35	8
	Misc plastic film		15
	Misc polystyrene foam	17	5
	Const debris		21
	Home items	10	6

Table B-3. Large Litter Survey Results for Road 3

Category	Items	Round 1	Round 2
BEVERAGE	Beer cans	3	4
	Beer bottles		2
	Soda cans		16
	Soda plastic bottles	4	10
	sports/other plastic bottles		7
	milk jugs/water/ juice HDPE		2
CUPS	Plastic disposable		2
	Plastic reusable		3
	Polystyrene foam	4	5
	Paper		4
	Plastic cup lids		4
BAGS	Plastic retail		2
	Zipper/sandwich		1
	Paper other		1
CONTAINERS	Corrugated cardboard	11	7
	paperboard boxes		21
	Plastic jars/bottles/boxes		4
FOOD WRAPS	Paper		9
	Paper/foil composites		23
TRAYS	Polystyrene foams		5
PACKAGING	Plastic	3	6
	Paper		4
	Plastic/paper combo		17
PAPER	Towel/Napkin	6	53
	Lottery		2
	Newspapers/Books/mags/advers		8
	Stationary/School/Business		11
OTHER	Misc paper	5	62
	Misc cardboard		9
	Misc plastic		12
	Misc plastic film		32
	Misc polystyrene foam		19
	Const debris		52
	Home items	2	22

Table B-4. Large Litter Survey Results for Road 4

Category	Items	Round 1
BEVERAGE	Soda cans	1
	Soda plastic bottles	7
CUPS	Plastic disposable	6
	Polystyrene foam	1
	Paper	9
BAGS	Plastic retail	6
PLATES	Polystyrene foam	1
PACKAGING	Paper	9
PAPER	Towel/Napkin	10
OTHER	Misc paper	5
	Misc cardboard	8
	Misc plastic	4
	Misc plastic film	5
	Const debris	3
	Home items	3

Table B-5. Large Litter Survey Results for Road 6

Category	Items	Round 1
BEVERAGE	Glass bottles	3
	Soda plastic bottles	4
CUPS	Paper	1
CONTAINERS	paperboard boxes	1
PACKAGING	Plastic	3
PAPER	Towel/Napkin	2
	Newspapers/Books/mags/advers	2
OTHER	Misc cardboard	1
	Misc polystyrene foam	2
	Home items	1

Table B-6. Large Litter Survey Results for Road 5

Category	Items	Round 1	Round 2
BEVERAGE	Glass bottles	1	
	Beer bottles	2	
	Soda cans	15	18
	Soda plastic bottles	13	11
	milk jugs/water/ juice HDPE	1	
CUPS	Plastic disposable	3	
	Plastic reusable	2	13
	Polystyrene foam	9	4
	Paper	8	7
	Plastic cup lids	4	18
BAGS	Paper	2	
	Plastic retail	15	
	Zipper/sandwich	4	
	Plastic other	9	
CONTAINERS	Corrugated cardboard	4	19
	paperboard boxes	2	5
FOOD WRAPS	Paper	1	4
	Paper/foil composites	24	
TRAYS	Polystyrene foams		3
PACKAGING	Plastic	13	50
	Paper	31	48
	Plastic/paper combo	10	
	Polystyrene foam	4	
PAPER	Towel/Napkin	67	75
	Lottery		3
	Newspapers/Books/mags/advers	19	23
OTHER	Misc paper	100	85
	Misc cardboard	9	4
	Misc plastic	15	62
	Misc plastic film	24	15
	Misc polystyrene foam	20	28
	Tire pieces	1	1
	Const debris	15	2
	Home items	15	10

Table B-7. Large Litter Survey Results for Road 7

Category	Items	Round 1	Round 2
BEVERAGE	Beer bottles	4	
	Soda cans	9	6
	Glass bottles		2
	Soda plastic bottles		6
	sports/other plastic bottles	3	
CUPS	Plastic disposable	4	
	Plastic reusable	2	1
	Polystyrene foam	3	5
	Paper	3	1
	Plastic cup lids		3
BAGS	Plastic retail	4	
	Zipper/sandwich	1	
	Plastic other	10	
CONTAINERS	Corrugated cardboard	4	4
	paperboard boxes		8
	Paper beverage casing	1	
FOOD WRAPS	Paper		1
	Paper/foil composites	5	
TRAYS	Polystyrene foams		6
PLATES	Polystyrene foam		1
PACKAGING	Plastic		45
	Paper	4	7
	Plastic/paper combo	7	
PAPER	Towel/Napkin	21	35
	Lottery	3	9
	Newspapers/Books/mags/advers	15	30
OTHER	Misc paper	35	62
	Misc cardboard	8	5
	Misc plastic	4	45
	Misc plastic film	18	10
	Misc polystyrene foam	4	16
	Const debris		2
	Home items	8	11
	Tire pieces	3	1

Table B-8. Large Litter Survey Results for Road 8

Category	Items	Round 1	Round 2
BEVERAGE	Beer bottles	4	
	Soda cans	5	9
	Glass bottles	4	2
	Soda plastic bottles		5
	sports/other plastic bottles	14	
CUPS	Plastic reusable		2
	Polystyrene foam	3	4
	Paper	5	2
	Plastic cup lids	5	3
BAGS	Plastic retail	10	
	Plastic other	6	
CONTAINERS	Corrugated cardboard	9	
	paperboard boxes	9	
FOOD WRAPS	Paper	10	
	Paper/foil composites	3	
TRAYS	Polystyrene foams	1	
PLATES	Polystyrene foam	1	5
PACKAGING	Plastic	9	27
	Paper	5	10
	Plastic/paper combo	6	
PAPER	Towel/Napkin	61	20
	Lottery	2	2
	Newspapers/Books/mags/advers	15	8
OTHER	Misc paper	40	28
	Misc cardboard	8	5
	Misc plastic	19	1
	Misc plastic film	6	12
	Misc polystyrene foam	13	8
	Const debris	3	
	Home items	8	1

Table B-9. Large Litter Survey Results for Road 9

Category	Items	Round 1	Round 2
BEVERAGE	Glass bottles	5	1
	Soda cans	16	6
	Soda plastic bottles	6	4
	sports/other plastic bottles	6	
CUPS	Plastic reusable	4	4
	Polystyrene foam	9	2
	Paper	3	3
	Plastic cup lids	4	5
BAGS	Plastic retail	8	
CONTAINERS	paperboard boxes	11	
PACKAGING	Plastic	9	15
	Paper		10
PAPER	Towel/Napkin	39	20
	Lottery	3	1
	Newspapers/Books/mags/advers	22	
OTHER	Misc paper	30	7
	Misc cardboard	21	
	Misc plastic	24	
	Misc polystyrene foam	28	1
	Home items	12	

Table B-10. Large Litter Survey Results for Road 10

Category	Items	Round 1	Round 2
BEVERAGE	Beer cans		10
	Beer bottles		2
	Soda cans	23	13
	Soda plastic bottles	8	7
	sports/other plastic bottles		8
	wine/liquor plastic bottles		1
	milk jugs/water/ juice HDPE	2	2
CUPS	Plastic disposable	2	6
	Plastic reusable		3
	Polystyrene foam	7	27
	Paper	4	2
	Plastic cup lids	7	10
BAGS	Plastic retail		10
	Zipper/sandwich		4
	Paper	7	1
	Plastic	22	
CONTAINERS	Corrugated cardboard	5	10
	paperboard boxes	8	5
	Plastic jars/bottles/boxes	1	
	Paperbeverage casing		2
FOOD WRAPS	Paper		2
	Paper/foil composites		49
TRAYS	Polystyrene foams		5
PLATES	Plastic	2	
	Polystyrene foam	5	1
PACKAGING	Plastic	26	10
	Paper	9	6
	Plastic/paper combo		11
	Polystyrene foam		1
PAPER	Towel/Napkin		68
	Lottery		1
	Newspapers/Books/mags/advers	26	52
	Stationary/School/Business		1
OTHER	Misc paper	93	129
	Misc cardboard	13	21
	Misc plastic	14	5
	Misc plastic film	42	62
	Misc polystyrene foam	12	24
	Const debris	3	12

Table B-11. Large Litter Survey Results for Road Segments 2 and 8

Category	Items	Round 1
BEVERAGE	Beer cans	1
	Beer bottles	2
	Soda cans	6
	sports/other plastic bottles	2
	milk jugs/water/ juice HDPE	1
CUPS	Plastic disposable	2
	Plastic reusable	1
	Polystyrene foam	3
	Paper	1
	Plastic cup lids	1
BAGS	Plastic retail	9
	Zipper/sandwich	3
CONTAINERS	paperboard boxes	1
FOOD WRAPS PACKAGING	Paper	4
	Paper/foil composites	10
	Plastic	7
	Plastic/paper combo	4
PAPER	Towel/Napkin	17
	Lottery	1
	Newspapers/Books/mags/advers	3
	Stationary/School/Business	11
OTHER	Misc paper	12
	Misc cardboard	1
	Misc plastic	4
	Misc polystyrene foam	2
	Home items	4

Table B-12. Large Litter Survey Results for Road Segments 2 and 8

Category	Items	Round 2
BEVERAGE	glass bottles	5
	Soda cans	14
	Soda plastic bottles	20
CUPS	Plastic disposable	6
	Plastic reusable	1
	Polystyrene foam	2
	Paper	2
	Plastic cup lids	5
CONTAINERS	Corrugated cardboard	10
TRAYS	Polystyrene foams	3
PACKAGING	Plastic	36
	Paper	17
PAPER	Towel/Napkin	17
	Lottery	2
	Newspapers/Books/mags/advers	12
OTHER	Misc paper	32
	Misc cardboard	1
	Misc plastic	9
	Misc plastic film	3
	Misc polystyrene foam	6
	Const debris	3
	Home items	6

Table B-13. Large Litter Classified based on Material (Landfill A)

Roads	Mixed	paper	Plastic	Aluminum	Glass	Steel	Composite
1	17	75	48	11	3	0	0
2	25	131	125	14	2	0	0
3	50	107	71	12	1	0	0
4	8	67	61	8	3	0	0
5	34	258	175	17	2	0	0
6	1	7	9	0	3	0	0
7	15	128	99	8	3	0	0
8	9	125	84	8	5	0	0
9	6	85	65	11	3	0	0
10	44	233	174	23	1	0	0

Table B-14. Large Litter Items Material Categories

ALUMINUM	**PLASTIC**
Beer cans	Milk jugs/juice
Soda cans	Misc. film
Aluminum cans	Misc. plastic
	Misc. polystyrene foam
COMPOSITE	plastic packaging
Foil pouches	plastic cups
Aseptic boxes	Misc. polystyrene foam
	Zipper/sandwich bags
GLASS	
Beer bottles	STEEL
Glass bottles	Aerosol cans
Sports/other glass bottles	Steel cans
Wine/liquor glass bottles	
MIXED	
Construction debris	
Paper/foil food wrap	
Home items	
Vehicle debris	
PAPER	
Cardboard boxes	
Lottery	
Misc. cardboard	
Misc. paper	
Misc. paperboard	
Newspaper/books/mags	
Paper cups	
Paper packaging	
Stationary/business	
Towels/napkins	

Table B-15. Large Litter Survey Results for Landfill B

Category	Items	Round 1	Round 2	Round 3
BEVERAGE	Soda cans	2	8	25
	Glass bottles	1	4	22
	Soda plastic bottles	0	8	12
CUPS	Plastic disposable	1	1	9
	Polystyrene foam	2	4	4
	Paper	0	2	5
BAGS	Plastic retail	59	219	102
PAPER	Towel/Napkin	26	13	29
	Lottery			
	Newspapers/Books/mags/advers	6	15	32
	Stationary/School/Business	35	16	41
OTHER	Misc paper	6	31	0
	Misc cardboard	5	7	4
	Misc plastic	0	24	3
	Misc plastic film	10	3	190
	Misc polystyrene foam	0	17	6
	Const debris			
	Home items	4	7	8
	Tire pieces			

APPENDIX C
SAMPLE CALCULATIONS

Highest VOC Concentration = 6.7 ppm as methane

In Landfill gas, $\frac{NMOC}{CH_4} \approx \frac{NMOC}{VOC} = 0.016$

Therefore, highest NMOC Conc. = 0.016×6.7=0.11 ppm < Odor threshold.

Also in Landfill gas, $\frac{H_2S}{CH_4} \approx \frac{H_2S}{VOC} = 8 \times 10^{-5}$

Therefore, highest H_2S Conc. = $8\times10^{-5}\times6.7$=0.5 ppb < Odor threshold.

APPENDIX D
STATISTICAL ANALYSIS

LARGE LITTER

F-TEST

Landfill A large litter : Mean ($\overline{y_1}$) =15, St. dev (S_1) =12, n_1=20.

FCSHWM 2002 large litter: Mean ($\overline{y_2}$) =35, St.dev (S_2) =3.15, n_2=670

H_0: $\sigma_1=\sigma_2$

H_1: $\sigma_1>\sigma_2$

F= $\frac{S_1^2}{S_2^2}=\frac{144}{9.9}=14.5$ > F $_{critical}$ (1.57) at 5 % level of significance.

Hence, enough evidence that population variances are different statistically at 5% level of significance.

T-TEST (Assuming unequal variances)

H_0: $\mu_1=\mu_2$

H1: $\mu_1 \neq \mu_2$

Degrees of freedom= $\frac{((S_1^2/n_1)+(S_2^2/n_2))^2}{\frac{(S_1^2/n_1)^2}{n_1-1}+\frac{(S_2^2/n_2)^2}{n_2-1}}$=22

T-statistic= $\frac{(\overline{y_1}-\overline{y_2})-0}{(\frac{(S_1^2)}{n_1}+\frac{(S_2^2)}{n_2})^{0.5}}$=7.44>T $_{critical}$ for 5% level of significance.

Hence, the difference between the large litter count values obtained from FCSHWM 2002 state wide survey and around landfill A was statistically significant.

SMALL LITTER

F-TEST

Landfill A small litter: Mean ($\overline{y_1}$) =3, St. dev (S_1) =3, n_1=20.

FCSHWM 2002 small litter: Mean ($\overline{y_2}$) =7, St.dev (S_2) =0.63, n_2=670

H_0: $\sigma_1=\sigma_2$

H_1: $\sigma_1>\sigma_2$

F= $\frac{S_1^2}{S_2^2}=\frac{9}{0.4}=22.6$ > $F_{critical}$ (1.57) at 5 % level of significance.

Hence, enough evidence that population variances are different statistically at 5% level of significance.

T-TEST (Assuming unequal variances)

H_0: $\mu_1=\mu_2$

H1: $\mu_1 \neq \mu_2$

Degrees of freedom= $\frac{((S_1^2/n_1)+(S_2^2/n_2))^2}{\frac{(S_1^2/n_1)^2}{n_1-1}+\frac{(S_2^2/n_2)^2}{n_2-1}}$=19

T-statistic= $\frac{(\overline{y_1}-\overline{y_2})-0}{(\frac{(S_1^2)}{n_1}+\frac{(S_2^2)}{n_2})^{0.5}}$=5.95>$T_{critical}$ for 5% level of significance.

Hence, the difference between the small litter count values obtained from FCSHWM 2002 state-wide survey and around landfill A was statistically significant.

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