COMPARISON BETWEEN SATELLITE IMAGE ANALYSIS AND SITE DATA FOR MONITORING TRAIL ROAD LANDFILL SITE

By

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ABSTRACT

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Human life affects the environment in different ways; therefore monitoring human's actions is very important to safeguarding the environment. Studying the human impact on nature is essential to protecting our environment from contaminations. Landfill sites are one of the most influential structures upon nature. Landfills pose a potential danger to the surrounding environment. Therefore they must be supervised for long periods of time to determine their impact. Monitoring the effects of the landfill sites on the surrounding area over a period of time is a useful tool to analyze and understand its effect on the environment. This research work presents a study which uses data analyzed from satellite images for the monitoring of landfill sites. The data collected from satellite images is compared with the data collected from ground measurements. The main goal of this research is to verify the usefulness of remote sensing as a tool for landfill site monitoring.

The ground measurement data used in this study is from yearly reports of a monitoring program by the City of Ottawa that are collected by Dillon Limited. The satellite images used are Landsat satellite images downloaded from the U.S. Geological Survey and Earth Resources, and analyzed by ERDAS IMAGINE and ArcMap software. The images are taken from four years: May 1992, August 1998, October 2000, and September 2001. The images are analyzed in terms of Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST).

Results from the LST and NDVI value of different years are compared with the results of the monitoring program that has been conducted for the City of Ottawa. Preliminary data analysis of the satellite images reveals that the surface temperature of the landfill site is always

higher than the immediate surrounding areas. Any significant changes in LST and NDVI value, especially in the surrounding vegetation areas, are regarded as suspect sites which may be influenced by the development of the landfill site.

The result of the comparison between testing and sampling at monitoring wells with satellite image analysis confirms the areas that are more contaminated. The polluted areas show the same locations from both analyses. However, changes at LST and NDVI value analysis could imply the pollution movement earlier than the traditional site sampling monitoring method. These results show the possibility of combining the ground sampling system and satellite image analysis to improve landfill site monitoring.

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LIST OF ACRONYMS

MOE	Ministry of Environment
NDVI	Normalized Difference Vegetation Index
LST	Land Surface Temperature
ETM+	Enhanced Thematic Mapper Plus
TM	Thematic Mapper
LIDAR	LIght Detection And Ranging
PET	Positron Emission Tomography
MRI	Magnetic Resonance Imaging
NIR	Near Infrared
SWIP	Short Wave Infrared
TIR	Thermal Infrared
EROS	Earth Resources Observation System
USGS	United States Geological Survey
EDC	Earth Data Centre
RAD	Radiance Value
DN	Digital Number
BBT	Black Body Temperature
R	Red Band Value
VOC	Volatile Organic Compounds
BOD	Biochemical Oxygen Demand
DOC	Dissolved Oxygen Carbon
TKN	Total Kjeldahl Nitrogen
PAR	Photosynthetically Active Radiation
DDS	Devise Decision Support Systems
SAR	Synthetic Aperture Radar

NATO	North Atlantic Treaty Organization
IEEE	Electrical and Electronics Engineers
L-band	Long wavelengths band
C-band	Conventional band

Chapter 1 : INTRODUCTION

1.1 General

North Americans generate waste at a rate of four pounds per day per person (lbs/d/per), which translates to roughly 120,000 tons per day, or 44 million tons per year (Alberta Environment, 2002). Some of these waste products get recycled or recovered and some are incinerated, but the majority of these wastes are buried in landfills. The problem with this process is that buried material may cause risks to long term health, safety, and environmental hazards. Landfill waste is controlled by different regulations that permit waste disposal, as long as they constitute no threats to human health and the surrounding environment.

The monitoring of landfills is performed to document the chemical composition of soil, groundwater, and surface water in the vicinity of the landfill, and to assess the extent of any impacts the landfill may have upon the environment. Groundwater monitoring programs include water level measurements and water sampling from monitoring wells. Additionally, each sample is chemically analyzed for a series of common leachate indicator parameters. The surface water sampling includes routine sampling from ditch, stream and pond stations around each landfill site, as well as rivers and natural water sources within the area (MOE Landfill Standards, April 2004).

Traditional monitoring programs include repetitive sampling and testing reports, which is both costly and time consuming. In this project a new way of environmental monitoring will be investigated for landfill sites. The new way is comprised of the analysis of satellite image data using different remote sensing techniques.

1.2 Motivation

Environmental protection is one of the important challenges that cities are facing. Protection plans require years of monitoring the earth's surface, water surface and ground water. Studying soil and water contamination requires taking sampling numerous times in different seasons. Testing the samples and analyzing the data takes a long time. Technicians with special knowledge are needed to collect samples. Further, special equipment is required in the lab to test the collected samples. After all of this procedure, an expert is needed to study the analyzed data. Comparing analyzed test results with standards will show the existence of contamination on soil or water. Following this a report will indicate the pollution and contamination of soil and water. This procedure is time consuming and expensive.

Landfill sites have potential environmental impact. However if they are designed, maintained, and monitored properly, then they are safe and useful. Monitoring landfills requires monitoring contaminations and their influences on soil, vegetation, water, and ground water. Collecting data and samples from landfills is an expensive process. Monitoring wells, borehole drilling, soil and water sampling is needed. Also specific equipment and professional laborers are required. Repetitive results are also required to assure that the findings are representative. However scientists are always looking for direct, cost-effective ways to collect the necessary data and information.

Remote sensing technology is able to collect information using satellite images, which saves both time and money compared to the sampling and testing process. This money may be used to improve landfill. Implementing remote sensing technology for collecting data may improve the environmental protection plans. Remote sensing techniques may develop cheaper, safer and more reliable ways of monitoring landfill sites. In this project, a comparison is done between the data captured from landfill sites by satellite images. The main purpose of the research is to investigate the possibility of using remote sensing analysis techniques to monitoring landfill sites.

1.3 Scope of the Thesis

Landfill monitoring systems currently require several site samples and site data collected from soil and water. The collected samples then have to be tested and examined in the lab to verify the environmental contamination caused by landfill sites. The testing and sampling have to be done constantly. Comparing the collected data over time shows the movement of contamination. This is the traditional method to monitor the landfill sites. Traditional monitoring is both time consuming and costly. Researchers are looking for a monitoring method to capture data from landfill sites that is possible with smaller amount of money yet maintains the same overall level of quality.

Satellite images have been used for different civil engineering applications around the world. However, satellite image data has not been used for monitoring landfills or landfill's data collection. For this research satellite images taken in four different years is used to calculate the Normalized Difference Vegetation Index (NDVI) value and Land Surface Temperature (LST). By calculating the values of the LST and NDVI for different years and comparing them with collected ground data, it might be possible to develop a method which combines the site sampling and remote sensing methods. The data collected from satellite images may capture the results earlier than the traditional site sampling monitoring method. This could introduce a better way for future investigation. This project investigates the use of a satellite image data analysis system to monitor the effects of landfill sites on environment.

1.4 Thesis Structure

There are seven chapters in this thesis. Chapter 1 gives the reader an introduction to the landfills and monitoring program, including the motivation to undertake writing this thesis. Additionally, the scope of the thesis is discussed. Chapter 2 is dedicated to landfills and satellite image uses via a literature review with the history of the landfill monitoring program. In this chapter there are some reviews to previous research on monitoring programs, as well as different uses of remote sensing and its background. Further, it explains how different methods of monitoring could be combined. Chapter 3 is method of analysis that explains the satellite images and how to obtain or extract the information out of satellite images. NDVI and LST calculations are explained in this chapter. Chapter 4 presents Trail Road landfill's background and the area of investigation. Different ground levels of Trail Road landfill are introduced in this chapter. Chapter 5 is dedicated to data analysis from remote sensing and the calculation of NDVI and LST for collected satellite images. Chapter 6 compares the results of different years, different locations and different methods. Finally, Chapter 7 concludes the thesis and introduces some recommendations for future studies.

Chapter 2 : LITERATURE REVIEW

2.1 General

Engineered landfills are designed structures which isolate the waste from the environment. One of the environmental challenges for the landfills is containing waste, so it does not cause contamination and pollution for its surrounding environment. To reach this purpose several studies have been conducted. There are many protection plans and bylaws for different cities and regions. Ontario has its own protection plan and bylaws for landfill sites and solid waste (MOE Landfill Standards, April 2004).

2.2 Monitoring Systems

Contamination measuring instruments have been designed for monitoring landfills to measure leachate quality, and water and soil contamination around the landfills. However, no preferred monitoring method has been introduced. Each monitoring method has its advantages and disadvantages. A research project has been conducted at the Technical University of Braunschweig to determine a landfill monitoring method, and measurement instruments for the determination of leachate discharge (Muennich et al., 2008). Different approaches have been attempted to reduce landfill monitoring costs, such as using a limited set of indicator parameters testing, or limited groundwater monitoring wells along the landfill's compliance boundary only at the down-gradient edge of the landfill. Monitoring costs have been reduced because fewer samples require testing. Further, fewer monitoring wells are required along the compliance boundary. This generates less data, which reduces management, validation, and reporting requirements. There are fewer samples and fewer tests, but the results produced are not as accurate. Researchers are looking for a landfill monitoring method that can decrease the cost and increase the representation of results.

2.3 Factors Influencing Contamination at Landfill Sites

Ground elevation and soil type has an influence on leachate movement and contamination movements. A vertical leachate movement through clay traps the contamination and keeps contamination isolated which stops it from spreading to different areas (Ahmed et al., 1991). Therefore, soil type and elevation are very important factors to monitoring landfills. Satellite images and remote sensing techniques are able to capture soil type and elevations (Podobnikar and Tomaz, 2008). With the help of digital models ground surface elevation and soil types can be captured. Therefore, remote sensing techniques could advance the landfill monitoring systems.

Studies have been done at the same landfill study area on leachate quality generated from landfills. It shows how the quality of the leachate generated from the landfill can affect the surrounding environment. The quality of lechate and its relationship with precipitation in the area has been monitored at Trail Road landfill. Investigation has been done on Trail Road landfill leachate quality. The results of the research indicate that there is a linear relationship between leachate quality and monthly precipitation in the Ottawa area (Bataineh et al., 2007). According to this research seasonal precipitation has a linear effect on leachate quality and also on the amount of leachate generated by the landfill. Therefore, seasonal precipitation and weather conditions are important factors in monitoring a landfill and must be considered. With the help of remote sensing methods it is easier to record and analyze data according to seasonal precipitation.

2.4 Remote Sensing Usage on Environment

Remote sensing techniques have been used to monitor and evaluate shoreline changes in both pre- and post-beach re-nourishment in terms of studying shoreline and shoreline erosion. In large scale events such as ocean circulation, current systems, upwelling and eddy formation, the oceanic application of remote sensing is used. Remote sensing has been used to identify hazards such as large storms, earthquakes, erosion, and flooding (Achard, Grassi, Herold, et al., 2008). With the help of remote sensing, causes prior to an event and the damage following the event can be assessed. Also, remote sensing data sets have been used to monitor urban sprawl, map and inventory wetlands, and delineate wildlife habitat. Once the land cover has been mapped, repeated collection of remote sensing data can be used to monitor and study the various types of habitat and vegetation (Coastal Service Centre, 2008). Since remote sensing methods have been used to capture environmental changes, therefore they could also be used to monitor environmental changes caused by landfills. Further, remote sensing technology can be used in many different areas where sampling and using site activities are hard or impossible, for instance under the deep snow or under water. With remote sensing technology, data can be collected in a short period of time instead of spending a long time collecting samples and analyzing them in the lab.

Remote sensing techniques have been used for monitoring methane gas generated by landfills. The influence of band overlapping in measuring methane at atmospheric pressure has been measured using remote sensing simulations (Vollmar et al., 2005). Atmospheric pressure is the force per unit area exerted against a surface by the weight of air above that surface in the Earth's atmosphere. Air quality and sea level can be calculated by measuring atmospheric pressure. GIS spatial analysis functions have been used to assess and monitor the environmental impact of landfill sites upon the surroundings. Then interpolation technique was determining the landfill methane emission for the whole site in order to assess the impact to the environment. Remote sensing has been used at Aston University of United Kingdom in 2008 to evaluate vegetation stress under the pollutants created from methane gas of the landfill sites. The results showed the surrounding area of the pollution to be warmer than other areas. Heat could cause vegetation stress under landfill gas migration influence (Aston University, 2008). Remote sensing techniques have been used to capture heat created by methane gas impacts of landfills. Therefore remote sensing techniques could potentially be used to capture heat created by leachate and contamination effects of the landfill as well.

Bagheri and Hordon et al. (1988) utilized aerial photo interpretation techniques to identify hazardous waste sites from black and white aerial photographs based on the shape, surrounding features, and spectral reflectance. The objective of the project was to identify all hazardous waste sites with aerial photos and remote sensing techniques. The use of air photo interpretation techniques provided a procedure for identifying waste sites. Therefore, aerial photos could be useful to identify a landfill's locations. Pope et al. (1996) proposed to derive characterization information about the disposal site using multi-temporal aerial images. Characteristics such as wavelength provide information on leaf sizes within the forest canopy. According to these studies, using remote sensing techniques could be useful to evaluate vegetation on the ground surface, such as landfills.

Silverstri and Omri et al. (2008) used image classification techniques to locate stressed vegetation associated with dumps to determine if they are potential illegal landfill sites with GIS information and human judgment. Biotto et al. (2009) further adopted GIS statistical analysis to produce a probability map to narrow down the set of possibly contaminated sites on Silverstri and Omri's dataset. Therefore, remote sensing methods could be a useful tool to determine contaminated areas based on the condition of vegetation.

Studies have been done at the University of Nebraska on stress caused by water deficiency in vegetation using visible spectrum reflectance by Zygielbaum et al. (2009). Knowledge of plant water status is vital to understanding the state or condition of vegetation, information which is essential to disciplines as diverse as agriculture, geography, and climatology. Plant water status allows the gathering of such information across wide geographic extents and over long periods of time. Monitoring vegetation remotely requires an understanding of how reflected light may be used to infer the water status of plants. Soybeans have been used to examine changes in reflectance as these plants were subjected to water deficiency and stresses caused by water. Remote sensing measurement techniques have been employed. A systematic increase in leaf-level visible light Photosynthetically Active Radiation (PAR) was discovered. PAR designates the spectral range or wave band of solar radiation that photosynthetic organisms are able to use in the process of photosynthesis. The increase in PAR reflectance was shown to be useful in estimating the water status of soy. According to the results of this research, remote sensing monitoring of vegetation on landfill areas could be useful to determine the location of contaminated water. Locating contaminated water at landfill sites could help to improve the monitoring system.

Landsat satellite imagery was used to find the impact of city size and vegetation coverage on the urban area by Gary Daniel et al. (2009). The Landsat imagery and temperature extraction from the Thermal-Infrared (TIR) band revealed that city size and the amount of high-density urban land use are directly related to higher than average surface temperatures. Vegetation analysis within the study areas revealed an average surface temperature reduction of 2°C with only 15% forest coverage within a 1km^2 area. Results obtained can be useful as a potential monitoring tool that can characterize relationships between tree coverage and surface temperature. The relationship between vegetation and surface temperature could be a helpful point to improve landfill monitoring systems using remote sensing technologies.

To assess the landfill gas migration, surface temperature derived from remote sensing techniques can be used. Kwarteng and Al-Enezi et al. (2004) adopted multi-temporal Landsat data to monitor a large landfill site in Kuwait in terms of its Land Surface Temperature (LST). The imagery provided a historical perspective of how the areas had changed over a 30 year period. Information of the landfill obtained from the satellite imagery included the spatial extent, spectral reflectance, and surface temperature. The landfill site showed higher surface temperatures compared to the immediate surrounding areas. According to this research, such datasets could be incorporated into a GIS for the long-term monitoring of landfill sites.

A Similar study conducted by Yang et al. (2008) assessed the impact of potential threats to public health with harmful bacteria in China with the surface temperature and difference vegetation index (NDVI) derived from a single Landsat ETM+ image. The NDVI spectral feature space is analyzed for monitoring surface dryness condition. The surface NDVI value is affected by the change of the land surface bio-physical factors such as vegetation, land surface temperature, soil moisture, etc. It has been documented that there is a strong correlation between

NDVI value and important factors of drought including LST and soil moisture. Therefore, seasonal weather and water conditions are critical to changing NDVI values.

2.5 Remote Sensing Limitations

There are limitations for using remote sensing techniques due to the variation of geographic location and weather conditions. Different years and seasons, can limit the effectiveness of analyzing satellite images due to precipitation, and soil moistures. In this study, ground measurements of landfills are introduced via a case study of the Trail Road landfill in the city of Ottawa. Operations at the Trail Road landfill are performed in accordance with the Trail Road operations and management report, submitted to the Ministry of Environment with certification of approval since February 1990. The City of Ottawa, who owns the landfill, has an annual contract with Dillon Consulting to monitor the landfill site (Dillon, 2007).

Chapter 3 : METHODS OF SATELLITE IMAGE ANALYSIS

3.1 General

With the advantage of remote sensing techniques, it becomes possible to analyze and calculate some characteristics of soil and water on the surface of the Earth. LST and NDVI have been used to analyze the effects of landfill sites on the environment. LST values and vegetation changes are noted over time. With LST and NDVI analysis we have the opportunity to determine the condition of vegetation in the area of study. Healthy vegetation grows on uncontaminated soil and water. If the vegetation is unhealthy, it may be the result of contamination in soil and water. Satellite images can be analyzed to determine LST and NDVI which indicates the contamination of soil and water by any hazardous materials. LST and NDVI calculation and analysis have been explained along with examples in this chapter.

The remote sensing instruments have been designed for long term continuity data collection at appropriate spatial, spectral, and temporal resolutions. The information and data are usually available at a very low cost. The satellite images, distributed by the U.S. Geological Society (USGS) or Earth Resources Observation System (EROS) Data Center (EDC) are radiometrically calibrated. USGS is a scientific agency of the United States Government which studies the landscape of natural resources and natural hazards that threaten it (Lyon, 1987).

The data downloaded from the USGS are taken in different years with different remote sensing devices. Older satellites, such as Landsat, record strictly in nadir which means a view directly below the satellite. The orbit defines the centre of the satellite's view. Modern satellites can now either turn themselves or their sensors sideways allowing for a faster coverage of any target area while at the same time creating a mosaic of image patches with different view angles and atmospheric conditions. The price of satellite data always varies, thus it is important to get a new quotation for each area. However the images that have been used by this research were free and they are from USGS archive.

Landsat satellite images are distributed by the USGS and Earth Resources Observation System (EROS) Data Center. The data downloaded from the USGS are taken in different years with different data layers. The images used for this study are from May 1992, which was the first image available from the study area, other periods being August 1998, October 2000, and September 2001. After 2001 a new satellite device has been used, so to avoid any complexity no images were chosen from after 2001. Analyzing the captured data is done using ERDAS IMAGINE software, which calculates the NDVI and LST of the landfill and the surrounding area. The change of LST and NDVI values over the time, or consistency over time, will show the vegetation and land surface temperature changes in the area.

3.2 Landsat Satellite Images

The Landsat program is a series of Earth-observing satellite missions jointly managed by NASA and the U.S. Geological Survey. Since 1972 Landsat satellites have collected information about Earth from space. Landsat satellites have taken specialized digital photographs of Earth's continents and surrounding coastal regions for over three decades, enabling people to study many aspects of our planet and to evaluate the dynamic changes caused by both natural processes and human practices.

Landsat 7 is one of the series of Landsat satellites, which started with the launch of Landsat 1 in 1972. The Enhanced Thematic Mapper Plus (ETM+) started with Landsat 7 was launched in 1999. ETM+ provides data in six visible bands such as the Near Infrared (NIR), Short Wave Infrared (SWIP) and Mid Infrared bands. In addition, ETM+ provides improved resolution for the Thermal infrared (TIR) band and a panchromatic band with 15m resolution. The spatial resolution of 15m is provided by an additional panchromatic channel, which was not available on the old Landsat satellite images. The Landsat 7 has been designed to retrieve data from the archive, and it distributes ETM+ products within 48 hours of receipt of the customer order, which is significantly more responsive than previous Landsat production systems. Landsat 4 was able to download images but Landsat 5 was not capable of doing so, and its images are more expensive and provide less radiometric information (Jenson, 2003).

TM data sensors on board the Landsat 5 satellite are one of the most frequently used images for environmental studies. Landsat TM image data consists of seven spectral bands with a spatial resolution of 30 meters for bands 1 to 5 and band 7. Spatial resolution for band 6 (thermal infrared) is 120 meters. But band 6 data is oversampled to 30 meter pixel size. Landsat 7 ETM+ imagery looks much the same as previous Landsat TM data as they both have a spatial resolution of 30m. Landsat ETM+ imagery has an extra panchromatic band that is able to produce panchromatic images (Jenson, 2003).

The TM sensor is an advanced, multispectral scanning, Earth resources instrument designed to achieve higher image resolution, sharper spectral separation, improved geometric fidelity, and great radiometric accuracy and resolution. The band coverage and their spatial resolution for TM data are summarized in Table 3.1.

Radiometrically, the ETM+ sensor has a quantization range of 256 Digital Numbers (DN), that is 8 bits, which permits observation of small changes in radiometric magnitudes in a given band and sensitivity to changes in relationships between bands. DN is the value of each pixel in a data set that is usually ranging from 0-255 (Jenson, 2003).

Band Coverage and spatial resolution for the TM			
Wavelength Landsat 4-5	Band Description	Spatial Resolution (µm)	Coverage (m)
Band 1	blue	0.45 - 0.52	30
Band 2	green	0.52 - 0.60	30
Band 3	red	0.63 - 0.69	30
Band 4	near-infrared	0.76 - 0.90	30
Band 5	short-wave infrared	1.55 - 1.75	30
Band 6	mid infrared	10.40 - 12.50	120
Band 7	thermal infrared	2.08 - 2.35	30

Table 3.1 – Landsat TM band width and Spatial Resolution

(Jenson, 2003)

The ETM+ bands are useful for water penetration, discriminating vegetation types and strength, plant and soil moisture measurements, differentiation of clouds, snow and ice, and identifying rock types. Similar to Landsat TM, Landsat ETM+ can be used for urban applications but its high spectral resolution makes it more suitable for making the natural characteristics of the landscape. All Landsat ETM+ imagery is available at all Path, Map and Ortho orientation and can be used accurately up to approximately 1:50000 scale (Jenson, 2003). The band coverage and their spatial resolution for ETM+ data are summarized in Table 3.2.

Band Coverage and spatial resolution for the ETM+			
Band	Band Description	Spatial Resolution (μm)	Coverage (m)
Band 1	blue	0.45 - 0.515	30
Band 2	green	0.525 – 0.605	30
Band 3	red	0.63 - 0.69	30
Band 4	near-infrared	0.75 – 0.90	30
Band 5	short-wave infrared	1.55 - 1.75	30
Band 6	mid infrared	3.09 - 2.35	60
Band 7	thermal infrared	10.40 - 12.50	30
Band 8	panchromatic	0.520 - 0.90	15

Table 3.2 – Landsat ETM+ band width and Spatial Resolution

(Jenson, 2003)

3.3 ERDAS IMAGINE Software and Data Analysis

Imagery is the most valuable source of geospatial data. Imagery captures events at specific times and places. Repeating imagery of a certain area over time allows for the tracking of changes. ERDAS IMAGINE is the world's leading remote sensing solution, providing tools to create, manage and analyze imagery to increase the value of your geospatial information

(Kusanagi, 2000). ERDAS IMAGINE software allows users to process images and extracts information. This software simplifies classification, orthorectification, mosaicking, reprojection and image interpretation, while maintaining the integrity of the geospatial data for updating GIS in multiple formats. Working in multiple datasets is possible with this software, which means that it reduces the time that would take to manually relate the information from various sources.

ERDAS IMAGINE is a raster graphics editor and remote sensing application designed by ERDAS, Inc. The latest version is 9.3. It is aimed primarily at geospatial raster and allows the user to prepare, display and enhance digital images for use in GIS or CAD software. The toolbox within the program allows the user to perform numerous operations on an image and generate an answer to specific geographical questions such as surface temperature and NDVI. After generating the answer for a specific purpose, the user is able to create the drawing with different colors displaying the calculated results. By manipulating data placement in imagery it is possible to see features that would not normally be visible. The level of brightness or reflectance of light from the surfaces in the image can be helpful with vegetation analysis, and for prospecting contamination in different levels of soil and water. There are other useful features for the extraction, generation of processing spatial models, and the import/export of data within ERDAS IMAGINE software, but only NDVI and surface temperature analysis has been used in this study. There are several types of software available on the market for analyzing satellite images for different purposes. However, the only software available at Ryerson University Civil Engineering Graduate lab to analyze Landsat images is ERDAS IMAGINE.

3.4 Spectral Reflectance

The fraction of energy reflected at a particular wavelength varies for different features. The reflectance of features varies at different wavelengths. For example two features that are impossible to differentiate in one spectral range may be very different in another portion of the spectrum. The unique spectral property of different features allows them to be identified and separated. There is a relationship between the size of an object or area to be identified and the spectral reflectance of the remote sensing system (Kusanagi, 2000).

The spectral property for healthy green vegetation, stressed vegetation, and severely stressed vegetation is displayed in Figure 3.1. The invisible region of the electromagnetic spectrum and three spectral signatures look similar, but in the near-infrared region of the spectrum the spectral look very different from each other. The healthy vegetation has the highest reflectance value while the severely stressed vegetation has the lowest reflectance value.

Studies show that sensors that are able to collect data in the near-infrared region of the spectrum are capable of measuring the chlorophyll contained in plant material. As a result of these studies the agricultural communities are using infrared remote sensing imagery because it can distinguish crop stress before the human eye can detect it (Kusanagi, 2000).

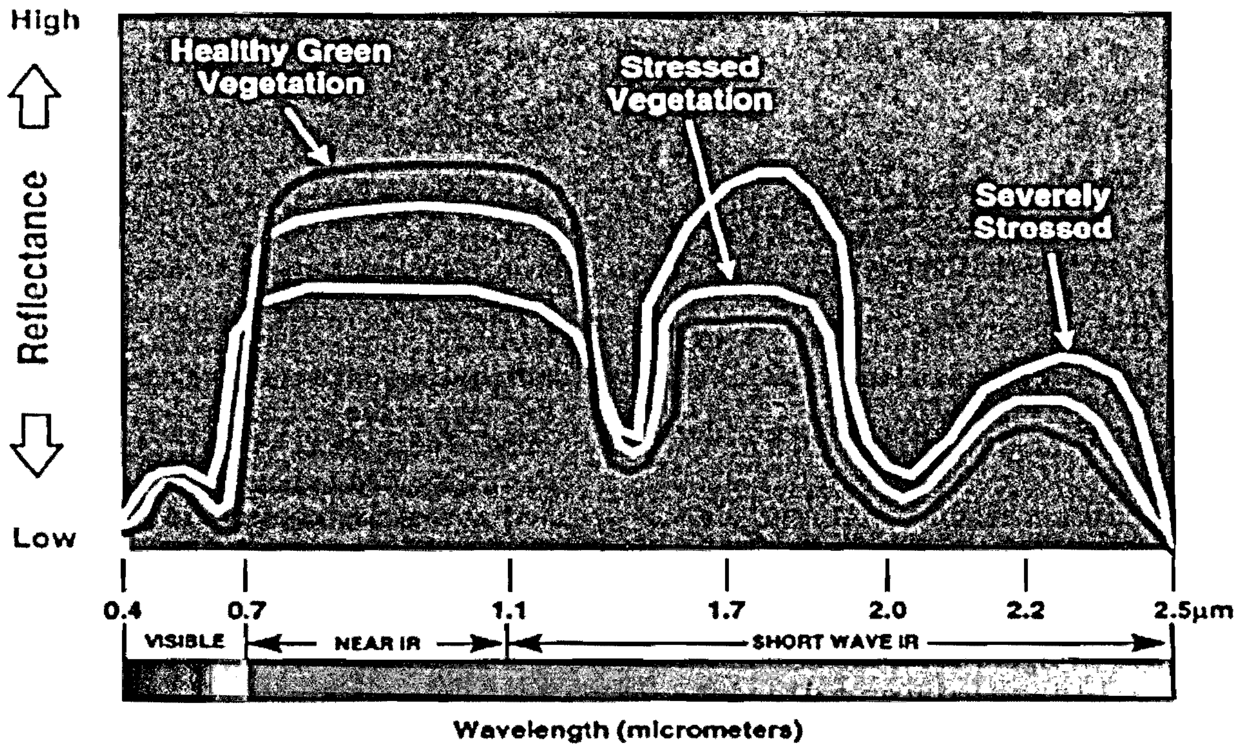
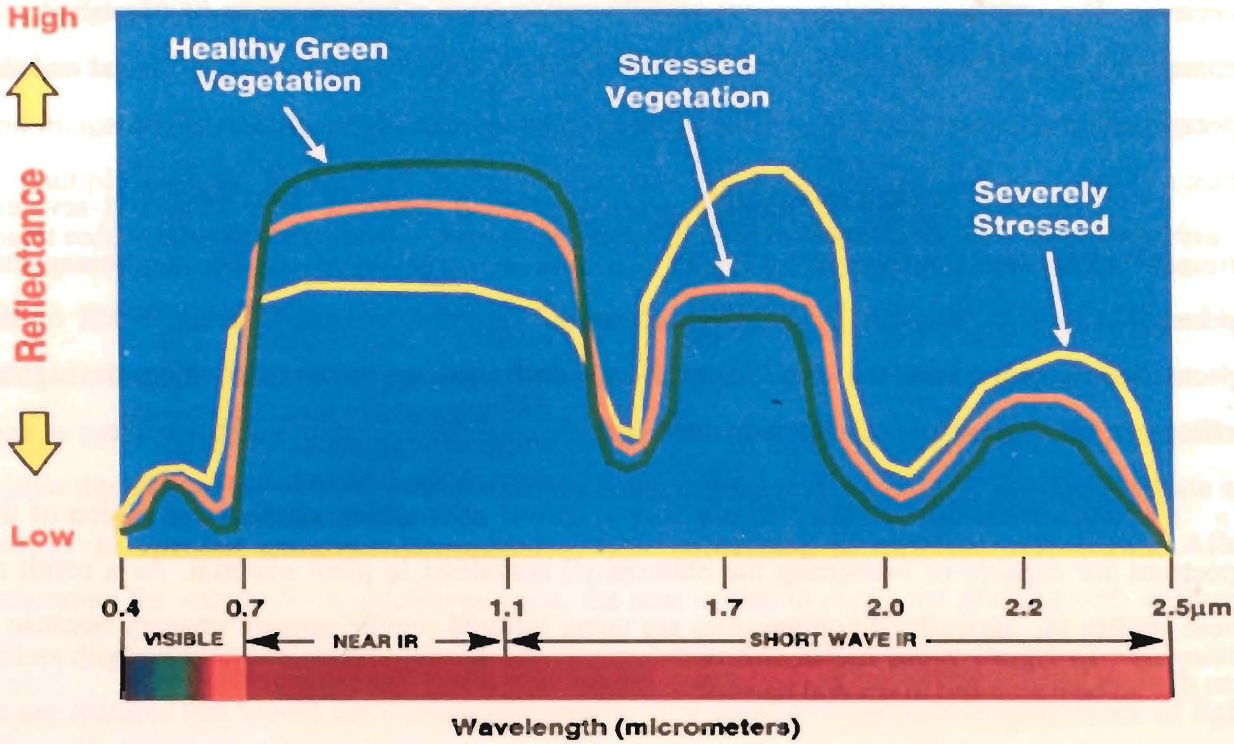


Figure 3.1 - Spectral Reflectance of Vegetation vs. Different Wavelengths

(Przyborski and Remer, 2009)

3.5 Land Surface Temperature Analysis

LST is variable depends on many different factors such as surface water, land usage, vegetation, and weather temperature. For example, temperature in an urban area tends to be higher than in rural areas. Therefore land use is one of the most important influences on surface temperature. Buildings, cars, people and their activities create heat. Therefore the urban area's temperature is relatively higher than rural areas. The collected data using remote sensing equipments such as aircraft and satellite thermal infrared data to measure ground surface



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Landsat TM (Before 2003):

Equation 3.1

$$Rad = \frac{15.303 - 1.2378}{255} \cdot DN + 1.2378$$

Equation 3.2

$$BBT = \frac{1260.56}{\log(\frac{607.76}{DN} + 1)}$$

Landsat ETM+ (Before 2003):

Equation 3.3

$$Rad = \frac{17.04 - 0}{255} \cdot DN + 0$$

Equation 3.4

$$BBT = \frac{1282.7}{\log(\frac{666.09}{DN} + 1)}$$

3.6 Normalized Difference Vegetation Index Analysis

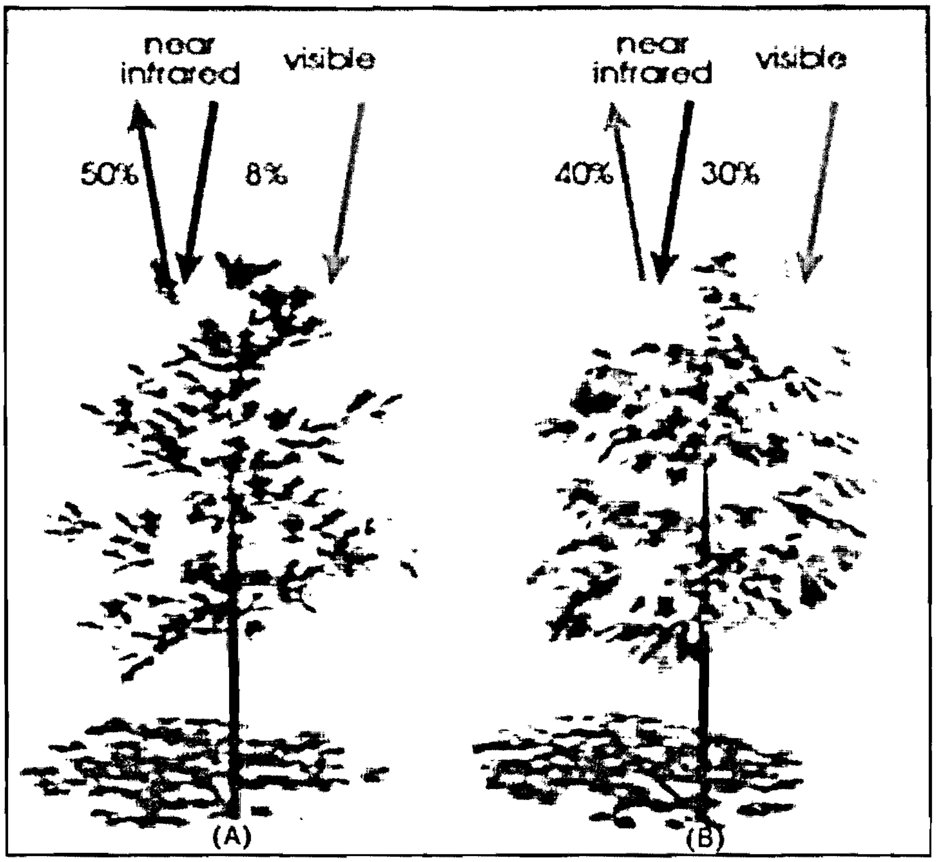
Analyzing NDVI value with the benefit of satellite remote sensing, it has become possible to understand the green leaf concentration or chlorophyll status of vegetation for a large area of the earth's surface with the help of digital imagery. These analyses not only highlight the vegetated areas of an image but also give an idea of how healthy the plants are in the study area (Jenson, 2003). The Landsat TM and ETM+ images are first imported into PCI Geomatics OrthoEngine to generate x.pix files for the multi-spectral bands with 30m spatial resolution. For each of the multi-spectral images, the NDVI is calculated using the following equation:

Equation 3.5

$$NDVI = (NIR - R) / (NIR + R)$$

Digital Number NIR band and Red Band value R band are recorded by the satellite sensor. NDVI values calculated by the equation represent the health status of the plant. The NDVI value always ranges from -1 to +1. Also, the areas devoid of any vegetation give a negative value or a value close to zero. Therefore, it is shown that the higher the value the healthier the vegetation. Near infrared light consists of light just beyond visible red light which means that NIR is the value of pixels in band 4. The R value is the pixel equal to the measured energy level of that pixel in band 3 (Jenson, 2003).

Figure 3.2 show that healthy vegetation absorbs more Red light than the unhealthy vegetation. Therefore when R value is lower, NDVI value is higher and vegetation is healthier.



$$\frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72 \qquad \frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14$$

Figure 3.2 – NDVI Calculation

(A) The healthy vegetation absorbs more Red light than (B) the unhealthy or stressed vegetation

(Przyborski and Remer, 2009)

Although the health of a plant depends on several environmental factors, it is often found that for a large area vegetation health depends on: how much moisture is available to the root zone of the plants, and how healthy the ground is. Therefore these properties are directly related to soil and groundwater conditions and availability. This means that healthy vegetation grows on healthy soil and water. (Jenson, 2003)

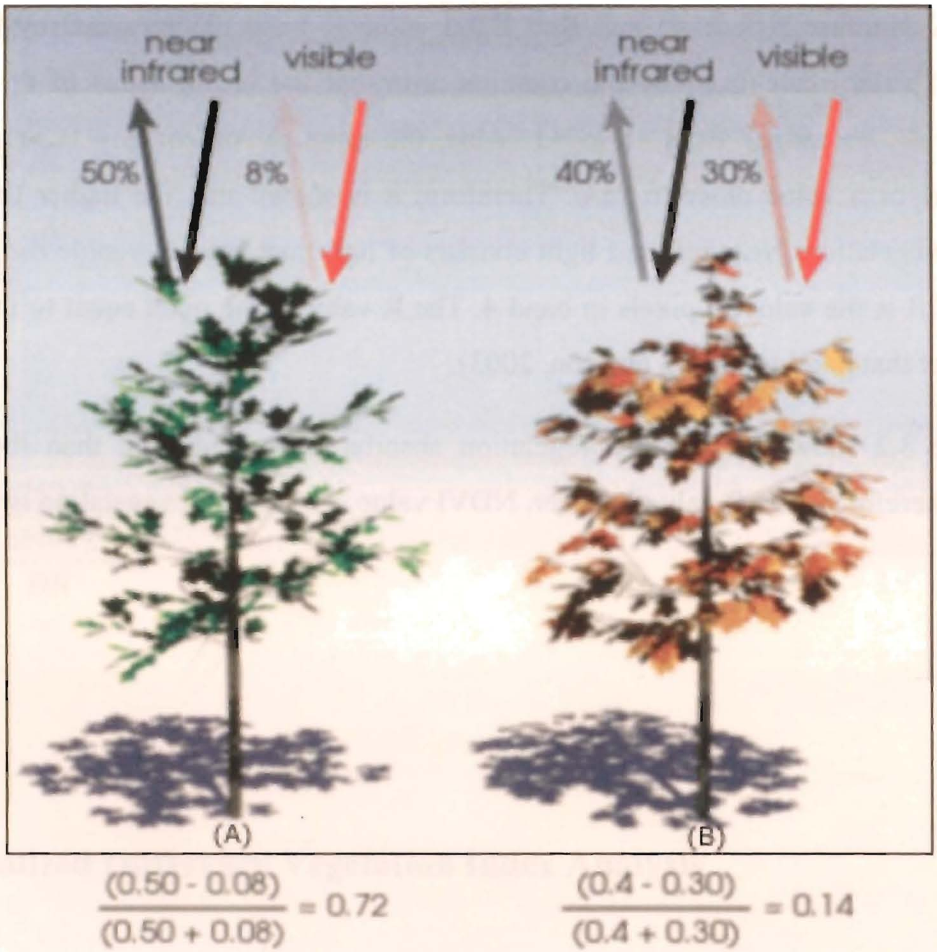


Figure 3.2 – NDVI Calculation

(A) The healthy vegetation absorbs more Red light than (B) the unhealthy or stressed vegetation (Przyborski and Remer, 2009)

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Figure 3.3 has been classified into four classes: Luxurious vegetation, Healthy vegetation, Stressed vegetation, and Areas with No vegetation. It can be observed that the areas close to the river channels have a good concentration of Luxurious and healthy vegetation when compared to the rest of the area.

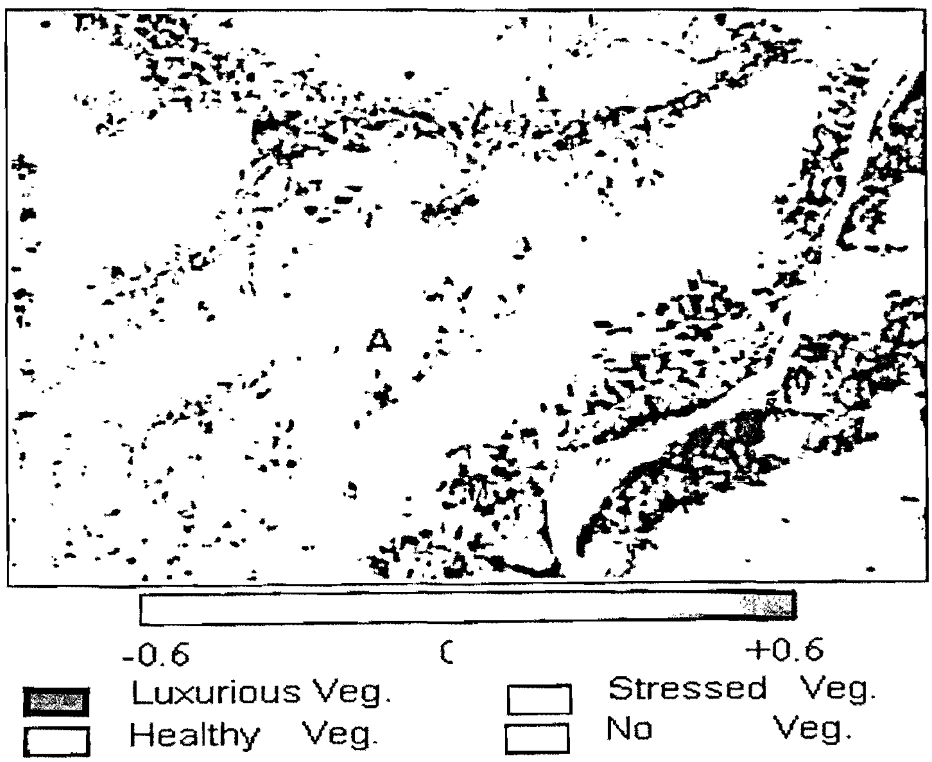

Figure 3.3 - The intensity of NDVI value

(Przyborski and Remer, 2009)

Classified and color coded to highlight the different vegetation health classes

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3.7 Comparison Method

Since monitoring of the landfills are required by MOE standars, having a monitoring system and management system is required even years after closing a landfill. Remote sensing can potentially provide important information for the identification of contaminated sites. Soil and water contamination have effects on the radiometric properties of vegetation. (MOE Landfill Standard, April 2004)

Distributed geographical information, such as the position of the road network, the population density, and historical lab results, have been used to select the most likely contaminated sites among identified landfills through remote sensing. Further, remote sensing is proposed as a useful technique for monitoring landfill sites for gas migration. In this research the satellite data analysis is used to calculate the NDVI value and determine the LST. This calculation is compared with the actual testing and sampling data collected from monitoring wells and boreholes at landfill sites. The comparison has been done in three different points of view: time, area and method of analysis.

Comparing LST at different years shows environmental changes at an area of the study over a period of time. Changing NDVI values over time indicates the vegetation condition changes through years. Comparing calculated NDVI and LST values at different areas will define the area with higher LST and lower NDVI. Comparing the LST and NDVI results of different years over the study area; shows whether or not affected areas are spreading within the time. Comparison between the results from different methods of analysis could be used as quality control of both methods. If the satellite image analysis method shows the same suspicious area as ground testing analysis results, then we may combine the two different methods of analysis to have a cheaper, easier and faster method of landfill monitoring.

Chapter 4 : STUDY AREA DESCRIPTION

4.1 History of the Trail Road Landfill

The Trail Road site is located within the Region of Ottawa-Carleton, Canada, which has a population of 750,000. The site, approximately 500 acres, is surrounded by light industry and farmland. The Trail Waste Facility or Trail Road Landfill is east of Moodie Drive and north of Trail Road in the City of Ottawa. The Trail Road Landfill is the primary disposal facility for municipal solid waste for the City of Ottawa. The Trial Road landfill and Nepean Landfill have a combined environmental monitoring program. However, they are reported separately due to differing approval and agreement requirements. The Nepean Landfill began operations in the early 1960s, and accepted waste until the early 1980s at which point in time it was considered full and the Trail Road Landfill was opened. The Trail Road Landfill is a municipal sanitary landfill that accepts non-hazardous waste including residential garbage, construction, commercial, institutional, and light industrial waste. (Dillon, 2007)

The Trail Road Landfill was opened in 1980 and it expanded through four stages. Stages 1 and 2 were designed as natural fill areas. Stages 3 and 4 are contained with clay and geomembrane bottom liner and a leachate collection system. Filling of the initially approved landfill capacity within Stages 1 to 4 proceeded progressively until mid-2007. The site was granted approval in 2005 for a vertical expansion over Stages 1-4 and the development of a new engineered cell (future Stage 5). Filling was transferred to the Stage 1 expansion after mid-2007. (Dillon, 2007)

The current Provisional Certificate of Approval for the Trail Road Landfill limits the remaining capacity and site life to the original height, volume, and footprint of the disposal area which was approved in 1977. The original proposed and approved height and footprint area of the Landfill were established based on a sketch of the new landfill over the new property area that was acquired adjacent to the Nepean Landfill in March, 1975 on the north side of Trail

Road. The original and current approved volume of the Landfill is based on a 1975 estimated quantity of material that was available on site for daily and final cover using the 1975 proposed landform and the original estimated refuse to cover ratios. Soil is currently being imported to this site for daily and final cover material. The RMOC Company started construction of the Trail Road Landfill in December, 1978, and waste disposal operations for the Trail Road Landfill began in May, 1980. (Dillon, 2007)

Based on historical waste quantities at the 1996 Annual Monitoring and Operating program, the Trail Road Landfill was expected to be full in 2005. Allowing for the effect of projected waste diversion quantities and optimization of operational practices, the expected life of the Landfill could be extended to 2009. The landfill coordinates and landfill elevation is shown in Table 4.1.

The surrounding area of the landfill is covered by grasslands and light forests. Running tangent to the eastern side of Trail Road Landfill is Highway 416. The southern side is bordered by a Lesser Road, Trail Road, which also borders the northeastern side of the Nepean Landfill which is located southwest of the Trail Road Landfill. Moodie Drive runs along the western boundary of the Nepean Landfill. The south end of the entire site is bordered by Barnsdale Road, and Cambrian Road runs northeast through the northern boundary of the site, but is not immediately adjacent to the landfills, as shown in Figure 4.1. Figure 4.2 shows the location of different landfill's stages. (Dillon, 2007)

Intersections Coordinates			
	Intersection Location	Elevation (m)	coordinates
1	Moodie Drive and Trail Road Intersection	104	45° 14′ 05.18″ N 75° 46′ 56.73″ W
2	Trail Road and Cambrian Road Intersection	102	45° 14′ 05.35″ N 75° 46′ 52.49″ W
3	The end of Cambrian Road close to Highway 416 or Veteran's Memorial Highway	93	45° 14′ 34.24″ N 75° 45′ 43.64″ W
4	End of Trail Road close to Highway 416	105	45° 13′ 50.34″ N 75° 45′ 08.85″ W
5	Cedarview Road and Barnsdale Road Intersection	99	45° 13′ 31.11″ N 75° 45′ 07.34″ W
6	Barnsdale Road and Moodie Drive Intersection	95	45° 13′ 01.45″ N 75° 46′ 20.25″ W

Table 4.1- Intersections Coordinates of Study Area

The leachate that originates from the unlined Nepean Landfill and stages 1 and 2 of the Trail Road Landfill has been detected in the groundwater below the site. The leachate consists of a complex mixture of organic and inorganic constituents as well as elevated levels of calcium, magnesium, chloride, sulphate, potassium, ammonia, other nitrogen compounds, other dissolved organic carbons, phenols, and iron.

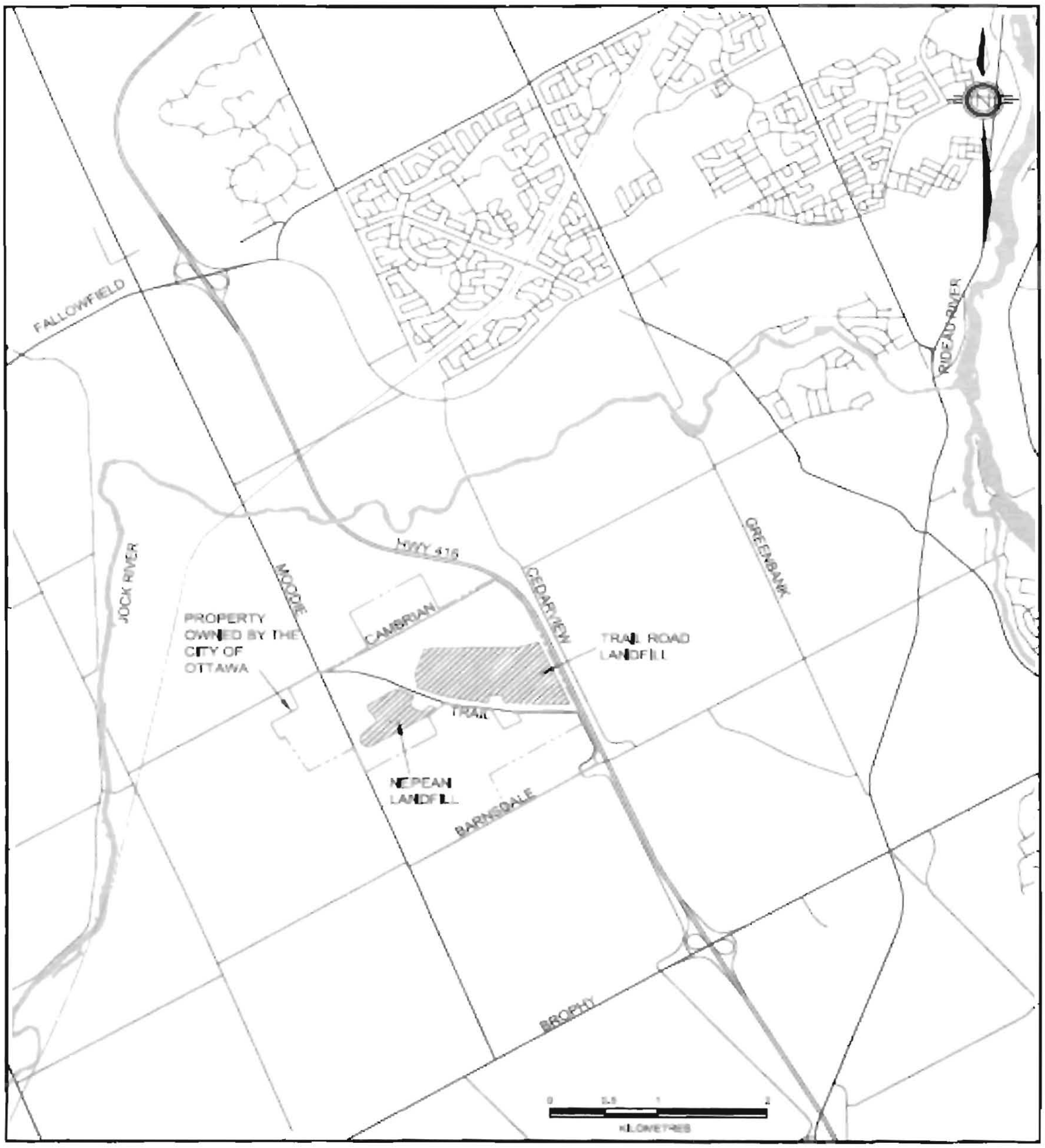


Figure 4.1- Location of Trail Road Landfill

(Dillon, 2006)

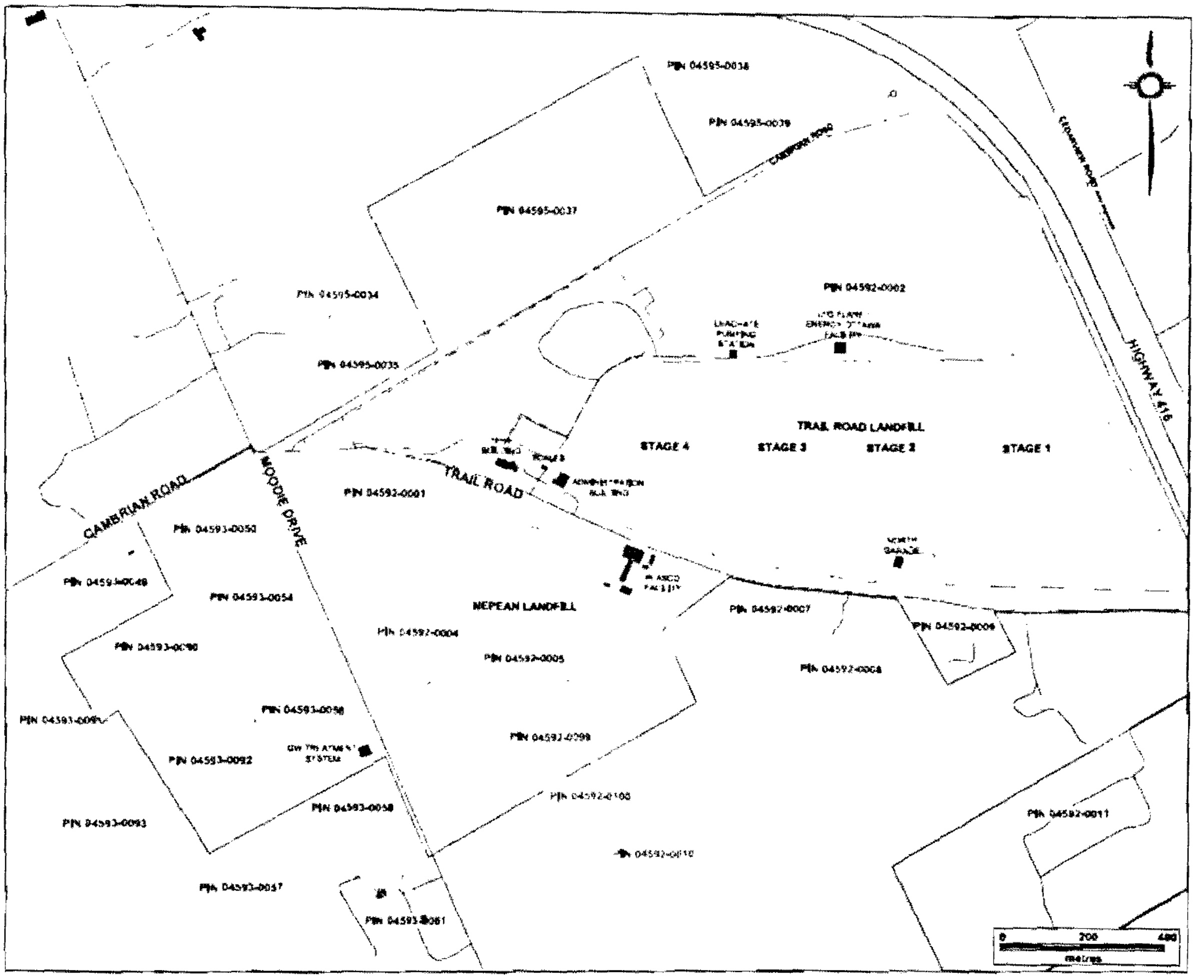
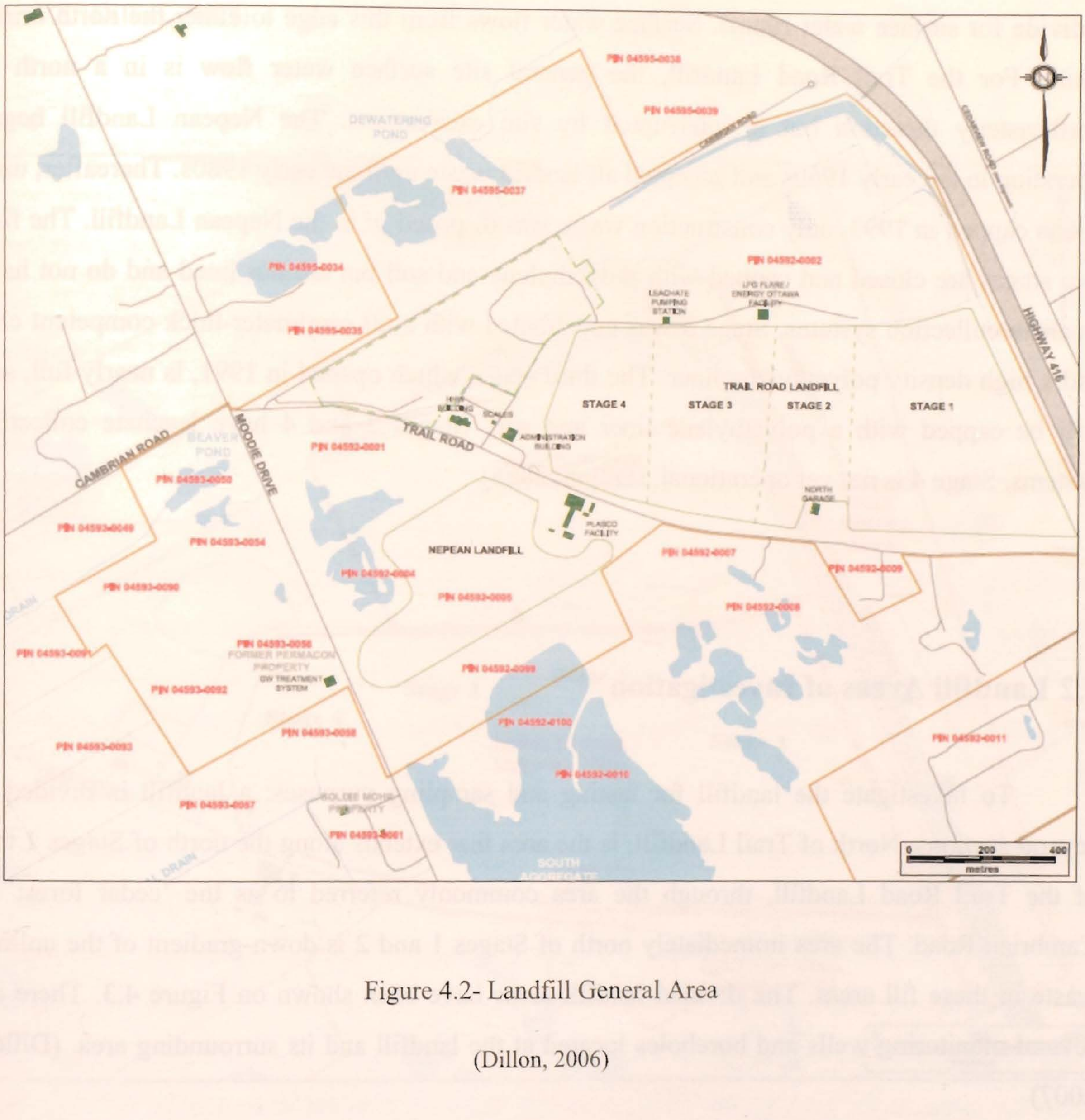


Figure 4.2- Landfill General Area

(Dillon, 2006)

The geotechnical background of the landfill and its soil type is a dense layer of silt and clay beneath which is a layer of sand and gravel overlay on limestone bedrock forming a deep aquifer, present at a depth of 10 to 30 meters. A clay layer is present beneath part of the Trail Road Landfill site. The clay layer separates the sand and gravel ridge into an upper and lower aquifer. (Dillon, 2007)



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There is a sand and gravel ridge located south of the Trail Road Landfill which serves as a divide for surface water runoff. Surface water flows from this edge to either the north or the south. For the Trail Road Landfill, the general site surface water flow is in a north to northeasterly direction but is interrupted by site excavations. The Nepean Landfill began operation in the early 1960s and accepted all landfill waste until the early 1980s. Thereafter, until it was capped in 1993, only construction waste was disposed of in the Nepean Landfill. The first two stages are closed and capped with polyethylene and soil but are not lined and do not have leachate collection systems. Stage 3 was constructed with a 60 centimeter-thick competent clay and a high density polyethylene liner. The third stage, which opened in 1991, is nearly full, and will be capped with a polyethylene liner and soil. Stages 3 and 4 have leachate collection systems. Stage 4 is not yet operational. (Dillon, 2006)

4.2 Landfill Areas of Investigation

To investigate the landfill for testing and sampling purposes; a landfill is divided to several sections. North of Trail Landfill, is the area that extends along the north of Stages 1 to 3 of the Trail Road Landfill, through the area commonly referred to as the 'cedar forest' to Cambrian Road. The area immediately north of Stages 1 and 2 is down-gradient of the unlined waste in these fill areas. The divided landfill areas have been shown on Figure 4.3. There are several monitoring wells and boreholes located at the landfill and its surrounding area. (Dillon, 2007)

East of Trail Landfill area extends to the east and northeast of the Trail Road Landfill along the eastern side of Highway 416 and is up-gradient to across-gradient of the unlined landfill in Stages 1 and 2. The actual landfill site is called Beneath Trail Landfill. South of Trail Landfill area extends along the southern margin of Stages 1 and 2 of the Trail Road Landfill.

This area is generally considered to be up gradient to across-gradient of the unlined fill in Stages 1 and 2. (Dillon, 2007)

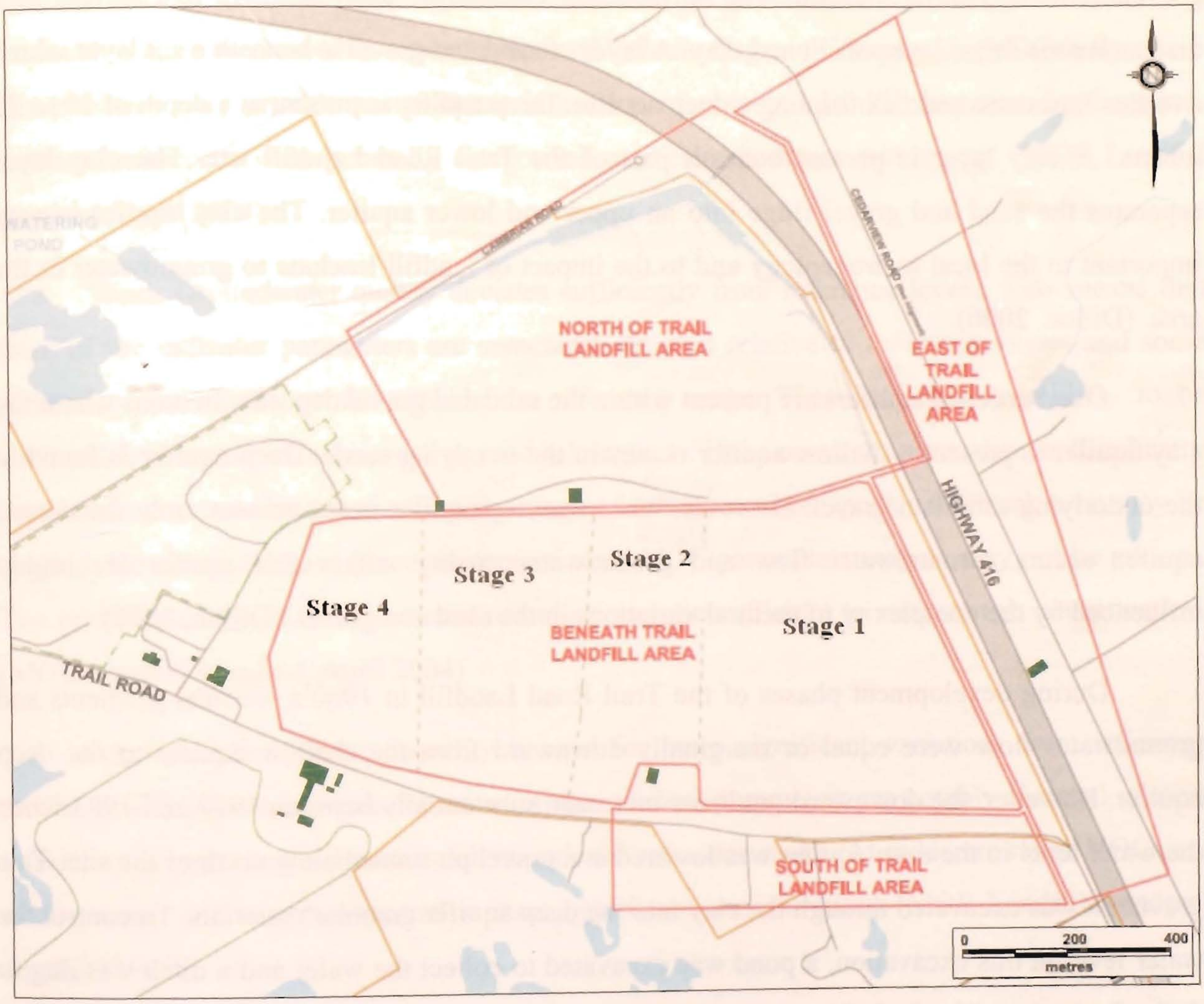


Figure 4.3- Landfill Stages

(Dillon, 2006)

4.3 Soil Types

The landfill site is on a glacial outwash plain which has a complex mixture of sands, gravels, cobbles, clays, and silt. The surface soil consists of approximately two meters of a discontinuous dense layer of silt and clay. A layer of sand and gravel is beneath a silt layer which overlies limestone bedrock forming a deep aquifer. Deep aquifer is present at a depth of 10 to 30 meters. A clay layer is present beneath part of the Trail Road Landfill site. The clay layer separates the sand and gravel ridge into an upper and lower aquifer. The clay aquifer is very important to the local hydrogeology and to the impact of landfill leachate to groundwater in the area. (Dillon, 2006)

Overburdened aquifers are present within the sand and gravel deposits. In areas where the clay aquifer is present a shallow aquifer occurs in the overlying sands. Deep aquifer is found in the underlying sand and gravel. However, when the clay aquifer is not present, only the deeper aquifer occurs. Groundwater flow and groundwater quality within this aquifer are highly influenced by the complexity of textural variations in the sand and gravel. (Dillon, 2006)

During development phases of the Trail Road Landfill in 1960's, vertical gradients and groundwater flow were equal or marginally downward from the shallow aquifer to the deep aquifer. However, the downward gradients increased substantially between 1977 and 1983 when the water level in the deep aquifer was lowered at a gravel pit immediately north of the site. This gravel pit was excavated through the clay into the deep aquifer granular materials. To control the water level in this excavation, a pond was excavated to collect the water and a ditch was dug to drain the water to the Jock River. As a result, the water level in the deep aquifer dropped by as much as 5 m below the site. The pond discharges to the ditch at an average of approximately 20 to 25 L/s. Geological and hydrogeological information has been obtained through monitoring programs, boreholes and monitoring wells. (Dillon, 2006)

4.4 Leachate Influence Assessment

In assessing potential leachate influences of the ground water and soil quality of each location, several tests and samplings were conducted. In general the reference water quality is assumed to have no detectable concentrations of Volatile Organic Compounds (VOCs); therefore this presence may provide a significant indication of potential landfill impacts. Furthermore, leachate influences were generally categorized as weak, moderate and strong. (MOE Landfill standard, April 2004)

Weak Groundwater quality deviates sufficiently from reference levels. This means that most of the indicator parameters are somewhat elevated relative to reference values and some parameter concentrations fall outside the reference range. These effects are unlikely to be attributable to another source, such as road salt impacts. If the concentrations of several indicator parameters are near the upper end of the range of reference water quality the weak term may be applied. However, the low concentrations of some VOC parameters may or may not be present. The presence of low VOC concentrations alone may be sufficient to warrant this classification. (MOE Landfill standard, April 2004)

Moderate Groundwater quality is used for more significant variations from reference levels. This designation means that most of the indicator parameters are notably elevated relative to reference, and many parameters fall outside the reference range. At moderate range VOCs are often present and may be detected at more significant concentrations (MOE Landfill standard, April 2004).

Strong Groundwater quality is clearly harmed due to leachate impact, with most of the indicator parameters quite significantly elevated relative to reference, such that they fall outside the reference range. VOC parameters are typically detected. The result of testing shows that in many cases, the level of impact was best described as transitional between these categories, for example weak to moderate or moderate to strong (MOE Landfill standard, April 2004).

Leachate, believed to originate from the unlined Nepean Landfill and the stages 1 and 2 of the Trail Road Landfill, has been detected in the groundwater below the site. The groundwater is monitored on a variable basis. All wells are monitored up to 3 times a year for indicators including chloride, boron, bromide, Biochemical Oxygen Demand (BOD), Dissolved Oxygen Carbone (DOC), and iron (Dillon, 2007; MOE Landfill standard, April 2004).

The effects of Leachate leakage are shown in the shallow aquifer to the north of Stages 1 and 2 of the Trail Landfill generally within the Cedar Forest area. The leachate impact in this area can be characterized in different levels and is typically expressed as elevated concentrations of a number of the indicator parameters, with some parameters being more concentrated at some locations. The most diluted and leading point of leachate appearance on ground water is at approximately 300 meters north of the Trail Landfill. Ground water concentration of boron and toluene has exceeded trigger levels at shallow aquifer trigger since 2006 in this area. Results from wider sampling programs completed in the Fall 2006 and Spring 2007 indicate that leachate impacts exceeding trigger concentrations in the Cedar Forest area are isolated to the vicinity of this well (Dillon, 2007).

Similar impacts have been observed along the northern margin of the forest, either at shallow aquifer monitoring wells or at surface water discharge locations. It concludes that the impacts have not extended farther north beyond the central portion of the Cedar Forest. These results have demonstrated that the Cedar Forest has a sufficient natural attenuation capacity to mitigate the historic leachate impact emanating from Stages 1 and 2 of the Trail Landfill (Dillon, 2007).

Some parameter concentrations increase in deep aquifer. These increases are shown at monitoring wells in the area north of Stages 2 and 3. The monitoring wells that are completed in the deep aquifer to the north of the Trail Landfill are indicative of leachate influences in those areas. Some leachate influences are also observed further down-gradient along the flow path to the Dewatering Pond, but not as far as the Pond itself. The leachate impact in this area is typically expressed as elevated concentrations of a number of the inorganic parameters and in some cases, low concentrations of some VOCs. It is noted that some leachate influences have also been observed to the north of Stage 4. The contamination at north of stage 4 is more likely to be related to spiral migration northwards from the Nepean Landfill. Leachate influenced groundwater has not migrated to City properties as of yet. The elevation of the river and city properties are higher than landfill property therefore chance of migrating pollution through water is very low. (Dillon, 2005)

At south of Stage 2 Trail Landfill, there is a minor zone of leachate influence to the deep aquifer. The impact in this area is localized and does not appear to be expanding. But an assessment of water quality at this location relative to Guideline B-7 (Appendix A) suggests that Reasonable Use Criteria for DOC may have been slightly exceeded during the 2007 sampling. There is not any significant impact with respect to chloride, boron, iron concentrations, and some other parameters which have traditionally shown a strong correlation with leachate influences at this site. The assessment concludes that the water quality at this location is not significantly affected by landfill leachate. (Dillon, 2007)

Data from different locations at this site indicates that DOC concentrations are generally higher at shallow aquifer locations, likely reflecting lower residence time following recharge of water with relatively higher DOC concentrations from precipitation, and snowmelt. The aggregate pit south of Trail Road may have a similar effect on DOC concentrations at this deep aquifer location. Based on these considerations, water quality is considered to be substantially in line with Guideline B-7. Some leachate influences have been detected at lower deep aquifer. The monitoring well that at shallow bedrock level resulted in the discovery that significant leachate impact is present at bedrock level (Dillon, 2006).

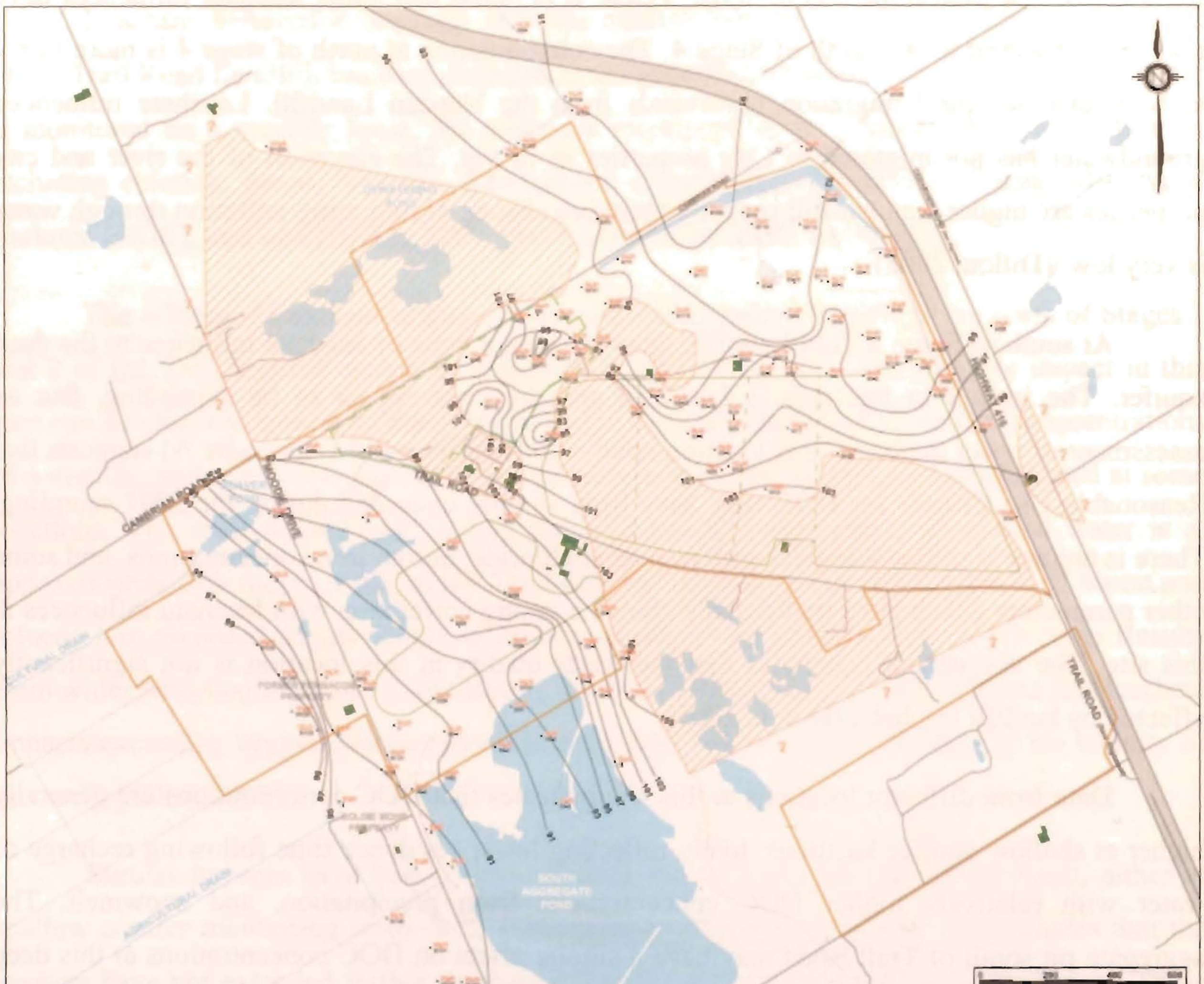


Figure 4.4- Elevations of the Landfill and the Surroundings Area

(Dillon, 2006)

4.4.1 Groundwater Elevation

Groundwater gradient has effects on the rate of pollution migration. Groundwater elevations, inorganic chemistry, and organic parameters such as dissolved organic carbon and volatile organic compounds have important effects on leachate migration. These parameters were analyzed at a select number of wells and provided additional evidence of potential leachate impacts. The ground water elevation is shown on Figure 4.4 (Dillon, 2006).

4.4.2 Flow Directions

Underground water and leachate flow direction is one of the most important aspects because it allows us to track the leakage and be able to stop distributing the contamination through nature. Flow directions in the shallow aquifer are shown on Figure 4.5. In the North of Trail Landfill Area, flow continues in a northerly direction, the same direction as the slope of the underlying clay layer. In this area of the site, groundwater discharges gradually from the Cedar Forest area as seepage emerges from the shallow aquifer it pinches out over the underlying clay materials. During periods of high recharge, some of the discharging groundwater may combine with rainwater and meltwater in spring and fall seasons. Therefore, the drainage from the northeast corner of the landfill flows to the stormwater management pond in the northeast corner of the property via ditching in this portion of the site. Further, surface water runoff from Stage 1 of the Trail landfill is directed to ditching to the east and north to a stormwater bypass discharging to a ditch that leads to the stormwater management pond (Dillon, 2007).

Shallow groundwater flow in the North of the Facility Area is more complex due to the variable topography of the underlying surface of the clay. There continues to be a certain degree of northward flow into the Cedar Forest area north of Stage 4 of the landfill. Groundwater flow is likely controlled by the topography of the clay, either flowing northeast to the Cedar Forest area, or draining to the deep aquifer where the clay pinches out. Flow from the far western corner of the property is southwest across Trail Road towards the Nepean Landfill (Dillon, 2006).

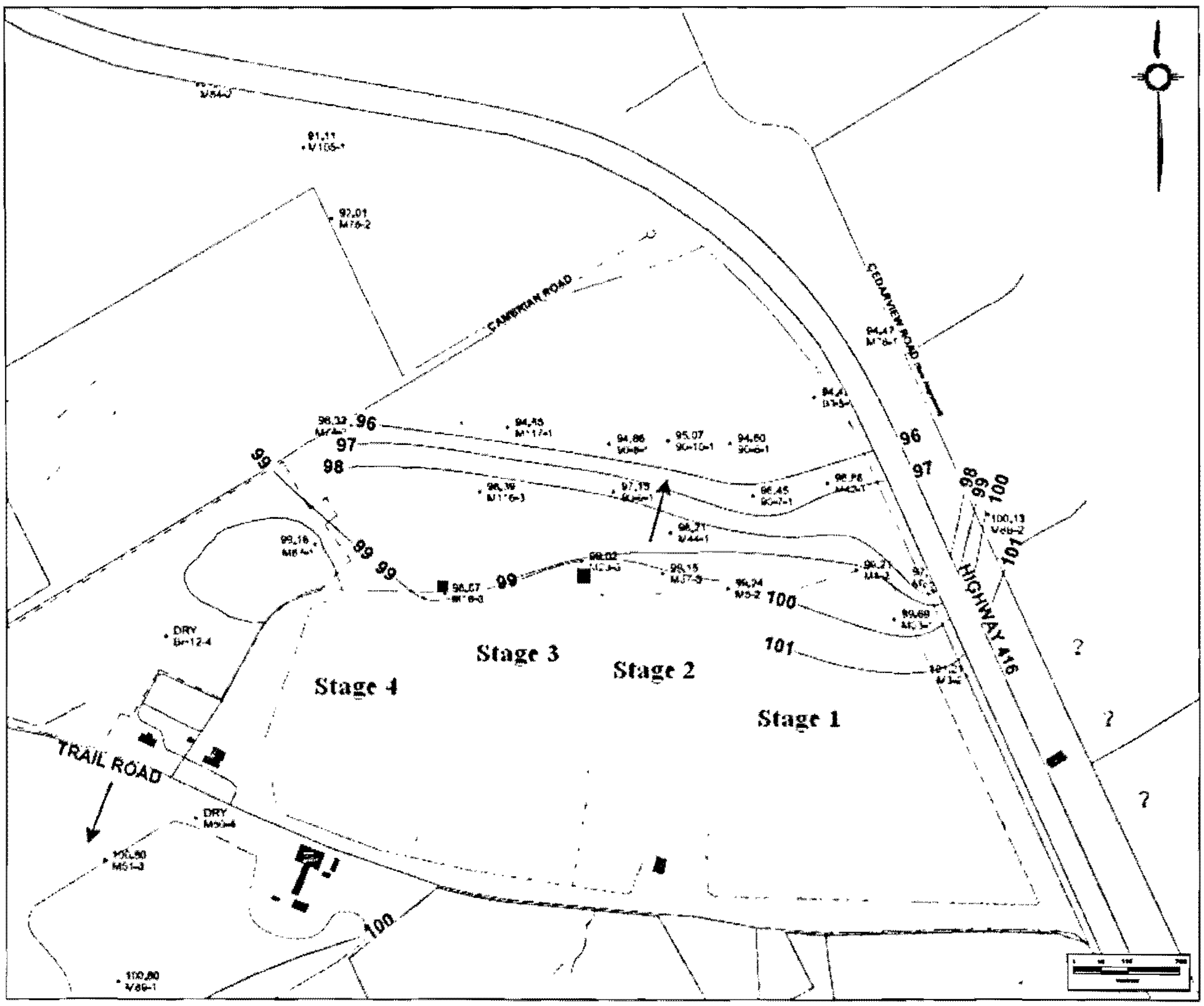


Figure 4.5 - Flow Directions from the Trail Road Landfill

(Dillon, 2006)

or draining to the deep aquifer where the clay pinches out. Flow from the far western corner of the property is southwest across Trail Road towards the Nepean Landfill (Dillon, 2006).

Figure 4.5 - Flow Directions from the Trail Road Landfill

(Dillon, 2006)

4.5 Land Temperature

Land temperature is one of the most important characteristics of landfill sites. Different features can be determined from heat at different level of ground. Temperature readings can indicate at what depths there is flowing groundwater, as well as aid in determining the location of exothermic chemical reactions from contamination. This information can be used to characterize the extent of leachate leakage and potential areas of groundwater contamination. The temperature can be variable with water flow or chemical reactions in the leachate. Therefore detecting temperature at different places shows the landfill's characteristics such as water level and leachate spill (Flower, Gilman, Leone, 1985).

4.6 Surface Water Monitoring

Surface water drainage from the Trail Road Landfill is directed to the stormwater management pond at the northeast corner of the site. From there, surface water flows eastward under Highway 416 and then continues northward via roadside ditches along Cedarview Road, ultimately discharging to the Jack River. Surface water flowing in this system consists primarily of surface runoff, but may also include a component of shallow aquifer groundwater discharge. No exceedances of surface water trigger concentrations were obtained at any stations that have been set up at the discharge points from the site. The locations of the monitoring stations are shown on Figure 4.6.

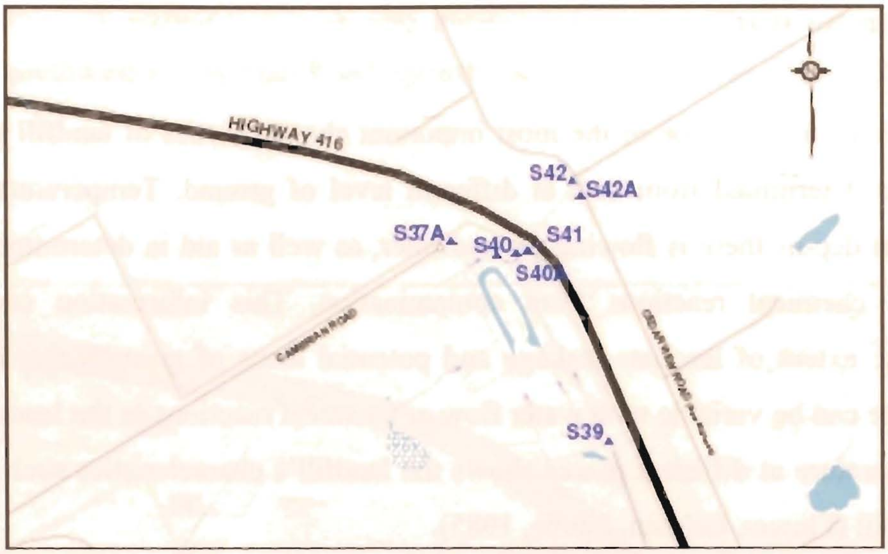


Figure 4.6 – Locations of Surface Monitoring Stations

(Dillon, 2006)

Because of the exceedances of groundwater boron and toluene in the Cedar Forest area surface water samples have been taken at all locations of visible surface water discharge from the forest. Elevated iron and total phosphorus levels are generally considered unrelated to the landfill, although, in the case of iron, leachate influences may be a contributing factor at some locations.

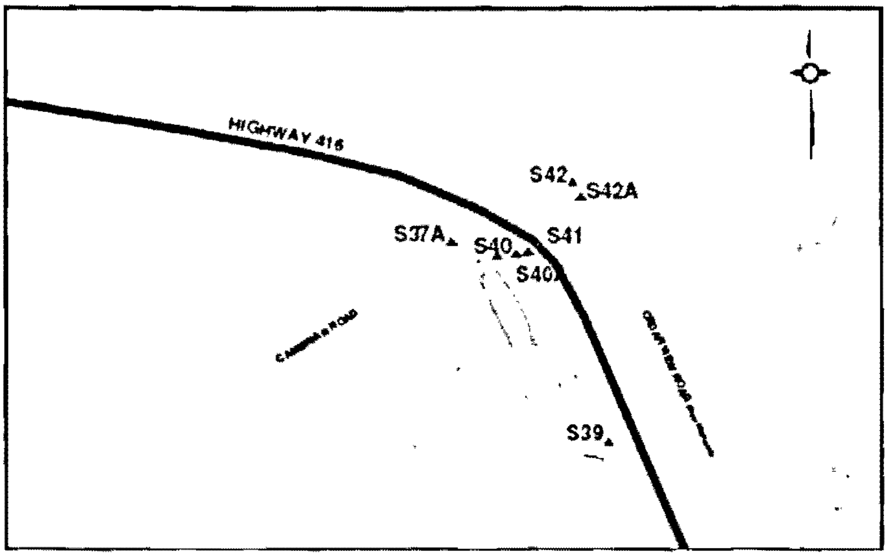


Figure 4.6 – Locations of Surface Monitoring Stations

(Dillon, 2006)

Because of the exceedances of groundwater boron and toluene in the Cedar Forest area surface water samples have been taken at all locations of visible surface water discharge from the forest. Elevated iron and total phosphorus levels are generally considered unrelated to the landfill, although, in the case of iron, leachate influences may be a contributing factor at some locations.

Chapter 5 : DATA ANALYSIS

5.1 General

Analyzing satellite data from landfills with ERDAS IMAGINE software, calculating LST and NDVI in different years then compares the data sets, environmental changes over time emerge. Poor environmental conditions are often the result of contamination. With the results of data analysis we are able to predict what is happening regarding contamination from the landfill. By comparing the analyzed remote sensing data with ground-based testing and sampling data from the site we can find out the accuracy of the long-distance data analysis.

To analyze the data the total landfill area has been divided to 9 smaller areas: A to I, as shown on Figure 5.1. The actual landfill site is located on area E, which is in the middle. Figures 5.2 and 5.3 show the general area photo of the landfill and its immediate surroundings. The coordinates and elevation of each area has been shown on Table 5.1.

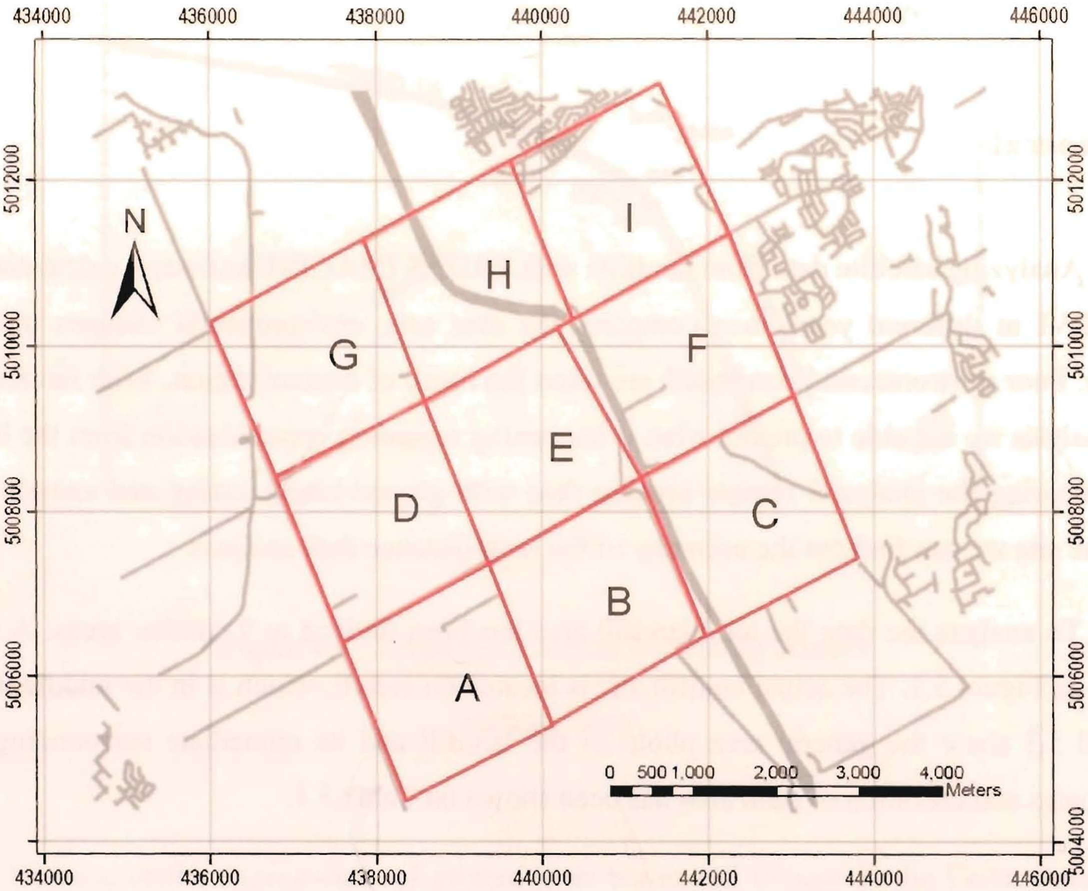


Figure 5.1 - General Study Area Divided Tiles

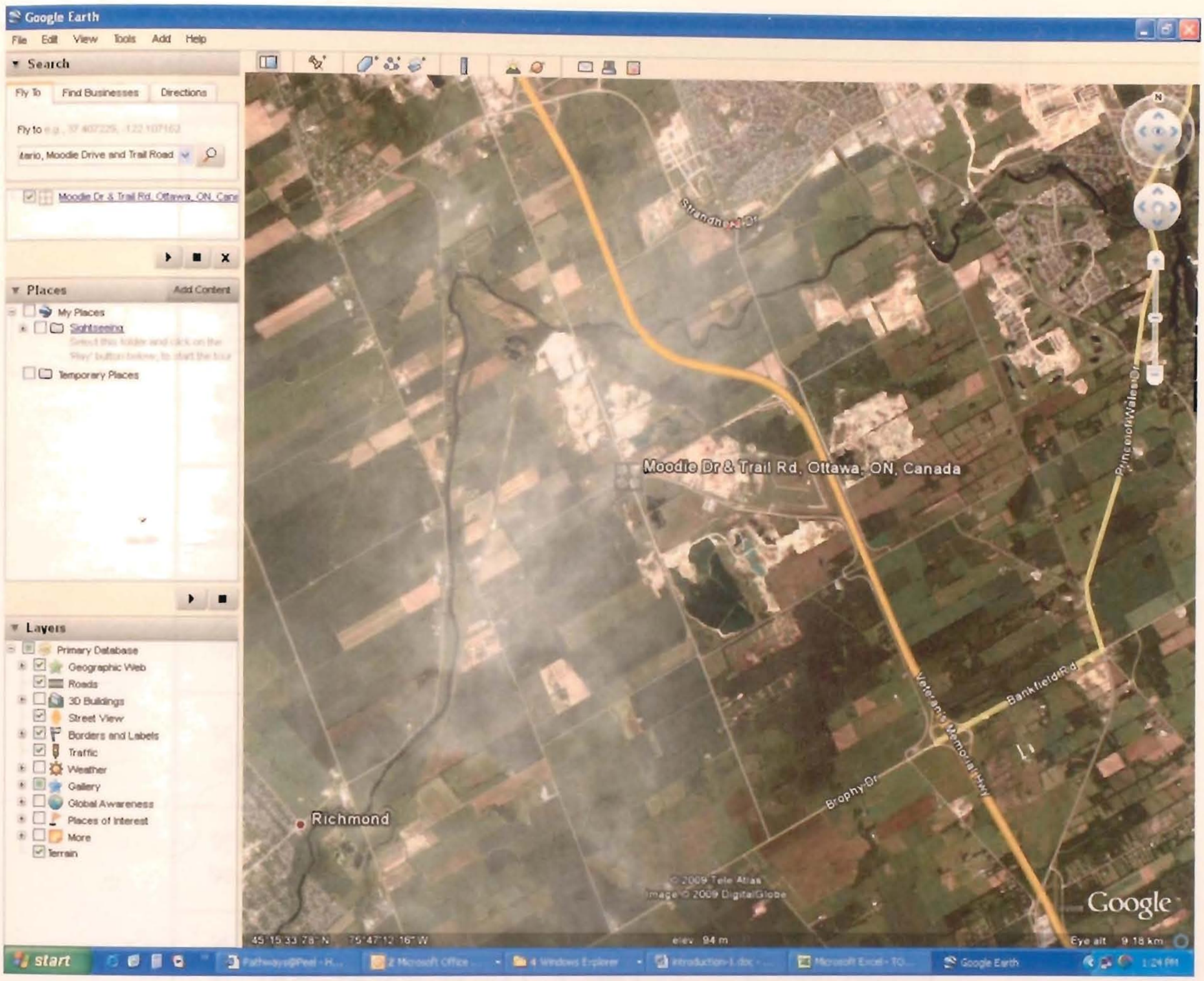


Figure 5.2 - General Study Area from Landsat

Landfill Coordinates				
Area	Location	Corner	Elevation (m)	coordinates
A	Twin Elm Road and Barnsdale Road Intersection	Top Left	93	45° 12′ 29.83″ N 75° 47′ 41.68″ W
	Barnsdale Road and Moodie Drive Intersection	Top Right	95	45° 13′ 01.45″ N 75° 46′ 20.25″ W
	Brophy Drive and Moodie Drive Intersection	Bottom Right	92	45° 11′ 57.67″ N 75° 45′ 44.61″ W
	Brophy Drive and Twin Elm Road Intersection	Bottom Left	94	45° 11′ 24.59″ N 75° 47′ 04.93″ W
B	Barnsdale Road and Moodie Drive Intersection	Top Left	95	45° 13′ 01.45″ N 75° 46′ 20.25″ W
	Barnsdale Road and Veteran's Memorial Highway Intersection	Top Right	99	45° 13′ 35.51″ N 75° 44′ 55.74″ W
	Bankfield Road and Veteran's Memorial Highway Intersection	Bottom Right	93	45° 12′ 34.91″ N 75° 44′ 12.94″ W
	Brophy Drive and Moodie Drive Intersection	Bottom Left	92	45° 11′ 57.67″ N 75° 45′ 44.61″ W
C	Barnsdale Road and Veteran's Memorial Highway Intersection	Top Left	99	45° 13′ 35.51″ N 75° 44′ 55.74″ W
	Barnsdale Road and Greenbank Road Intersection	Top Right	97	45° 14′ 08.45″ N 75° 43′ 32.59″ W
	Bankfield Road and Greenbank Road Intersection	Bottom Right	98	45° 13′ 04.92″ N 75° 42′ 57.13″ W
	Bankfield Road and Veteran's Memorial Highway Intersection	Bottom Left	93	45° 12′ 34.91″ N 75° 44′ 12.94″ W

Table 5.1 – Landfill Coordinates and Elevations

Landfill Coordinates				
Area	Location	Corner	Elevation (m)	coordinates
D	Twin Elm Road and Cambrian Road Intersection	Top Left	93	45° 13′ 32.51″ N 75° 48′ 18.55″ W
	Moodie Drive and Trail Road Intersection	Top Right	104	45° 14′ 05.18″ N 75° 46′ 56.73″ W
	Barnsdale Road and Moodie Drive Intersection	Bottom Right	95	45° 13′ 01.45″ N 75° 46′ 20.25″ W
	Twin Elm Road and Barnsdale Road Intersection	Bottom Left	93	45° 12′ 29.83″ N 75° 47′ 41.68″ W
E	Moodie Drive and Trail Road Intersection	Top Left	104	45° 14′ 05.18″ N 75° 46′ 56.73″ W
	Cambrian Road and Cedarview Road Intersection	Top Right	93	45° 14′ 38.63″ N 75° 45′ 31.07″ W
	Barnsdale Road and Veteran's Memorial Highway Intersection	Bottom Right	99	45° 13′ 35.51″ N 75° 44′ 55.74″ W
	Barnsdale Road and Moodie Drive Intersection	Bottom Left	95	45° 13′ 01.45″ N 75° 46′ 20.25″ W
F	Cambrian Road and Cedarview Road Intersection	Top Left	93	45° 14′ 38.63″ N 75° 45′ 31.07″ W
	Greenbank Road and Cambrian Road Intersection	Top Right	92	45° 15′ 11.08″ N 75° 44′ 09.25″ W
	Barnsdale Road and Greenbank Road Intersection	Bottom Right	97	45° 14′ 08.45″ N 75° 43′ 32.59″ W
	Barnsdale Road and Veteran's Memorial Highway Intersection	Bottom Left	99	45° 13′ 35.51″ N 75° 44′ 55.74″ W

Table 5. 1 - (Continued) Landfill Coordinates and Elevations

Landfill Coordinates				
Area	Location	Corner	Elevation (m)	coordinates
G	Richmond Road and Rushmore Road	Top Left	94	45° 14′ 35.07″ N 75° 48′ 55.63″ W
	Moodie Drive and McKenna Casey Drive Intersection	Top Right	93	45° 15′ 06.70″ N 75° 47′ 32.38″ W
	Moodie Drive and Trail Road Intersection	Bottom Right	104	45° 14′ 05.18″ N 75° 46′ 56.73″ W
	Twin Elm Road and Cambrian Road Intersection	Bottom Left	93	45° 13′ 32.51″ N 75° 48′ 18.55″ W
H	Moodie Drive and McKenna Casey Drive Intersection	Top Left	93	45° 15′ 06.70″ N 75° 47′ 32.38″ W
	Cedarview Road and Standherd Drive Intersection	Top Right	91	45° 15′ 34.41″ N 75° 46′ 02.78″ W
	Cambrian Road and Cedarview Road Intersection	Bottom Right	93	45° 14′ 38.63″ N 75° 45′ 31.07″ W
	Moodie Drive and Trail Road Intersection	Bottom Left	104	45° 14′ 05.18″ N 75° 46′ 56.73″ W
I	Cedarview Road and Standherd Drive Intersection	Top Left	91	45° 15′ 34.41″ N 75° 46′ 02.78″ W
	Market Place Avenue and Greenbank Road Intersection	Top Right	99	45° 16′ 08.00″ N 75° 44′ 43.61″ W
	Greenbank Road and Cambrian Road Intersection	Bottom Right	92	45° 15′ 11.08″ N 75° 44′ 09.25″ W
	Cambrian Road and Cedarview Road Intersection	Bottom Left	93	45° 14′ 38.63″ N 75° 45′ 31.07″ W

Table 5. 1 - (Continued) Landfill Coordinates and Elevation

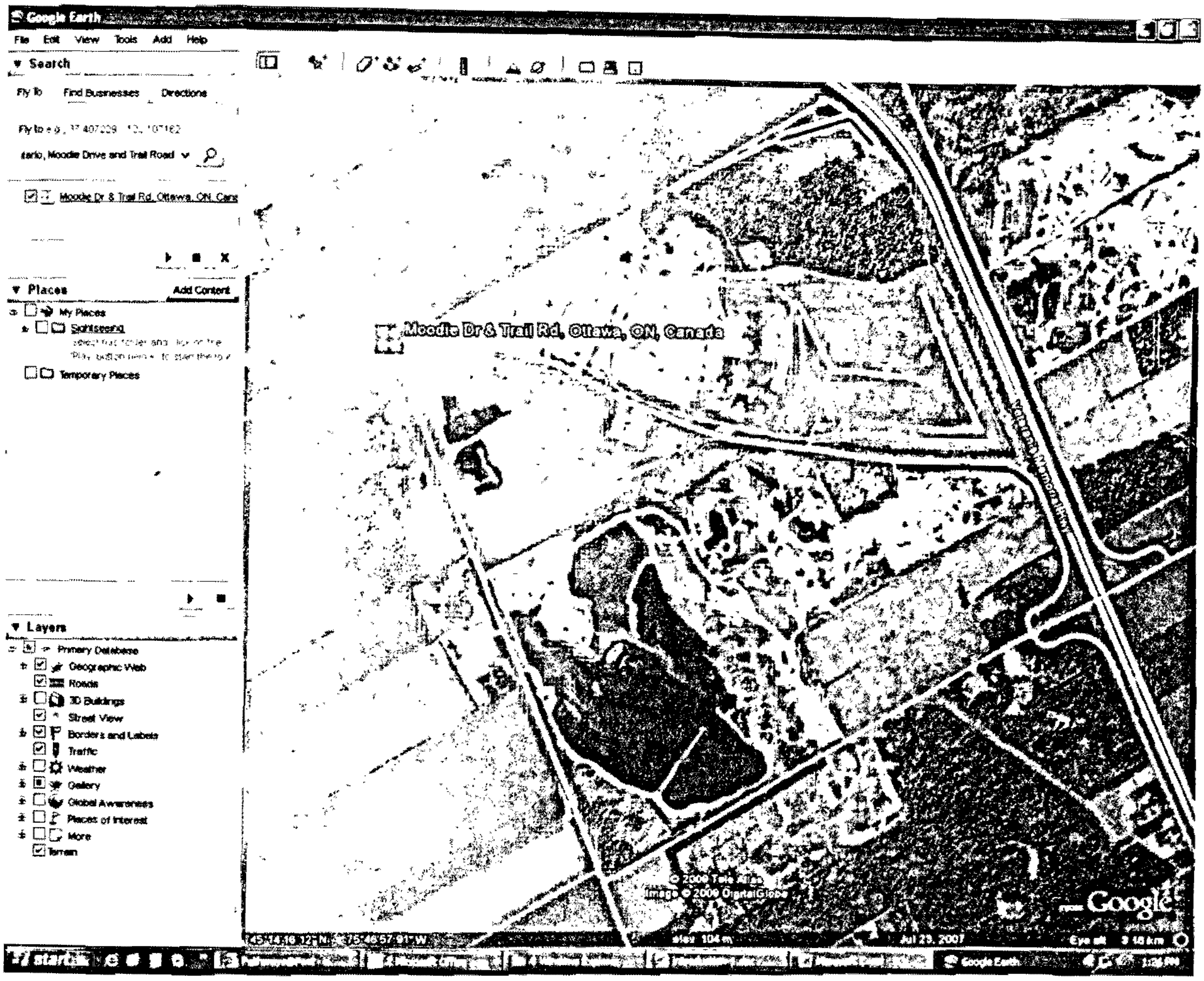


Figure 5.3 - Trail Road Landfill from Landsat

5.2 Yearly Image Data Analysis

Images were collected from the USGS site for May 1992, August 1998, October 2000 and September 2001. The LST and NDVI values were calculated for these years for each of the

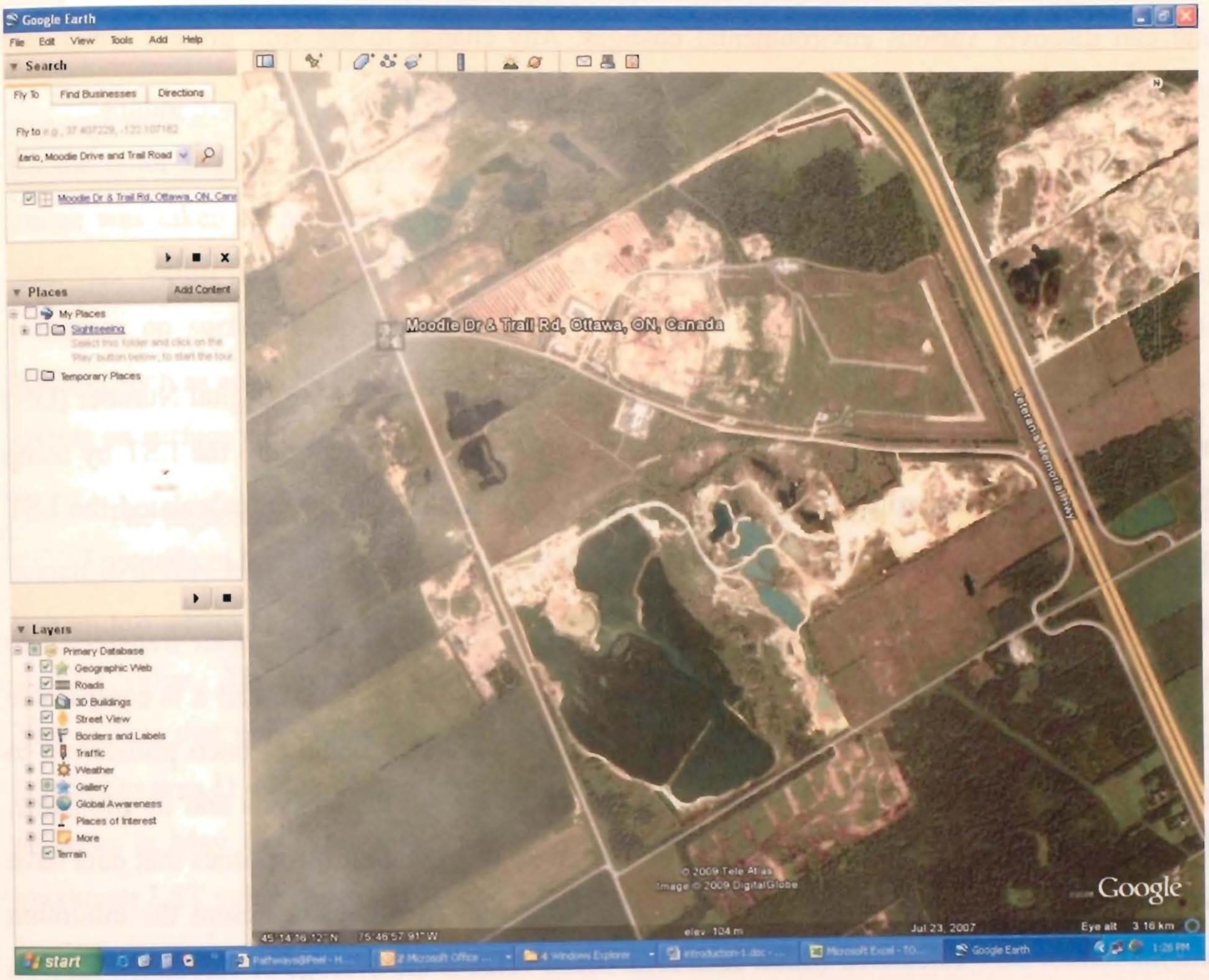


Figure 5.3 - Trail Road Landfill from Landsat

5.2 Yearly Image Data Analysis

Images were collected from the USGS site for May 1992, August 1998, October 2000 and September 2001. The LST and NDVI values were calculated for these years for each of the

9 individual areas. By comparing the results of the Calculated LST and NDVI for different years one can discover various environmental changes. Any change to the soil, ground water and surface water in the area through years of use as a landfill is recorded.

5.2.1 Calculation of the Land Surface Temperature

The LST of each thermal image is calculated by first converting the Digital Number (DN) into Radiance Value (RAD) Values. The RAD values are then converted into the LST by using the Black Body Temperature (BBT) equation. ERDAS IMAGINE software calculated the LST for all 9 divided areas at collected years using equation 3.1 that was mentioned in chapter 3.

Figures 5.4 to 5.7 are from ERDAS IMAGINE software that has been transferred to ARCVIEW for different years. Temperatures are shown by different colors, and it is comparable to each of the divided areas for the selected years. All calculated LST has been transferred to table 5.2 to 5.5 for different years. Each table shows the area of the analysis and its tile name. There is column for the name of the count that is representing the number of times that data have been calculated in that specific tile. Minimum and Maximum columns represent the minimum and maximum LST calculated within each area. Mean value is the average of calculated LST on each tile. Standard Deviation (STD) is a statistical value to determine how the data has been spread out and how close each individual piece of data is to the mean value. The larger STD value implies that the individual pieces of data are further from the average value. Therefore larger STD value shows sudden value changes. There is a column by the name of summation (SUM) that is representing combine calculated LST values for all the areas in the specific tile.

5.2.1.1 Land Surface Temperature Value for Year 1992

Figure 5.4 displays the LST calculated for year 1992 with ERDAS IMAGINE software. As the color indicates, ground surface temperature is between 12 and 32 degree Celsius. The image was taken on May 29, 1992. The external temperature recorded for the daytime of that date was within the range of 8 to 12 degree Celsius. Further, the vegetation has a significant influence on surface temperature. In spring time there are lots of movement on the ground surface, such as animals, insects and vegetation. They all cause heat which in turn can have small effects on surface temperature in the area.

The highest LST is obscured in the bottom right corner of area H at 32.7 degrees Celsius, which is a very high LST. The lowest LST accrued in area E at 12.7 degrees Celsius, on the bottom left where the dewatering pond is located. Therefore, surface water might have an effect on LST value. The highest standard deviation calculated at area E, which is the landfill area. This means that area E has the most variable LST value. However, the highest average LST belongs to area D with 26.5 degrees Celsius. Table 5.2 shows the summary of LST calculated for all areas in May 1992. Minimum LST value calculated at area E at 12.7 degrees Celsius, and maximum LST value happened at area H in the area south of landfill site.

5.2.1.2 Land Surface Temperature Value for Year 1998

Figure 5.5 shows the calculated LST on August 1998. As the color of the legend indicates, the LST value calculated for this date is between 20 and 32 degrees Celsius. This image was acquired during the summer, and the weather temperature range was between 22 and 26 degrees Celsius. There shall be other likely causes to influence the LST values.

LST YEAR 1992/05/29

NUMBER	YEAR	TILE NAME	COUNT	AREA	MIN	MAX	MEAN	STD	SUM
1	5/29/1992	A	5087.0	4131920.0	16.951	30.732	24.937	3.743	126854.0
2	5/29/1992	B	5367.0	4359350.0	15.576	31.951	20.815	3.070	111713.0
3	5/29/1992	C	5349.0	4344730.0	16.036	31.546	23.452	2.902	125444.0
4	5/29/1992	D	5281.0	4289490.0	16.495	31.140	26.538	2.954	140149.0
5	5/29/1992	E	5061.0	4110800.0	12.775	31.546	24.317	3.988	123069.0
6	5/29/1992	F	5720.0	4646070.0	15.576	29.502	22.502	2.888	128711.0
7	5/29/1992	G	5178.0	4205830.0	16.036	31.546	23.339	3.413	120849.0
8	5/29/1992	H	5143.0	4177400.0	15.576	32.758	21.845	3.021	112346.0
9	5/29/1992	I	5182.0	4209080.0	16.036	31.140	24.116	3.488	124969.0

Table 5.2 - LST Calculated on May 29, 1992

The highest LST value captured at West side of area F at 31.9 degrees Celsius, an area that is very close to the landfill's location. All areas have approximately the same range of low temperature at 20 to 21 degrees Celsius. The highest standard deviation calculated at area E, the landfill area itself, with significant differentiation from the other areas. The highest average LST belongs to area E as well, with 27.1 degrees Celsius. Table 5.3 shows the summary of LST calculated for each of the areas in July 1998. The high average indicates that most of the LST values are relatively higher than normal LST values. The minimum LST of all areas is in the same range, between 20 and 21 degrees Celsius.

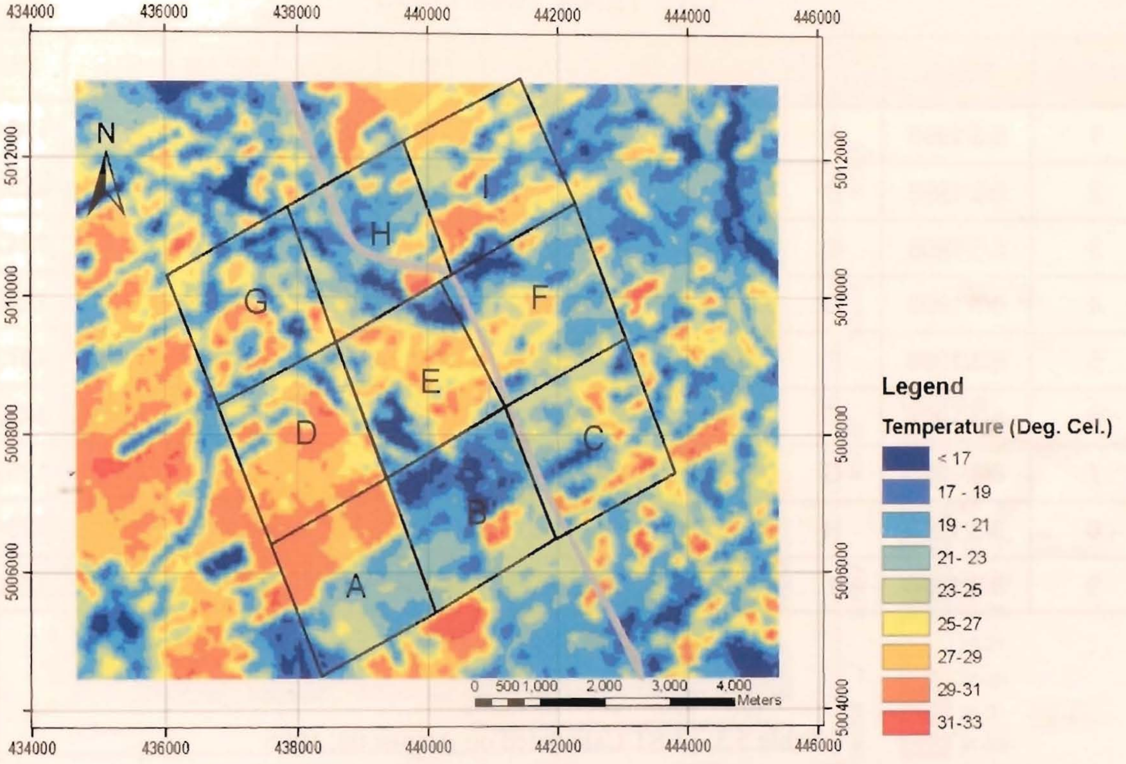


Figure 5.4 - LST on May 29, 1992

LST YEAR 1998/08/03									
NUMBER	YEAR	TILE NAME	COUNT	AREA	MIN	MAX	MEAN	STD	SUM
1	8/3/1998	A	5087.0	4131920.0	20.543	26.585	22.887	1.425	116424.0
2	8/3/1998	B	5367.0	4359350.0	20.543	29.502	23.330	1.485	125211.0
3	8/3/1998	C	5349.0	4344730.0	20.543	28.260	23.226	1.688	124235.0
4	8/3/1998	D	5281.0	4289490.0	20.984	29.502	22.885	1.775	120858.0
5	8/3/1998	E	5061.0	4110800.0	20.543	35.544	27.144	2.861	137376.0
6	8/3/1998	F	5720.0	4646070.0	20.984	31.951	25.049	2.212	143282.0
7	8/3/1998	G	5178.0	4205830.0	20.984	31.140	24.187	2.182	125240.0
8	8/3/1998	H	5143.0	4177400.0	20.984	31.140	23.995	1.922	123408.0
9	8/3/1998	I	5182.0	4209080.0	20.984	30.732	22.974	1.634	119053.0

Table 5.3 - LST Calculated on August 03, 1998

5.2.1.3 Land Surface Temperature Value for Year 2000

Figure 5.6 displays the LST values calculated with ERDAS IMAGINE software in October 2000. This figure indicates that the general temperature is lower than the previous figures. The temperature range is between 12 and 25 degrees Celsius. This image was taken in October 2000 (during autumn) and the external temperature is usually in range of 13 to 17 degrees Celsius. Further, the vegetation which influences LST is almost dead in this season. The activities of animals and plants are less than in spring and summer, and thus the lower LST is to be expected.

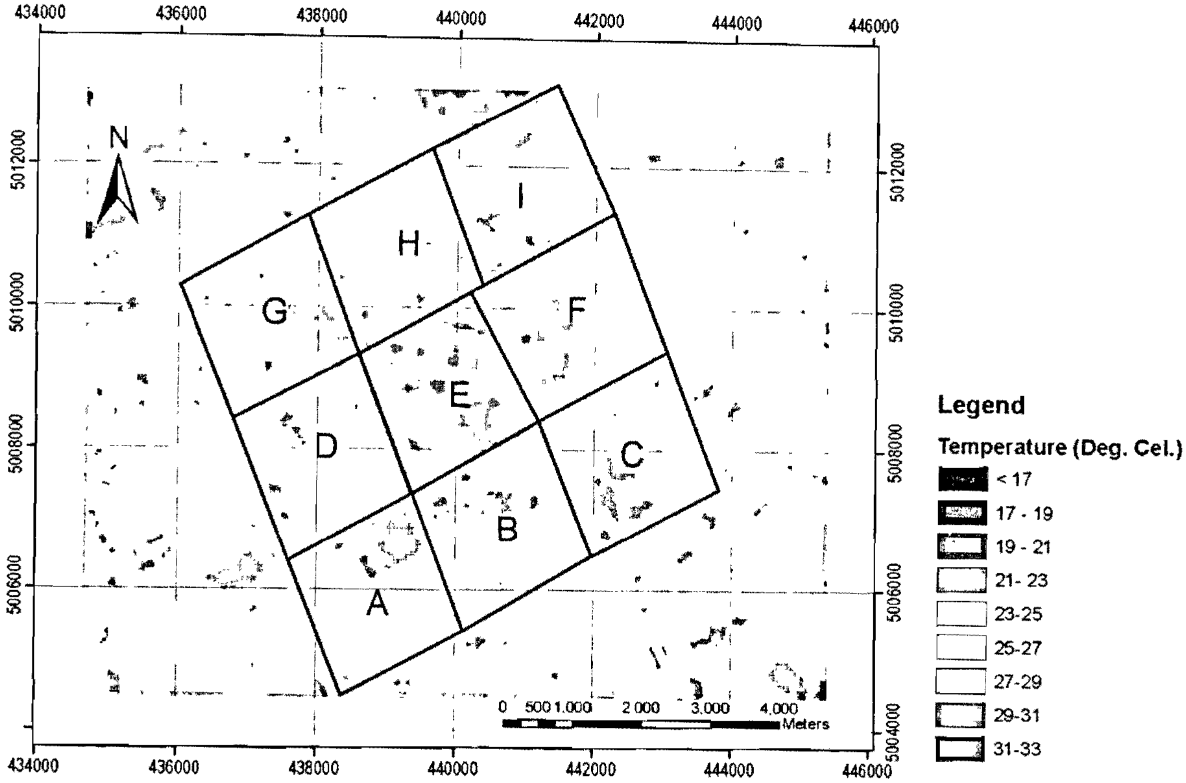


Figure 5.5 – LST on August 03, 1998

The highest LST indicated at this time was on the north side of area E, at 25.7 degrees Celsius, which is located directly on the landfill site. Additionally, the highest standard deviation is also accrued in area E amidst the landfill itself. The highest average LST value surface temperature also occurs at area E, at 19 degrees Celsius. Table 5.4 shows the summary of LST calculated for all nine divided areas at October 2000. LST values calculated for year 2000 indicates that the minimum and maximum LST value, highest average LST value, and standard deviation value all occurred in area E in the areas that are used for the landfill. This might be one of the negative effects of a landfill upon environment. These negative results could be caused by leachate leakage and contamination from the landfill.

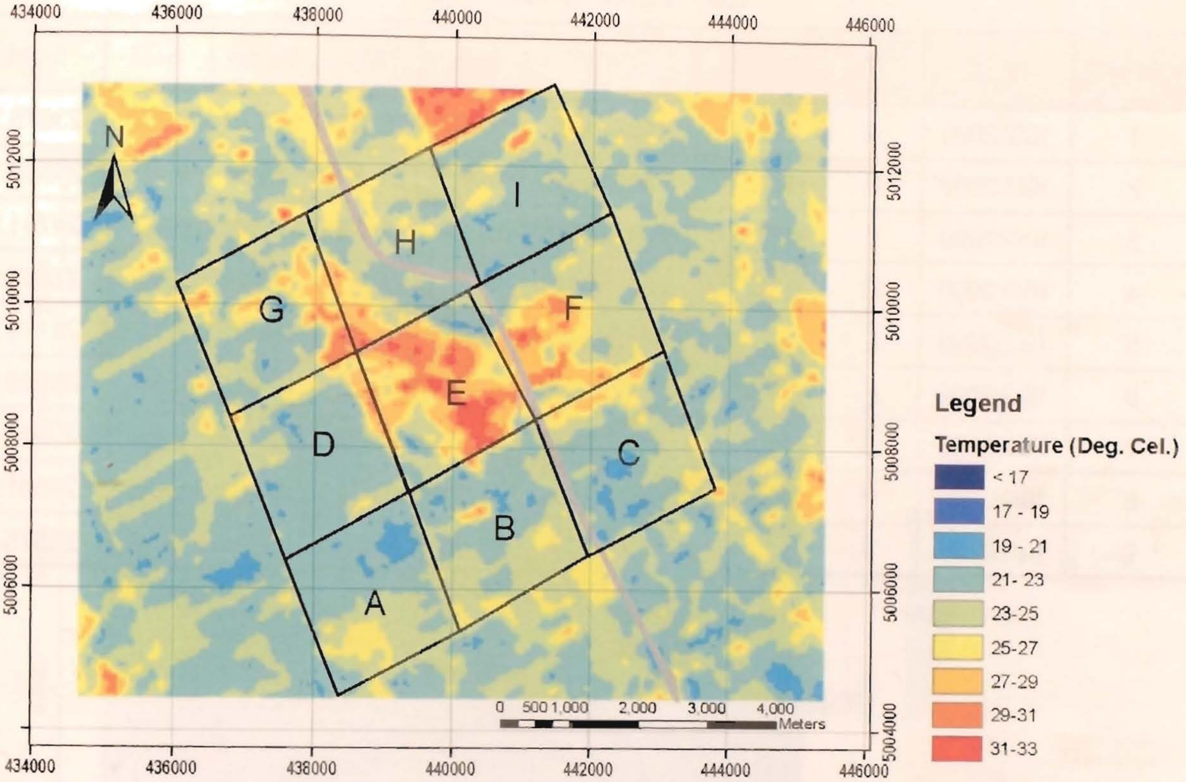


Figure 5.5 – LST on August 03, 1998

The highest LST indicated at this time was on the north side of area E, at 25.7 degrees Celsius, which is located directly on the landfill site. Additionally, the highest standard deviation is also accrued in area E amidst the landfill itself. The highest average LST value surface temperature also occurs at area E, at 19 degrees Celsius. Table 5.4 shows the summary of LST calculated for all nine divided areas at October 2000. LST values calculated for year 2000 indicates that the minimum and maximum LST value, highest average LST value, and standard deviation value all occurred in area E in the areas that are used for the landfill. This might be one of the negative effects of a landfill upon environment. These negative results could be caused by leachate leakage and contamination from the landfill.

LST YEAR 2000/10/2									
NUMBER	YEAR	TILE NAME	COUNT	AREA	MIN	MAX	MEAN	STD	SUM
1	10/2/2000	A	1272.0	4132730.0	16.981	22.725	18.770	0.871	23875.2
2	10/2/2000	B	1342.0	4360160.0	15.363	21.701	18.296	0.773	24553.5
3	10/2/2000	C	1338.0	4347160.0	16.444	21.186	18.499	0.863	24751.2
4	10/2/2000	D	1320.0	4288680.0	16.444	21.186	18.101	0.806	23893.6
5	10/2/2000	E	1263.0	4103490.0	12.615	25.746	19.092	2.186	24113.2
6	10/2/2000	F	1429.0	4642820.0	14.819	22.214	18.831	0.969	26910.1
7	10/2/2000	G	1292.0	4197710.0	14.819	22.725	18.246	1.196	23574.2
8	10/2/2000	H	1286.0	4178210.0	14.819	23.234	18.508	1.092	23801.0
9	10/2/2000	I	1299.0	4220450.0	14.819	21.701	18.380	1.009	23875.8

Table 5.4 - LST Calculated on October 02, 2000

5.2.1.4 Land Surface Temperature Value for Year 2001

Figure 5.7 shows the LST of the area collected on September 2001. The range of the LST is between -14 and 28 degrees Celsius. This image was taken during the Fall season, and the external temperature is commonly within the range of 17 to 23 degrees Celsius. Additionally, the activities of micro organism, animals and plants are less than in the spring and summer months, so therefore the lower temperature can be expected. The highest LST occurred at the north and centre of area E, at 28.2 degrees Celsius overtop of the landfill site. The highest average LST also accrued at area E, with 23.1 degrees Celsius. The reason for the -14 degrees Celsius LST at I area is unknown, and it may be a software error. The highest standard division is 8.9 degrees Celsius, which indicates unusual LST values in area F. Table 5.5 shows the summary of surface temperature calculated for all nine divided areas during September 2001.

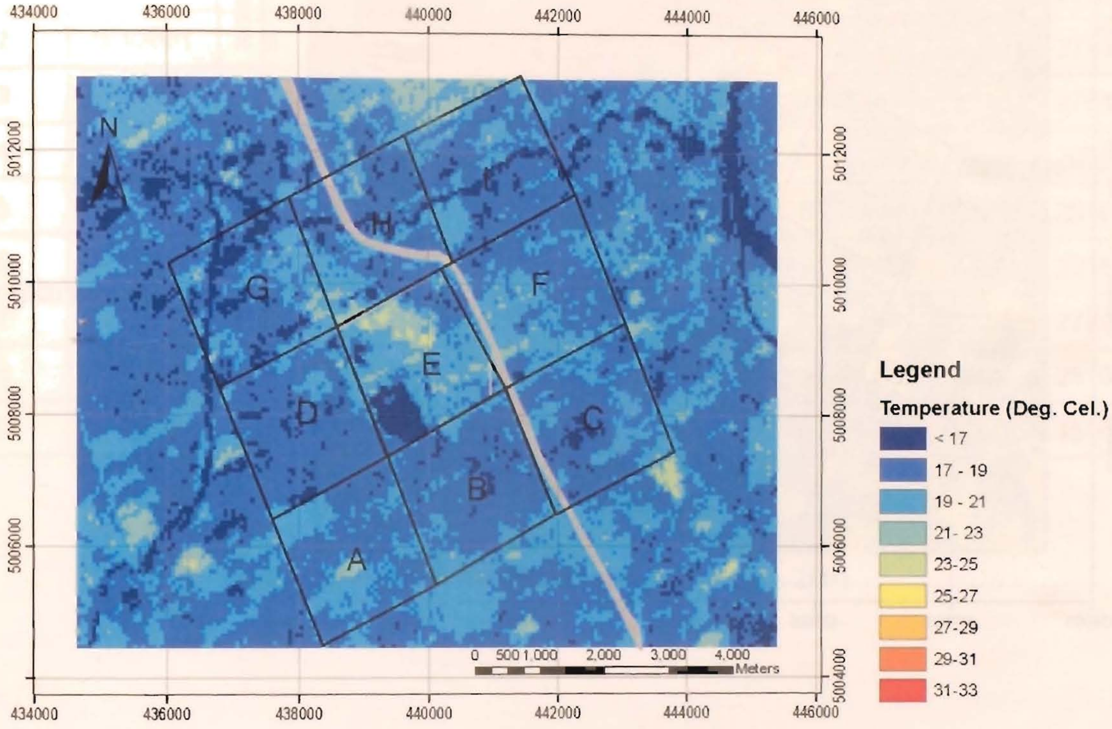


Figure 5.6 - LST on October 02, 2000

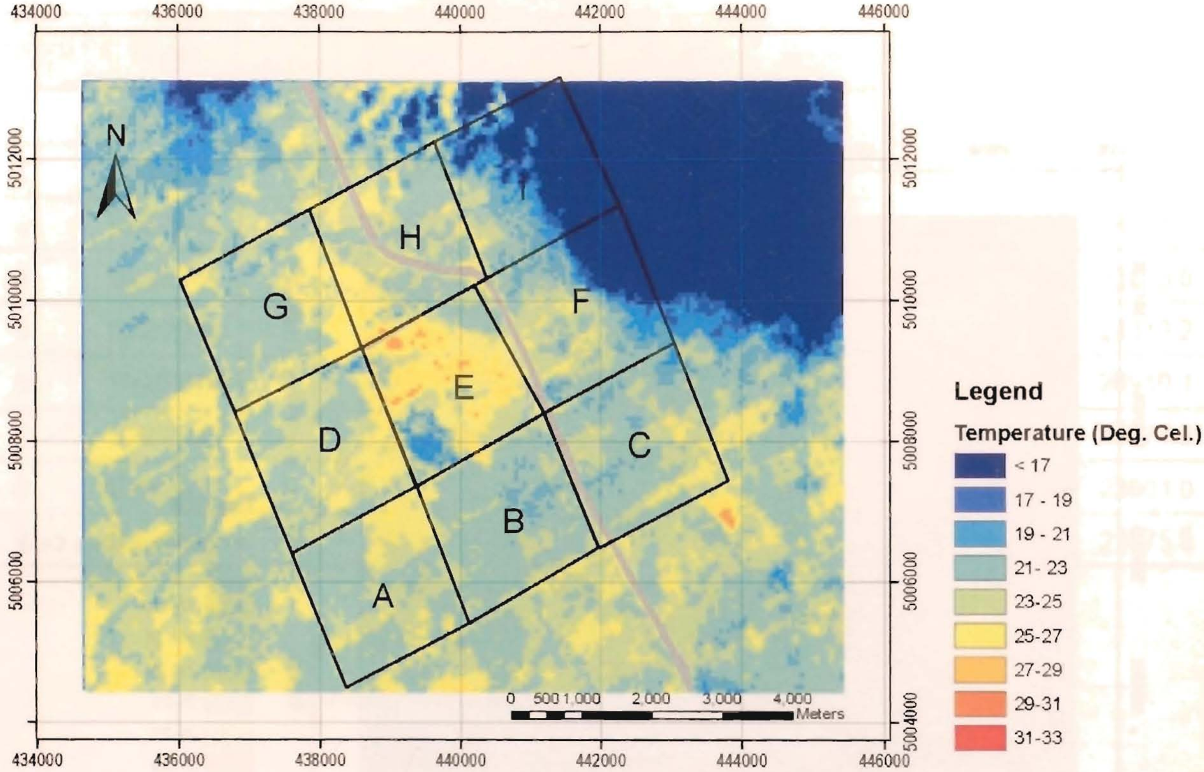


Figure 5.7 – LST on September 03, 2001

LST YEAR 2001/09/03

NUMBER	YEAR	TILE NAME	COUNT	AREA	MIN	MAX	MEAN	STD	SUM
1	9/3/2001	A	1272.0	4132730.0	19.102	25.247	21.536	1.349	27393.8
2	9/3/2001	B	1342.0	4360160.0	16.981	26.736	20.442	1.254	27432.5
3	9/3/2001	C	1338.0	4347160.0	15.363	25.247	20.814	1.555	27848.8
4	9/3/2001	D	1320.0	4288680.0	16.444	26.242	21.882	1.425	28884.7
5	9/3/2001	E	1263.0	4103490.0	16.444	28.208	23.095	2.566	29169.3
6	9/3/2001	F	1429.0	4642820.0	-13.221	24.747	16.202	8.860	23152.9
7	9/3/2001	G	1292.0	4197710.0	17.515	26.736	21.461	1.651	27727.4
8	9/3/2001	H	1286.0	4178210.0	14.819	27.229	21.899	1.670	28162.1
9	9/3/2001	I	1296.0	4210700.0	-14.684	23.740	11.703	8.226	15167.6

Table 5.5 - LST Calculated on September 03, 2001

5.2.2 Normalized Difference Vegetation Index Value

The Landsat TM and ETM+ images are multi-spectral bands with spatial resolution in 30m spatial resolution. For each of the multi-spectral images, the NDVI is calculated using equation 3.3 which was explained in chapter 3. This equation has been used by ERDAS IMAGINE software to calculate the NDVI values for all 9 areas at different years. Near Infrared (NIR) and Red band value (R) are recorded by the satellite sensor. An NDVI value calculated by the equation represents the health status of the plant. The NDVI value always ranges from -1 to +1. Additionally, the areas devoid of any vegetation give a negative value or a value close to zero. In other words, the higher the NDVI value the healthier the vegetation.

Although the health of a plant depends on several environmental factors, it is often found vegetation health depends on the availability of moisture for the root zone of the plants and healthy soil. Therefore these properties are connected directly to soil and groundwater condition and availability. This means that the healthy vegetations are grown on healthy soil and with uncontaminated water. NDVI values may be monitored in a seasonal and annual basis, and changes will show the effects of different environmental danger on vegetation, soil, water, wild life and humans in the area. The results are sometimes interrupted with multiplicative noise such as sun illumination differences, cloud shadows, some atmospheric attenuation, and some topographic variations, but the results are trustworthy. The reason for this is that several images are available at different times for several years. Therefore the comparison between the calculated results indicates their accuracy.

The following sections present the NDVI results of the landfill area at four different years. The NDVI values are within a range of -1 to +1, and the higher the value the healthier the vegetation. The different NDVI values are shown with different colors: the green and yellow are negative values, and orange and red represent of positive values. NDVI values that were calculated at different years are summarized in table 5.6 to 5.9. These tables indicate the maximum and minimum NDVI values calculated for each tile. Average NDVI value and standard Deviation value is also shown on each of the tables. Standard Deviation (STD) value indicates the amplitude of the difference between each calculated value with Mean NDVI value for each tile. Low STD value means most of calculated NDVI values are in the same range. The last column on the summary tables show that the SUM that is indicated add up to the value of all NDVI values calculated in each tile.

5.2.2.1 Normalized Difference Vegetation Index Value for Year 1992

The NDVI values calculated for May 1992 are shown in Figure 5.8. Table 5.6 shows the summary of calculated NDVI values for all nine divided areas in May 1992. This image was taken during the spring, when the vegetation has started growing new leaves and branches. The lowest NDVI, which is the unhealthiest vegetation, occurred in area E, amidst the landfill site, with a NDVI value of -0.4. Figure 5.8 shows that the lowest NDVI values calculated at stage 3 and 4 of Trial Road landfill, and all of the Nepean Landfill. However, the lowest NDVI average happened in area D with a value of 0.1. This average value means that the vegetations are in normal condition within the general area.

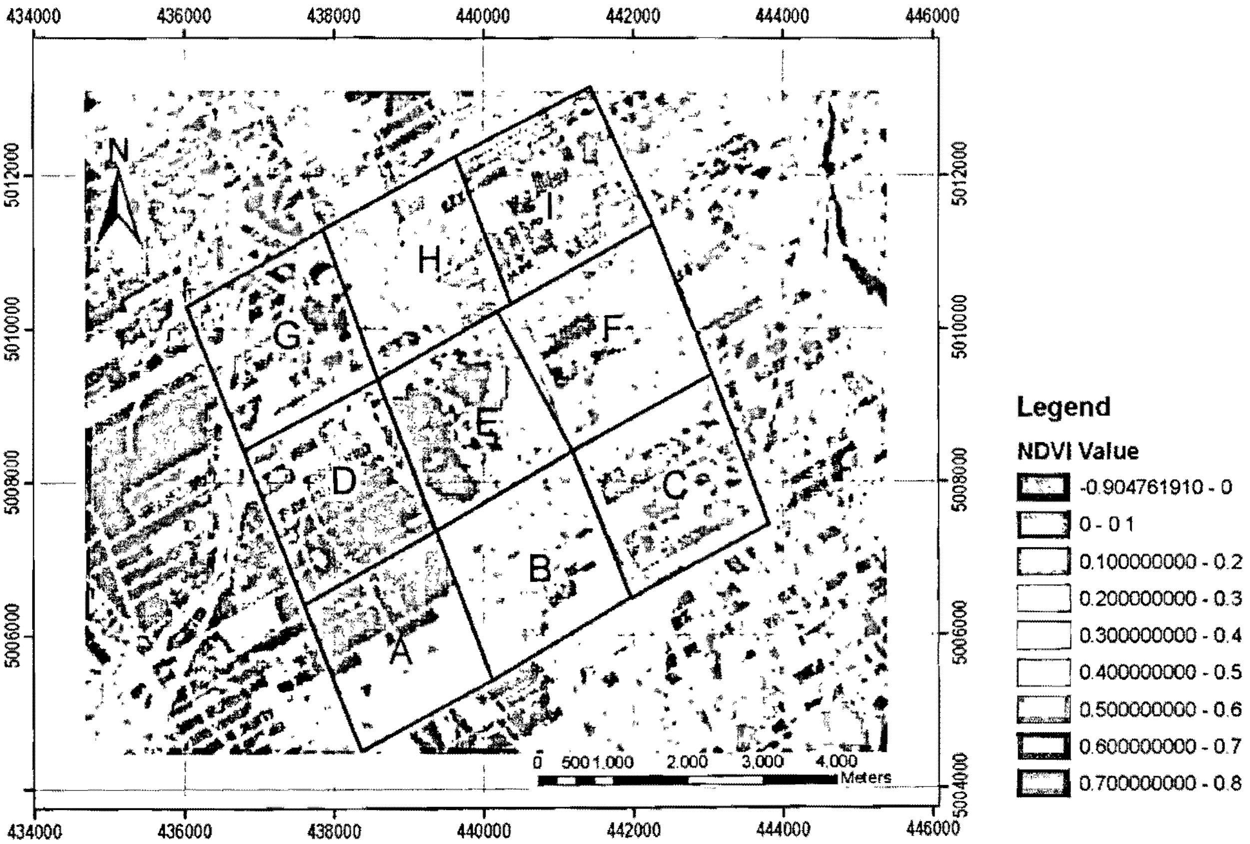


Figure 5.8 - Calculated NDVI Values on May 29, 1992

taken during the spring, when the vegetation has started growing new leaves and branches. The lowest NDVI, which is the unhealthiest vegetation, occurred in area E, amidst the landfill site, with a NDVI value of -0.4. Figure 5.8 shows that the lowest NDVI values calculated at stage 3 and 4 of Trial Road landfill, and all of the Nepean Landfill. However, the lowest NDVI average happened in area D with a value of 0.1. This average value means that the vegetations are in normal condition within the general area.

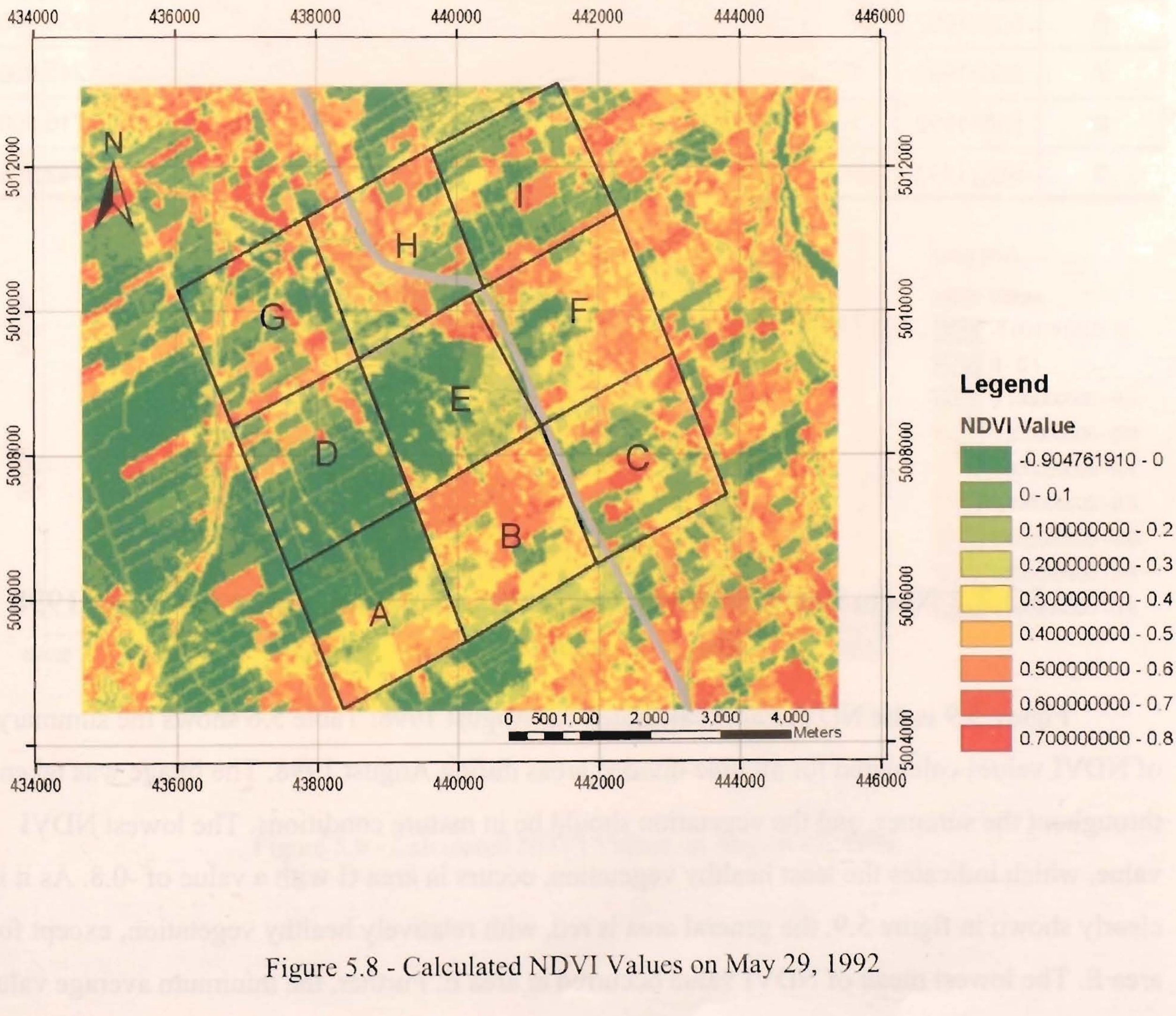


Figure 5.8 - Calculated NDVI Values on May 29, 1992

NDVI YEAR 1992/05/29

NUMBER	YEAR	TILE NAME	COUNT	AREA	MIN	MAX	MEAN	STD	SUM
1	5/29/1992	A	5087.0	4131920.0	-0.057	0.610	0.192	0.194	978.323
2	5/29/1992	B	5367.0	4359350.0	-0.041	0.641	0.394	0.145	2114.950
3	5/29/1992	C	5349.0	4344730.0	-0.084	0.705	0.288	0.201	1538.550
4	5/29/1992	D	5281.0	4289490.0	-0.188	0.632	0.114	0.173	604.428
5	5/29/1992	E	5061.0	4110800.0	-0.381	0.642	0.135	0.208	682.547
6	5/29/1992	F	5720.0	4646070.0	-0.119	0.634	0.341	0.172	1951.510
7	5/29/1992	G	5178.0	4205830.0	-0.240	0.718	0.240	0.210	1245.050
8	5/29/1992	H	5143.0	4177400.0	-0.182	0.641	0.334	0.190	1716.690
9	5/29/1992	I	5187.0	4213140.0	-0.149	0.654	0.220	0.213	1142.900

Table 5.6 - Calculated NDVI Value on May 29, 1992

5.2.2.2 Normalized Difference Vegetation Index Value for Year 1998

Figure 5.9 is the NDVI value calculated for August 1998. Table 5.6 shows the summary of NDVI values calculated for all nine divided areas during August 1998. The image was taken throughout the summer, and the vegetation should be in mature conditions. The lowest NDVI value, which indicates the least healthy vegetation, occurs in area G with a value of -0.8. As it is clearly shown in figure 5.9, the general area is red, with relatively healthy vegetation, except for area E. The lowest mean of NDVI value occurred at area E. Further, the minimum average value that was recorded in area E is higher than zero, which means that the vegetation is still within healthy NDVI range for the whole area.

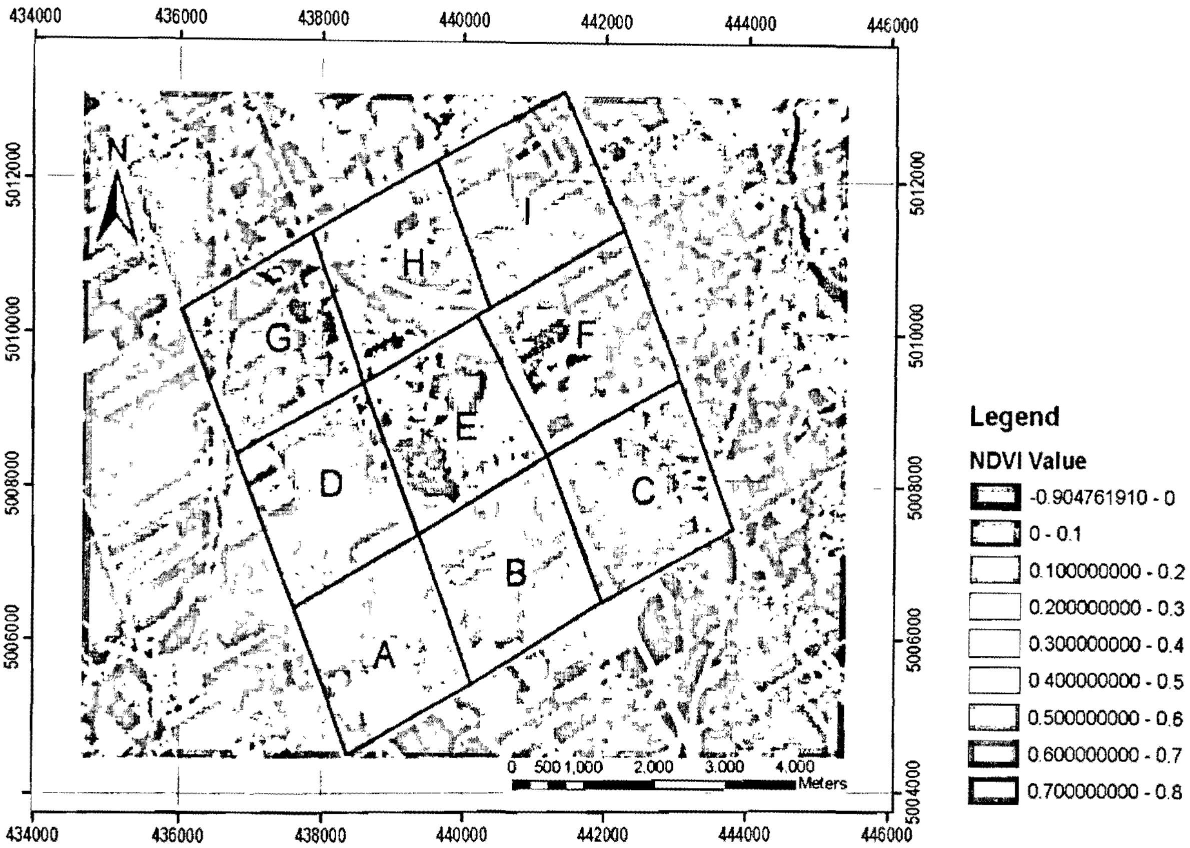


Figure 5.9 - Calculated NDVI Values on August 03, 1998

that was recorded in area E is higher than zero, which means that the vegetation is still within healthy NDVI range for the whole area.

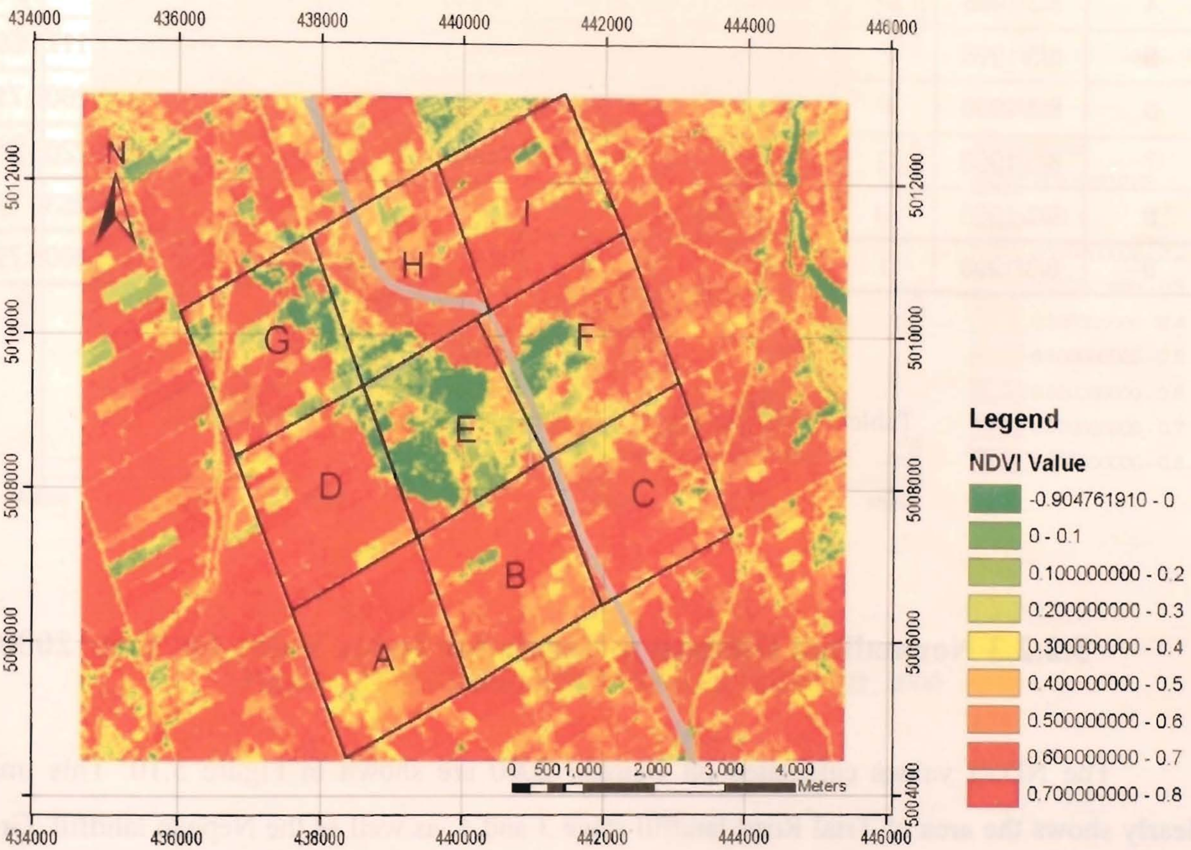


Figure 5.9 - Calculated NDVI Values on August 03, 1998

NDVI YEAR 1998/08/03									
NUMBER	YEAR	TILE NAME	COUNT	AREA	MIN	MAX	MEAN	STD	SUM
1	8/3/1998	A	5087.0	4131920.0	0.074	0.803	0.604	0.127	3070.040
2	8/3/1998	B	5367.0	4359350.0	-0.046	0.748	0.564	0.122	3026.540
3	8/3/1998	C	5349.0	4344730.0	-0.143	0.799	0.565	0.137	3024.360
4	8/3/1998	D	5281.0	4289490.0	-0.200	0.794	0.574	0.178	3033.710
5	8/3/1998	E	5061.0	4110800.0	-0.632	0.741	0.231	0.265	1171.560
6	8/3/1998	F	5720.0	4646070.0	-0.250	0.748	0.456	0.202	2606.710
7	8/3/1998	G	5178.0	4205830.0	-0.800	0.789	0.437	0.241	2263.960
8	8/3/1998	H	5143.0	4177400.0	-0.647	0.789	0.492	0.188	2530.120
9	8/3/1998	I	5187.0	4213140.0	-0.778	0.768	0.580	0.154	3006.790

Table 5.7 - Calculated NDVI Value on August 03, 1998

5.2.2.3 Normalized Difference Vegetation Index Value for Year 2000

The NDVI values calculated on October 2000 are shown in Figure 5.10. This image clearly shows the area of Trial Road landfill stage 3 and 4, as well as the Nepean landfill. Green color in Figure 5.10 shows the landfill and its area have a low NDVI value. The general calculated NDVI for the entire area is low. One of the reasons for this might be the Fall season. All the vegetation is usually in their final stage of life. The range of the NDVI value is between -0.5 and 0.6. The lowest NDVI, indicating the least healthy vegetation, occurred in area E at value of -0.5. Although the lowest mean NDVI occurred at area A, still the worst vegetation area is the landfill site within area E. The minimum average value is still higher than zero, indicating that the vegetation is generally in normal health levels.

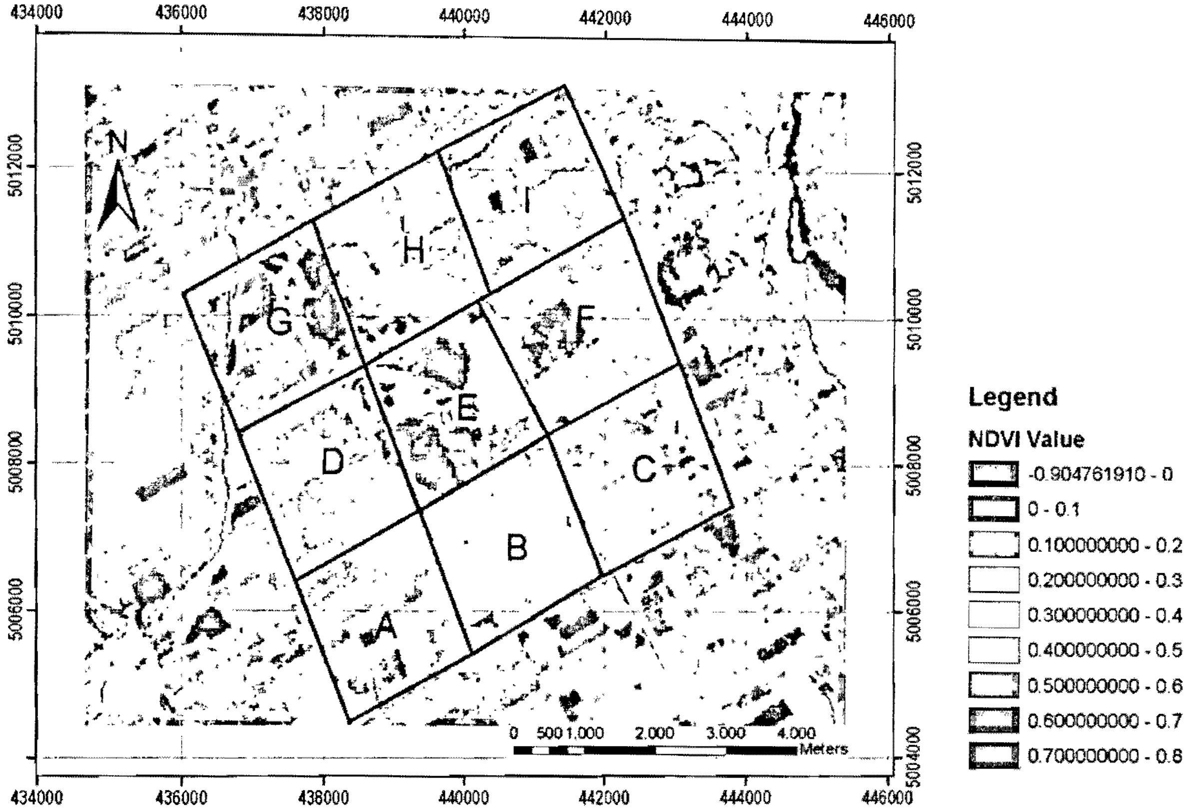


Figure 5.10 - Calculated NDVI Values on October 02, 2000

Table 5.8 shows the summary of NDVI values calculated for all nine divided areas on October 2000.

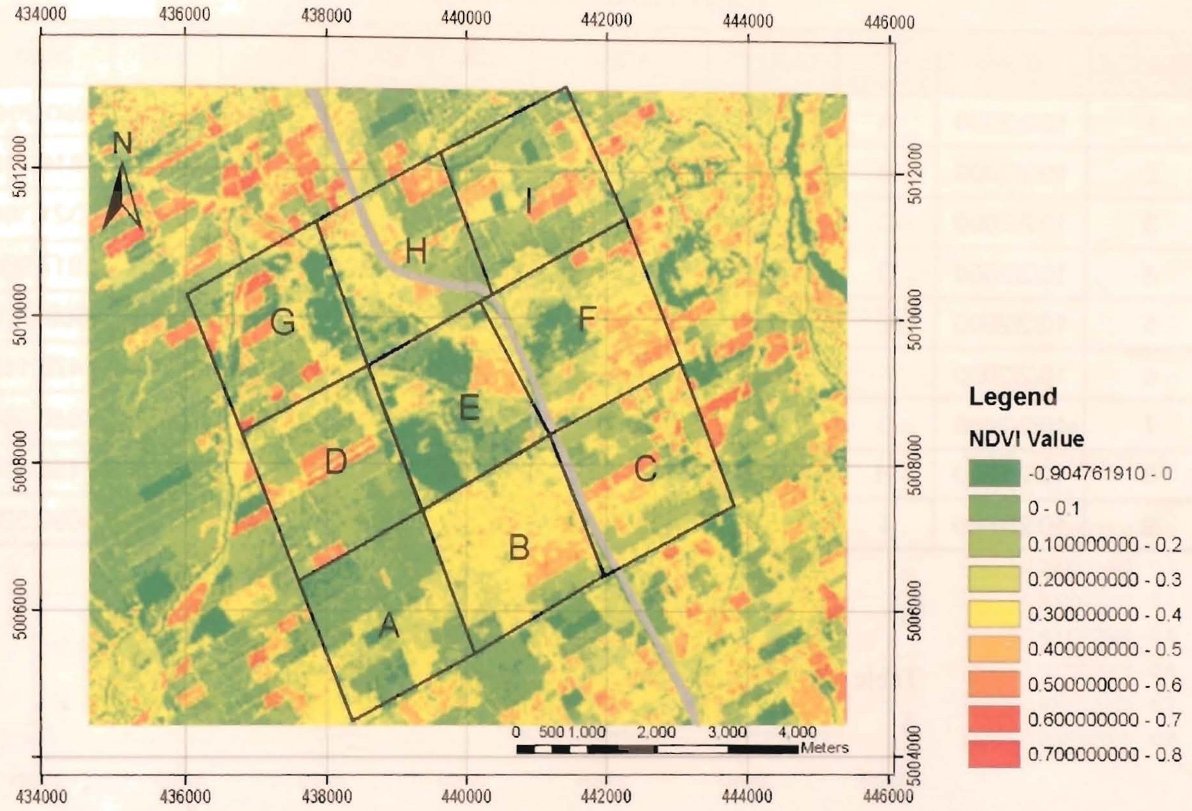


Figure 5.10 - Calculated NDVI Values on October 02, 2000

Table 5.8 shows the summary of NDVI values calculated for all nine divided areas on October 2000.

NDVI YEAR 2000/10/2									
NUMBER	YEAR	TILE NAME	COUNT	AREA	MIN	MAX	MEAN	STD	SUM
1	10/2/2000	A	5087.0	4131920.0	-0.118	0.536	0.136	0.111	690.204
2	10/2/2000	B	5367.0	4359350.0	-0.178	0.564	0.302	0.104	1619.710
3	10/2/2000	C	5349.0	4344730.0	-0.139	0.629	0.247	0.137	1321.360
4	10/2/2000	D	5281.0	4289490.0	-0.356	0.660	0.193	0.145	1017.960
5	10/2/2000	E	5061.0	4110800.0	-0.532	0.529	0.119	0.203	600.951
6	10/2/2000	F	5720.0	4646070.0	-0.434	0.626	0.258	0.157	1478.110
7	10/2/2000	G	5178.0	4205830.0	-0.414	0.667	0.202	0.197	1046.580
8	10/2/2000	H	5143.0	4177400.0	-0.451	0.650	0.225	0.150	1158.440
9	10/2/2000	I	5182.0	4209080.0	-0.296	0.604	0.210	0.156	1090.520

Table 5.8 - Calculated NDVI Value on October 02, 2000

5.2.2.4 Normalized Difference Vegetation Index Value for Year 2001

The NDVI value calculated on September 2001 is displayed in Figure 5.11. This image visually illustrates the conditions of the vegetation at the landfill site. It is quite clear that the calculated NDVI value of the landfill is in the negative range. The low NDVI values indicate that the vegetation within the landfill area is not in a healthy condition. The general calculated NDVI values are also in low range. All the vegetation is almost at their final stages of life during the Fall season. The range of the NDVI value is between -0.7 and 0.6. The lowest NDVI value, displaying the least healthy vegetation, occurred at area E, with value of -0.68, throughout the landfill site. The lowest mean clearly occurred at area E, with a NDVI value of -0.05.

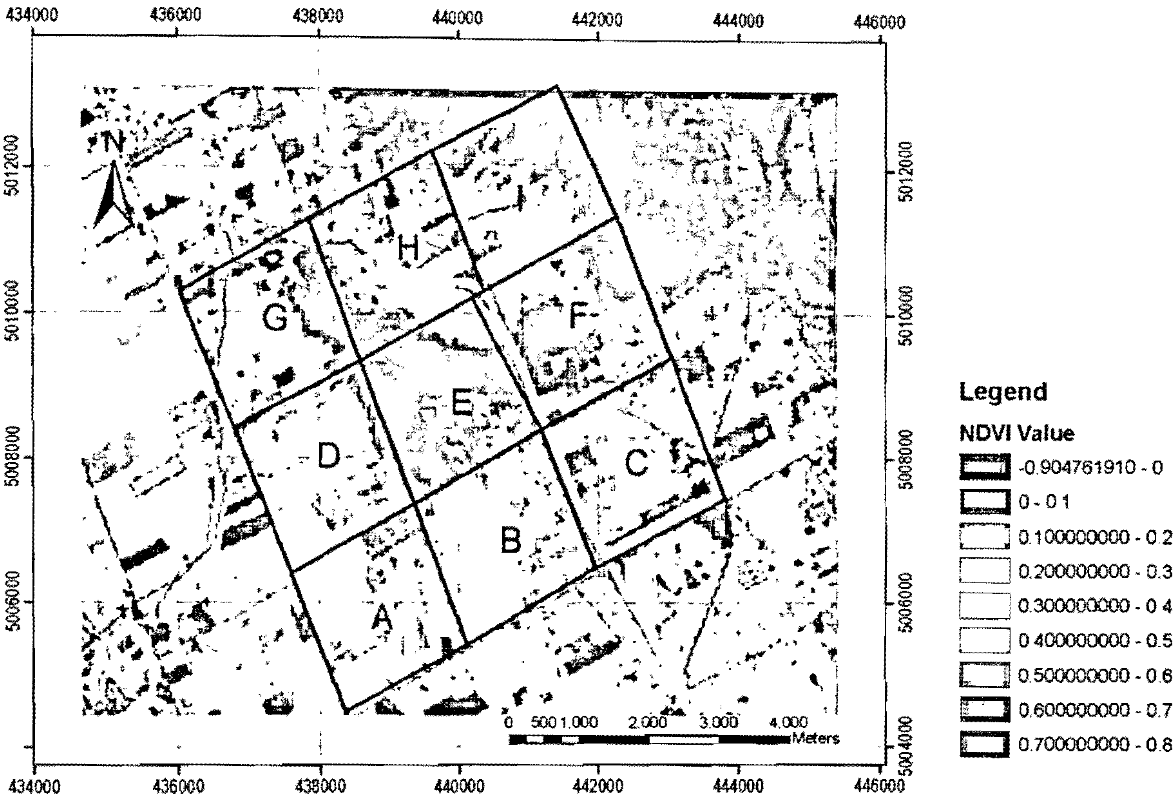


Figure 5.11 - Calculated NDVI Values on September 03, 2001

Table 5.9 shows the summary of NDVI values calculated for all nine divided areas at September 2001.

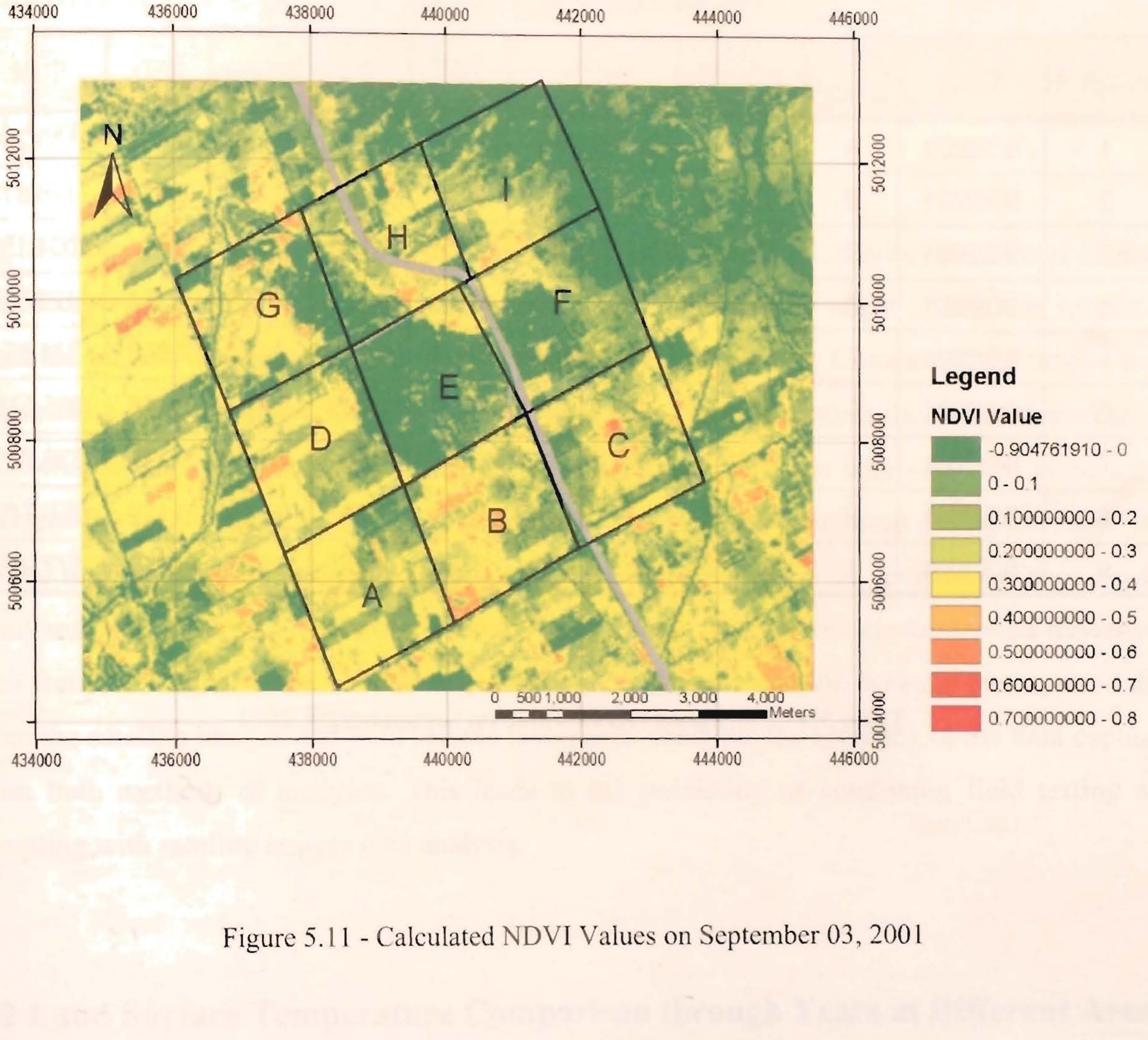


Figure 5.11 - Calculated NDVI Values on September 03, 2001

Table 5.9 shows the summary of NDVI values calculated for all nine divided areas at September 2001.

NDVI YEAR 2001/09/03									
NUMBER	YEAR	TILE NAME	COUNT	AREA	MIN	MAX	MEAN	STD	SUM
1	9/3/2001	A	5087.0	4131920.0	-0.287	0.547	0.222	0.134	1130.240
2	9/3/2001	B	5367.0	4359350.0	-0.310	0.556	0.257	0.140	1376.810
3	9/3/2001	C	5349.0	4344730.0	-0.338	0.569	0.188	0.161	1004.150
4	9/3/2001	D	5281.0	4289490.0	-0.393	0.522	0.213	0.154	1123.510
5	9/3/2001	E	5061.0	4110800.0	-0.689	0.475	-0.054	0.203	-274.864
6	9/3/2001	F	5720.0	4646070.0	-0.424	0.463	0.050	0.165	285.175
7	9/3/2001	G	5178.0	4205830.0	-0.614	0.556	0.142	0.225	736.775
8	9/3/2001	H	5143.0	4177400.0	-0.531	0.527	0.146	0.179	750.749
9	9/3/2001	I	5182.0	4209080.0	-0.235	0.471	0.073	0.159	377.925

Table 5.9 - Calculated NDVI Value on September 03, 2001

Chapter 6 : ANALYZED DATA COMPARISON

6.1 General

Comparing LST and NDVI values from different years indicates environmental changes that occurred throughout those years. These changes might be the result of leachate migration from the landfill through soil, water, ground water, and vegetation. Comparing the results from the satellite image analysis with the data captured from the site confirm the contaminated areas. This chapter includes three different types of comparison between data sets. The comparison between the results captured from satellite image analysis at different areas during the same year shows the potentially contaminated area around the landfill site. The comparison between the analyzed satellite image data from different years shows the possible contamination movement area from the landfill to the surrounding environment. The comparison between the captured data from the satellite images and field sample test results confirms the accuracy of the data captured from both methods of analyses. This leads to the possibility of combining field testing and sampling with satellite images data analysis.

6.2 Land Surface Temperature Comparison through Years at Different Areas

Higher LST means more heat on the surface level. Higher temperatures are equal to more micro-organisms and bacterial movements, more insects and worms. Heat, methane gas and leachate are the result of the composting process. Composting is a natural process which breaks down the organic material through the interaction with micro-organisms. More composting equates to more methane gas, pollution and contamination. Higher LST means less vegetation and lower environment conditions. Table 6.1 shows the LST comparison at different years. The landfill site had generally higher LST at years 2000 and 2001. High LST might be the result of several factors. Air and surface water temperature are the most important effects on LST changes. Vegetation is another example for the changes that influence LST.

Table 6.1 shows the LST summary and the areas with maximum temperature. Each row of the table represents the maximum LST for a different year. Date, tile name, and the area of the tiles have been indicated, and count column is representing the number of times LST have been calculated for each tile. Min and Max columns represent the minimum and maximum LST for each specific tile. Mean is the average LST value calculated for each tile. Standard Deviation (STD) shows the difference between each individual LST value with the mean value. The higher STD value shows that the area has variable LST values. Area E was the highest LST for the years 2000 and 2001. As it has been shown in Figure 5.1, area F is located to the east of area E, and area H is located to the north of area E. Therefore, it indicates activities are at the landfill area and the immediate vicinity. The hottest spot in year 1992 is located to the south east of area H, and is very close to area E. The north east corner of area E has the lowest elevation within area E. The slope of the ground is towards the north east corner of area E, south east corner of the area H, and west and north west of area F. These are the areas that have the maximum LST during different years.

LST COMPARISON AT GENERAL AREA

DATE	TILE NAME	COUNT	AREA	MIN	MAX	MEAN	STD	SUM
5/29/1992	H	5143.0	4177400.0	15.576	32.758	21.845	3.021	112346.0
8/3/1998	F	5720.0	4646070.0	20.984	31.951	25.049	2.212	143282.0
10/2/2000	E	1263.0	4103490.0	12.615	25.746	19.092	2.186	24113.2
9/3/2001	E	1263.0	4103490.0	16.444	28.208	23.095	2.566	29169.3

Table 6.1 - LST Comparison at General Study Area

Elevation is an important contributing factor to transfer the leachate and contamination. Usually leachate and pollution move from upstream to downstream through underground water and ground elevation. According to Table 6.3, regarding the elevation of the top right of area D, the top left of the area E, and bottom left of area H have the highest elevation. Pollution and contamination are not able to pass this point. Most of the contaminations are going to stay in the middle of area E or move towards north, north east and east of area E. The LST and NDVI values that have been calculated in chapter 5 verify this statement.

6.3 Land Surface Temperature Comparison at Landfill Area

Micro-organisms and bacteria mostly survive at a temperature between 0 to 40 degrees Celsius. The proportion of worms and bacteria is directly related to the temperature, and a large bacterial population may cause temperatures change. This might explain the higher temperature throughout area E in general. Methane gas caused by landfill activities is another important factor for increasing LST. The maximum temperature occurred at August 1998, and the air temperature might be a contributing factor for the higher LST. As shown in Figure 5.5 the highest LST occurred underneath of the landfill cell areas, that is area E, or on the north part of Trail Road landfill area. The highest LST at landfill area occurred during the year 1998. Table 6.2 demonstrates the landfill LST calculated from different years that indicates that during 1998 the landfill site had the highest LST over the recorded time period.

Figure 5.5 indicates that the landfill area is clearly warmer than the rest of the areas. Therefore it explains some of the activities to posit the cause as sources of heat underneath of the landfill. Composting is a biological process which breaks down organic material through the activities of micro-organisms. The decomposition process elevates temperatures, the production of carbon dioxide, water, and leachate. Heat generated by the composting process has a strong effect on LST at the landfill location. Raising temperature is harmful for the environment, especially the vegetation surrounding area E. Micro-organisms' activities and movements are not necessary harmful. It is simply the process of composting wastes beneath the soil. But high temperatures could be harmful for vegetation in the area and may in fact cause damage to the plant life.

LST COMPARISON AT LANDFILL AREA

DATE	TILE NAME	COUNT	AREA	MIN	MAX	MEAN	STD	SUM
5/29/1992	E	5061.0	4110800.0	12.775	31.546	24.317	3.988	123069.0
8/3/1998	E	5061.0	4110800.0	20.543	35.544	27.144	2.861	137376.0
10/2/2000	E	1263.0	4103490.0	12.615	25.746	19.092	2.186	24113.2
9/3/2001	E	1263.0	4103490.0	16.444	28.208	23.095	2.566	29169.3

Table 6.2 - LST Comparison at Landfill Site

Landfill's Divided Areas Elevation		
Area	Corner	Elevation (m)
A	Top Left	93
	Top Right	95
	Bottom Right	92
	Bottom Left	94
B	Top Left	95
	Top Right	99
	Bottom Right	93
	Bottom Left	92
C	Top Left	99
	Top Right	97
	Bottom Right	98
	Bottom Left	93
D	Top Left	93
	Top Right	104
	Bottom Right	95
	Bottom Left	93
E	Top Left	104
	Top Right	93
	Bottom Right	99
	Bottom Left	95
F	Top Left	93
	Top Right	92
	Bottom Right	97
	Bottom Left	99
G	Top Left	94
	Top Right	93
	Bottom Right	104
	Bottom Left	93
H	Top Left	93
	Top Right	91
	Bottom Right	93
	Bottom Left	104
I	Top Left	91
	Top Right	99
	Bottom Right	92
	Bottom Left	93

Table 6.3 - Study Areas Elevations

6.4 Normalized Difference Vegetation Index Value Comparison at General Study Area

NDVI value is used for assessing the type, extent, and condition of vegetation over an area. Researchers use data captured from Landsat and other satellite's images to locate vegetation that is heavily impacted by natural or stresses caused by humans such as pesticides, fire, disease or pollution, and to delimit boundaries between such areas as wetlands or old growth forests. These sets of data, when taken over regular intervals of time and compared to one another, can help one understand how vegetation changes over time. Comparing the calculated NDVI value for Trail Road landfill and its area over time shows the changes of the vegetation's condition.

The lower the NDVI value, the poorer the vegetation's condition is. Table 6.4 confirms that the lowest value occurred in area E, except during August 1998, when it was supplanted by area G. Figure 5.9 shows that the area that has the lower NDVI value is located at east of area G and does not have any vegetation, therefore the NDVI value is low. Area E has the lowest NDVI value which means the lowest mean is consisting occurring within area E. This validates the hypothesis that area E does not have healthy vegetation.

NDVI COMPARISON AT GENERAL AREA								
DATE	TILE NAME	COUNT	AREA	MIN	MAX	MEAN	STD	SUM
5/29/1992	E	5061.0	4110800.0	-0.381	0.642	0.135	0.208	682.547
8/3/1998	G	5178.0	4205830.0	-0.800	0.789	0.437	0.241	2263.960
10/2/2000	E	5061.0	4110800.0	-0.532	0.529	0.119	0.203	600.951
9/3/2001	E	5061.0	4110800.0	-0.689	0.475	-0.054	0.203	-274.864

Table 6.4 - NDVI Value Comparison at General Study Area

6.5 Normalized Difference Vegetation Index Value Comparison at Landfill Area

Comparing the NDVI value at area E between different years shows that the NDVI value decreased as time elapsed. Further, we can conclude there were some condition changes in the vegetation through time. Figure 5.11 shows almost all the landfill area has the same NDVI value on year 2001. The landfill boundaries are very clear on this image. Therefore, the landfill and its area's vegetation are not healthy. Table 6.5 shows the NDVI value calculated for the landfill site at different years. The highlighted area shows that the lowest NDVI value occurred on year 2001.

NDVI COMPARISON AT LANDFILL AREA								
DATE	TILE NAME	COUNT	AREA	MIN	MAX	MEAN	STD	SUM
5/29/1992	E	5061.0	4110800.0	-0.381	0.642	0.135	0.208	682.547
8/3/1998	E	5061.0	4110800.0	-0.632	0.741	0.231	0.265	1171.560
10/2/2000	E	5061.0	4110800.0	-0.532	0.529	0.119	0.203	600.951
9/3/2001	E	5061.0	4110800.0	-0.689	0.475	-0.054	0.203	-274.864

Table 6.5 - NDVI Value Comparison at Landfill Area

Figure 5.11 shows the low NDVI value calculated for typical urban areas, such as city properties, roads and landfill area that correlates with area E, the south east and south west of area G, H and east of area F. NDVI values calculated within urban areas are always low because of the roads and houses which impede the growth of enough vegetation or healthy vegetation to produce higher NDVI values. One of the central reasons for pollution under the landfill is leachate leakage through soil and water in the area. These actions have negative effects on the vegetation within the landfill site. Therefore vegetation analysis may be the good source to draw upon in order to find polluted areas around landfills. To find out the accuracy of the satellite images' data a comparison between actual data taken from the site sampling and data obtained from the satellite images was performed.

6.6 Landfill Leachate Influence on Study Area

Leachate leakage is one of the most prominent causes polluting the environment around the landfill especially around the older landfills with none or poor bottom liner system. The leakage at Trail Road Landfill could be through the geomembrane liner from stage 3 and 4 of Trail Road landfill. However, the higher contamination possibility is from stage 1 and 2 of Trail Road Landfill and Nepean landfill due to the lack of bottom liner and the ground water flow pattern. Monitoring wells are used to determine the influence leachate has upon an area. The locations of monitoring wells are chosen relative to leachate contamination sources.

The leachate influence is being monitored on groundwater, surface water and soil through sampling from the monitoring wells. Also, non-landfill contamination sources such as road salt, fertilizer have been tested. Water quality is tested for the Trial Road Landfill site on an annual basis, according to O. Reg. 232/98 (MOE standard, April 2004). Groundwater monitoring data for the last five years describes groundwater unaffected by landfill leachate influences. This is the result of the water quality background but quantifying the true background values is difficult in this setting. This is because of the presence of a silty clay unit at the bottom of the landfill sites; it is difficult to access up-gradient groundwater quality in the face of the relatively long history of waste disposal activities on this site. Leachate samples are collected from the leachate pumping station at the leachate sampling tap. Further, leachate samples are not filtered. The leachate impact is measured and complies with Guideline B-7 (MOE standard, April 2004).

The results of the samples from groundwater are characterized as weak to moderate with some parameters being more concentrated at some locations. Since contamination moves with gravity through ground elevation with ground water movement, it is possible to track the leachate expansion. Figure 6.1 shows the flow direction of the landfill. It helps to understand the contamination movements. Groundwater flow in the shallow aquifer is generally northwards from the northern portion of the Trail landfill. The availability of clay and the elevation of the area that is shown in Figure 6.1 are the results of the pattern of the flow's direction. The shallow aquifer discharges gradually as seepage through the Cedar Forest area, where the ground surface elevation drops to the north towards Cambrian Road. Therefore, the pollution progress through the landfill is as follows.

6.6.1 Contamination at North Part of the Landfill

North of Trail Road landfill is located at northern margin of Stages 1, 2, 3 and 4 of the Trail Road Landfill up to Highway 416 and Cambrian Road, which has been shown in Figure 4.3. Leachate influences to the groundwater at the site generally occur to the north of the landfill area with respect to groundwater flow. Off-site migration of groundwater might be influenced by leachate from the landfill. Although the groundwater migration northwards in the shallow aquifer is limited, because the aquifer pinches out through the Cedar Forest area. Figure 6.1 shows the ground water movements clearly, the ground water movement indicates the direction of leachate and contamination expansion. It is noted that the clay aquifer underlies the northern portions of Stages 1 and 2, therefore leachate influences to the deep aquifer in this area would only be expected within the western portions of the discussion area, since groundwater flows in a west to northwest direction towards the Dewatering Pond (Dillon, 2006).

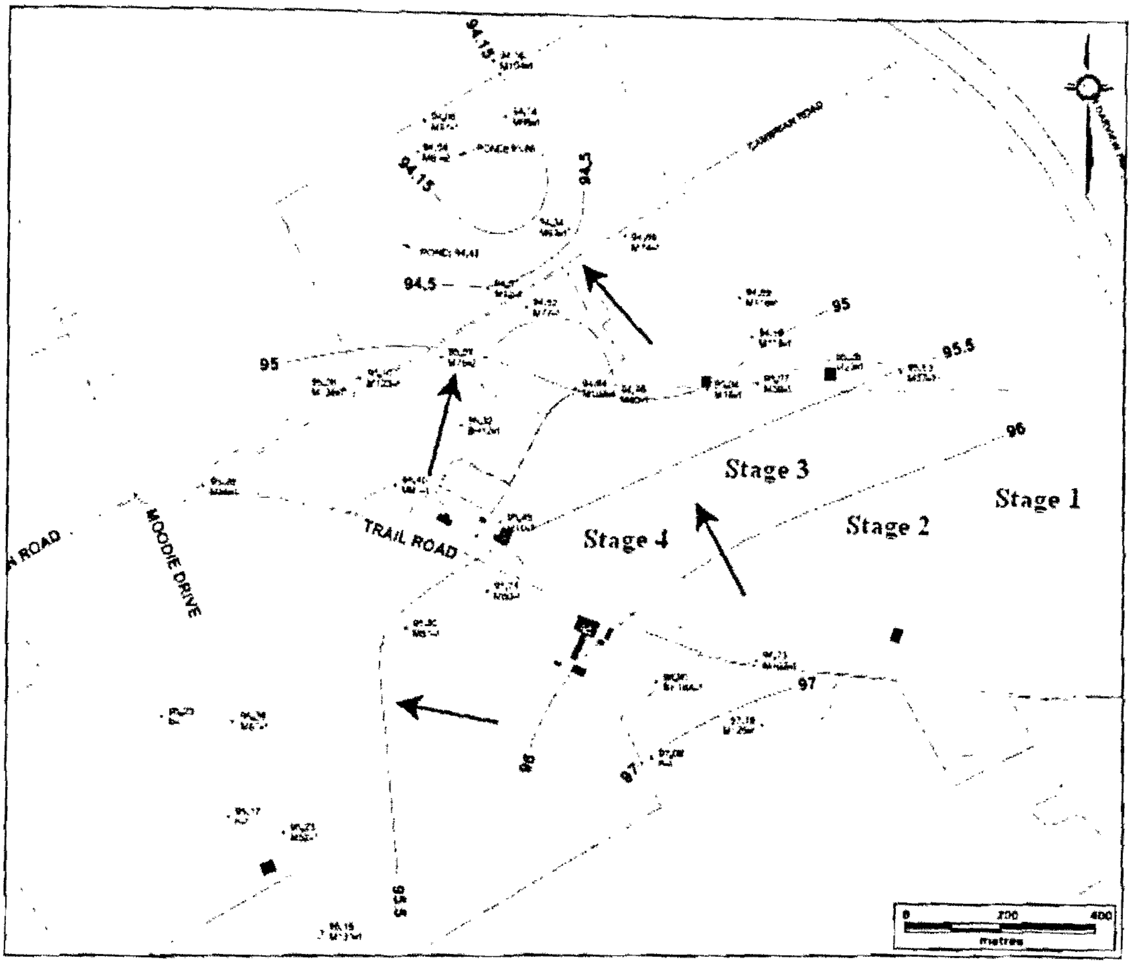
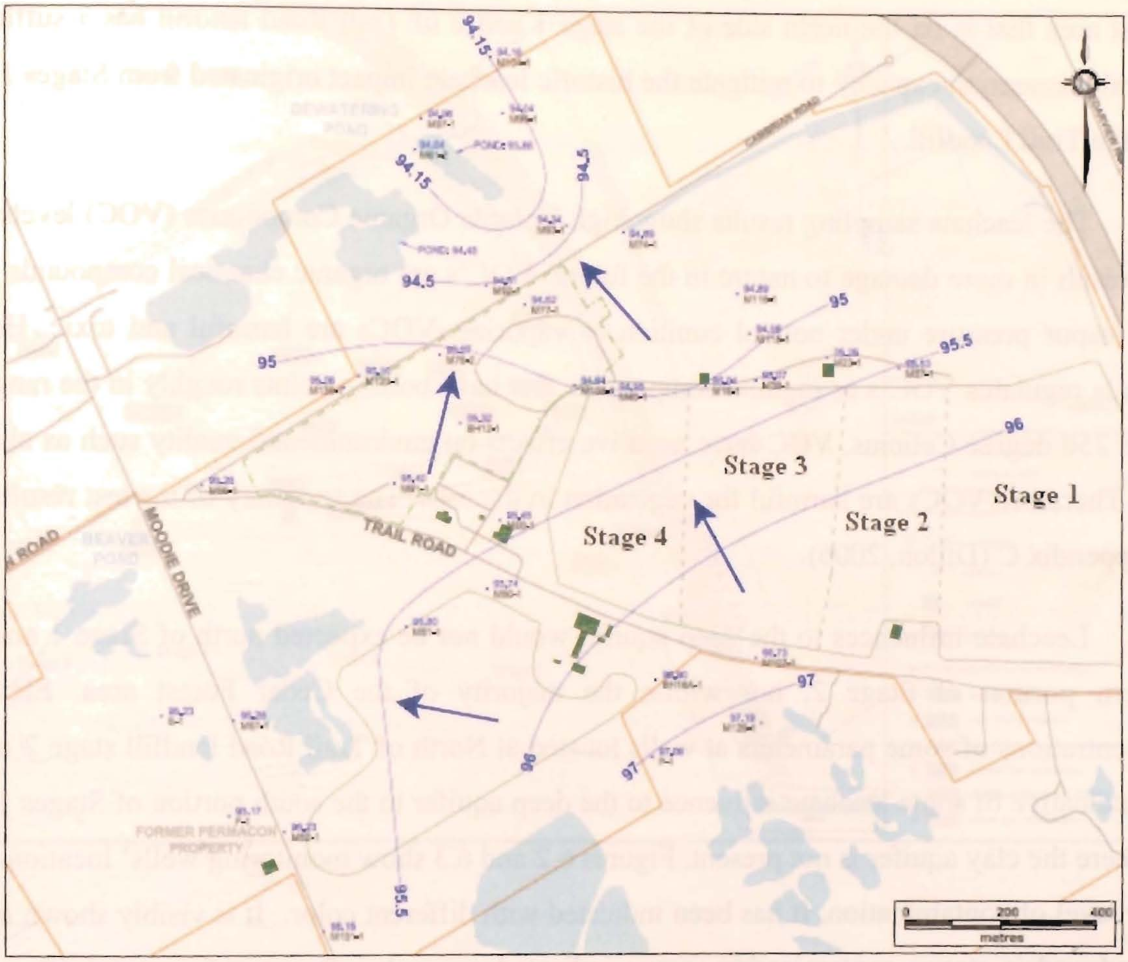


Figure 6.1 - Landfill Flow Directions

(Dillon, 2006)

The general pattern of the groundwater flow is in the north to north west direction. To capture the impact of leachate upon the groundwater migrating beyond the site boundaries, samples were taken from outside of the landfill. The results of this sampling were very similar. Elevated concentrations of boron and toluene were observed at 90-7-1, located at north of Trail Road landfill stage 1 or north east of area E. This location was found to be isolated and the Cedar



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Forest area that is on the north side of the stage 1 and 2 of Trail Road landfill has a sufficient natural attenuation capacity to mitigate the historic leachate impact originated from Stages 1 and 2 of the Trail Landfill.

The leachate sampling results show high Volatile Organic Compounds (VOC) levels that will result in more damage to nature in the future. VOC's are organic chemical compounds with high vapor pressure under normal conition to vaporize. VOCs are harmful and toxic. Health Canada regulates VOC's as organic componants that have boiling points roughly in the range of 50 to 250 degree Celicius. VOC have negative effects on environmental quality such as air and soil. Therefore VOCs are harmful for vegetation in the area. The summary of the test results are in Appendix C (Dillon, 2006).

Leachate influences to the deep aquifer would not be expected north of Stage 1 and the eastern portion of Stage 2, nor within the majority of the Cedar Forest area. Elevated concentrations of some parameters at wells located at North of Trail Road landfill stage 2 and 3 are indicative of some leachate influence to the deep aquifer in the south portion of Stages 1 and 2, where the clay aquifer is not present. Figures 6.2 and 6.3 show monitoring wells' locations and their level of contamination. It has been indicated with different color. It is visibly shown in the legend, red is strong contamination, green indicated as weak influence of contamination, and blue shows no contamination. Monitoring wells located to the north of stage 3 may be indicative of vertical variation due to gradation within the deep aquifer (Dillon, 2006).

Because of the abundance of groundwater boron and toluene in the Cedar Forest area, surface water samples are taken at all locations of visible surface water discharge from the forest. Surface water was sampled using calibrated equipment to measure different parameters, such as pH, conductivity, dissolved oxygen and temperature (MOE standard, April 2004). The results of this sampling showed no indications of significant leachate impact discharging from the forest and flowing in to the north-east corner drainage area. Data from these locations also indicated that the total phosphorus concentration in water discharging from this area was not significantly elevated. The surface water sampling stations have been shown on Figure 4.6.

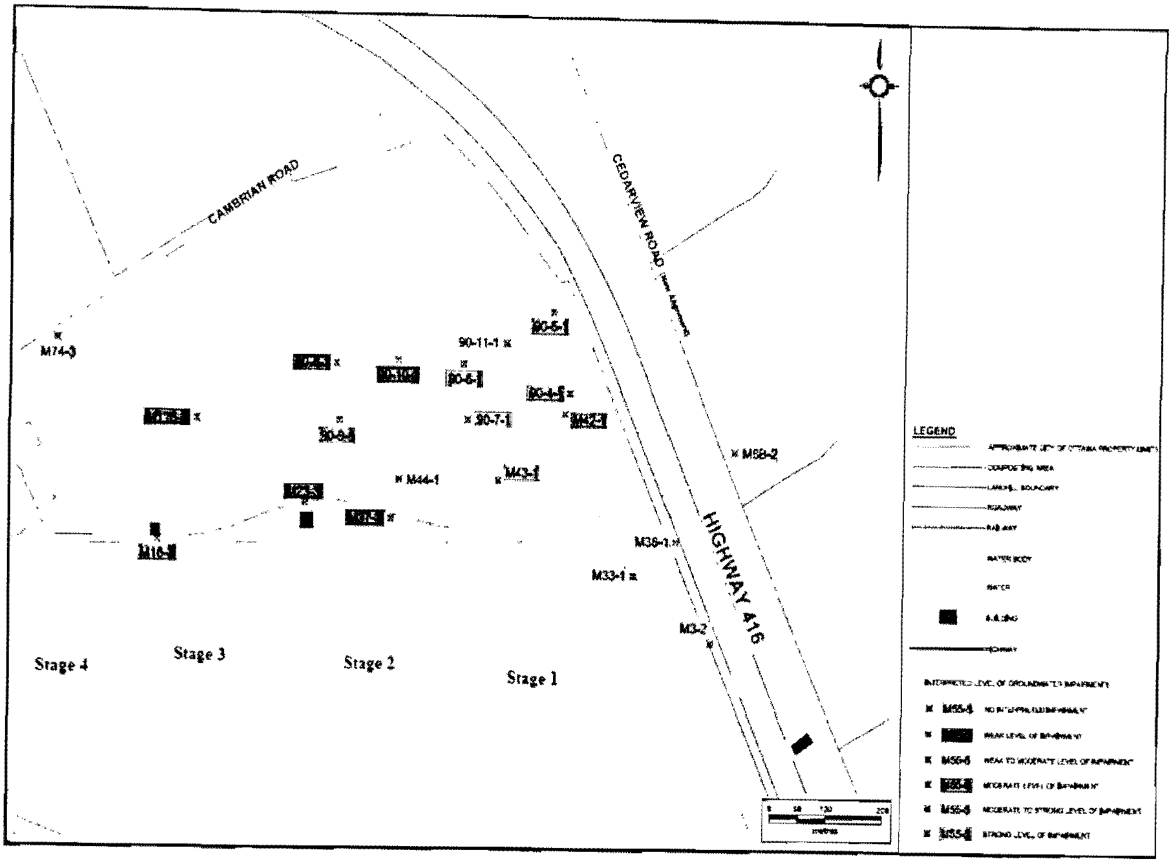
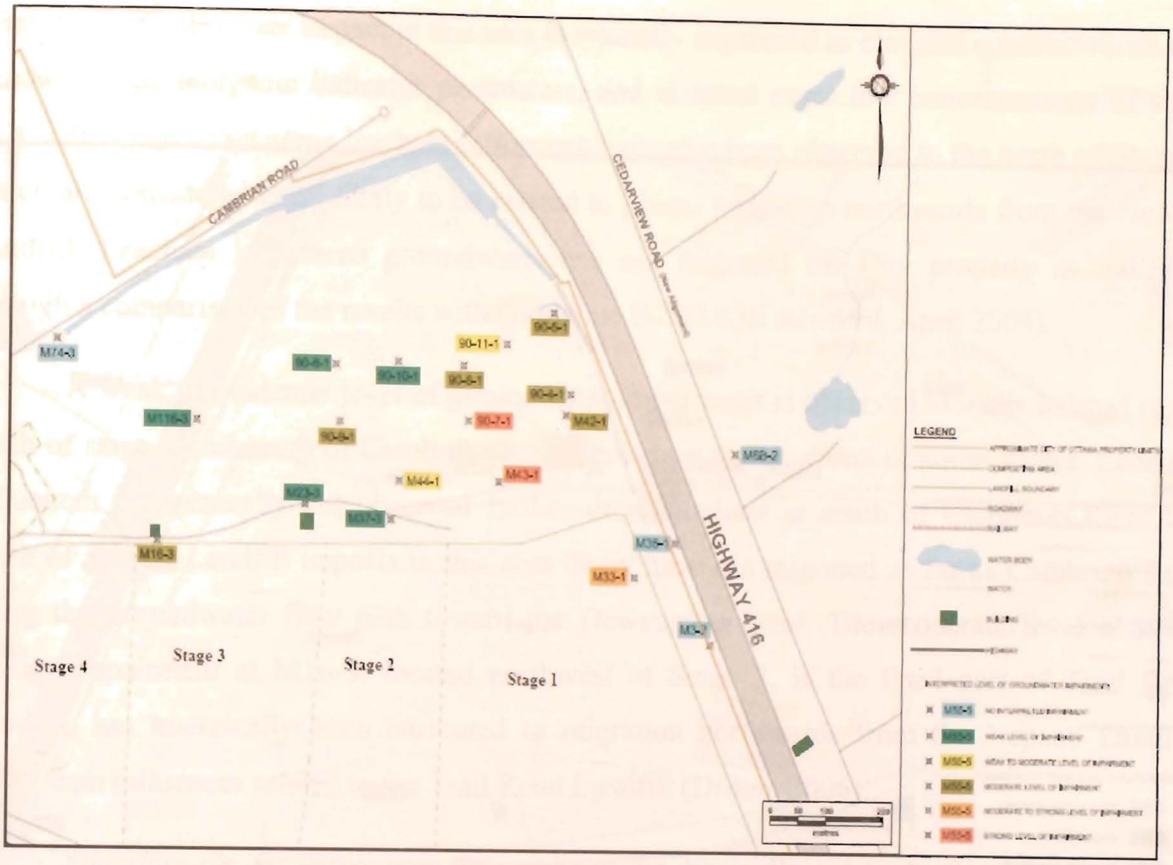


Figure 6.2 – Locations of Monitoring Wells at North Part of the Trail Road Landfill

(Dillon, 2006)

In general, the results from the surface water stations in the northeast corner of the site and off-site indicate that inorganic parameter concentrations remain steady, fluctuating within the range of concentrations recorded previously for sample locations in this area. Higher concentrations of sodium and chloride observed at some stations are the result of road salt influences (Dillon, 2006). It confirms the high surface water temperature and low NDVI value within the area. It could have been determined before all the damages happened to the environment, through analyzing the satellite images.



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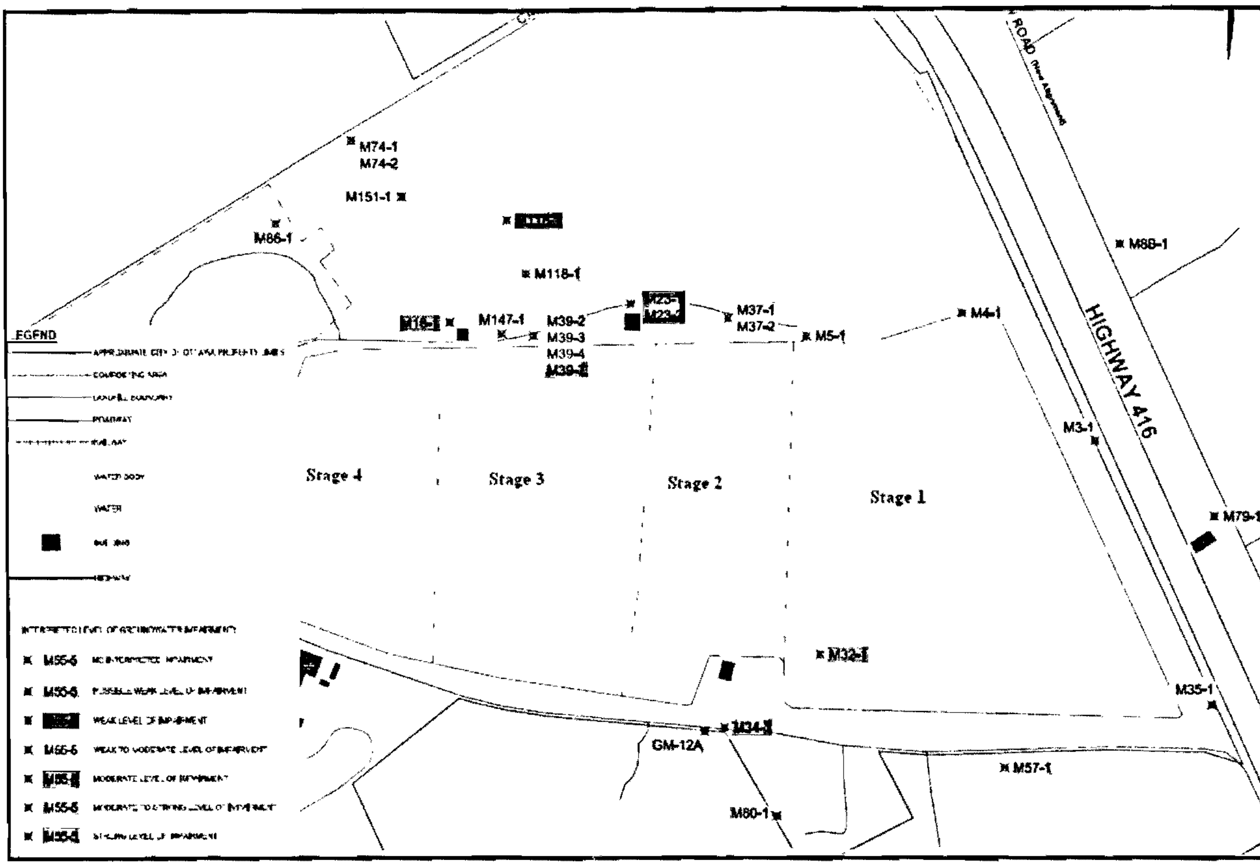


Figure 6.3 – Locations of Monitoring Wells at North and South Part of Trail Road Landfill

(Dillon, 2006)

Increases in some parameter concentrations at monitoring wells completed in the deep aquifer to the north of the Trail Landfill are indicative of weak to moderate leachate influences in the area immediately to the north of Stages 2 and 3. Some leachate influences are also observed further down-gradient along the flow path to the Dewatering Pond, although not as far as the

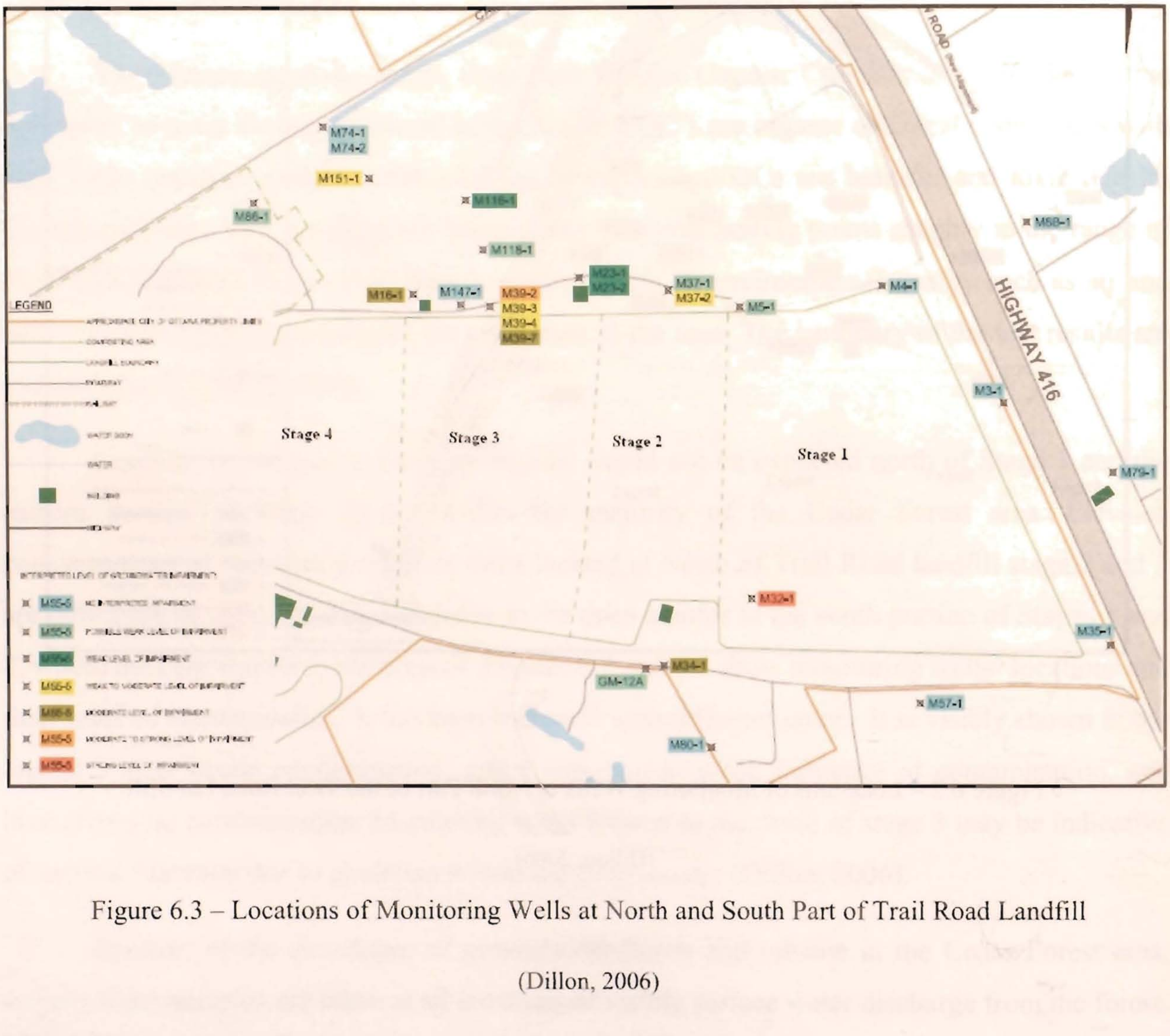


Figure 6.3 – Locations of Monitoring Wells at North and South Part of Trail Road Landfill

(Dillon, 2006)

Increases in some parameter concentrations at monitoring wells completed in the deep aquifer to the north of the Trail Landfill are indicative of weak to moderate leachate influences in the area immediately to the north of Stages 2 and 3. Some leachate influences are also observed further down-gradient along the flow path to the Dewatering Pond, although not as far as the

Pond itself. The leachate impact in this area is typically expressed as elevated concentrations of a number of the inorganic indicator parameters, and in some cases low concentrations of some VOCs. It is noted that some leachate influences have also been observed to the north of Stage 4, which are considered more likely to be related to plume migration northwards from the Nepean Landfill. Leachate influenced groundwater has not migrated off City property as indicated through a comparison of the results with Guideline B-7 (MOE standard, April 2004).

A weak to moderate level of groundwater impairment is observed at wells located to the north of stage 4 and south of Cambrain Road, including the detection of some VOCs. Leachate influences are generally not observed further down-gradient at south of Cambrain Road and north of area E. Landfill impacts in this area likely have not migrated as far as Cambrian Road along the groundwater flow path toward the Dewatering Pond. The moderate level of water quality impairment at M16-3, located northwest of Stage 3, is the lined part of Trail Road Landfill, has historically been attributed to migration northwards from the Nepean Landfill, rather than influences related to the Trail Road Landfill (Dillon, 2006).

Therefore we can summarize the results of the data collected on north of the Trail Road Landfill shows evidence of a weak to moderate level of water quality at most locations. Somewhat stronger effects are observed at M42-1, 90-5-1 and 90-9-1, but the most notable impacts are seen at M43-1 and 90-7-1 which are all located in the northern part of Trail Road Landfill stage 1, west of Highway 416, or northeast of area E. Concentrations of leachate indicator parameters were generally stable, with the exception of some increasing concentrations at M42-1 located close to Highway 416, and some decreasing concentrations at M44-1 north part of stage 2. Several indicator parameters continue to generally decrease at M44-1, where concentrations were highest in the late 1990s. This information is summarized in Figures 6.2 and 6.3 (Dillon, 2006).

6.6.2 Contamination at the South Part of Trail Road Landfill

Leachate concentration appears to be stable at the south part of Trail Road Landfill. South of Trail Road Landfill is located at the southern margin of Stages 1 and 2 of the Trail Road Landfill, as shown in Figure 4.3. Groundwater flow direction is generally from northwest through this area. A moderate level of water quality was observed at M34-1 at south of Trail Road Landfill stage 2 is considered migrating from the unlined Stages 1 and 2 of the Trail Road Landfill. This migration is explained by groundwater flow and landfill surface drainage. This well has historically shown some leachate influences. However, the leachate impact in this area does not seen to be expanding, and some impact was present at monitor GM-12A located at south of Trail Road landfill stage 2, or the centre part of area E, near the limit of the landfill property.

In review of the available data at M57-1 and M80-1, which are located at south of Trail Road landfill stage 1, continues to show no evidence of leachate influences at these locations that are at centre part of area E. Figure 6.3 shows the location of monitoring wells. The south part of Trail Road Landfill is a deep aquifer. Dissolved Oxygen Carbone (DOC) generally represents significant natural variation. Data collected from different locations indicates that DOC concentrations are generally higher at shallow aquifer locations. The area with lower residence has relatively higher DOC concentrations from precipitation, and snowmelt. The GM-12A located at the extensive aggregate pit south of Trail Road may have a similar effect on DOC concentrations at this deep aquifer location.

All measured concentrations at GM-12A were below the guidelines except DOC. The lack of any significant impact of chloride, boron, iron and bromide concentrations, which have traditionally shown a strong correlation with leachate influences at this location, suggests that the water quality is not significantly affected by landfill leachate. DOC represents a parameter that is also known to be subject to significant natural variation. DOC concentrations are generally higher at shallow aquifer locations because of recharging water from precipitation, and snowmelt. Well GM-12A is located at an extensive aggregate pit south of Trail Road has similar effect on DOC concentrations at this deep aquifer location, because of its lower groundwater residence times. All test results are attached in appendix C.

Similarly to the north part, groundwater migration in the deep aquifer is controlled by the Dewatering Pond within the south limit of the property. Some leachate influences to groundwater deep aquifer have been monitored within an isolated area to the south of the landfill, which is the result of the general pattern of groundwater flow in the deep aquifer.

To summarize the leachate influence on the south part of Trail Road Landfill: groundwater flow in the deep aquifer of the Trail Landfill is generally in the northwest area towards the Dewatering Pond which is in the north east corner of area E. Weak leachate effects can be found at well M34-1, located south of Stage 2 in the centre part of area E. Bedrock monitoring results generally showed that no VOCs were detected at this well. It is noted that reference concentrations are not available for the bedrock aquifer. The available data suggests that no significant leachate impacts are present in the central and north east parts of area E.

6.6.3 Contamination at the East Part of Trail Road Landfill

Figures 6.2 and 6.3 shows the monitoring wells located to the east of Trail Road Landfill, which is the same location as west of area F and east of area E. No leachate influences are attributable to the east of Trial Road Landfill area. Well M3-2, located to the west of Highway 416 and east of area E, serves as a reference location for the shallow aquifer. Well M8B-2, M79-1 and M8B-1 which are all located at east of Highway 416 or west of area F, continuously shows some possible evidence of residual road salt impact from Cedarview Road and Highway 416. However, at the M8B-2 location sodium and chloride concentrations have generally decreased since 2004. Road salt influences were also observed at M36-1, located west of Highway 416 or east of area E, where elevated concentrations of alkalinity, chloride and hardness were measured (Dillon, 2006).

Surface water has been monitored at monitoring stations within the drainage area at the northeast corner of the landfill's property, as well as at downstream locations along the drainage course to the Jock River, and within the Jock River itself. This northeast corner of the property represents the location of surface drainage from the landfill. The storm-water management pond in this area was completed prior to expansion of the landfill in Stage 1. Surface water drains from the site via the Dewatering Pond to the north; although this location does not receive surface drainage from the Trail landfill and groundwater impacts, it has been attributed to the closed Nepean Landfill.

6.6.4 Contamination at Beneath Part of Trail Road Landfill

The actual landfill site is called Beneath Trail Landfill and it is located at the centre part of area E. Strong leachate effects continue to be observed at monitoring well M32-1, located in the south of Stage 1 of the Trail Landfill, or the centre part of area E. Well M32-1 is shown in Figure 6.2. Several indicator parameters, including alkalinity, chloride, ammonia, iron, Total Kjeldahl Nitrogen (TKN) and hardness were observed to be significantly elevated at this location relative to the reference concentration range. Low VOC concentrations were also measured at location Well M33-1 located near the northeastern corner of Stage 1, which is in the eastern part of area E. Well M33-1 has been shown in Figure 6.2. This location was previously only monitored for water levels. The majority of the parameters were exceeded at this location, which is characterized by a moderate to strong level of water quality impairment due to leachate impacts. The summaries of test results are in appendix C.

6.7 Site Collected and Satellite Images Data Comparison

Three types of comparison have been done to clarify the results captured from different methods. Comparing the satellite image analysis result at different years shows the environment changes through time. The comparison of satellite image analysis results from different areas illustrates the contaminated and polluted areas. This comparison helps to establish the movement of contamination. Comparing results obtained from satellite images with site sampling confirms the location of contaminants and the possibility of a new monitoring program. If satellite data analysis verifies the contamination location and its movement, ground testing and sampling could become solely focused on confirmation and chemical analysis. The satellite image analysis shows the same location with high LST and low NDVI value as the site sampling shows the contaminated wells.

As an example, testing at monitoring well M39 at shallow bedrock located to the north of Trail Road landfill area shows the vertical extent of leachate impacts down-gradient of the unlined landfill area. This is the result of leachate influences that have been observed in lower deep aquifer monitors in this area. This contamination could have been noticed and prevented years before all the vegetation died at this area. Low NDVI value in 1992 showed unhealthy vegetation at the area and is the result of an unhealthy environment in terms of groundwater and soil.

Gradual increase of some parameter concentrations at monitoring wells completed in the deep aquifer to the north of the Trail Landfill, that is north and north east of area E, are indicative of weak to moderate leachate influences in the area immediately to the north of Stages 2 and 3. Some leachate influences are also observed further down-gradient along the flow path to the Dewatering Pond, although not as far as the Pond itself, which is to the south and southeast of area H.

The leachate impact in this area is typically expressed through elevated concentrations of a number of the inorganic indicator parameters and low concentrations of VOCs. This area has the highest surface temperature for the years 1992 and 2000. It is noted that some leachate influences have also been observed to the north of Stage 4 that are considered more likely to be related to plume migration northwards from the Nepean Landfill. However, the leachate influenced groundwater has not migrated off landfill property.

Leachate influence to the deep aquifer is also observed to the south of Stage 2 of the Trail landfill at well M34-1 in the centre part of area E. This location is very close to the site of the highest LST calculated on 1992 and the lowest NDVI value at the same year. It is reported by the monitoring program that the impact in this area is localized and does not expand. Yet impacts are present at monitor GM-12, located at a deep aquifer to the south of Trail Road landfill stage 2, near the limit of landfill's properties. The satellite image analysis shows that the contaminated area is the large section and it is not isolated. The lack of any significant impact with respect to chloride, boron and iron concentrations, as well as some of the other parameters which have traditionally shown a strong correlation with leachate influences at GM-12, indicates the water quality at this location is not significantly affected by landfill leachate. However, the location of the lowest NDVI value over 1992, 2000 and 2001 is very close to this area. As a result the contamination at this area cannot be minor because of the clay aquifer; the contamination might have stayed near the surface. Low NDVI value means low vegetation or non healthy vegetation which could be the result of contaminated ground water and soil in the area. Low NDVI value and high LST could have different reasons, such as low or high levels of precipitation. However in this research it was assumed the precipitation was uniform on all areas, and therefore was not considered. On Chapter 5 seasonal precipitation was considered regarding evaluation of LST and NDVI values.

The Following Figures combine the results captured from the two methods of collection during 2001 at the Trail Road landfill study area. Comparing different years of data analysis from both methods indicates increasing levels and movement of contamination.

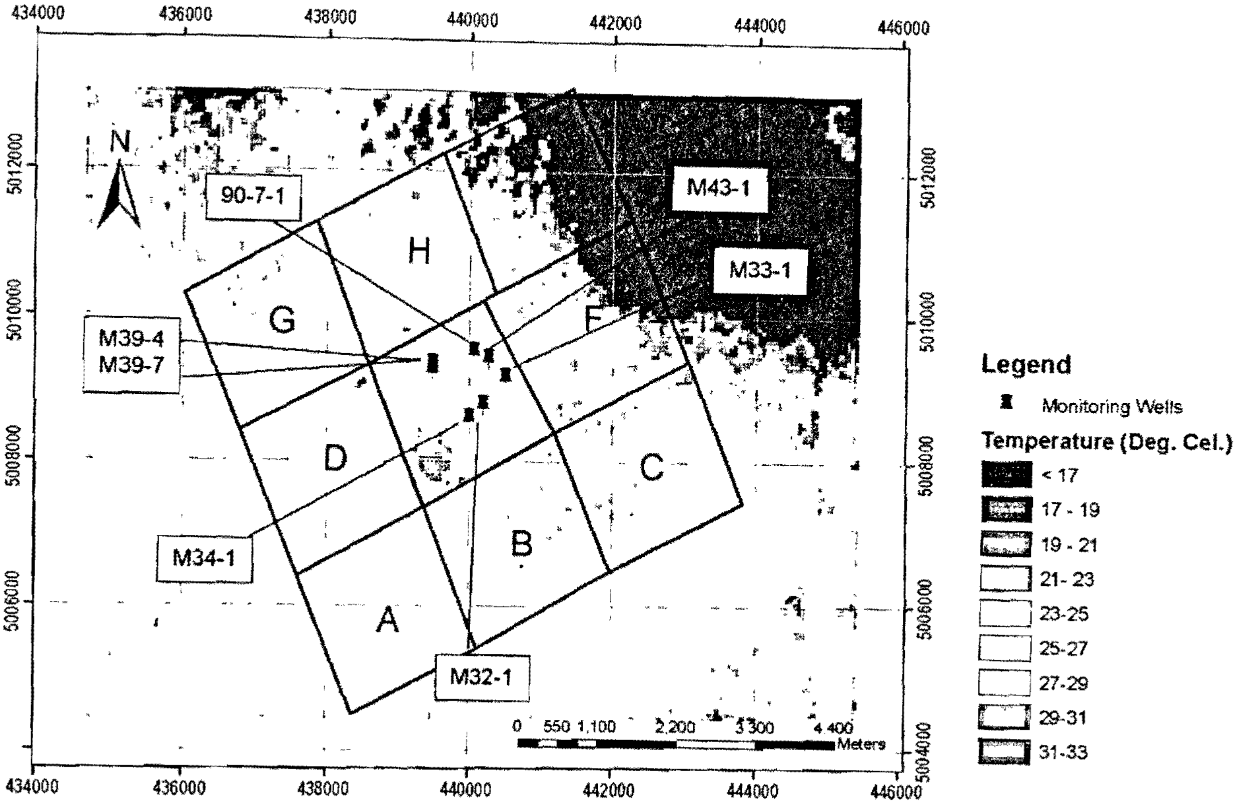
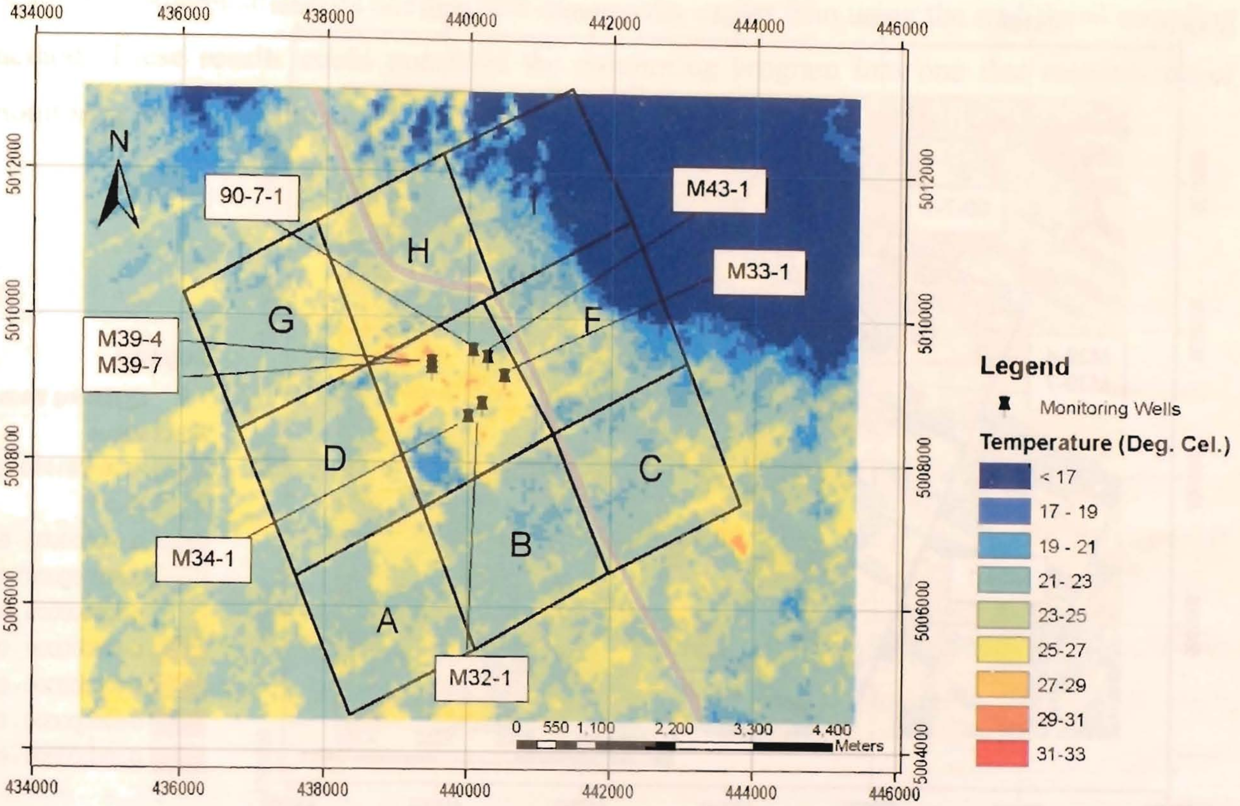


Figure 6.4 – LST Calculated During September 2001 and Locations of Monitoring Wells

At Trail Road landfill study area both data analysis results show the same locations, which is northwest and southwest of the Cedar Forest area in the north part of Trail Road landfill, that is north and northeast of area E. Figures 6.4 and 6.5 show the well locations on LST and NDVI values calculated from 2001. The combination of these two methods explains the reasons for low NDVI value and high LST. The same combinations of two methods over a period of time will explain the results of the contamination and its movement.



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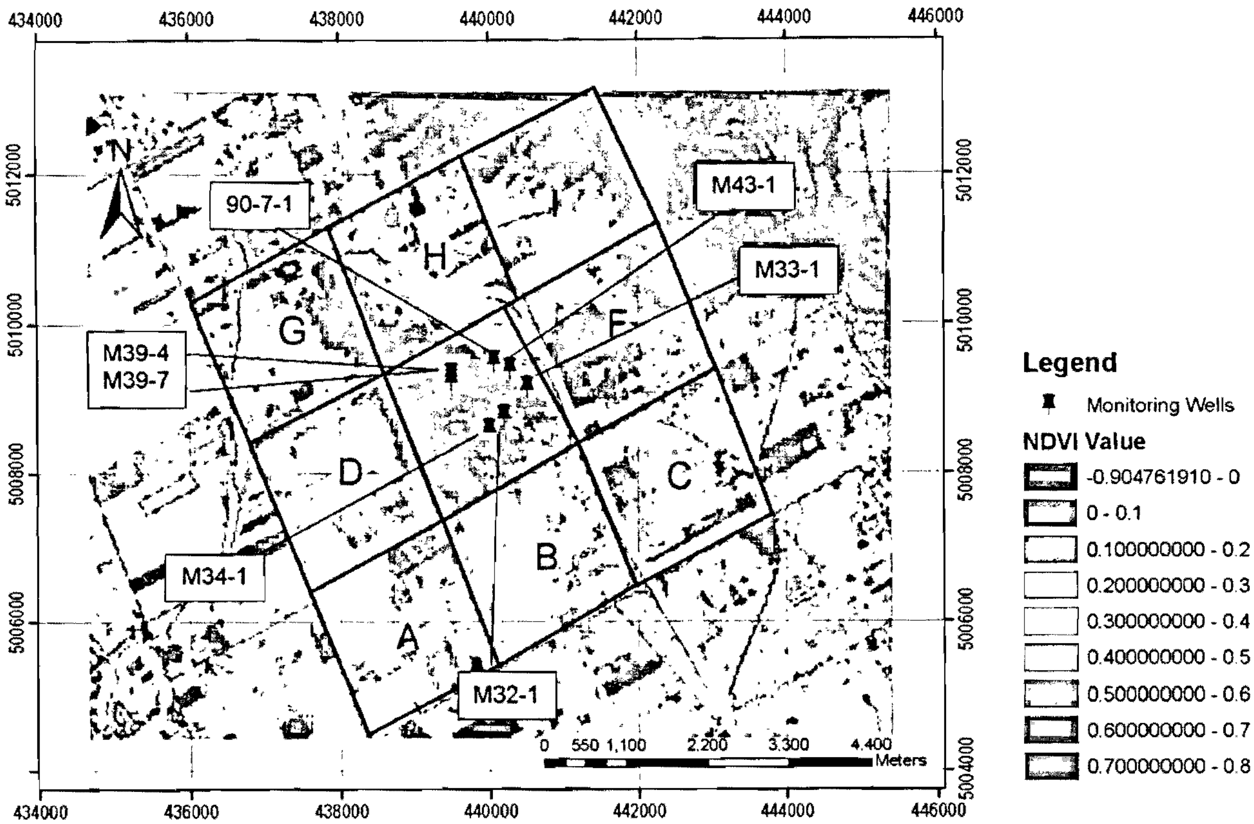

Figure 6.5 – NDVI Calculated During September 2001 and Locations of Monitoring Wells

LST analysis at different years indicates that the LST of the landfill and its surrounding area are higher than other areas, which means LST captured at area E is higher than all the other areas. NDVI value comparison between different years indicates that the landfill's NDVI value is lower, and decreasing over the years. Figure 6.4 shows the location of the most contaminated monitoring wells on LST calculated during 2001. Figure 6.4 shows that all contaminated areas are located on high LST locations. Also, Figure 6.5 confirms that more contaminated monitoring wells are located on low NDVI value areas. Therefore, as a result of this comparison; combining remote sensing and satellite analysis methods with site testing and sampling methods could

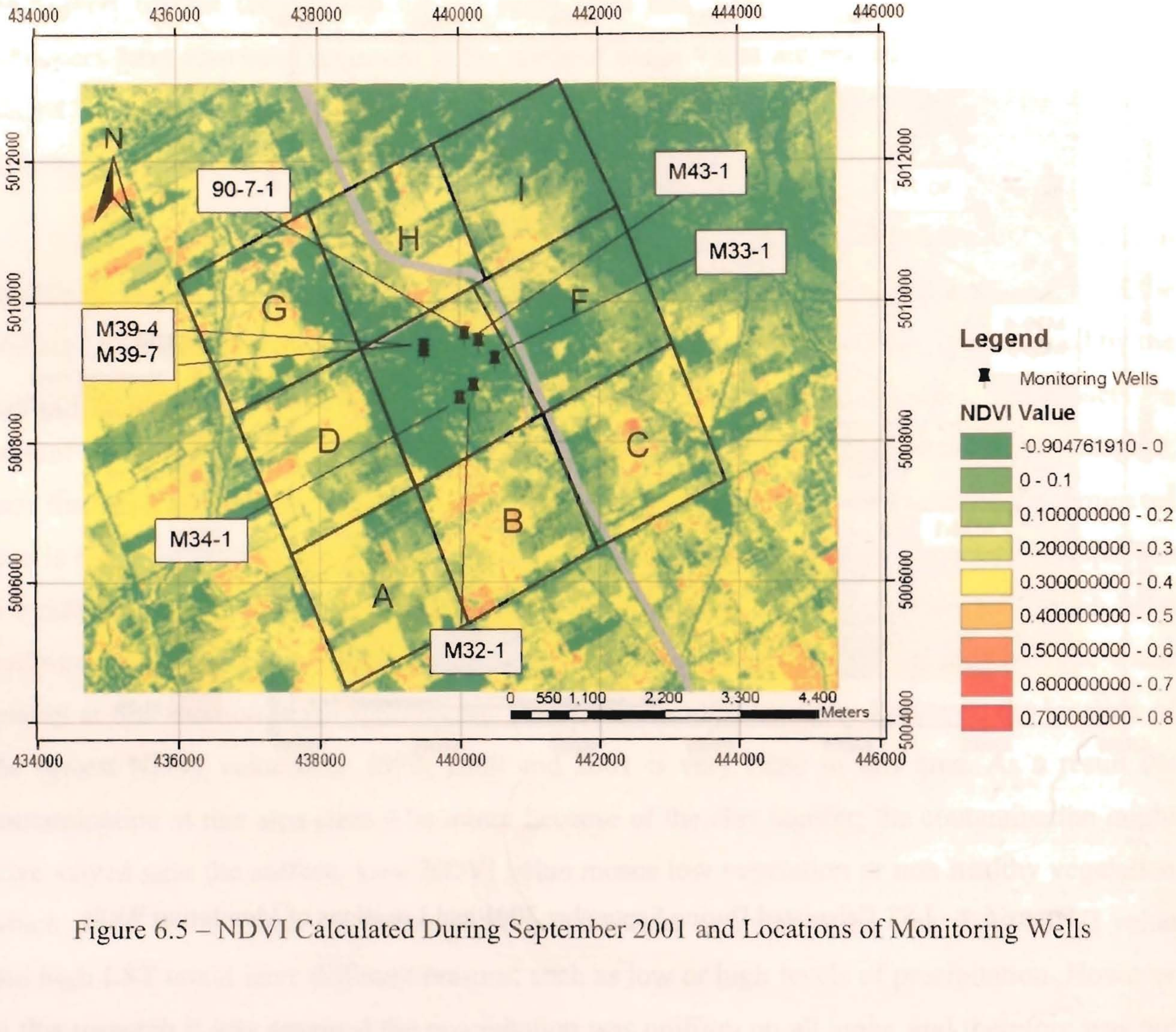

Figure 6.5 – NDVI Calculated During September 2001 and Locations of Monitoring Wells

LST analysis at different years indicates that the LST of the landfill and its surrounding area are higher than other areas, which means LST captured at area E is higher than all the other areas. NDVI value comparison between different years indicates that the landfill's NDVI value is lower, and decreasing over the years. Figure 6.4 shows the location of the most contaminated monitoring wells on LST calculated during 2001. Figure 6.4 shows that all contaminated areas are located on high LST locations. Also, Figure 6.5 confirms that more contaminated monitoring wells are located on low NDVI value areas. Therefore, as a result of this comparison; combining remote sensing and satellite analysis methods with site testing and sampling methods could locate the contaminated area and leachate movements earlier than using the traditional sampling method. These results could transform the monitoring program into one that requires fewer monitoring wells and site samples, yet obtain more representative and reliable results.

Chapter 7 : CONCLUSIONS AND RECOMMENDATIONS

7.1 General

Landfill sites have potential environmental impact. According to MOE standards and regulations, landfills must be monitored. The traditional monitoring method is testing contaminations and their influences on soil, vegetations, water and ground water. Repetitive sampling and testing of the landfill's soil and water over long period of time is needed. Collecting data and samples from landfills is an expensive process. Monitoring wells, borehole drilling, soil and water sampling are required. Also, specific equipment and professional laborers are mandatory. Representative results are also required to assure representative samples. However, scientists are always looking for direct, cost-effective ways to collect the necessary data and information.

The purpose of this thesis is to find an easier, cheaper, and faster method to monitor landfills. This thesis investigates the possibility of combining satellite data collection methods or remote sensing methods to site sampling and lab testing analysis. The data collection process and testing are both time and money consuming. Although there are quality control methods, the risk of mistake, such as lost and mistaken samples, or error during sampling or testing, is high. Satellite image analysis is able to capture the contamination movement earlier than the traditional testing method. Additionally, satellite image analysis could be used as a means of quality control and quality assurance of site sampling through cross-reference. Furthermore, this type of analysis could be used for all contaminated sites rather than exclusively landfills.

7.2 Conclusion

LST and NDVI values have been calculated for all nine divided areas of the Trail Road landfill and its surrounding area via collected satellite images that have been shown in Chapter 5. The data comparison performed in Chapter 6 indicates that area E, which is the landfill area, has generally higher LST and lower NDVI values. The comparison between the results captured from satellite images and site sampling showed almost all points with higher LST and lower NDVI are close to contaminated areas. Therefore the results of the comparison between testing and sampling at monitoring wells through satellite image analysis confirm which areas are more contaminated. However, changes in LST and NDVI value analysis indicate pollutant movement and contaminated areas earlier than the site sampling method. Therefore, these results exhibit the possibility of combining the testing and sampling system with satellite image analysis technology for more efficient monitoring of landfills. This study shows the possibility of partially replacing site sampling and site data collection with image analysis to monitor landfill sites.

Analyzing satellite images over a period of time and comparing NDVI value and LST results indicates that there is a possibility for combining the traditional monitoring method with remote sensing and satellite analysis methods. Remote sensing analysis could be used to find the representative sample location. Representative borehole and monitoring well locations will lead to more representative test result. Instead of drilling wells by trial and error on non-representative areas and collecting more samples and having more tests done, combining the site sampling method and remote sensing methods grants the opportunity to have less monitoring wells, less testing and sampling, but with more representative results. Site sampling and remote sensing analysis results have been captured and shown on previous chapters in this study.

7.3 Recommendation

Comparing the sampling and testing results from the year 2007 with LST and NDVI values analyzed from years 1992, 1998, 2000 and 2001 confirmed the analyzed data captured from the satellite images, and shows the same contaminated area years before the traditional test results. Omitting the testing and sampling program is not practical. Areas with a higher risk of contamination and leachate movements should be monitored on a regular basis. The monitoring wells locations ought to be chosen based on satellite analysis results. It is recommended to choose the location of wells in the landfills surrounding area via the satellite image analysis results. Using satellite analysis helps to have fewer sampling wells but representative results.

The groundwater monitoring program should continue with some modifications. The locations with high contamination levels, such as Cedar Forest Area, northeast of the Trail Road landfill and area E, should be under continuous remote sensing investigation. As an example it is recommended the area around the Dewatering Pond located in the south part of area H and north of Cambrian Road be tested and monitored because of the NDVI value in 2001 was low at this area. Therefore investigation is needed in order to further assess the background groundwater quality conditions in this area.

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APPENDIXES

APPENDIX A

GUIDELINE B-7

(Formerly 15-08)

Incorporation of the Reasonable Use Concept into MOEE Groundwater Management Activities

Legislative Authority:

The Ontario Water Resources Act **Responsible Director**:

Director, Program Development Branch

Last Revision Date:

April, 1994

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6.0 DETERMINATION OF CONTAMINANT LIMITS AND ATTENUATION ZONES

SYNOPSIS

This guideline establishes the basis for determining the "reasonable use" of groundwater on property adjacent to sources of contaminants and for determining the levels of contaminant discharges considered acceptable by the Ministry.

The guideline is designed to facilitate implementation of the groundwater quality management directions contained in Procedure B-1-1: "Water Management -- Guidelines and Procedures of the Ministry of Environment and Energy," which are predicated on the protection of existing and potential reasonable uses of water. The reasonable use concept, in this context, applies only to groundwater quality management.

The technical details necessary for the application of the reasonable use approach shall be found in Procedure B-7-1: "Determination of Contaminant Limits and Attenuation Zones."

1.0 Introduction

The Ministry is charged with the conservation of the groundwater resources of the Province and the control of the use of these resources in an effective manner for the public good. To this end, the Ministry may wish to discourage the use of some environments for waste disposal and encourage the use of other environments. The Ministry position is that disposal sites should be placed in environments where their impact will be limited, that acceptable disposal methods should be used and that these methods should be compatible with those particular environments.

2.0 Objectives and Application of Reasonable Use Approach

This document explains the role of a "reasonable use" approach in the Ministry's activities related to the protection of groundwater quality. It establishes procedures for determining what constitutes the reasonable use of groundwater on property adjacent to sources of contaminants and establishes limits on the discharge of contaminants from facilities, approved by the Ministry, that are used for the disposal of waste into the shallow subsurface (referred to as "disposal sites" or "disposal facilities" in this document).

The impact a disposal facility may have on the reasonable use of neighboring properties shall be limited to an amount that would not justify an award for damages in a civil law suit.

This guideline facilitates implementation of the Ministry procedures document B-1-1, "Water Management -- Goals, Policies, Objectives and Implementation Procedures of the Ministry of Environment and Energy," which are designed to protect existing and potential uses of water.

This guidelines applies to matters which fall under the authority of the Environmental Protection Act or the Ontario Water Resources Act (subject to appeal). In cases where the Environmental Assessment Act or the Consolidated Hearings Act is utilized, the decision-making power lies outside the Ministry, and the Ministry can only make recommendations.

The reasonable use concept applies only to groundwater quality management. Ministry surface water quality management guidelines are presented in procedures document B-1-1.

This guideline does not apply to the restoration of groundwater supplies that have been contaminated by "unregulated" sources, such as closed landfills or spills. These situations are addressed by Guideline B-9 (formerly 15-10): "The Resolution of Groundwater Quality Interference Problems."

2.1 Definitions

The terms "disposal site," "contaminant attenuation zone," and "adjacent property" are defined in Procedure B-7-1: "Determination of Contaminant Levels and Attenuation Zones."

3.0 The Administrative Basis for the Reasonable Use Approach

3.1 Guidelines

The Ministry position, as presented in the procedures document B-1-1, requires sufficient levels of environmental control to protect reasonable uses of the groundwater for present and future users in the Province.

This guideline is intended to assist in making decisions about current and future activities of the Ministry. It is not intended that all disposal facilities be investigated immediately to determine if they meet the levels for contaminant discharge described in this document.

3.2 Determination of Reasonable Use

The Ministry decision as to what constitutes reasonable uses of groundwater (either existing or potential) on land associated with, or adjacent to, disposal sites shall be made on a case-by-case basis. This is necessary because the wide variation in the quality, quantity and availability of groundwater makes a fixed approach impractical.

The responsibility for deciding what constitutes the reasonable use of the groundwater, as well as what uses should be protected, shall normally rest with the Regional Director. The Director's decision shall be made with input from a proponent and/or an assessment by staff. If this decision becomes a major issue, it may be made subject to a public hearing.

Reasonable current and potential uses shall be established, with respect to specific soil and water-bearing units in the subsurface, and would apply to all of the ground lying beneath a particular property.

The decision as to the reasonable use of the groundwater at a particular location shall be based on three major considerations:

3.2.1 The present use of groundwater in the vicinity

This is easily determined by a survey of the uses being made of the groundwater by nearby land owners and from data contained in Ministry files. In most instances, the current use shall be taken as the reasonable use.

3.2.2 The potential use of groundwater in the vicinity

Where there is no current use being made of the groundwater, criteria shall be established on the basis of the potential reasonable use(s) of that water, based on the existing quality and quantity of groundwater and the current use(s) of groundwater in the general area. In addition, planning agencies and others may provide input in determining potential land use (which might affect the use of the groundwaters).

3.2.3 The existing quality and quantity of the groundwater in the vicinity

The existing quality of the groundwater, and the amount that would be available to wells, shall be assessed by using data contained in Ministry files and a general knowledge of the hydrogeology in the area.

3.3 Potential for Domestic Consumption

The potential use of groundwater in Ontario will almost always be for domestic consumption. This is because:

(a) there are virtually no areas of Ontario where the quantity of groundwater that could be collected by a well would not meet the basic needs of a single family; and

(b) although there are parts of Ontario where the quality of the groundwater does not meet the Ontario Drinking Water Objectives, in most cases, individual owners have used such waters on a continuing basis over many years.

The presence of piped or surface water supplies does not, necessarily, mean that the groundwater is unsuitable for domestic consumption. However, such supplies may be a contributing factor in a determination where other considerations, such as groundwaters of poor quality and/or limited quantity, would detract from the usefulness of the groundwater.

The desirable qualities of drinking water are specified in the document "Ontario Drinking Water Objectives." Water quality objectives for the protection of fish and aquatic life and for agricultural use are stipulated in Tables 1 and 5 of the procedures document B-1-1. Each publication contains, in addition to the numerical objectives, directions as to their application.

It is also advisable to check with the Ministry for current Provincial Water Quality Objectives and Ontario Drinking Water Objectives.

In those instances where there is no Ministry objective for a given parameter, the Regional Director may specify what is considered to be an appropriate objective based on current scientific evidence.

3.4 Other Land Uses

Related land uses which could be affected by contaminants transported by groundwater, and which are compatible with a reasonable use approach, include:

(a) the use of the soil for agricultural activities;

(b) the use of the sub-surface for facilities such as sewers, electrical conduits or building foundations; or

(c) the use of the soil as fill.

4.0 The Technical Basis for the Reasonable Use Approach

A number of general technical considerations have been taken into account in the development of this document.

4.1 Good Groundwater Management Practices

The Ministry considers that the following positions shall represent good ground water management practice:

(a) By selecting a suitable location and employing appropriate technology, no substantial groundwater resource in Ontario need be degraded by a waste disposal site or facility. However, there are subsurface units that contain groundwater that is unlikely to be used for water supplies. This may be because the groundwater in these units has naturally poor quality (e.g. brine), or the yield is too low for practical use, or the groundwater has been contaminated (by, for example, urban development) and this contamination is expected to continue. A beneficial and reasonable use of such a unit may be to receive and naturally attenuate or treat contaminants that have been generated as a result of the disposal of waste.

(b) Allocation of all of the attenuation capacity in a particular area to a single source of contaminants may not be prudent, because it may not be possible to prevent additional contaminant loadings in the future. Anticipated contaminant loadings shall be assessed, on a case-by-case basis.

(c) Provision shall be made for alleviating unacceptable environmental impacts, to the extent possible, should this prove to be necessary in the future. Unexpected events or failures shall be dealt with in a contingency plan. Those events that can reasonably be expected to occur shall be dealt with as part of the site design.

4.2 Safety Margins

Using current technology, it is not generally possible to estimate accurately the quantity or the quality of contamination which will be discharged by a disposal facility. Uncertainty factors, on the order of at least five-fold, are common in the measurement of parameters such as hydraulic conductivity. Therefore, safety margins shall be considered in all estimates of contaminant discharge.

The appropriate safety margin would have to be calculated on a case-by-case basis and depend on the complexity of the hydrogeological environment, the characteristics of the waste treated and the contaminants produced the value of the resource, and the consequences of failure. A higher level of certainty is possible when an existing contaminant plume is present and can be used in an assessment.

4.3 Hydrogeological Aspects

There are some practical differences in the hydrogeological aspects of facilities used for the disposal of solid waste and those used for liquid waste. These differences, which can be considered in applying this guideline, are:

(a) As a contaminant plume will generally develop more rapidly from liquid than solid wastes, the monitoring data needed to measure the performance of a liquid waste disposal facility may be collected relatively quickly. The technical, administrative and financial concerns associated with long-term monitoring of a solid waste disposal facility are greater.

(b) Contingency measures for a liquid waste disposal facility include shutting off the waste discharge and providing pre-treatment for the effluent. Such relatively simple contingency measures are probably impractical for a solid waste disposal facility.

4.4 Adjacent Land Use

The use of land adjacent to a disposal facility, in addition to those uses associated with water supplies, can be affected by liquid or gaseous contaminants transported by the groundwater or moving through the unsaturated zone in the subsurface. The protection of these uses is also the responsibility of the Ministry. This is addressed in Guideline D-4 (formerly 07-07) "Land Use On or Near Landfills and Dumps."

5.0 Environments Unsuitable for Waste Disposal

The Ministry may not support proposals for facilities for the disposal of waste in the following environments:

5.1 No appreciable attenuation can be provided

A disposal facility may not be supported in a location where no appreciable attenuation can be provided in the subsurface and an excessive amount of the attenuation required for acceptable discharge must be provided by dilution in surface waters. The impact on surface water by contaminants carried from a disposal site by the groundwater will almost always be undetectable. However, unacceptable circumstances might exist where the subsurface travel time for contaminants is very short and the time for the degradation of the easily biodegradable organic contaminants is inadequate to substantially reduce their concentrations.

5.2 Natural attenuation capacity is weak

A disposal facility may not be supported in a location where the ability of the natural environment to attenuate contaminants is weak, as in fractured rocks, and as compensation, a very large area is required for the attenuation of contaminants. For technical reasons, environments where this is necessary are generally quite expensive to evaluate and contingency plans in such environments are seldom practical.

5.3 The subsurface is suited for better use

A disposal facility may not be supported in a location where the subsurface beneath the facility is particularly suited for a better use. For example, waste disposal may not be supported in an esker of sand and gravel where the esker might be needed at some future date for the development of a water supply.

5.4 The consequences of failure are unacceptable

A disposal facility may not be supported in a location where the consequences of failure are unacceptable. For example, waste disposal may not be supported where failure and a resulting contaminant discharge might affect the sole source of a community water supply to an unacceptable degree.

6.0 Determination of Contaminant Limits and Attenuation Zones

The technical details necessary for the application of the reasonable use approach to proposed disposal sites, operating disposal sites, and disposal sites requesting approval for expansion shall be found in Procedure B-7-1 "Determination of Contaminant Limits and Attenuation Zones." In this document, guidance is provided for:

(a) Determining quantitatively the acceptable levels of various contaminants originating in disposal sites and impinging on adjacent properties; and

(b) Assessing the suitability of a contaminant attenuation zone, and the limits of a disposal site

APPENDIX B

PROCEDURE B-7-1

(Formerly referenced by 15-08)

Determination of Contaminant Limits and Attenuation Zones

Legislative Authority:

The Ontario Water Resources Act **Responsible Director**:

Director, Program Development Branch

Last Revision Date:

April, 1994

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1.0 Introduction

In this document, the reasonable use concept is applied to: (a) determining quantitatively the acceptable levels of various contaminants originating in disposal sites and impinging on adjacent properties; and (b) assessing the suitability of a contaminant attenuation zone, and a disposal site. Terms are specifically defined in Section 3.0.

2.0 Ministry Responsibility and Authority

The Ministry is charged with the conservation of the groundwater resources of the Province and the control of the use of these resources in an effective manner for the public good. To this end, the Ministry may wish to discourage the use of some environments for waste disposal and encourage the use of other environments. The Ministry position is that disposal sites should be placed in environments where their impact will be limited, that acceptable disposal methods should be used and that these methods should be compatible with those particular environments.

For waste disposal activities the Ministry has the management authority to:

(a) Issue a Certificate of Approval which would permit the use of property for contaminant attenuation or treatment. Discharge to neighbouring property must have no more than a negligible or trivial effect on the existing and potential reasonable use of this property. This is accomplished by limiting any increases in contaminant levels caused by this discharge to those specified in Section 5.1. The question of whether the effect is negligible, if challenged, could be established by the courts, which would decide if there is damage and how it can be measured in terms of dollars. This is inherent in the approach used by the Ministry in other situations, such as the issuance of air approvals.

(b) Prevent the owner of a disposal site, or a proposed disposal site, from using the sub-surface beneath the site for waste disposal purposes if this use is not felt to be in the public interest.

This management authority is subject to the limitations and qualifications in Guideline B-7, "Incorporation of the Reasonable Use Concept into MOEE Groundwater Management Activities."

3.0 Definition of Terms

For the purpose of this document, the Ministry will consider three areas in assessing waste disposal proposals: the disposal site, the contaminant attenuation zone, and the adjacent property. These are defined in the following Sections.

3.1 The Disposal Site

For the purposes of this document the term "disposal site" includes, but is not limited to the following:

(a) a "waste disposal site" under Part VI of the Environmental Protection Act (EP Act) and a "landfilling site" as defined in O. Regulation 309;

(b) an "exfiltration lagoon" defined as a "sewage works" under the Ontario Water Resources Act (OWRA);

(c) a "large subsurface sewage disposal system" under Part VIII of the EP Act and as defined in Notice 3/87, July 15 1987.

The intention is to identify the areas that receive waste and the adjoining land that is necessary for proper site operation. For example, in the case of a landfill, the disposal site or waste disposal site comprises the area on or in which wastes are deposited, (the "fill area"), and any bordering land, (the "peripheral area"), as shown on the accompanying diagram. In the case of an "exfiltration lagoon" or a "large subsurface sewage disposal system," terminology is defined in the appropriate guidelines.

The following comments apply to a disposal site:

(a) Future use of the land should be strictly controlled. Based on technical considerations, such control should be permanent or continued until it can be shown that such control is no longer necessary.

(b) As there are environments which the Ministry does not believe are appropriate for waste disposal, the Ministry will either oppose the use of such environments or will insist that stringent safeguards be incorporated in any design for the disposal site and that there be appropriate monitoring and contingency plans. These safeguards may include provision for the collection and treatment of any contaminants which will be produced. Guidelines for identifying environments unsuitable for waste disposal are presented in Section 5.0 of Guideline B-7.

3.2 The Contaminant Attenuation Zone

The purpose of a "contaminant attenuation zone" is to allow the limited impairment of use of off-site property by means of easements or other methods without imposing the severe restrictions on land use which apply to the disposal site.

Where appropriate, a contaminant attenuation zone may be supported. It is outside of the disposal site and it is defined both with respect to the area of land which it underlies and also with respect to the depth at which it lies.

In the contaminant attenuation zone, it is intended that contaminants will be naturally attenuated to levels compatible with the reasonable use of the adjacent property as discussed in Guideline B-7, Section 3.2 and in order to meet the criteria specified in Section 5.1, below, contaminant levels in the contaminant attenuation zone may impair some uses of that zone. The operator of the disposal site must obtain the right to the use of this zone by reaching agreement with the property owner. The agreement should be registered on the title to this land.

Circumstances and environments favoring the designation of a contaminant attenuation zone are discussed in Section 4.0.

3.3 The Adjacent Property

The "adjacent property" is the land bordering the disposal site or the contaminant attenuation zone. Discharge of contaminants to adjacent property will have no more than a negligible effect on the present or potential reasonable use of that property. This will ensure that:

(a) the presence of the contaminant will not interfere with the construction, installation or good operation of any usual facility in the subsurface, such as utility conduits;

(b) the soil will not be contaminated to a degree which would interfere with its use;

(c) the groundwater will not be contaminated to a degree which would impair its reasonable use, as addressed in Guideline B-7 (Section 3.2).

4.0 Circumstances and Environments Suitable for a Contaminant Attenuation Zone

The Ministry may support an application for a disposal site involving the acquisition of land or an easement for a contaminant attenuation zone only under the following circumstances:

4.1 Alternate Sources of Water Available

An application may be supported where an alternate source of water is far superior to any associated with a contaminant attenuation zone. Here the Ministry may support the use of the groundwater for dilution and attenuation in a contaminant attenuation zone and take the position that the effect on reasonable uses on adjacent property would be negligible or insignificant, because that groundwater would not need to be used in any case.

This circumstance could arise as follows:

(a) where two water-bearing units are present, one being far superior to the other with respect to the quality, quantity and the accessibility of the water contained in it, the Ministry may accept the inferior unit as a contaminant attenuation zone, provided that this will not interfere with the use of the superior unit; or

(b) where good supplies of water are available, either from surface water sources or from municipal systems, and the groundwater supplies in a particular unit are marginal with respect to their quality and/or their quantity, the Ministry may support the use of that groundwater as a contaminant attenuation zone.

4.2 Contaminant Zone Limited

An application may be supported where only an acceptably small, clearly defined and hydrogeologically restricted portion of a subsurface unit will be degraded and this subsurface unit is not likely to be required for a higher use.

This procedure would allow the Ministry to support the use of certain Crown Lands in Northern Ontario or well defined zones of groundwater flow such as may be present in flood plains, as contaminant attenuation zones despite their physical ability to yield groundwater in "useful" quantities.

4.3 High Levels of Dissolved Solids Present

An application may be supported, under special circumstances and on a case-by-case basis, where naturally high levels of iron, manganese and/or total dissolved solids (where these are associated with hardness) are present in the groundwater and as a result, the limits imposed in Section 5.1 cannot be met (see situations described in Section 5.2, examples 2 and 3). It is necessary to assess on a case-by-case basis because:

(a) unlike the case in surface waters, concentrations of iron, manganese and total dissolved solids commonly in excess of the Ontario Drinking Water Objectives are naturally present in Ontario groundwaters, and these groundwaters are routinely used for domestic supplies;

(b) these parameters are not related to health, at the levels stated in the Ontario Drinking Water Objectives, and in addition can be removed from a water supply with commonly available techniques; and

(c) it is not practical to eliminate waste disposal in a large percentage of the Province where the presence of iron, manganese and total dissolved solids naturally occurs in excess of the Ontario Drinking Water Objectives.

4.4 Areas Suitable in the Judgment of the Regional Director

An application may be supported where, in the judgment of the Regional Director, the most appropriate use of that environment would be as a contaminant attenuation zone, although it is suitable for other purposes as well.

5.0 The Determination of Limits for Proposed Disposal Sites

5.1 Basic Approach

In accordance with the appropriate criteria for particular reasonable uses, such as those specified in the Guideline B-1: "Water Management -- Guidelines and Procedures of the Ministry of Environment and Energy", a change in quality of the groundwaters on the adjacent property will be acceptable only as follows:

"Quality cannot be degraded by an amount in excess of 50% of the difference between background and the quality criteria for any designated reasonable use except in the case of drinking water. In the case of drinking water, the quality must not be degraded by an amount in excess of 50% of the difference between background and the Ontario Drinking Water Objectives for non-health related parameters and in excess of 25% of the difference between background and the Ontario Drinking Water Objectives for health-related parameters. Background is considered to be the quality of the groundwater prior to any man-made contamination."

This approach imposes a permanent upper limit to the amount of contamination that the owner of the adjacent property should have to tolerate. In accordance with Section 2.0, it is the Ministry's judgment that such increases in contaminant levels will have no more than a negligible or trivial effect on the existing or potential reasonable use of the adjacent property.

In assessing the amount of degradation that is acceptable, consideration is given to the natural, uncontaminated quality of the groundwater, the present quality of the groundwater and potential contamination of the groundwater from all sources.

5.2 Examples of the Application of the Concept

Examples of the application of this concept to three different situations are provided below:

Example 1 -- Where the designated reasonable use of groundwater allows no change in quality, no change is acceptable.

Example 2 -- Where the designated reasonable use of the groundwater is drinking water and the groundwater quality is presently better than the Ontario Drinking Water Objectives, a lowering of water quality on the adjacent property will be acceptable in accordance with the formula stated above.

Example 3 -- Where one or more groundwater quality parameters are currently at concentrations greater than the limits specified in the Ontario Drinking Water Objectives, but the groundwater is nonetheless in use as a drinking water source, then no further increase in the levels of these water quality parameters will be acceptable (see Section 4.3 for possible exception). Under these circumstances, increases in other parameters may be allowed in accordance with Section 5.1.

5.3 Examples of the Calculations

Two calculations are required to determine the amount of contamination that can discharge from a disposal site onto the adjacent property. The first calculation addresses the total contaminant impact at that location from all sources of contamination. The second addresses the permissible impact from the particular disposal site.

The maximum concentration (Cm) of a particular contaminant that would be acceptable in the groundwater beneath the adjacent property is calculated in accordance with the following relationship:

$$Cm = Cb + x(Cr - Cb)$$

The terms are defined as follows:

Cb This is the background concentration of the particular contaminant in the groundwater before it has been affected by human activity (Section 5.1). This allows consideration to be given to the amount of increase in contaminant level.

Cr This is the maximum concentration of the particular contaminant that should, in accordance with the Province's water management guideline be present in the groundwater. This value is dependent on the use (reasonable use) to be made of that groundwater (see Guideline B-7). It allows consideration of the total amount of contamination.

This is a constant that reduces the contamination to a level that is considered by the Ministry to have only a negligible effect on the use of the water. For drinking water x is 0.5 for non-health related parameters or 0.25 for health related parameters. For other reasonable uses it is 0.5 (Section 5.1).

Levels of contamination greater than **Cm** may have an appreciable effect on the use of the adjacent property and the Ministry will not support an application for a disposal site with contaminant discharges which would cause this level to be exceeded.

The maximum concentration of a particular contaminant (**Cw**) originating in the disposal site that can be permitted to reach the adjacent property and still not cause Cm to be exceeded can be calculated in accordance with the following relationship:

Cw = Cm - Cp - Co

The terms are defined as follows:

Cp This is the concentration of the particular contaminant in the groundwater at the time of assessment, (i.e. the present background). This water may already contain some contaminants (Section 5.1). These contaminant levels must be subtracted to determine the contaminant increment that can be permitted from the disposal site.

Co This is the potential contaminant increase from other sources with a high degree of probability (see Guideline B-7, Section 4.1(b)). For example, potential chloride contamination from a highway under construction next to the site must be subtracted to determine Cw.

Using chloride from a landfill as an example, the maximum allowed chloride level (Cm) in the **x** groundwater beneath the adjacent property and the maximum chloride discharge (Cw) to the adjacent property from a hypothetical landfill are calculated as follows:

(a) The reasonable use of the groundwater beneath the adjacent property has been determined to be for domestic supplies.

(b) The Ontario Drinking Water Objective for chloride is 250 mg/L. This represents Cr.

(c) The natural uncontaminated background concentration of chloride is estimated to have been 10 mg/L. This represents Cb.

(d) The measured concentration of chloride at the time of the assessment is 40 mg/L. This represents Cp.

(e) The expected additional chloride increase from a nearby highway that is presently under construction is estimated to be 20 mg/L. This represents Co.

(f) Chloride is considered to be a non-health-related parameter and therefore the constant (x) is 0.5.

The maximum allowed concentration (Cm) of chloride beneath the adjacent property, in accordance with the relationship:

Cm = Cb + x (Cr-Cb) is therefore:

10 + 0.5 (250-10) = 130 mg/L

The maximum concentration of chloride (Cw) from the disposal site that can be permitted to reach the adjacent property, in accordance with the relationship Cw = Cm - Cp - Co is therefore:

130 - 40 - 20 = 70 mg/L

It should be noted that the chloride ion may not be the critical contaminant (i.e. the contaminant parameter which will most closely approach its maximum allowed value, Cm, and thus represent the limit to which the site is designed). However, it is commonly used in contaminant investigations because of its usefulness as a "tracer". The critical contaminant is dependent on several factors including the characteristics of the wastes and the hydrogeologic environment and is determined on a case-by-case basis.

5.4 Site Assessment

The assessment of the proposed disposal site should be carried out in accordance with any pertinent Ministry guidelines. In addition, Section 4.0, "The Technical Basis for the Reasonable Use Approach," of Guideline B-7 should be considered with particular reference to those parts relating to the provision of a safety margin in making estimates of contaminant discharges (Section 4.2).

6.0 Limits for Operating Disposal Sites

An operating disposal site is handled as follows:

(a) An operating site should meet the same limits for contaminant discharge (Section 5.1) as a proposed site.

(b) The judgement as to the amount of off-site impact that the site will produce may be based on actual off-site measurements of contaminant levels or on predictions of off-site contaminant levels which are based on on-site measurements. This reduces the requirements for a safety margin in calculations (Guideline B-7, Section 4.2).

(c) If contaminant concentrations exceed the limits specified in Section 5.1, the site should be closed in a manner to minimize environmental damage, or the operation should be modified. It is acceptable to modify the operation of the disposal site, for example in the case of a landfill by collecting a part of the leachate, in order to meet the specified limits. However, if these levels are exceeded, all waste disposal, except that done in conjunction with a reasonable plan for closure or with remedial activities, should be terminated until the specified limits have been met, or until monitoring data indicate that these limits will be met. Determinations on the replacement of contaminated water supplies and the abatement of the contaminant plume must be made on a case-by-case basis in accordance with Guideline B-9 (formerly 15-10) entitled: "Resolution of Groundwater Quality Interference Problems."

7.0 Limits for Disposal Sites Requesting Approval for Expansion

An Approval for a disposal site requesting expansion will be handled in the same manner as an Approval for a new site or a proposed site (i.e. it must meet the limits specified for contaminant discharge in Section 5.1).

APPENDIX C

Test Results Summary

By Dillon 2007

TABLE 3.1

Summary of 2007 Reference Groundwater Quality for Leachate Indicator Parameters (excluding other sources of chemical loading)

Parameter	Units	Shallow Aquifer		Deep Aquifer	
		median[1]	range[2]	median[1]	range[2]
Alkalinity	mg/L	210	65-310	220	93-452
Boron	mg/L	0.02	0.009-0.05	0.01	0.004-0.05
Bromide	mg/L	0.05	0.05-0.25	0.05	0.05-0.25
Chloride	mg/L	24	4-99	6	1.8-103
DOC	mg/L	2.7	0.8-3.8	1.1	0.5-2.3
Iron	mg/L	0.01	0.005-0.24	0.01	0.005-0.33
Hardness	mg/L	269	57-468	214	97-398
Ammonia	mg/L	0.02	0.008-0.21	0.011	0.003-0.15
TKN	mg/L	0.25	0.05-0.53	0.1	0.02-0.26

[1] median concentrations of groundwater monitoring data for the last five years
[2] range of concentrations of groundwater monitoring data for the last five years

TABLE 3-2 Summary of Monitoring Results; North of Trail Landfill Area – Shallow Aquifer		
Location	**Groundwater Quality**	**Comments**
M42-1	• Most indicator parameters exceed the reference concentration range (trigger location – see **Section 3.5**);	Moderate level of impairment; several parameter concentrations increasing
M43-1	• The majority of parameters exceed the reference concentration range; some VOCs detected (see ***Table 3-4, Figure 3-10***)	Strong level of impairment
M44-1	• Several parameters exceed the reference concentration range; no VOCs detected	Weak to moderate level of impairment; concentrations generally decreasing
90-4-1	• Chloride, iron, ammonia and TKN slightly elevated relative to the median reference concentrations; no VOCs detected	Weak level of impairment

TABLE 3-2
Summary of Monitoring Results; North of Trail Landfill Area – Shallow Aquifer

Location	Groundwater Quality	Comments
90-5-1	• Many of the parameters exceed the reference concentration range, bromide diminished relative to 2006; no VOCs detected; chloride gradually increasing (potential road salt influences)	Moderate level of impairment
90-6-1	• Most of the parameters exceed the reference concentration range; no VOCs detected	Moderate level of impairment
90-7-1	• The majority of the parameters exceed the reference concentration range; some VOCs detected (see ***Table 3-4, Figure 3-10***); (trigger location – see ***Section 3.5***)	Strong level of impairment
90-8-1	• Chloride, iron, ammonia and TKN exceed median reference concentrations; no VOCs detected	Weak level of impairment
90-9-1	• Most of the parameters exceed the reference concentration range; (trigger location – see ***Section 3.5***)	Moderate level of impairment
90-10-1	• Many of the parameters exceed median reference concentrations; no VOCs detected	Weak level of impairment
90-11-1	• Most of the parameters exceed median reference concentrations; no VOCs detected	Weak to moderate level of impairment
M16-3	• Most of the parameters exceed the reference concentration range; no VOCs detected	Moderate level of impairment; some concentrations increasing
M23-3	• Several parameters exceed median reference concentrations but are within the reference concentration range	Weak level of impairment
M37-3	• Several parameters exceed median reference concentrations but are within the reference concentration range; no VOCs detected	Weak level of impairment
M74-3	• Reference location	No water quality impairment
M116-3	• Some parameters exceed median reference concentrations; no VOCs detected; (trigger location – see ***Section 3.5***)	Weak level of impairment; several parameter concentrations decreasing

TABLE 3-3
VOCs Detected in Shallow Aquifer

Location	VOCs Detected			Change From Previous Results
	Spring 2007	Summer 2007	Fall 2007	
90-7-1	1,1-dichloroethane		1,1-dichloroethane	stable
	1,2-dichloroethane		1,2-dichloroethane	increasing
			1,3,5-trimethylbenzene	1st detection
	benzene		benzene	increasing
	ethylbenzene	**ethylbenzene**	**ethylbenzene**	increasing
	m/p-xylene	m/p-xylene	m/p-xylene	increasing
	o-xylene	o-xylene	o-xylene	decreasing
	toluene	**toluene**	**toluene**	stable
	vinyl chloride		**vinyl chloride**	stable
M33-1	1,1-dichloroethane			stable
	1,2-dichloroethane			decreasing
	1,4-dichlorobenzene			decreasing
	benzene	no sample	no sample	stable
	m/p-xylene			decreasing
	o-xylene			decreasing
	t-1,2-dichloroethylene			decreasing
M43-1	1,1-dichloroethane		1,1-dichloroethane	stable
	1,2-dichloroethane	no sample	1,2-dichloroethane	stable
	benzene			decreasing
			toluene	stable

Note: Entries in bold represent locations where ODWS values have been exceeded.

TABLE 3-4 Summary of Monitoring Results, North of Trail Landfill Area – Deep Aquifer			
Location	Aquifer	Groundwater Quality	Comments
M4-1 (re-installed)	Deep (upper/mid)	• Most parameters within reference concentration range; ammonia and TKN slightly elevated; no VOCs detected	No water quality impairment
M5-1	Deep (upper/mid)	• Chloride, DOC and iron exceed median reference concentrations; ethylbenzene detected	Possible weak level of impairment
M16-1	Deep (lower)	• Most parameters exceed median reference concentrations, some exceed reference range; VOCs detected	Moderate level of impairment – may be influenced by Nepean landfill plume
M23-1	Deep (lower)	• Bromide, DOC and iron exceed reference concentration range	Weak level of impairment
M23-2	Deep (upper/mid)	• Bromide, chloride, DOC and iron exceed the reference concentration range; 1,1-dichloroethane detected	Weak level of impairment; chloride increasing
M37-1	Deep (lower)	• Similar to reference, iron and chloride are slightly elevated; no VOCs detected	Possible weak level of water quality impairment; chloride increasing
M37-2	Deep (upper/mid)	• Bromide, DOC, iron, hardness and TKN exceed the reference concentration range; no VOCs detected	Weak to moderate level of impairment; chloride increasing
M39-2	Deep (lower)	• Most indicator parameters exceed the reference concentration range; VOCs detected	Moderate to strong level of impairment; TKN and ammonia increasing
M39-3	Deep (upper/mid)	• DOC, iron and hardness exceed the reference concentration range	Weak to moderate leachate effects
M39-4	Deep (upper/mid)	• Most indicator parameters exceed median reference concentrations, some exceed reference range; VOCs detected	Weak to moderate level of impairment
M39-7	Deep (upper/mid)	• Most indicator parameters exceed the reference concentration range; 1,1-dichloroethane and vinyl chloride detected	Moderate level of impairment
M74-1	Deep (lower)	• Chloride and iron exceed median reference concentrations; no VOCs	No water quality impairment; chloride increasing

TABLE 3-4 Summary of Monitoring Results, North of Trail Landfill Area – Deep Aquifer			
Location	Aquifer	Groundwater Quality	Comments
		detected	
M74-2	Deep (upper/mid)	• Chloride, iron, ammonia and TKN exceed median reference concentrations; no VOCs detected	No water quality impairment; chloride increasing
M86-1	Deep (upper/mid)	• Several parameters exceed median reference concentrations; no VOCs detected	Possible weak level of impairment
M116-1	Deep (lower)	• DOC and iron exceed the reference concentration range	Weak level of impairment
M118-1	Deep (lower)	• Several parameters exceed median reference concentrations	Possible weak level of impairment
M147-1	Bedrock	• Boron slightly elevated; no VOCs detected	No obvious water quality impact
M151-1 (new well)	Deep (upper/mid)	• Boron, bromide, DOC, iron and hardness elevated relative to reference concentration range; 1,1-dichloroethane and vinyl chloride detected	Weak to moderate level of impairment

TABLE 3-5 Summary of Monitoring Results, South of Trail Landfill Area – Deep Aquifer			
Location	Aquifer	Groundwater Quality	Comments
M7-1	Deep (upper/mid)	• Reference location	No water quality impairment
M34-1	Deep (upper/mid)	• Most of the parameters exceed the median reference concentrations, DOC, hardness, ammonia and TKN exceed the reference range	Moderate level of impairment; concentrations generally stable
M57-1	Deep (upper/mid)	• Reference location	No water quality impairment
M80-1	Deep (upper/mid)	• Reference location	No water quality impairment
GM-12	Deep (upper/mid)	• Some parameters exceed the median reference concentrations	Possible weak level of impairment

TABLE 3-7 Summary of Monitoring Results, East of Trail Landfill Area – Deep Aquifer			
	Aquifer	Groundwater Quality	Comments
M3-1	Deep (upper/mid)	• Reference location	No water quality impairment
M8B-1	Deep (upper/mid)	• Elevated alkalinity, chloride, sodium and hardness indicate road salt impact	No water quality impairment (due to leachate influences); concentrations generally decreasing
M35-1	Deep (upper/mid)	• Reference location	No water quality impairment
M79-1	Deep (upper/mid)	• Several parameters exceed the reference concentration range; elevated alkalinity, chloride, sodium and hardness indicate road salt impact	No water quality impairment (due to leachate influences); concentrations generally decreasing

TABLE 3-8 VOCs Detected in Deep Aquifer		
Location	VOCs Detected	Change from Previous
M5-1 (upper/mid)	ethylbenzene	decreasing
M16-1 (lower)	1,1-dichloroethane c-1,2-dichloroethylene t-1,2-dichloroethylene vinyl chloride	increasing increasing stable decreasing
M23-2 (upper/mid)	1,1-dichloroethane	gradually decreasing
M32-1 (upper/mid)	1,2-dichlorobenzene 1,3,5-trimethylbenzene **1,4-dichlorobenzene** benzene **ethylbenzene** m/p-xylene o-xylene monochlorobenzene **toluene** trichloroethylene vinyl chloride	increasing increasing increasing stable stable stable stable first detection stable sporadic detections stable
M39-2 (lower)	1,1-dichloroethane 1,2-dichlorobenzene 1,3-dichlorobenzene 1,4-dichlorobenzene benzene	stable first detection first detection first detection stable
M39-4 (upper/mid)	1,1-dichloroethane 1,2-dichlorobenzene 1,3-dichlorobenzene 1,4-dichlorobenzene benzene vinyl chloride	stable first detection first detection first detection first detection stable
M39-7 (upper/mid)	1,1-dichloroethane vinyl chloride	stable increasing
M151-1 (upper/mid)	1,1-dichloroethane vinyl chloride	no previous data

Note: Entries in bold represent locations where ODWS values have been exceeded.

Parameter	PWQO	S39 Spring	S40 Spring	S40 Summer	S40 Fall	S40A Spring	S40A Fall	S41 Spring	S41 Fall	S52 Fall	S52 Fall
Alkalinity as CaCO3		290	230	210	390	240	230	370	300	182	210
Boron	0.2	0.05	0.05	0.093	0.053	0.04	0.036	0.03	0.017	0.06	0.033
Bromide		< 0.05	< 0.05	< 0.25	< 0.25	< 0.05	< 0.25	< 0.1	0.61	<0.25	0.25
Calcium		95	106	80	140	104	101	111	179	85	99
Chloride		25	77	96	38	68	155	450	880	133	164
Chemical Oxygen Demand		17	41	42	17	27	32	34	57	-	36
Conductivity		61	88	82	96	81	101	210	320	888	101
Dissolved Organic Carbon		7.8	15	11.2	4.4	10.8	11	6.9	4.5	11.9	13
Ethylbenzene		-	-	-	-	-	-	-	-	0.14	< 0.5
Iron	0.3	0.1	**0.82**	**0.38**	0.189	**0.64**	0.21	0.23	0.031	0.14	0.2
Hardness as CaCO3 mg/L		299	372	282	502	358	363	405	669	307	354
Potassium		1.63	5.2	6.2	6.5	4.3	4.9	5.6	4.1	5	4.7
Magnesium		15	26	20	37	24	27	31	54	23	26
Sodium		15.6	38	60	23	33	68	260	410	68	72
N-NH3 (ammonia)		0.008	0.003	0.007	< 0.003	< 0.003	0.008	< 0.003	< 0.003	<0.02	0.009
pH	6.5-8.5	8.27	8.24	8.09	7.92	8.24	8.14	8.16	8.03	8.32	8.21
Phenols	0.001	< 0.001	< 0.001	-		< 0.001	-	< 0.001	-	<0.001	-
Sulphate		13.3	124	66	89	102	65	85	97	71	62
Total Kjeldahl Nitrogen		0.49	0.56	0.97	0.23	0.56	0.63	0.32	0.36	0.73	0.67
Total Phosphorus	0.03	0.012	0.014	**0.055**	0.011	0.013	0.019	0.011	0.01	<0.02	0.019
Total Suspended Solids		2	52	14	16	14	7	9	1	3	3

TABLE 3-12 Total Phosphorus Data from N-E Corner Surface Water		
	Cedar Forest Discharge*	N-E Corner Locations**
Fall 2006 Average	0.025	0.061
Fall 2006 Range	0.016 to 0.039	0.014 to 0.11
Spring 2007 Average	0.013	0.013
Spring 2007 Range	0.01 to 0.019	0.011 to 0.014

Note: all concentrations in mg/L

* locations CF1, CF2, CF3, CF4, and CF6

** locations S39, S40, S40A and S41

Parameter	PWQO	S12 Spring	S12 Summer	S12 Fall	S9 Spring	S9 Summer	S9 Fall
Alkalinity as CaCO3		168	163	280	182	195	240
Boron	0.2	< 0.02	0.035	0.022	< 0.02	0.039	0.032
Bromide		< 0.05	< 0.05	< 0.25	< 0.05	< 0.05	< 0.25
Calcium		52	48	104	61	62	100
Chloride		25	67	118	45	88	210
Chemical Oxygen Demand		35	39	67	34	54	68
Conductivity		44	55	97	56	70	114
Dissolved Organic Carbon		9.7	11.6	13.4	8.4	10.2	10.3
Iron	0.3	0.061	0.092	**1.26**	0.056	0.069	**5.5**
Hardness as CaCO3 mg/L		185	189	379	215	241	348
Potassium		1.38	1.4	3.6	1.82	1.93	4.2
Magnesium		13.3	16.9	29	15.2	21	24
Sodium		13.4	35	44	25	45	101
N-NH3 (ammonia)		0.009	< 0.003	0.21	0.011	< 0.003	0.047
pH	6.5-8.5	8.15	8.4	7.76	8.16	8.48	7.89
Phenols	0.001	0.001	-	-	< 0.001	-	-
Sulphate		8.2	17.9	57	19.1	31	51
Total Kjeldahl Nitrogen		0.5	0.72	0.86	0.53	0.65	0.83
Total Phosphorus	0.03	0.017	**0.036**	**0.132**	0.019	**0.033**	**0.081**
Total Suspended Solids		4	6	38	3	4	122
Silver	0.075	< 0.005	< 0.001	< 0.0001	< 0.005	< 0.001	< 0.0001
Aluminum	0.0001	**< 0.001**	< 0.0002		**0.001**	< 0.0002	

Notes
Bold and shaded values exceed PWQO criterion.
-: data not available

Parameter	Trigger Concentrations	Surface Water Trigger Locations			
		S40A		S52	
		Spring	Summer	Nov.	Dec.
Boron	0.2	0.04	dry	0.033	0.06
Ethylbenzene	0.008	<0.0005		-	<0.0005
Toluene	0.0008	<0.0005		<0.0005	<0.0005
N-NH3 (ammonia)		0.003		0.009	<0.02
pH	6.5-8.5	8.02		7.71	na
Temperature		13.9		7.3	na
NH3 - Fract. Union. (%)		2.562		0.763	na
NH3 - Union.	0.02	0.00008		0.00007	na