BIOREMEDIATION OF PETROLEUM CONTAMINATED SOIL USING COMPOSTING

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ABSTRACT

Petroleum-contaminated sites are a common occurrence in today's environment. One such site in Saskatchewan consists of an earthen pit excavated in the ground and filled with petroleum waste (used oil, gasoline, diesel fuel, paint thinners). This pit was in use for approximately 20 to 25 years. When environmental regulations in Saskatchewan started to become more stringent, the process of disposing of wastes in the pit was discontinued and the remainder of the pit was filled with soil. The organization that owns the site is now considering moving its operation to a new site and must decommission the existing site. As part of the decommissioning of the site, it must remediate the waste oil disposal pit.

It was determined, based on field investigation and study, that bioremediation was a suitable alternative for remediation of the contaminated soil in and around the pit. Bioremediation has been used extensively to remediate petroleum-contaminated soil. Many different methods of bioremediation are available. One method that has shown considerable potential, but has not received widespread use is, composting. Therefore, it was decided to conduct a bench scale treatability study to assess the potential for successful bioremediation of the site using composting.

Two reactors were set up; both contained a nutrient amendment (ammonium phosphate fertilizer). One reactor also contained a high-energy source (a mixture of grass clippings and sheep manure) and the other reactor did not. The high-energy source was added in an effort to determine if the composting process could be accelerated by the addition of these abundantly available waste materials.

The results of the study showed that the site could be remediated using composting. Based on the results of the treatability study, the half-life of the petroleum hydrocarbons at the subject site was estimated to be 36.3 days and 121.6 days with the addition of a high energy source (Reactor 1) and without the addition of the high energy source (Reactor 2), respectively. Based on the half-life of the contaminant in each reactor, it was estimated that it would take approximately 192 and 643 days to remediate a volume of soil using the amendments of Reactors 1 and 2, respectively.

ACKNOWLEDGEMENTS

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NOMENCLATURE

ASTM	American Society for Testing and Materials
Br	Bromine
BTEX	Benzene, toluene, ethylbenzene, xylenes
C	Carbon
C	Contaminant concentration
CCME	Canadian Council of Ministers for the Environment
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
cfu	Colony forming unit
CH	Carbon-hydrogen atom
Cl	Chlorine
CO_2	Carbon dioxide
CN	Cyanide
C:N:P:K	Carbon to nitrogen to phosphorus to potassium ratio
C_x	Denotes a carbon chain length (number of carbon atoms) in a molecule of a petroleum hydrocarbon product, where x is any whole number
C_0	Initial contaminant concentration
$C_5H_7O_2N$	Chemical formula of biomass produced during biodegradation processes
$C_{22}H_{44}$	Assumed chemical formula for petroleum contaminant of concern
dC/dt	Rate of change of contaminant concentration with time
$\ddot{e}$	electron
EA	Electron acceptor
ED	Electron Donor
EOCl	Extractable organic chlorine
GC	Gas chromatography
g	Gram
H	Hydrogen
H^+	Hydrogen ion
H_2O	Water
I	Iodine
IR	Infrared
K	Degradation rate constant
k_m	maximum substrate utilization rate
K_s	Half-velocity coefficient
Kg	Kilogram
MAHs	Monocyclic aromatic hydrocarbons
mg/L	Milligrams per litre
N	Nitrogen
NH_3	Ammonia
NH_4PO_4	Ammonium phosphate
NO_3	Nitrate
O_2	Oxygen
PAHs	Polycyclic aromatic hydrocarbons
PCBs	Polychlorinated biphenyls

PCP	Pentachlorophenol
pH	Hydrogen ion concentration
ppm	Parts per million
SERM	Saskatchewan Environment and Resource Management
T	Time
TPH	Total petroleum hydrocarbons
TSH	Total semi-volatile hydrocarbons
USEPA	United States Environmental Protection Agency
X	Microbial concentration
°C	Degrees Celsius

CHAPTER ONE

INTRODUCTION

1.1 General

Petroleum-contaminated sites are common in today's environment. Sites become contaminated with petroleum through various avenues, including releases from underground and/or aboveground storage tanks, improper disposal of waste lubricating oils, accidental releases from petroleum handling facilities (e.g. tank farms, pipelines, etc.), and spills (while transporting, loading/unloading). With regulatory agencies becoming more concerned with the release of petroleum products into our environment, there is a growing need to develop more effective and less expensive technologies to remediate the petroleum-contaminated soils from these sites to acceptable standards.

There are numerous technologies available to remediate petroleum-contaminated sites to acceptable standards. The selection of a suitable method for the remediation of a contaminated site depends on such factors as site characteristics, hazardous waste characteristics, regulatory guidelines and cost.

1.2 Background

During the early 1960's, a company in Saskatchewan, Canada excavated a pit on their property and used it to dispose of petroleum wastes such as used oil, gasoline, diesel fuel and paint thinners. At the time, there were few environmental restrictions on such practices, and the company found this was the least costly option to dispose of such wastes. This practice continued until the early 1980's when environmental regulations concerning the disposal of hazardous wastes started becoming more stringent. Regulations (Hazardous Substances and Waste Dangerous Goods Regulations) for the disposal of hazardous materials, including petroleum hydrocarbons, were introduced in the early 1980's. The practice was discontinued and the remainder of the pit was filled in with soil. The company is now planning to move their operation to a new site and, as part of the decommissioning of the existing site, it must remediate the area of the waste oil disposal pit to comply with current regulatory guidelines in Saskatchewan.

The company did not keep records of the types and amount of wastes that were deposited in the pit and, although the waste pit was intended for disposal of waste petroleum products only, the company was unsure of the type of contaminants that may be present. In addition, the company was uncertain of the exact location and dimensions of the pit.

A site investigation and laboratory analyses program was conducted to determine the types of contaminants present in the pit, the approximate dimensions of the pit, and the areal extent and depth of contaminated soil in the vicinity of the pit.

The field investigation consisted of two phases. The first phase involved drilling 21 test holes to depths between 4.6 m and 10.7 m in the assumed area of the pit. These test holes were drilled to obtain samples for characterization of the waste contained in the pit (i.e. the types and concentrations of contaminants) as well as to provide an estimate of the areal extent and depth of impacted soil. The second phase of test drilling involved drilling an additional 40 test holes to depths between 1.5 m and 6.1 m within and around the estimated boundaries of the pit. Samples were not taken from these test holes because they were drilled strictly for the purpose of refining the estimated physical boundaries of the pit and the estimated extent of impacted soil based on visual and olfactory evidence of impacted soil and the results of ambient temperature headspace measurements. The locations of the test holes and the estimated boundaries of the pit are shown in Figure 1.1.

The bore hole logs (Appendix A) indicated that the soil stratigraphy at the site consisted of clay till and/or lacustrine clay over silty sand. The clay till was medium plastic and was generally in a moist and very stiff condition. The clay fill was highly plastic, although there were some more sandy and less plastic zones. It was generally in a moist and very stiff condition, although some more moist and less stiff areas were encountered. The sand was weathered (brown) and was generally in a moist and dense condition. Significant petroleum odour and staining were observed at many of the test holes.

The site hydrogeology consisted of two aquifer formations situated on top of one another and separated by a clay till aquitard. The upper aquifer consists of the fine sand encountered in the lower part of the deeper test holes drilled at the site. This aquifer is approximately 10m to 25m thick (Maathuis and van der Kamp, 1988). It generally changes from a fine grained, silty sand to a coarse grained sand with some gravel. The

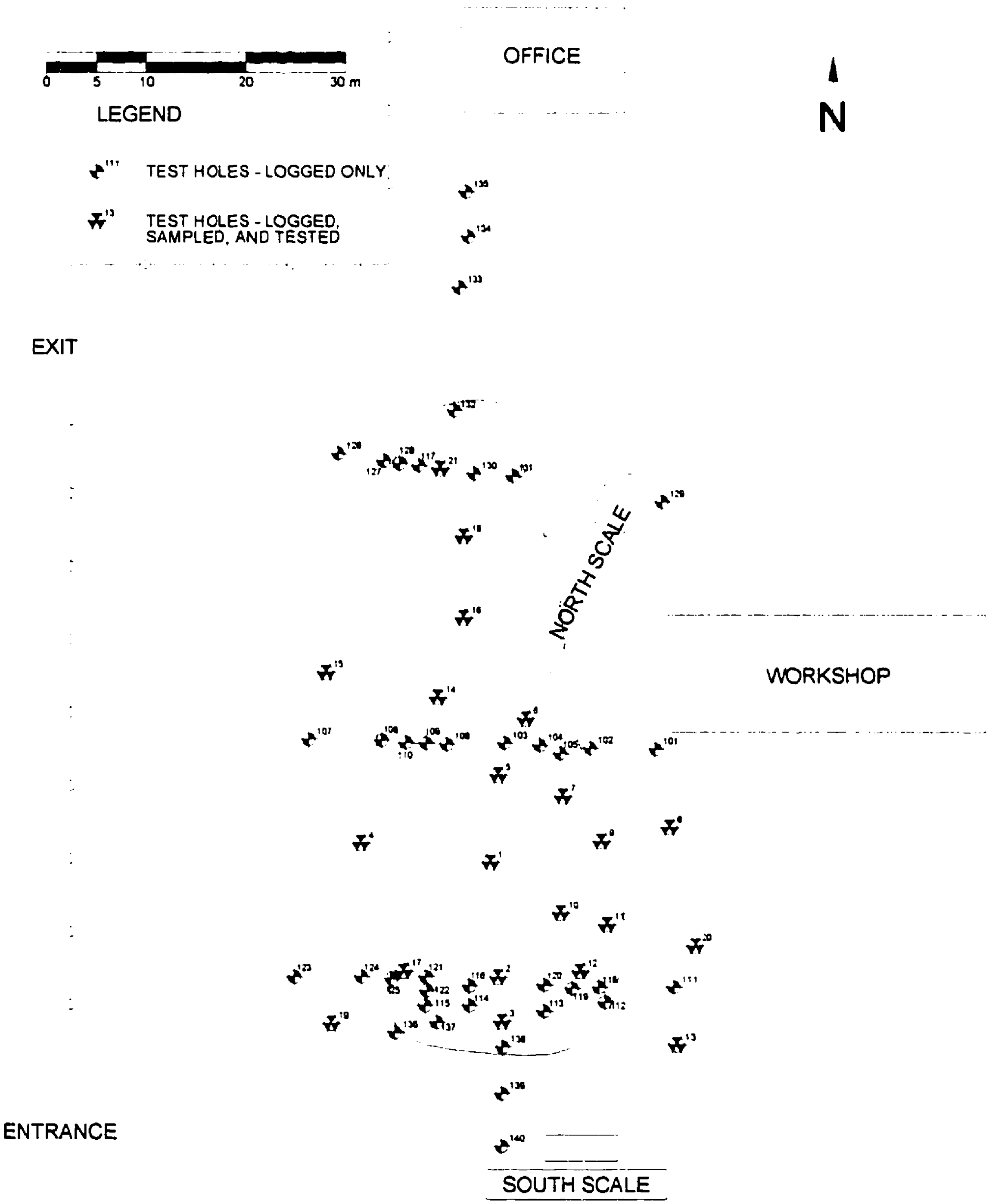


Figure 1.1: Site plan showing locations of test holes and boundaries of pit

piezometric surface lies approximately 20m below the ground surface and groundwater flow is toward the west-southwest (Maathuis and van der Kamp, 1988).

The lower aquifer is approximately 23 m to 50 m below the ground surface and varies in thickness from 4 m to 40 m (Maathuis and van der Kamp, 1988). It is generally composed of medium sized sand particles with some gravel. The aquifer is under artesian pressure with a piezometric surface which lies approximately 30m below the ground surface. Groundwater flow is to the south-southwest (Maathuis and van der Kamp, 1988).

Seventy-eight soil samples were selected for laboratory analyses of potential contaminants. The analyses consisted of the following contaminants: total petroleum hydrocarbons (TPH), benzene, toluene, ethylbenzene, xylenes (BTEX), total semi-volatile hydrocarbons (TSH), phenoxy neutral herbicides, phenols, polychlorinated biphenyls (PCBs), heavy metals and trace elements, ethylene glycol and extractable organic chlorine (EOCl). Table 1.1 presents the number of samples analyzed for each of the contaminants.

Table 1.1: Number of soil samples analysed for each potential contaminant

Parameter	Number of Samples Analysed
TPH	78
BTEX	11
TSH	19
Phenoxy-neutral Herbicides	7
Phenols	7
PCBs	4
Heavy Metals and Trace Elements	4
Ethylene Glycol	4
EOCl	4

Saskatchewan Environment and Resource Management's (SERM's) "Risk-Based Corrective Actions at Petroleum Contaminated Sites" (1995) and the Canadian Council of Ministers of the Environment (CCME) "Interim Canadian Environmental Quality Criteria for Contaminated Sites" (1991) were used to assess the analytical results and the requirement for site remediation. These two sets of guidelines are intended to provide a basis for assessment and remediation of contaminated property, depending upon the intended use of the property, such as agricultural, residential/parkland or commercial/industrial.

The present land use in the area surrounding the site primarily consisted of agriculture with several commercial operations and one residential holding located north and south of the site, respectively. In addition, it was considered possible that following closure of the site, the site could be converted to a passive park area. Therefore, the analytical results were evaluated using Saskatchewan Environment and Resource Management (SERM) residential/parkland criteria which were the most stringent criteria in consideration of the existing surrounding land use and anticipated future land use.

An examination of the gas chromatographs from the TSH analyses indicated that gasoline, paint thinners, diesel fuel, lubricating oil and/or crude oil were the primary petroleum compounds found in the soil samples. Table 1.2 presents a summary of the different types of petroleum hydrocarbons found based on test hole number and depth.

Table 1.2: Types of petroleum hydrocarbons present in soil

Test Hole	Depth (m)	Type of Petroleum Hydrocarbon
1	3.3	Gasoline, paint thinners, diesel fuel, lube oil
2	2.2	Gasoline, paint thinners, diesel fuel, lube oil
3	1.5	Gasoline, paint thinners, diesel fuel, lube oil
6	3.8	Gasoline, paint thinners, diesel fuel, lube oil
7	3.8	Gasoline, paint thinners, diesel fuel, lube oil
9	3.0	Gasoline, paint thinners, diesel fuel
10	3.8	Gasoline, paint thinners, diesel fuel, crude oil
11	5.0	Diesel fuel
12	2.3	Diesel fuel
16	6.1	Diesel fuel, lube
17	3.0	Gasoline, paint thinners, diesel fuel, lube oil
18	5.3	Gasoline, paint thinners, diesel fuel, lube oil
20	3.8	Diesel fuel
21	5.3	Diesel fuel, lube oil

Total petroleum hydrocarbon concentrations were above the 1,000 ppm guideline (SERM, 1995) in approximately 67 percent of the samples analyzed. The highest concentration was 270,000 ppm which was observed in Test Hole 1 at a depth of 3.8 m. The lowest concentration was 4 ppm which was observed in Test Holes 13 and 19 at depths of 3.8 m and 1.5 m, respectively. TPH concentrations generally exceeded the guideline value at depths of between 1.5 m and 6.1m, at the majority of the test holes which were sampled (Test Holes 1 to 21), although, some test holes did have concentrations above the guideline value outside of this depth range. The weighted average TPH concentration was calculated for each test hole. The weighted averages at the test hole locations were averaged to obtain an average TPH concentration of 31,051 ppm over the site. Table 1.3 presents data on TPH concentrations.

Table 1.3: TPH concentrations in soil

Test Hole	Sample Depth (m)	TPH Concentration (ppm)	Weighted Ave. TPH Concentration in Test Hole (ppm)
1	1.5	1,110	91,280
	2.2	15,000	
	3.8	270,000	
	6.8	79,600	
	7.6	34,000	
	9.1	12	
2	1.5	6,890	80,189
	3.8	160,000	
	5.3	110,000	
	6.1	101,000	
3	2.3	19	46
	3.8	119	
	4.6	11	
4	1.5	140,000	58,484
	2.3	1,940	
	4.6	16	
5	2.3	681	14,632
	3	6,000	
	5.3	37,400	
	6.1	51,200	
6	1.5	73	26,809
	4.6	71,000	
	6.1	24	
7	2.3	2,100	27,134
	5.3	68,600	
	6.1	68,000	
8	3.8	66	3,406
	4.6	60	
	7.6	17,000	
9	2.3	9,500	40,801
	4.6	86,900	
	6.1	68,000	
10	3	26,000	42,711
	5.2	105,000	
11	3	7,600	53,465
	3.8	144,000	
	4.6	117,000	
	5.3	154,000	
	6.1	212	
12	2.3	18,600	67,413
	3.8	73,000	
	5.3	213,000	
	6.1	106	
13	2.3	1,020	1,537
	4.6	<4	
	5.3	8,000	
	6.1	14	
14	3.8	47,000	28,888
	6.1	36,400	
	7.6	3,160	
	10.7	17	
15	2.3	63	49
	4.6	5	
16	1.5	1,200	28,754
	2.3	239	
	4.6	103,000	
	5.3	21,000	
	6.1	16,500	
17	2.3	4,700	12,073
	3.0	39,600	
	4.6	5,200	
	5.3	37	
18	2.3	37,000	44,016
	3.0	1,880	
	5.3	97,800	
	6.1	40,100	
19	0.8	640	169
	1.5	4	
	4.6	22	
20	0.8	139	2,962
	1.5	5,000	
	3.8	3,840	
	4.6	31	
21	2.3	39,000	56,480
	3.0	124,000	
	4.6	1,550	
	5.3	129,000	
	6.1	124	

BTEX and phenol concentrations were above the SERM (1995) and CCME (1991) criteria for residential/parkland land use in the samples from Test Holes 1 (3.3 and 3.8m), 2 (2.2m), 12 (3.0m), 14 (3.0m), 17 (3.0m) and 21 (5.3m) (Table 1.4). This indicated that there were high concentrations of volatile petroleum hydrocarbons present in the soil.

Table 1.4: BTEX and phenol concentrations (ppm) in soil

Test Hole	Benzene	Toluene	Ethylbenzene	Xylenes	Phenols
1 (3.3 and 3.8m)	47	36	37	835	---
2 (2.2m)	11	---	5.5	26	2.5
12 (3.0m)	---	9.5	6.0	36	---
14 (3.0m)	---	---	---	5.1	---
17 (3.0m)	2.3	---	---	97	---
21 5.3m)	1.5	---	---	---	---
SERM residential/parkland criteria	0.5	3.0	5.0	5.0	---

Ethylene glycol, PCB and trace element concentrations (Appendix B) were below method detection limits and were, therefore, not of concern.

Results of the solvent scan, herbicide scan, and EOCl scan (Appendix B) were below or very near the method detection limits and, therefore, these parameters were not of concern.

The boundaries of the pit were estimated by a visual examination of the soil to determine the presence of fill soil. The transition from fill soil to native soil was assumed to be the boundary of the pit. The estimated boundary of the pit was approximately as shown in Figure 1.1. The boundary of the pit consisted of two portions; a long narrow section to the north, 15m wide by 40m long, and a wider, trapezoidal shaped section to the south, 28m by 28m.

The areal extent and depth of the contaminated soil requiring remediation was estimated using TPH values. Based on the values presented in Table 1.3, the estimated volume of soil requiring remediation was 8,000 m^3.

A preliminary feasibility analysis was conducted for the subject site in 1995 (Viraraghavan et al). The feasibility study evaluated various technologies for remediation of the site. Costs from the literature used for analysis of several remediation alternatives are shown in Figure 1.2. From the preliminary feasibility analysis, it was determined that bioremediation should be examined further for remediation of the contaminated soil from this site.

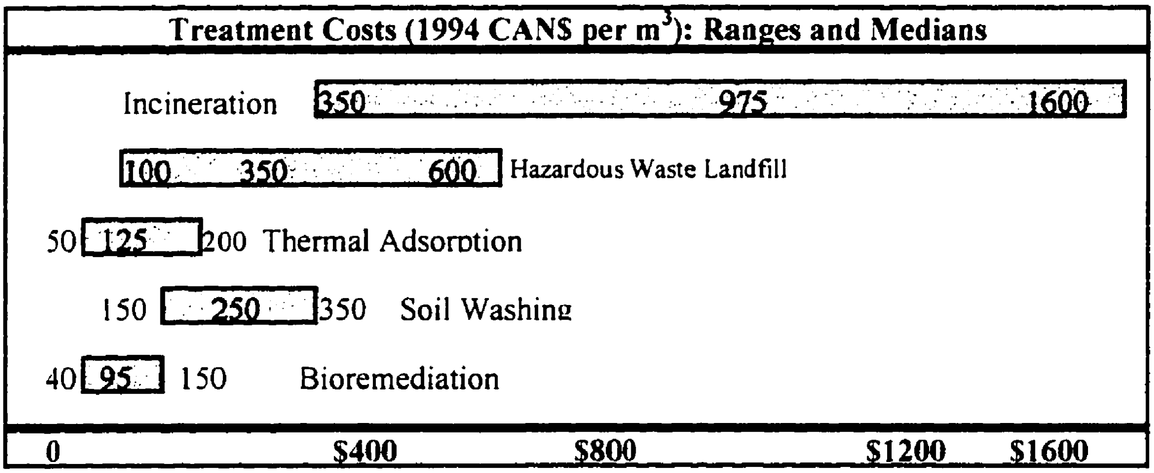


Figure 1.2: Treatment Costs for Petroleum Contaminated Soil (Leahy and Brown, 1994)

An analysis of several bioremediation alternatives was then conducted in order to choose the option that could be used to remediate the site at the lowest possible cost and within a reasonable length of time. The alternatives that were evaluated were landfarming, composting, accelerated composting (biopile composting) and enhanced biopile/biofiltration. It was determined that accelerated composting would provide most effective remediation at a reasonable cost.

1.3 Objectives of the Study

The objective of this study was to conduct a bench-scale biotreatability study using a composting process which would demonstrate a reduction in the concentration of the petroleum hydrocarbons (presumably to below the SERM guideline criteria). The components of the study used to acheive the overall objective were as follows:

1. analysis of the nutrients in the soil and the need for nutrient additions;
2. identification of the presence and types of hydrocarbon degrading bacteria in the petroleum hydrocarbon contaminated soil at the site;
3. enumeration of the bacterial population; and
4. evaluation of the contaminant half life.

1.4 Scope of the Study

The scope of the study included a review of literature on bioremediation of contaminated soil using the composting process. Laboratory studies were conducted to determine whether or not the concentration of petroleum hydrocarbons in the soil could be reduced to below the SERM guideline value of 1000 ppm.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 General

The literature review is presented in three sections. The first section discusses the development of composting of petroleum-contaminated soil. The second section of the literature review covers the important factors which determine the efficiency of composting operations. The third and fourth sections outline the procedures for conducting treatability studies, and the degradation kinetics used to predict final cleanup levels for bioremediation processes, respectively.

2.2 Development of Composting

2.2.1 Definition of Composting

In order to understand the composting process one must first define composting. There is no universally accepted definition of composting. Haug (1980) defined composting as follows:

"biological decomposition and stabilization of organic substrates under conditions which allow development of thermophilic temperatures as a result of biologically produced heat, with a final product sufficiently stable for storage and application to land without adverse environmental effects".

This definition is basically accurate with reference to composting municipal wastes; however, it may not be totally accurate when considering the composting of hazardous wastes. Cookson (1995) reported that composting of some hazardous compounds does not require the higher temperatures that are typical in composting municipal wastes and which are required for the destruction of pathogenic organisms. He further stated that if no pathogenic organisms are associated with the wastes, then the higher temperatures are not necessary. In fact, he stated that composting of hazardous compounds had been successfully pilot tested at ambient temperatures. Considering the above, it appears that composting need not allow the development of thermophilic temperatures as stated by Haug (1980). The definition of composting given by Golueke (1977) may be more appropriate for application to composting of both hazardous and non-hazardous wastes.

"Composting is a method of solid waste management whereby the organic component of the solid waste stream is biologically decomposed under controlled conditions to a state in which it can be handled, stored, and/or applied to the land without adversely affecting the environment".

2.2.2 Process Description

Composting is a natural process whereby microbiological transformations, known as bioremediation, convert hazardous materials to harmless inorganic products in a simple, inexpensive and environmentally safe manner (Williams and Myler, 1990). Until recently, composting has been used primarily to treat wastewater sludges, processing wastes and municipal refuse. The primary reasons for composting these materials are to reduce moisture content and volume, to destroy pathogens and odour-producing nitrogen and sulphur-containing compounds, and to stabilize the waste for ultimate disposal or use as a marketable product. The objective in composting hazardous materials is to convert the hazardous substances into innocuous end products. In general, no matter what the material being composted, the composting process employed is virtually the same. However, the shift in objectives between composting non-hazardous wastes and hazardous wastes requires that a more tightly controlled and aggressive approach be employed for composting hazardous wastes.

Modern composting systems are usually divided into three types: windrow, aerated static pile (biopile) and in-vessel. Each is described below.

Windrow System

In the windrow composting system (Figure 2.1), the contaminated soil is usually mixed with a bulking agent to facilitate air permeation through the soil. Other items that may be mixed with the soil and bulking agents include fertilizer or nutrients from other sources, organic material (such as municipal waste, animal wastes, grass clippings, leaves) and bacterial innoculants. The purpose of the addition of these materials is described later in this chapter. The mixture is then distributed in long rows on an impervious liner. The rows are typically 1.2m to 1.5m in height and 3.0m to 3.7m in width. The length of the rows will vary depending upon the land available for the process. The rows of contaminated soil are mixed or turned daily to maintain an aerobic condition by convective air flow and diffusion. Mixing is usually done using a front-end loader or specially designed equipment. Front-end loaders are generally less expensive than specially designed equipment, however, the quality of the mix is usually better (i.e.

nutrients are mixed better and aeration is better) when specially designed equipment is used.

The rows of contaminated soil are usually constructed on an impervious liner to prevent the contaminant(s) from seeping into the native soil and into groundwater systems. Some berming or ditching may also be required around the area to prevent contaminants from moving off-site and entering surface waters.

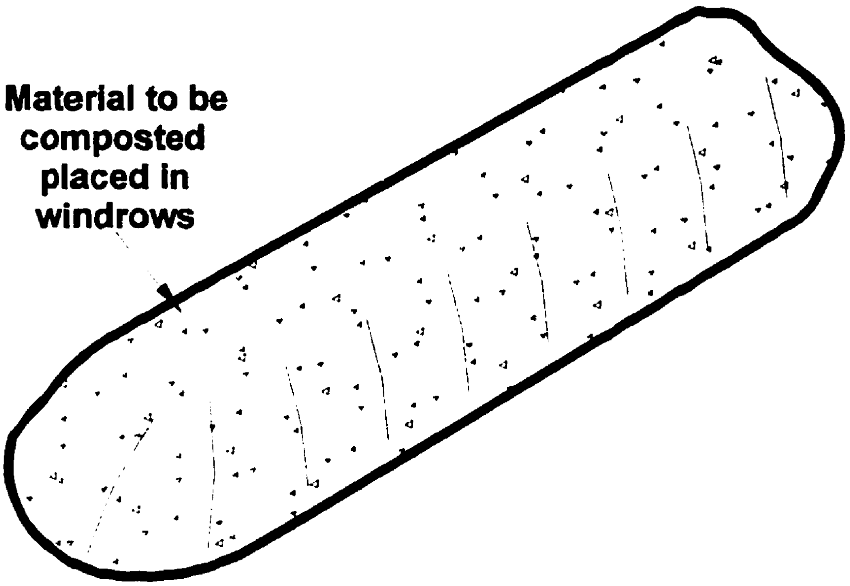


Figure 2.1: Windrow composting system (Tchobanoglous, 1993)

Static Pile System

The static pile composting system (Figure 2.2) uses forced aeration to maintain aerobic decomposition in a much larger pile mass than is possible with the windrow system (Cookson, 1995). Aeration is typically provided by a system of perforated pipes installed under the static pile(s). The contaminated soil is mixed with various amendments as described for the windrow system and placed in piles over the perforated pipe. The

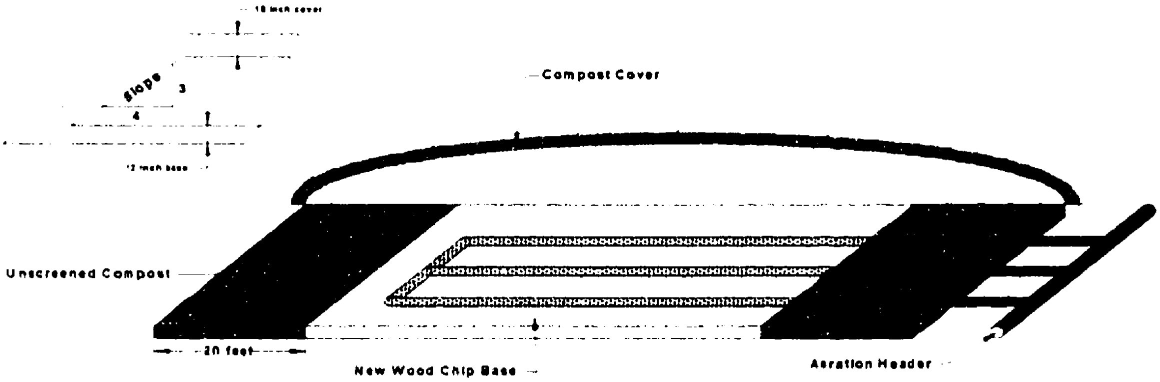


Figure 2.2: Static pile composting system (Albrecht, 1983)

perforated pipes are connected to a non-perforated header pipe which is connected to fans which either draw air or force air through the pile. It is preferrable to draw air through the pile as this will allow treatment of volatile emissions. In a system which forces air through the pile, the system of pipes may be covered with a layer of highly permeable material such as wood chips or gravel to allow the air being released from the pipes to be more evenly distributed under the pile. This will allow more even percolation of air through the pile. The piles can be up to 6 m in height. The height of the piles is limited by the capabilities of the front-end loader or backhoe that is used in their construction. As with the windrow system, the piles are usually constructed on an impervious liner to prevent the contaminant(s) from seeping into the native soil and into ground water systems. Some berming or ditching may also be required around the area to prevent contaminants from moving off-site and entering surface waters.

In-vessel System

The process used for in-vessel composting is identical to that described in windrow and static pile composting. The mixture is placed inside enclosed reactors where the actual composting takes place. The major advantage is that ditches, berms, etc. are not required due to the enclosed reactor, however, in-vessel operations do not allow the degree of process flexibility of the open systems (Cookson, 1995). For example, if a material handling problem such as compaction of the mix in the vessel should occur, correction by remixing with the front-end loader is not an option (Cookson, 1995). Therefore, most in-vessel systems use sophisticated mixing equipment and, hence, are very expensive. In-vessel composting uses pug mills and plow blade mixers for mixing, and belt conveyors, screw conveyors, cleated belt conveyors and drag conveyors for material transport.

There are two types of in-vessel composting reactors: plug flow (horizontal (Figure 2.3) and vertical (Figure 2.4)) and agitated-bed reactors (Figure 2.5). In plug flow reactors,

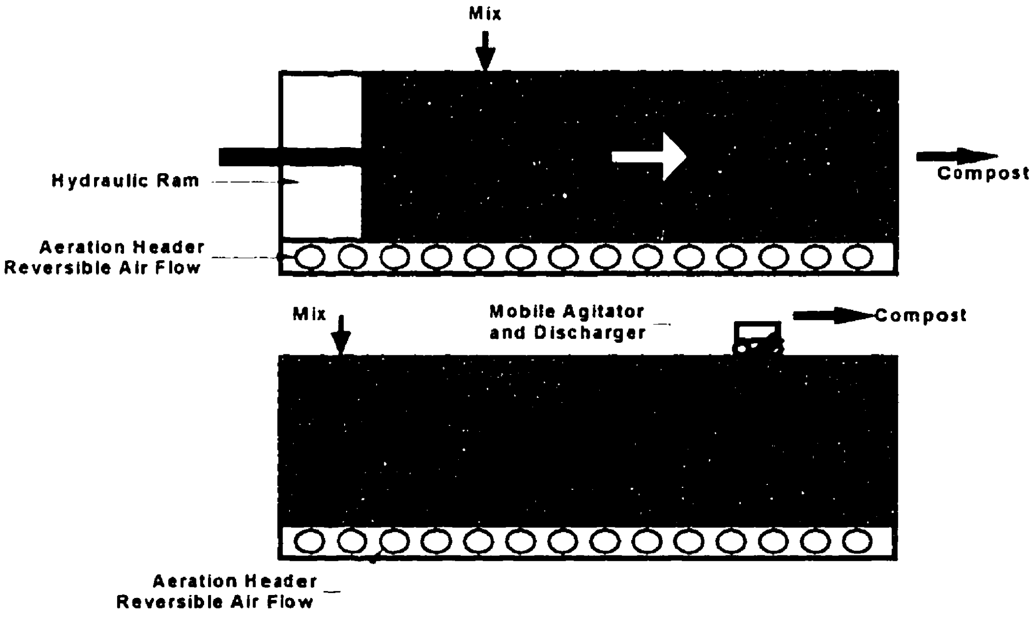


Figure 2.3: Horizontal-bed in-vessel composting reactor (U. S. EPA, 1989)

the mixing is such that the mix moves either from top to bottom or horizontally through the reactor chamber (Cookson, 1995). Most vertical plug flow reactors use a screw for material discharge (Cookson, 1995). In horizontal plug flow reactors, the material is transported by a moving floor or a hydraulic door (Cookson, 1995). The agitated bed reactors use mechanical mixing to mix the compost either in place or as it moves through the reactor (Cookson, 1995).

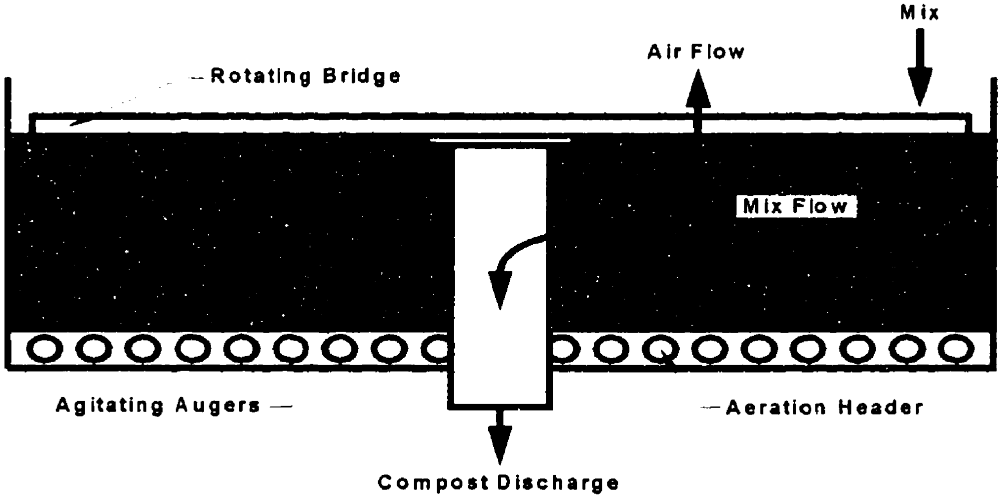


Figure 2.4: Vertical-bed in-vessel composting reactor (U. S. EPA, 1989)

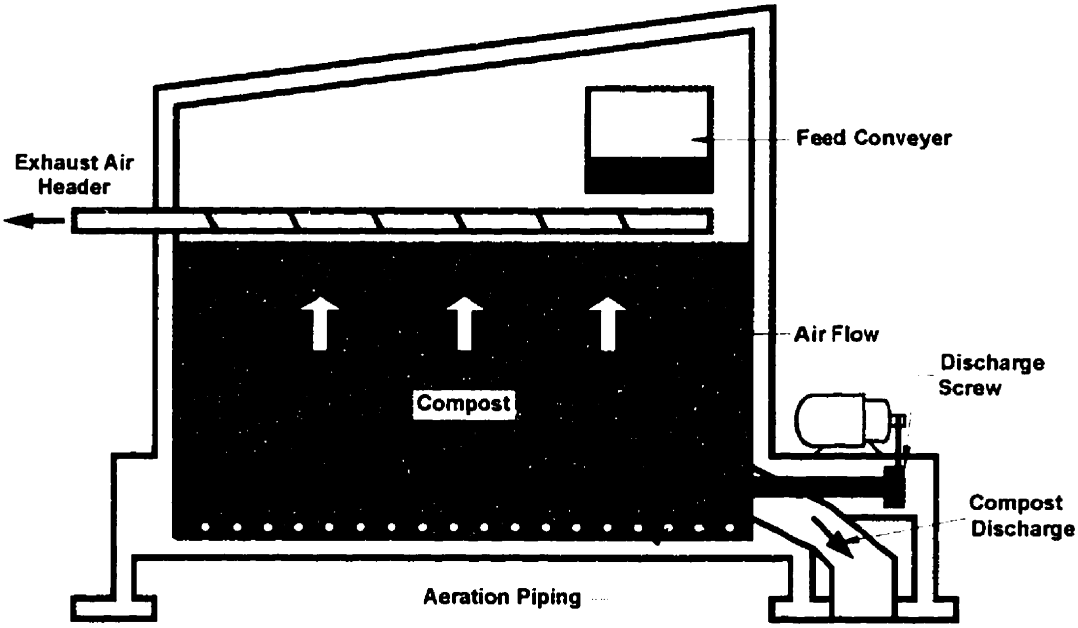


Figure 2.5: Agitated-bed in-vessel composting reactor (U. S. EPA, 1989)

2.2.3 Soil Contamination

The three most common types of hazardous materials released to the environment in decreasing order are petroleum products, creosote and volatile organic compounds (Cookson, 1995).

The widespread usage and storage of petroleum products have made them the most widespread soil and groundwater contaminant (Cookson, 1995). Leaking underground storage tanks have been cited as one of the most common sources of soil and groundwater contamination (Demque, 1994). It is estimated that across Canada there are 200,000 underground storage tanks installed, and as many as 30,000 may be leaking products into the underground environment (Demque, 1994).

2.2.4 Disposal of Contaminated Soil in Saskatchewan

In Saskatchewan, contaminated sites are evaluated using the SERM "Risk Based Corrective Actions for Petroleum Contaminated Sites in Saskatchewan (SERM, 1995)." The guidelines allow two methods of evaluating contaminated sites. One method is to evaluate the need for and degree of cleanup based on a risk assessment, and the other method is to evaluate these requirements based on future land use. Table 2.1 presents the future land use criteria published by SERM.

Table 2.1: SERM future land-use criteria (SERM, 1995)

Analyte	μg/g		
	Agricultural	Residential/Parkland	Commercial/Industrial
Benzene	0.05	0.5	5.0
Toluene	0.1	3.0	30
Ethylbenzene	0.1	5.0	50
Xylenes	0.1	5.0	50
Lead	375	500	1,000
TPH	1,000	1,000	1,000

Until approximately ten to fifteen years ago, landfilling was the most common method of disposing of contaminated soil. However, regulatory agencies are imposing greater restrictions on the disposal of contaminated soil in landfills. Landfilling of contaminated soil without some kind of treatment is no longer an acceptable form of disposal. Many landfills are setting up treatment facilities (usually bioremediation) to treat petroleum-contaminated soils. However, most landfills have an upper limit for the concentrations of petroleum in the soil that they will accept for treatment. The limit in Saskatchewan is 2 percent by weight or 20,000 μg/g. Soil with a petroleum hydrocarbon concentration greater than 20,000 μg/g usually requires the soil to be treated on-site or excavated and transported to a hazardous waste treatment facility. Off-site disposal at a hazardous waste treatment facility is usually very expensive. On-site treatment (usually ex-situ, biological treatment) is usually chosen because it is less expensive and eliminates the liability associated with the transportation of hazardous waste; however, it usually requires extensive permitting and regulatory approvals.

2.2.5 Chemical Nature of Petroleum Products

There are many different types of petroleum products, such as gasoline, diesel fuel, crude oil, solvents, pesticides, PCBs, PCP, and paint thinners. All these products are made of hydrocarbon compounds, which are, as the name implies, chemical compounds made up of hydrogen and carbon atoms (Rowell *et al.*, 1992). The carbon atoms are linked together in chains, in a ring, or in more than one ring (polycyclic hydrocarbons) (Rowell *et al.*, 1992). Petroleum products such as gasoline, diesel fuel and crude oil are sometimes grouped according to their "carbon number". The carbon number is simply the number of carbon atoms in a molecule of the product (Rowell *et al.*, 1992). For example C10 is a product that has 10 carbon atoms in one molecule of the product. Gasoline is typically in the C1 to C9 range, diesel fuel is typically in the C10 to C20, and crude oils are in the C21 to C30 range.

The composition of petroleum products varies with such factors as their origin, method of storage, treatment, and weathering conditions. Regardless of its source, a single petroleum product is usually made up of a large mixture of hydrocarbon compounds. For example, regular gasoline contains approximately 50 different hydrocarbon compounds (Cookson, 1995).

The focus of this research is degradation of gasoline, diesel fuel, used lubricating oil and small amounts of paint thinners and crude oil. The most common types of hydrocarbon structures contained in petroleum products such as these are aliphatic hydrocarbons and aromatic hydrocarbons.

2.2.5.1 Petroleum Aliphatic Hydrocarbons

Aliphatic hydrocarbons are straight or branched-chain hydrocarbons of various lengths (Cookson, 1995). They are divided into the families: alkanes, alkenes, alcohols, aldehydes, ketones, acids, and alkynes. Typical structures are shown in Figure 2.6.

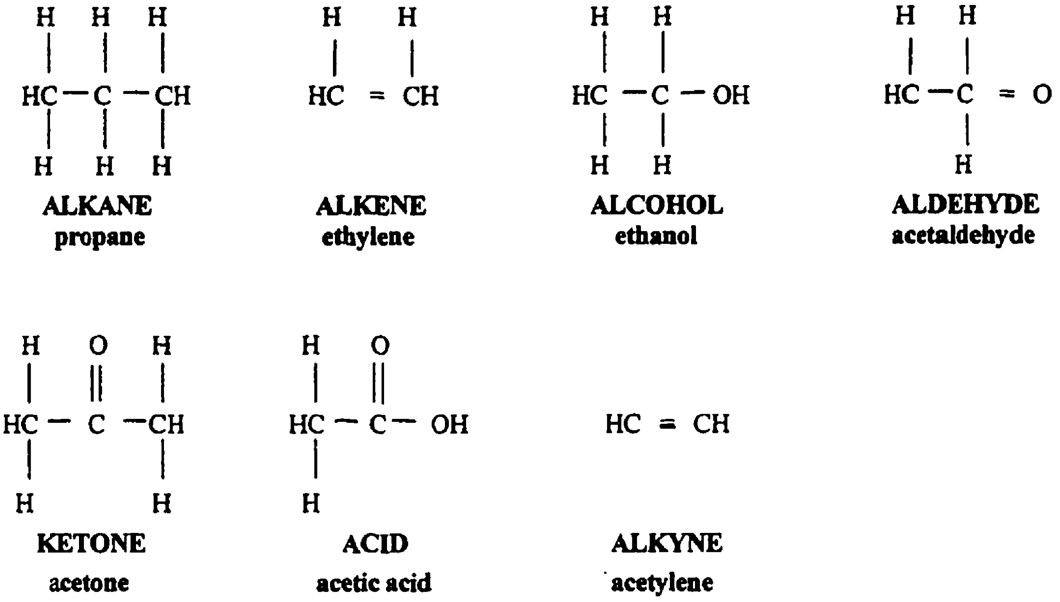


Figure 2.6: Petroleum aliphatic hydrocarbons (Cookson, 1995)

2.2.5.2 Aromatic Hydrocarbons

Aromatic hydrocarbons contain the benzene ring as the parent hydrocarbon. The benzene ring is represented by double bonds between alternate carbon atoms (Figure 2.7). Benzene ring compounds are further divided into monocyclic aromatic hydrocarbons (MAHs) and polycyclic or polynuclear aromatic hydrocarbons (PAHs). The MAHs are those that contain a single benzene ring. These consist of benzene, toluene, ethylbenzene and xylene (BTEX) compounds. Typical structures of MAHs are shown in Figure 2.8. PAHs are those compounds where several benzene rings are joined at two or more ring carbons. The hydrogen may or may not be substituted by other compounds. Some of the more common substitutes are chloro (Cl), bromo (Br), iodo (I), nitro (NO_2), and cyano (CN). Structures of some common PAHs are shown in Figure 2.9.

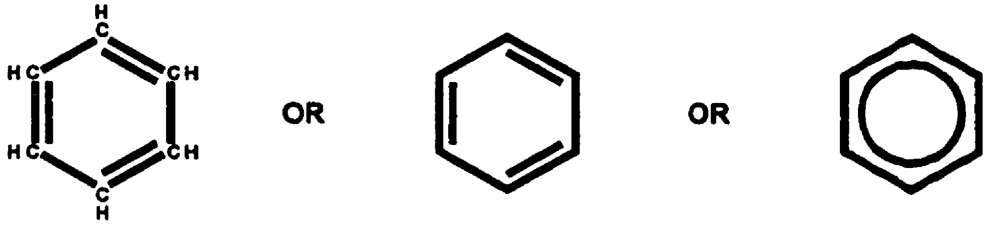
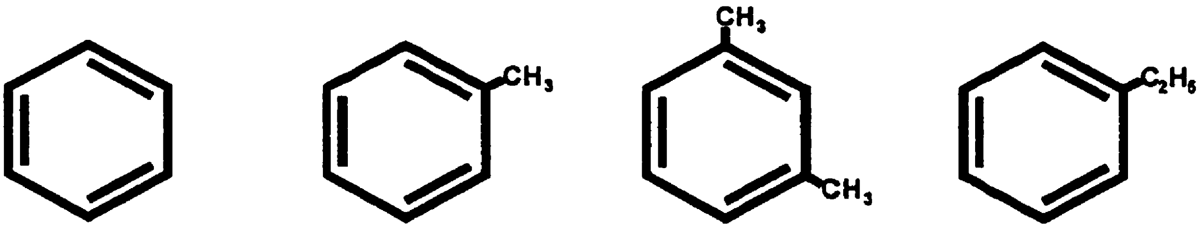
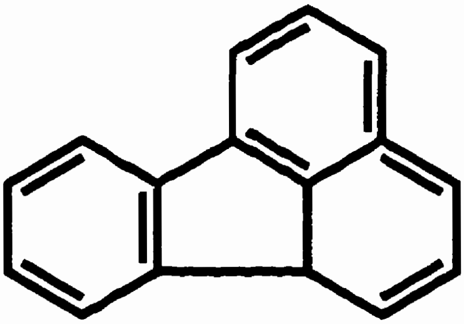


Figure 2.7: Benzene ring (Cookson, 1995)

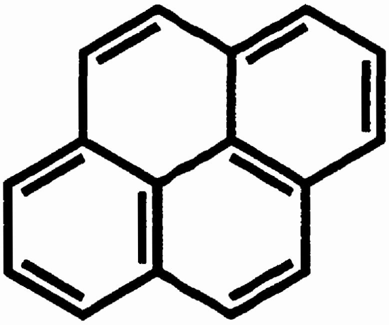


Benzene Toluene m-Xylene Ethylbenzene

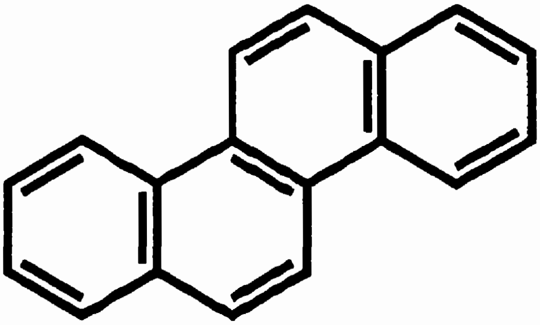
Figure 2.8: Single-ring aromatic hydrocarbons (Cookson, 1995)



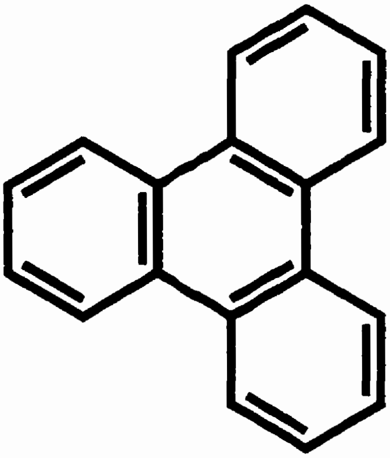
Fluoranthene



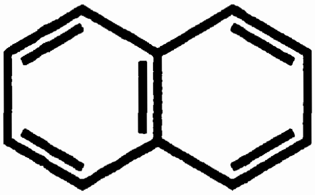
Pyrene



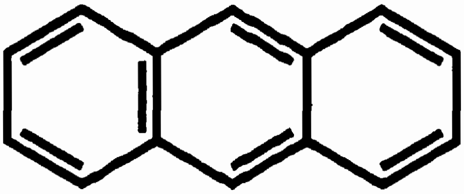
Chrysene



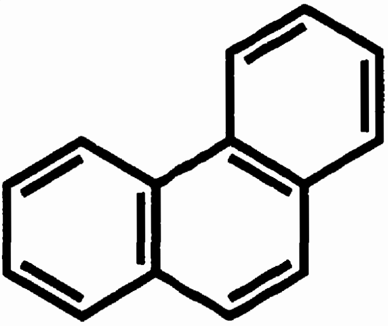
Triphenylene



Naphthalene



Anthracene



Phenanthrene

Figure 2.9: Multi-ring aromatic hydrocarbons (Cookson, 1995)

2.2.6 Microbial Decomposition of Petroleum Hydrocarbons by Bioremediation

Bioremediation is a process in which microorganisms in the soil convert complex organic materials (such as petroleum hydrocarbons) into cell biomass and other non-toxic by-products such as carbon dioxide (CO_2) and water (H_2O). This is accomplished through a catalyzed oxidation-reduction reaction in which the catalyst (enzyme), supplied by the microorganism, causes the destruction of the contaminant.

Detailed environmental control is necessary for the catalyst production and the desired reaction (Cookson, 1995). Therefore, successful bioremediation, requires a tightly controlled process with the presence of a suitable energy source, an electron donor-acceptor system, and adequate nutrients and moisture level. The appropriate combination of these conditions is critical to the performance of the bioremediation process.

In a bioremediation process, microorganisms in the soil obtain energy by metabolizing the organic compound (contaminant). Indigenous microorganisms can readily degrade the naturally occurring organics in a soil. However, contaminated soils may contain man-made organics which are more difficult to degrade. Therefore, the indigenous microorganisms in the soil must first acclimate themselves to the man-made chemicals before the degradation process can occur. As the microorganisms become acclimated to the contaminant, they will start to reproduce and the biodegradation rate will gradually increase.

Bioremediation has been shown by numerous researchers to be a viable method for remediating soil contaminated with petroleum products (Albrecht *et al.*, 1983, Beaudin, *et al.*, 1996, Demque, 1994, Pruess and Saberiyan, 1996, St. Cyr *et al.*, 1992,). Bioremediation technologies usually result in the lowest cost method of remediation if the contaminant of concern is biodegradable and the biological processes are optimized. Optimization of the processes can require significant scientific analyses and testing but, if found to be an appropriate method for remediating the contaminant of concern, usually results in the lowest cost when compared with technologies such as incineration, thermal adsorption, soil washing, or excavation and disposal at a hazardous waste disposal facility (Leahy and Brown, 1994).

2.3 Factors Affecting Composting

Composting of hazardous wastes is essentially the same process that is used in composting of municipal wastes. The objective in composting of hazardous wastes is to create an ideal environment, in either the windrow, static pile or enclosed reactor, in which the indigenous microorganisms will biodegrade the petroleum contaminants in the soil to innocuous carbon dioxide, water and organic matter (humus). Before the composting operation can begin, many factors must be considered to ensure that a favourable environment exists. The factors affecting composting can be grouped into the headings "physical", "chemical" and "nutritional". These factors include the following:

- substrate (nutritional)
- nutrients (nutritional)
- temperature (physical)
- pH (chemical)
- moisture content (physical)
- aeration (physical, chemical)
- bulking agent (physical)

Of the above factors aeration is the most critical (St-Cyr *et al.*, 1992). The rate of biodegradation is proportional to the rate of aeration (St-Cyr *et al.*, 1992).

2.3.1 Substrate

The physical and chemical nature of the substrate is one of the most important factors in determining the rate and potential success of the biodegradation of the waste. Substrate simply refers to the presence and accessibility of organic food sources. The organic food source in a hazardous waste composting system is usually the contaminant of concern (e.g. petroleum products). In composting of municipal solid waste, the waste usually provides the organic food source and the energy (thermal) source. However, most hazardous wastes do not contain a high enough concentration of organic material to sustain composting and, therefore, require the waste to be mixed with another material which contains a high concentration of organic material such as grass clippings, animal manures, etc. The highly organic/biodegradable material serves as a high energy (thermal) source for microorganisms which provide the microbial heat generation which is required for destruction of pathogenic organisms present in some wastes (both hazardous and non-hazardous). If no pathogenic organisms are present (as is the case in this thesis) in the contaminated waste, elevated temperatures are not required. Cookson (1995) states that composting of hazardous waste has been successfully pilot tested at ambient temperatures.

2.3.2 Nutrients

Microorganisms require inorganic nutrients for growth and reproduction. Carbon (C), nitrogen (N), phosphorus (P) and potassium (K) are the macronutrients required for the growth of microorganisms. Trace nutrients are also required, but if the optimum N:P:K ratio is satisfied then the amount of trace nutrients is usually satisfied as well (Demque, 1994). The typical N:P:K ratio is 100:10:1 (Pruess and Saberiyan, 1996). Typically, the rate limiting nutrients are N, P and K (Cookson, 1995). Nutrient deficiencies are usually corrected by adding nutrient sources such as normal lawn or agricultural fertilizer. Carbon is supplied by the hazardous waste being composted.

2.3.3 Temperature

The common belief is that composting must involve the development of high temperatures (in the 50 to 60 °C range) in order to be effective. It has been stated that composting can be successful under ambient temperature conditions (i.e. 20 to 30 °C) (Cookson, 1995). Furthermore, the development of high temperatures is not necessary when composting some hazardous wastes, such as petroleum products, because pathogenic organisms are not present. Cold temperatures, such as those experienced in Saskatchewan during winter months, retard and can stop bacterial activity (St Cyr, 1992). Cold temperature, however, is merely a constraint; it does not necessarily prevent effective bioremediation (St Cyr, 1992).

The temperature attained during the composting process is dependent upon the type of bacteria that are present to degrade the contaminant. Some microorganisms are mesophilic which means they thrive in environments where the temperature is in the 20 to 50 °C range. Other bacteria are thermophilic and prefer temperatures in the 45 to 70°C range. There are also different optimum temperatures for the different microorganisms that exist within each of these temperature ranges. So, for example, if a compost pile has three mesophilic microorganisms present, each with a different optimum temperature, the chances of the temperature being optimum for every microorganism at any given instant is virtually impossible. Therefore, the temperature of the pile usually adjusts to a temperature that can be described as a compromise between the optimums of all the organisms present.

Beaudin *et al.* (1996) conducted a study in which they used the composting process to degrade mineral oil and grease from soil. They found that temperature fluctuated throughout the degradation process. They concluded that changing temperatures are an indication of the microbial diversity that develops in a composting system and is necessary to achieve more complete degradation of contaminants. They referenced several studies (Atlas 1975; Westlake *et al.* 1974; Jobson *et al.* 1972) which indicated that different hydrocarbon components may be degraded at different temperatures.

2.3.4 Moisture Content

It is essential to have an adequate moisture content in the soil being remediated. Inadequate moisture content causes bacterial desiccation. Elevated moisture content reduces the oxygen supply by reducing forced soil-gas flow and decreases the biodegradation rate.

Optimum moisture content of the compost mix is dependent on the amount of organic material in the mix and the type of soil (i.e. sand, gravel, clay, etc.). Municipal wastes require a moisture content in the range of 40 to 60 percent by weight for optimal composting of the waste. Stegmann *et al.*, (1991) conducted a study to determine the effect of water content on the degradation rate of oil-contaminated soil. A compost mix composed of 8 parts contaminated clayey soil and 1 part compost obtained from a municipal waste composting plant was used in laboratory respiration studies. The mix had a maximum water holding capacity of 48 percent by weight. The maximum oxygen uptake of the microorganisms occurred at a moisture content of 60 percent of the maximum water holding capacity of the soil/compost mixture. Saberiyan et al. (1996) reported that the optimum moisture content of the soil for biodegradation of petroleum should be approximately 40 percent of soil saturation. The optimum moisture content for most contaminated soils would be in the 20 to 40 percent by weight range.

2.3.5 pH

Most microorganisms perform efficiently at pH ranges between 6 and 8. Typically in bioremediation experiments, the pH will rise to about 8 and then fall back to near 7 at the end of the experiment when most of the petroleum product has been degraded. This is because during the first stages of the biodegradation process organo-nitrogen compounds are broken down which releases NH^+_4 and causes the pH to rise (LaGrega *et al.*). This is followed by the gradual increase in microbial activity producing CO_2 which causes the pH to decrease (Golueke, 1977).

2.3.6 Aeration

Composting can be conducted in either an aerobic (in the presence of oxygen) or anaerobic (without oxygen) mode. Composting of non-hazardous wastes such as municipal sludges is usually done under aerobic rather than anaerobic conditions. The disadvantage of anaerobic systems for municipal sludges is the generation of odourous compounds such as hydrogen sulphide, mercaptans, and disulphides. Aerobic composting provides a much greater degree of stablilization of municipal wastes (Cookson, 1995). The use of anaerobic systems can be advantageous in composting some types of hazardous wastes. Halogenated or complex chemicals are treated more successfully under anaerobic conditions than under aerobic conditions (Cookson, 1995).

The method of aeration depends on the type of composting system. In windrow composting, aeration is usually conducted by turning the pile periodically. In static pile composting, aeration is usually conducted using a series of pipes placed under the compost pile(s) and connected to a blower or vacuum pump. The air is blown through the pipes and then percolates through the pile. These types of systems were described previously.

The amount and thoroughness of aeration will determine the rate and extent of the destruction of the contaminant, provided other conditions are satisfied. The amount of oxygen and the rate of aeration is a function of the chemistry of the contaminant (different contaminants require different amounts of oxygen and hence different aeration rates). Tchobanoglous *et al.* (1993) and Battaglia and Morgan (1994) have outlined methods for determining the approximate air requirements in a static pile or enclosed reactor system.

2.3.7 Bulking Agent

Most composting systems require a bulking agent. A bulking agent increases the porosity of the contaminated soil which allows greater air (oxygen) flow through the soil and distributes the air more evenly throughout the pile/reactor. The material used as the thermal source can also be used as the bulking agent (i.e. grass clippings, straw, manure, wood chips, etc.). This eliminates the need for screening/separation of the bulking agent from the compost following the composting phase, thereby, reducing the cost of the treatment process. Bulking agents that can not serve as a thermal source include gravel and shredded rubber tires.

Savage *et al.* (1985) define the ideal bulking agent as one that:

- provides ample porosity under all moisture conditions;
- is an absorbent;

- resists compaction;
- degrades very slowly, if at all; and
- can be easily recovered from the composted wastes and subsequently recycled.

Screening of the compost mix is common to recover the bulking agent for recycling. Screening involves the use of very expensive equipment, such as vibrating screens, rotary screens and trammels (Cookson, 1995). Therefore, the capital cost of screening must be compared with the cost of lost bulking agent if it is not recycled. This evaluation is dependent on the expected life of the cleanup operation, the treatment required and the final deposition of the treated soil (Cookson, 1995).

2.4 Treatability Studies

2.4.1 General

Before a full-scale composting operation (or any bioremediation operation) can be designed, it is necessary to conduct treatability studies to determine the potential for success and the expected performance of the proposed bioremediation system. A treatability study may consist of laboratory or bench-scale studies, a pilot-scale study or both. Generally, a proper treatability study would consist of both laboratory-scale studies and pilot-scale studies. Laboratory-scale studies determine the potential for successful biodegradation of the specific contaminant. Pilot- scale studies follow the laboratory-scale studies and would use the results of such studies to develop the design criteria, cost, and performance over a period of months of operation. Pilot-scale studies would be very similar to a full-scale operation except that the pilot-scale operation is scaled down in size.

2.4.2 Objectives

The first step of a treatability study is to determine the objectives that you want to achieve. Typical objectives of a bioremediation treatability study are shown in Table 2.2. It is not required to achieve all of these objectives under a single treatability study, nor would it be possible. If a treatability study is to accomplish several objectives it may be more feasible to conduct the treatability study in phases. Conducting treatability studies in phases has the advantage of being able to implement the results of initial phases in subsequent phases to either confirm or change the results of the preceding phases. The major disadvantage of conducting multiple objective treatability studies in phases is that significant time requirements, ranging from a few weeks to a few months or even several years, may be necessary.

Table 2.2 – Typical objectives of bioremediation treatability studies (Cookson, 1995)

1. Evaluate the capability of the microorganisms to degrade the target compounds.
2. Evaluate the enhancement capability of seed microorganisms.
3. Evaluate the optimum range for environmental parameters:
   Moisture
   pH
   Nutrients
   Trace minerals
4. Evaluate the need and effect of supplemental substrates and electron acceptors.
5. Determine the feed and starvation cycle for primary substrates.
6. Evaluate the need to provide supplemental electron donors.
7. Evaluate the rate of degradation for target compounds under ideal laboratory conditions or modified conditions to represent expected field response.
8. Evaluate the expected duration of the bioremediation project.
9. Determine the attainable level of treatment.
10. Evaluate potential soil-water reactions and clogging potential of in-situ treatment.
11. Evaluate the potential for toxicity changes due to mixing, surfactants, or buildup of intermediates.
12. Evaluate the degree of volatization.
13. Determine the cost effectiveness of various optimization measures.
14. Evaluate the monitoring frequency for process control.
15. Evaluate the operational limits on process control parameters without significant decrease in performance.

Once the objectives of the treatability study have been determined, the experimental design can be formulated. The experimental design consists of development of specific protocols or procedures that will be used to satisfy the objectives. Development of specific protocols are based on the following considerations or bases (Cookson, 1995):

1. Determine how one is to accomplish, quantify, and document the treatability study;
2. Determine if a customized treatability protocol will be developed or if standardized protocols are appropriate;
3. Determine if the treatability study will be conducted under ideal laboratory conditions or under conditions that simulate those at the site;
4. Determine the level of quality control to be applied to all test protocols and analytical data;
5. Determine if analytical data will be collected to provide statistically significant data and, if so, to what level of confidence; and
6. Determine what analytical protocols will be applied to data collection.

Once the above points have been considered, specific protocols can be developed. Protocols are simply a set of instructions or procedures that will be followed for a particular treatability study to achieve the specific objectives. The protocols must be stated in a detailed step-by-step procedure which leaves nothing to another's interpretation. Protocols can be either standardized or customized. Standardized protocols are those that are contained in government standards or other guidance documents. Two examples of guidance documents available in the United States from the U.S. Environmental Protection Agency (EPA) under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) are as follows:

Guide for Conducting Treatability Studies under CERCLA: Biodegradation Remedy Selection, U. S. EPA, 2nd and Final Draft, March 1993; and

Guide for Conducting Treatability Studies under CERCLA: Aerobic Biodegradation Remedy Screening , U. S. EPA, EPA/54012-91/-13A, July 1991.

Customized protocols are those developed by the researchers who are conducting the treatability study and are specific to the treatability study being conducted. Customized protocols are developed when standard protocols are inadequate to satisfy the objectives of the treatability study. Customized protocols may be simply a standardized protocol with a slight modification or it may be a completely new protocol.

2.4.3 Costs

The cost of a treatability study can range from as low as several thousand dollars to as much as several hundred thousands of dollars. The budget available for treatability studies is influenced largely by the overall anticipated remediation cost of the project. In the case of a multimillion dollar bioremediation project there is certainly a justification to budget several hundred thousand dollars for treatability studies. Several hundred thousand dollars spent on a well designed treatability study may save millions on the final remediation cost. On the other hand, in the case of a $50,000 bioremediation project, little in the way of treatability studies can be supported. At most, $1000 or $2000 may be available for treatability studies.

2.4.4 Equipment

Equipment used for solid phase treatability studies can be as simple as a couple of beakers or baking pans to specially designed and constructed pilot-scale facilities. Typically, laboratory treatability studies are conducted using very low-tech, inexpensive equipment such as pans, beakers, flasks, tubs, etc. as the reactors and polyethylene tubing and simple compressed air supplies as the aeration system. Some researchers have gone to great lengths and expense to fabricate bench scale reactors or "microcosms" which accurately simulate the actual field conditions in a laboratory setting including such things as automated watering/humidified air supplies, insulated, stainless steel enclosed reactors and computerized oxygen-carbon dioxide respirometers.

2.5 Degradation Kinetics

The Monod equation is commonly used to model substrate degradation and microbial growth (Saberiyan *et al.* 1996). The Monod equation assumes that a single substrate and single type of microorganism are involved. In reality, there are usually multiple substrates and multiple microorganisms involved. However, the Monod equation is usually selected for ease in analyzing data, and it offers adequate accuracy. The Monod model takes advantage of the fact that the biodegradation rate is a function of substrate concentration. The Monod equation takes the form in equation 2.1, when substrate concentration (C) is small compared to K_s:

$$\frac{dC}{dt} = -k_m \times \frac{X}{K_s} \times C \qquad (2.1)$$

where,

C = contaminant concentration at time t (mg/kg)

k_m = maximum substrate utilization rate (day^{-1})

K_s = half-velocity coefficient (substrate concentration at one-half the maximum growth rate (mg/kg)

X = microbial concentration (mg/kg)

t = time (days)

Assuming ,

$$K = k_m \times \frac{X}{K_s} \qquad (2.2)$$

where K=degradation rate constant, and where k_m, X and K_s are constants for the system, then equation (2.1) reduces to a first-order equation,

$$\frac{dC}{dt} = -KC \qquad (2.3)$$

$$\frac{dC}{C} = -Kdt \qquad (2.4)$$

$$\ln C = -Kt + C_1 \qquad (2.5)$$

if $C = C_0$ at t = 0

then, $\ln C_0 = C_1$

and

$$\ln C = -Kt + \ln C_0 \qquad (2.6)$$

$$\ln C - \ln C_0 = -Kt \tag{2.7}$$

$$\ln \frac{C}{C_0} = -K \times t \tag{2.8}$$

The value K is measured empirically from a biotreatability study by plotting the natural log of C/C_0 vs time and performing a regression analysis. The degradation rate constant can then be used in Equation (2.8) to calculate the length of time required to degrade a specific waste to half of its initial concentration. This is commonly referred to as the half-life of the contaminant.

CHAPTER THREE

MATERIALS AND METHODS

3.1 General

The initial site investigation was considered as background information to the treatability study, which is the subject of this thesis. Therefore, the methods used in the initial site investigation were presented in Chapter One of the thesis under Section 1.2 – Background Information. The methods used in the treatability study are presented in the following subsections.

Analytical methods used in analyzing the various parameters identified in the following sections are available in detail in other sources. Therefore, the detailed procedures are not presented here, however, the methods used for analysis of each parameter are indicated.

3.2 Bulk Sample Collection

A bulk sample of the contaminated soil from the pit described in subsection 1.2 was collected on May 15, 1997. The location where the bulk sample was obtained is shown on Figure 3.1. The location for sampling was selected such that the TPH concentration of the sample would be approximately the same as the average TPH concentration over the site which was stated in subsection 1.2 as 31,051 ppm. During the site investigation and characterization phase, Test Hole 17 at a depth of 3.0m exhibited a TPH concentration of 39,600 ppm. Therefore, this was the chosen location for bulk sample collection. Once the location for the bulk sample collection was identified, a backhoe was used to excavate the area. The bulk sample was put into a 205 L capacity plastic drum which had been thoroughly cleaned with warm soapy water prior to sample collection. The bulk sample was then transported to the laboratory where the treatability study was conducted.

At the laboratory, a smaller subsample consisting of approximately 10 kg (wet weight) of soil was removed from the bulk sample barrel. The 10 kg sample was broken down into smaller pieces using a 7mm (0.25 inch) screen. The sample was then put into a plastic tub and mixed thoroughly, by hand, so that the waste petroleum in the soil was evenly distributed throughout the sample. A second subsample consisting of approximately 4 kg of soil was removed from the 10 kg subsample. The 4 kg sample was designated as the test sample. The remainder of the 10 kg was put into a plastic bag and stored in the freezer in case it was required at a later date. Part of the 4 kg sample was put into 250 ml certified clean laboratory glass jars with teflon lined lids to be used for analyses of parameters for initial characterization of the soil and contaminant(s).

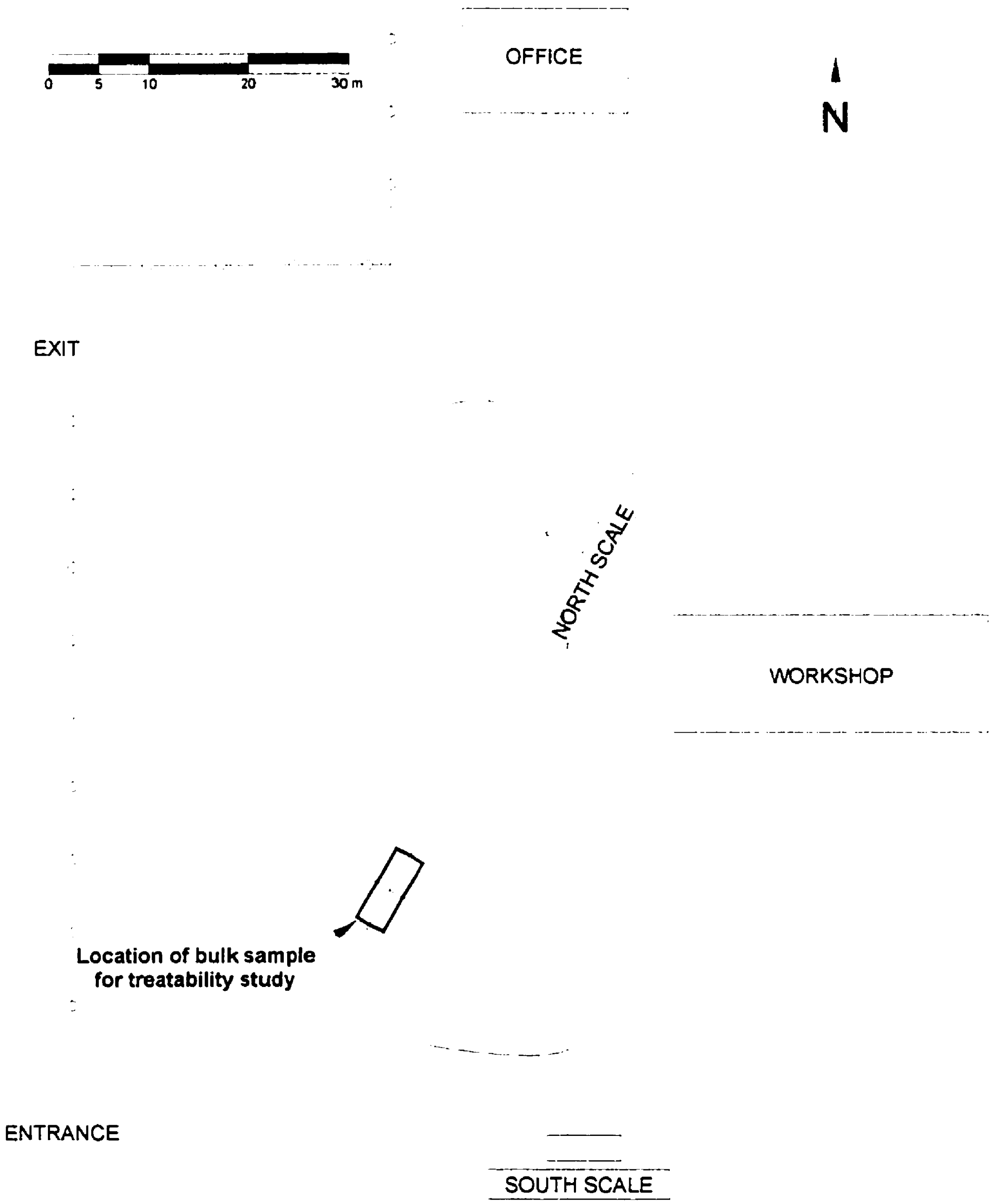


Figure 3.1: Site plan showing location where bulk test sample was obtained

3.3 Soil Contaminant Characterization

It was necessary to determine the initial concentrations and types of petroleum hydrocarbons in the soil sample. The petroleum hydrocarbons in the soil collected from the site were characterized and quantified by the following analytical methods:

- Hydrocarbon fingerprint by GC (EPA Method 3550/8000), (U. S. EPA, 1986); and
- Total petroleum hydrocarbons by the infrared method (EPA Method 418.1 Modified) (USEPA, 1986).

3.4 Nutrient Analyses

It was necessary to determine the amount of nutrients in the initial soil sample in order to evaluate the need for, and amount of, nutrient additions to achieve the optimal C:N:P:K ratio. The initial pH of the soil was also required to determine if pH adjustment was required. The following analyses were conducted using the analytical methods shown:

- available phosphorus (Method 4.43), (McKeague, 1978);
- available nitrate nitrogen (Method 4.34), (McKeague, 1978);
- available ammonia nitrogen (Method 4.3), (McKeague, 1978);
- available potassium (Method 4.51), (McKeague, 1978); and
- pH (Method 4.13), (McKeague, 1978).

3.5 Bacterial Enumeration and Characterization

A procedure outlined by Pruess and Saberiyan (1996) was used for bacterial enumeration. Ten grams of soil and 100 ml of sterile water were agitated vigorously for approximately one minute, after which the soil was allowed to settle from the supernatant. One millilitre of supernatant was mixed with nine millilitres of sterile Bushnell-Haas broth. The sample supernatant was then ten-fold serially diluted twice more to a 10^{-3} dilution. Small (0.1 ml) aliquots from each dilution were plated in triplicate on Bushnell-Haas agar. Oil (0.1 ml), to serve as the carbon source, was placed on filter paper within each sealed Petri plate. Control plates (sterile water added in place of supernatant)) were also prepared and incubated in the presence of petroleum product to monitor possible cross contamination. All plates were incubated for eight days at 30°C. Following the incubation period, bacterial colonies were enumerated on each plate. The counts were averaged to determine the number of colony forming units (cfu's) per gram of soil. In addition to plate count analysis, the species of bacteria present in the soil were determined in order to confirm that they were capable of degrading hydrocarbons.

3.6 Laboratory Composting Studies

3.6.1 General

The experimental phase of the study was conducted to determine the reduction of the contaminant (petroleum hydrocarbons) with time using a laboratory composting apparatus which simulated an aerated static pile composting system. TPH was chosen as the indicator parameter for the reduction of the contaminant because it was consistent with that used by other researchers for similar contaminants and the equipment was readily available. The theoretical nutrient additions as calculated were used. It was also decided to determine what effect, if any, the addition of a highly biodegradable material had on the rate and degree of biodegradation of the petroleum product. The high-energy source chosen was partially composted grass clippings as it was felt that this was a low cost, readily available energy source.

3.6.2 Preparation of Soil Samples

Approximately 2 kg of soil was taken from the previously prepared 4 kg sample. The 2-kg sample was split into two approximately equal samples (by weight) using a soil sample splitter. These samples were designated as 1 and 2. Nutrients, in the amount calculated previously (40.3 grams/kg of soil), were added in the form of granular lawn fertilizer. The granular fertilizer was dissolved in approximately 50 ml of water. The two 1-kg soil samples were each placed in a mixing pan and the water (with dissolved fertilizer) was sprinkled over each soil sample and subsequently mixed thoroughly into each soil sample.

Next, approximately 25 percent by weight of sandy gravel was added to each of the contaminated clay soil samples. The gravel was used as the bulking agent to provide a more permeable medium and, thereby, facilitate greater air flow through the soil. Gravel was chosen as the bulking agent because it was readily available and required no preparation prior to its use. Following this, approximately 25 percent by weight of the total soil mixture (i.e. contaminated clay soil and gravel bulking agent) of grass clippings was added to reactor #1. These materials were thoroughly mixed into the nutrient amended contaminated soil.

3.6.3 Laboratory Composting Apparatus

A schematic of the experimental set-up and the details of each reactor are shown in Figure 3.2. An aerated static pile system was simulated in the laboratory using two 4-litre glass jars as reactors. The aeration was supplied to each reactor by a compressed air system. The pressure and flow rate of the air in the compressed air line was reduced using a pressure regulator installed in the line. A line was then constructed from the regulator to each of the reactors using 7.5 mm I. D. polyethylene tubing and a plastic tee connector. A cone-shaped porous stone, used in fish aquariums, was connected to the end of each line. The porous stones were used to disperse the air in all directions in order to provide more even air distribution in the reactors.

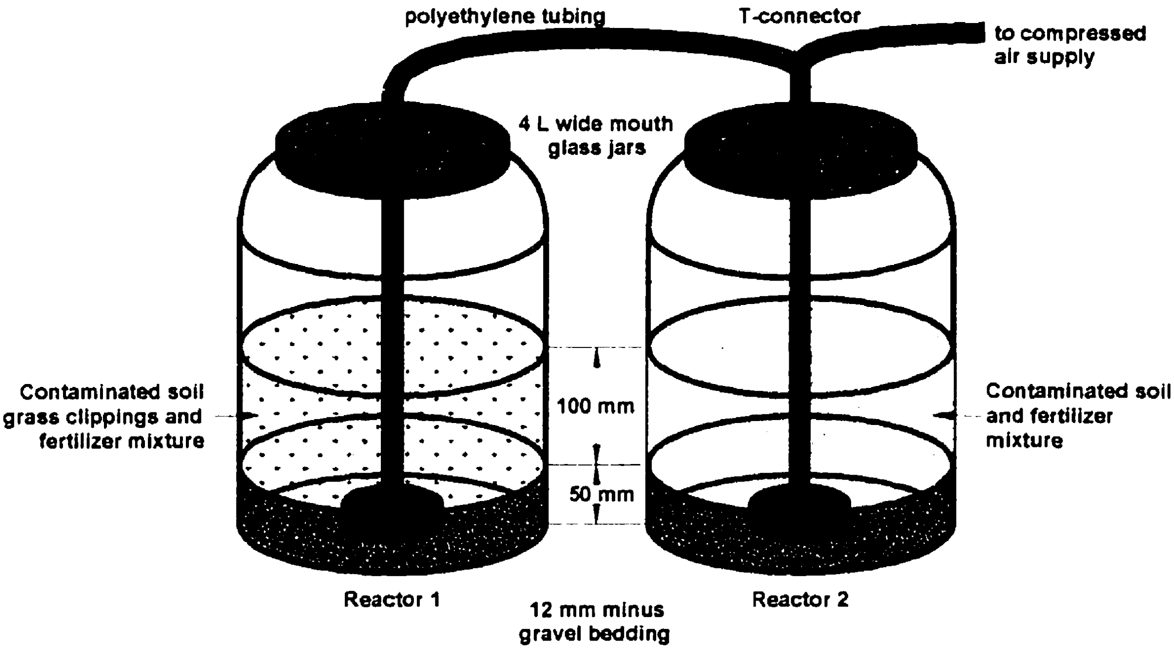


Figure 3.2: Schematic of reactor system

3.6.4 Monitoring

TPH, moisture content, temperature, pH, and the growth of microorganisms were monitored, at various frequencies, throughout the experiment. The following subsections describe the monitoring and sampling that was conducted throughout the experiment.

3.6.4.1 TPH

TPH concentration in the soil was monitored on a regular basis throughout the experiment. The TPH concentration was used as the primary indicator of petroleum degradation and the completeness of the experiment. Each experimental cell was sampled (approximately 100 gram samples) for determination of TPH concentrations at days 26, 55, 74 and 181. These sampling times were essentially chosen at random.

3.6.4.2 Moisture Content

Moisture content was determined on the same occasions and samples as for TPH analyses. As mentioned in section 3.6.4.1 the sample size taken for TPH and moisture content was 100 grams. This was adequate for TPH as only 50 grams of soil is required. Moisture content in accordance with ASTM D2216 requires a sample size of approximately 250 grams and only 50 grams was used. However, a simple test was conducted to determine the effect of a smaller sample size on the results of the moisture content test. The test consisted of conducting a moisture content test on a sample of the experimental soil using the sample size stated in ASTM D2216 and using the smaller, 50 gram sample size. This was replicated three times. The test indicated that the moisture content was approximately 2 percent lower, on average, when the smaller sample size was used. This was considered an acceptable degree of error for purposes of this experiment, since a soil moisture content of 30 percent was used. Moisture content was adjusted as required to maintain it at approximately 30 percent by sprinkling water over the composting soil. The saturation point of the site soil was assumed to be approximately equal to its plastic limit which was determined using procedure ASTM D4318.

3.6.4.3 Temperature

Temperature was determined within the contaminated soil mass in each reactor using a mercury thermometer. Temperature was measured daily for the first 12 weeks of the experiment and then it was measured approximately twice per week thereafter.

3.6.4.4 pH

pH was measured at days 0, 74 and 181. Similar to the moisture content testing, the pH test had to be slightly modified to use a smaller sample size than is required due to the lack of sample in the reactors. A sample size of 50 grams was used for this test.

3.6.4.5 Bacterial Enumeration

Bacterial enumerations were conducted at the beginning of the experiment, at day 96 and at the conclusion of the experiment (day 182). The enumerations consisted of a heterotrophic plate count using the method previously described in section 3.5 of the thesis.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Nutrient Analyses

Results of the initial nutrient analyses on the soil are shown in Table 4.1.0. The nutrient analyses indicated that available nitrogen (in the form of ammonia and nitrate) was very low and available phosphorus was also low. Nutrient supplementation for nitrogen and phosphorus deficiency was necessary. The required amounts were calculated from the stoichiometric relationships developed in 4.1.2. It was determined that approximately 40.3 grams of ammonium phosphate fertilizer was required for nitrogen supplementation. Based on the typical N:P:K ratio of 10:1:0.1, it was also determined that 30 grams of fertilizer was required for phosphorus supplementation; however, this amount was less than that required for nitrogen supplementation and the requirement for phosphorus would be satisfied with the addition of the required amount of fertilizer for nitrogen supplementation. Available potassium was adequate for microbial growth based on the typical N:P:K ratio of 100:10:1.

Table 4.1 – Results of initial nutrient analyses

Nutrient	Concentration (mg/L)
Available ammonia	5.0
Available nitrate	23.8
Available phosphorus	1.0
Available potassium	443

4.1.2 Determination of Nutrient Deficiency

The results of the nutrient analyses suggested that the soil had fairly low levels of nitrogen (nitrite/nitrate and ammonia) and high levels of phosphorus and potassium. The soil had a pH of 7.49 which is ideal for bioremediation.

The hydrocarbon fingerprint analysis indicated that the contaminant of concern was mainly oil with minor amounts of diesel fuel and/or weathered gasoline, paint thinners, and solvents. The gas chromatographs (Appendix C) indicated an average carbon chain length of approximately C_{22}. Therefore, the following calculations for determination of the nutrient requirements assume that the contaminant has an average carbon chain length of C_{22}. The stoichiometric relationship is as follows:

1) Energy Reaction:

Electron Donor (ED) = $C_{22}H_{44}$

Electron Acceptor (EA) = O_2

ED half reaction:

$$C_{22}H_{44} + 44H_2O \rightarrow 22CO_2 + 132H^+ + 132\ddot{e}$$

EA half reaction:

$$4H^+ + 4\ddot{e} + O_2 \rightarrow 2H_2O$$

Energy reaction = ED + EA

$$\frac{1}{132}C_{22}H_{44}+\frac{44}{132}H_2O\rightarrow\frac{22}{132}CO_2+H^{+}+\ddot{e}$$

$$H^{+}+\ddot{e}+\frac{1}{4}O_2\rightarrow\frac{2}{4}H_2O$$

$$\frac{1}{132}C_{22}H_{44}+\frac{1}{4}O_2\rightarrow\frac{1}{6}CO_2+\frac{1}{6}H_2O$$

2) Synthesis Reaction:

$$\frac{1}{4}CO_2+\frac{1}{20}NH_3+H^{+}+\ddot{e}\rightarrow\frac{1}{20}C_5H_7O_2N+\frac{2}{5}H_2O$$

$$\frac{1}{132}C_{22}H_{44}+\frac{1}{3}H_2O\rightarrow\frac{1}{6}CO_2+H^{+}+\ddot{e}$$

$$\frac{1}{132}C_{22}H_{44}+\frac{1}{20}NH_3+\frac{1}{12}CO_2\rightarrow\frac{1}{20}C_5H_7O_2N+\frac{1}{15}H_2O$$

Overall reaction = A (energy reaction) + synthesis reaction:

Assume A = 1

$$\frac{1}{132}C_{22}H_{44}+\frac{1}{4}O_2\rightarrow\frac{1}{6}CO_2+\frac{1}{6}H_2O$$

$$\frac{1}{132}C_{22}H_{44}+\frac{1}{20}NH_3+\frac{1}{12}CO_2\rightarrow\frac{1}{20}C_5H_7O_2N+\frac{1}{15}H_2O$$

$$\frac{1}{66}C_{22}H_{44}+\frac{1}{4}O_2+\frac{1}{20}NH_3\rightarrow\frac{1}{12}CO_2+\frac{1}{20}C_5H_7O_2N+\frac{7}{30}H_2O$$

or

$$C_{22}H_{44}+16.5O_2+3.3NH_3\rightarrow5.5CO_2+3.3C_5H_7O_2N+15.4H_2O$$

For each mole of $C_{22}H_{44}$ there are: 16.5 moles of O_2 utilized;

3.3 moles of NH_3 utilized;

5.5 moles of CO_2 produced;

3.3 moles of biomass produced; and

15.4 moles of water produced.

Converting from moles to mass, the mass ratio is:

Mw $C_{22}H_{44}$ = 22 X 12 + 44 = 308 g/mole

Mw N = 3.3 NH_3 per mole of $C_{22}H_{44}$ X 14 = 46.2 g/mole

Mw N/Mw $C_{22}H_{44}$ = 46.2/308 = 0.15

Using the theoretical mass ratio above and assuming used oil ($C_{22}H_{44}$) contaminant concentrations of 39,800 ppm, the required level of available nitrogen can be estimated as

39,800 X 0.15 = 5970 ppm of nitrogen required

The soil was estimated to have only 28.81 ppm of available nitrogen. Therefore, approximately 5941 ppm has to supplemented. To estimate the unit mass of nutrient amendment (fertilizer) required, the following calculation was done:

Molecular weight of ammonium phosphate (NH_4PO_4) = 95 grams

Molecular weight of nitrogen in ammonium phosphate = 14 grams

(95/14) X (5941 mg/kg/1000 g/mg) = 40.3 grams of ammonium phosphate fertilizer per kg of soil.

The phosphorus concentration is also of concern in bioremediation. Typically, a ratio of 10:1 for N:P is necessary to optimize biological activity. Therefore, a theoretical concentration of 597 ppm is predicted. There is currently only 1 ppm of available phosphorus in the soil. Therefore, 596 ppm had to be supplemented. Similar to the calculation for nitrogen supplementation, the calculation for phosphorus is as follows:

Molecular weight of ammonium phosphate (NH_4PO_4) = 95 grams; and

Molecular weight of phosphorus in ammonium phosphate = 31 grams

(95/31) X (594 mg/kg/1000 g/mg) = 1.8 grams of ammonium phosphate fertilizer per kg of soil.

Therefore, the amount of ammonium phosphate calculated for nitrogen supplementation will also satisfy the phosphorus requirement.

4.2 Microbial Characterization of Soil Samples

4.2.1 Enumeration of Bacteria

The results of microbial enumeration in the soil in each experimental cell are shown in Table 4.2. Generally, there was an increase in the microbial population in both cells. The microbial population in Cell #1, which was amended with a high energy source, increased by approximately three orders of magnitude throughout the duration of the experiment. The microbial population in cell #2, which did not have the high energy source added to it, stayed constant for the first three months of the experiment and then increased by approximately one order of magnitude during the last three months.

Quinn *et al.* (1997) found that biological counts remained relatively constant over the 13 weeks of a study which used static pile composting to degrade diesel fuel from soil. Although the biological counts did not increase over the course of the experiment, they were significantly higher than those obtained from a sample of the experimental soil to which no amendments were added.

Table 4.2 – Heterotrophic plate count results

Time (days)	Date	Cell #1 (cfu/g of soil)	Cell #2 (cfu/g of soil)
0	97/06/06	4.3×10^6	1.3×10^7
96	97/09/10	1.1×10^8	1.1×10^7
182	97/12/06	2.4×10^9	3.1×10^8

4.2.2 Identification of Bacteria

The types of hydrocarbon degrading bacteria identified in the initial soil samples are shown in Table 4.3.

Table 4.3 – Types of hydrocarbon degrading bacteria identified

Bacteria Identified
Aspergillus spp
Actinomycetes spp
Pseudomonas spp
Citrobacter freundi
Pseudomonas fluorescence

Three genera of microorganisms listed in Table 4.3 have been frequently identified as active members of microbial consortiums in bioremediation of hazardous wastes: *Actinomycetes spp, Pseudomonas spp* and *Pseudomonas fluorescence* (Cookson, 1995). The group found with the highest frequency consists of those belonging to the genus *Pseudomonas*. *Pseudomonas* consist of gram-negative, aerobic chemoheterotrophic organisms (Cookson, 1995). About 30 species have been identified, each of which is capable of utilizing 60 to 100 different organic compounds as their sole carbon and energy source (Cookson, 1995). It is not surprising, therefore, to find them as the predominant group in contaminated soil and groundwater. Two species of *Pseudomonas* were found in the experimental soil. These two species are capable of degrading the petroleum hydrocarbons found in the soil at the site (Cookson, 1995).

4.3 Temperature

The results of temperature monitoring throughout the experiment for Reactors 1 and 2 are summarized in Tables 4.4 and 4.5, respectively, and in Figure 4.1. Temperature did not increase significantly throughout the experiment, as one would have expected in a composting experiment. This may be attributed to any one of or a combination of the following:

- the aeration rate was quite high (5 litres/min) and may have cooled the reactors which prevented a temperature increase;
- the amount of thermal source (grass clippings) may not have been sufficient to produce the temperature rise characteristic in municipal waste composting; and/or
- *Pseudomonas spp.* and *Pseudomonas fluorescens* were found to be present in the soil and, as stated earlier, are two types of microorganisms that are frequently

identified as the active members of microbial consortiums (Cookson, 1995). The temperature for growth of *Psuedomonas spp.* has been reported to be in the –10°C to 20°C range (Cookson, 1995). The temperature for growth of *Pseudomonas fluorescens* has been reported to be in the range of 20 to 25°C. The optimum temperature which would satisfy the requirements of these organisms is likely around 20°C, which was approximately where the temperature of the soil remained throughout the experiment.

As stated earlier in this thesis, it has been found by other researchers that composting can be successful under ambient temperature conditions (i.e. 20 to 30 °C) (Cookson, 1995). Furthermore, the development of high temperatures is not necessary when composting some hazardous wastes, such as petroleum products, because pathogenic organisms are not present.

Table 4.4 – Results of temperature monitoring for Reactor 1

Date (1997)	Temperature (°C)	Date (1997)	Temperature (°C)
Jun 6	21	Aug 5	27
Jun 7	22	Aug 12	25
Jun 8	21	Aug 15	26
Jun 9	21	Aug 20	25
Jun 10	22	Aug 23	24
Jun 11	22	Aug 27	25
Jun 12	21	Aug 31	26
Jun 13	21	Sep 4	26
Jun 14	22	Sep 10	25
Jun 15	23	Sep 15	24
Jun 16	22	Sep 22	23
Jun 17	23	Sep 26	24
Jun 18	23	Sep 30	23
Jun 19	22	Oct 5	23
Jun 20	23	Oct 10	22
Jun 21	23	Oct 16	23
Jun 22	23	Oct 20	24
Jun 23	24	Oct 24	23
Jun 24	24	Oct 27	23
Jun 25	23	Oct 30	23
Jun 26	23	Nov 3	23
Jun 30	24	Nov 6	23
Jul 4	25	Nov 10	21
Jul 9	25	Nov 14	22
Jul 14	24	Nov 20	21
Jul 17	24	Nov 26	22
Jul 23	25	Nov 30	22
Jul 30	25	Dec 5	21

Table 4.5 – Results of temperature monitoring for Reactor 2

Date (1997)	Temperature (°C)	Date (1997)	Temperature (°C)
Jun 6	21	Aug 5	26
Jun 7	22	Aug 12	25
Jun 8	22	Aug 15	24
Jun 9	23	Aug 20	24
Jun 10	22	Aug 23	25
Jun 11	23	Aug 27	26
Jun 12	22	Aug 31	25
Jun 13	22	Sep 4	25
Jun 14	24	Sep 10	25
Jun 15	24	Sep 15	24
Jun 16	24	Sep 22	24
Jun 17	23	Sep 26	24
Jun 18	25	Sep 30	23
Jun 19	24	Oct 5	23
Jun 20	22	Oct 10	22
Jun 21	23	Oct 16	22
Jun 22	24	Oct 20	23
Jun 23	23	Oct 24	22
Jun 24	23	Oct 27	22
Jun 25	24	Oct 30	23
Jun 26	22	Nov 3	22
Jun 30	24	Nov 6	22
Jul 4	25	Nov 10	21
Jul 9	25	Nov 14	23
Jul 14	25	Nov 20	22
Jul 17	26	Nov 26	23
Jul 23	27	Nov 30	22
Jul 30	26	Dec 5	22

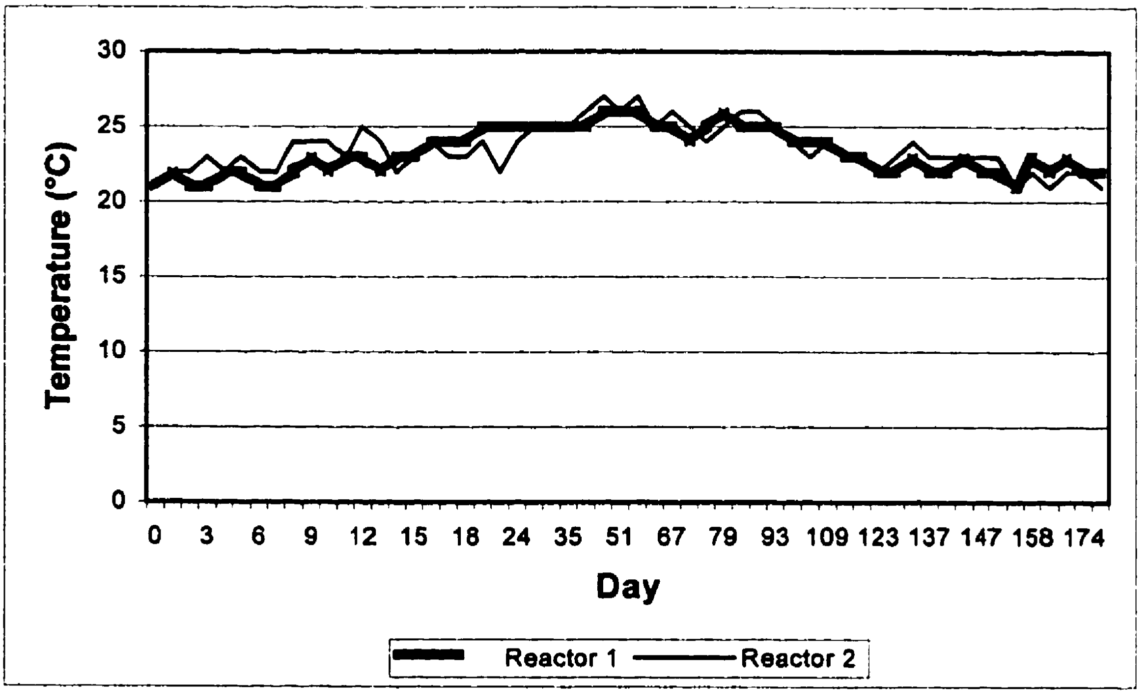


Figure 4.1 Temperature vs time for Reactors 1 and 2

4.4 TPH Concentrations, Moisture Content and pH

TPH concentrations, moisture content and pH of the soil in each experimental cell are shown in Table 4.6. The TPH concentration, pH and moisture content versus time are shown in Figures 4.2, 4.3 and 4.4, respectively.

TPH concentrations in Reactor 1 and Reactor 2 decreased from 39100 ppm to 1300 and 11000 ppm, respectively, in 181 days. These reductions in the TPH concentrations correspond to removals of approximately 96.7 percent and 71.9 percent for Reactors 1 and 2, respectively. The difference between Reactors 1 and 2 was the addition of a highly biodegradable material to Reactor 1 and not to Reactor 2. The addition of a highly biodegradable source (grass clippings) resulted in a significantly higher overall removal of TPH. These results compare very well with a pilot-scale study conducted by Quinn *et al.*, (1997) where aerated static piles were used to reduce the concentration of diesel fuel in contaminated soil from 3000 ppm to less than 200 ppm in 13 weeks.

pH of the compost mix in each reactor was monitored three times during the course of the study, at the beginning, approximately halfway through and at the end. The pH profile was essentially the same for both reactors. pH started at approximately 7.49 in both reactors, then increased to 8.23 and 8.03 in Reactors 1 and 2, respectively, halfway through the study and then it decreased to 7.25 and 7.05 in Reactors 1 and 2, respectively, at the end of the study. This is because during the first stages of the biodegradation process organo-nitrogen compounds are broken down which releases NH^{+}_{4} and causes the pH to rise (LaGrega *et al.*). This is followed by the gradual increase in microbial activity producing CO_2 which causes the pH to decrease (Golueke, 1977). The pH profile was consistent with that expected based on other similar studies reported in the literature.

The moisture content of the compost mixture remained between 29 and 33 percent in both reactors which corresponds to approximately 45% to 51% saturation. The saturation point of the soil at the site was determined to be approximately 65 percent moisture by weight of soil. This is consistent with the literature which suggests an optimum moisture content for biodegradation of hydrocarbons in soil of approximately 40 to 48 percent of soil saturation (Saberiyan *et al.*, 1996 and Stegmann *et al.*, 1991).

Table 4.6 – Results of TPH, moisture content and pH in reactors

		Reactor 1			Reactor 2		
Time (Days)	Date (1998)	TPH (ppm)	Moisture (%)	pH	TPH (ppm)	Moisture (%)	pH
0	Jun 6	39100	30.5	7.49	39100	30.5	7.49
26	Jul 2	27000	29.7	-	19000	30.4	-
55	Jul 31	10000	30.9	-	14000	31.3	-
74	Aug 19	4300	31.2	8.23	11000	32.6	8.03
181	Dec 4	1300	29.2	7.25	11000	32.4	7.05

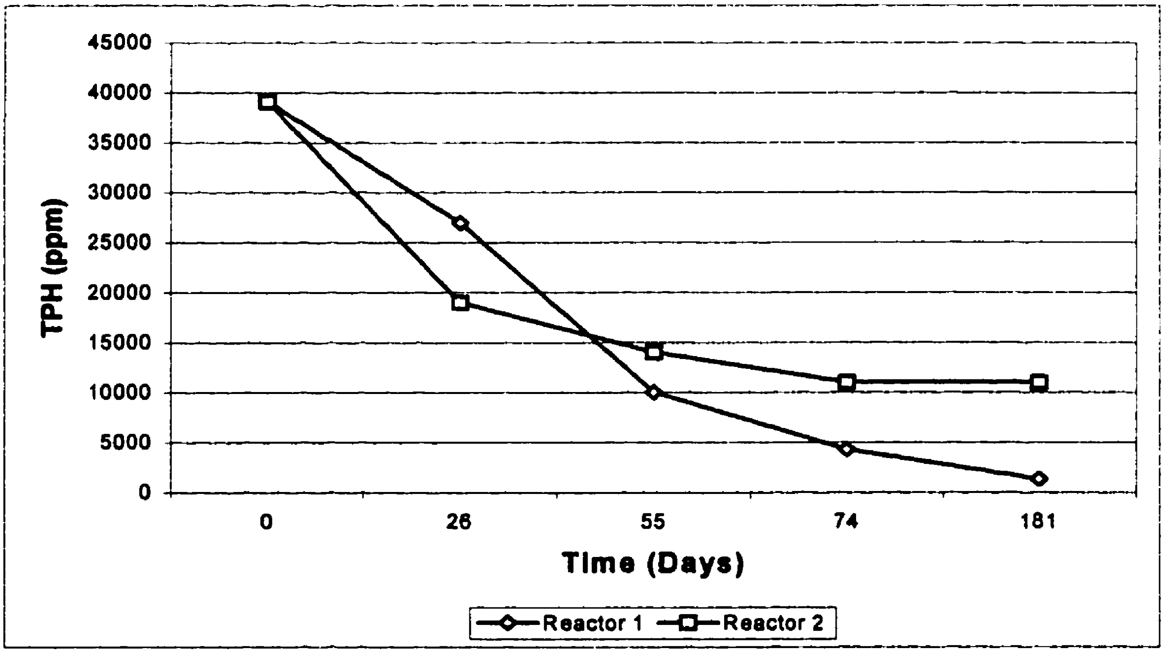


Figure 4.2 TPH vs time for Reactors 1 and 2

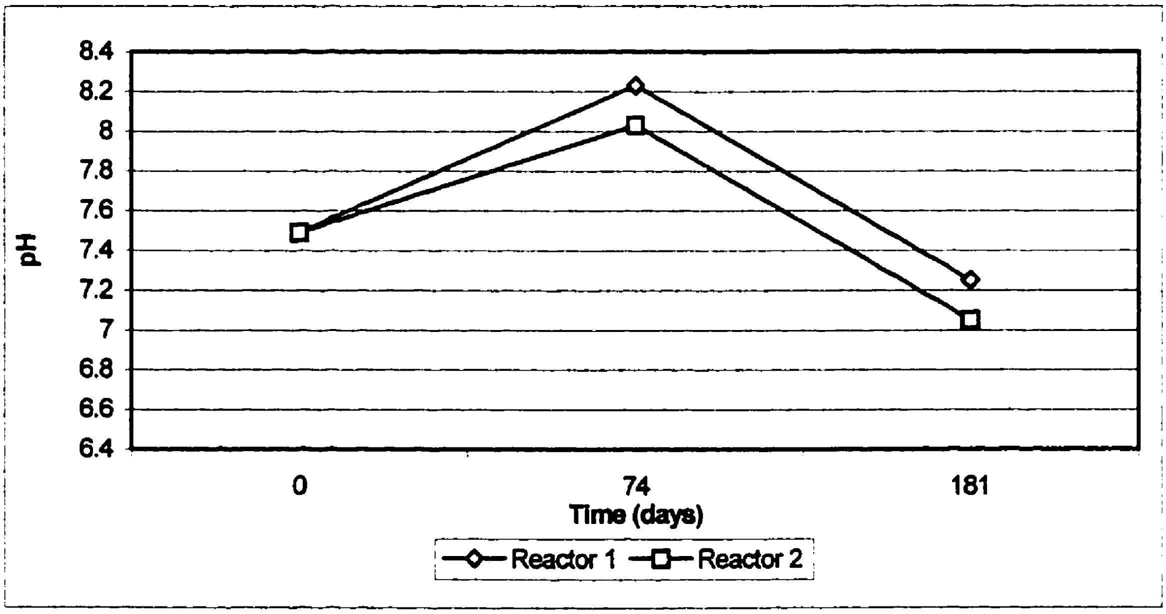


Figure 4.3 pH vs time for Reactors 1 and 2

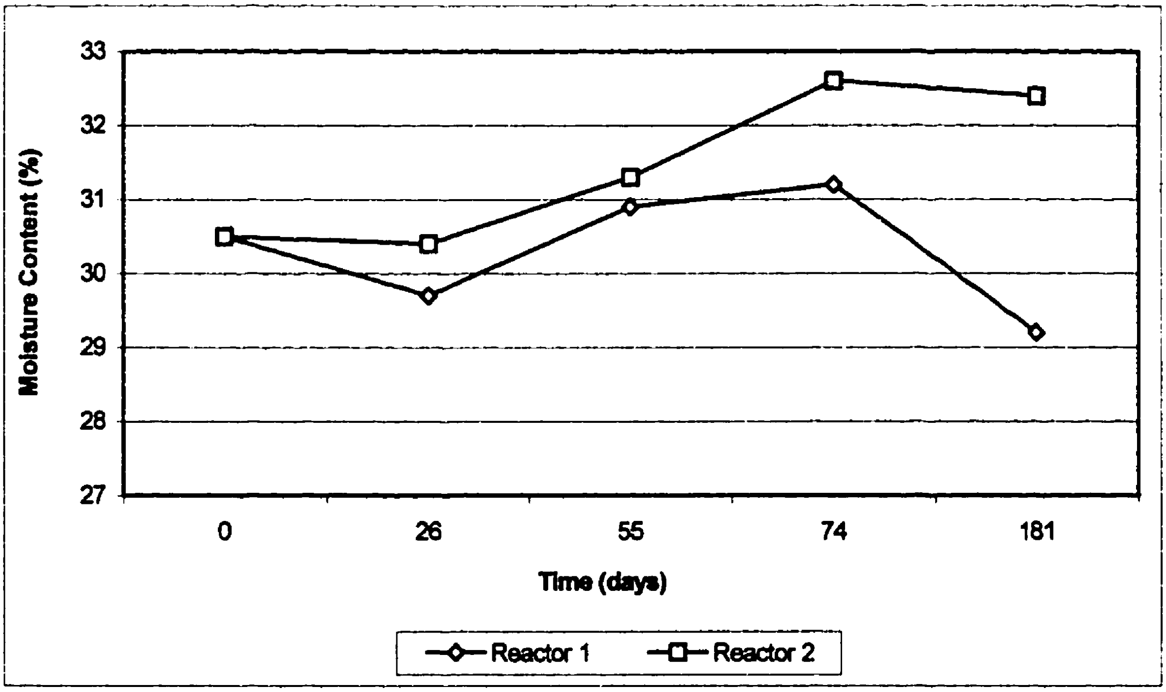


Figure 4.4 Moisture content vs time for Reactors 1 and 2

4.5 Calculation of Rate Constants

Values of ln (C/C_0) are plotted vs time in days in Figure 4.5. Regression analysis was used to determine the rate constants for each reactor. The regression equation for each of the reactors are shown on the graph in Figure 4.5. The rate constants for Reactors 1 and 2 are simply the slopes of the two lines in Figure 4.5. The rate constants are -0.019/day and -0.006/day for Reactors 1 and 2, respectively. Using these rate constants and equation (2.8) developed previously the half-life of the contaminant can be calculated as follows:

$$\ln(C/C_0) = -Kt \tag{4.1}$$

or, rearranging

$$t = \frac{-\ln(C/C_0)}{K} \tag{4.2}$$

where,

C_0 = initial contaminant concentration in soil
C = final or target concentration in soil
K = degradation rate constant
t = degradation time

For Reactor 1, K = -0.019/day, C_0 = 39 100 ppm and C = 39 100/2 = 19 550 ppm. Therefore, using equation (2), the half-life of the contaminant using the amendments of Reactor 1 is 36.3 days. Similarly, for Reactor 2, K = -0.006/day, C_0 = 39 100 ppm and C = 19 550 ppm, the half-life of the contaminant is 121.6 days.

The regulatory criteria for TPH concentration in contaminated soil in Saskatchewan is 1000 ppm. The estimated time to remediate the soil in each of the reactors used in this study can be calculated using equation (2) and the following variables:

C_0 = 39 100 ppm
C = 1000 ppm
K = -0.019/day for Reactor 1 and K = -0.006/day for Reactor 2

The resulting period to remediate a batch of soil from the site, assuming an average initial TPH concentration of 39 100 ppm would be 192 days and 643 days for Reactors 1 and 2, respectively.

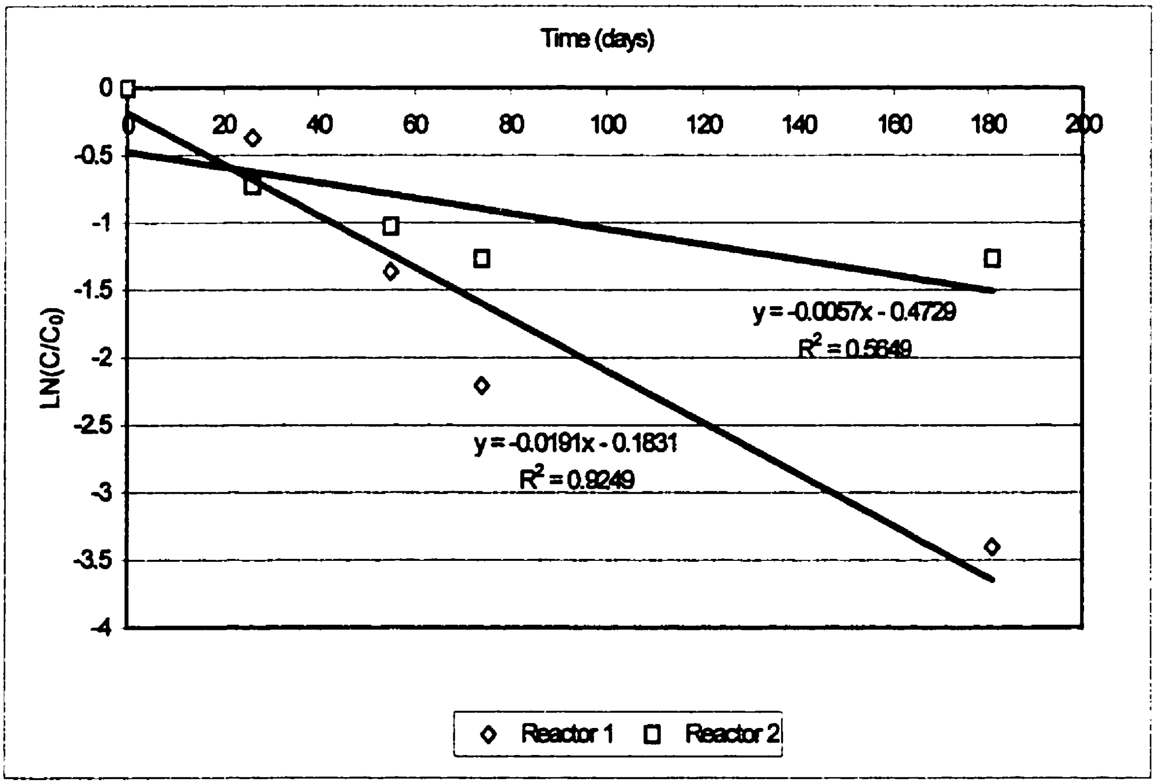


Figure 4.5 ln (C/C_0) vs time for Reactors 1 and 2

The degradation time of 192 days for Reactor 1 compares very well with the 184 to 230 day range that Viraraghavan *et al.* (1997) reported for biopile composting petroleum hydrocarbon contaminated soil. Their estimate of degradation time was based on degradation rate reported in the literature (Howard *et al.*, 1991). Howard *et al.* (1991) reported degradation rate constants for various hydrocarbon components (BTEX) in the range of -0.027/day for xylenes to -0.18/day for ethylbenzene. Based on several case studies reported by Viraraghavan *et al.* (1997), the average degradation rates reported for TPH was –0.030/day. Saberiyan *et al.* (1996) reported degradation constants for TPH in soil (consisting of diesel fuel and motor oil) of -0.056/day and –0.065/day (consisting of diesel fuel only). These rate constants compare very well to the degradation rate constant of –0.019/day obtained for Reactor 1. The slight difference between the rate constant obtained for Reactor 1 and those obtained by Saberiyan *et al* (1996) can be explained by the fact that the soil used in this study was mainly contaminated with used oil and those that Saberiyan (1996) reported on were based on a mixture of diesel fuel and motor oil and diesel fuel alone.

Statistical analysis of the data (Appendix D) indicates that the data obtained for Reactor 1 is statistically significant at the 95 percent confidence level. That is, the predicted values of ln (C/C_o) agree very well with the obtained values. However, the analysis shows that the data from Reactor 2 is not significant at the 95 percent confidence level.

4.6 Preliminary Design of Composting System

Based on the results reported in the thesis and by Viraraghavan et al (1997), it is evident that biopile composting is a feasible alternative for this site. It is further evident that remediation time may be reduced by as much as two thirds if grass clippings or some other source of highly biodegradable solids are added to the contaminated soil.

A static pile composting system could be constructed on the north side of the subject site. It is expected that due to the high volume of soil that must be treated at the site, it would have to be done in batches over a two to three year period. The soil would have to be treated in three batches over a period of three summers. Each batch would be treated in four piles, each with dimensions of approximately 30m X 15m X 2m high. A preliminary, conceptual design and construction plan for a composting system is presented in the following points:

- An area large enough to treat the desired batch of soil would be prepared to prevent runoff and leachate from the piles from entering surface or groundwater systems. This would likely consist of a bermed area with an impermeable liner (either synthetic or a natural soil liner). If a synthetic liner is used, it would have to be covered by a layer of soil to protect it during pile construction.

- The pile(s) would then be constructed within the bermed area on top of the impermeable liner. The pile(s) would likely be constructed in 0.5m to 1.0m layers.

- The contaminated soil would be excavated from the pit and stockpiled for preparation to place into piles. The soil would be mixed with gravel by placing a windrow of each material side by side and then blading the two together to form a mixture of the correct proportions. Once the soil and gravel are mixed together, the grass clippings and fertilizer would be mixed in. This may be accomplished using the windrow method as well.

- Once the components are mixed together adequately, the pile would be constructed. Construction of the pile would consist of placing a 0.5 m thick layer of the mixture on the impermeable liner, then laying a grid of perforated PVC pipe over the layer. Following this, another layer, approximately 1m thick (can be thicker than first layer because aeration pipes are above and below rather than just above), would be added over the piping, then another grid of pipes. This process would continue until the desired pile height is achieved. This would be no more than 6m. The length of the pile would have to be constructed in short sections to prevent the need for construction equipment to travel over the constructed portions of the pile and prevent compaction of the pile and breakage of the piping. The length of the pile would vary and would depend on the area of land available for treatment.

- After the pile is constructed, the piping would be connected to an air supply.

- It is expected that the air would be blown through the pile and vented to the atmosphere. Adequate moisture within the piles would be maintained by manually sprinkling the pile with water and also from precipitation as it is available. The moisture content would be maintained at approximately 30 percent. This would be ensured through monitoring of the moisture content.

- As each batch of soil is remediated it would be stockpiled until all contaminated soil is excavated. The remediated soil could then be used to refill the excavation.

A schematic of the conceptual composting system is shown in Figure 4.6.

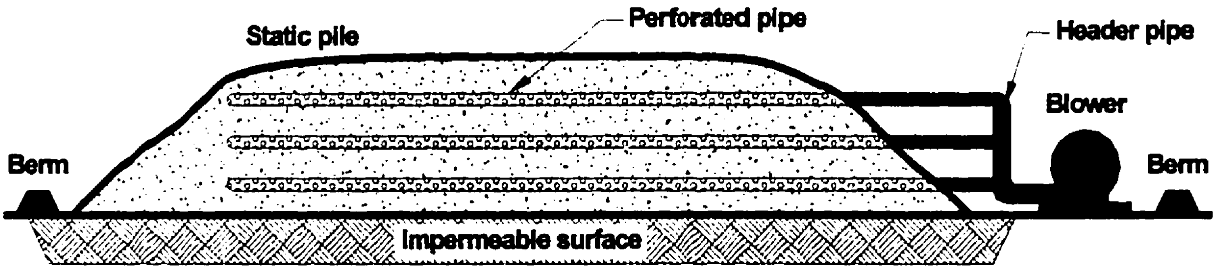


Figure 4.6: Schematic diagram of composting system

CHAPTER 5

SUMMARY, CONCLUSIONS AND FURTHER RESEARCH NEEDS

5.1 Summary

A bioremediation treatability study was conducted, using a composting process, to degrade TPH from soil. The treatability study compared the use of different amendments in an attempt to determine if the remediation time would be affected by the addition of certain amendments to the soil. It was apparent from the study that the type of high-energy source added to the soil would have an effect on the degradation rate of the TPH.

5.2 Conclusions

The following conclusions were drawn from the present study:

- The contaminated soil from the site contains hydrocarbon degrading bacteria. The genus and species of bacteria identified were *Aspergillus spp*, *Actinomycetes spp*, *Pseudomonas spp*, *Citrobacter freundi*, and *Pseudomonas fluorescence*. The indigenous bacteria, currently present at the subject site, were found to be capable of degrading the contaminant of concern, namely petroleum products.

- Nutrient levels in the soil suggested insufficient amounts of nitrogen and phosphorus for bioremediation to occur at an optimum rate. To compensate, a nutrient supplement of 40.3 g of ammonium nitrate fertilizer per kg of soil may be needed.

- Based on the results of the treatability study, the half-life of the contaminant at the subject site was estimated to be 36.3 days and 121.6 days with the addition of grass clippings (Reactor 1) and without the addition of grass clippings (Reactor 2), respectively.

- Based on the reaction rate of the contaminant in each reactor, it was estimated that it would take approximately 192 and 643 days to remediate a volume of soil to an acceptable level of TPH using the amendments of Reactors 1 and 2, respectively.

- Neither of the reactors exhibited significant temperature increase during the course of the composting process and the decrease just prior to completion of the composting process that is characteristic of municipal waste composting systems. This was likely due to the fact that the aeration rate was quite high and may have cooled the reactors, preventing a temperature increase, or the percentage of the high energy source (grass clippings) was not sufficient to cause the characteristic temperature rise.

5.3 Further Research Needs

The following studies could be considered in future:

- Further treatability studies to optimize the amount of fertilizer required.

- Further treatability studies utilizing different types and amounts of highly organic substances to determine if the composting process can be accelerated further so that a batch of soil can be remediated in less than the 192 days as indicated by the present study.

- Further treatability studies using different concentrations of contaminants ranging from the lowest to the highest found at the site. This may show an upper limit of petroleum hydrocarbon concentration that may be toxic to the microorganisms and prevent bioremediation.

- A study to determine the optimum air flow rate through the compost pile.

- A pilot-scale study, using the results of this and any other treatability studies that are conducted, to determine the potential success of a full-scale operation.

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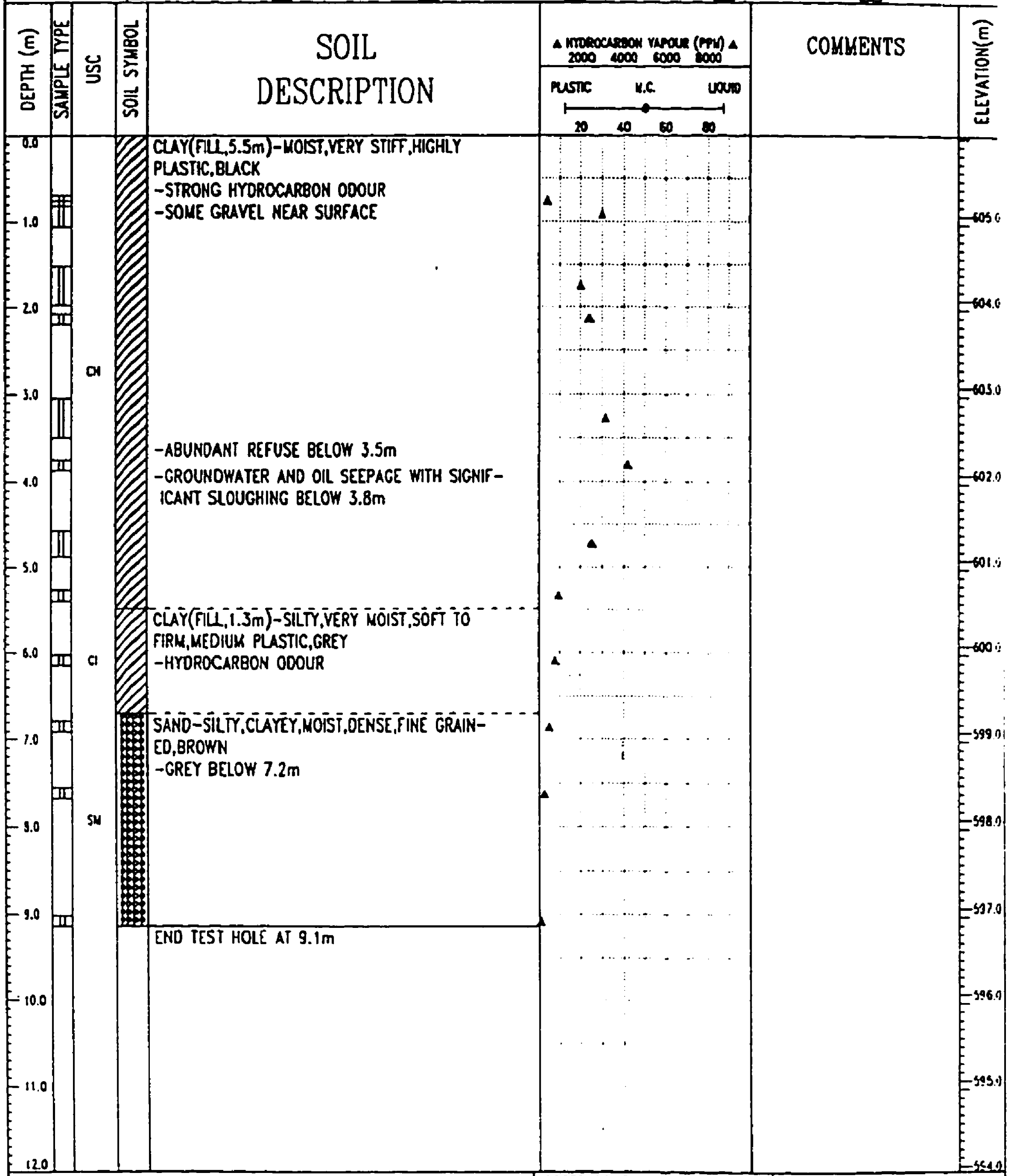
APPENDIX A

TEST HOLE LOGS

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: TH1
FLEET STREET LANDFILL	DRILL METHOD: HOLLOW STEM AUGER WITH	PROJECT NO: JX30012
CITY OF REGINA	SPLIT SPOON CORE SAMPLER	ELEVATION: 605.93 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



SOIL DESCRIPTION

CLAY(FILL,5.5m)-MOIST,VERY STIFF,HIGHLY PLASTIC,BLACK
-STRONG HYDROCARBON ODOUR
-SOME GRAVEL NEAR SURFACE

-ABUNDANT REFUSE BELOW 3.5m
-GROUNDWATER AND OIL SEEPAGE WITH SIGNIFICANT SLOUGHING BELOW 3.8m

CLAY(FILL,1.3m)-SILTY,VERY MOIST,SOFT TO FIRM,MEDIUM PLASTIC,GREY
-HYDROCARBON ODOUR

SAND-SILTY,CLAYEY,MOIST,DENSE,FINE GRAINED,BROWN
-GREY BELOW 7.2m

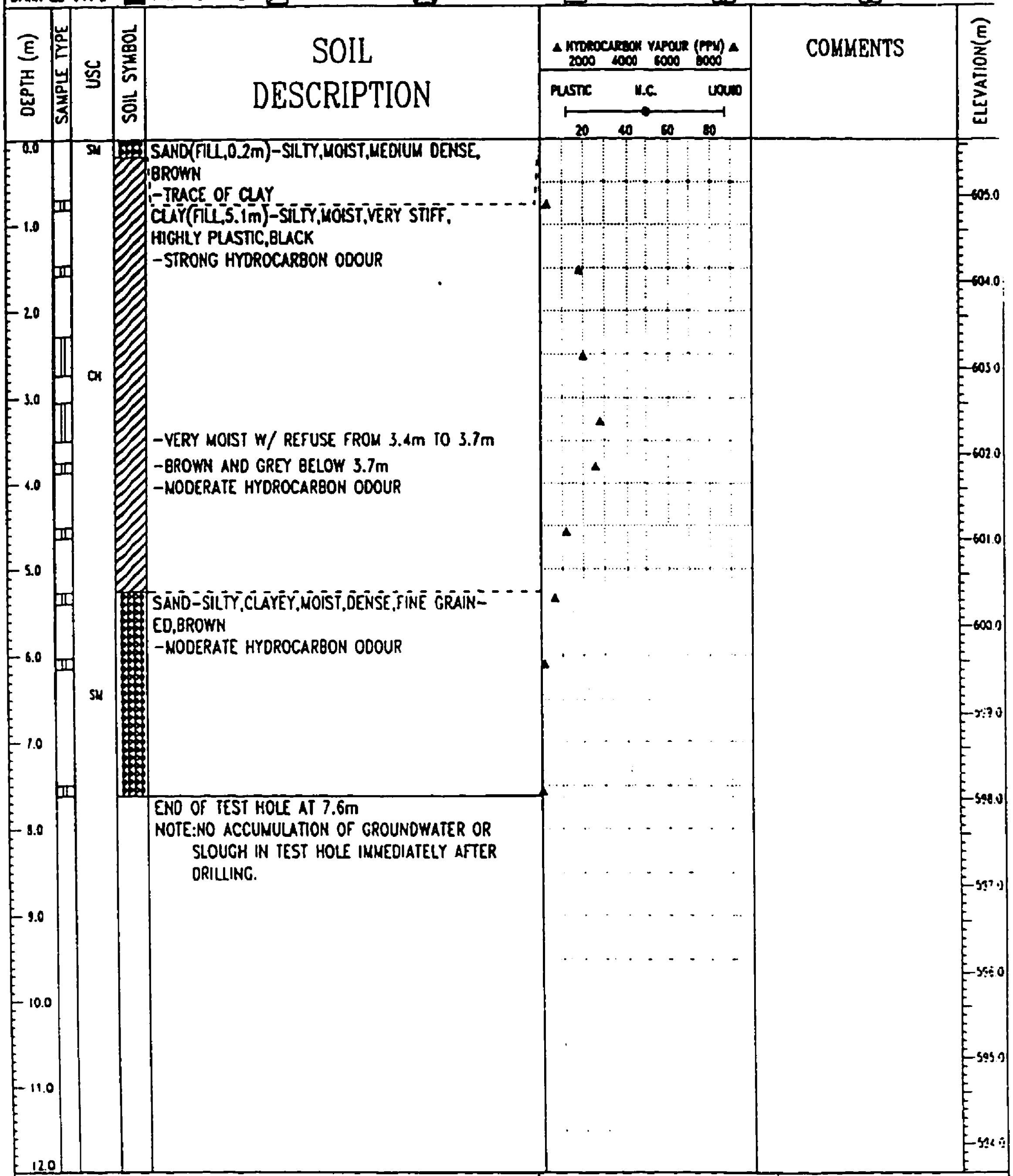
END TEST HOLE AT 9.1m

COMMENTS

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 9.1 m
	REVIEWED BY: EDF DJM	COMPLETE: 12/13/93
	Fig. No: 4	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: TH2
FLEET STREET LANDFILL	DRILL METHOD: HOLLOW STEM AUGER WITH	PROJECT NO: JX30012
CITY OF REGINA	SPLIT SPOON CORE SAMPLER	ELEVATION: 605.66 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯▯ HOLLOW STEM ▯ CORE



SAND(FILL,0.2m)-SILTY,MOIST,MEDIUM DENSE, BROWN
-TRACE OF CLAY

CLAY(FILL,5.1m)-SILTY,MOIST,VERY STIFF, HIGHLY PLASTIC,BLACK
-STRONG HYDROCARBON ODOUR

-VERY MOIST W/ REFUSE FROM 3.4m TO 3.7m
-BROWN AND GREY BELOW 3.7m
-MODERATE HYDROCARBON ODOUR

SAND-SILTY,CLAYEY,MOIST,DENSE,FINE GRAINED,BROWN
-MODERATE HYDROCARBON ODOUR

END OF TEST HOLE AT 7.6m
NOTE:NO ACCUMULATION OF GROUNDWATER OR SLOUGH IN TEST HOLE IMMEDIATELY AFTER DRILLING.

ACRA Earth & Environmental Limited	LOGGED BY: TK	COMPLETION DEPTH: 7.6 m
	REVIEWED BY: EDF DJM	COMPLETE: 12/14/93
Regina, Saskatchewan	Fig. No: 5	Page 1 of 1

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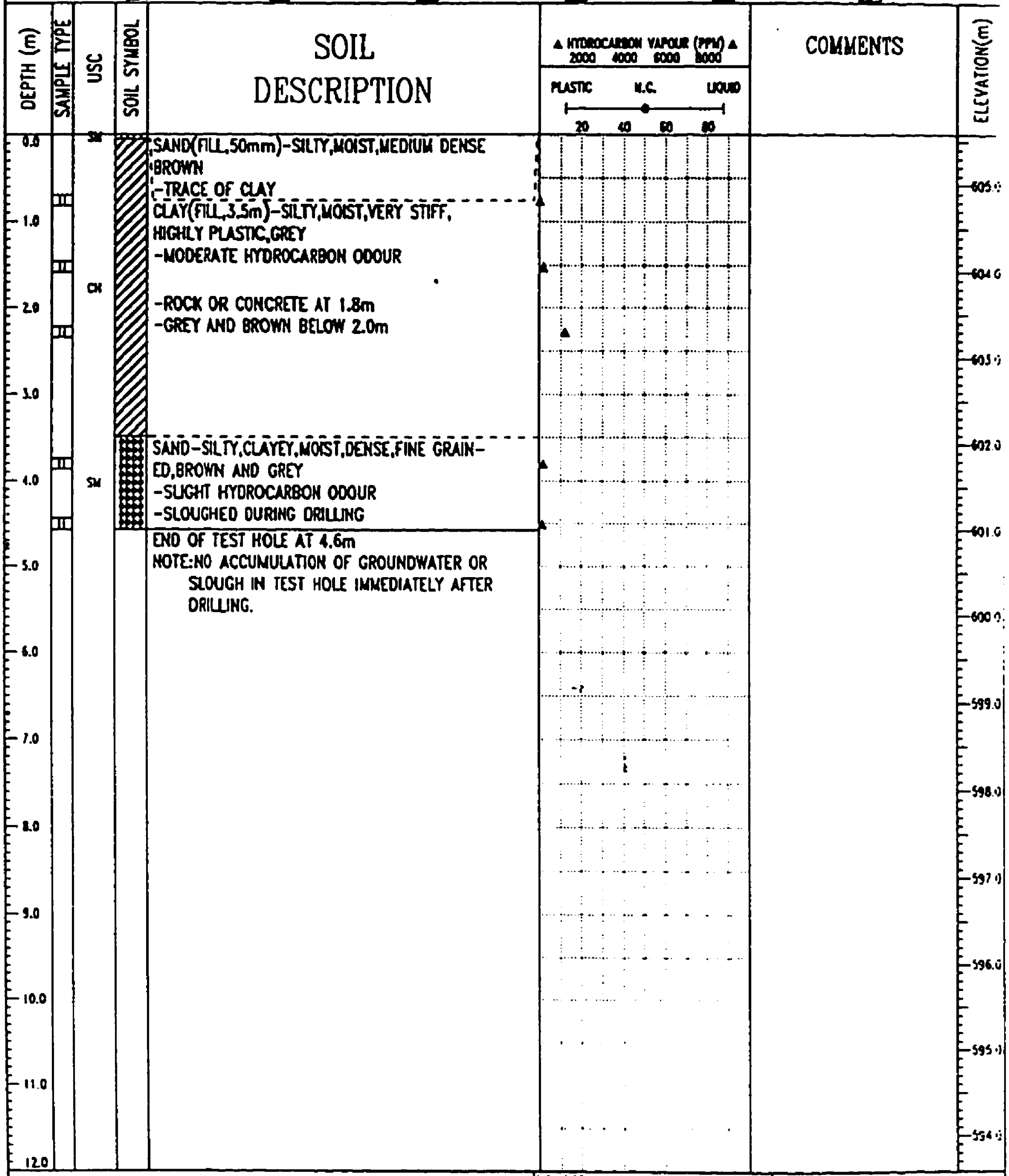
OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: TH3
FLEET STREET LANDFILL	DRILL METHOD: HOLLOW STEM AUGER WITH	PROJECT NO: JX30012
CITY OF REGINA	SPLIT SPOON CORE SAMPLER	ELEVATION: 605.58 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▥ HOLLOW STEM ▯ CORE



SAND(FILL,50mm)-SILTY,MOIST,MEDIUM DENSE
BROWN
-TRACE OF CLAY

CLAY(FILL,3.5m)-SILTY,MOIST,VERY STIFF,
HIGHLY PLASTIC,GREY
-MODERATE HYDROCARBON ODOUR

-ROCK OR CONCRETE AT 1.8m
-GREY AND BROWN BELOW 2.0m

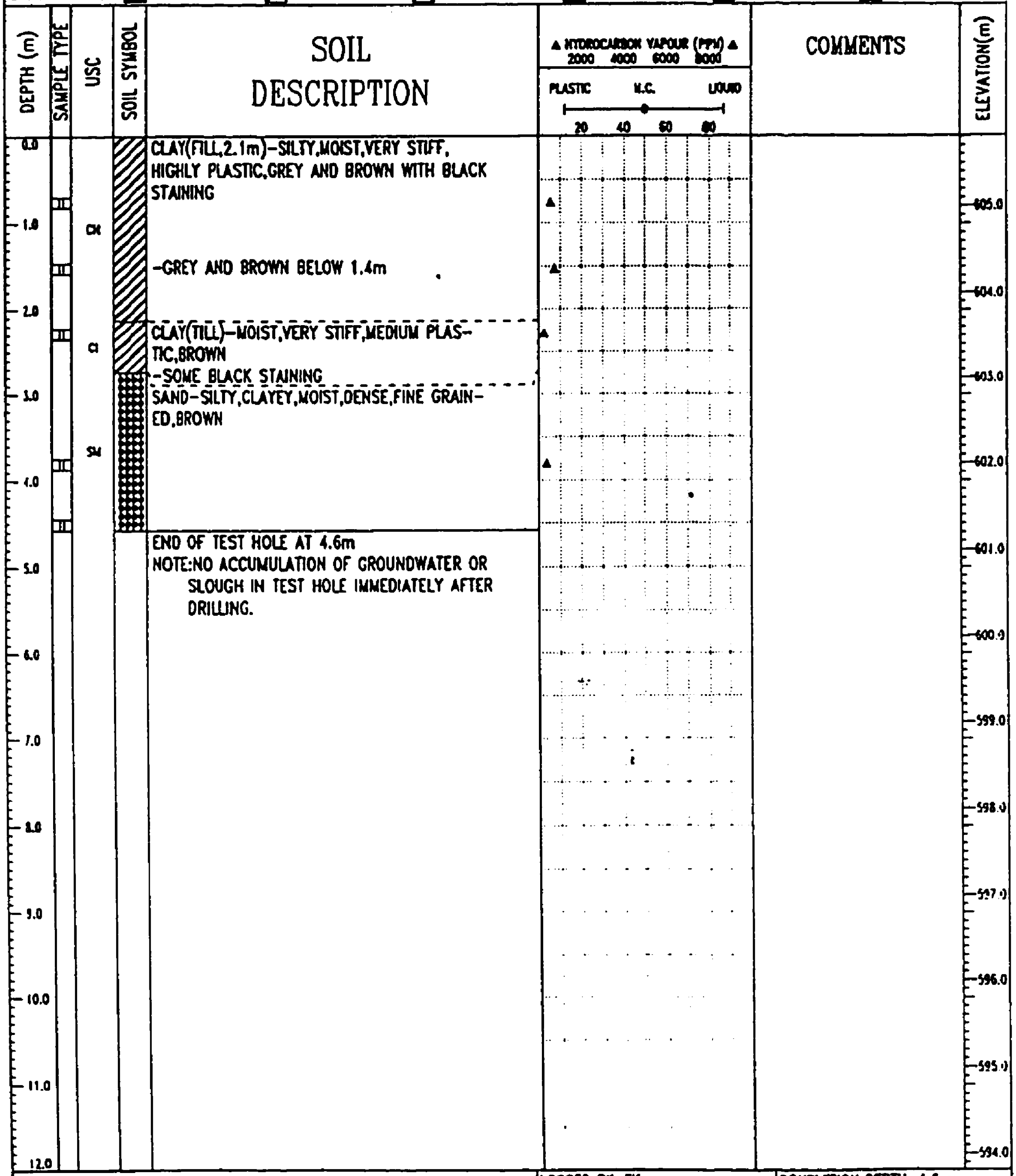
SAND-SILTY,CLAYEY,MOIST,DENSE,FINE GRAINED,BROWN AND GREY
-SLIGHT HYDROCARBON ODOUR
-SLOUGHED DURING DRILLING

END OF TEST HOLE AT 4.6m
NOTE:NO ACCUMULATION OF GROUNDWATER OR SLOUGH IN TEST HOLE IMMEDIATELY AFTER DRILLING.

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 4.6 m
	REVIEWED BY: EDF DJM	COMPLETE: 12/14/93
	Fig. No: 6	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: TH4
FLEET STREET LANDFILL	DRILL METHOD: HOLLOW STEM AUGER WITH	PROJECT NO: JX30012
CITY OF REGINA	SPLIT SPOON CORE SAMPLER	ELEVATION: 605.81 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



SOIL DESCRIPTION

COMMENTS

CLAY(FILL,2.1m)–SILTY,MOIST,VERY STIFF, HIGHLY PLASTIC,GREY AND BROWN WITH BLACK STAINING

–GREY AND BROWN BELOW 1.4m

CLAY(TILL)–MOIST,VERY STIFF,MEDIUM PLASTIC,BROWN

–SOME BLACK STAINING

SAND–SILTY,CLAYEY,MOIST,DENSE,FINE GRAINED,BROWN

END OF TEST HOLE AT 4.6m

NOTE:NO ACCUMULATION OF GROUNDWATER OR SLOUGH IN TEST HOLE IMMEDIATELY AFTER DRILLING.

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 4.6 m
	REVIEWED BY: EDF DJM	COMPLETE: 12/14/93
	Fig. No: 7	Page 1 of 1

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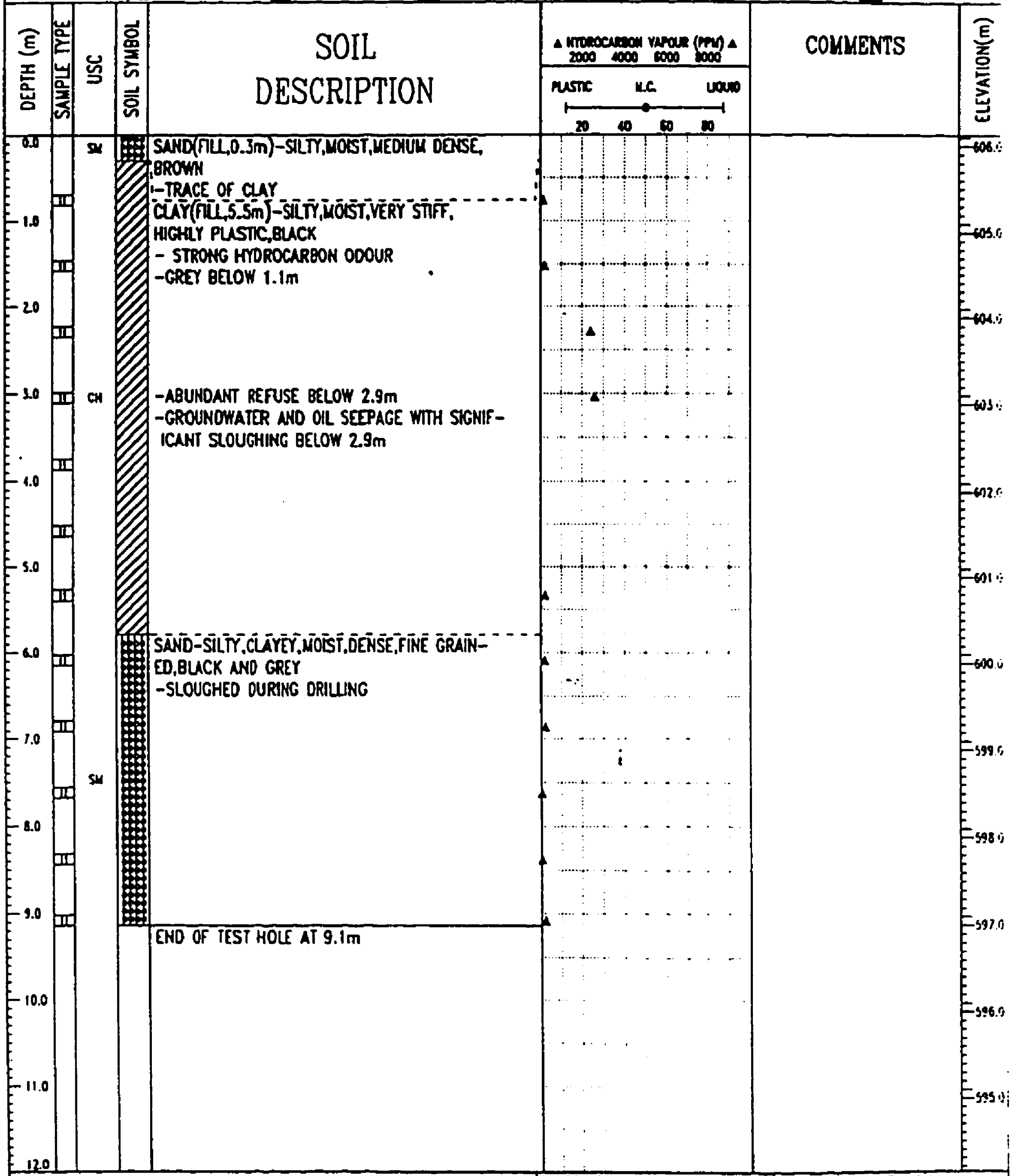
OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: TH5
FLEET STREET LANDFILL	DRILL METHOD: HOLLOW STEM AUGER WITH	PROJECT NO: JX30012
CITY OF REGINA	SPLIT SPOON CORE SAMPLER	ELEVATION: 606.13 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▮ CORE



SAND(FILL,0.3m)-SILTY,MOIST,MEDIUM DENSE, BROWN
-TRACE OF CLAY

CLAY(FILL,5.5m)-SILTY,MOIST,VERY STIFF, HIGHLY PLASTIC,BLACK
- STRONG HYDROCARBON ODOUR
-GREY BELOW 1.1m
-ABUNDANT REFUSE BELOW 2.9m
-GROUNDWATER AND OIL SEEPAGE WITH SIGNIFICANT SLOUGHING BELOW 2.9m

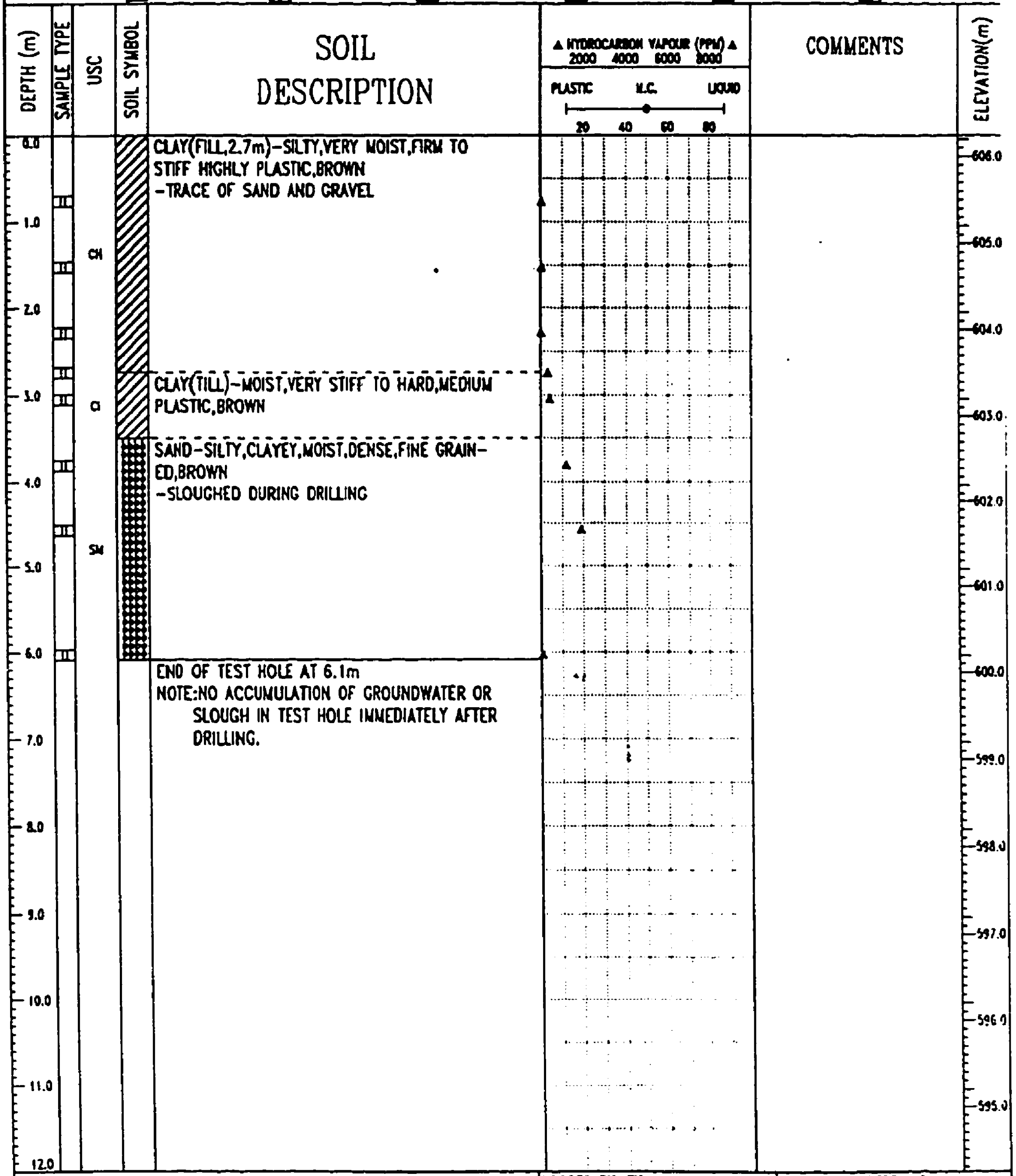
SAND-SILTY,CLAYEY,MOIST,DENSE,FINE GRAINED,BLACK AND GREY
-SLOUGHED DURING DRILLING

END OF TEST HOLE AT 9.1m

AGRA Earth & Environmental Limited	LOGGED BY: TK	COMPLETION DEPTH: 9.1 m
	REVIEWED BY: EDF DJM	COMPLETE: 12/14/93
Regina, Saskatchewan	Fig. No: 8	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: TH6
FLEET STREET LANDFILL	DRILL METHOD: HOLLOW STEM AUGER WITH	PROJECT NO: JX30012
CITY OF REGINA	SPLIT SPOON CORE SAMPLER	ELEVATION: 606.24 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▥ HOLLOW STEM ▯ CORE



CLAY(FILL,2.7m)-SILTY,VERY MOIST,FIRM TO STIFF HIGHLY PLASTIC,BROWN
-TRACE OF SAND AND GRAVEL

CLAY(TILL)-MOIST,VERY STIFF TO HARD,MEDIUM PLASTIC,BROWN

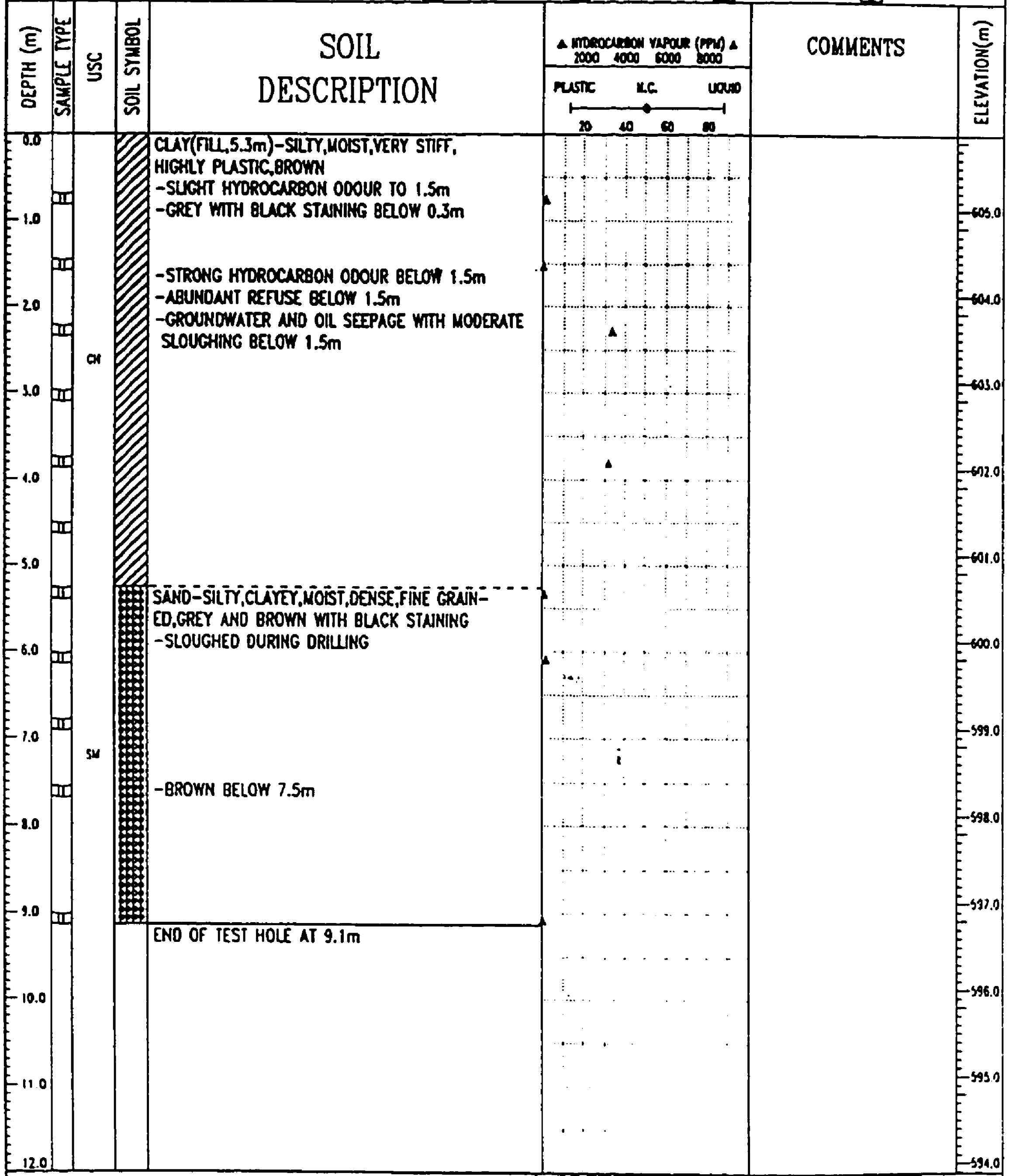
SAND-SILTY,CLAYEY,MOIST,DENSE,FINE GRAINED,BROWN
-SLOUGHED DURING DRILLING

END OF TEST HOLE AT 6.1m
NOTE:NO ACCUMULATION OF GROUNDWATER OR SLOUGH IN TEST HOLE IMMEDIATELY AFTER DRILLING.

AGRA Earth & Environmental Limited	LOGGED BY: TK	COMPLETION DEPTH: 6.1 m
	REVIEWED BY: EDF DJM	COMPLETE: 12/14/93
Regina, Saskatchewan	Fig. No: 9	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: TH7
FLEET STREET LANDFILL	DRILL METHOD: HOLLOW STEM AUGER WITH	PROJECT NO: JX30012
CITY OF REGINA	SPLIT SPOON CORE SAMPLER	ELEVATION: 605.88 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



CLAY(FILL,5.3m)-SILTY,MOIST,VERY STIFF, HIGHLY PLASTIC,BROWN
-SLIGHT HYDROCARBON ODOUR TO 1.5m
-GREY WITH BLACK STAINING BELOW 0.3m

-STRONG HYDROCARBON ODOUR BELOW 1.5m
-ABUNDANT REFUSE BELOW 1.5m
-GROUNDWATER AND OIL SEEPAGE WITH MODERATE SLOUGHING BELOW 1.5m

SAND-SILTY,CLAYEY,MOIST,DENSE,FINE GRAINED,GREY AND BROWN WITH BLACK STAINING
-SLOUGHED DURING DRILLING

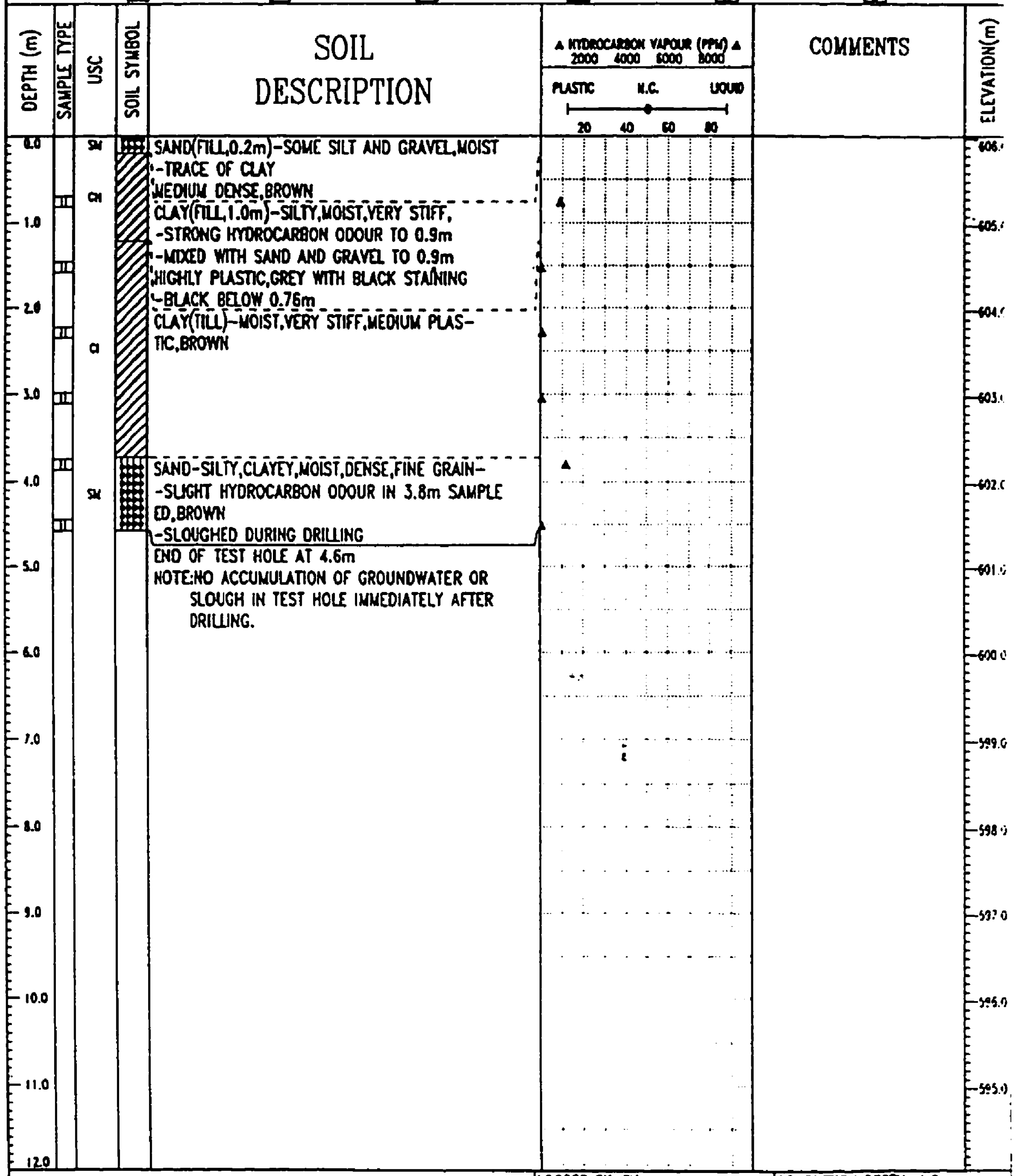
-BROWN BELOW 7.5m

END OF TEST HOLE AT 9.1m

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 9.1 m
	REVIEWED BY: EDF DJM	COMPLETE: 12/14/93
	Fig. No: 10	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: TH8
FLEET STREET LANDFILL	DRILL METHOD: HOLLOW STEM AUGER WITH	PROJECT NO: JX30012
CITY OF REGINA	SPLIT SPOON CORE SAMPLER	ELEVATION: 606.03 (m)

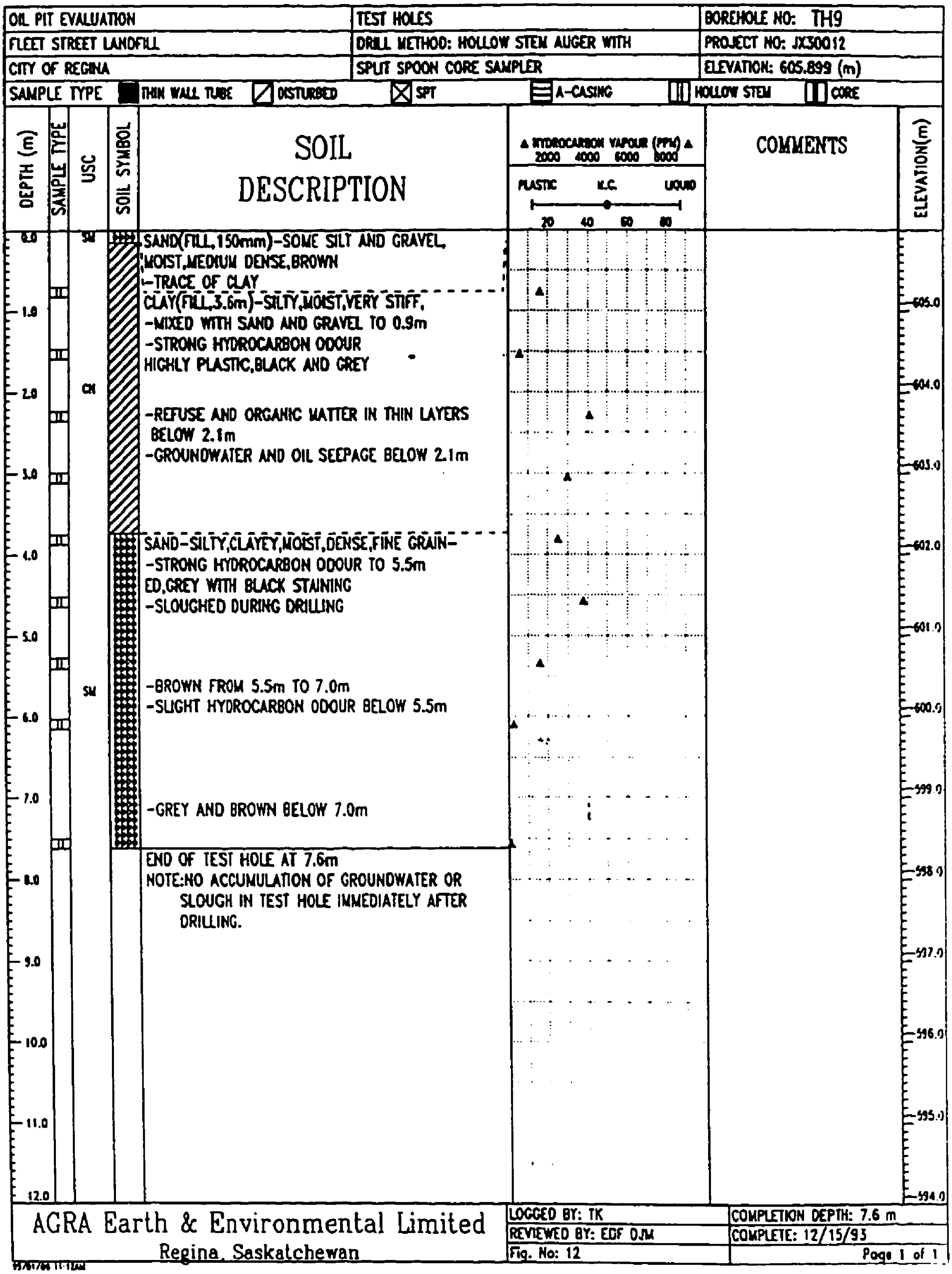
SAMPLE TYPE ■ THIN WALL TUBE ◪ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



SAND(FILL,0.2m)-SOME SILT AND GRAVEL,MOIST
-TRACE OF CLAY
MEDIUM DENSE,BROWN
CLAY(FILL,1.0m)-SILTY,MOIST,VERY STIFF,
-STRONG HYDROCARBON ODOUR TO 0.9m
-MIXED WITH SAND AND GRAVEL TO 0.9m
HIGHLY PLASTIC,GREY WITH BLACK STAINING
-BLACK BELOW 0.76m
CLAY(TILL)-MOIST,VERY STIFF,MEDIUM PLASTIC,BROWN

SAND-SILTY,CLAYEY,MOIST,DENSE,FINE GRAINED,BROWN
-SLIGHT HYDROCARBON ODOUR IN 3.8m SAMPLE
-SLOUGHED DURING DRILLING
END OF TEST HOLE AT 4.6m
NOTE:NO ACCUMULATION OF GROUNDWATER OR SLOUGH IN TEST HOLE IMMEDIATELY AFTER DRILLING.

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 4.6 m
	REVIEWED BY: EDF DJM	COMPLETE: 12/15/93
	Fig. No: 11	Page 1 of 1



OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: TH9
FLEET STREET LANDFILL	DRILL METHOD: HOLLOW STEM AUGER WITH	PROJECT NO: JX30012
CITY OF REGINA	SPLIT SPOON CORE SAMPLER	ELEVATION: 605.899 (m)

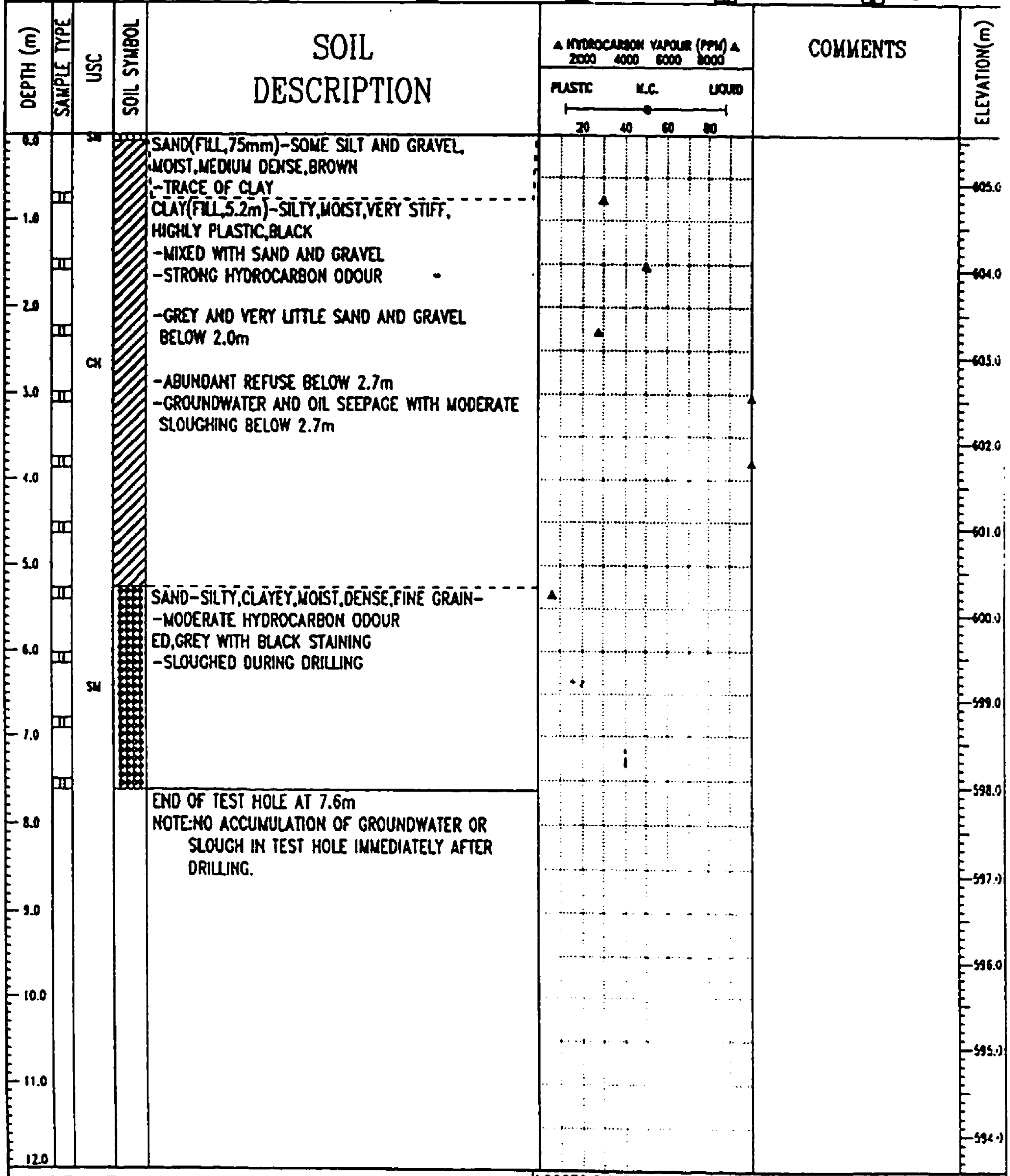
SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▥ HOLLOW STEM ▯ CORE

DEPTH (m)	USC	SOIL DESCRIPTION
0.0	SM	SAND(FILL,150mm)-SOME SILT AND GRAVEL, MOIST,MEDIUM DENSE,BROWN -TRACE OF CLAY
	CH	CLAY(FILL,3.6m)-SILTY,MOIST,VERY STIFF, -MIXED WITH SAND AND GRAVEL TO 0.9m -STRONG HYDROCARBON ODOUR HIGHLY PLASTIC,BLACK AND GREY -REFUSE AND ORGANIC MATTER IN THIN LAYERS BELOW 2.1m -GROUNDWATER AND OIL SEEPAGE BELOW 2.1m
	SM	SAND-SILTY,CLAYEY,MOIST,DENSE,FINE GRAIN- -STRONG HYDROCARBON ODOUR TO 5.5m ED,GREY WITH BLACK STAINING -SLOUGHED DURING DRILLING -BROWN FROM 5.5m TO 7.0m -SLIGHT HYDROCARBON ODOUR BELOW 5.5m -GREY AND BROWN BELOW 7.0m
		END OF TEST HOLE AT 7.6m NOTE:NO ACCUMULATION OF GROUNDWATER OR SLOUGH IN TEST HOLE IMMEDIATELY AFTER DRILLING.

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 7.6 m
	REVIEWED BY: EDF DJM	COMPLETE: 12/15/93
	Fig. No: 12	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: TH10
FLEET STREET LANDFILL	DRILL METHOD: HOLLOW STEM AUGER WITH	PROJECT NO: JX30012
CITY OF REGINA	SPLIT SPOON CORE SAMPLER	ELEVATION: 605.58 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A–CASING ▥ HOLLOW STEM ▯ CORE



SAND(FILL,75mm)-SOME SILT AND GRAVEL, MOIST,MEDIUM DENSE,BROWN
-TRACE OF CLAY

CLAY(FILL,5.2m)-SILTY,MOIST,VERY STIFF, HIGHLY PLASTIC,BLACK
-MIXED WITH SAND AND GRAVEL
-STRONG HYDROCARBON ODOUR

-GREY AND VERY LITTLE SAND AND GRAVEL BELOW 2.0m

-ABUNDANT REFUSE BELOW 2.7m
-GROUNDWATER AND OIL SEEPAGE WITH MODERATE SLOUGHING BELOW 2.7m

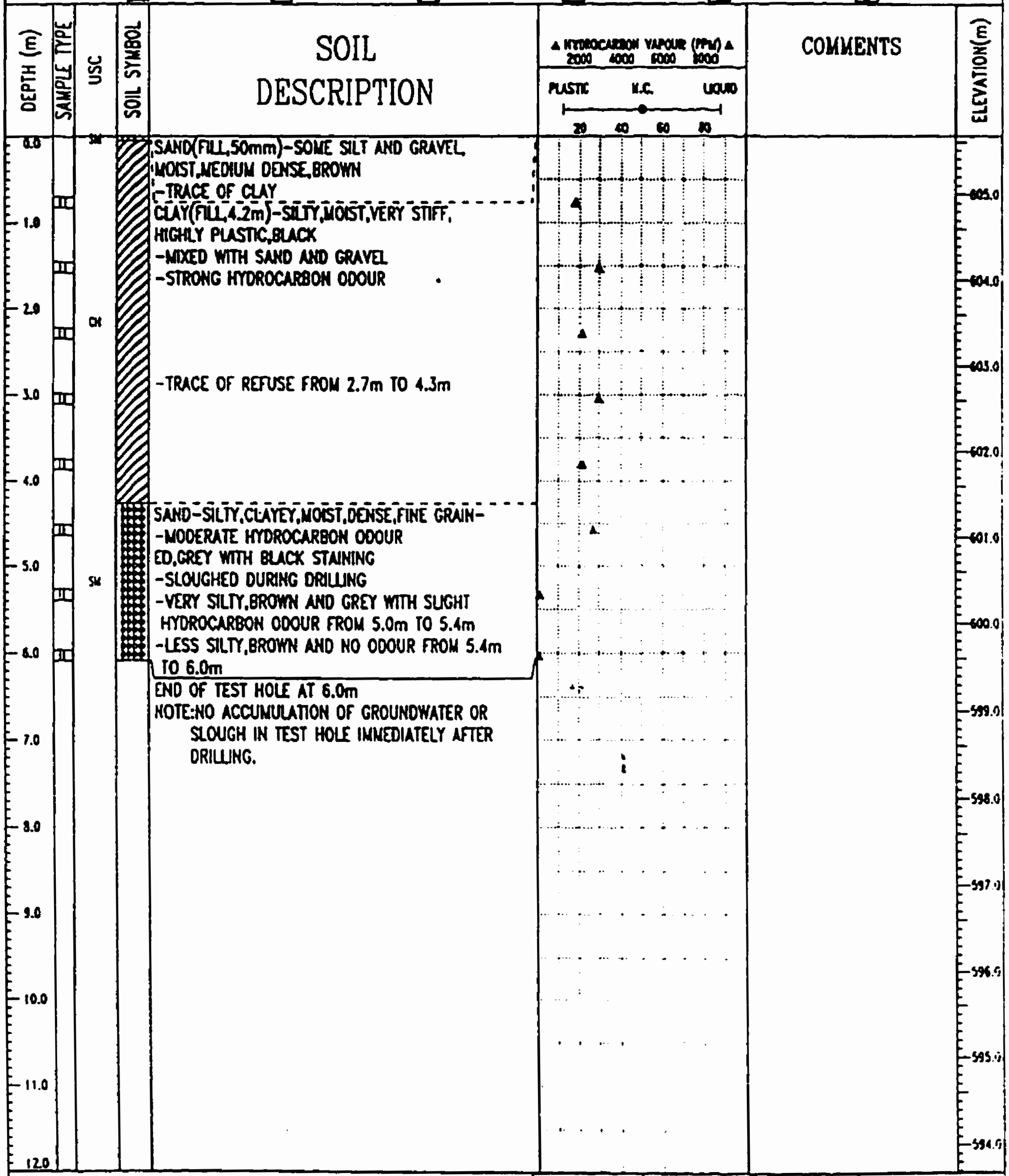
SAND-SILTY,CLAYEY,MOIST,DENSE,FINE GRAIN-
-MODERATE HYDROCARBON ODOUR
ED,GREY WITH BLACK STAINING
-SLOUGHED DURING DRILLING

END OF TEST HOLE AT 7.6m
NOTE:NO ACCUMULATION OF GROUNDWATER OR SLOUGH IN TEST HOLE IMMEDIATELY AFTER DRILLING.

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 7.6 m
	REVIEWED BY: EDF DJM	COMPLETE: 12/15/93
	Fig. No: 13	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: TH11
FLEET STREET LANDFILL	DRILL METHOD: HOLLOW STEM AUGER WITH	PROJECT NO: JX30012
CITY OF REGINA	SPLIT SPOON CORE SAMPLER	ELEVATION: 605.67 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



SAND(FILL,50mm)-SOME SILT AND GRAVEL, MOIST,MEDIUM DENSE,BROWN
-TRACE OF CLAY

CLAY(FILL,4.2m)-SILTY,MOIST,VERY STIFF, HIGHLY PLASTIC,BLACK
-MIXED WITH SAND AND GRAVEL
-STRONG HYDROCARBON ODOUR

-TRACE OF REFUSE FROM 2.7m TO 4.3m

SAND-SILTY,CLAYEY,MOIST,DENSE,FINE GRAINED,GREY WITH BLACK STAINING
-MODERATE HYDROCARBON ODOUR
-SLOUGHED DURING DRILLING
-VERY SILTY,BROWN AND GREY WITH SLIGHT HYDROCARBON ODOUR FROM 5.0m TO 5.4m
-LESS SILTY,BROWN AND NO ODOUR FROM 5.4m TO 6.0m

END OF TEST HOLE AT 6.0m

NOTE:NO ACCUMULATION OF GROUNDWATER OR SLOUGH IN TEST HOLE IMMEDIATELY AFTER DRILLING.

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 6.1 m
	REVIEWED BY: EDF DJM	COMPLETE: 12/15/93
	Fig. No: 14	Page 1 of 1

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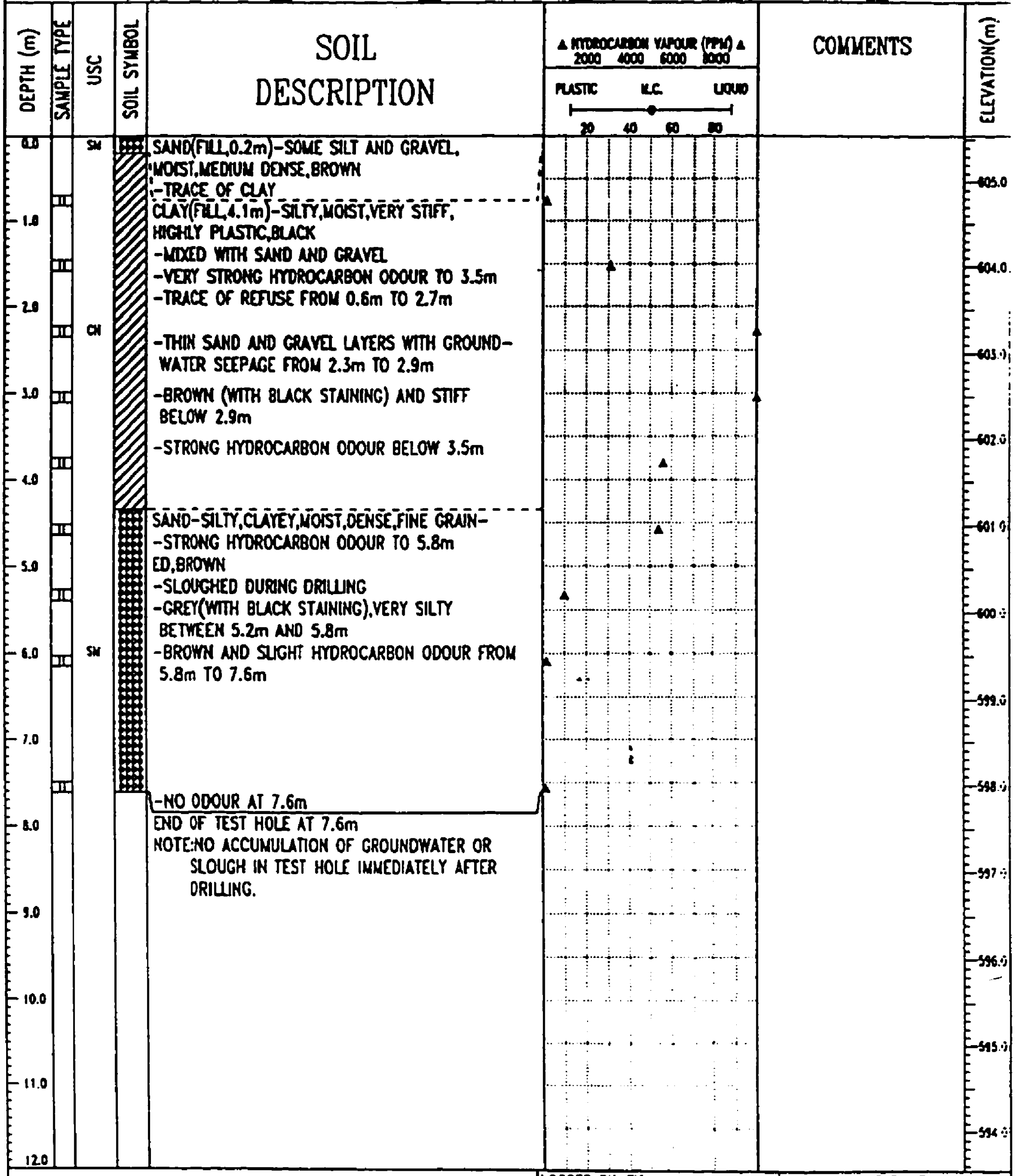
OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: TH12
FLEET STREET LANDFILL	DRILL METHOD: HOLLOW STEM AUGER WITH	PROJECT NO: JX30012
CITY OF REGINA	SPLIT SPOON CORE SAMPLER	ELEVATION: 605.539 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ◫ HOLLOW STEM ◫ CORE



SOIL DESCRIPTION

SAND(FILL,0.2m)-SOME SILT AND GRAVEL,
MOIST,MEDIUM DENSE,BROWN
-TRACE OF CLAY

CLAY(FILL,4.1m)-SILTY,MOIST,VERY STIFF,
HIGHLY PLASTIC,BLACK
-MIXED WITH SAND AND GRAVEL
-VERY STRONG HYDROCARBON ODOUR TO 3.5m
-TRACE OF REFUSE FROM 0.6m TO 2.7m

-THIN SAND AND GRAVEL LAYERS WITH GROUNDWATER SEEPAGE FROM 2.3m TO 2.9m

-BROWN (WITH BLACK STAINING) AND STIFF
BELOW 2.9m

-STRONG HYDROCARBON ODOUR BELOW 3.5m

SAND-SILTY,CLAYEY,MOIST,DENSE,FINE GRAIN-
-STRONG HYDROCARBON ODOUR TO 5.8m
ED,BROWN
-SLOUGHED DURING DRILLING
-GREY(WITH BLACK STAINING),VERY SILTY
BETWEEN 5.2m AND 5.8m
-BROWN AND SLIGHT HYDROCARBON ODOUR FROM
5.8m TO 7.6m

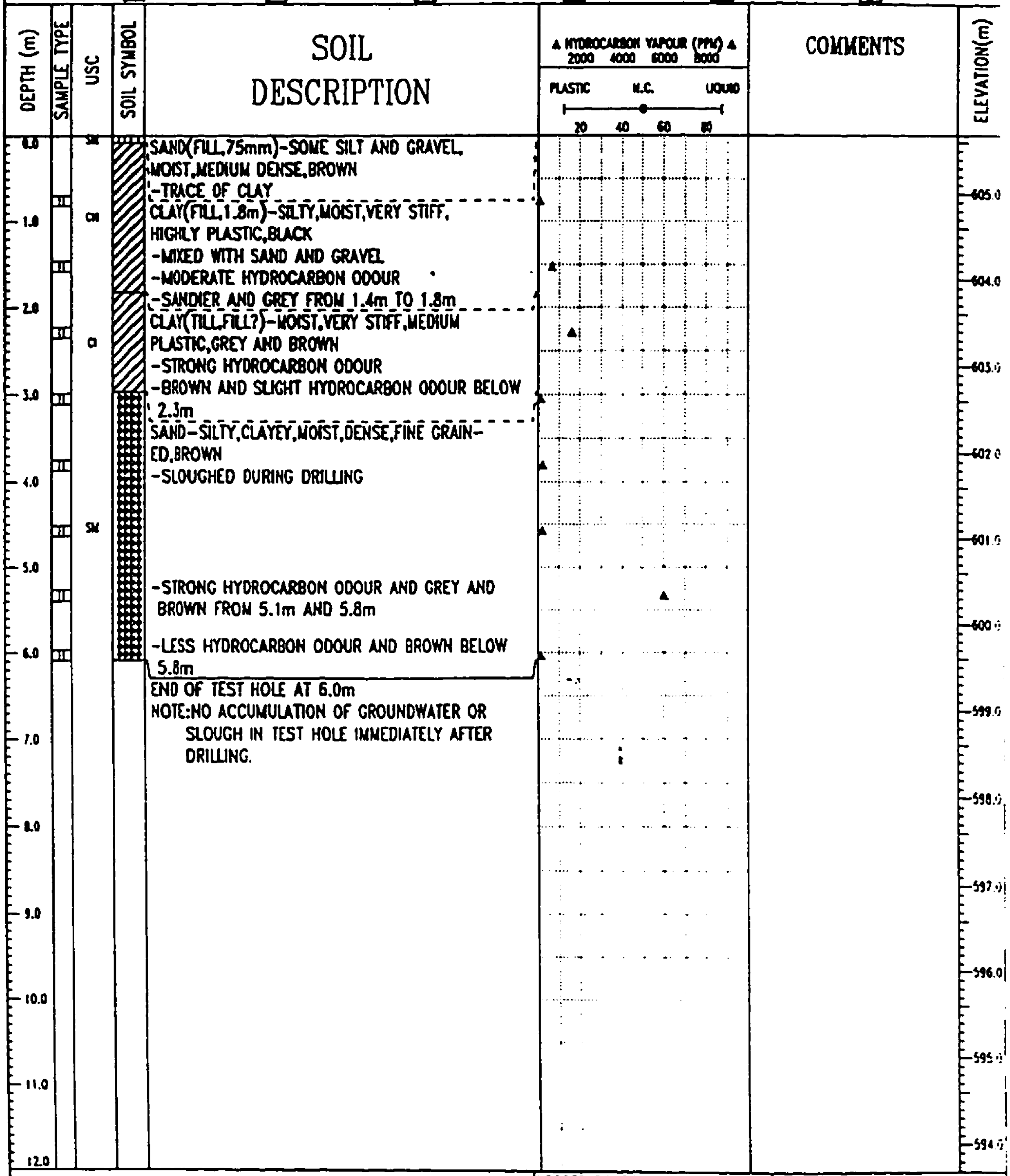
-NO ODOUR AT 7.6m

END OF TEST HOLE AT 7.6m
NOTE:NO ACCUMULATION OF GROUNDWATER OR
SLOUGH IN TEST HOLE IMMEDIATELY AFTER
DRILLING.

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 7.6 m
	REVIEWED BY: EDF DJM	COMPLETE: 12/15/93
	Fig. No: 15	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: TH13
FLEET STREET LANDFILL	DRILL METHOD: HOLLOW STEM AUGER WITH	PROJECT NO: JX30012
CITY OF REGINA	SPLIT SPOON CORE SAMPLER	ELEVATION: 605.68 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



SOIL DESCRIPTION

SAND(FILL,75mm)-SOME SILT AND GRAVEL, MOIST,MEDIUM DENSE,BROWN
-TRACE OF CLAY

CLAY(FILL,1.8m)-SILTY,MOIST,VERY STIFF, HIGHLY PLASTIC,BLACK
-MIXED WITH SAND AND GRAVEL
-MODERATE HYDROCARBON ODOUR
-SANDIER AND GREY FROM 1.4m TO 1.8m

CLAY(TILL,FILL?)-MOIST,VERY STIFF,MEDIUM PLASTIC,GREY AND BROWN
-STRONG HYDROCARBON ODOUR
-BROWN AND SLIGHT HYDROCARBON ODOUR BELOW 2.3m

SAND-SILTY,CLAYEY,MOIST,DENSE,FINE GRAINED,BROWN
-SLOUGHED DURING DRILLING

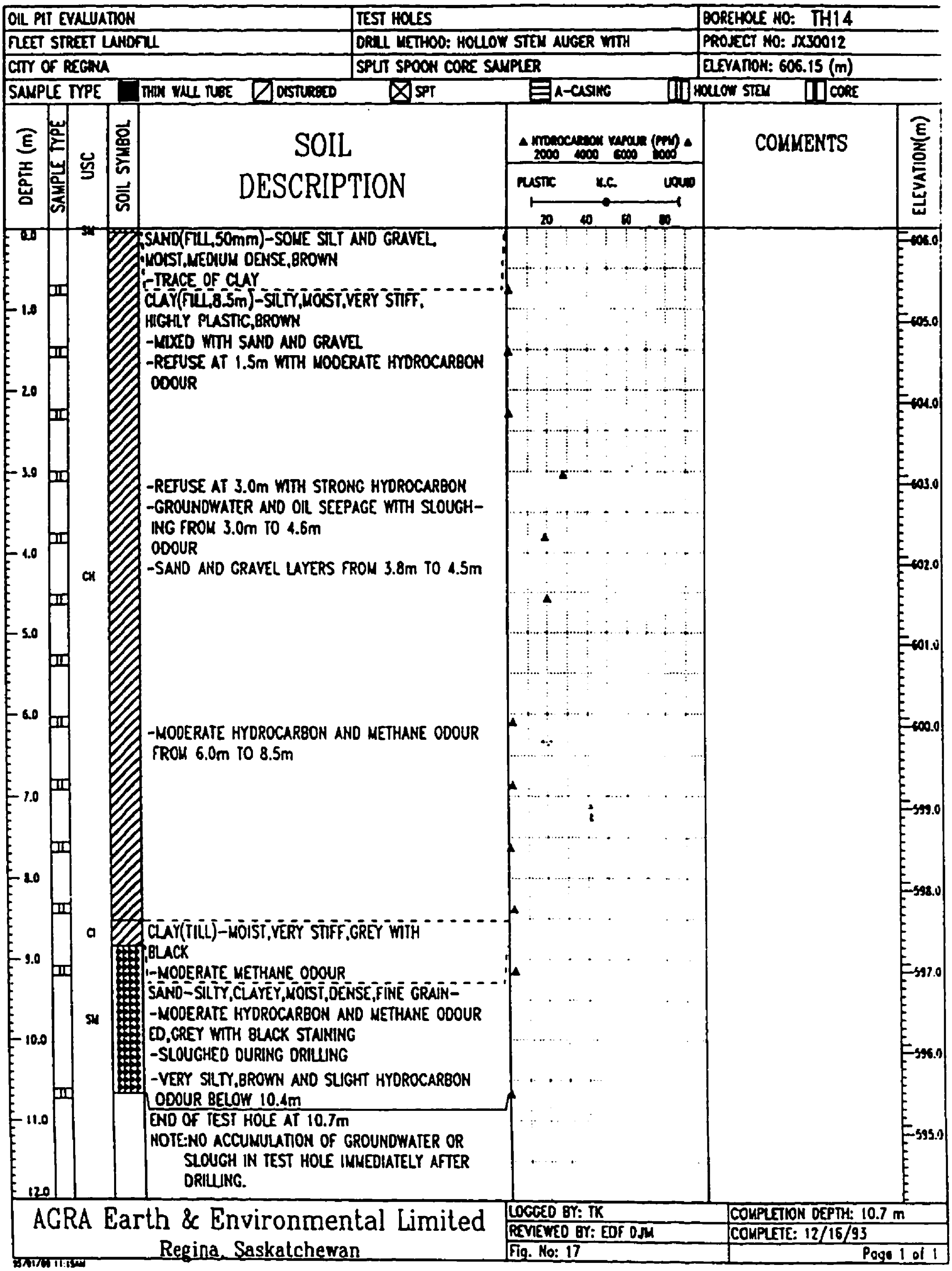
-STRONG HYDROCARBON ODOUR AND GREY AND BROWN FROM 5.1m AND 5.8m

-LESS HYDROCARBON ODOUR AND BROWN BELOW 5.8m

END OF TEST HOLE AT 6.0m

NOTE:NO ACCUMULATION OF GROUNDWATER OR SLOUGH IN TEST HOLE IMMEDIATELY AFTER DRILLING.

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 6.1 m
	REVIEWED BY: EDF DJM	COMPLETE: 12/15/93
	Fig. No: 16	Page 1 of 1



OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: TH14
FLEET STREET LANDFILL	DRILL METHOD: HOLLOW STEM AUGER WITH	PROJECT NO: JX30012
CITY OF REGINA	SPLIT SPOON CORE SAMPLER	ELEVATION: 606.15 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE

SOIL DESCRIPTION

SAND(FILL,50mm)-SOME SILT AND GRAVEL,
MOIST,MEDIUM DENSE,BROWN
-TRACE OF CLAY

CLAY(FILL,8.5m)-SILTY,MOIST,VERY STIFF,
HIGHLY PLASTIC,BROWN
-MIXED WITH SAND AND GRAVEL
-REFUSE AT 1.5m WITH MODERATE HYDROCARBON
ODOUR

-REFUSE AT 3.0m WITH STRONG HYDROCARBON
-GROUNDWATER AND OIL SEEPAGE WITH SLOUGHING FROM 3.0m TO 4.6m
ODOUR
-SAND AND GRAVEL LAYERS FROM 3.8m TO 4.5m

-MODERATE HYDROCARBON AND METHANE ODOUR
FROM 6.0m TO 8.5m

CLAY(TILL)-MOIST,VERY STIFF,GREY WITH
BLACK
-MODERATE METHANE ODOUR

SAND-SILTY,CLAYEY,MOIST,DENSE,FINE GRAIN-
-MODERATE HYDROCARBON AND METHANE ODOUR
ED,GREY WITH BLACK STAINING
-SLOUGHED DURING DRILLING
-VERY SILTY,BROWN AND SLIGHT HYDROCARBON
ODOUR BELOW 10.4m

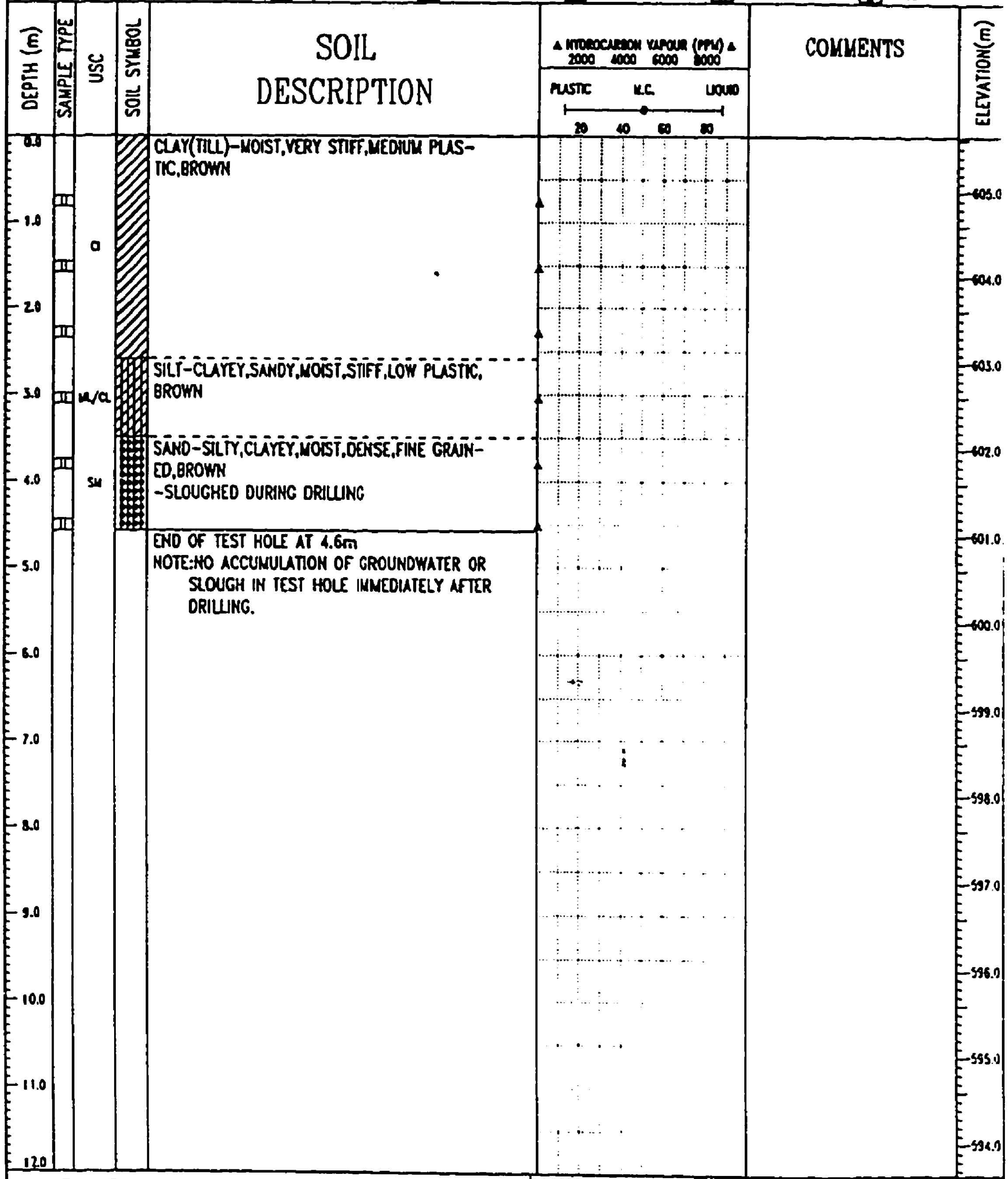
END OF TEST HOLE AT 10.7m
NOTE:NO ACCUMULATION OF GROUNDWATER OR
SLOUGH IN TEST HOLE IMMEDIATELY AFTER
DRILLING.

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 10.7 m
	REVIEWED BY: EDF DJM	COMPLETE: 12/16/93
	Fig. No: 17	Page 1 of 1

95/01/00 11:15AM

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: TH15
FLEET STREET LANDFILL	DRILL METHOD: HOLLOW STEM AUGER WITH	PROJECT NO: JX30012
CITY OF REGINA	SPLIT SPOON CORE SAMPLER	ELEVATION: 605.63 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



CLAY(TILL)-MOIST,VERY STIFF,MEDIUM PLASTIC,BROWN

SILT-CLAYEY,SANDY,MOIST,STIFF,LOW PLASTIC, BROWN

SAND-SILTY,CLAYEY,MOIST,DENSE,FINE GRAINED,BROWN
-SLOUGHED DURING DRILLING

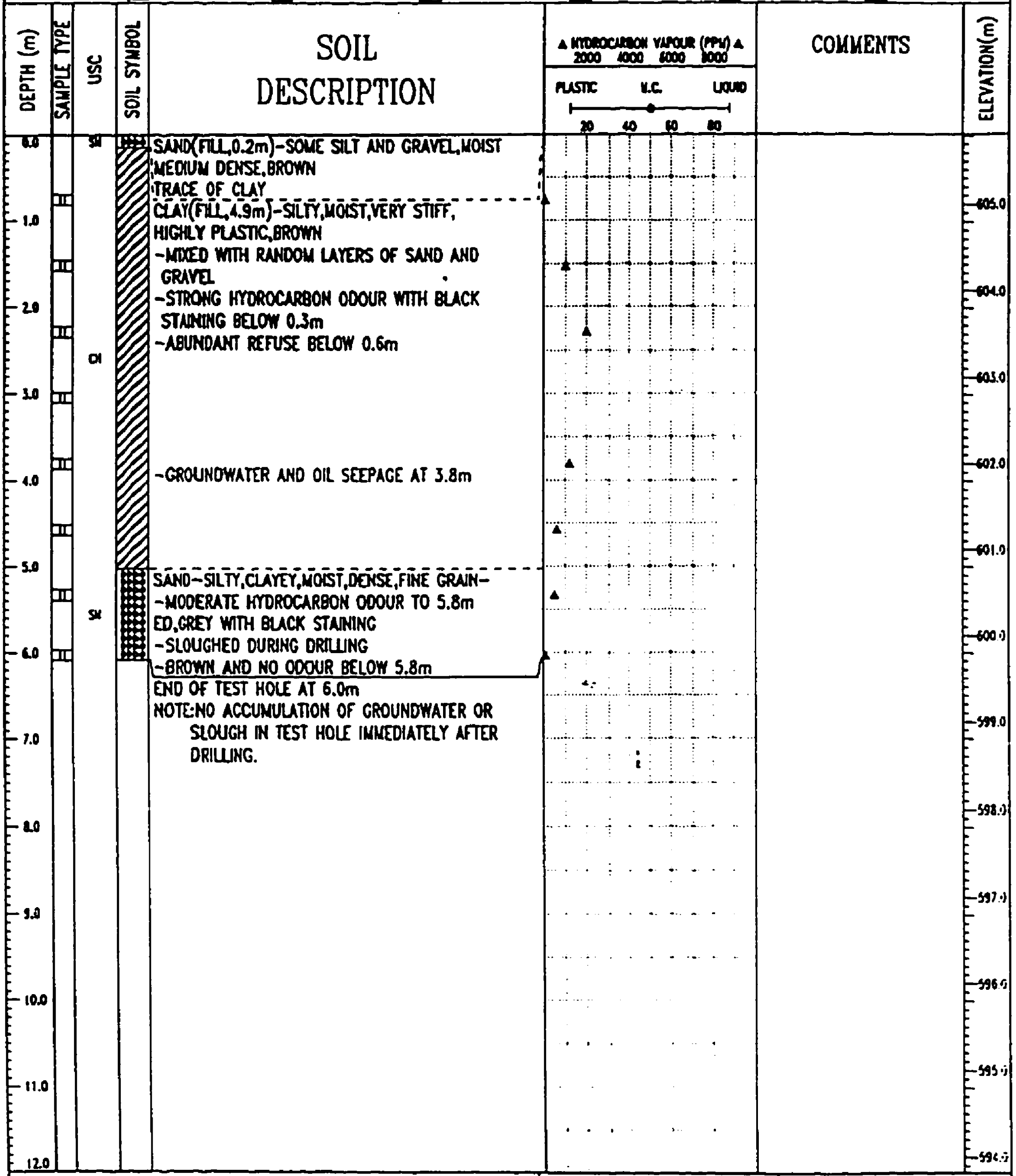
END OF TEST HOLE AT 4.6m
NOTE:NO ACCUMULATION OF GROUNDWATER OR SLOUGH IN TEST HOLE IMMEDIATELY AFTER DRILLING.

AGRA Earth & Environmental Limited	LOGGED BY: TK	COMPLETION DEPTH: 4.6 m
Regina, Saskatchewan	REVIEWED BY: EDF DJM	COMPLETE: 12/16/93
	Fig. No: 18	Page 1 of 1

93/01/00 11:20AM

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: TH16
FLEET STREET LANDFILL	DRILL METHOD: HOLLOW STEM AUGER WITH	PROJECT NO: JX30012
CITY OF REGINA	SPLIT SPOON CORE SAMPLER	ELEVATION: 605.82 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



SAND(FILL,0.2m)-SOME SILT AND GRAVEL,MOIST
MEDIUM DENSE,BROWN
TRACE OF CLAY
CLAY(FILL,4.9m)-SILTY,MOIST,VERY STIFF,
HIGHLY PLASTIC,BROWN
-MIXED WITH RANDOM LAYERS OF SAND AND
GRAVEL
-STRONG HYDROCARBON ODOUR WITH BLACK
STAINING BELOW 0.3m
-ABUNDANT REFUSE BELOW 0.6m

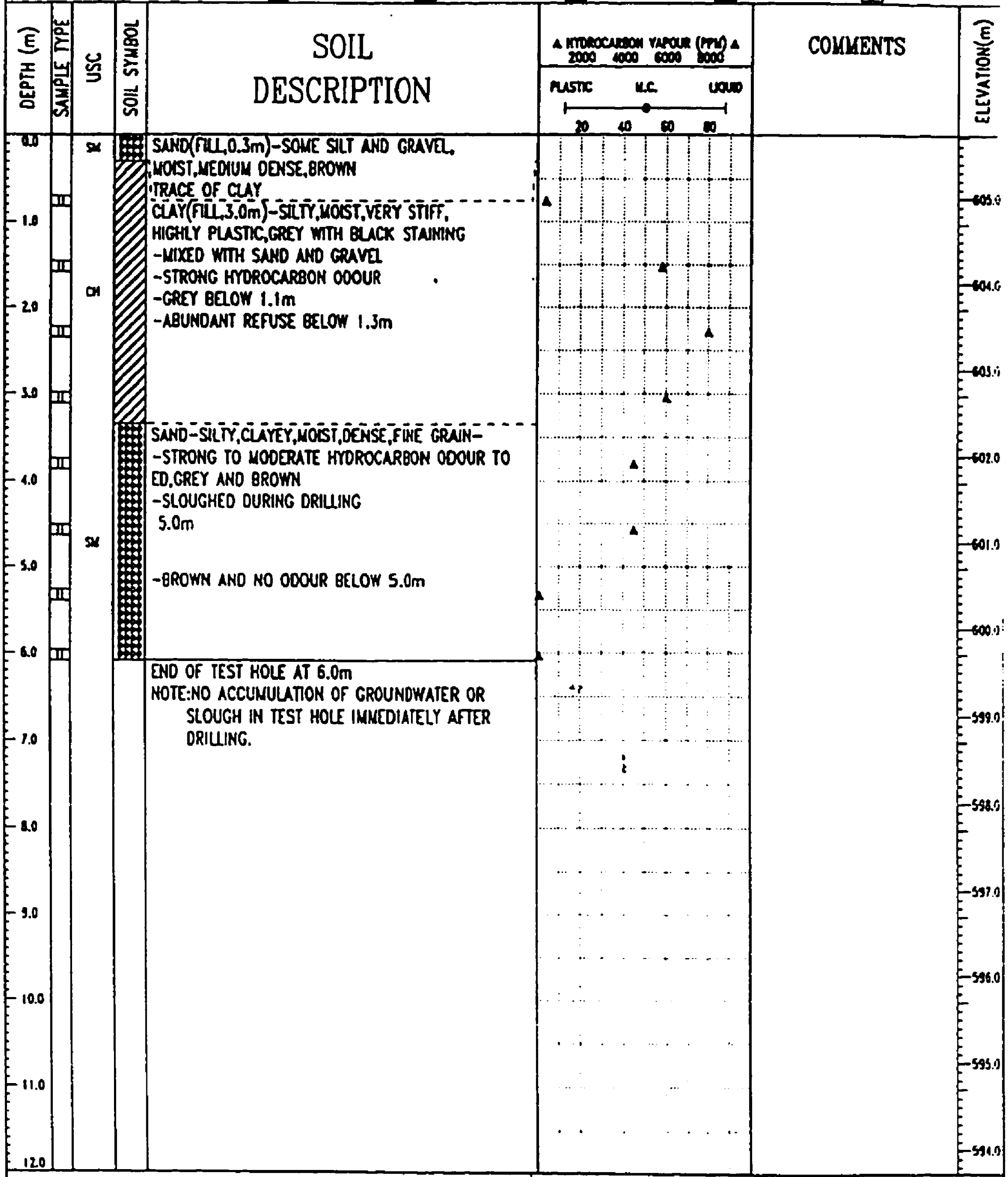
-GROUNDWATER AND OIL SEEPAGE AT 3.8m

SAND-SILTY,CLAYEY,MOIST,DENSE,FINE GRAIN-
-MODERATE HYDROCARBON ODOUR TO 5.8m
ED,GREY WITH BLACK STAINING
-SLOUGHED DURING DRILLING
-BROWN AND NO ODOUR BELOW 5.8m
END OF TEST HOLE AT 6.0m
NOTE:NO ACCUMULATION OF GROUNDWATER OR
SLOUGH IN TEST HOLE IMMEDIATELY AFTER
DRILLING.

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 6.1 m
	REVIEWED BY: EDF DJM	COMPLETE: 12/16/93
	Fig. No: 19	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: TH17
FLEET STREET LANDFILL	DRILL METHOD: HOLLOW STEM AUGER WITH	PROJECT NO: JX30012
CITY OF REGINA	SPLIT SPOON CORE SAMPLER	ELEVATION: 605.72 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



SAND(FILL,0.3m)-SOME SILT AND GRAVEL,
MOIST,MEDIUM DENSE,BROWN
TRACE OF CLAY

CLAY(FILL,3.0m)-SILTY,MOIST,VERY STIFF,
HIGHLY PLASTIC,GREY WITH BLACK STAINING
-MIXED WITH SAND AND GRAVEL
-STRONG HYDROCARBON ODOUR
-GREY BELOW 1.1m
-ABUNDANT REFUSE BELOW 1.3m

SAND-SILTY,CLAYEY,MOIST,DENSE,FINE GRAIN-
-STRONG TO MODERATE HYDROCARBON ODOUR TO
ED,GREY AND BROWN
-SLOUGHED DURING DRILLING
5.0m

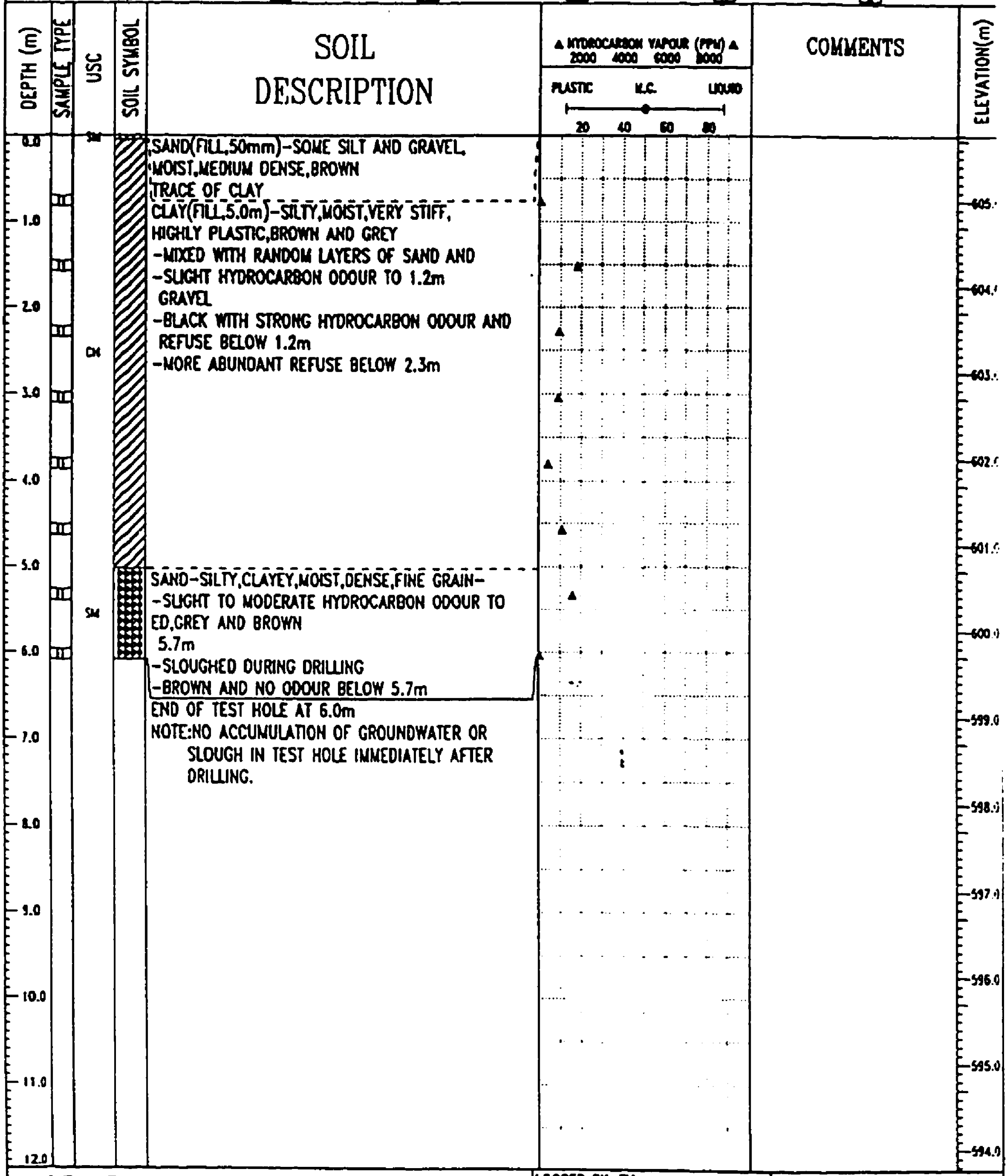
-BROWN AND NO ODOUR BELOW 5.0m

END OF TEST HOLE AT 6.0m
NOTE:NO ACCUMULATION OF GROUNDWATER OR
SLOUGH IN TEST HOLE IMMEDIATELY AFTER
DRILLING.

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 6.1 m
	REVIEWED BY: EDF OJM	COMPLETE: 12/16/93
	Fig. No: 20	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: TH18
FLEET STREET LANDFILL	DRILL METHOD: HOLLOW STEM AUGER WITH	PROJECT NO: JX30012
CITY OF REGINA	SPLIT SPOON CORE SAMPLER	ELEVATION: 605.76 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



SOIL DESCRIPTION

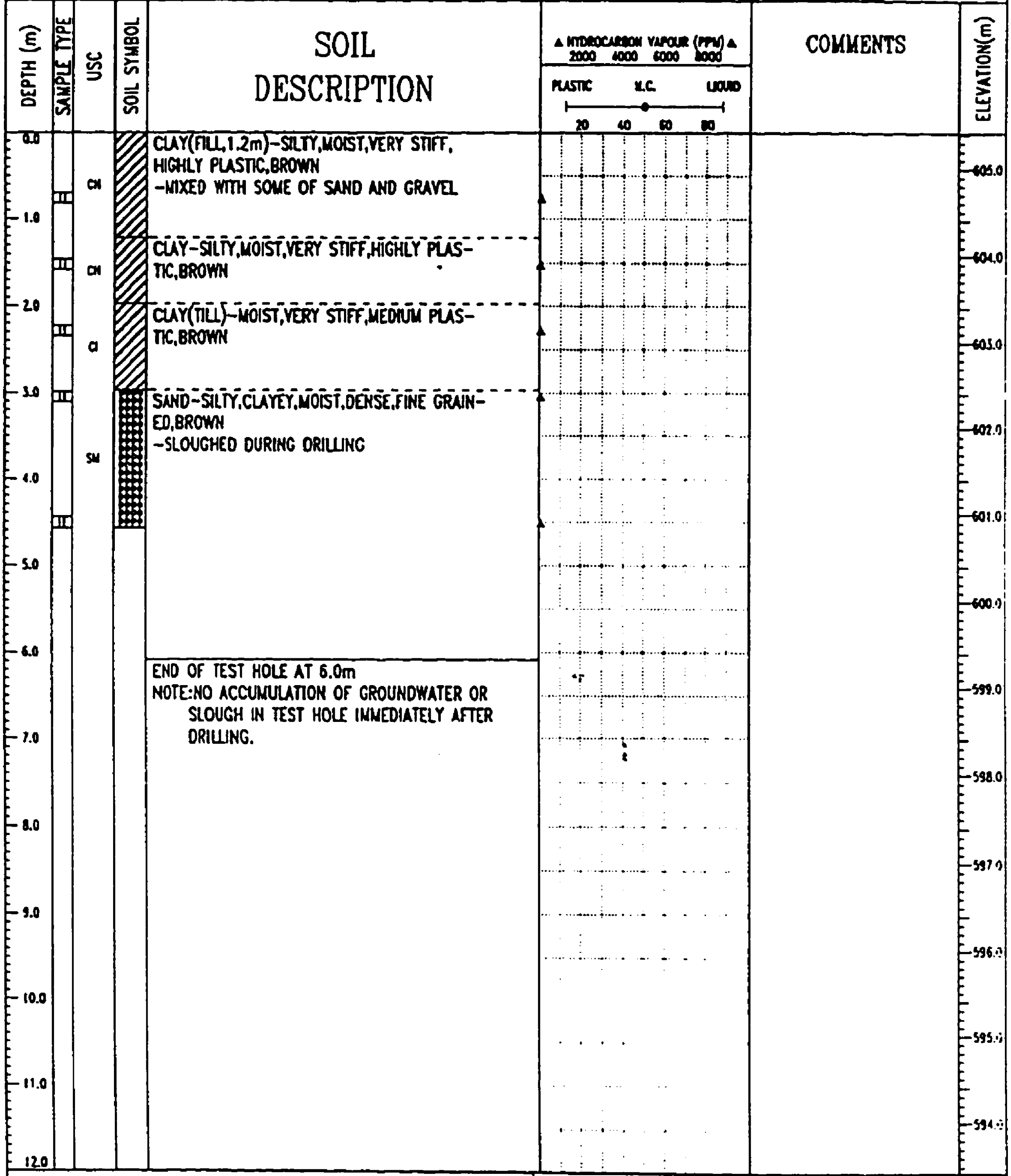
SAND(FILL,50mm)-SOME SILT AND GRAVEL,
MOIST,MEDIUM DENSE,BROWN
TRACE OF CLAY
CLAY(FILL,5.0m)-SILTY,MOIST,VERY STIFF,
HIGHLY PLASTIC,BROWN AND GREY
-MIXED WITH RANDOM LAYERS OF SAND AND
-SLIGHT HYDROCARBON ODOUR TO 1.2m
GRAVEL
-BLACK WITH STRONG HYDROCARBON ODOUR AND
REFUSE BELOW 1.2m
-MORE ABUNDANT REFUSE BELOW 2.3m

SAND-SILTY,CLAYEY,MOIST,DENSE,FINE GRAIN-
-SLIGHT TO MODERATE HYDROCARBON ODOUR TO
ED,GREY AND BROWN
5.7m
-SLOUGHED DURING DRILLING
-BROWN AND NO ODOUR BELOW 5.7m
END OF TEST HOLE AT 6.0m
NOTE:NO ACCUMULATION OF GROUNDWATER OR
SLOUGH IN TEST HOLE IMMEDIATELY AFTER
DRILLING.

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 6.1 m
	REVIEWED BY: EDF DJM	COMPLETE: 12/16/93
	Fig. No: 21	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: TH19
FLEET STREET LANDFILL	DRILL METHOD: HOLLOW STEM AUGER WITH	PROJECT NO: JX30012
CITY OF REGINA	SPLIT SPOON CORE SAMPLER	ELEVATION: 605.42 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



CLAY(FILL,1.2m)-SILTY,MOIST,VERY STIFF, HIGHLY PLASTIC,BROWN
-MIXED WITH SOME OF SAND AND GRAVEL

CLAY-SILTY,MOIST,VERY STIFF,HIGHLY PLASTIC,BROWN

CLAY(TILL)-MOIST,VERY STIFF,MEDIUM PLASTIC,BROWN

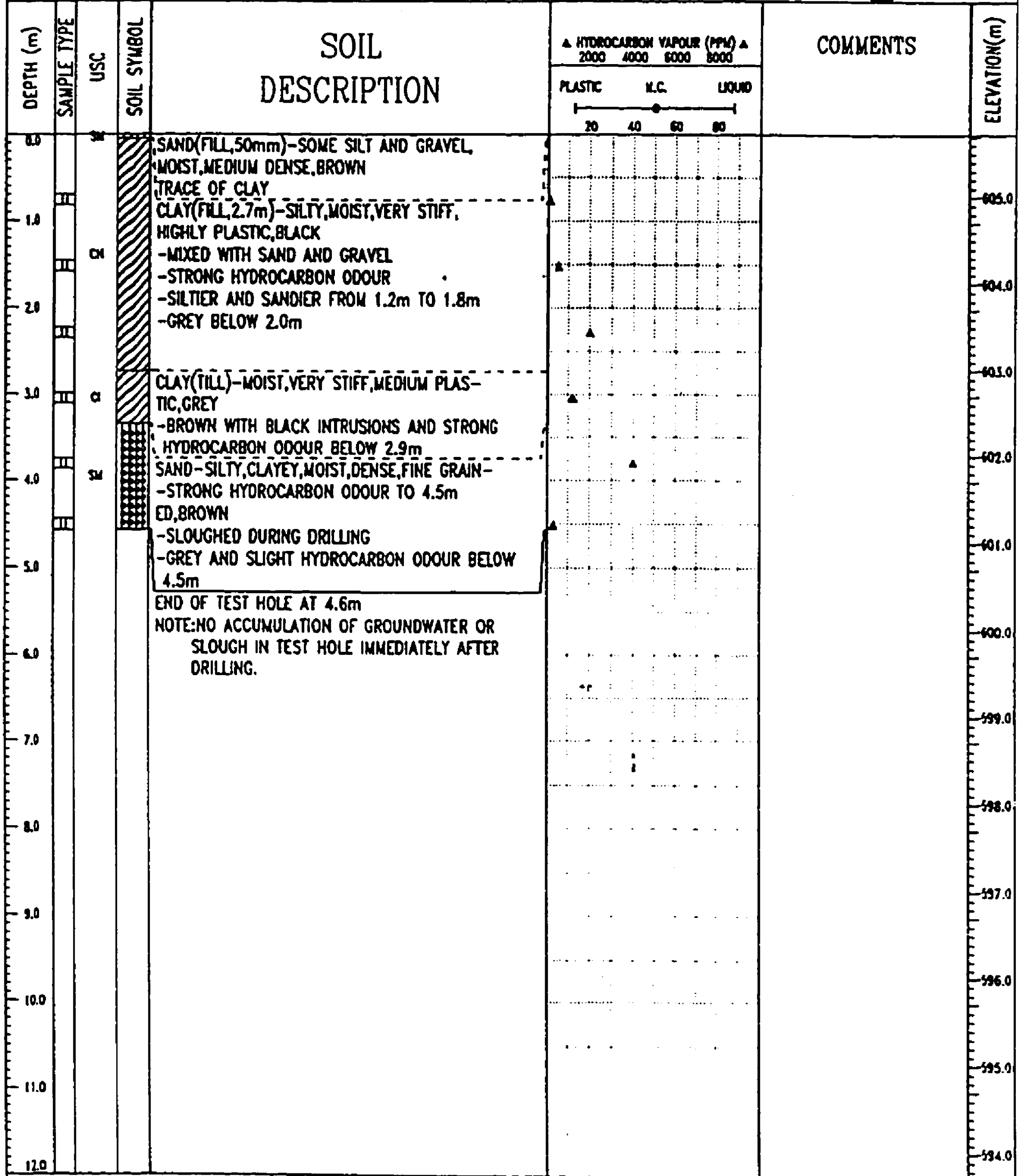
SAND-SILTY,CLAYEY,MOIST,DENSE,FINE GRAINED,BROWN
-SLOUGHED DURING DRILLING

END OF TEST HOLE AT 6.0m
NOTE:NO ACCUMULATION OF GROUNDWATER OR SLOUGH IN TEST HOLE IMMEDIATELY AFTER DRILLING.

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 4.6 m
	REVIEWED BY: EDF DJM	COMPLETE: 12/16/93
	Fig. No: 22	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: TH20
FLEET STREET LANDFILL	DRILL METHOD: HOLLOW STEM AUGER WITH	PROJECT NO: JX30012
CITY OF REGINA	SPLIT SPOON CORE SAMPLER	ELEVATION: 605.72 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▥ HOLLOW STEM ▯ CORE



SAND(FILL,50mm)-SOME SILT AND GRAVEL, MOIST,MEDIUM DENSE,BROWN
TRACE OF CLAY

CLAY(FILL,2.7m)-SILTY,MOIST,VERY STIFF, HIGHLY PLASTIC,BLACK
-MIXED WITH SAND AND GRAVEL
-STRONG HYDROCARBON ODOUR
-SILTIER AND SANDIER FROM 1.2m TO 1.8m
-GREY BELOW 2.0m

CLAY(TILL)-MOIST,VERY STIFF,MEDIUM PLASTIC,GREY
-BROWN WITH BLACK INTRUSIONS AND STRONG HYDROCARBON ODOUR BELOW 2.9m

SAND-SILTY,CLAYEY,MOIST,DENSE,FINE GRAIN-
-STRONG HYDROCARBON ODOUR TO 4.5m
ED,BROWN
-SLOUGHED DURING DRILLING
-GREY AND SLIGHT HYDROCARBON ODOUR BELOW 4.5m

END OF TEST HOLE AT 4.6m

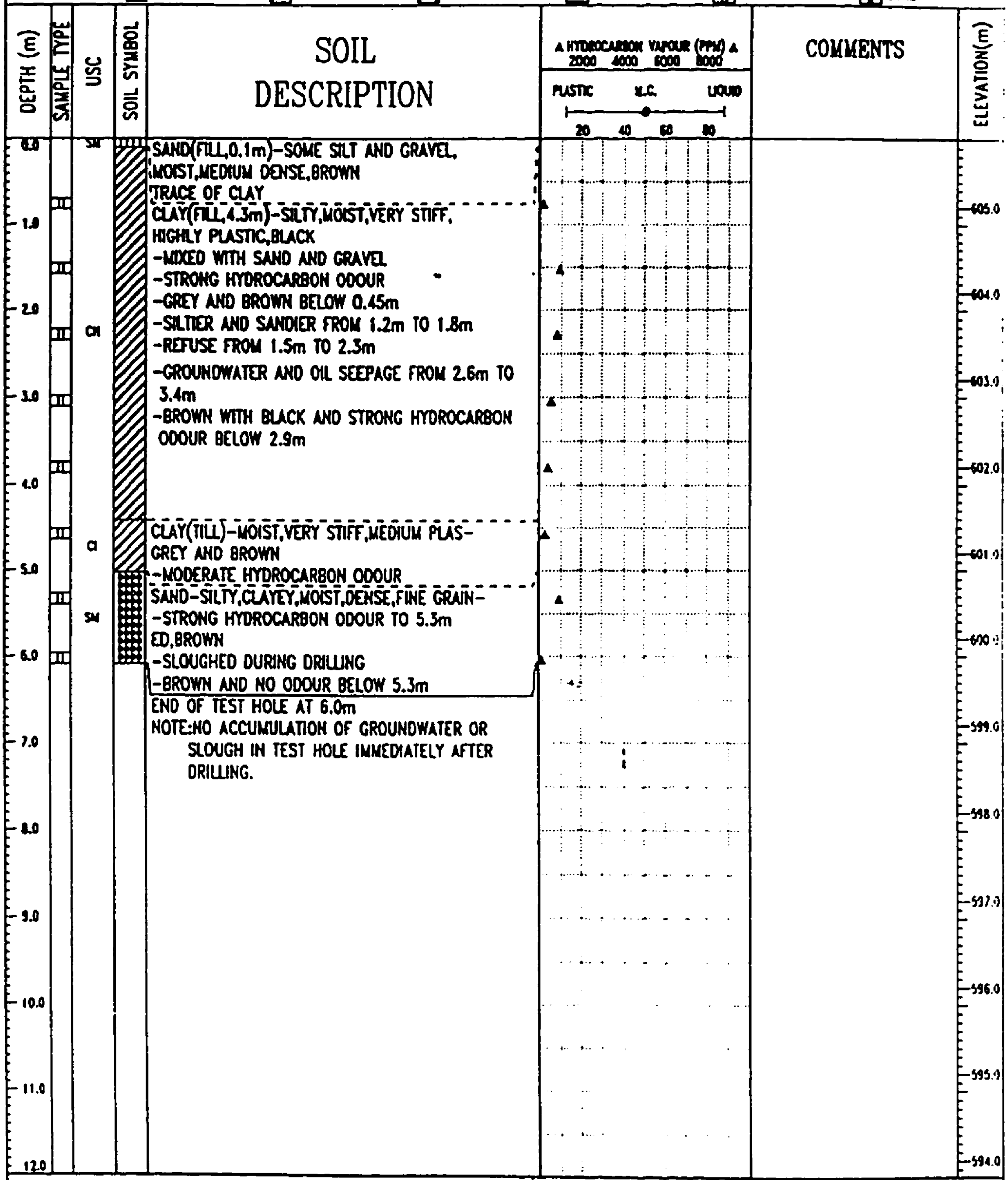
NOTE:NO ACCUMULATION OF GROUNDWATER OR SLOUGH IN TEST HOLE IMMEDIATELY AFTER DRILLING.

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 4.6 m
	REVIEWED BY: EDF DJM	COMPLETE: 12/17/93
	Fig. No: 23	Page 1 of 1

95/01/06 11:24AM

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: TH21
FLEET STREET LANDFILL	DRILL METHOD: HOLLOW STEM AUGER WITH	PROJECT NO: JX30012
CITY OF REGINA	SPLIT SPOON CORE SAMPLER	ELEVATION: 605.799 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▥ HOLLOW STEM ◫ CORE



SAND(FILL,0.1m)-SOME SILT AND GRAVEL, MOIST,MEDIUM DENSE,BROWN TRACE OF CLAY

CLAY(FILL,4.3m)-SILTY,MOIST,VERY STIFF, HIGHLY PLASTIC,BLACK
- -MIXED WITH SAND AND GRAVEL
- -STRONG HYDROCARBON ODOUR
- -GREY AND BROWN BELOW 0.45m
- -SILTIER AND SANDIER FROM 1.2m TO 1.8m
- -REFUSE FROM 1.5m TO 2.3m
- -GROUNDWATER AND OIL SEEPAGE FROM 2.6m TO 3.4m
- -BROWN WITH BLACK AND STRONG HYDROCARBON ODOUR BELOW 2.9m

CLAY(TILL)-MOIST,VERY STIFF,MEDIUM PLAS-GREY AND BROWN
- -MODERATE HYDROCARBON ODOUR

SAND-SILTY,CLAYEY,MOIST,DENSE,FINE GRAIN-
- -STRONG HYDROCARBON ODOUR TO 5.3m ED,BROWN
- -SLOUGHED DURING DRILLING
- -BROWN AND NO ODOUR BELOW 5.3m

END OF TEST HOLE AT 6.0m

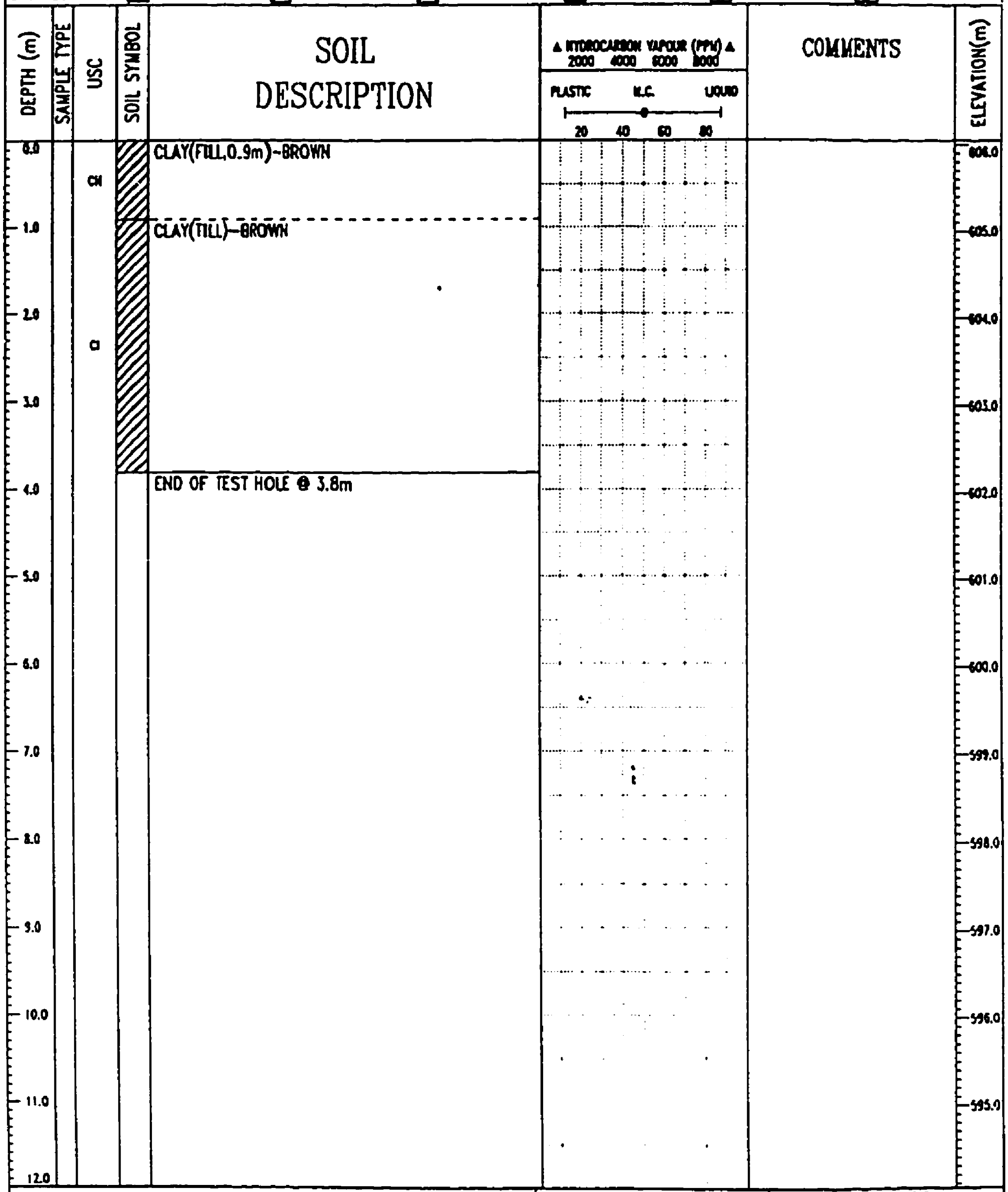
NOTE:NO ACCUMULATION OF GROUNDWATER OR SLOUGH IN TEST HOLE IMMEDIATELY AFTER DRILLING.

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 6.1 m
	REVIEWED BY: EDF DJM	COMPLETE: 12/17/93
	Fig. No: 24	Page 1 of 1

11/01/94 11:25AM

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 101
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 606.05 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



CLAY(FILL,0.9m)-BROWN

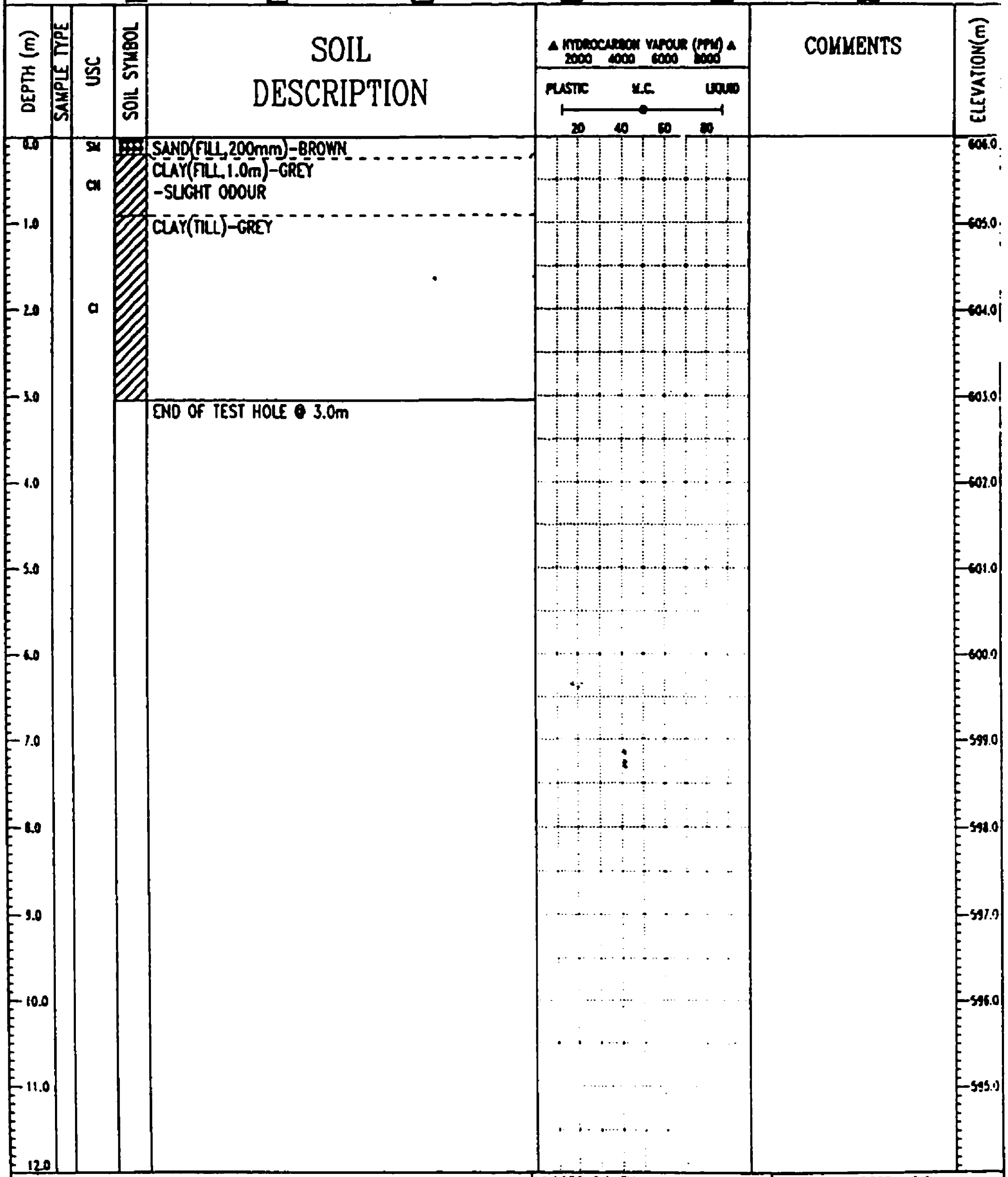
CLAY(TILL)-BROWN

END OF TEST HOLE @ 3.8m

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 3.8 m
	REVIEWED BY: DJM EDF	COMPLETE: 94/11/09
	Fig. No: 25	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 102
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 606.02 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



SAND(FILL,200mm)-BROWN

CLAY(FILL,1.0m)-GREY
-SLIGHT ODOUR

CLAY(TILL)-GREY

END OF TEST HOLE @ 3.0m

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 3.0 m
	REVIEWED BY: DJM EDF	COMPLETE: 94/11/09
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OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 103
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 606.22 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE

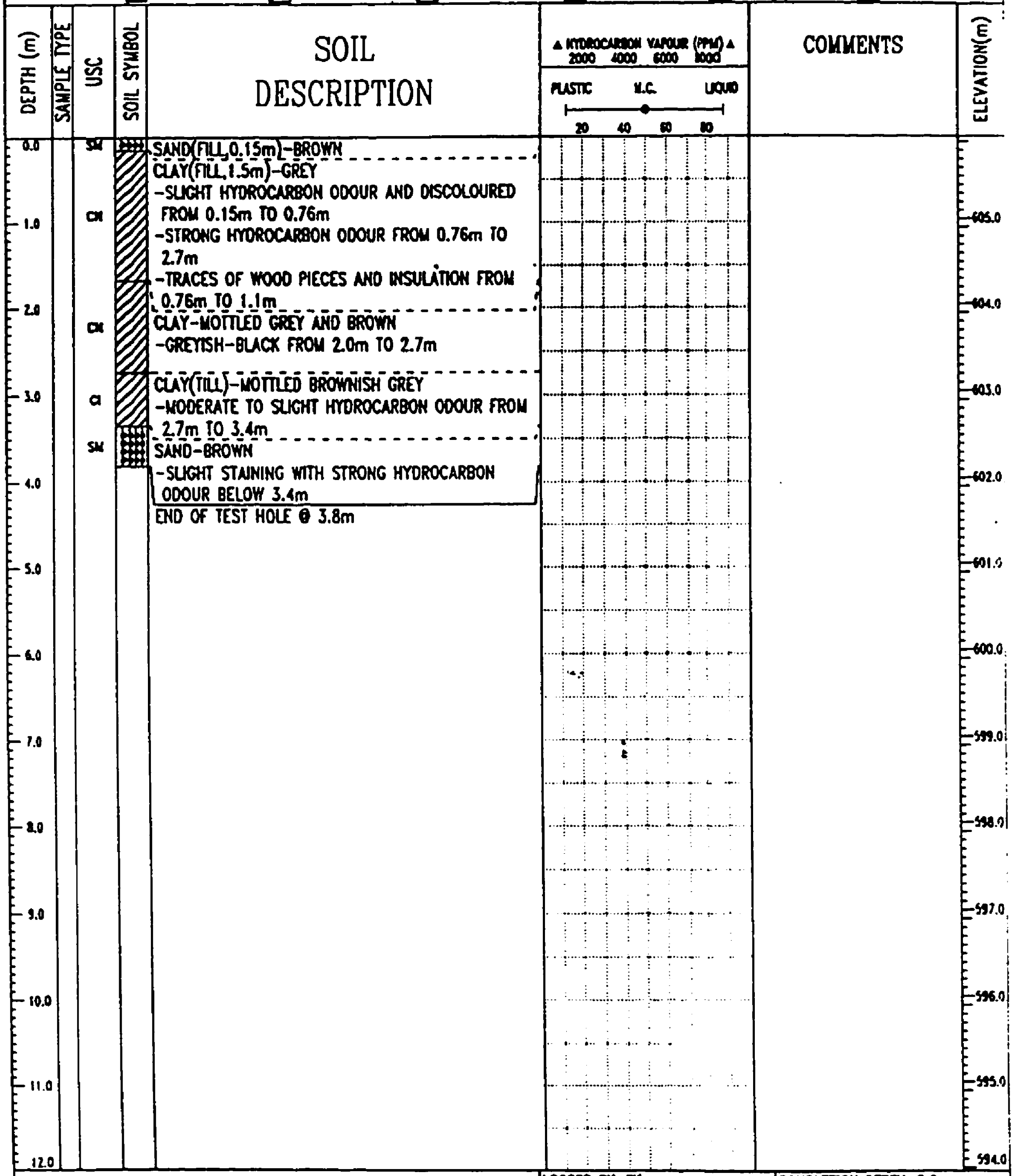
DEPTH (m)	SAMPLE TYPE	USC	SOIL SYMBOL	SOIL DESCRIPTION	▲ HYDROCARBON VAPOUR (PPM) ▲ 2000 4000 6000 8000 PLASTIC M.C. LIQUID 20 40 60 80	COMMENTS	ELEVATION(m)
0.0			▨	CLAY(FILL,2.4m)-BROWN			606.0
1.0		CH	▨	-GREY WITH STRONG HYDROCARBON ODOUR BELOW 0.7m -TRACE OF ROOTLETS AND GLASS PIECES @ 1.2m			605.0
2.0			▨	-TRACES OF WOOD,GLASS AND BRICK PIECES FROM 1.8m TO 2.4m CLAY(TILL)-GREYISH BLACK			604.0
3.0		CI SM	▨ ▦	SAND-GREYISH BLACK END OF TEST HOLE @ 3.8m			603.0
4.0							602.0
5.0							601.0
6.0							600.0
7.0							599.0
8.0							598.0
9.0							597.0
10.0							596.0
11.0							595.0
12.0							

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 3.8 m
	REVIEWED BY: DJM EDF	COMPLETE: 94/11/09
	Fig. No: 27	Page 1 of 1

95/01/06 01:20PM

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 104
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 605.96 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



SAND(FILL,0.15m)-BROWN

CLAY(FILL,1.5m)-GREY
-SLIGHT HYDROCARBON ODOUR AND DISCOLOURED FROM 0.15m TO 0.76m
-STRONG HYDROCARBON ODOUR FROM 0.76m TO 2.7m
-TRACES OF WOOD PIECES AND INSULATION FROM 0.76m TO 1.1m

CLAY-MOTTLED GREY AND BROWN
-GREYISH-BLACK FROM 2.0m TO 2.7m

CLAY(TILL)-MOTTLED BROWNISH GREY
-MODERATE TO SLIGHT HYDROCARBON ODOUR FROM 2.7m TO 3.4m

SAND-BROWN
-SLIGHT STAINING WITH STRONG HYDROCARBON ODOUR BELOW 3.4m

END OF TEST HOLE @ 3.8m

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 3.8 m
	REVIEWED BY: OJM EDF	COMPLETE: 94/11/09
	Fig. No: 28	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 105
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 605.98 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE

DEPTH (m)	SAMPLE TYPE	USC	SOIL SYMBOL	SOIL DESCRIPTION	▲ HYDROCARBON VAPOUR (PPM) ▲ 2000 4000 6000 8000 PLASTIC M.C. LIQUID 20 40 60 80	COMMENTS	ELEVATION(m)
0.0		SM		SAND-BROWN			
		CH	▨	CLAY(FILL,0.61m)-GREY -SLIGHT HYDROCARBON ODOUR -PIECES OF WOOD AND PLASTIC			
1.0			▨	CLAY(TILL)-BROWN			605.0
2.0		CI	▨	-BLACK STAINING AND STRONG HYDROCARBON ODOUR FROM 2.1m TO 3.0m			604.0
3.0				END OF TEST HOLE @ 3.0m			603.0
4.0							602.0
5.0							601.0
6.0							600.0
7.0							599.0
8.0							598.0
9.0							597.0
10.0							596.0
11.0							595.0
12.0							594.0

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 3.0 m
	REVIEWED BY: OJM EDF	COMPLETE: 94/11/09
	Fig. No: 29	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 106
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 605.65 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE

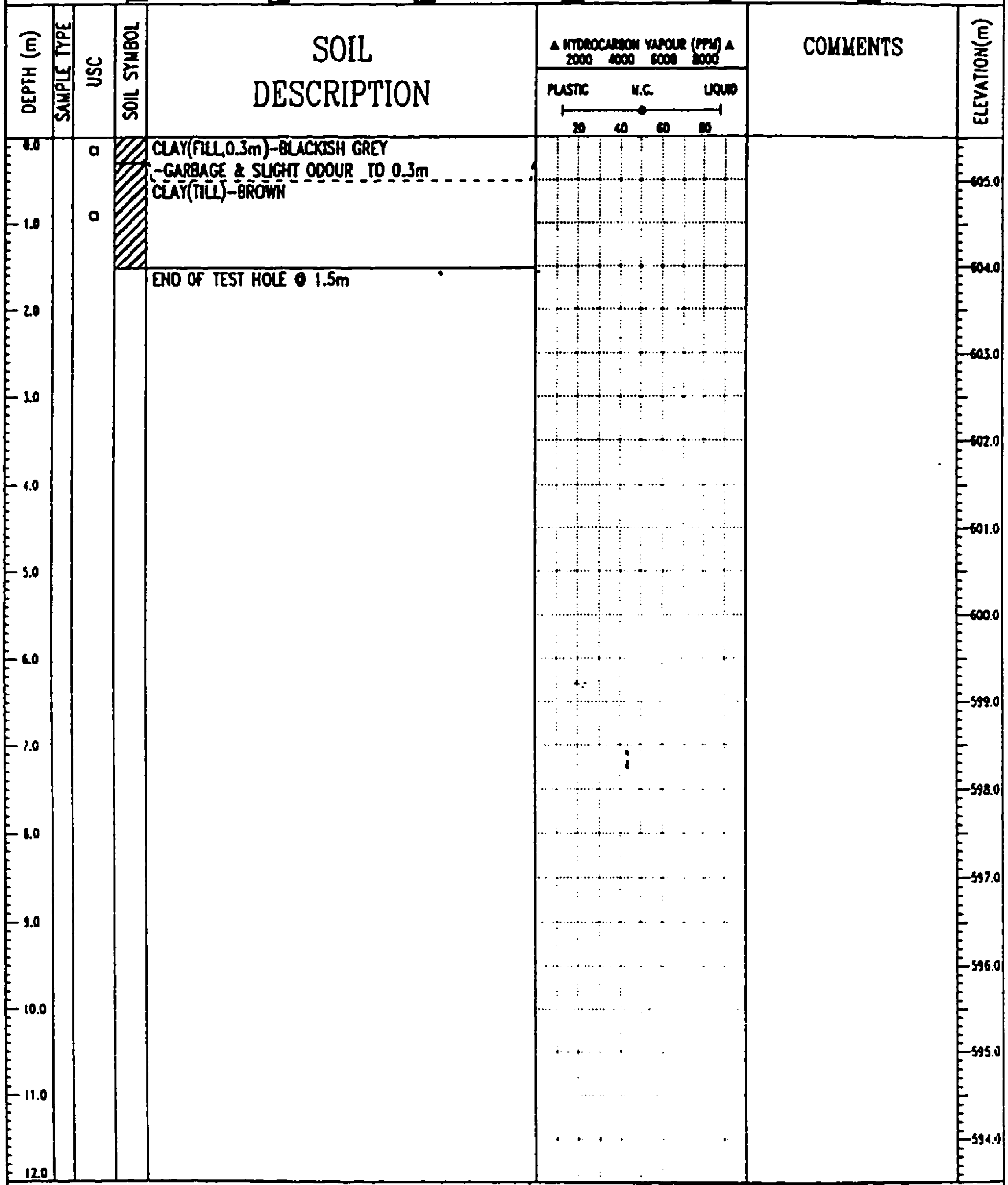
DEPTH (m)	SAMPLE TYPE	USC	SOIL SYMBOL	SOIL DESCRIPTION	▲ HYDROCARBON VAPOUR (PPM) ▲ 2000 4000 6000 8000 PLASTIC M.C. LIQUID 20 40 60 80	COMMENTS	ELEVATION(m)
0.0		CI	▨	CLAY(FILL,1.1m)-BROWN -RUBBLE INTERMIXED & BLACKISH-GREY WITH STRONG HYDROCARBON ODOUR FROM 0.3m TO 1.1m			605.0
1.0			▨	CLAY(TILL)-BROWN -BLACKISH-GREY WITH STRONG HYDROCARBON ODOUR BELOW 1.2m			604.0
2.0		CI	▨				603.0
3.0				END OF TEST HOLE @ 3.0m			602.0
4.0							601.0
5.0							600.0
6.0							599.0
7.0							598.0
8.0							597.0
9.0							596.0
10.0							595.0
11.0							594.0
12.0							

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 3.0 m
	REVIEWED BY: DJM EDF	COMPLETE: 09/11/94
	Fig. No: 30	Page 1 of 1

95/01/09 11:48AM

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 107
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 605.51 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



CLAY(FILL,0.3m)-BLACKISH GREY
-GARBAGE & SLIGHT ODOUR TO 0.3m

CLAY(TILL)-BROWN

END OF TEST HOLE @ 1.5m

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 1.5 m
	REVIEWED BY: DJM EDF	COMPLETE: 09/11/94
	Fig. No: 31	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 108
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 606.14 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE

DEPTH (m)	SAMPLE TYPE	USC	SOIL SYMBOL	SOIL DESCRIPTION	▲ HYDROCARBON VAPOUR (PPM) ▲ 2000 4000 6000 8000 PLASTIC M.C. LIQUID 20 40 60 80	COMMENTS	ELEVATION(m)
0.0			▨	CLAY(FILL,4.6m)-GREYISH BROWN			606.0
1.0			▨	-MOTTLED GREY-BROWN WITH SLIGHT ODOUR FROM 0.9m TO 1.2m -STAINED GREY WITH STRONG HYDROCARBON ODOUR BELOW 1.2m			605.0
2.0		CI	▨	-TRACE OF WOOD & ROOTS FROM 1.2m TO 2.7m			604.0
3.0			▨	-SEEPAGE AND WIRE @ 3.4m			603.0
4.0			▨				602.0
5.0				END OF TEST HOLE @ 4.6m NOTE: UNABLE TO DRILL PAST 4.6m DUE TO LARGE QUANTITY OF WIRE.			601.0
6.0							600.0
7.0							599.0
8.0							598.0
9.0							597.0
10.0							596.0
11.0							595.0
12.0							

AGRA Earth & Environmental Limited	LOGGED BY: TK	COMPLETION DEPTH: 4.6 m
Regina, Saskatchewan	REVIEWED BY: DJM EDF	COMPLETE: 09/11/94
	Fig. No: 32	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 109
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 605.86 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE

DEPTH (m)	SAMPLE TYPE	USC	SOIL SYMBOL	SOIL DESCRIPTION	▲ HYDROCARBON VAPOUR (PPM) ▲ 2000 4000 6000 8000 PLASTIC M.C. LIQUID 20 40 60 80	COMMENTS	ELEVATION(m)
0.0			▨	CLAY(FILL,4.9m)-MOTTLED GREY BROWN WITH BLACK			
1.0			▨	-SLIGHT ODOUR FROM 0.7m TO 1.2m -GARBAGE INTERMIXED BELOW 0.7m -GREYISH-BLACK WITH STRONG ODOUR BELOW 1.2m			605.0
2.0		CI	▨	-SLIGHT SEEPAGE @ 2.6m			604.0
3.0			▨	-SEEPAGE,WIRE & WOOD @ 3.7m			603.0
4.0			▨	-TRACE OF GREEN DISCOLORATION @ 4.3m			602.0
5.0		SM	▦	SAND-MOTTLED GREY BLACK -STRONG ODOUR THROUGHOUT END OF TEST HOLE @ 5.3m			601.0
6.0							600.0
7.0							599.0
8.0							598.0
9.0							597.0
10.0							596.0
11.0							595.0
12.0							594.0

AGRA Earth & Environmental Limited	LOGGED BY: TK	COMPLETION DEPTH: 5.3 m
	REVIEWED BY: DJM EDF	COMPLETE: 09/11/94
Regina, Saskatchewan	Fig. No: 33	Page 1 of 1

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OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 110
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 605.75 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE

DEPTH (m)	SAMPLE TYPE	USC	SOIL SYMBOL	SOIL DESCRIPTION	▲ HYDROCARBON VAPOUR (PPM) ▲ 2000 4000 6000 8000 PLASTIC M.C. LIQUID 20 40 60 80	COMMENTS	ELEVATION(m)
0.0		CI/CH	▨	CLAY(FILL,3.4m)-MOTTLED GREY BROWN WITH BLACK -STRONG ODOUR THROUGHOUT -WOOD & RUBBLE FORM 0.7m TO 3.4m -SEEPAGE,WIRE & WOOD @ 2.7m			
		SM	▦	SAND-MOTTLED GREY BLACK			
				END OF TEST HOLE @ 3.8m			

DEPTH (m): 0.0 – 1.0 – 2.0 – 3.0 – 4.0 – 5.0 – 6.0 – 7.0 – 8.0 – 9.0 – 10.0 – 11.0 – 12.0

ELEVATION(m): 605.0 – 604.0 – 603.0 – 602.0 – 601.0 – 600.0 – 599.0 – 598.0 – 597.0 – 596.0 – 595.0 – 594.0

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 3.8 m
	REVIEWED BY: DJM EDF	COMPLETE: 09/11/94
	Fig. No: 34	Page 1 of 1

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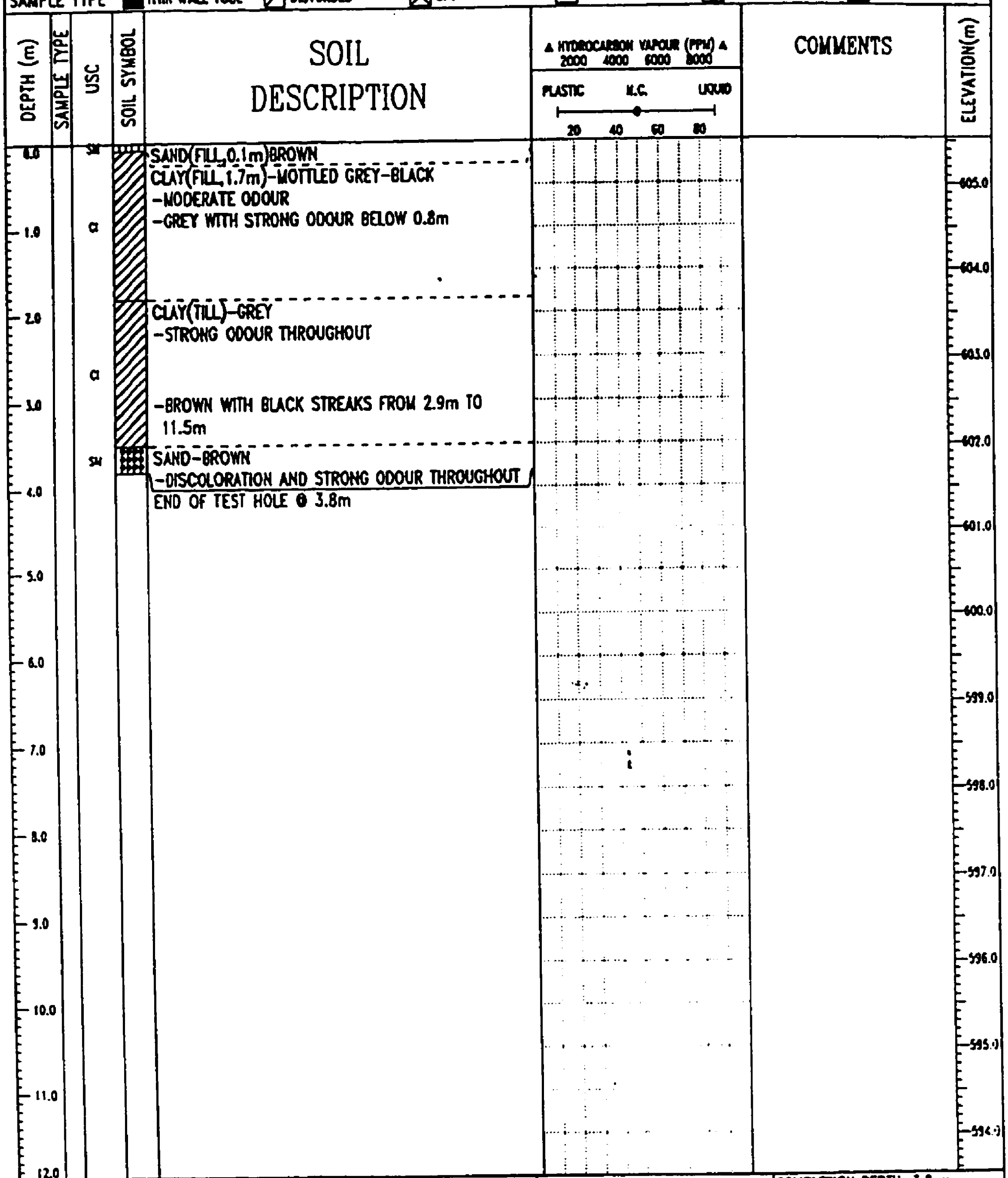
OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 111
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 605.54 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



SAND(FILL,0.1m)BROWN

CLAY(FILL,1.7m)-MOTTLED GREY-BLACK
-MODERATE ODOUR
-GREY WITH STRONG ODOUR BELOW 0.8m

CLAY(TILL)-GREY
-STRONG ODOUR THROUGHOUT

-BROWN WITH BLACK STREAKS FROM 2.9m TO 11.5m

SAND-BROWN
-DISCOLORATION AND STRONG ODOUR THROUGHOUT

END OF TEST HOLE @ 3.8m

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 3.8 m
	REVIEWED BY: DJM EDF	COMPLETE: 09/11/94
	Fig. No: 35	Page 1 of 1

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OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 112
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 605.52 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE

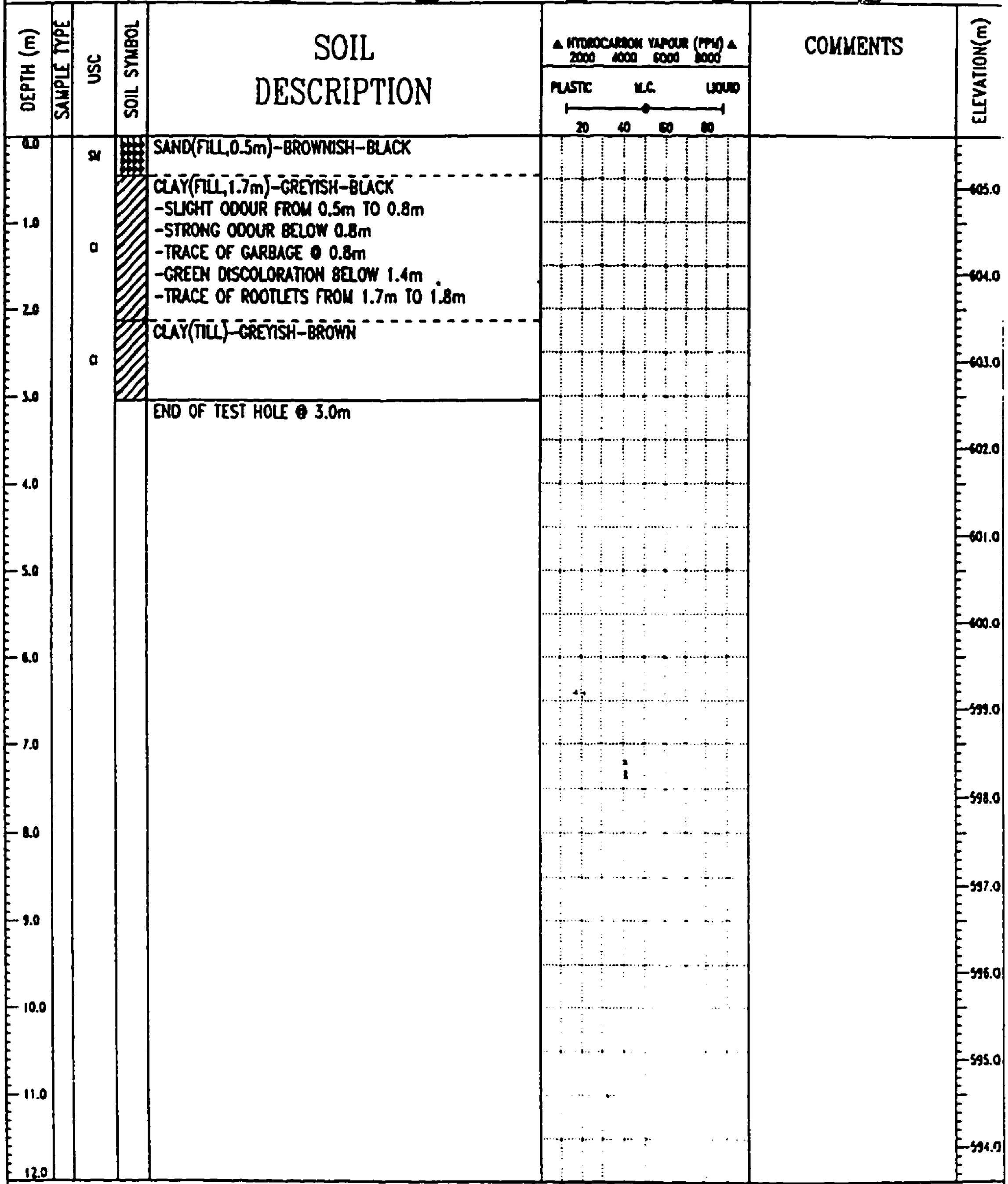
DEPTH (m)	SAMPLE TYPE	USC	SOIL SYMBOL	SOIL DESCRIPTION	▲ HYDROCARBON VAPOUR (PPM) ▲ 2000 4000 6000 8000 PLASTIC M.C. LIQUID 20 40 60 80	COMMENTS	ELEVATION(m)
0.0		SM	▦	SAND(FILL,0.3m)-BROWNISH-BLACK			
			▨	CLAY(FILL,1.5m)-GREYISH-BLACK -STRONG ODOUR THROUGHOUT			605.0
1.0		CH	▨				
			▨				604.0
2.0			▨	CLAY(TILL)-GREYISH-BROWN -DISCOLORED & STRONG ODOUR THROUGHOUT			
		CI	▨				603.0
3.0			▨				
		SM	▦	SAND-GREYISH BROWN -DISCOLORED WITH MODERATE TO STRONG ODOUR THROUGHOUT			602.0
4.0				END OF TEST HOLE @ 3.8m			
							601.0
5.0							
							600.0
6.0							
							599.0
7.0							
							598.0
8.0							
							597.0
9.0							
							596.0
10.0							
							595.0
11.0							
							594.0
12.0							

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 3.8 m
	REVIEWED BY: DJM EDF	COMPLETE: 09/11/94
	Fig. No: 36	Page 1 of 1

95/01/06 11:32AM

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 113
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 605.60 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



SOIL DESCRIPTION

SAND(FILL,0.5m)-BROWNISH-BLACK

CLAY(FILL,1.7m)-GREYISH-BLACK
-SLIGHT ODOUR FROM 0.5m TO 0.8m
-STRONG ODOUR BELOW 0.8m
-TRACE OF GARBAGE @ 0.8m
-GREEN DISCOLORATION BELOW 1.4m
-TRACE OF ROOTLETS FROM 1.7m TO 1.8m

CLAY(TILL)-GREYISH-BROWN

END OF TEST HOLE @ 3.0m

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 3.0 m
	REVIEWED BY: DJN EDF	COMPLETE: 09/11/94
	Fig. No: 37	Page 1 of 1

15/01/98 11:33AM

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 114
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 605.55 (m)

SAMPLE TYPE ■ THIN WALL TUBE ◩ DISTURBED ☒ SPT ☰ A-CASING ▥ HOLLOW STEM ▯ CORE

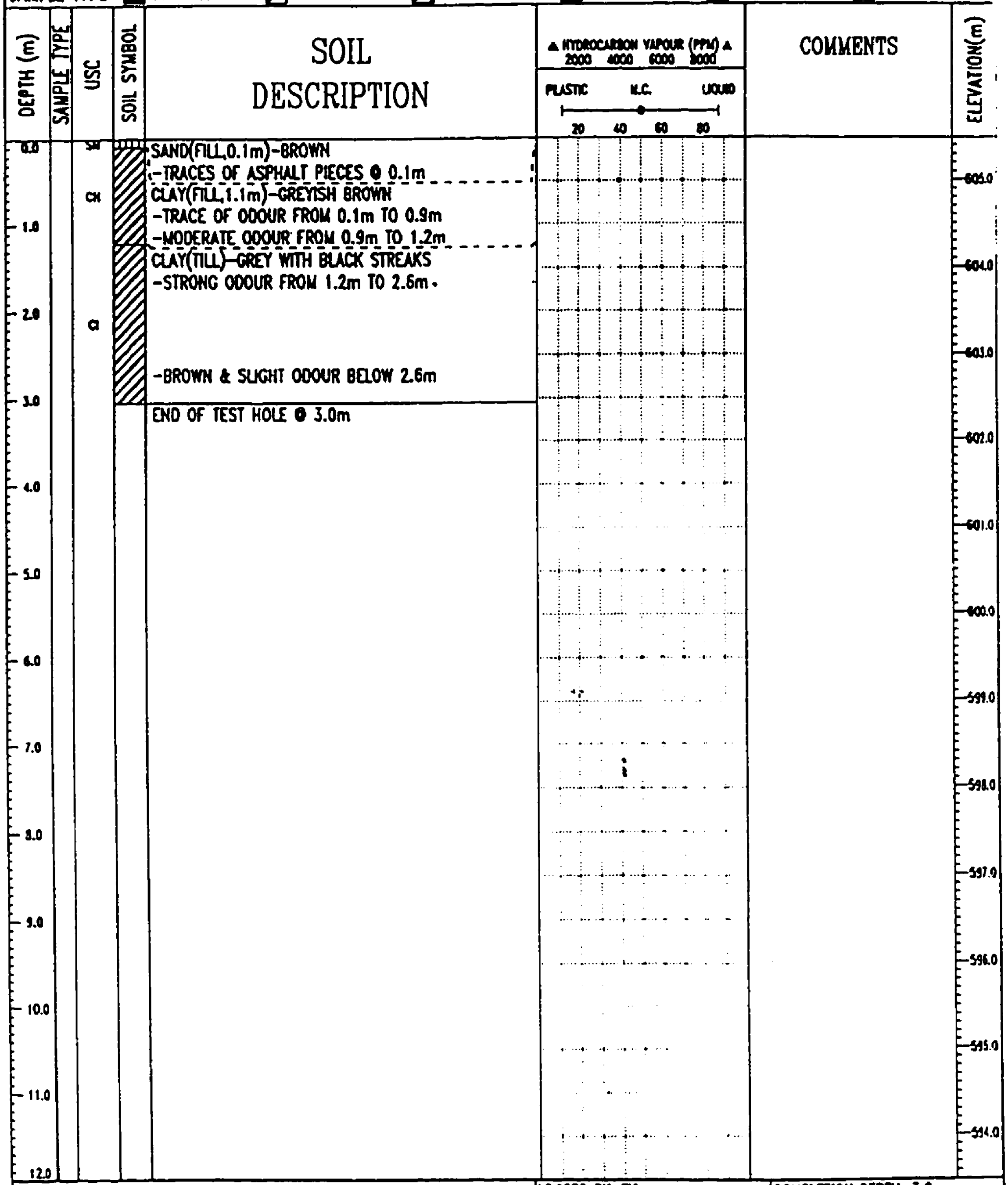
DEPTH (m)	SAMPLE TYPE	USC	SOIL SYMBOL	SOIL DESCRIPTION	▲ HYDROCARBON VAPOUR (PPM) ▲ 2000 4000 6000 8000 PLASTIC M.C. LIQUID 20 40 60 80	COMMENTS	ELEVATION(m)
0.0		SM	▨	SAND(FILL,50mm)-BROWN			
		CH	▨	CLAY(FILL,1.2m)-GREY-BLACK -SLIGHT ODOUR TO 0.8m -STRONG ODOUR FROM 0.8m TO 1.2m -TRACE OF PLASTIC @ 0.8m			605.0
1.0							
		CI	▨	CLAY(TILL)-GREYISH-BROWN -GREEN DISCOLORATION AND STRONG ODOUR THROUGHOUT			604.0
2.0							
							603.0
3.0							
		SM	▦	SAND-GREYISH-BROWN -GREEN DISCOLORATION AND STRONG ODOUR THROUGHOUT			602.0
4.0				END OF TEST HOLE @ 3.8m			
							601.0
5.0							
							600.0
6.0							
							599.0
7.0							
							598.0
8.0							
							597.0
9.0							
							596.0
10.0							
							595.0
11.0							
							594.0
12.0							

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 3.8 m
	REVIEWED BY: DJM EDF	COMPLETE: 09/11/94
	Fig. No: 38	Page 1 of 1

95/01/09 11:55AM

OIL PIT EVALUATION | TEST HOLES | BOREHOLE NO: 115
FLEET STREET LANDFILL | DRILLING METHOD:150mm SOLID STEM AUGER | PROJECT NO: JX30012A
CITY OF REGINA | | ELEVATION: 605.49 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



SAND(FILL,0.1m)-BROWN
-TRACES OF ASPHALT PIECES @ 0.1m

CLAY(FILL,1.1m)-GREYISH BROWN
-TRACE OF ODOUR FROM 0.1m TO 0.9m
-MODERATE ODOUR FROM 0.9m TO 1.2m

CLAY(TILL)-GREY WITH BLACK STREAKS
-STRONG ODOUR FROM 1.2m TO 2.6m.

-BROWN & SLIGHT ODOUR BELOW 2.6m

END OF TEST HOLE @ 3.0m

AGRA Earth & Environmental Limited
Regina, Saskatchewan

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REVIEWED BY: DJM EDF
Fig. No: 39
COMPLETION DEPTH: 3.0 m
COMPLETE: 09/11/94
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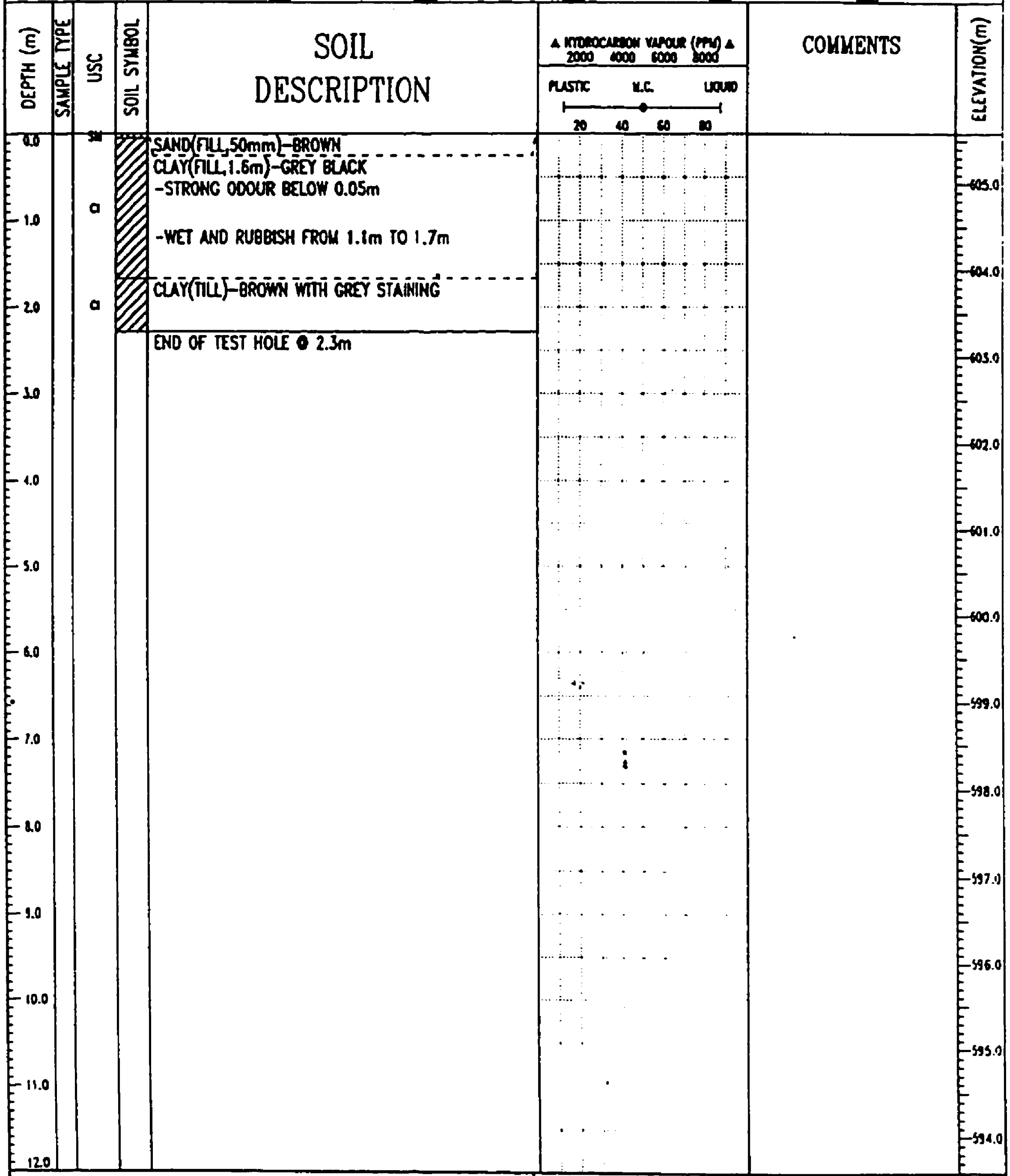
OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 116
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 605.58 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▧ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



SAND(FILL,50mm)–BROWN

CLAY(FILL,1.6m)–GREY BLACK
-STRONG ODOUR BELOW 0.05m

-WET AND RUBBISH FROM 1.1m TO 1.7m

CLAY(TILL)–BROWN WITH GREY STAINING

END OF TEST HOLE @ 2.3m

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 2.3 m
	REVIEWED BY: DJM EDF	COMPLETE: 09/11/94
	Fig. No: 40	Page 1 of 1

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OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 117
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 605.74 (m)

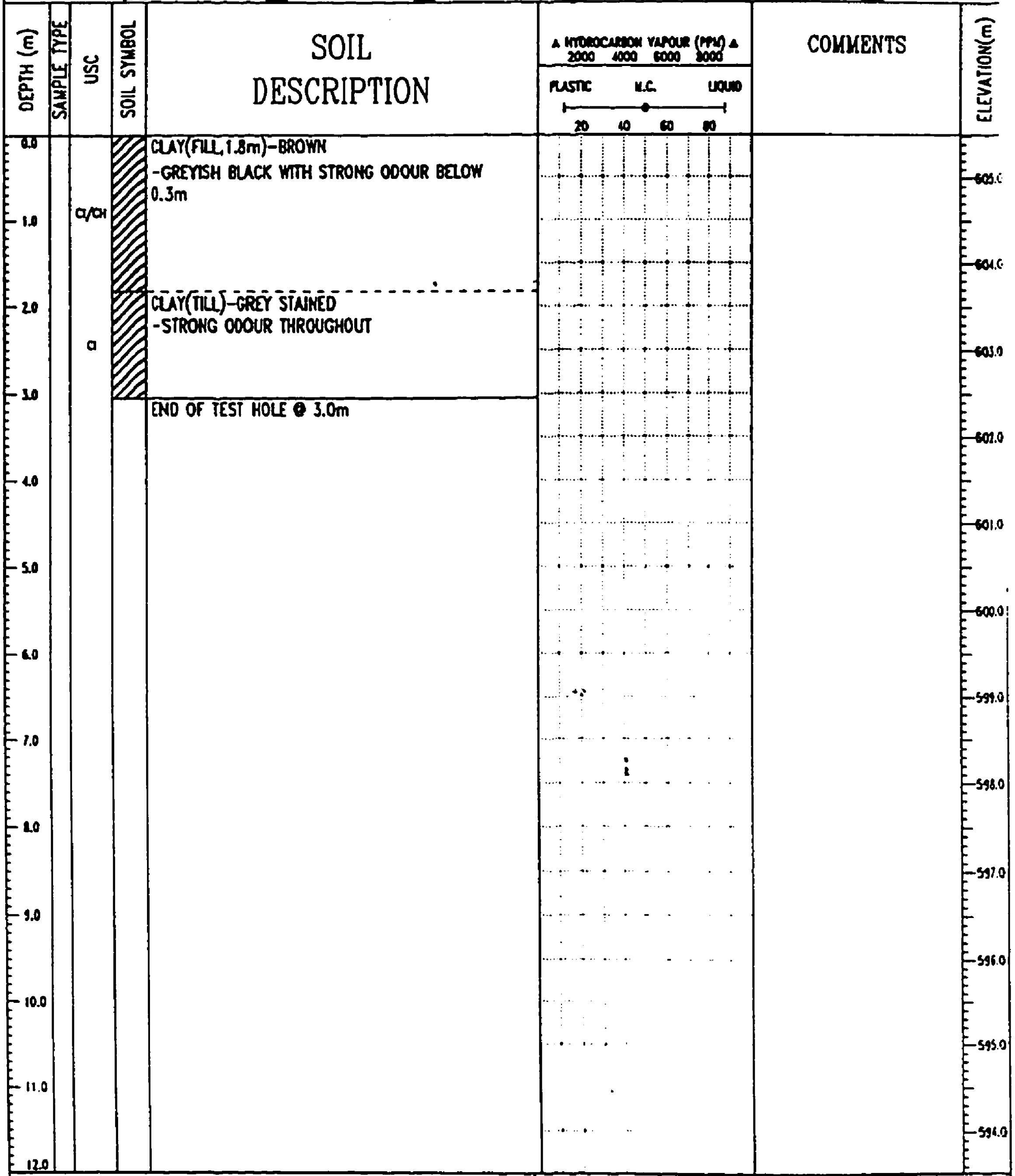
SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯▯ HOLLOW STEM ▯▯ CORE

DEPTH (m)	SAMPLE TYPE	USC	SOIL SYMBOL	SOIL DESCRIPTION	▲ HYDROCARBON VAPOUR (PPM) ▲ 2000 4000 6000 8000 / PLASTIC M.C. LIQUID 20 40 60 80	COMMENTS	ELEVATION(m)
0.0		SM		SAND(FILL,0.1m)-BROWN			
		CH	▨	CLAY(FILL,1.4m)-BROWN -GREYISH BLACK & STRONG ODOUR BELOW 0.5m -RUBBLE & WOOD WITH SEEPAGE BELOW 1.1m			605.0
1.0							
		CI	▨	CLAY(TILL)-GREY WITH BLACK STREAKS -STRONG ODOUR THROUGHOUT			604.0
2.0							603.0
3.0		SM		SAND-GREY BROWN WITH BLACK STREAKS -STRONG ODOUR THROUGHOUT			
				END OF TEST HOLE @ 3.0m			602.0
4.0							601.0
5.0							600.0
6.0							599.0
7.0							598.0
8.0							597.0
9.0							596.0
10.0							595.0
11.0							594.0
12.0							

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 3.0 m
	REVIEWED BY: DJM EDF	COMPLETE: 09/11/94
	Fig. No: 41	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 118
FLEET STREET LANDFILL	DRILLING METHOD: 150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 605.52 (m)

SAMPLE TYPE ■ THIN WALL TUBE ◩ DISTURBED ☒ SPT ☰ A-CASING ▯▯ HOLLOW STEM ▯▯ CORE



CLAY(FILL,1.8m)-BROWN
-GREYISH BLACK WITH STRONG ODOUR BELOW 0.3m

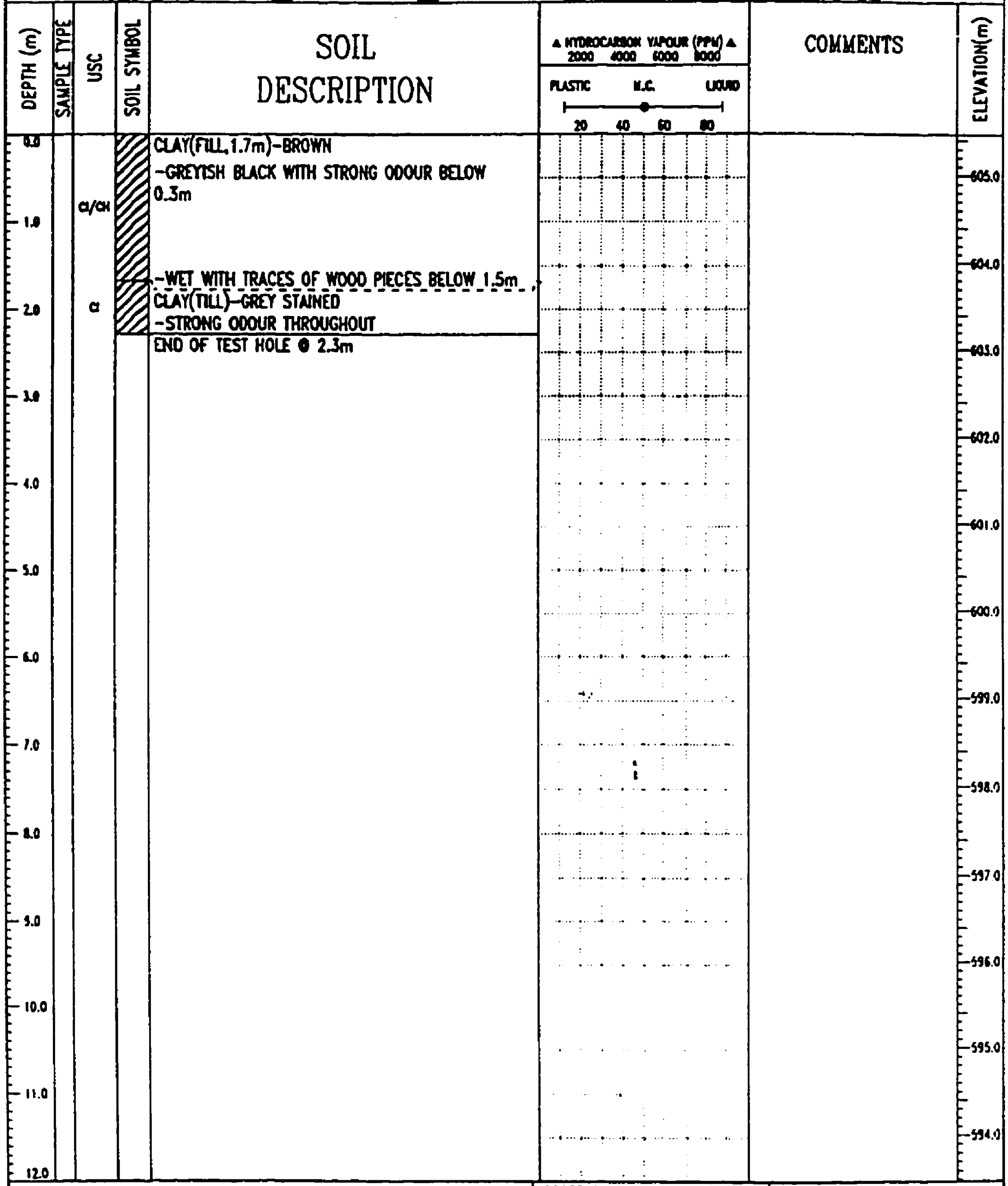
CLAY(TILL)-GREY STAINED
-STRONG ODOUR THROUGHOUT

END OF TEST HOLE @ 3.0m

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 3.0 m
	REVIEWED BY: DJM EDF	COMPLETE: 09/11/94
	Fig. No: 42	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 119
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 605.47 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



CLAY(FILL,1.7m)-BROWN

-GREYISH BLACK WITH STRONG ODOUR BELOW 0.3m

-WET WITH TRACES OF WOOD PIECES BELOW 1.5m

CLAY(TILL)-GREY STAINED

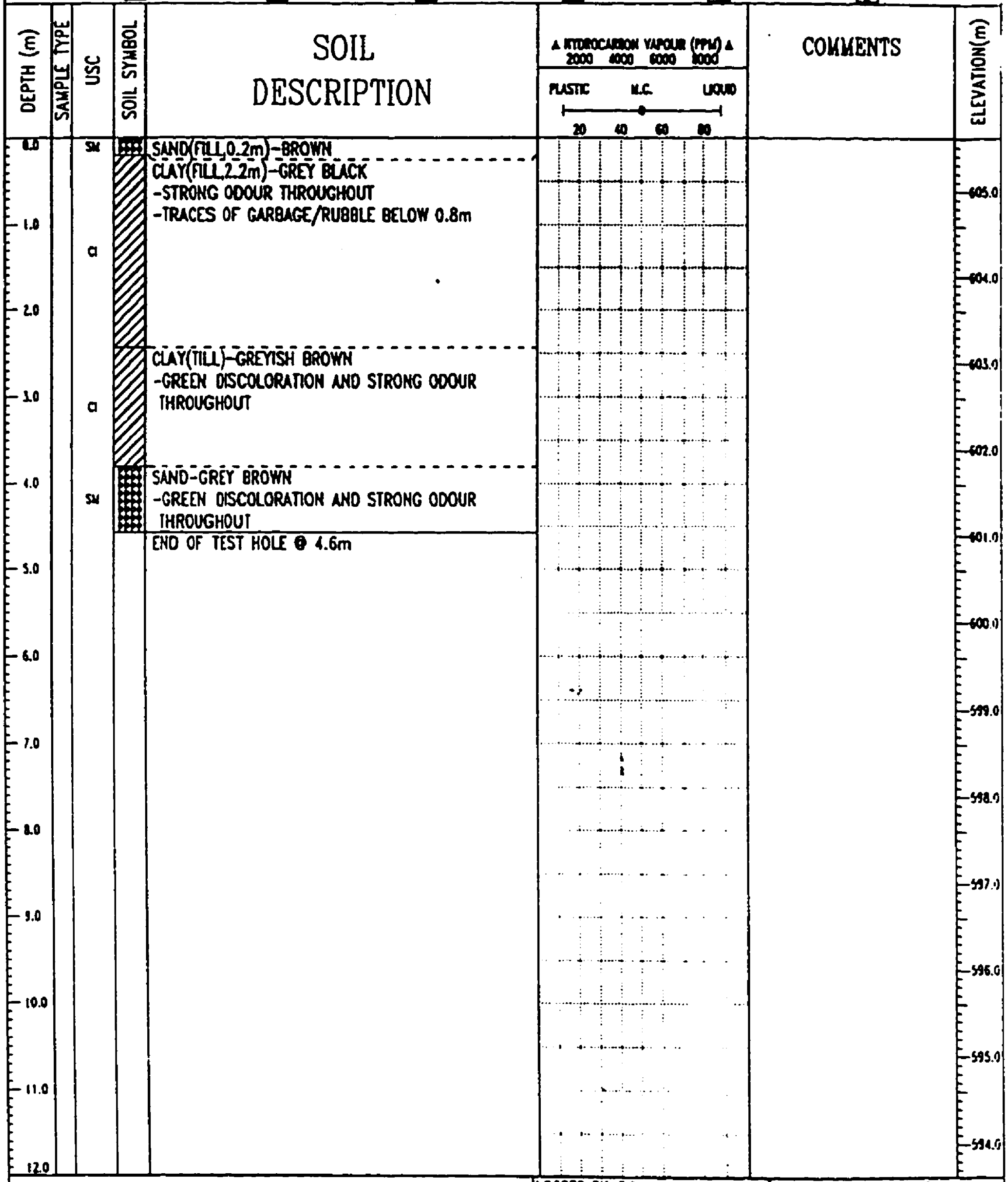
-STRONG ODOUR THROUGHOUT

END OF TEST HOLE @ 2.3m

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 2.3 m
	REVIEWED BY: DJN EDF	COMPLETE: 09/11/94
	Fig. No: 43	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 120
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 605.61 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



USC	SOIL DESCRIPTION
SM	SAND(FILL,0.2m)-BROWN
CI	CLAY(FILL,2.2m)-GREY BLACK -STRONG ODOUR THROUGHOUT -TRACES OF GARBAGE/RUBBLE BELOW 0.8m
CI	CLAY(TILL)-GREYISH BROWN -GREEN DISCOLORATION AND STRONG ODOUR THROUGHOUT
SM	SAND-GREY BROWN -GREEN DISCOLORATION AND STRONG ODOUR THROUGHOUT
	END OF TEST HOLE @ 4.6m

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 4.6 m
	REVIEWED BY: DJM EDF	COMPLETE: 09/11/94
	Fig. No: 44	Page 1 of 1

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OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 121
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 605.64 (m)

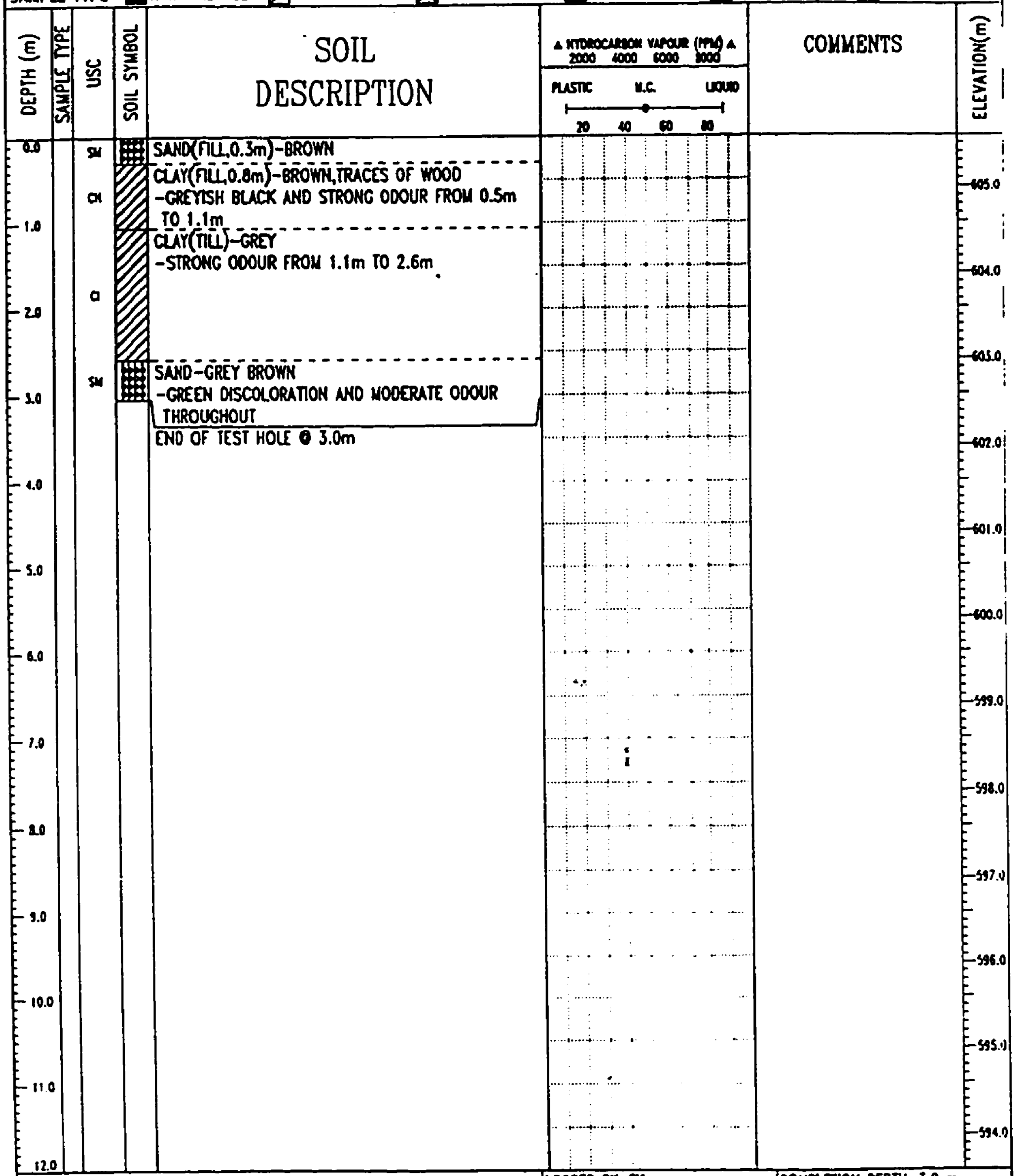
SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE

DEPTH (m)	SAMPLE TYPE	USC	SOIL SYMBOL	SOIL DESCRIPTION	▲ HYDROCARBON VAPOUR (PPM) ▲ 2000 4000 6000 8000 PLASTIC M.C. LIQUID 20 40 60 80	COMMENTS	ELEVATION(m)
0.0		SM	▨	SAND(FILL,50mm)-BROWN			
			▨	CLAY(FILL,2.8m)-BROWN			605.0
1.0			▨	-GREYISH BROWN AND STRONG ODOUR FROM 0.6m TO 1.2m			
		CI	▨	-TRACES OF GARBAGE/RUBBLE @ 0.8m,1.2m TO 1.4m			604.0
2.0			▨	-TRACES OF WOOD/ROOTLETS FROM 2.1m TO 2.7m			603.0
3.0		SM	▦	SAND-GREY BROWN -GREEN DISCOLORATION AND STRONG TO MODERATE ODOUR THROUGHOUT			
				END OF TEST HOLE @ 3.0m			602.0
4.0							601.0
5.0							600.0
6.0							599.0
7.0							598.0
8.0							597.0
9.0							596.0
10.0							595.0
11.0							594.0
12.0							

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 3.0 m
	REVIEWED BY: DJM EDF	COMPLETE: 09/11/94
	Fig. No: 45	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 122
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 605.59 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



SAND(FILL,0.3m)-BROWN

CLAY(FILL,0.8m)-BROWN,TRACES OF WOOD
-GREYISH BLACK AND STRONG ODOUR FROM 0.5m TO 1.1m

CLAY(TILL)-GREY
-STRONG ODOUR FROM 1.1m TO 2.6m

SAND-GREY BROWN
-GREEN DISCOLORATION AND MODERATE ODOUR THROUGHOUT

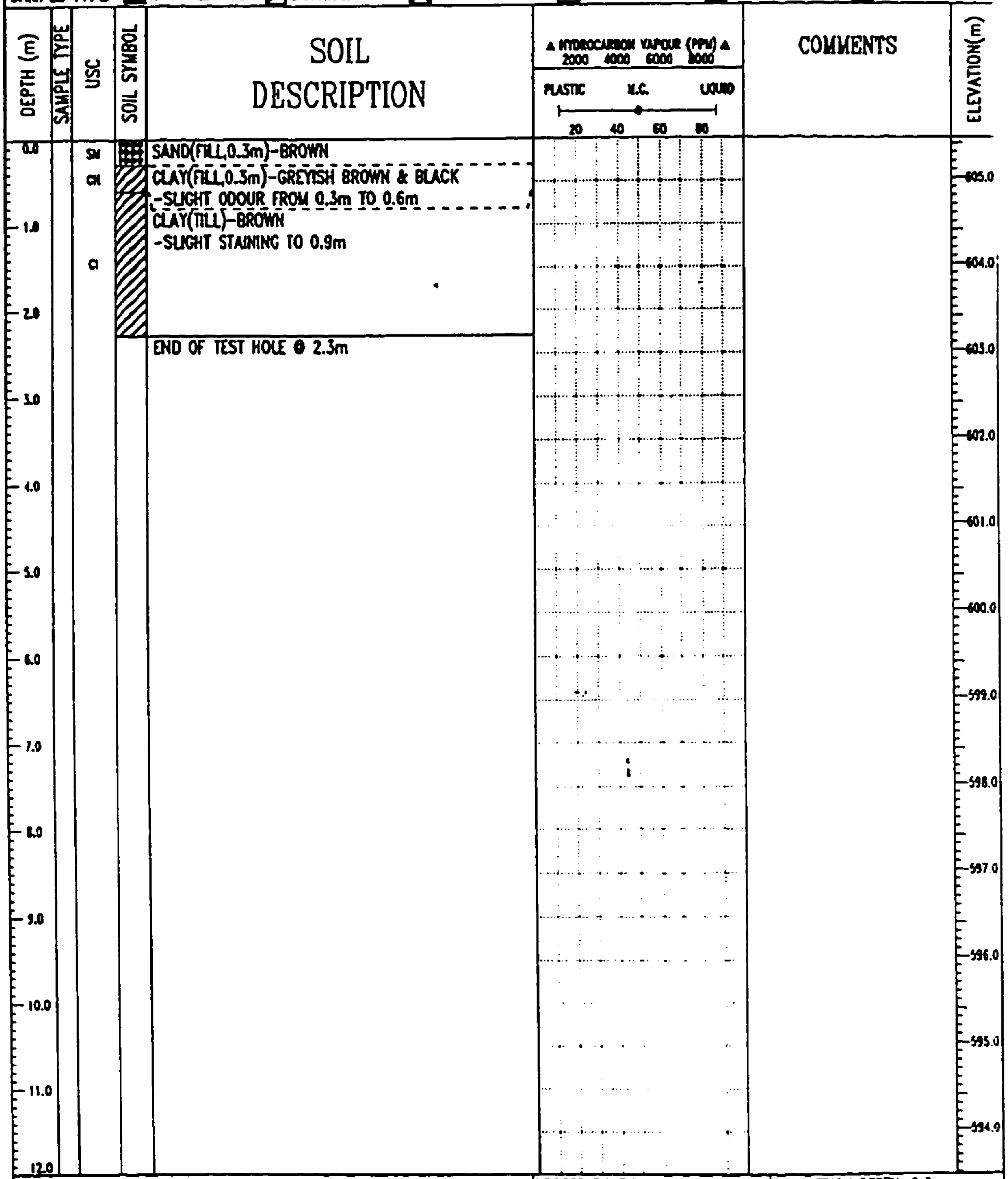
END OF TEST HOLE @ 3.0m

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 3.0 m
	REVIEWED BY: DJM EDF	COMPLETE: 09/11/94
	Fig. No: 46	Page 1 of 1

95/01/06 01:59PM

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 123
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 605.47 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



SAND(FILL,0.3m)-BROWN

CLAY(FILL,0.3m)-GREYISH BROWN & BLACK
-SLIGHT ODOUR FROM 0.3m TO 0.6m

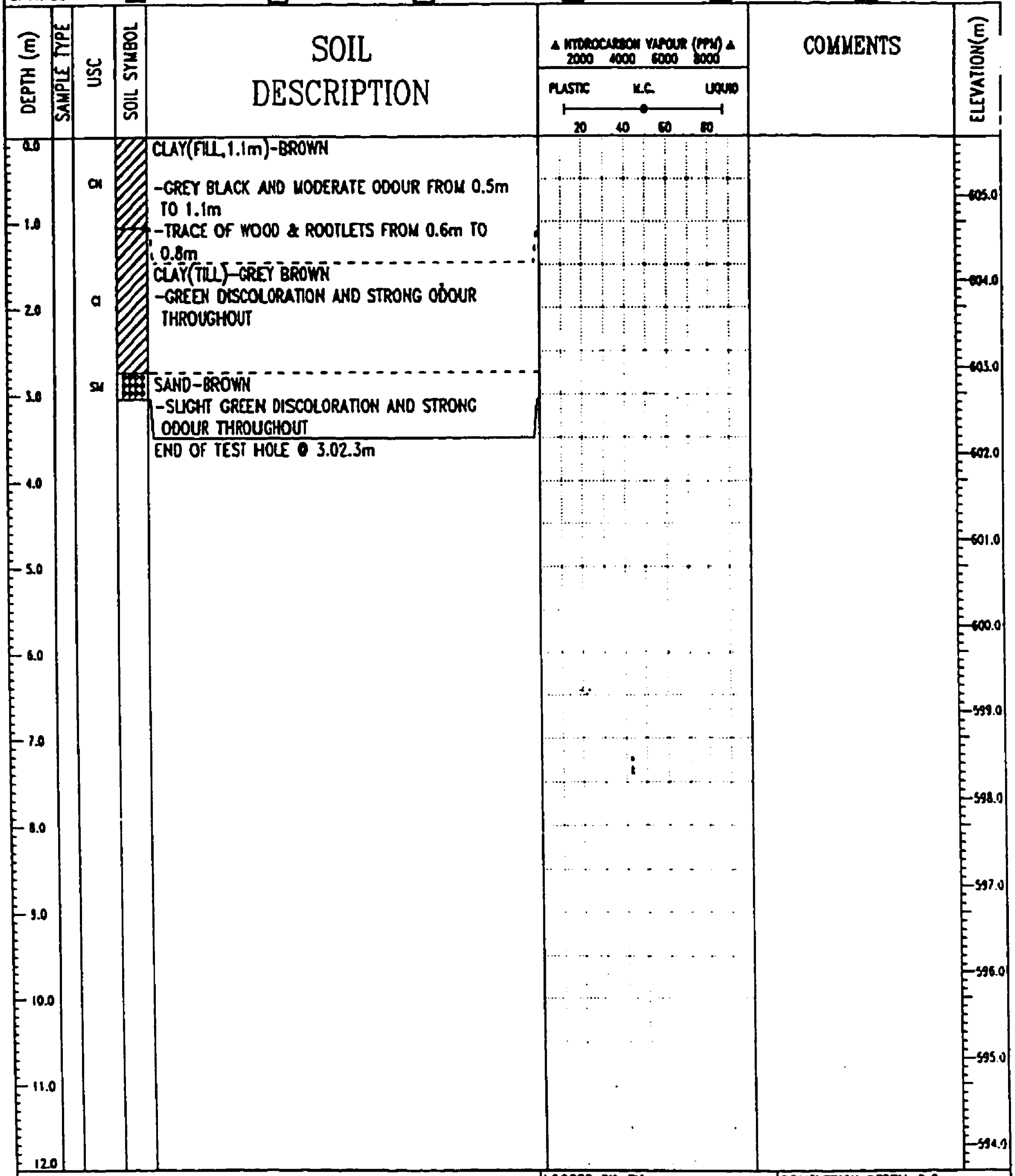
CLAY(TILL)-BROWN
-SLIGHT STAINING TO 0.9m

END OF TEST HOLE @ 2.3m

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 2.3 m
	REVIEWED BY: DJM EDF	COMPLETE: 09/11/94
	Fig. No: 47	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 124
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 605.70 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



CLAY(FILL,1.1m)-BROWN

-GREY BLACK AND MODERATE ODOUR FROM 0.5m TO 1.1m

-TRACE OF WOOD & ROOTLETS FROM 0.6m TO 0.8m

CLAY(TILL)-GREY BROWN

-GREEN DISCOLORATION AND STRONG ODOUR THROUGHOUT

SAND-BROWN

-SLIGHT GREEN DISCOLORATION AND STRONG ODOUR THROUGHOUT

END OF TEST HOLE @ 3.02.3m

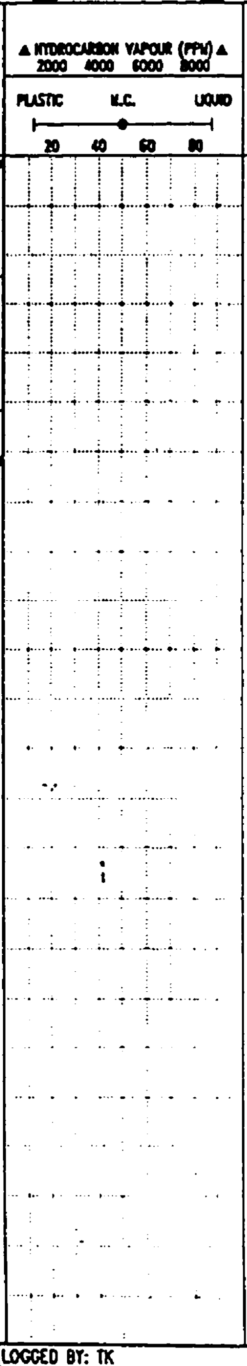
AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 3.0 m
	REVIEWED BY: DJM EDF	COMPLETE: 09/11/94
	Fig. No: 48	Page 1 of 1

95/01/09 01:31PM

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 125
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 605.64 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▥ HOLLOW STEM ▯ CORE

DEPTH (m)	SAMPLE TYPE	USC	SOIL SYMBOL	SOIL DESCRIPTION	COMMENTS	ELEVATION(m)
0.0		SM	▨	SAND(FILL,50mm)-BROWN		
		CH	▨	CLAY(FILL,1.2m)-GREY AND BLACK -STRONG ODOUR FROM 0.6m TO 1.2m		605.0
1.0						
		CI	▨	CLAY(TILL)-GREY BLACK -STRONG ODOUR FROM 1.2m TO 1.8m . -GREEN DISCOLORATION AND MODERATE FROM 1.8m TO 2.6m		604.0
2.0						
		SM	▦	SAND-BROWN -SLIGHT DISCOLORATION AND MODERATE ODOUR BELOW 2.6m		603.0
3.0				END OF TEST HOLE @ 3.0m		
						602.0
4.0						
						601.0
5.0						
						600.0
6.0						
						599.0
7.0						
						598.0
8.0						
						597.0
9.0						
						596.0
10.0						
						595.0
11.0						
						594.0
12.0						



AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 3.0 m
	REVIEWED BY: DJM EDF	COMPLETE: 09/11/94
	Fig. No: 49	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 126
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 605.65 (m)

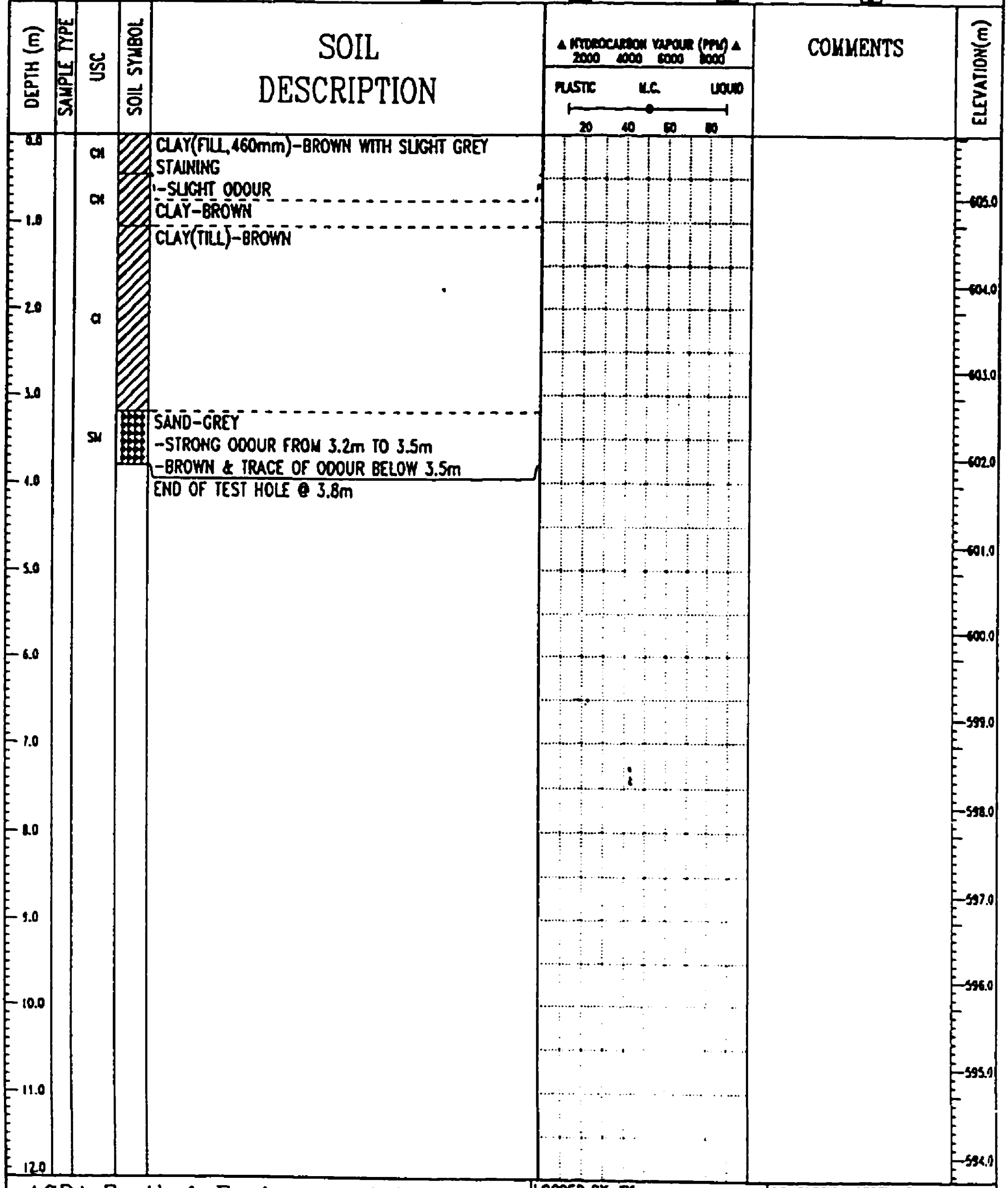
SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE

DEPTH (m)	SAMPLE TYPE	USC	SOIL SYMBOL	SOIL DESCRIPTION	▲ HYDROCARBON VAPOUR (PPM) ▲ 2000 4000 6000 8000 PLASTIC M.C. LIQUID 20 40 60 80	COMMENTS	ELEVATION(m)
0.0		CH	▨	CLAY(FILL,0.3m)-BROWN			
		CH	▨	CLAY-BROWN			605.0
1.0			▨	CLAY(TILL)-BROWN			
			▨				604.0
2.0		CI	▨				
			▨				603.0
3.0				END OF TEST HOLE @ 3.0m			
							602.0
4.0							
							601.0
5.0							
							600.0
6.0							
							599.0
7.0							
							598.0
8.0							
							597.0
9.0							
							596.0
10.0							
							595.0
11.0							
							594.0
12.0							

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 3.0 m
	REVIEWED BY: DJM EDF	COMPLETE: 10/11/94
	Fig. No: 50	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 127
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 605.73 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



CLAY(FILL,460mm)-BROWN WITH SLIGHT GREY STAINING
-SLIGHT ODOUR

CLAY-BROWN

CLAY(TILL)-BROWN

SAND-GREY
-STRONG ODOUR FROM 3.2m TO 3.5m
-BROWN & TRACE OF ODOUR BELOW 3.5m

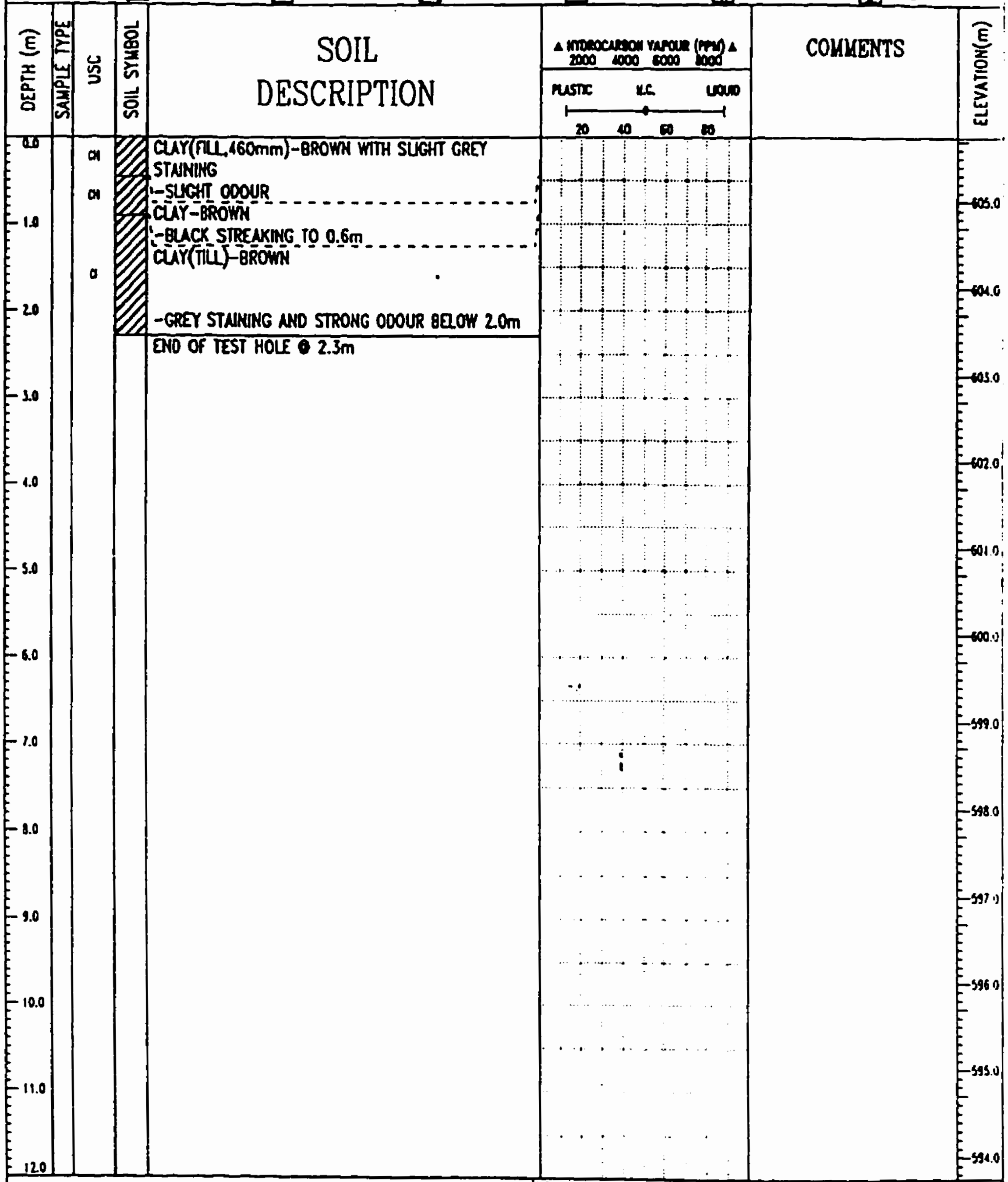
END OF TEST HOLE @ 3.8m

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 3.8 m
	REVIEWED BY: DJM EDF	COMPLETE: 10/11/94
	Fig. No: 51	Page 1 of 1

15/01/96 01:33PM

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 128
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 605.74 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE

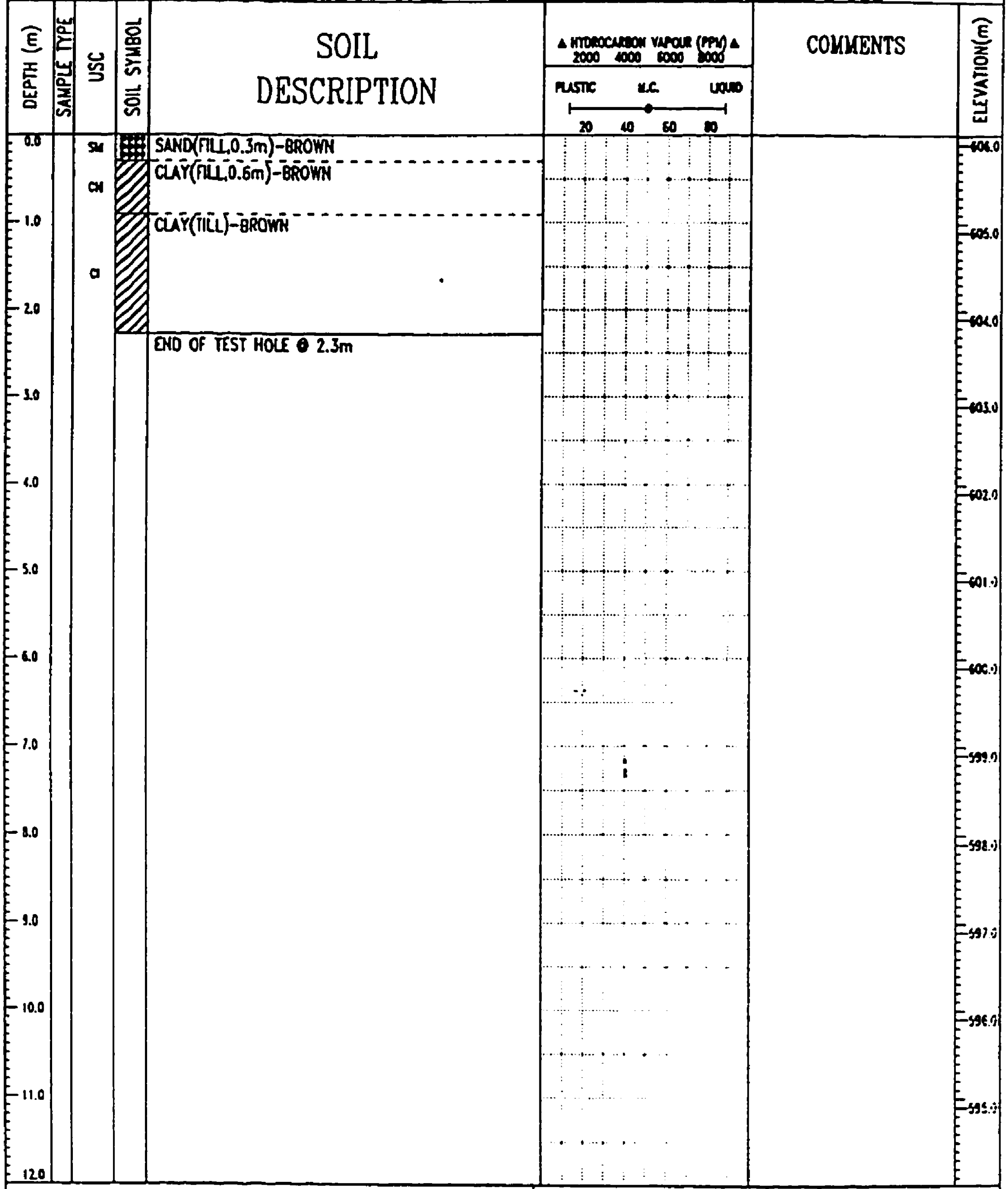


USC	SOIL DESCRIPTION
CH	CLAY(FILL,460mm)-BROWN WITH SLIGHT GREY STAINING
CH	-SLIGHT ODOUR
	CLAY-BROWN
	-BLACK STREAKING TO 0.6m
CI	CLAY(TILL)-BROWN
	-GREY STAINING AND STRONG ODOUR BELOW 2.0m
	END OF TEST HOLE @ 2.3m

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 2.3 m
	REVIEWED BY: DJN EDF	COMPLETE: 10/11/94
	Fig. No: 52	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 129
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 606.11 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE

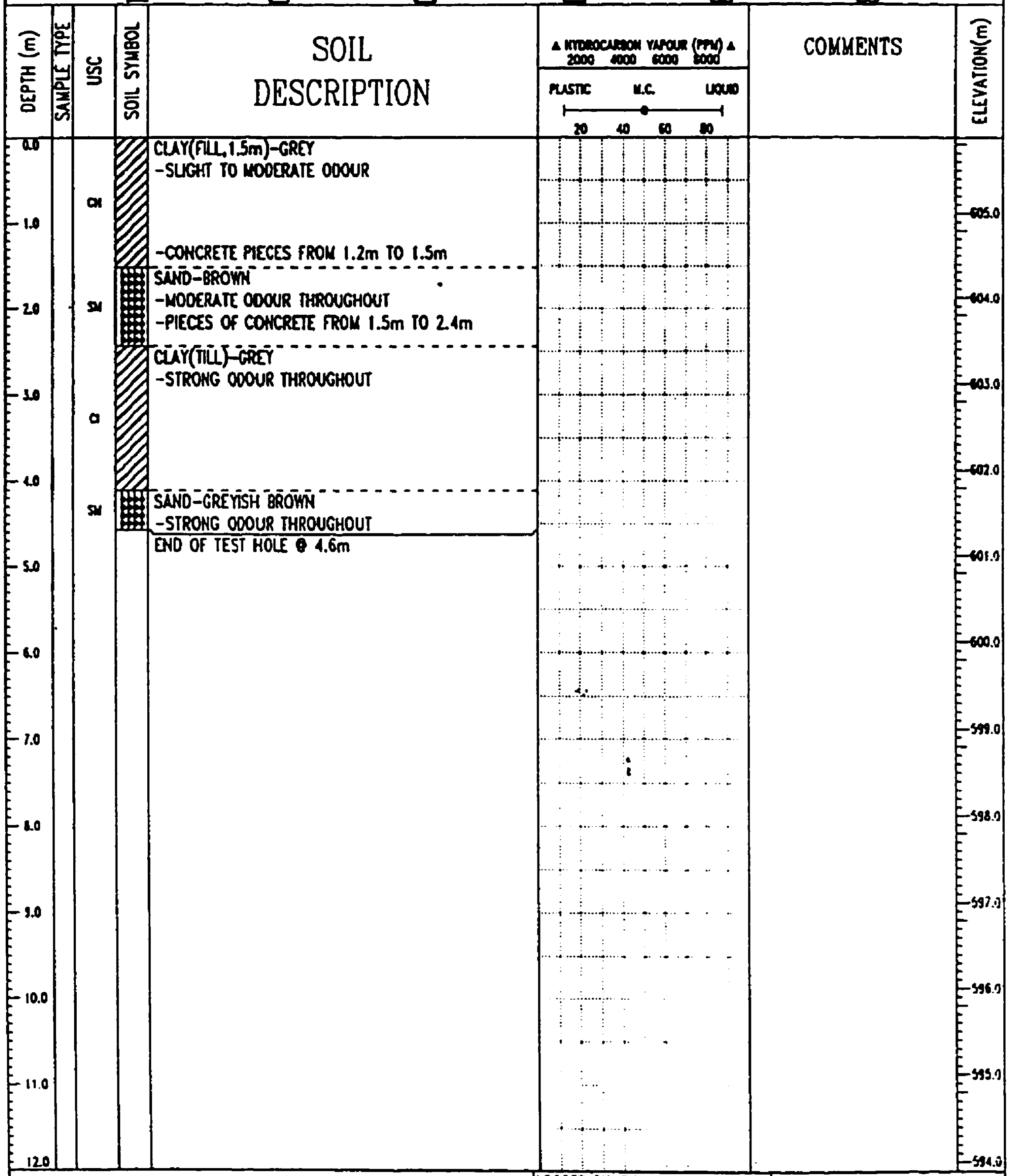


USC	SOIL DESCRIPTION
SM	SAND(FILL,0.3m)-BROWN
CH	CLAY(FILL,0.6m)-BROWN
CI	CLAY(TILL)-BROWN
	END OF TEST HOLE @ 2.3m

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 2.3 m
	REVIEWED BY: DJM EDF	COMPLETE: 10/11/94
	Fig. No: 53	Page 1 of :

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 130
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 605.88 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▥ HOLLOW STEM ▯ CORE



CLAY(FILL,1.5m)-GREY
-SLIGHT TO MODERATE ODOUR

-CONCRETE PIECES FROM 1.2m TO 1.5m

SAND-BROWN
-MODERATE ODOUR THROUGHOUT
-PIECES OF CONCRETE FROM 1.5m TO 2.4m

CLAY(TILL)-GREY
-STRONG ODOUR THROUGHOUT

SAND-GREYISH BROWN
-STRONG ODOUR THROUGHOUT

END OF TEST HOLE @ 4.6m

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 4.6 m
	REVIEWED BY: DJM EDF	COMPLETE: 10/11/94
	Fig. No: 54	Page 1 of 1

95/01/09 01:55PM

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 131
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 605.94 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE

DEPTH (m)	SAMPLE TYPE	USC	SOIL SYMBOL	SOIL DESCRIPTION	▲ HYDROCARBON VAPOUR (PPM) ▲ 2000 4000 6000 8000 PLASTIC M.C. LIQUID 20 40 60 80	COMMENTS	ELEVATION(m)
0.0		CH	▨	CLAY(FILL,0.9m)-BROWN WITH SLIGHT GREY STAINING & ODOUR			
1.0		CL	▨	CLAY(FILL,0.9m)-BROWN WITH SLIGHT GREY STAINING & ODOUR			605.0
2.0		CL	▨	CLAY-GREY -STRONG ODOUR FROM 1.8m TO 2.6m			604.0
3.0		CL	▨	CLAY(TILL)-BROWN WITH BLACK STREAKING -MODERATE ODOUR FROM 2.6m TO 3.5m			603.0
		SM	▦	SAND-BROWN			
4.0				END OF TEST HOLE @ 3.8m			602.0
5.0							601.0
6.0							600.0
7.0							599.0
8.0							598.0
9.0							597.0
10.0							596.0
11.0							595.0
12.0							594.0

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 3.8 m
	REVIEWED BY: DJM EDF	COMPLETE: 10/11/94
	Fig. No: 55	Page 1 of 1

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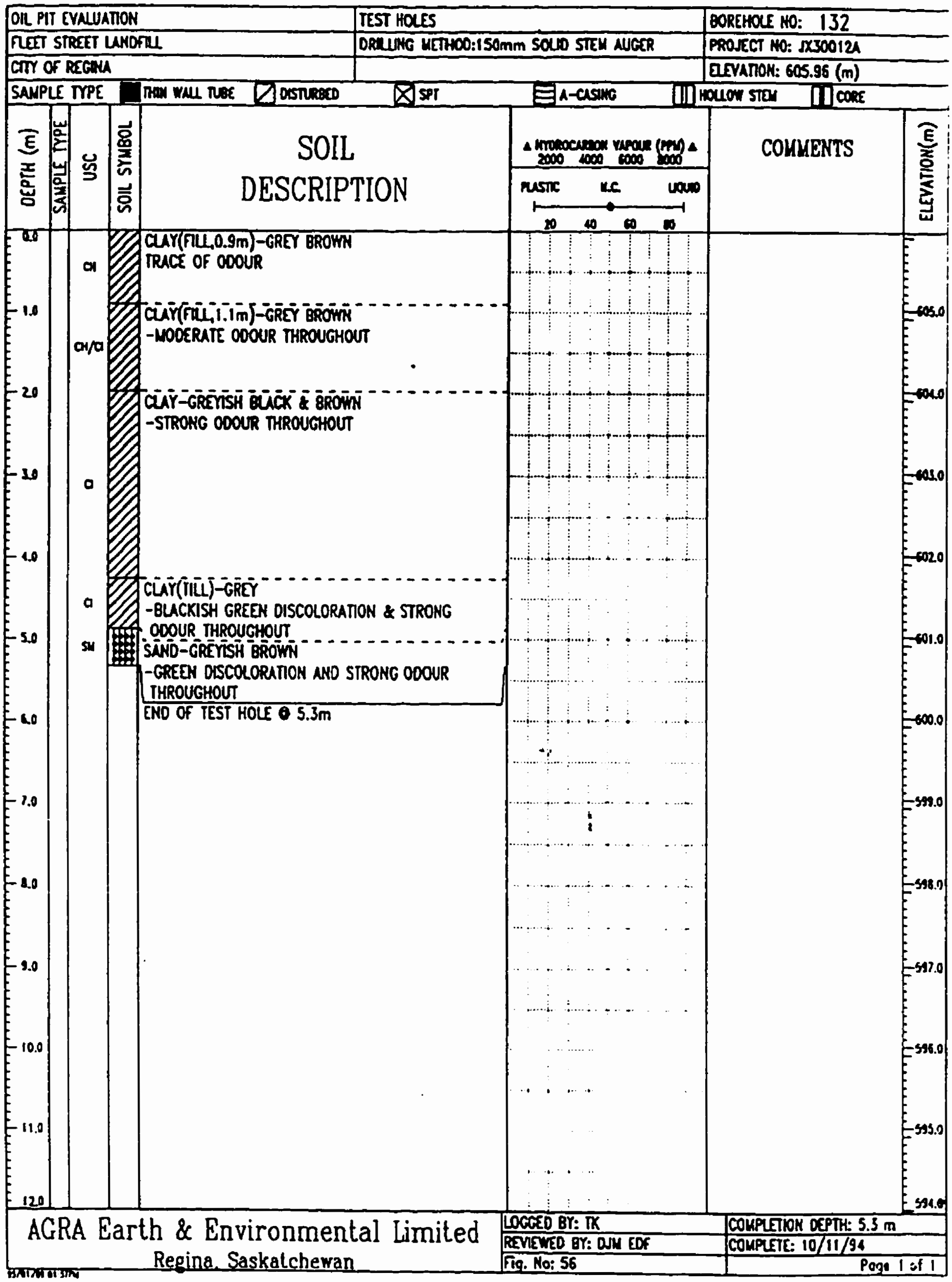


OIL PIT EVALUATION
FLEET STREET LANDFILL
CITY OF REGINA

TEST HOLES
DRILLING METHOD:150mm SOLID STEM AUGER

BOREHOLE NO: 132
PROJECT NO: JX30012A
ELEVATION: 605.96 (m)

SOIL DESCRIPTION

CLAY(FILL,0.9m)-GREY BROWN
TRACE OF ODOUR

CLAY(FILL,1.1m)-GREY BROWN
-MODERATE ODOUR THROUGHOUT

CLAY-GREYISH BLACK & BROWN
-STRONG ODOUR THROUGHOUT

CLAY(TILL)-GREY
-BLACKISH GREEN DISCOLORATION & STRONG ODOUR THROUGHOUT

SAND-GREYISH BROWN
-GREEN DISCOLORATION AND STRONG ODOUR THROUGHOUT

END OF TEST HOLE @ 5.3m

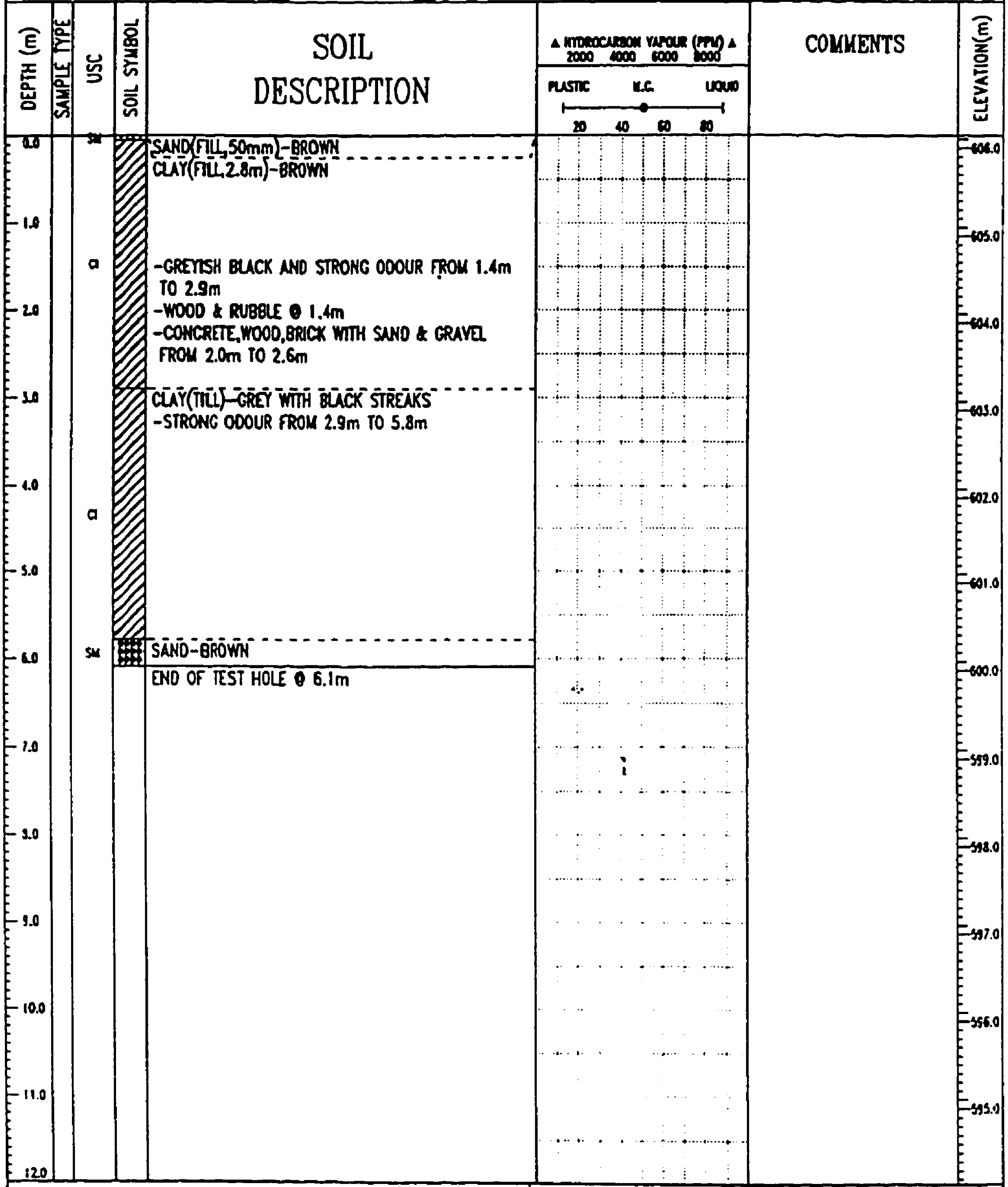
AGRA Earth & Environmental Limited
Regina, Saskatchewan

LOGGED BY: TK
REVIEWED BY: DJM EDF
Fig. No: 56

COMPLETION DEPTH: 5.3 m
COMPLETE: 10/11/94
Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 133
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 606.14 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



SAND(FILL,50mm)-BROWN

CLAY(FILL,2.8m)-BROWN

-GREYISH BLACK AND STRONG ODOUR FROM 1.4m TO 2.9m

-WOOD & RUBBLE @ 1.4m

-CONCRETE,WOOD,BRICK WITH SAND & GRAVEL FROM 2.0m TO 2.6m

CLAY(TILL)-GREY WITH BLACK STREAKS

-STRONG ODOUR FROM 2.9m TO 5.8m

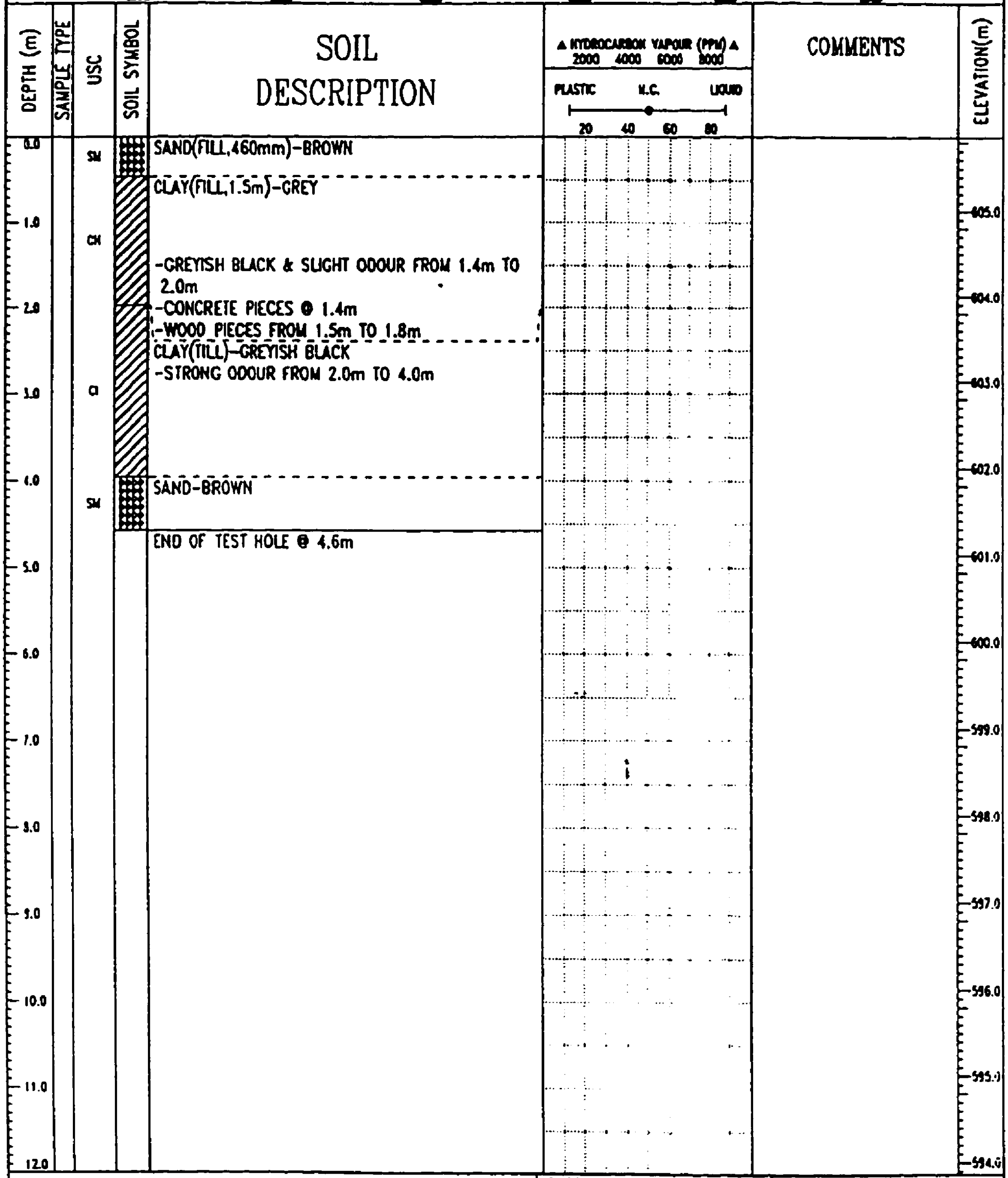
SAND-BROWN

END OF TEST HOLE @ 6.1m

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 6.1 m
	REVIEWED BY: OJM EDF	COMPLETE: 10/11/94
	Fig. No: 57	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 134
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 605.86 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE

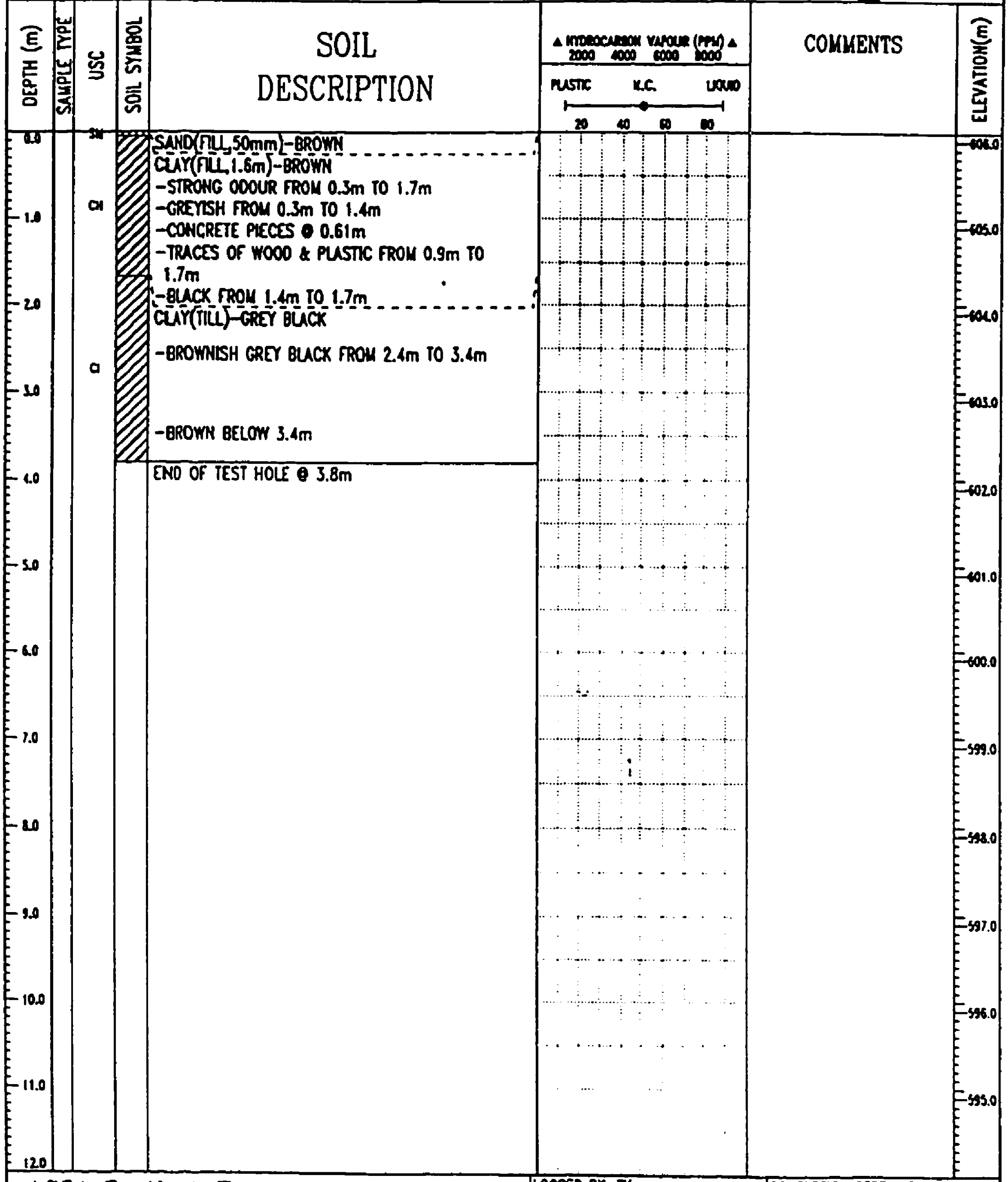


USC	SOIL DESCRIPTION
SM	SAND(FILL,460mm)-BROWN
CH	CLAY(FILL,1.5m)-GREY -GREYISH BLACK & SLIGHT ODOUR FROM 1.4m TO 2.0m -CONCRETE PIECES @ 1.4m -WOOD PIECES FROM 1.5m TO 1.8m
CI	CLAY(TILL)-GREYISH BLACK -STRONG ODOUR FROM 2.0m TO 4.0m
SM	SAND-BROWN
	END OF TEST HOLE @ 4.6m

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 4.6 m
	REVIEWED BY: DJM EDF	COMPLETE: 10/11/94
	Fig. No: 58	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 135
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 606.10 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



SOIL DESCRIPTION

SAND(FILL,50mm)-BROWN

CLAY(FILL,1.6m)-BROWN
-STRONG ODOUR FROM 0.3m TO 1.7m
-GREYISH FROM 0.3m TO 1.4m
-CONCRETE PIECES @ 0.61m
-TRACES OF WOOD & PLASTIC FROM 0.9m TO 1.7m
-BLACK FROM 1.4m TO 1.7m

CLAY(TILL)-GREY BLACK
-BROWNISH GREY BLACK FROM 2.4m TO 3.4m
-BROWN BELOW 3.4m

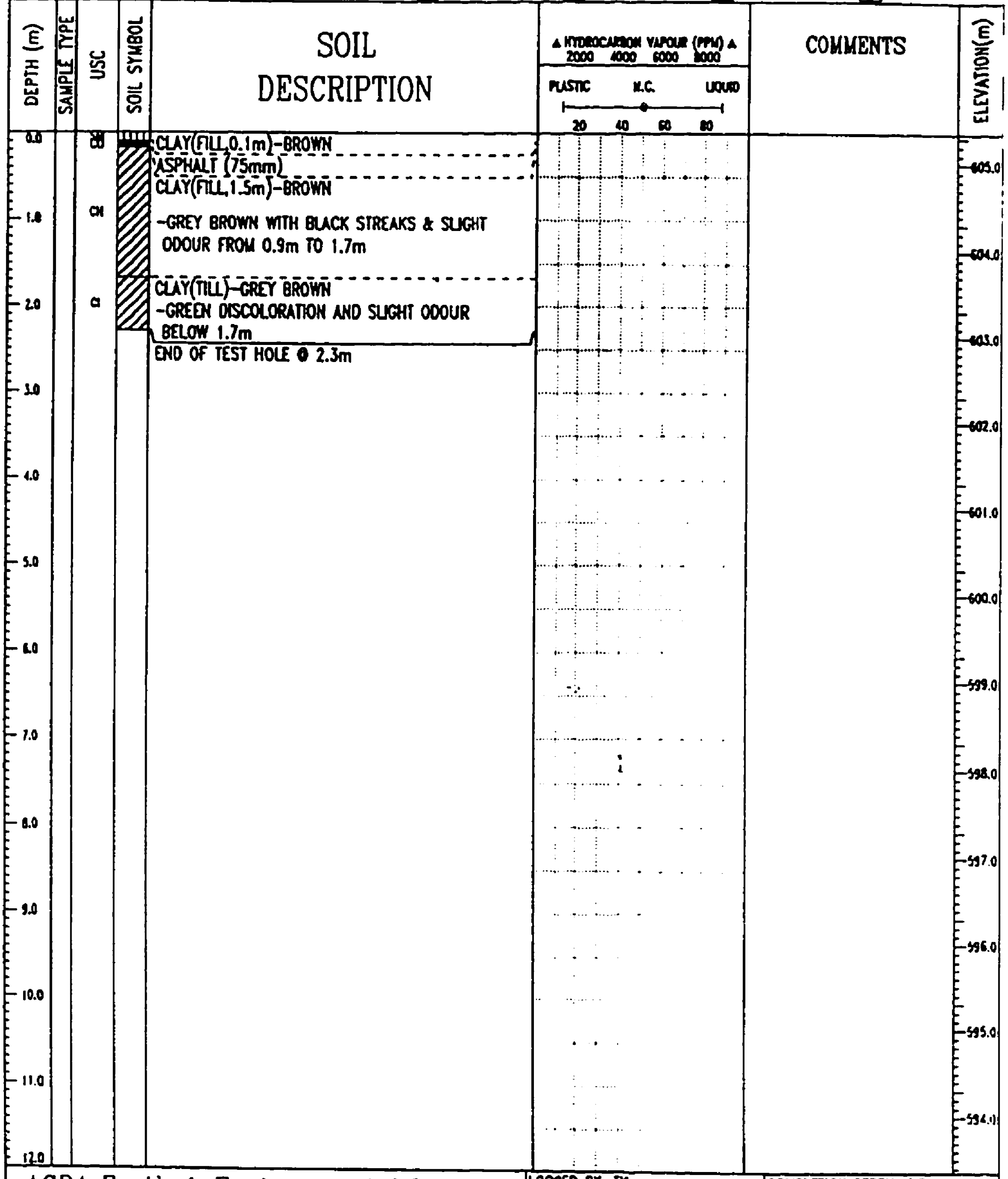
END OF TEST HOLE @ 3.8m

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 3.8 m
	REVIEWED BY: DJM EDF	COMPLETE: 10/11/94
	Fig. No: 59	Page 1 of 1

[illegible]

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 136
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 605.35 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



CLAY(FILL,0.1m)-BROWN

ASPHALT (75mm)

CLAY(FILL,1.5m)-BROWN

-GREY BROWN WITH BLACK STREAKS & SLIGHT ODOUR FROM 0.9m TO 1.7m

CLAY(TILL)-GREY BROWN

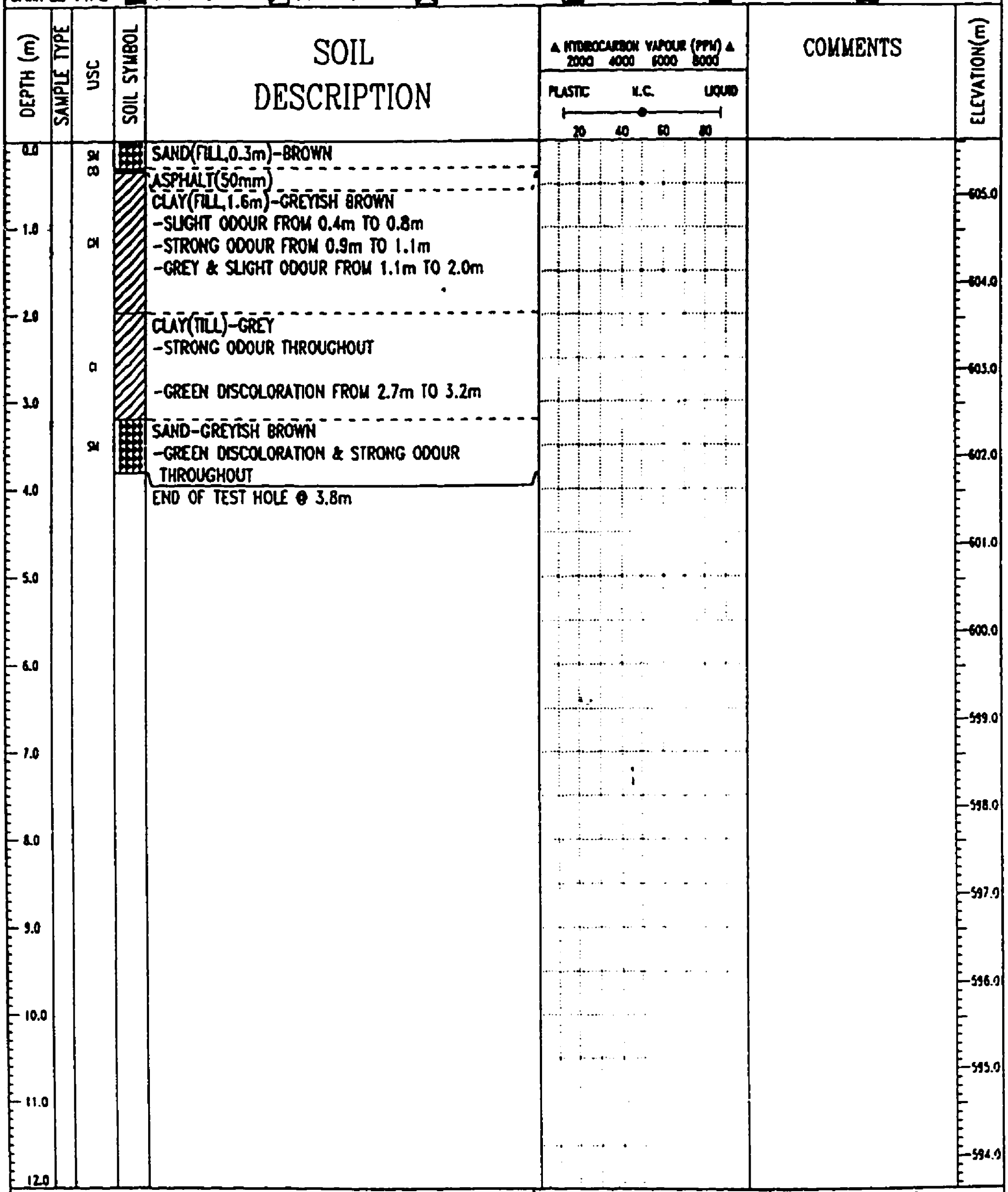
-GREEN DISCOLORATION AND SLIGHT ODOUR BELOW 1.7m

END OF TEST HOLE @ 2.3m

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 2.3 m
	REVIEWED BY: DJM EDF	COMPLETE: 10/11/94
	Fig. No: 60	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 137
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012A
CITY OF REGINA		ELEVATION: 605.633 (m)

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE



SAND(FILL,0.3m)-BROWN

ASPHALT(50mm)

CLAY(FILL,1.6m)-GREYISH BROWN
-SLIGHT ODOUR FROM 0.4m TO 0.8m
-STRONG ODOUR FROM 0.9m TO 1.1m
-GREY & SLIGHT ODOUR FROM 1.1m TO 2.0m

CLAY(TILL)-GREY
-STRONG ODOUR THROUGHOUT

-GREEN DISCOLORATION FROM 2.7m TO 3.2m

SAND-GREYISH BROWN
-GREEN DISCOLORATION & STRONG ODOUR THROUGHOUT

END OF TEST HOLE @ 3.8m

AGRA Earth & Environmental Limited Regina, Saskatchewan	LOGGED BY: TK	COMPLETION DEPTH: 3.8 m
	REVIEWED BY: DJM EDF	COMPLETE: 10/11/94
	Fig. No: 61	Page 1 of 1

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 138
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012
CITY OF REGINA		ELEVATION:

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▥ HOLLOW STEM ▯ CORE

DEPTH (m)	SAMPLE TYPE	USC	SOIL SYMBOL	SOIL DESCRIPTION	▲ HYDROCARBON VAPOUR (PPM) ▲ 2000 4000 6000 8000 PLASTIC M.C. LIQUID 20 40 60 80	COMMENTS	ELEVATION(m)
0.0				ASPHALT(225mm)			0.0
		CH	▨	CLAY(FILL,1.0m)-GREYISH BROWN -SLIGHT ODOUR			
1.0							-1.0
		CI	▨	CLAY(TILL)-BROWN -SLIGHT STAINING TO 2.1m			
2.0							-2.0
3.0							-3.0
		SM	▦	SAND-BROWN -SLIGHT HYDROCARBON ODOUR			
4.0				END OF TEST HOLE @ 4.0m			-4.0
5.0							-5.0
6.0							-6.0
7.0							-7.0
8.0							-8.0
9.0							-9.0
10.0							-10.0
11.0							-11.0
12.0							-12.0

AGRA Earth & Environmental Limited
Regina, Saskatchewan

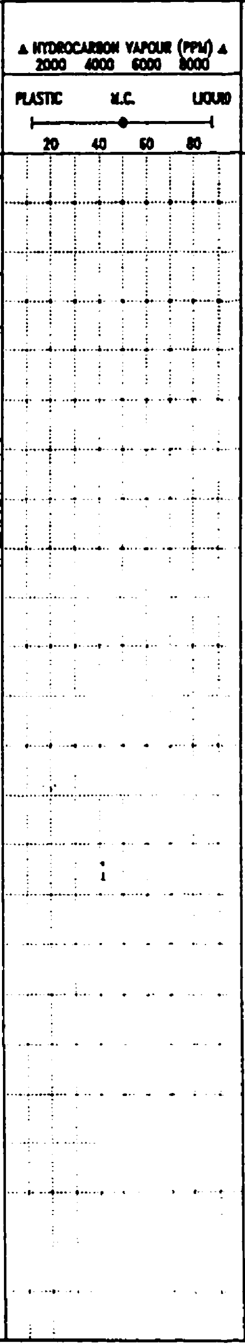
LOGGED BY: TK	COMPLETION DEPTH: 4.0 m
REVIEWED BY: DJM EDF	COMPLETE: 22/12/94
Fig. No: 62	Page 1 of 1

[illegible]

OIL PIT EVALUATION	TEST HOLES	BOREHOLE NO: 139
FLEET STREET LANDFILL	DRILLING METHOD:150mm SOLID STEM AUGER	PROJECT NO: JX30012
CITY OF REGINA		ELEVATION:

SAMPLE TYPE ■ THIN WALL TUBE ▨ DISTURBED ☒ SPT ☰ A-CASING ▯ HOLLOW STEM ▯ CORE

DEPTH (m)	SAMPLE TYPE	USC	SOIL SYMBOL	SOIL DESCRIPTION	COMMENTS	ELEVATION(m)
0.0				ASPHALT(225mm)		0.0
		CH	▨	CLAY(FILL,1.0m)-GREYISH BROWN -SLIGHT HYDROCARBON ODOUR		
1.0		CI	▨	CLAY(TILL)-BROWN		-1.0
2.0						-2.0
3.0		SM	▦	SAND-BROWN		-3.0
4.0				END OF TEST HOLE @ 4.0m		-4.0
5.0						-5.0
6.0						-6.0
7.0						-7.0
8.0						-8.0
9.0						-9.0
10.0						-10.0
11.0						-11.0
12.0						-12.0



AGRA Earth & Environmental Limited
Regina, Saskatchewan

LOGGED BY: TK	COMPLETION DEPTH: 4.0 m
REVIEWED BY: DJM EDF	COMPLETE: 22/12/94
Fig. No: 63	Page 1 of 1

APPENDIX B

OTHER ANALYTICAL RESULTS

BTEX, TSH, PEHNOLS, ETHYLENE GLYCOL AND PCBs									
Test Hole	**Depth (m)**	**Parameter**							
		Benzene	**Toluene**	**Ethyl-benzene**	**Xylenes**	**TSH**	**Phenols**	**Ethylene Glycol**	**PCBs**
1	3.3	--	--	--	--	180,000	--	--	--
1	3.8	47	36	37	835	--	--	<2	<0.1
2	2.2	11	2.9	5.5	26	14,000	2.5	--	--
2	6.1	1.2	1.7	1.8	14	--	0.53	--	--
3	1.5	--	--	--	--	4,900	--	--	--
5	2.3	--	--	--	--	89	--	--	--
6	3.8	--	--	--	--	33,000	--	--	--
7	3.8	--	--	--	--	120,000	--	--	--
8	3.8	--	--	--	--	<1	--	--	--
9	3.0	--	--	--	--	29,000	--	--	--
10	3.8	--	--	--	--	190,000	--	--	--
11	1.5	--	--	--	--	16,000	--	--	--
12	2.3	--	--	--	--	15,000	--	--	--
12	3.0	<0.1	9.5	6.0	36	--	--	<2	<0.1
13	2.3	--	--	--	--	<1	--	--	--
14	3.0	<0.1	0.5	3.3	5.1	--	--	<2	<0.1
16	2.3	<0.005	<0.005	<0.005	<0.005	<1	0.07	--	--
16	6.1	<0.005	0.078	<0.005	0.070	6,700	<0.02	--	--
17	2.3	2.3	0.8	3.8	97	--	--	<2	<0.1
17	3.0	--	--	--	--	31,000	--	--	--
18	5.3	--	--	--	--	60,000	--	--	--
19	4.6	<0.005	<0.005	<0.005	<0.005	<1	0.04	--	--
20	3.8	0.26	0.23	1.2	1.1	18,000	0.05	--	--
21	5.3	1.5	1.2	0.071	1.9	69,000	0.42	--	--
SERM Guideline		0.5	3.0	5.0	5.0	N/A	N/A	N/A	N/A
CCME Guideline		0.5	3.0	5.0	5.0	N/A	1.0	N/A	5

Notes: "<" means that the result was less than the method detection limit indicated.
"—" denotes that these samples were not analyzed for the parameter indicated.
N/A denotes that a guideline concentration does not exist for that parameter.

SOLVENT SCAN RESULTS						
Parameter	**Concentration (mg/kg)**					
	Test Hole and Depth (m)					
	1(3.8)	**2(2.2)**	**2(6.1)**	**12(3.0)**	**14(3.0)**	**16(2.3)**
Acetone	0.7	96	1.71	0.8	1.1	0.39
Benzene	47	5.77	0.31	<0.1	<0.1	<0.01
n-Butyl Alcohol	<0.2	<0.02	<0.02	<0.2	<0.2	<0.02
Carbon Disulfide	0.5	<0.02	12.8	0.3	0.2	<0.02
Cresols/Cresylic Acids	<0.5	<0.2	<0.2	<0.5	<0.5	<0.2
Cyclohexanone	<0.5	<0.2	<0.2	<0.5	<0.5	<0.2
Ethyl Acetate	<1.0	<0.2	<0.2	<0.1	<1.0	<0.2
Ethyl Benzene	37	<0.02	1.43	6.0	3.3	<0.02
Ethyl Ether	<0.2	1.51	<0.02	<0.2	<0.2	<0.02
Isobutanol	<0.2	<0.02	<0.02	<0.2	<0.2	<0.02
Methanol	<0.4	<0.05	0.34	<0.4	<0.4	<0.05
Methyl Ethyl Ketone	10	3.22	0.20	10	4.3	<0.02
Nitrobenzene	<0.4	<0.1	<0.1	<0.4	<0.4	<0.1
2-Nitropropane	<0.5	<0.1	<0.1	<0.5	<0.5	<0.1
Pyridine	<0.8	44.0	1.19	<0.8	<0.8	<0.3
Toluene	36	0.46	0.32	9.5	0.5	<0.02
Xylenes	835	5.06	7.03	36	5.1	<0.02

SOLVENT SCAN RESULTS (cont'd)					
Parameter	**Concentration (mg/kg)**				
	Test Hole and Depth (m)				
	16(6.1)	**17(2.3)**	**19(4.6)**	**20(3.8)**	**21(3.8)**
Acetone	0.66	<0.1	<0.01	0.15	19.6
Benzene	<0.01	<0.1	<0.01	<0.01	0.63
n-Butyl Alcohol	<0.02	<0.2	<0.02	<0.02	2.94
Carbon Disulfide	<0.02	<0.2	<0.02	<0.02	2.1
Cresols/Cresylic Acids	<0.2	<0.5	<0.2	<0.2	<0.2
Cyclohexanone	<0.2	<0.5	<0.2	<0.2	<0.2
Ethyl Acetate	<0.2	<1.0	<0.2	<0.2	6.7
Ethyl Benzene	<0.02	<0.2	<0.02	0.93	0.68
Ethyl Ether	<0.02	<0.2	<0.02	<0.02	<0.02
Isobutanol	<0.02	<0.2	<0.02	<0.02	<0.02
Methanol	<0.05	<0.4	<0.05	<0.05	1.15
Methyl Ethyl Ketone	<0.02	<0.2	<0.02	<0.02	0.36
Nitrobenzene	<0.1	<0.4	<0.1	<0.1	<0.1
2-Nitropropane	<0.1	<0.5	<0.1	<0.1	<0.1
Pyridine	<0.3	<0.8	<0.3	3.3	7.20
Toluene	<0.02	<0.2	<0.02	<0.02	0.21
Xylenes	<0.02	<0.2	<0.02	0.69	1.54

Note: "<" means that the result was less than the method detection limit indicated.

HERBICIDE SCAN RESULTS							
Parameter	**Concentration (µg/kg)**						
	Test Hole and Depth (m)						
	2(2.2)	**2(6.1)**	**16(2.3)**	**16(6.1)**	**19(4.6)**	**20(3.8)**	**21(5.3)**
Bromoxynil	<40	<40	<40	<40	<40	<40	<40
Dicamba	<40	<40	<40	<40	<40	<40	<40
2,4-D	<20	<20	<20	<20	<20	<20	<20
Diclofop-methyl	<10	<10	<10	<10	<10	<10	<10
Picloram	<50	<50	<50	<50	<50	<50	<50
MCPA	<20	<20	<20	<20	<20	<20	<20
Trifluralin	<20	<20	<20	<20	<20	<20	<20
Triallate	<40	<40	<40	<40	<40	<40	<40

Note: "<" means that the result was less than the method detection limit indicated.

EXTRACTABLE ORGANO-CHLORINE RESULTS				
Parameter	**Test Hole and Depth (m)**			
	1(3.8)	**12(3.0)**	**14(3.0)**	**17(2.3)**
Bromine	0.76	0.21	<0.2	<0.2
Chlorine	13	1.9	9.1	1.8

ICP TRACE ELEMENT SCAN RESULTS					
Parameter	**Concentration**				
	Test Hole and Depth (m)				
	1(3.8)	**12(3.0)**	**14(3.0)**	**17(2.3)**	**CCME Guideline**
Aluminum	7520	8410	11100	14100	N/A
Arsenic	8.9	7.4	7.5	8.3	30
Barium	138	167	133	186	500
Beryllium	<0.1	<0.1	<0.1	<0.1	4
Cadmium	<0.5	<0.5	<0.5	<0.5	5
Calcium	31000	22100	19900	21300	N/A
Chromium	17	18	18	28	250
Cobalt	7	7	8	10	50
Copper	52	28	26	82	100
Iron	12500	12700	12900	16000	N/A
Lead	131	90	35	110	500
Magnesium	7970	9760	8720	9630	N/A
Manganese	385	237	376	357	N/A
Mercury	0.5	<0.1	<0.1	<0.1	2
Molybdenum	<5	<5	<5	<5	10
Nickel	17	14	16	22	100
Phosphorus	313	317	342	376	N/A
Potassium	1930	1730	2560	2990	N/A
Selenium	0.4	0.2	0.3	0.2	3
Sodium	1060	651	698	412	N/A
Thallium	<10	<10	<10	<10	N/A
Vanadium	21	21	27	32	200
Zinc	72	63	51	273	500

Notes: "<" means that the result was less than the method detection limit indicated.
N/A denotes that a guideline concentration does not exist for that parameter.

APPENDIX C

GAS CHROMATOGRAPHS

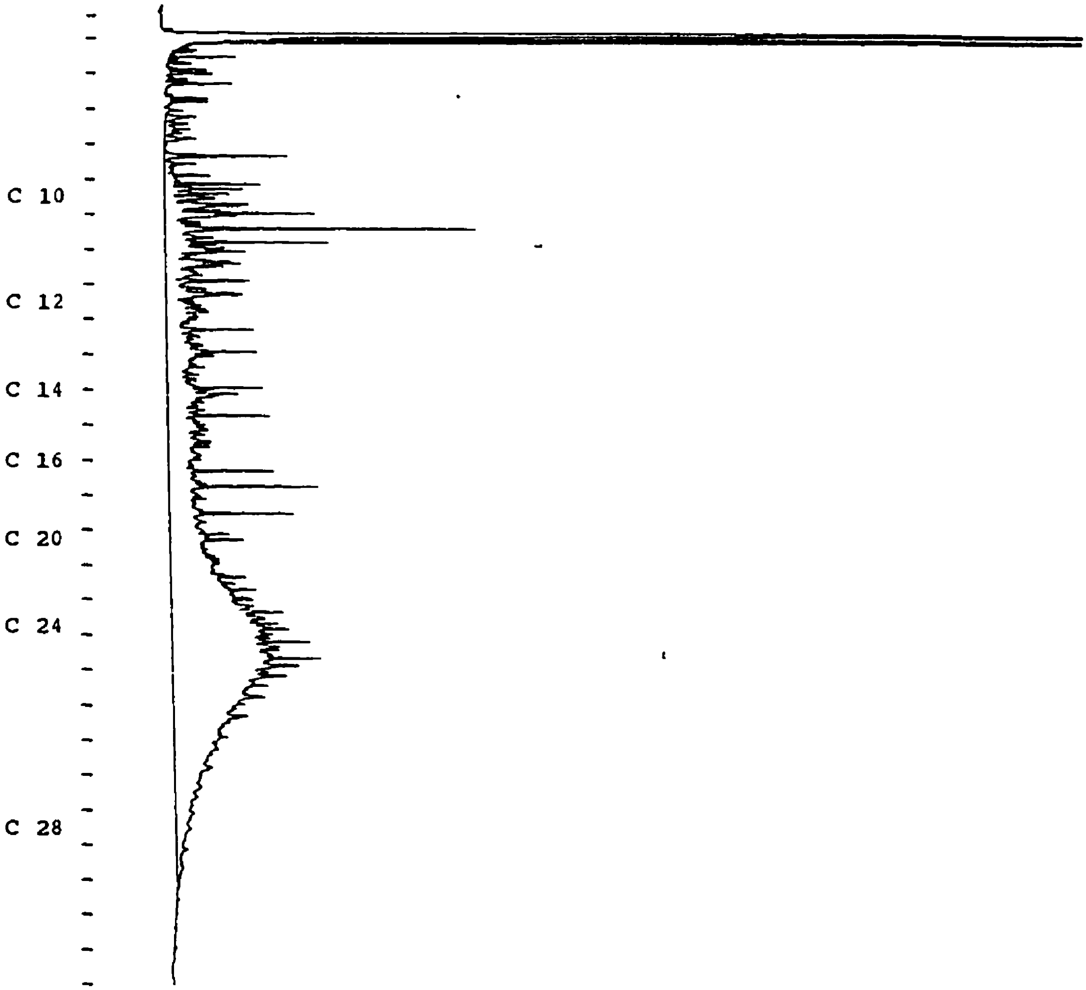
```
Run File     : C:\Star\module16\sval094.run
Method File : C:\STAR\SEMCAL.MTH
Sample ID    : 4254jx30012,3-2-5

Injection Date: 7-JUL-94 7:05 AM

Operator    : B. Chomin                Detector Type: ADCB (1 Volt)
Workstation: MS-DOS_6                  Bus Address   : 16
Instrument : 3400                      Sample Rate   : 10.00 Hz
Channel     : A = fid                  Run Time      : 28.002 min

*********** Varian GC Star Workstation ************ Version A2 ****************

Chart Speed =    0.60 cm/min   Attenuation =     100       Zero Offset = 5%
Start Time  =   0.000 min      End Time    =  28.000 min   Min / Tick  = 1.00
```



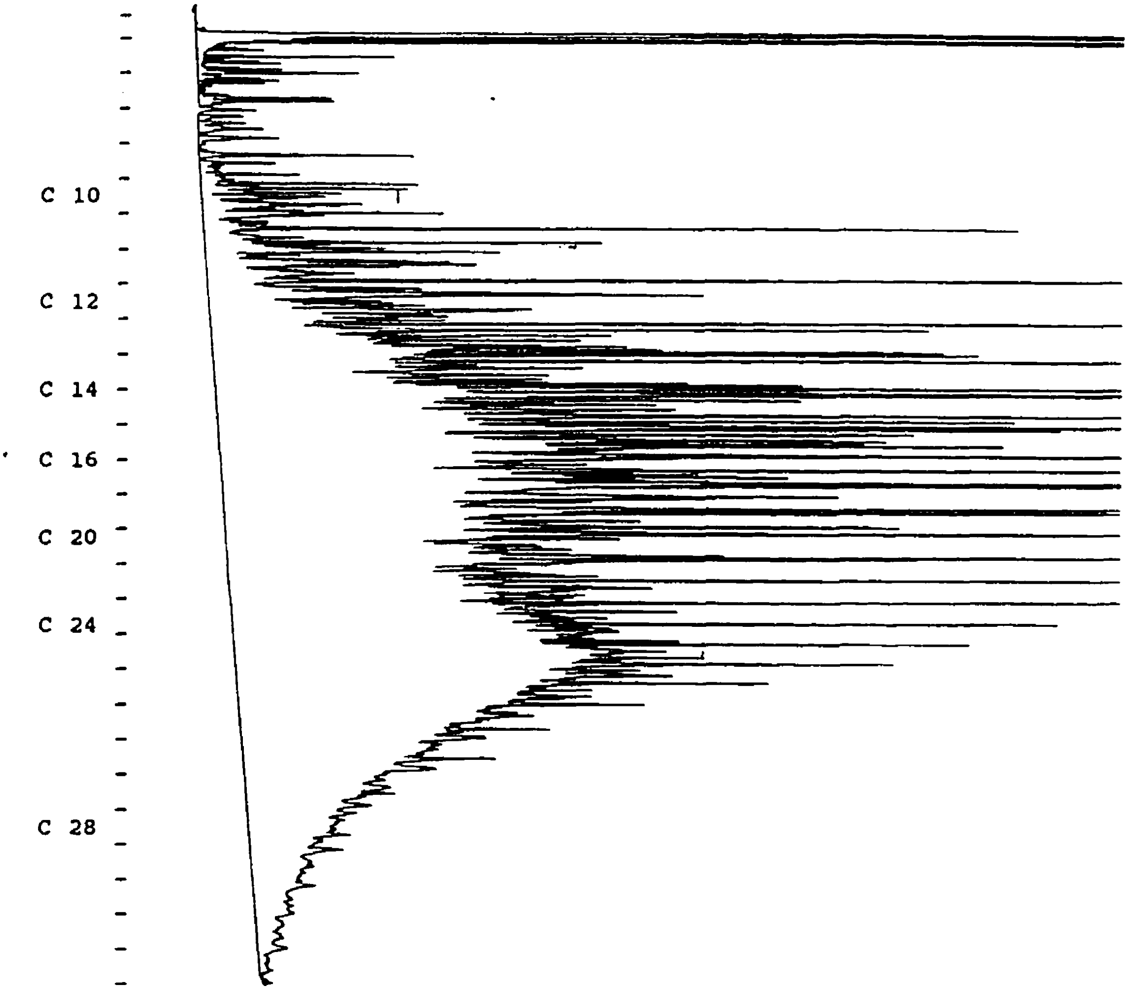
```
Method File : C:\STAR\SEMCAL.MTH
Sample ID   : 4263x30012,6-6-12

Injection Date: 7-JUL-94 11:38 AM

Operator    : B. Chomin                  Detector Type: ADCB (1 Volt)
Workstation: MS-DOS_6                    Bus Address  : 16
Instrument : 3400                        Sample Rate  : 10.00 Hz
Channel     : A = fid                    Run Time     : 28.002 min

*********** Varian GC Star Workstation ************ Version A2 *****************

Chart Speed =    0.60 cm/min   Attenuation =     100      Zero Offset = 5%
Start Time  =   0.000 min      End Time    =  28.000 min  Min / Tick  = 1.00
```



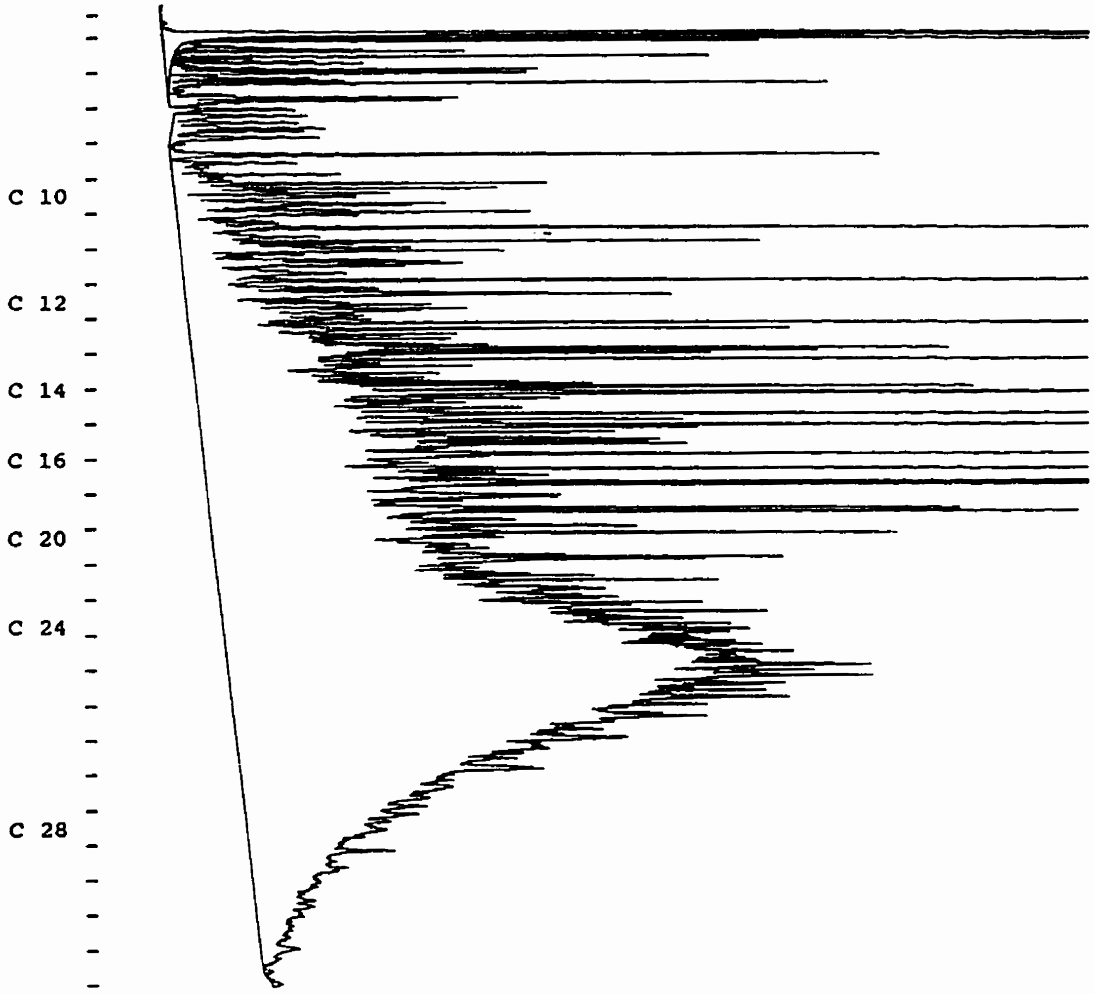
```
Run File     : C:\STAR\MODULE16\svar111.RUN
Method File : C:\STAR\SEMCAL.MTH
Sample ID    : 4265x30012,7-5-12

Injection Date: 7-JUL-94 6:02 PM

Operator    : B. Chomin                Detector Type: ADCB (1 Volt)
Workstation: MS-DOS_6                  Bus Address  : 16
Instrument : 3400                      Sample Rate  : 10.00 Hz
Channel     : A = fid                  Run Time     : 28.002 min

*********** Varian GC Star Workstation ************ Version A2 *****************

Chart Speed =    0.60 cm/min   Attenuation =     100      Zero Offset = 5%
Start Time  =   0.000 min      End Time    =  28.000 min  Min / Tick  = 1.00
```



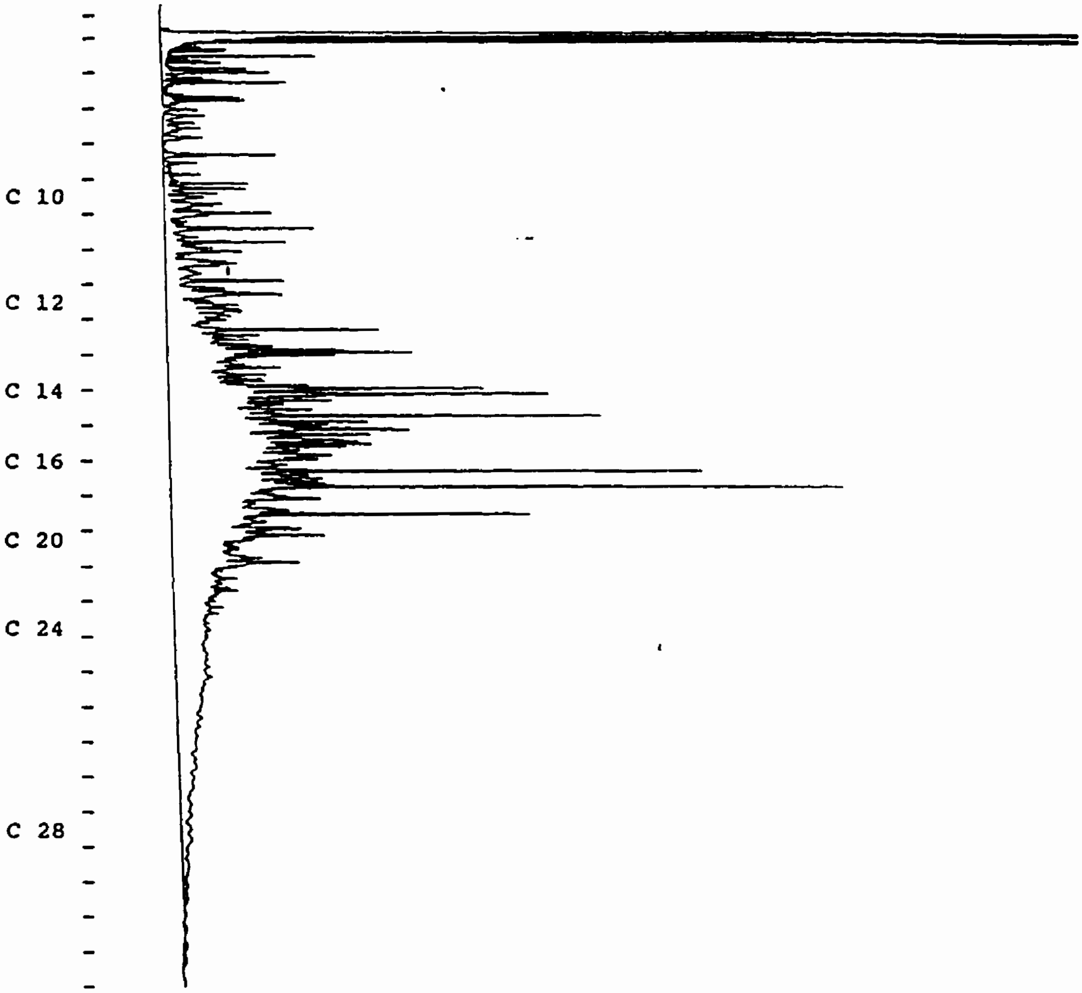
```
[illegible]     : C:\STAR\MODULE16\svar103.RUN
Method File : C:\STAR\SEMCAL.MTH
Sample ID   : 4270x30012,9-4-10

Injection Date: 7-JUL-94 1:12 PM

Operator    : B. Chomin                 Detector Type: ADCB (1 Volt)
Workstation: MS-DOS_6                   Bus Address  : 16
Instrument : 3400                       Sample Rate  : 10.00 Hz
Channel     : A = fid                   Run Time     : 28.002 min

************ Varian GC Star Workstation ************ Version A2 *****************

Chart Speed =    0.60 cm/min   Attenuation =     100        Zero Offset = 5%
Start Time  =   0.000 min      End Time    =  28.000 min    Min / Tick  = 1.00
```



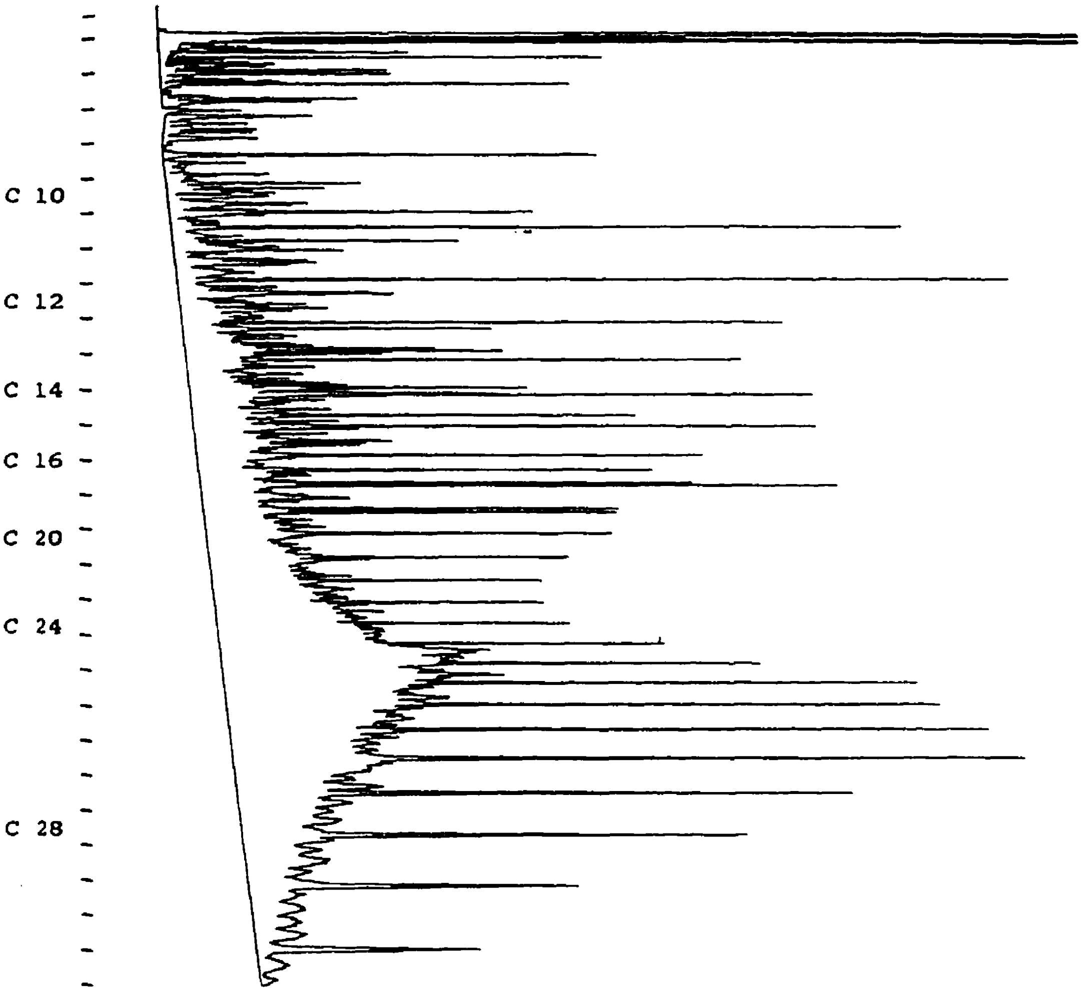
```
Run File     : C:\STAR\MODULE16\svar105.RUN
Method File  : C:\STAR\SEMCAL.MTH
Sample ID    : 4273x30012,10-5-12

Injection Date: 7-JUL-94 2:25 PM

Operator    : B. Chomin                Detector Type: ADCB (1 Volt)
Workstation: MS-DOS_6                  Bus Address  : 16
Instrument  : 3400                     Sample Rate  : 10.00 Hz
Channel     : A = fid                  Run Time     : 28.002 min

*********** Varian GC Star Workstation ************ Version A2 *****************

Chart Speed =    0.60 cm/min   Attenuation =     100       Zero Offset = 5%
Start Time  =   0.000 min      End Time    =  28.000 min   Min / Tick  = 1.00
```



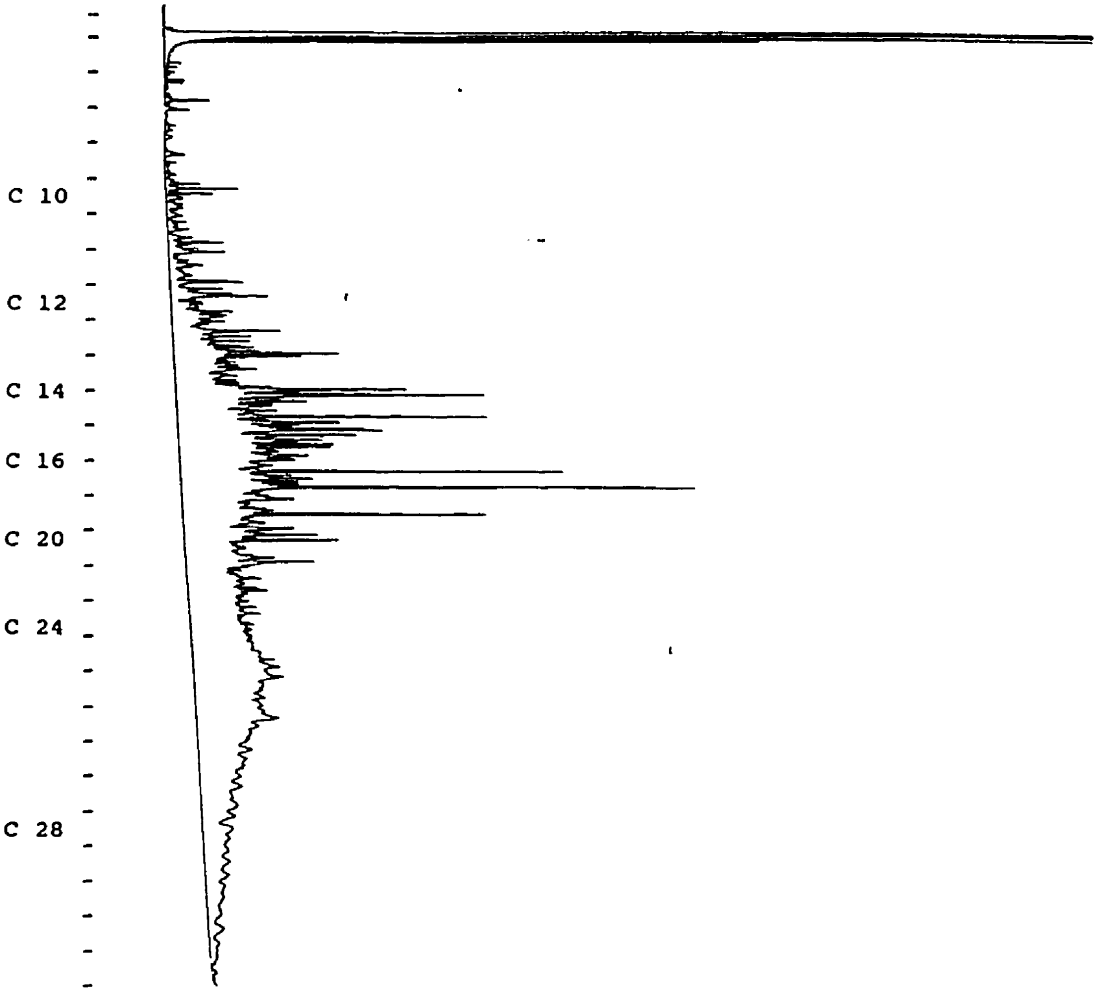
```
Run File     : C:\STAR\MODULE16\svar108.RUN
Method File : C:\STAR\SEMCAL.MTH
Sample ID    : 4275x30012,11-2-6

Injection Date: 7-JUL-94 4:14 PM

Operator    : B. Chomin                    Detector Type: ADCB (1 Volt)
Workstation: MS-DOS_6                      Bus Address  : 16
Instrument : 3400                          Sample Rate  : 10.00 Hz
Channel     : A = fid                      Run Time     : 28.002 min

*********** Varian GC Star Workstation ************ Version A2 *****************

Chart Speed =    0.60 cm/min    Attenuation =      100       Zero Offset = 5%
Start Time  =   0.000 min       End Time    =  28.000 min    Min / Tick  = 1.00
```



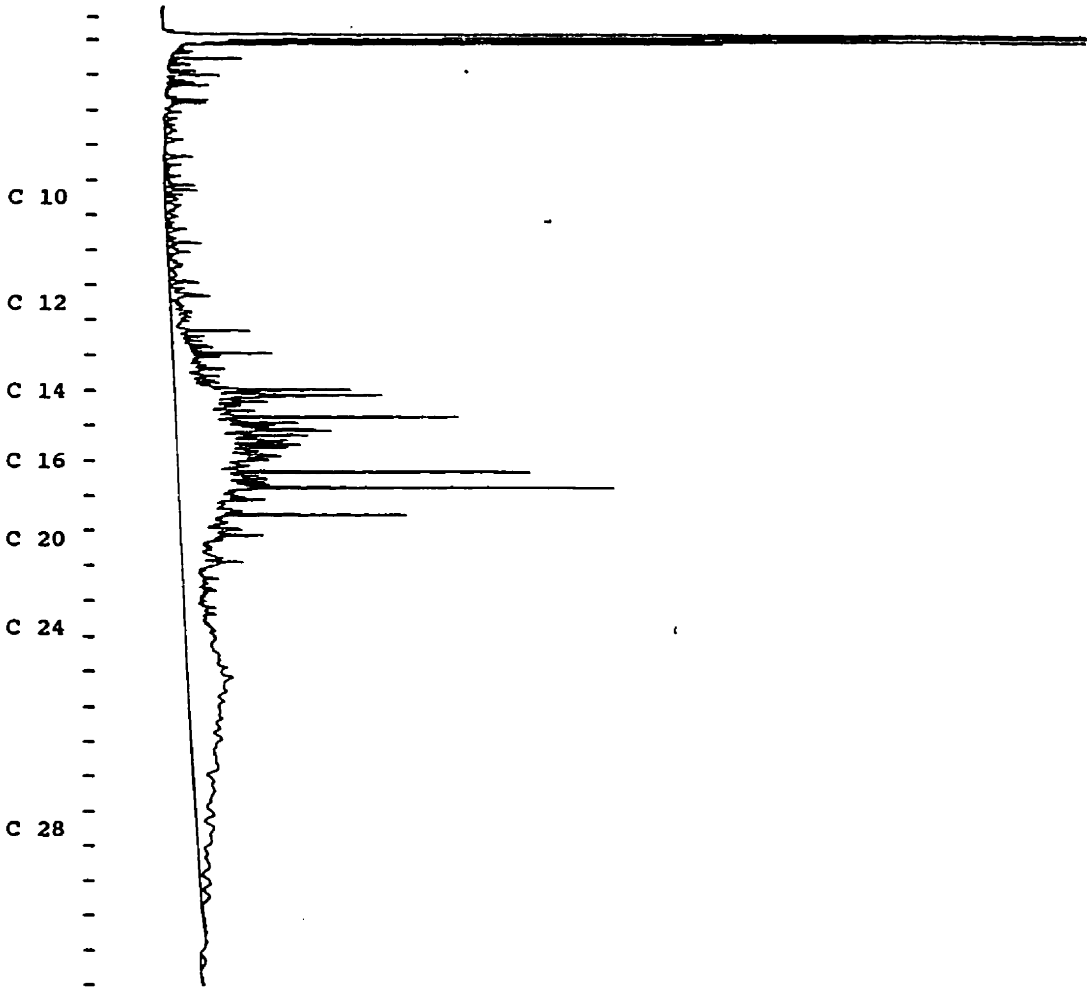
```
Title        : TOTAL SEMI-VOLATILE HYDROCARBONS
Run File     : C:\STAR\MODULE16\svar109.RUN
Method File  : C:\STAR\SEMCAL.MTH
Sample ID    : 4280x30012,12-3-7

Injection Date: 7-JUL-94 4:50 PM

Operator    : B. Chomin                  Detector Type: ADCB (1 Volt)
Workstation: MS-DOS_6                    Bus Address  : 16
Instrument : 3400                        Sample Rate  : 10.00 Hz
Channel     : A = fid                    Run Time     : 28.002 min

*********** Varian GC Star Workstation ************ Version A2 *****************

Chart Speed =    0.60 cm/min   Attenuation =     100       Zero Offset = 5%
Start Time  =   0.000 min      End Time    =  28.000 min   Min / Tick  = 1.00
```



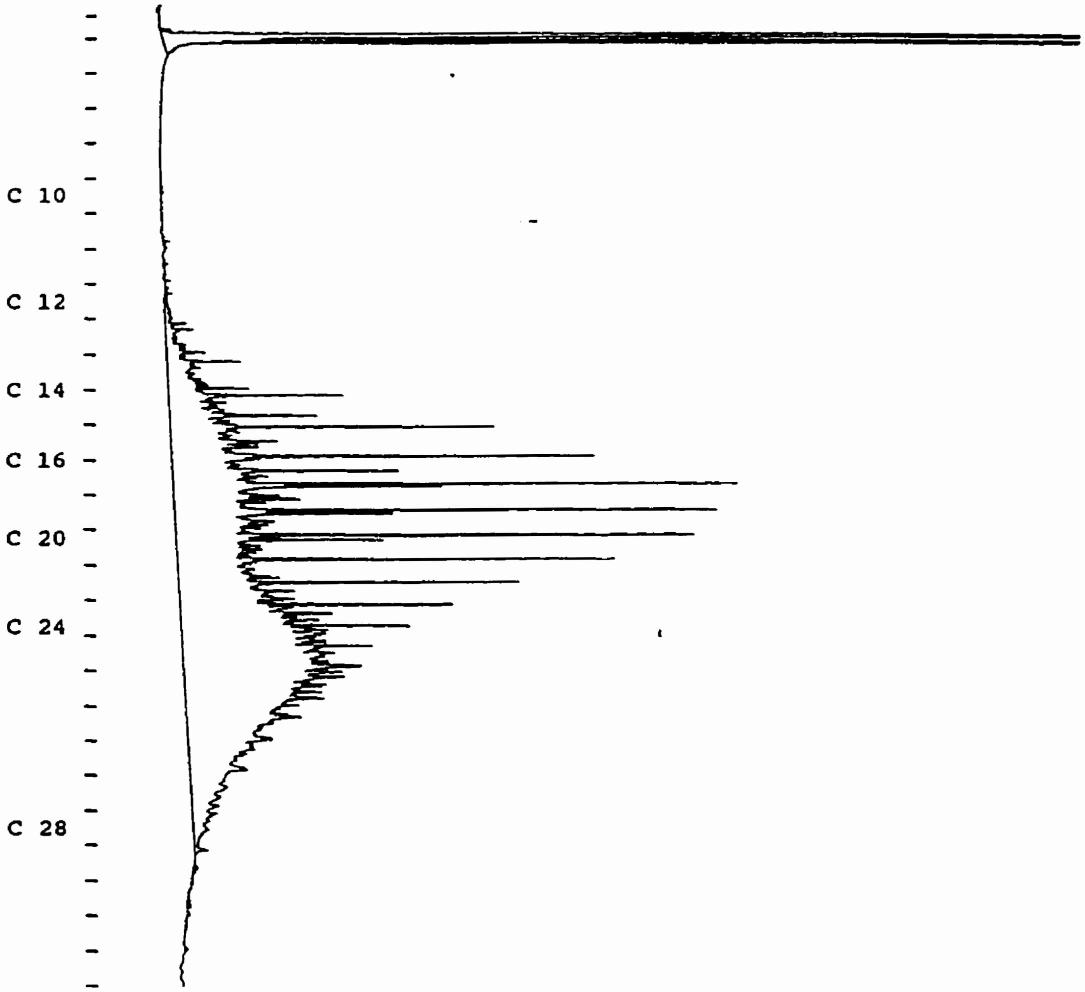
```
Run File     : c:\star\module16\svar092.run
Method File  : C:\STAR\SEMCAL.MTH
Sample ID    : 4294jx30012;16-8-20

Injection Date: 7-JUL-94 5:53 AM

Operator    : B. Chomin               Detector Type: ADCB (1 Volt)
Workstation: MS-DOS_6                 Bus Address  : 16
Instrument : 3400                     Sample Rate  : 10.00 Hz
Channel     : A = fid                 Run Time     : 28.002 min

*********** Varian GC Star Workstation ************ Version A2 *****************

Chart Speed =    0.60 cm/min    Attenuation =     100      Zero Offset = 5%
Start Time  =   0.000 min       End Time    =  28.000 min  Min / Tick  = 1.00
```



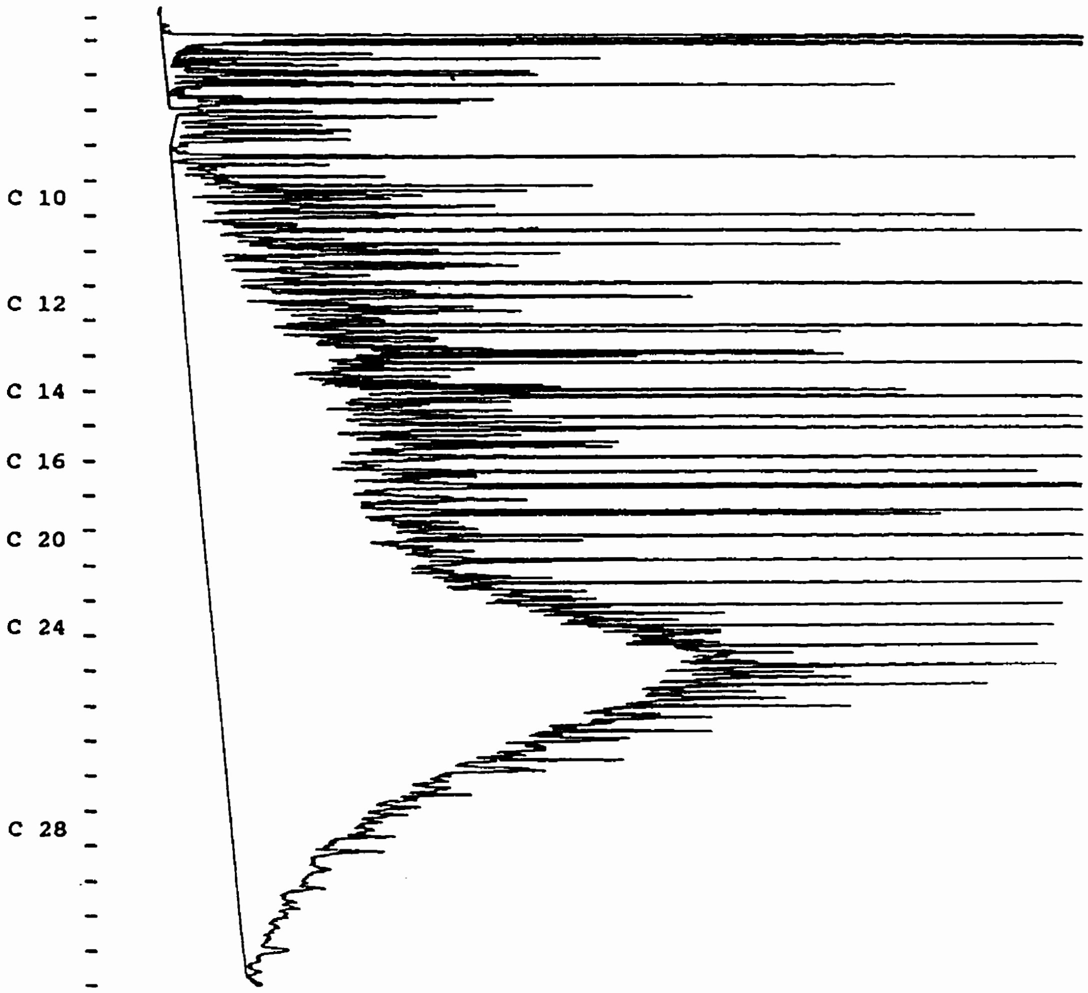
```
Run File     : C:\STAR\MODULE16\SVAR100.RUN
Method File  : C:\STAR\SEMCAL.MTH
Sample ID    : 4295x30012,17-4-10

Injection Date: 7-JUL-94 11:02 AM

Operator    : B. Chomin                 Detector Type: ADCB (1 Volt)
Workstation: MS-DOS_6                   Bus Address  : 16
Instrument : 3400                       Sample Rate  : 10.00 Hz
Channel     : A = fid                   Run Time     : 28.002 min

*********** Varian GC Star Workstation ************ Version A2 ****************

Chart Speed =    0.60 cm/min    Attenuation =     100        Zero Offset = 5%
Start Time  =   0.000 min       End Time    =  28.000 min    Min / Tick  = 1.00
```



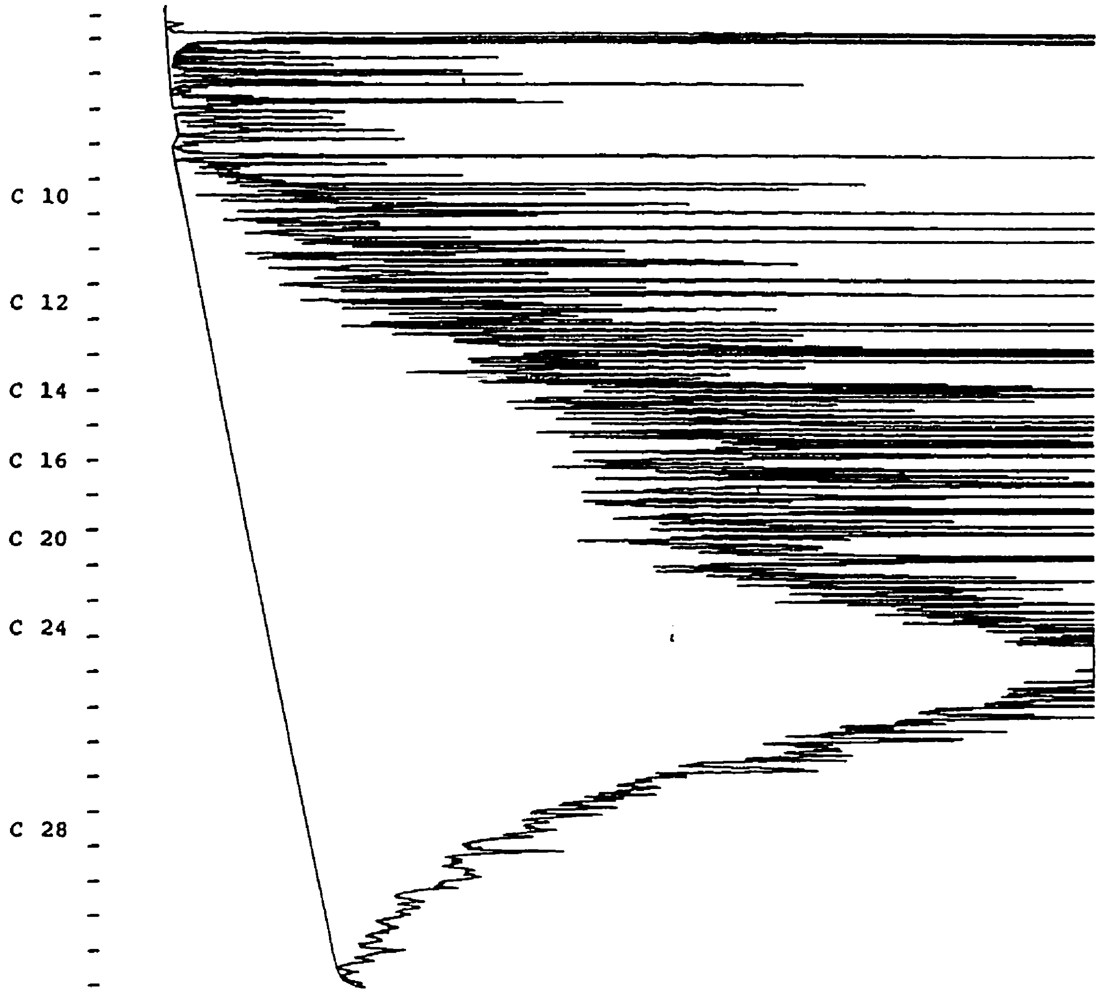
```
Run File    : C:\STAR\MODULE16\svar106.RUN
Method File : C:\STAR\SEMCAL.MTH
Sample ID   : 4299x30012,18-7-17

Injection Date: 7-JUL-94 3:01 PM

Operator    : B. Chomin                Detector Type: ADCB (1 Volt)
Workstation: MS-DOS_6                  Bus Address  : 16
Instrument : 3400                      Sample Rate  : 10.00 Hz
Channel     : A = fid                  Run Time     : 28.002 min

************ Varian GC Star Workstation ************ Version A2 *****************

Chart Speed =    0.60 cm/min   Attenuation =     100       Zero Offset = 5%
Start Time  =   0.000 min      End Time    =  28.000 min   Min / Tick  = 1.00
```



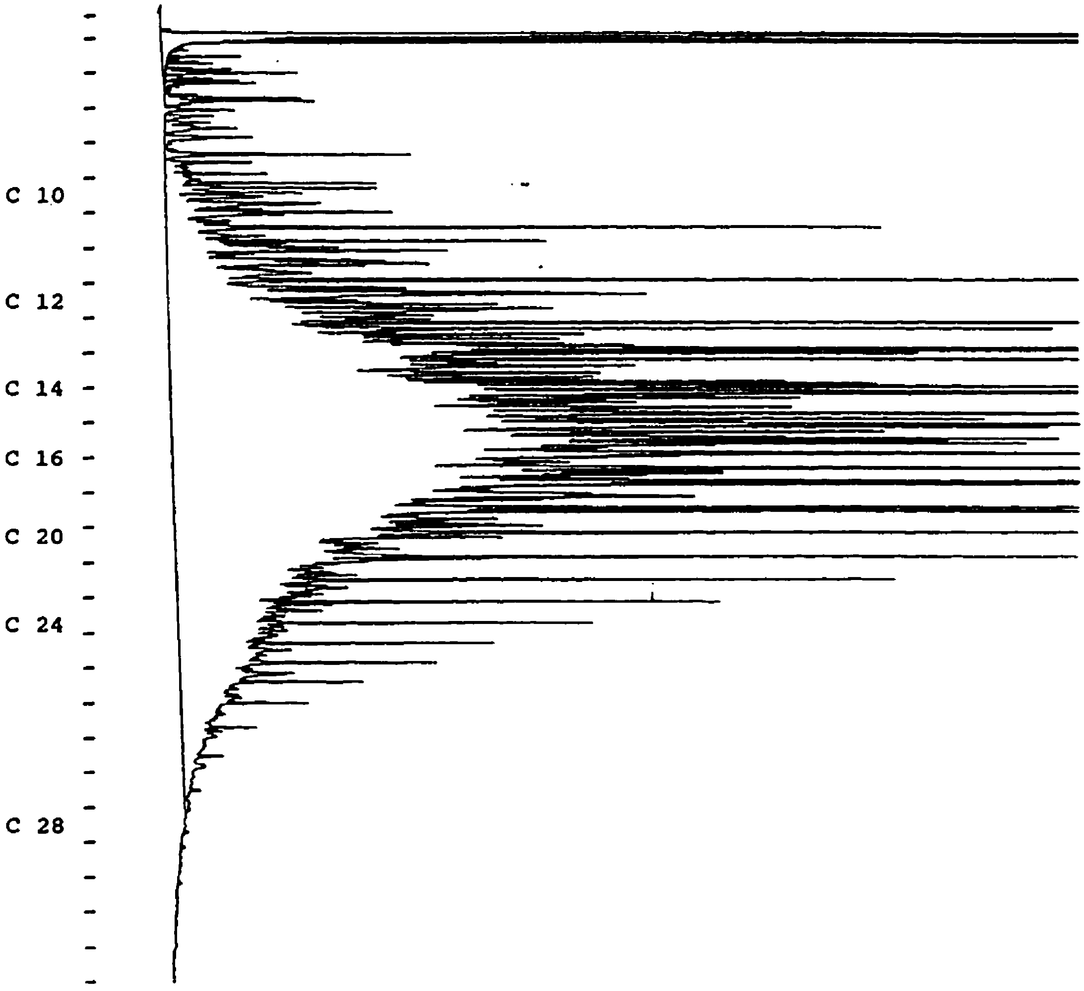
```
Title        : TOTAL SEMI-VOLATILE HYDROCARBONS
Run File     : C:\STAR\MODULE16\SVAR097.RUN
Method File  : C:\STAR\SEMCAL.MTH
Sample ID    : 4304x30012,20-5-12

Injection Date: 7-JUL-94 8:54 AM

Operator    : B. Chomin                Detector Type: ADCB (1 Volt)
Workstation: MS-DOS_6                  Bus Address  : 16
Instrument : 3400                      Sample Rate  : 10.00 Hz
Channel     : A = fid                  Run Time     : 28.002 min

*********** Varian GC Star Workstation ************ Version A2 *****************

Chart Speed =   0.60 cm/min   Attenuation =     100       Zero Offset = 5%
Start Time  =  0.000 min      End Time    =  28.000 min   Min / Tick  = 1.00
```



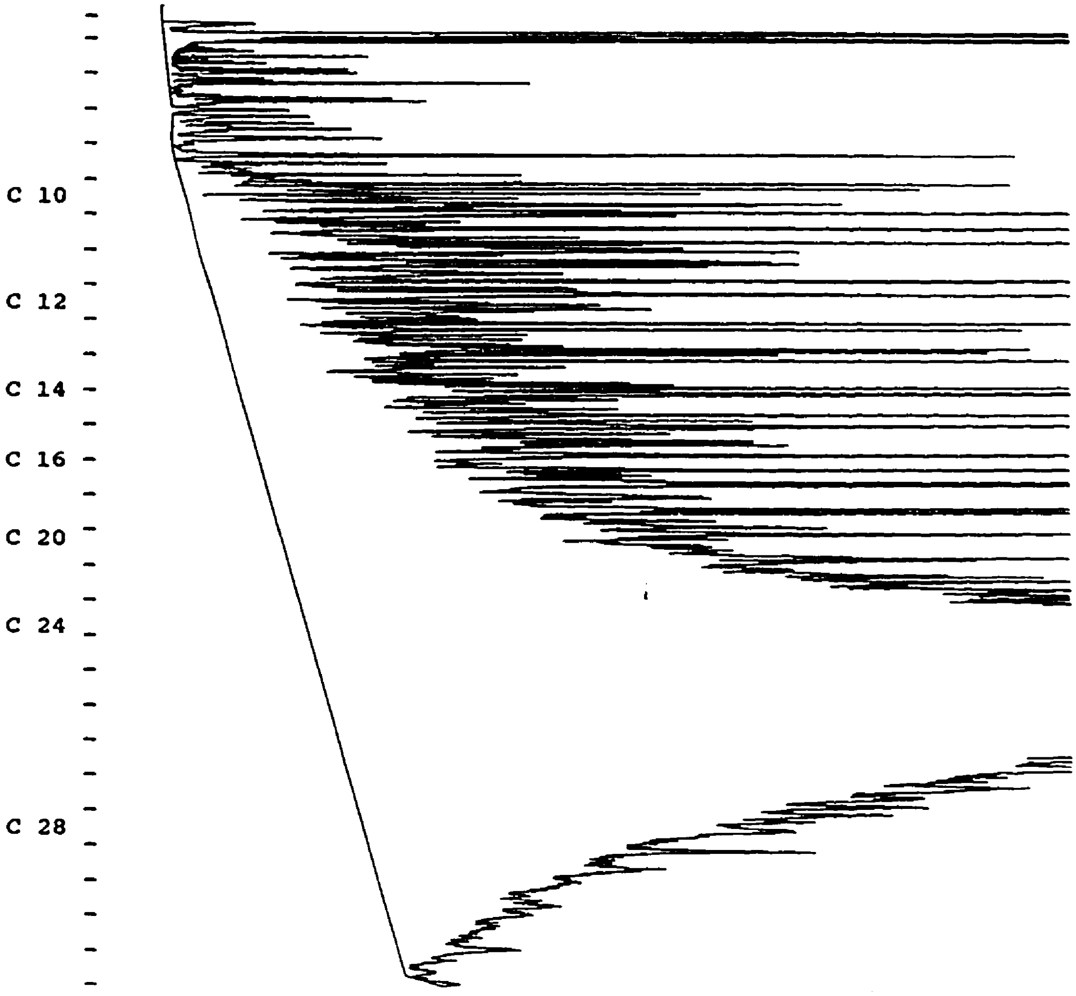
```
Title        : TOTAL SEMI-VOLATILE HYDROCARBONS
Run File     : C:\STAR\MODULE16\svar104.RUN
Method File  : C:\STAR\SEMCAL.MTH
Sample ID    : 4308x30012,21-7-17

Injection Date: 7-JUL-94 1:49 PM

Operator    : B. Chomin                 Detector Type: ADCB (1 Volt)
Workstation: MS-DOS_6                   Bus Address  : 16
Instrument : 3400                       Sample Rate  : 10.00 Hz
Channel     : A = fid                   Run Time     : 28.002 min

*********** Varian GC Star Workstation ************ Version A2 ****************

Chart Speed =    0.60 cm/min   Attenuation =     100      Zero Offset = 5%
Start Time  =   0.000 min      End Time    =  28.000 min  Min / Tick  = 1.00
```



APPENDIX D

STATISTICAL ANALYSES

REGRESSION ANALYSIS

SUMMARY OUTPUT (Reactor 1)

Regression Statistics	
Multiple R	0.961696708
R Square	0.924860558
Adjusted R Squ	0.899814078
Standard Error	0.438217632
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	7.091028722	7.091028722	36.92576911	0.00894699
Residual	3	0.576104078	0.192034693		
Total	4	7.6671328			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-0.183070562					
X Variable 1	-0.019138831	0.003149565	-6.076657725	0.00894699	-0.029162163	-0.009115499

RESIDUAL OUTPUT

Observation	*Predicted Y*	*Residuals*	*Standard Residuals*
1	-0.183070562	0.183070562	0.482389711
2	-0.680680166	0.310680166	0.818640167
3	-1.235706263	-0.128293737	-0.338053142
4	-1.59934405	-0.60865595	-1.603804371
5	-3.647198959	0.243198959	0.640827635

SUMMARY OUTPUT (Reactor 2)

Regression Statistics	
Multiple R	0.751617393
R Square	0.564928706
Adjusted R Squ	0.419904941
Standard Error	0.402916769
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.632390232	0.632390232	3.8954216	0.142933386
Residual	3	0.487025768	0.162341923		
Total	4	1.119416			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-0.472919169					
X Variable 1	-0.005715489	0.00289585	-1.973682244	0.142933386	-0.014931386	0.003500409

RESIDUAL OUTPUT

Observation	*Predicted Y*	*Residuals*	*Standard Residuals*
1	-0.472919169	0.472919169	1.355317179
2	-0.621521871	-0.100478129	-0.287955624
3	-0.78727104	-0.23972896	-0.687028144
4	-0.895865322	-0.372134678	-1.066483567
5	-1.507422599	0.239422599	0.686150155