Investigation of leachate from a sanitary landfill in Saudi Arabia

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Civil Engineering

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Abstract

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This study also recommended that the collected contaminated groundwater should be diluted and treated in an existing municipal wastewater treatment plant. The detailed evaluation reveals that the capacity of the plant is more than adequate for satisfactorily treating this groundwater.

Investigation of Leachate from a Sanitary Landfill in Saudi Arabia

by

Ramzi Fouad Hejazi

A Thesis Presented to the

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In

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Dedicated
to
my ever loving wife,
Mona
for her never ending
support, patience
and
understanding
. . .

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الخلاصــــــة

لقد اختيرت احدى مناطق البلديات لدفن القمامة في المنطقة الشرقية بالمملكة العربية السعودية لتقييم نتائج رشح القمامة المدفونة على المياه الجوفية. وتعتبر منطقة دفن القمامة هذه نموذجا لمناطق دفن القمامة بالمملكة العربية السعودية بدون نظام التبطين او نظام تجميع الرشح. أضف الى ذلك فان منطقة دفن القمامة هذه موجودة فوق مستودع الماء الأرضي في أم الرضمة والتي تقع (من ٦٦ الى ٧٣ قدما تحت منطقة الدفن) ويعتبر هذا من المستودعات المائية الرئيسية في المنطقة الشرقية.

وأن مستودع المياه الضحلة والموجود مباشرة تحت مكان دفن القمامة وعلى عمق ٣١ قدما تقريبا يبدو أنه ملوثا بفعل الرشح، وقد أظهر تحليل عينات من مياه الرشح والمياه الجوفية الضحلة كثيرا من المواد المركزة العضوية والبكتيريا وبعض المعادن الثقيلة.

وأظهر البحث الجيولوجي المائي بأن مستودع مياه أم الرضمة تحميه ثلاثة طبقات من الصلصال ولهذا فان هذا المستودع (أم الرضمة) محمي من التلوث الحالي الموجود في مستودع المياه الضحلة.

وقد جرى تقييم عدة اجراءات تصحيحية للتقليل من تأثير المياه الجوفية الضحلة الملوثة. ومن بين الأساليب التي جرى تقييمها بالتفصيل من أجل هذه الدراسة حفر خندق من الطين السائل، والرفع بالشفط، وعمل حاجز من الاسمنت المائع. وتمت التوصية أخيرا بطريقة حفر خندق من الطين السائل مع آبار متسعة لجمع المياه الجوفية وان هذه الطريقة من الناحية الفنية ممكن تطبيقها او استخدامها بشكل أفضل، وكذلك تتوفر الامكانية لعملها.

وقد أوصت هذه الدراسة بأنه يجب تخفيف المياه الجوفية الملوثة والتي تم تجميعها، ومعالجتها في محطة موجودة تابعة للبلدية لمعالجة المياه العادمة. ويظهر التقييم التفصيلي بأن قدرة محطة المعالجة أكثر من كافية للحصول على نتائج مرضية لمعالجة هذه المياه الجوفية.

ABSTRACT

A municipal landfill in the Eastern Province of Saudi Arabia was selected to evaluate the effects of landfill leachate on the underlying groundwater. This landfill represents a typical Saudi Arabian landfill; without liner or leachate collection system. Furthermore, this landfill was located over the Umm Er Radumah (UER) aquifer (66-73 feet beneath the landfill), a principal aquifer in the Eastern Province.

The shallow aquifer immediately beneath the landfill at approximately 31 feet seems to be contaminated by leachate. The analyses of leachate and shallow groundwater samples showed elevated concentrations of organic matter, coliforms, and some heavy metals.

The hydrogeological investigation revealed that the UER aquifer is protected by three clay layers. Therefore, the UER aquifer is protected from contamination present in the shallow aquifer.

Several remedial actions to mitigate the impact of the contaminated shallow groundwater were evaluated. Among these, the slurry trench cut-off, the suction lift, and the grout curtain methods were evaluated in detail for this study. The slurry trench cut-off method with extended groundwater collection wells was finally recommended. This method is technically the most applicable and feasible.

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CHAPTER I

INTRODUCTION

1.1 Justification of the Study

The importance of groundwater resources in Saudi Arabia can be easily seen when we realize that with the exception of few desalination plants located at the Arabian Gulf and the Red Sea, the country's only other source of water supplies is groundwater aquifers. Saudi Arabia lies in an arid zone with most parts of the country receiving yearly rainfall ranging between 2 to 4 inches. The only exceptions to this are the south of Asir which receives between 8 to 24 inches of rainfall per year and the Red Sea heights and the northeast part of the country receiving between 4 to 8 inches of rainfall every year (Ministry of Agriculture, 1984). Because of the low rainfall intensity in Saudi Arabia, the groundwater recharge rates are very slow to a minimum in most cases. Thus, protecting the groundwater from contamination has become an important necessity in the Kingdom. Contamination of groundwater is a severe problem because contaminants generally travel unobserved until detected in a water supply well. Once contaminated, the process to decontaminate is irreversible and prohibitive in cost. The contaminant disperses in the groundwater, becoming more difficult to remove, and may persist for decades.

Contaminants include inorganic chemicals, organic chemicals, biological matter, and radioactive compounds from municipal, industrial, agricultural, natural, domestic and underground sources.

Although industrial wastes represent the principal sources of groundwater contamination at global level, the leachate for the municipal landfills represent the principal sources of groundwater contamination in Saudi Arabia. This is due to many poorly designed and randomly located municipal landfills that are spread all over the country. Due to the most economical option of disposing solidwaste, sanitary landfilling is a commonly used method. However, unless landfill sites are carefully selected and properly designed they will continue to be the major source of groundwater contamination in Saudi Arabia.

It is estimated that about 9 million tons of municipal solid waste are disposed every year in Saudi Arabia by two basic methods: open dumping and sanitary landfilling (Khan, et al., 1987). Open dumping is simply disposing the waste on any land without any consideration of environmental protection. This method causes water and air pollution and also poses a direct health hazard to people living nearby since it provides an excellent breeding ground for insects, rodents and other disease carriers. Sanitary Landfilling is an engineered method of disposing of solid wastes on land by spreading the wastes in thin layers, compacting the wastes, and covering the compacted wastes with soil each working day in a manner that protects the environment. This method is the most recommended method due to low cost and simplicity.

In an investigation to determine disposal methods at different Saudi Arabian Cities, the disposal sites at nine cities were visited. These cities were Al-Hasa, Al-Khobar, Dammam, Dhahran, Abqaiq, Jubail, Al-Qatif, Riyadh and Jiddah. The methods of solid waste disposal and their effects on the environment were evaluated. This study indicated that with the exception of the Jubail landfill all the other sites were operating in a manner that can lead to groundwater contamination. The Jubail landfill is the only site that is taking measures to protect the groundwater. In addition each of these sites operates according to their own disposal requirements as a result of the absence of solid waste disposal laws and regulations in the Kingdom. More than half of these sites were improperly designed and operated.

In order to determine the impact of landfill on the underlying aquifers and to prevent contamination of groundwater due to leachate resulting from the landfill, a detailed study was conducted for a typical landfill in the Kingdom of Saudi Arabia.

1.2 OBJECTIVES

The main objectives of this study are as follows:

(a) To evaluate an existing landfill in Saudi Arabia from an environmental perspective.

(b) To make recommendations on the preventive measures of groundwater contamination and to design leachate collection and treatment systems that would be applicable for any sanitary landfill constructed in Saudi Arabia and in similar arid environment.

1.3 Scope Of Work

Inorder to accomplish the above objectives, the study was carried out in the following sequencies:

I Field Work

Three piezometers adjacent to a selected landfill were installed in order to obtain water samples, determine groundwater levels, and to study the strata under the site. Also four lysimeters were installed inside the landfill in order to collect leachate samples. Eight existing wells and piezometers inside and outside the landfill were also used in order to obtain water samples and to supplement groundwater level data.

II Laboratory Work

Water and leachate samples were collected and analyzed to determine their composition and to identify any contaminants present. This work was carried according to both ASTM and Standard Methods Procedure.

III Leachate Evaluation

In addition to determining leachate composition in the lab, the quantity of generated leachate was estimated using recommended methods. Also the factors that affect leachate generation were evaluated.

IV Hydrogeological Investigation

Information obtained from the drilling logs and from the analysis of groundwater were used to assess in the hydrogeological investigation.

V Remedial Actions

Methods to collect and treat both leachate and contaminated groundwater were evaluated. Based on this evaluation the best method for collection and treatment was recommended.

CHAPTER II

LITERATURE REVIEW

Many reports revealed that sanitary landfills are potentially dangerous sources of contamination for groundwater aquifers. This is the result of the generated effluent known as leachate (Raveh and Avnimelech, 1979 and Johansen and Carlson, 1976). Many incidences were reported in the U.S.A. where leachate has contaminated the surrounding soil and polluted an underlaying groundwater aquifer or nearby surface water. In one of the cases, municipal water supply was polluted by leachate from a garbage dump located about 1650 feet of the well field (Chian and DeWalle, 1976). The indication of leachate migration away from a landfill site was demonstrated by a research project conducted at several landfills in Wisconsin (Gerhardt, 1984). Johnson, et al., (1981) in his discussion of using observation wells stated that the majority of the monitoring wells at three sanitary landfill that he studied, have not been effected by leachate but contamination was detected almost solely by samples of soil moisture. He also stated that given enough time and more careful placement of monitoring wells, the contamination of groundwater probably can be observed.

Two factors should be considered when determining whether leachate can reach the underneath groundwater or not. These factors are geohydrologic conditions beneath landfills and the amount of water infiltrating the landfills. Zenone, et al., (1975) in a study conducted at three solid-waste disposal sites concluded that differences in local geohydrologic conditions influence groundwater quality. He also stated that unless refuse is saturated by being deposited directly into standing water or below the local groundwater table, leachate may not be produced, also if the mean annual precipitation is less than 15 inches with short duration this will prevent saturation of the refuse mass from the top. Lu, et al., (1985) used the gross estimation method for estimating the quantity of generated leachate using the following mass balance relationship.

Ann. L = Ann. p - Ann. R - Ann. E

The period of consideration for this equation can be a year, a month, or same specially selected period.

The character of landfill leachates has been described in numerous investigations. Both field studies and controlled experiments have been conducted to define the nature of leachate and their patterns of variability in terms of composition, strength, and environmental impact (Koch and Cameron, 1980 and Johansen and Carlson, 1976). Lee, et al., (1986) listed a summary of the available data on the typical characteristics of sanitary landfill leachate. When leachate is known to exist beneath a landfill, it is very important to try to identify the component of this leachate. This can be done by collecting samples of the leachate and analyzing it in the laboratory. Gas chromatography combined with mass spectrometry (GC-MS) is the best method to identify the organic composition of leachate and contaminated groundwater (Schultz and Kjeldsen, 1986 and Albaiges, et al., 1986).

Leachate collection is applicable when a landfill is properly designed and a collection system is installed. Wong (1977) explained the design parameters of a system for collecting leachate from a lined landfill site. Ghassemi (1986) explained different design considerations for leachate collection system. Dietzler (1984) discussed how to design and construct a leachate collection system and recommended using PVC plastic pipes. If a landfill doesn't have a collection system then leachate can only be collected as part of a recovery system for leachate and/or contaminated groundwater. Concepts for recovery and treatment of contaminated groundwater are well established. Recovery is accomplished using a variety of single or combined techniques. Quince and Gardner (1982) described three major techniques of groundwater treatment and recovery and they are; the gravity collection, the suction lift and the positive displacement. The gravity collection which is accomplished through the installation of interceptor trenches is applied to contaminants in shallow flow systems for recovery of leachate and contaminated groundwater.

Dornbush (1984) has evaluated groundwater quality underneath a solid waste landfill at Brookings, South Dakota, USA, he also reevaluated the effectiveness of a groundwater intercepting trench method used to protect downstream groundwater from leachate. In an article in Water Engineering and Management magazine (1987), three innovative techniques used for groundwater remediation at a Kansas, USA landfill were described. These methods were: Drainage Trench System, Low-Permeability Cover, and Groundwater Extraction System. Welton (1985) explained how Fresno county in California has restored its groundwater aquifer that was contaminated by leachate from a solid waste disposal site, also he supports the contention that groundwater restoration is expensive. An article in the Public Works Journal (1984) explained how a slurry trench cut-off method was successfully applied at bluebonnet sanitary landfill in northeast Houston for preventing groundwater from entering beneath the landfill. The design of the soil-bentonite backfill mix used in slurry trench cut-off method was explained by Schulze, et al., (1986). The application of the slurry cut-off in the first EPA superfund project including design and specifications were described by Ayres, et al., (1986).

Different methods of leachate treatment have been given in the literature. These methods include physical, chemical, and biological processes. Chian (1976) conducted a study on a number of pilot and actual sanitary landfills to develop criteria for selecting methods for leachate treatment. He also evaluated the treatment efficiences obtained from these different methods. Foree and Reid (1973) evaluated the treatability of a sanitary landfill leachate using two anaerobic biological methods: the anaerobic digester and the submerged anaerobic filter. Venkataramani, et al., (1984) evaluated three treatment methods: aerobic biostabilization, anaerobic biostabilization, and physical/chemical treatment processes. Henry, et al., (1987) discussed the anaerobic filter method. Kennedy, et al., (1988) discussed the anaerobic fixed film and sludge bed systems. Wright and Austin (1986) presented a detail design for a high rate anaerobic treatment facility for a landfill leachate at Nova Scotia, Canada. The biological treatment of leachate from municipal sanitary landfills is a successful method of purification. Stegmann and Ehrig (1980); Qasim and Tarapada (1977); Bull, et al., (1983); Graham and Mavinic (1979); and Boyle and Ham (1974) discussed successful experiences in treating leachate with biological methods. Henry, et al., (1987) showed how heavy metals may be removed from leachate prior to biological treatment. The results of full-scale chemical-physical treatment of sanitary landfill leachate were presented by Keenan, et al., (1984). Robinson and Maris (1983) discussed a method of treatment that combined recirculation through a landfill and aerobic treatment. They also discussed aerobic biological treatment of a medium-strength leachate in a 1982 report. The aerobic bio-treatment of a high-strength leachate was explained by Uloth and Mavinic (1977). Boyle and Ham (1974) explained their work on chemical treatment at leachates to remove COD, iron, chloride, total solids, pH, alkalinity, hardness and color. Thornton and Blanc (1973) examined the possibilities of treating leachate by chemical coagulation and precipitation with regard to removal of BOD, iron, calcium and magnesium. Keenan, et al., (1983) indicated the need for pretreatment (physical and chemical) of leachate in order to render it amenable to active sludge processing. In a paper written by Henry (1985), he described a number of aerobic and anaerobic methods and the advantages and shortcomings of each of them. Also he described some supplementary processes including nitrification, nitrogen removal, land spraying, etc.

Concepts for prevention and control of leachate are also well established. Prevention starts at the design stage of landfills. Salvato, et al., (1971) discussed the major points on leachate prevention and control. Data from New York City landfills were used in his discussion. Dilaj and Lenard (1975) describes a procedure for leachate control that depends on both minimizing surface water infiltration and the control of groundwater flow beneath the landfill. Application of this procedure at a landfill site at Columbia, Connecticut, USA was also described.

As a result of federal regulations in the US that came out in 1980, all sanitary landfills need closure plans. Gee (1987) discussed how an effective closure plans can be prepared. Johnson (1984) emphasized on the need to put cover system on closed landfills and describes how such covers can control leachate after landfill closure.

CHAPTER III

SITE DESCRIPTION

3.1 OVERVIEW OF THE SELECTED SITE

3.1.1 Site Location: The site which is located near Dhahran in the Eastern Province of Saudi Arabia, started operating in 1978 to serve a community of about 45,000 people. It is bordered by a highway on the north and northwest, a natural ridge along the southwest and flat scrub land to the east. In addition, a wastewater disposal spray field is located at a distance of about .6 mile to the east where several million gallons of treated, secondary effluent are disposed there daily.

3.1.2 Site Description: The size of the site is 204.3 hectares. It has an L-shape and the ground elevation gently sloping towards the east and northeast. The site topography is generally flat with irrigular batches of sandy hills and some low lying trenches. The soil on top of the site is sandy. The only vegetation present on site is scrub.

3.1.3 Site Design: When the site was opened in 1978, the trench method of landfilling was used (Figure 1) in which the solid waste was spread and compacted in an excavated trenches. The excavated material was used as cover material. In 1987 the method of landfilling was changed to a progressive slope method (Figure 2) in which solid waste is placed against the natural ridge at the southwest of the site and progressively compacted and covered. This results in the landfilling moving towards the northeast. The reason for changing the method was to increase the life span of the site for landfilling. In an investigation conducted on the site it was estimated that the life span of the site has been increased by about 7 years by adopting the progressive slope method. This site has an existing unpaved access road from the highway to the center of the landfill to carry regular heavy vehicles such as dump trucks, compactor trucks, etc. In 1984 three groundwater monitoring wells were installed at the site for groundwater monitoring. No measure has been taken to protect the groundwater from contamination by leachate. The site is not lined and there is no leachate collection system.

3.1.4 **Site Operation:** The landfilling method used prior to 1987 was the trench method. Trenches were excavated to depths exceeding twelve feet. The waste was spread, compacted and covered with the excavated material. The present operation is the progressive slope method in which the solid waste is filled against the natural ridge southwest of the site, soil being excavated in front of the active face and stockpiled for later use as cover material. At the end of each working day the waste is covered and the soil is compacted. No measurements are taken to ensure that the cover material is to a desired thickness or for the slope of the working face.

3.1.5 **Types of Wastes:** Wastes disposed at the site include garbage from homes and offices, construction debris, crushable and noncrushable bulky items, animal carcasses, waste consisting wholly or mainly of certain obnoxious materials (e.g. sewage sludge, septage, hospital

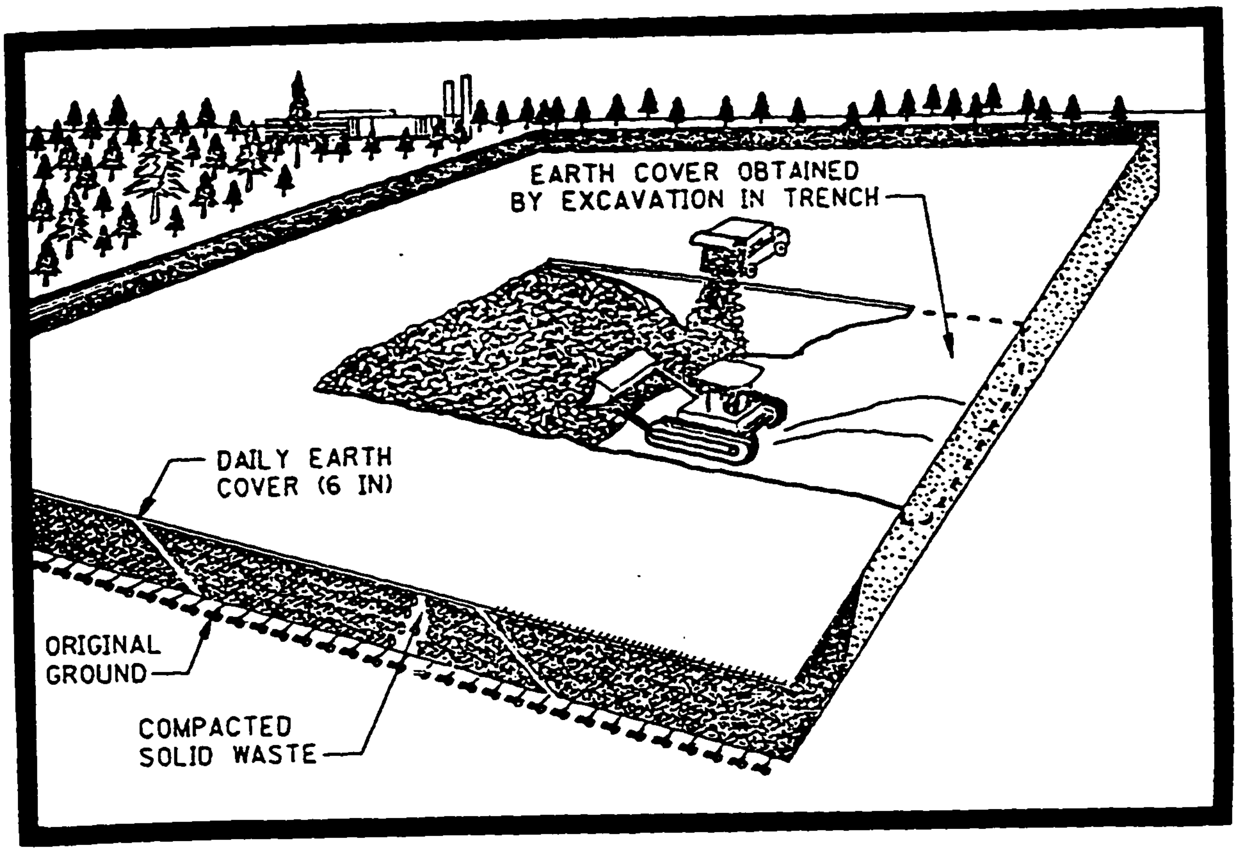


FIGURE 1. TRENCH METHOD OF SANITARY LANDFILLING

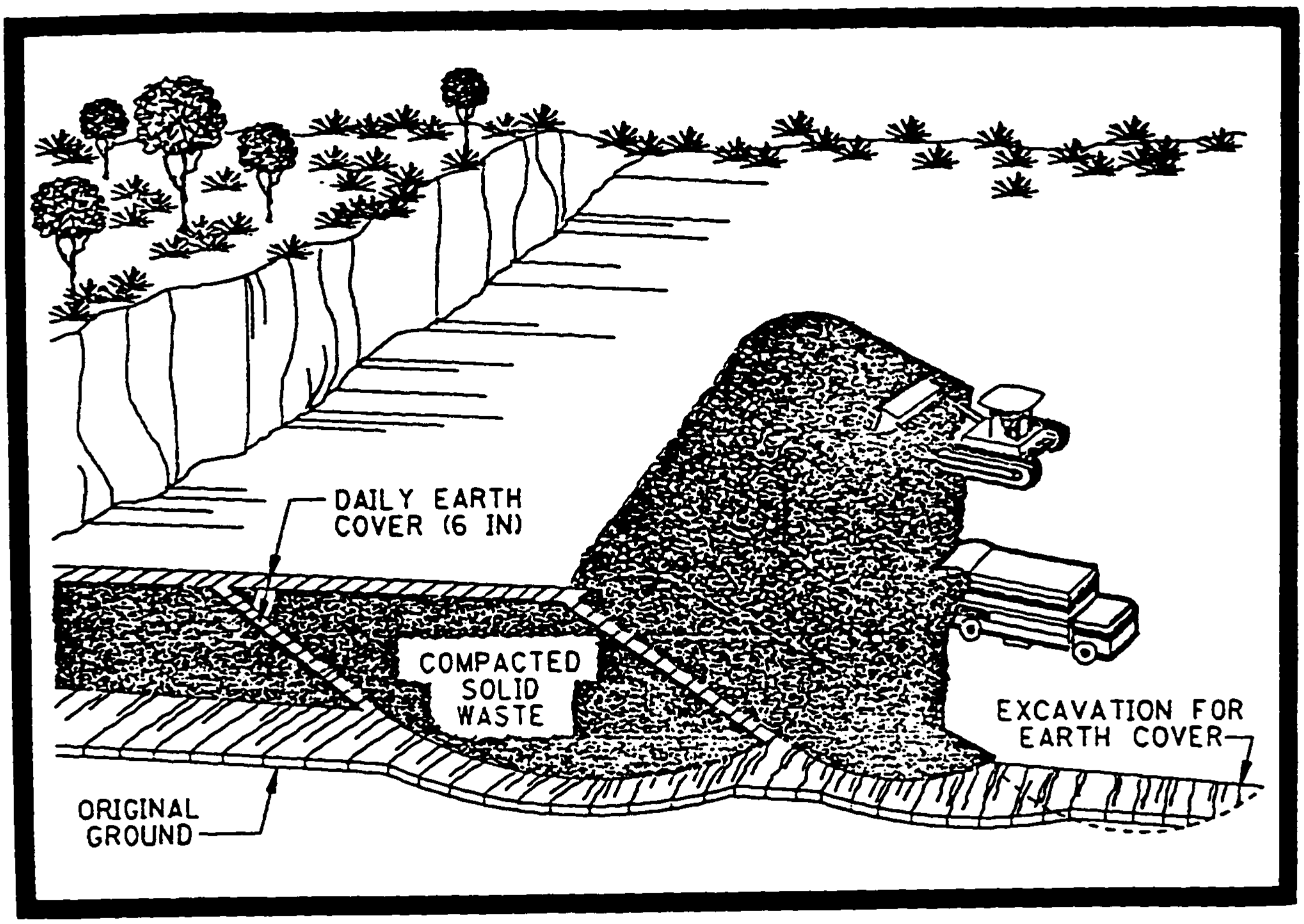


FIGURE 2. PROGRESSIVE SLOPE METHOD OF SANITARY LANDFILLING

wastes), tires, trees, grass, etc. No hazardous material or oily waste is allowed in the site but the absence of any control or records leaves doubt whether such material has been disposed in the site.

3.2 Previous Work

A previous study (Husain, 1984) indicated that the quality of the shallow aquifer beneath the site was affected as a result of the degradation of the buried waste. The analysis of groundwater samples from three boreholes, two upstream and one downstream of the landfill, during that study indicated an increase in the concentration of pollutants in the downstream samples compared with the upstream samples. The study recommended that the groundwater quality in deeper aquifers beneath the landfill be investigated. This would determine the effect of the landfill operation on groundwater resources. A list of the main pollutants are listed in Table 1.

3.3 Potential Groundwater Contamination Problems

The subject landfill was designed and built with no natural and/or man made liner. Further there are also no provision existing at the facility to collect leachate samples in order to determine the quality of the leachate and its effect on groundwater.

The stratigraphy formation underlying this specific landfill is not very well defined at this point, and for this reason it is highly unpredictable how the migration of leachate will contaminate the underlying aquifer.

Table 1 Landfill Groundwater Analysis

Parameters	Average Concentration (mg/L)	
	Upstream	Downstream
Biochemical Oxygen Demand (BOD)	2.4	6.5
Chemical Oxygen Demand (COD)	11.5	23.5
Total Organic Carbon (TOC)	10.0	34.3
Ammonia-Nitrogen	0.11	0.37
Organic Nitrogen	0.15	0.29
Iron	0.161	0.176
Zinc	0.116	0.146
Nickel	0.034	0.054

Source: Husain (1984)

CHAPTER IV

FIELD AND LABORATORY INVESTIGATION

4.1 Field work

4.1.1 Installation of Piezometers: Three piezometers P-4, P-5 and P-6 were installed to the southeast of the landfill (Figure 3) to depths of 90, 70 and 60 feet respectively, with Teflon® screens installed in the last five feet of each piezometer. The distance between P-4 and P-5 is 24.4 feet and between P-5 and P-6 is 23.9 feet, their elevations are shown in Table 2. P-4 was drilled using the coring method. The complete boring log of this piezometer is provided in Figure 4. The samples obtained during the coring of P-4 will determine the properties of the subsurface (geologic and hydraulic characteristics) in order to assess the movement of groundwater, the formation and migration of leachate and the migration of specific contaminants and their attenuation. P-5 and P-6 were drilled using the tricone method. The drilling of the three piezometers was completed on September 20, 1988.

4.1.2 Installation of Lysimeters: Four lysimeters L-1, L-2, L-3, and L-4 were installed inside the landfill to a depth of 18 feet each. Each lysimeter had two feet of stick-up above grade. The lysimeters were installed so that the lower three feet of each was under the last layer of the buried garbage. Each lysimeter consists of 4 Teflon^R screens connected by threadings. Each screen is five feet long. It was decided to use Teflon® screens in order to maximize the leachate infiltration inside the lysimeters. The locations and elevations of

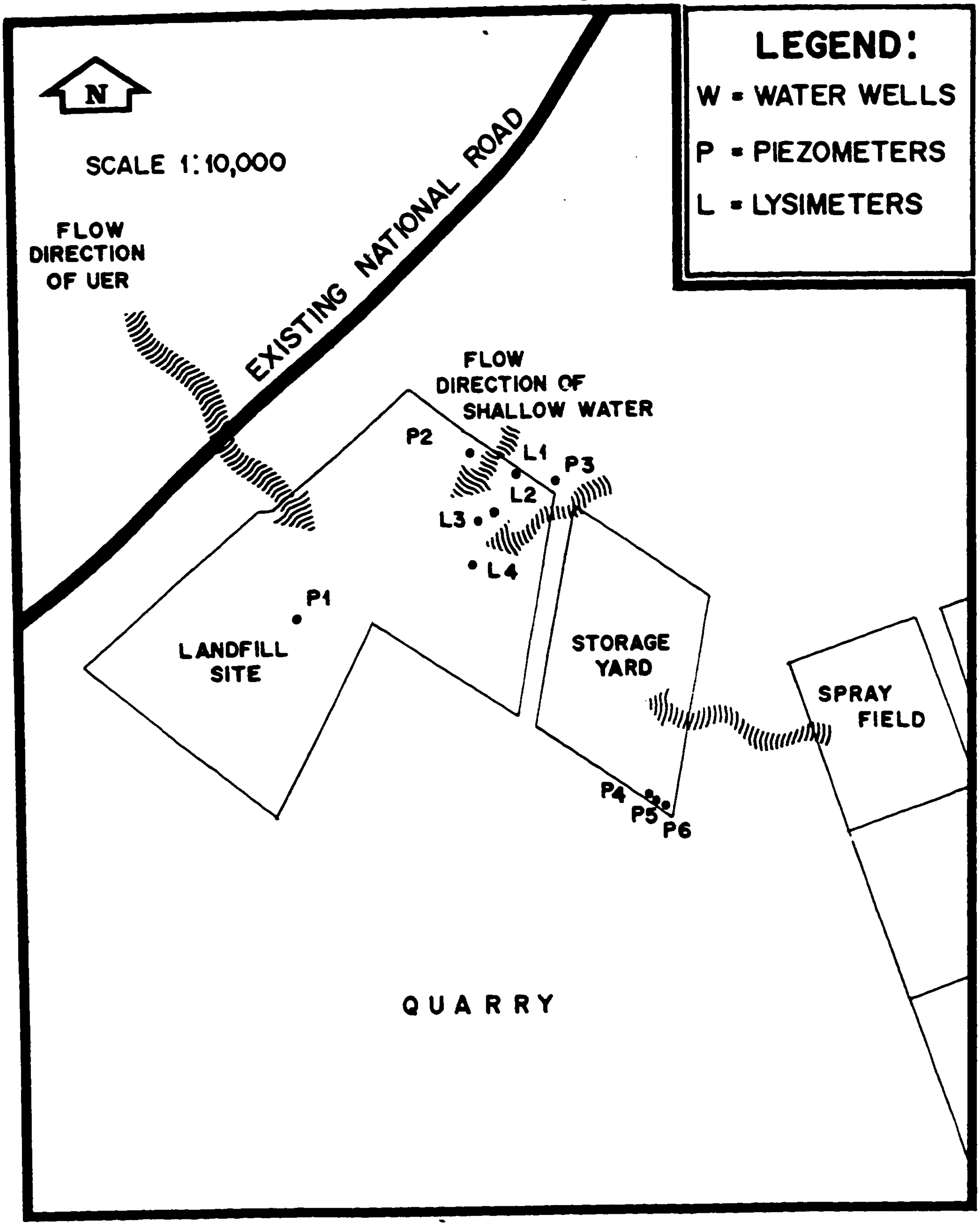


FIGURE 3. LOCATIONS OF PIEZOMETERS & LYSIMETERS AT THE LANDFILL SITE

Table 2 Ground Elevations and Water Levels

WELL NUMBER	ELEVATION (Feet)		* WATER LEVEL (Feet)
	GROUND	TOP OF PIPE	
L-1	69.27	71.34	-
L-2	69.40	71.54	-
L-3	71.47	73.54	-
L-4	67.93	69.80	-
P-1	69.24	71.31	42.84
P-2	65.57	67.04	31.98
P-3	66.19	66.19	31.59
P-4	90.72	93.25	64.94
P-5	90.33	92.79	50.54
P-6	89.71	92.56	44.41
P-7	79.67	80.52	42.80
W-1	92.46	92.79	55.99
W-2	109.22	110.01	86.76
W-3	109.16	109.85	75.11
W-4	112.70	112.70	89.94

* WATER LEVEL DIST. = HEIGHT FROM TOP OF PIPE TO WATER LEVEL

DEPTH IN FEET	SAMPLE TYPE & NUMBER	SAMPLER BLOWS PER 6"	SOIL SYMBOL	CLASSIFI-CATION	DESCRIPTION
				SM	WHITE TO YELLOWISH BROWN SILTY SAND WITH GRAVEL
				SP	PALE BROWN, POORLY GRADED FINE SAND
5	SPT 1	24 44-22		SM	WHITE TO YELLOWISH BROWN SILTY SAND WITH CLAY LENSE AND LIMESTONE GRAVELS
10	SPT 2	8 32-42		CH	HARD YELLOWISH BROWN CLAY WITH IRON OXIDE STAINS, TRACE OF LIMESTONE GRAVELS.
15	SPT 3	23-47 50/2"			
20	R-1			HWR	WHITE WEATHERED LIMESTONE INTERBED WITH CALCAREOUS SILTY CLAY. PRESENCE OF CHERT NODULES AND SOLUTION CAVITIES.
25	R-2				VERY PALE BROWN
30	R-3			CH	LIGHT YELLOWISH BROWN WITH GRAY STREAKS SLIGHTLY INDURATED CALCAREOUS CLAY WITH CHERT AND MARL NODULES
35	R-4				-DO-

SHEET 1 OF 3

FIGURE 4. BORING LOG OF P-4

DEPTH IN FEET	SAMPLE TYPE & NUMBER	SAMPLER BLOWS PER 6"	CLASSIFICATION	DESCRIPTION
				-DO-
			RK	VERY PALE BROWN, SANDY LIMESTONE
	R-5			YELLOWISH BROWN CLAY, INTERBEDDED WITH SILTY LIMESTONE
40				
	R-6			VERY PALE BROWN, SILTY LIMESTONE
45				
	R-7			LIGHT TO DARK GRAY HARD TO SLIGHTLY INDURATED CALCAREOUS CLAY, INTERBEDDED WITH LIMESTONE LAYER
	R-8		CH	
50				
	R-9			LIGHT GRAY BECOMING SILTY
55				
				VERY PALE BROWN, HARD TO SLIGHTLY INDURATED CALCAREOUS SILT
	R-10			
60				
			MH	PRESENCE OF CHERTY AND MARLY NODULES
65				-DO- BUT
	R-11			GRAYISH BROWN
70				

SHEET 2 OF 3

FIGURE 4. (CONTINUED)

DEPTH IN FEET	SAMPLE TYPE & NUMBER	SAMPLER BLOWS PER 6"		SOIL SYMBOL	CLASSIFI-CATION	DESCRIPTION
75	R-12					-DO- BUT YELLOWISH BROWN TO GREENISH GRAY
80	R-13				CH	BLUISH GRAY, HARD CALCAREOUS CLAY, LAMINATED. INTERBEDDED WITH HARD SILTY LIMESTONE
85	R-14					
90	R-15				RK	GRAY LIMESTONE, POROUS AND WITH FOSSIL REMAINS
						TERMINATE BORING AT 90.0 FEET.

SHEET 3 OF 3

FIGURE 4. (CONTINUED)

each lysimeter are shown in Figure 3 and Table 2 respectively. The four lysimeters were installed at an area which was used between 1978 and 1982.

I- **Installation of L-1:** Drilling was done on February 14, 1989. The method used for drilling was tricone and the soil that came out was sandy with some silt. Drilling was to a depth of 25 feet and the lysimeter was installed to a depth of 18 feet underground. Garbage did not come out during drilling which indicates that the lysimeter is located outside the boundary of the landfill, but it was decided to keep this lysimeter in order to collect some leachate that might spread horizontally.

II- **Installation of L-4:** Five attempts were made before L-4 was installed. Drilling started on February 15, 1989 and was completed on February 20, 1989. Hollow stem augering was used in the drilling technique. In the second, third and fourth attempt refusal occurred at 7, 10 and 11 feet, respectively. Garbage started appearing following the fifth drilling attempt at 2.5 feet. The soil was very dark and contained decomposed material. Very strong odor which smelled like H_2S was noticed at 2.5 feet. Two soil samples were collected during drilling: the first at 7.5 feet and the second at 18 feet.

III- **Installation of L-3:** Four attempts were made before L-3 was installed. Drilling started on February 20, 1989 and was completed on February 21, 1989. The method of drilling was hollow stem augering. In the first attempt no garbage appeared down to 20 feet depth so the location was changed. A second attempt was tried and garbage appeared at 3 feet depth but refusal occurred at 7 feet when pieces of steel wire came out. In the third attempt, the location was changed again and refusal occurred at 9 feet. Pieces of the October 11, 1987 Al-Yaum newspaper were picked up. This indicated that the garbage is two years old. The fourth attempt was successful and garbage started appearing at 4 feet. A strong sweet odor was notice at 5 feet and it was different than the odor from L-4. Two soil samples were collected from this hole: the first at 14 feet and the second at 18 feet.

IV **Installation of L-2:** Two attempts were made before L-2 was installed. Drilling started and was completed on February 22, 1989. The method of drilling was hollow stem augering. In the first attempt refusal occurred at 5 feet. The second attempt was successful and garbage started appearing at 2 feet. One soil sample was collected from this hole at 17 feet.

4.1.3 **Locating Existing Wells, Piezometers and Lysimeters:** A total of 15 wells, piezometers and lysimeters were used in this study of which 3 piezometers and 4 lysimeters were installed during the course of this study. The other eight are four water supply wells W-1, W-2, W-3 and W-4, one piezometer P-6 located outside the landfill and three piezometers P-1, P-2 and P-3, that were installed inside the landfill in 1984. The 15 wells, piezometers and lysimeters were used to obtain water samples, leachate samples, supplement groundwater level data, and to determine if groundwater beneath the site is contaminated. They were also surveyed to determine their exact locations, ground elevation and water level (see Figure 5). Table 2 shows the ground elevation and water levels. The location of the wells, piezometers and lysimeter inside and in the vicinity of the landfill are also shown in Figure 5.

4.1.4 **Sampling:** Originally it was intended to sample all the 15 wells, piezometers and lysimeters to obtain water samples and leachate. But as the work progressed it was decided that sampling should also include soil beneath the site and gas from the installed lysimeters.

I- **Collection of Water Sample:** This work was carried out according to the sampling protocol that was prepared for this study. This protocol was prepared to assure that the collected samples are representative groundwater samples. Seven piezometers were sampled each three times. The sampling was conducted in November 1988, March 1989 and April 1989. The four community water supply wells were sampled only once in November 1988.

II- **Collection of Leachate Samples:** Among the four lysimeters sampled, the leachate was obtained only from L-4 and L-3. The other two lysimeters were completely dry. Leachate was sampled twice. The first time was April 16, 1989. This date was chosen because it followed a heavy rain that fell on the area which was the first rainstorm since the lysimeters were installed. The quantity collected was very small totalling 150 cc from each of the two lysimeters. The second sampling date which again followed

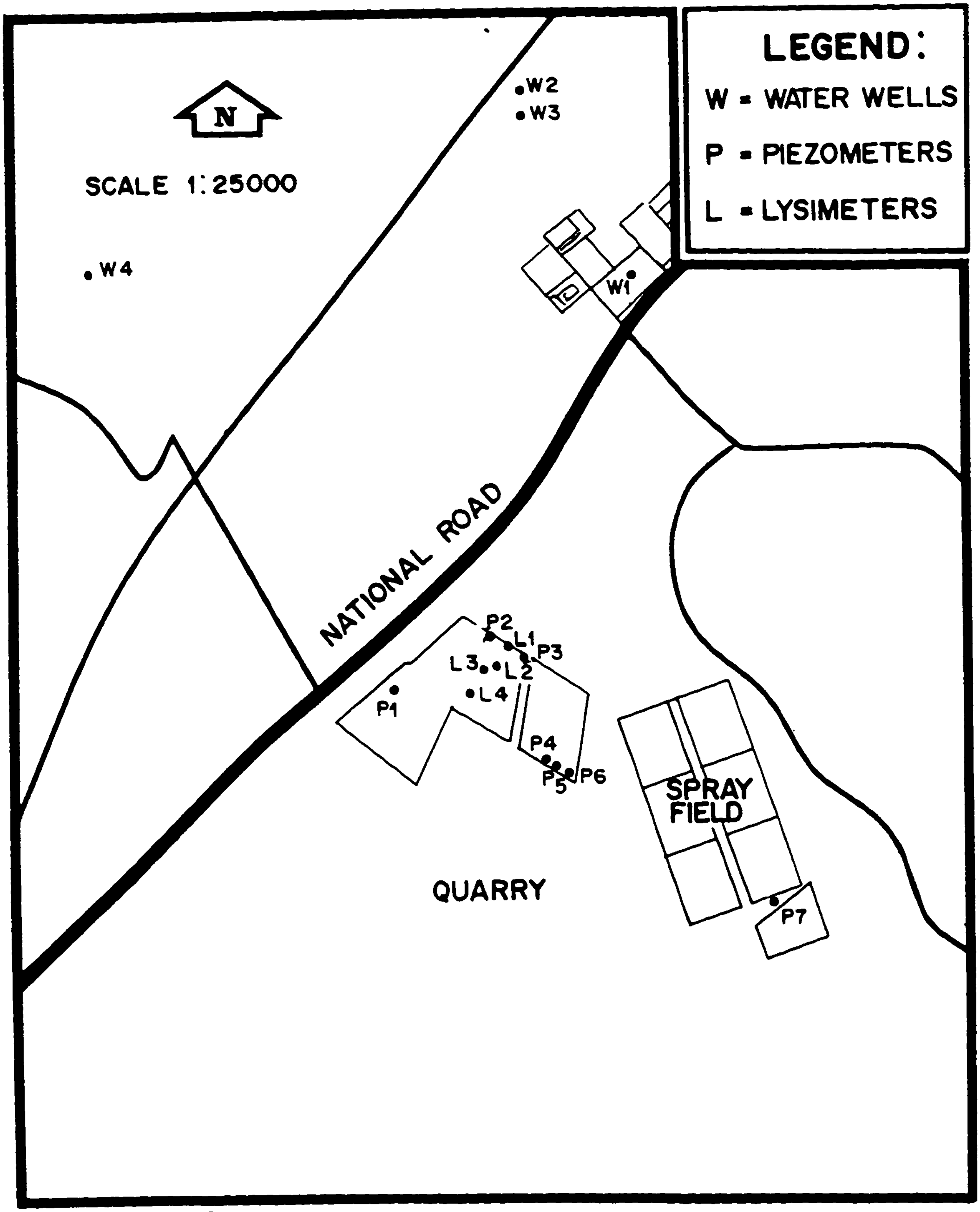


FIGURE 5. LOCATIONS OF WATER WELLS, PIEZOMETERS AND LYSIMETERS INSIDE AND OUTSIDE THE LANDFILL SITE

a rainstorm was May 1, 1989. No samples were obtained from any of the four lysimeters on that date due to light rain. Subsequently leachate generation was negligible.

III- **Collection of Soil Samples:** Soil samples were collected from beneath the landfill. As previously reported, one sample was collected from L-2, two samples were collected from L-3 and two samples were collected from L-4. No samples were collected from L-1. Samples were sent to the Laboratory for analysis.

IV- **Collection of Gas Samples:** After the 4 lysimeters were installed, a strong odors were noticed coming from L-2, L-3 and L-4. A decision to analyze gas samples was then made. Gas samples were collected on April 1, 1989 from the four lysimeters.

4.1.5 **Perform Hydrogeological Investigation:** A hydrogeological investigation to determine groundwater quality and direction and to provide information on the characteristics of the strata beneath the site was performed. Information of the groundwater quality was obtained from sampling the wells and piezometers inside and outside the site. Direction of shallow underground water was determined from the water levels and chemical analysis of the water samples. Characteristics of the underlying strata were obtained from the drilling log of P-4. Information of the regional aquifer was obtained from water atlas (Ministry of Agriculture, 1984).

4.1.6 HYDROGEOLOGICAL ANALYSIS

Eight piezometers and four community water supply wells were used in the study of hydrogeological analysis. Information pertaining the ground elevations, water quality and water levels from these wells and piezometers were used to evaluate the conditions beneath and adjacent to the landfill. Other information includes: boring log of P-4, mound beneath landfill, the regional aquifer in the area, the water quality of the aquifer, its flow direction, and the formation. Reasons for performing the hydrogeological investigation are:

- To determine the effect of the landfill on the shallow aquifer and on the regional aquifer.
- To study the effect of the spray field on the landfill.

A Regional Aquifer

The regional aquifer in the eastern province of Saudi Arabia is Umm er Radumah (UER) which is located directly under the site. This aquifer is the main water supply for the area. The community water wells W-1, W-2, W-3 and W-4 are pumping water directly from this aquifer. The main characteristics of the formation of UER is that it consists of porous gray limestone with fossil remains.

The depth of UER at the location of P-4 is 88 feet. From the difference between the ground elevation of P-4 and P-1, P-2 and P-3 it is estimated that the UER is between 66 and 73 feet deep.

This aquifer has a gradient towards the East and South East (Ministry of Agriculture, 1984). The aquifer is confined due to the pressure of the Rus formation on top of it. This can be seen from boring log of P-4 where the screen of the well is between 94 and 88 feet while the measured water table is at 65 feet.

The formation on top of UER is the Rus formation. This formation has a low permeability as a result of the clay and marl layer deposits. From the boring log of P-4 it was determined the Rus formation extends up to 85 feet depth at the location of P-4. This indicates that this formation is between 59 and 66 feet beneath the landfill.

B Composition of the Formation Beneath the Site

The boring log of P-4 describes specifically the composition of the strata underneath the area. It is assumed that the strata beneath the landfill is an extension of the strata at which P-4 was installed (See Figure 4 for detailed analysis of the strata). The important thing to note from the boring log is the presence of 3 clay layers. The thickness of the 3 layers ranges between 9 to 13 feet each.

C Evaluation of Conditions Beneath the Site

As stated earlier the UER is located beneath the landfill at a depth ranging between 66 and 73 feet. The UER is well below the bottom of the landfill. The presence of highly impermeable clay layers between the bottom of the landfill and the top of the UER (See Figure 4) will prevent the leachate from reaching the UER. In addition the 3 piezometers inside the landfill P-1, P-2, and P-3 are showing the presence of a water body at a depth ranging between 32 and 43 feet beneath the landfill. This water which is contained in the Rus formation will also act as a zone that will prevent the leachate from infiltrating further and reaching the UER.

The origin of the water beneath the landfill is not exactly known. One of the hypothesis is that it is the product of old fassil water. The second hypothesis is that this water is the result of the million of gallons of treated wastewater that is sprayed in the spray field. The analysis of the water samples obtained from P-5 which is installed on the spray field and those from P-1, P-2 and P-3 and the elevation of the water level in those wells strongly support the second hypothesis. The chemical analysis of TDS, chloride, sulfate and the pH of P-1 and P-7 are almost identical and they support this hypothesis (See Table 7 and 8). The water from the spray field is infiltrating the ground and creating a water table (mound) beneath the spray field. As a result of the continuous spraying, this mound continued to extend and has reached the landfill area. This water table is within the upper rus formation above the UER. Its hydraulic to the UER is unknown. However, the boring log of P-4 reduce this possibility due to the presence of three impervious clay and silt layers. These layers should act as sealant to prevent the contamination due to leachate.

The gradient of the water table created by the spray field is in the opposite direction of the gradient of UER (Figure 3). This is another indication that this water table is a mound created by the spray field.

At present the depth of the shallow water resulting from the spray field is lower than the bottom of the landfill (water depth is between 32 and 43 feet, while the bottom of the landfill is between 12.8 and 23 feet below the ground surface). Thus if the spray field is to be kept at the same level as it is now, there will be no danger that the water table will become high and reaches the bottom of the landfill where the leachate is present. The only remaining danger is if the leachate from the landfill reaches the shallow water table. The water analyses from P-1, P-2 and P-3 show the presence of certain contaminants which indicate that the leachate is reaching the shallow water table.

The results of the hydrogeological investigation indicates that the presence of the 3 clay layers beneath the shallow aquifer and the depth of the UER are factors that will prevent the leachate from reaching the UER. Also the present location of the spray field is developing a mound of water that has reached the area under the landfill. If the quantity of sprayed water is increased this will lead to more problems specially if this mound leaks into the UER. Measures to monitor this water should be conducted. Plans to collect and treat this water should also be developed.

4.2 LABORATORY ANALYSIS

The parameters of the obtained samples that can be analyzed are numerous. A total of 36 parameters were chosen based on literature review and personnel judgment. The 36 parameters were divided into five groups; metals, anions, organics, pesticides/herbicides, and others (See Table 3).

The analytical work was carried out according to U.S. Environmental Protection Agency (EPA) recommendations and procedures, ASTM methods and "Standard Methods for the Examination of Water and Wastewater". Specific conductance and pH were measured in the field. The other tests were performed in the laboratories. The procedure in "Methods for Chemical Analysis of Water and Wastes" by the EPA was followed for preserving and handling the samples. The analytical procedures adopted for use in this study are shown in Table 4.

Table 3 Analytical Parameters

METALS

Arsenic
Barium
Cadmium
Chromium (total)
Copper
Iron
Lead
Manganese
Mercury
Nickel
Selenium
Sodium
Silver
Zinc

ANIONS

Chloride
Fluoride
Nitrite
Nitrate
Sulfate

OTHER

Ammonia (as Nitrogen)
Biochemical Oxygen Demand (BOD)
Chemical Oxygen Demand (COD)
Coliform
Hydrogen Iron Concentration (pH)
Specific Conductance
Total Dissolved Solids (TDS)

ORGANICS

Organic Nitrogen
Phenols
Total Organic Carbon (TOC)
Total Organic Halides (TOX)
Trihalomethanes

PESTICIDES/HERBICIDES

Endrin
Lindane
Methoxychlor
Toxaphene
2, 4 - D
2, 4, 5 - TP Silvex

Table 4 Analytical Procedures

Arsenic	Atomic absorption spectrophotometric	(ASTM)
Barium	Atomic absorption spectrophotometric	(ASTM)
Cadmium	Atomic absorption spectrophotometric	(ASTM)
Chromium	Atomic absorption spectrophotometric	(ASTM)
Copper	Atomic absorption spectrophotometric	(ASTM)
Iron	Atomic absorption spectrophotometric	(ASTM)
Lead	Atomic absorption spectrophotometric	(ASTM)
Manganese	Atomic absorption spectrophotometric	(ASTM)
Mercury	Atomic absorption spectrophotometric	(ASTM)
Nickel	Atomic absorption spectrophotometric	(ASTM)
Selenium	Atomic absorption spectrophotometric	(ASTM)
Sodium	Atomic absorption spectrophotometric	(ASTM)
Silver	Atomic absorption spectrophotometric	(ASTM)
Zinc	Atomic absorption spectrophotometric	(ASTM)
Chloride	Alpkem Auto Analyser	(ASTM)
Sulfate	Alpkem Auto Analyser	(ASTM)
Nitrite	Alpkem Auto Analyser	(ASTM)
Nitrate	Alpkem Auto Analyser	(ASTM)
Fluoride	Ion Selective Electrode	(ORION)
Ammonia	Ion Selective Electrode	(ASTM)
BOD	Five-day 20°C, oxygen electrode	(Standard Methods No. 507)
COD	Closed Reflux, Titrimetric Method	(Standard Methods No. 508B)

Table 4 (Continued)

Coliform	Standard Total Coliform Multiple Tube (MPN) Tests	(Standard Methods No. 908-A)
pH	Portable Beckman pH meter with Combination Electrode	
Specific Conductance	Portable conductivity meter	(HACH)
TDS	EPA Gravimetric	(Evaporation)
Organic Nitrogen	Macro-Kjeldahl Method	(Standard Methods No. 420-A)
Phenols	Phenols Method GC-FID	(EPA No. 604)
TOC	Persulfate-Ultraviolet Oxidation Method	(Standard Methods No. 505-B)
Trihalomethanes	GC-ECD	(Standard Method)
Endrin	GC-ECD	According to EPA Procedure for pesticide in water
Lindane	GC-ECD	According to EPA Procedure for pesticide in water
Methoxychlor	GC-ECD	According to EPA Procedure for pesticide in water
Toxaphene	GC-ECD	According to EPA Procedure for pesticide in water
2, 4, D	Chlorinated Phenoxy Acid Herbicides GC-ECD	(Standard Method No. 509-B)
2, 4, 5 Tp SiLvx	Chlorinated Phenoxy Acid Herbicides GC-ECD	(Standard Method No. 509-B)

4.2.1 Leachate Analysis

1 Factors Affecting Leachate Generation

Leachate can be described as a solution containing high concentrations of dissolved and finely suspended organic and inorganic matters and microbial waste products. Leachate is the result of the process of decomposition of waste material in the landfills followed by water (i.e., rainfall water, surface water or groundwater) moving through the waste and accumulating suspended and/or dissolved chemical and biological matter. The major pollutants in leachate are usually BOD, COD, chloride, nitrate, coliform and toxic metals.

In order to study the effect of leachate on groundwater, it is essential to know the quantity and composition of leachate. Four items to be considered to determine the value of leachate are:

- Availability of water;
- Types of waste;
- Landfill surface conditions; and
- Underlying soil conditions.

I **Availability of Water:** There are five factors that should be evaluated in order to assess the availability of water:

A- Precipitation: This is the principal factor for leachate generation for most landfills. The amount, intensity, duration and frequency of precipitation are to be considered. The average rainfall in the study area is 3.1 inches per year. The maximum number of rainy days in one year was 32 in 1982 with total rain of 7.6 inches and the minimum was 4 in 1968 with total rain of 0.23 inch. (Hejazi, 1989). The expected 50-year intensity for a rainfall of one hour duration is 2 inches. Again this figure is considered to be low.

B- **Surface Run-off:** The factors that affect surface run-off include: surface topography, cover material, vegetation, soil permeability and drainage systems. The topography of the site (as described earlier) indicates that the site was part of a quarry and the ground elevation slightly decreases towards the east. A few low areas at which rain water collects were found on the site. The surface of the site is irregular due to the landfilling techniques used. The cover material used on site is sand which is highly permeable. The only vegetation present on the site is scrub. No drainage systems are located to carry any water away from the site. All the above indicates that any water entering the site will infiltrate, and the run off will be negligible.

C- **Groundwater Intrusion:** Groundwater intrusion will occur if the base of the landfill is below the groundwater table. This is not applicable to the selected site. Groundwater table is at a depth of 30.8 feet while the bottom of the landfill is only 7.0 feet above the groundwater table.

D- Refuse Decomposition: Depending upon the conditions prevailing, aerobic and anaerobic decomposition takes place in a landfill. In both reactions water is generated.

<u>For Aerobic</u>

Organic matter + oxygen $\longrightarrow H_2O + CO_2$ + acids + inorganic matter

<u>For Anaerobic</u>

Organic matter $\longrightarrow H_2 + CO_2$ + acids + methane + ammonia + decomposed organics + inorganic minerals

The inorganic minerals include PO_4, SO_4, NO_s, NH_3 etc. (Lu, et al., 1985).

Decomposition due to aerobic reaction is much faster than anaerobic reaction. This leads to the generation of more water during the early stage of decomposition. Other factors that are involved include pH of the interstitial moisture, temperature, amount of oxygen, size and composition of the refuse, types of bacteria present, and degree of mixing.

From the above it can be seen that calculating the rate of refuse degradation is difficult. However the amount of water generated from this process will be minimum compared to other sources (Lu, et al., 1985).

E- **Liquid Wastes/Sludge Codisposal:** According to the landfill supervisor no liquid waste was ever placed in the landfill. However, some people stated that in 1980 and 1981 some municipal sludge was disposed which could not be verified. If this is true, the sludge would have contributed some water to the site.

II **Types of Waste:** Factors that must be evaluated to determine the contribution of types of waste to leachate generation include composition of garbage and its condition. In a study conducted in 1986, it was found that 33.5% of the disposed waste was domestic garbage, 28.3% was construction debris and 38.2% was miscellaneous materials. The miscellaneous materials included trash, garden trim, wood, cartons, etc. In the selected landfill, all household garbage was disposed loosely in the site until 1984. After 1984 it was required that all garbage be collected and disposed in plastic bags. This, however, does not mean that all garbage presently disposed are in plastic bags.

III **Landfill Surface Conditions:** The factors such as evaporation and infiltration must be evaluated to determine landfill surface condition effects on leachate generation. The evaporation rates for the area in which the landfill is located differ from month to month. The maximum evaporation rate is 8 inches for the month of July and the minimum is 2 inches for both January and December. (Ministry of Agriculture, 1984). The infiltration rate is expected to be very high because garbage is covered with sand which is highly permeable material.

IV **Underlying Soil Conditions:** The permeability of the underlying soil is very important in determining the percolation rates of water. The strata of the underlying soil in the subject landfill can be seen from the drilling log of piezometer P-4.

2 ESTIMATING THE QUANTITY OF GENERATED LEACHATE

The method reported for estimating the quantity of generated leachate is the gross estimation method (Lu et al., 1985). Basically this method is a water balance method in which precipitation, evapotranspiration and surface run-off are considered. The equation used to calculate the generated leachate is

Ann. L = Ann. p - Ann. R - Ann. E

Where:

Ann. L = Annual leachate generation

Ann. p = Annual precipitation

Ann. R = Annual surface run-off

Ann. E = Annual evapotration

When this equation is applied at the site, annual leachate generation is zero because:

Ann. p = 3.1 inches

Ann. E = 67.3 inches

Ann. R = 0 inch

Ann. L = 3.1 - 67.3 = - 64.2 inches

which means the Ann. L = 0

But this calculation is not applicable for this site because while evaporation occur throughout the year, precipitation occur only between November and April. That is why the generated leachate should be calculated on monthly basis or even on daily basis. But the total monthly evaporation for this area is also larger than the total monthly precipitation (Ministry of Agriculture, 1984). Therefore, the monthly leachate generation between January and December is zero for every month. The fact that leachate was collected at this site, indicates that leachate does occur. But it was recorded that the leachate which was collected on April 16, 1989 followed a rainfall that hit the area on March 29, 1989. The value recorded of this rainfall is 1.2 inches at 30 minutes duration. Since only 5.9 inches of leachate was collected in two of the lysimeters, this indicates that leachate generation due to precipitation is minimal.

From the above analysis, we conclude that leachate generated at the landfill is small in quantity. It might never be possible to calculate the exact quantity generated. The best that can be done is to sample the lysimeter following every rainfall.

It should also be mentioned that the second attempt to collect leachate on May 1, 1989 at which no leachate was collected, followed two rain storms. On April 25 and 29, 1989 .06 inch of rain fell on the area on each day. Neither rainfall resulted in the generation of any leachate.

3 The Composition of Leachate

The exact composition of leachate depends upon the following factors:

- Solid waste composition
- Operation of the fill
- Condition within the fill, such as temperature, pH, moisture, chemical and biological activities, and age of the fill.
- Climate of the area
- Hydrogeological conditions at the landfill site.

These factors vary considerably from one landfill to another. This is why a large variation in leachate composition has been reported for many studies (see Table 5). The only method to exactly identify leachate composition for a particular landfill is to conduct laboratory analyses on leachate sample. The sampling, laboratory analyses, results, and discussion are presented in subsequent sections.

Table 5 Concentration Ranges for Components of Landfill Leachate

Parameter mg/l	Concentration Range*	"Typical" Concentration Range**
BOD_5	4-57,700	1,000-30,000
COD	39-89,250	1,000-50,000
TOC	0-28,500	700-10,000
Total volatile acids (as acetic acid)	70-27,700	-
BOD/COD (ratio)	0.02-0.87	0.6-0.8
COD/TOC (ratio)	0.4-4.8	1-4
Total Kjeldahl nitrogen (as N)	7-1,970	10-500
Nitrate (as N)	0-51	0.1-10
Ammonia (as N)	0-1,966	-
Total Phosphates	0.2-130	0.5-50
Orthophosphates	0.2-130	-
Total alkalinity (as $CaCO_3$)	0-20,850	500-10,000
Total hardness (as $CaCO_3$)	0-22,800	500-10,000
Total solids	0-59,200	3.000-50,000
Total dissolved solids	584-44,900	1.000-20,000
Specific conductance (umhos/cm)	1,400-17,100	2.000-8,000
pH (units)	3.7-8.8	5-7.5
Calcium	60-7,200	100-3,000
Magnesium	17-15,600	30-500
Sodium	0-7,700	200-1,500
Chloride	4.7-4,816	100-2,000
Sulfate	10-3,240	10-1,000
Chromium (total)	0.02-18	0.05-1
Cadmium	0.03-17	0.001-0.1
Copper	0.005-9.9	0.02-1
Lead	0.001-2.0	0.1-1
Nickel	0.02-79	0.1-1
Iron	4.0-2,820	10-1,000
Zinc	0.06-370	0.5-30
Methane gas (percent composition)	(up to 60%)	-
Carbon dioxide (percent composition)	(up to 40%)	-

Source: Lee et al., (1986)

4 THE ANALYSIS OF OBTAINED LEACHATE SAMPLES

The leachate samples collected from lysimeters L-3 and L-4 were analyzed in the laboratory. The results are presented in Table 6.

The pH of both samples was measured on site immediately after sampling. The values for L-3 and L-4 were 7.4 and 7.8, respectively. Neither of them is in the acidic range. The analysis of leachate obtained from the subject landfill for heavy metals (cadmium, chromium, copper, iron and silver) agree with Koch, (1980). The relatively high value of pH (7.4 and 7.8) also indicate that organic acids are low in concentration and that the biological decomposition rate is very slow or that an effective leachate and solid waste stabilization is taking place in the second stage of the anaerobic process. Again this agrees with Koch, (1980).

Most heavy metals are classified as hazardous elements. Leachate always contains heavy metals, however their concentrations vary from one landfill to another. The concentrations of heavy metals are function of the complex formation with organics, the pH and the carbon species. In general the concentration increases with low pH and decreases with increasing concentrations of carbonate species (Johansen and Carlson, 1976). The values of the analyzed heavy metals (arsenic, cadmium, chromium (total), copper, iron and silver), for L-3 are .029, .012, .13, .11, .86 and less than .05 mg/l, respectively. The values for L-4 are .041, .015, .05, .07, .44 and less than .05 mg/l, respectively.

Table 6 Leachate Concentration Data

Parameters (mg/l)	Lysimeters No.	
	L-3	L-4
BOD	2006	104
COD	3320	875
TOC	1020	76
TKN	96	245
TDS	1500	2000
Coliform	10	2000
Arsenic	.029	.041
Cadmium	.012	.015
Chromium (total)	.13	.05
Copper	.11	.07
Iron	.86	.44
Silver	ND	ND
pH	7.4	7.8
Specific Conductance *	2450	3150

* Units are in Micromhos/Cm

ND = Not Detected

In general these values are low. The iron concentration in both lysimeter samples is maximum which might be expected at a landfill containing significant amounts of iron and steel. The low concentration of heavy metals was expected because of the high pH.

Conductivity is a numerical expression of the ability of an aqueous solution to carry an electric current. Fresh distilled water has a conductivity range of .5 to 2 micromhos/cm. Raw water has a conductivity range from 50 to 1,500 micromhos/cm which is near that of domestic wastewater. The specific conductance of L-3 and L-4 were 2450 and 3150 micromhos/cm respectively. These numbers are within the expected ranges (Johansen and Carlson, 1976).

TKN is the sum of ammonia nitrogen and organic nitrogen. Leachate TKN values vary appreciably from landfill to landfill. Koch and Cameron (1980) reported a range from 8.7 to 494 mg/l. The values obtained from L-3 and L-4 are 96 and 245 mg/l, respectively. Ammonia is expected to contribute from 60 to 90% of TKN. Nitrite and nitrate values are expected to be nearly zero due to the anaerobic conditions inside a landfill. Because of the small leachate quantity, nitrite and nitrate tests could not be done.

Municipal solid waste contains a large microbial population and may be heavily contaminated with pathogenic microorganisms. Coliform which is a fecal-indicator bacteria indicates the presence of microbial pathogens in municipal leachates. Coliform values from L-3 and L-4 were 10 and more than 2000, respectively. This indicates that pathogenic microorganisms are present in the leachate.

The presence of BOD and COD is a clear indicator of organic contamination (Husain, 1984). BOD's of leachates are strictly related to the content of nitrogen compounds (Johansen and Carlson, 1976). This type of contamination indicates that the pollutants are of a group that can be oxidized biologically or chemically. The values of BOD for L-3 and L-4 were 2006 and 104 mg/l, respectively and the values of COD for L-3 and L-4 were 3320 and 875 mg/l, respectively. Since the concentrations of BOD and COD can vary daily, it is more beneficial and recommended to use the ratio of BOD/COD. This ratio is used to indicate the age of the fill, to give indication of the biodegradabilities of the leachate and as a measure to select the treatment process. When the BOD/COD ratio is greater than or equal to .5, the fill is considered to be young (less than 2 years). If BOD/COD is between .1 - .5 then the fill is considered to be of medium age (3 to 5 years) and when the ratio is less than or equal to .1 then the fill is old (more than 5 years) (Chian and DeWalle, 1976). The BOD/COD for L-3 is .604 and the BOD5/COD at L-4 is .119. This indicates that the fill at L-3 is much younger than that under L-4. This was also verified from the operators at the landfill. In addition as the BOD/COD ratio decreases, the leachate becomes less amenable to biological treatment.

Another means for measuring the organic matter present in the leachate is the TOC test. The values of TOC at L-3 and L-4 were 1020 and 76 mg/l, respectively. It can be noted that both the BOD and TOC for L-3 are high while both are low for L-4.

TDS includes two groups: cations and anions. Cations include potassium, sodium, magnesium and calcium. Anions include sulfate, chloride, carbonate and bicarbonate. The values of TDS from L-3 and L-4 were 1500 and 2000 mg/l, respectively. This indicates that the salts dissolve easily in the water which comes in contact with the garbage, but still the TDS values were not that particularly high in this landfill.

4.2.2 WATER ANALYSIS

Water samples were obtained from three piezometers installed inside the landfill (P-1, P-2 and P-3), four piezometers installed in the vicinity of landfill (P-4, P-5, P-6 and P-7) and four community water supply wells (W-1, W-2, W-3 and W-4). The seven piezometers inside and in the vicinity of the landfill were analyzed for 36 parameters. Three samples were obtained for each parameter at three different times. The four community wells were also analyzed for the same 36 parameters, but sampling was only conducted once. Tables 7 and 8 show the average concentrations of analyzed parameters of groundwater samples from the three piezometers inside the landfill and the four piezometers in the vicinity of the landfill, respectively. Table 9 shows the concentrations of the analyzed parameters of groundwater samples from the four community water supply wells. The following is a discussion of the results showns in the tables.

Table 7 Groundwater Average Concentration Data from Inside the Landfill

Parameters (mg/l)	Piezometers No.		
	P-1	P-2	P-3
BOD	2.4	2	11
COD	35.65	12.75	32.35
TOC	8.85	1.4	9.45
Ammonia-N	4.6	0.5	0.65
Organic-N	13.7	5.97	5.77
Phenols	ND	ND	ND
Trihalomethanes (ppb)	ND	ND	ND
TDS	5998	3548	2630
Coliform (MPN)	2	94	706
Arsenic	.024	ND	ND
Barium	ND	ND	ND
Cadmium	ND	ND	ND
Chromium (total)	ND	ND	ND
Copper	ND	ND	ND
Iron	1.235	.13	.83
Lead	.115	ND	.06
Manganese	.105	ND	ND

ND = Not Detected

Table 7 (Continued)

Parameters (mg/l)	Piezometers No.		
	P-1	P-2	P-3
Mercury	ND	ND	ND
Nickel	ND	ND	ND
Selenum	.125	.03	.022
Sodium	1097	342	297
Silver	ND	ND	ND
Zinc	17.77	ND	ND
Chloride	2166	745	611
Fluoride	.76	.96	.24
Nitrite	ND	ND	ND
Nitrate	1.1	.5	.9
Sulfate	1260	673	721
Endrin (ppb)	ND	ND	ND
Lindane (ppb)	ND	ND	ND
Methoxychlor (ppb)	ND	ND	ND
Toxaphene (ppb)	ND	ND	ND
2, 4 - D (ppb)	ND	ND	ND
2, 3, 5 - TP Silex (ppb)	ND	ND	ND
pH	6.8	7.65	7.35
Spec. Conductance x	8250	3850	4150

x Units are in Micromhos/Cm

Table 8 Groundwater Average Concentration Data from Outside the Landfill

Parameters (mg/l)	Piezometers No.			
	P-4	P-5	P-6	P-7
BOD	2	2	2	2
COD	12.9	11.2	30.1	34
TOC	1.05	.75	.95	2.0
Ammonia-N	.37	.4	.4	.4
Organic-N	2.2	.77	2.8	7.9
Phenols	ND	ND	ND	ND
Trihalomethanes (ppb)	ND	ND	ND	ND
TDS	3137	2406	13050	6291
Coliform (MPN)	2	2	2	40
Arsenic	ND	ND	ND	ND
Barium	.16	.25	.12	.05
Cadmium	ND	ND	ND	ND
Chromium (total)	ND	ND	ND	ND
Copper	ND	ND	ND	ND
Iron	.11	.36	.26	ND
Lead	ND	ND	ND	ND
Manganese	ND	ND	ND	ND

MPN = Most probable number

ND = Not Detected

Table 8 (Continued)

Parameters (mg/l)	Piezometers No.			
	P-4	P-5	P-6	P-7
Mercury	ND	ND	ND	ND
Nickel	ND	ND	ND	ND
Selenum	.04	.07	.13	ND
Sodium	567	493	1738	880
Silver	ND	ND	ND	ND
Zinc	ND	ND	ND	ND
Chloride	1144	1016	4150	2083
Fluoride	.46	.20	.36	.70
Nitrite	.6	ND	ND	ND
Nitrate	1.17	1.13	1.4	40
Sulfate	560	168	2178	1190
Endrin (ppb)	ND	ND	ND	ND
Lindane (ppb)	ND	ND	ND	ND
Methoxychlor (ppb)	1.1	.7	.2	ND
Toxaphene (ppb)	ND	ND	ND	ND
2, 4 - D (ppb)	ND	ND	ND	ND
2, 3, 5 - TP Silvex (ppb)	ND	ND	ND	ND
pH	7.98	10.65	7.55	6.85
Spec. Conductance [x]	4700	4317	15100	8466

x Units are in Micromhos/Cm

Table 9 Groundwater Concentration Data from Community Water Supply Wells

Parameters (mg/l)	Well No.			
	W-1	W-2	W-3	W-4
BOD	2	2	2	2
COD	10.6	6.4	6.7	10.3
TOC	ND	ND	ND	.8
Ammonia-N	.2	.2	.2	ND
Organic-N	.1	.1	.1	.1
Phenols	ND	ND	ND	ND
Trihalomethanes (ppb)	ND	ND	ND	ND
TDS	3124	3160	3388	3080
Coliform (MPN)	2	2	2	2
Arsenic	ND	ND	ND	ND
Barium	.09	.07	.08	.08
Cadmium	ND	ND	ND	ND
Chromium (total)	ND	ND	ND	ND
Copper	ND	ND	ND	ND
Iron	.1	.1	.55	.64
Lead	ND	ND	ND	ND
Manganese	ND	ND	ND	ND

MPN = Most probable number

ND = Not Detected

Table 9 (Continued)

Parameters (mg/l)	Well No.			
	W-1	W-2	W-3	W-4
Mercury	ND	ND	ND	ND
Nickel	ND	ND	ND	ND
Selenum	ND	ND	ND	ND
Sodium	620	600	630	610
Silver	ND	ND	ND	ND
Zinc	ND	ND	ND	ND
Chloride	1205	1158	1211	1237
Fluoride	.78	.76	.77	.42
Nitrite	ND	ND	ND	ND
Nitrate	10.9	10.9	10.7	.5
Sulfate	409	407	405	324
Endrin (ppb)	ND	ND	ND	ND
Lindane (ppb)	ND	ND	ND	ND
Methoxychlor (ppb)	ND	ND	ND	ND
Toxaphene (ppb)	ND	ND	ND	ND
2, 4 - D (ppb)	ND	ND	ND	ND
2, 3, 5 - TP Silvex (ppb)	ND	ND	ND	ND
pH	6.6	6.7	6.7	8.6
Spec. Conductance [x]	4850	4675	5000	4375

x Units are in Micromhos/Cm

In Table 7, Samples were obtained from P-1, P-2 and P-3 to determine whether the shallow aquifer beneath the landfill has been contaminated by the generated leachate. The results of the analyzed parameters clearly indicate the presence of certain contaminants in the aquifer. The analyses of iron, selenium and sodium show high levels in all three piezometers compared to the levels at the four community supply wells. In addition the levels of lead, manganese and zinc are also high in P-1. The levels of chloride and sulfate are high in the three piezometers, especially in P-1. They are almost double the levels of the other two piezometers. The presence of BOD, COD and TOC in the water samples from the three piezometers clearly indicate that the groundwater is contaminated with organic matter. BOD at P-3 is 11 mg/l. COD's at P-1, P-2 and P-3 are 35.65, 12.75 and 32.35 mg/l, respectively. TOC ranges between 1.4 and 9.45 in the piezometers. The levels of TDS and Specific Conductance are also high in the three piezometers. The levels of both parameters in P-1 are much higher than in P-2 and P-3. This is expected because P-1 is the downstream piezometer while the other two are the upstream ones. P-2 and P-3 show high levels of coliform bacteria. These levels are 94 and 706 MPN respectively. P-1 which is the down stream piezometer does not show any presence of coliform. This could be the result of types and quantity of garbage dumped at the area on which P-2 and P-3 are located and also because both piezometer, especially P-3, are much closer to the spray field. The presence of coliform indicates bacterial contamination in the water.

When all of the above results are combined, it is obvious that the shallow aquifer underlying the landfill is contaminated. The contamination results from organics, coliform bacteria and certain heavy metals migrating into the groundwater from the landfill garbage. Also the higher level of most parameters in P-1 than P-2 and P-3 is a clear indicator that P-1 is downstream and the other two are upstream.

In Table 8, Samples were obtained from P-4, P-5, P-6 and P-7. The reasons for analyzing the water from P-4, P-5 and P-6 are:

- To determine if the three piezometers are in the same aquifer or in different aquifers.
- To determine if the aquifer in which P-6 was installed is the same as the shallow aquifer beneath the landfill.
- To determine the quality of water in the vicinity of the landfill in order to ascertain whether the contamination beneath the landfill is natural or due to the landfilling operation.

The reasons for analyzing the water from P-7 are:

- To determine the effect of secondary treated wastewater disposed in the spray fields on the underlying aquifer.
- To determine whether the groundwater beneath the spray field has any effect on the groundwater beneath the landfill.

Analyses of water samples collected from P-4 (Table 8) clearly indicates that the water quality in P-4 is the same as that of the UER. Based on analysis of the Ministry of Agriculture, (1984). The depth of P-4 (93.25 feet) also confirms that this piezometer is in the top of UER formation. (See section 4.1.6)

Both P-5 and P-6 are located in different water table than the UER. They are both located in the Rus formation. P-5 is located in a strata that represent the bottom of the Rus formation and the top of the UER. This explains the reason why analysis obtained from P-5 is similar to that of P-4.

The analyses of water samples from P-4 and P-5 show an expected high chloride content, TDS and specific conductance levels. This is the general case in the Eastern Province of Saudi Arabia. In addition, COD and certain heavy metals were found at elevated levels. For P-4 and P-5, the COD levels are 12.9 and 11.2 mg/l, the iron levels are .11 and .36 mg/l and barium levels are .16 and .25 mg/l. COD, barium and iron are also at high levels in the samples obtained from the community water supply wells (see Table 9). It can then be concluded that the aquifers into which P-4 and P-5 have been installed contain organics and heavy metals not contributed by landfill operation.

For P-4 the pH is 7.98 and for P-5 it is 10.65. The value of 10.65 is the average of 10 readings taken between November 1988 and May 1989. The highest recorder value was 11.2 and the lowest was 9.5. The value of 10.65 is unusual for aquifers. The high value can be attributed to the result of the chemical characteristics of the strata, or could be due to the presence of some high alkaline formation material. For P-6 it is located in the same formation as P-5. It is located at the upper part of the Rus formation but above the water mound from the spray field

The chemical analysis of water obtained from P-6 are different than the ones obtained from P-4, P-5 or from the samples obtained from the piezometers inside the landfill.

For P-6 the TDS, sodium, chloride, sulfate and specific conductance were extremely high. They were 13050, 1738, 4150, 2178 and 15100 mg/l, respectively. These values are more than double the levels of P-4 and P-5, and also much higher than those of the leachate and the water obtained from beneath the landfill. In addition, the COD level which is 30.1 mg/l is similar to the COD levels from both water beneath the landfill and from water beneath the spray field. Heavy metals were also present but at the same levels as those found in the community water supply wells. In summary there are some organic and heavy metal contaminants found in this aquifer that are not the result of the landfill but a naturally occurring contamination.

Methoxychlor, a pesticide, was detected in P-4, P-5 and P-6. A peak eluting at the same retention time as methoxychlor was detected; however, its identity could not be verified by GC-MS due to the low levels at which it was present in the samples.

For P-7 the results indicated the presence of certain contaminants such as COD, organic nitrogen, coliform and nitrate. The levels were 34, 79, 40, and 40 mg/l, respectively. These types of pollutants are the result of the million of gallons of secondary effluent that are sprayed daily on the spray fields. This contamination does not result from the landfill operation. In an investigation conducted on the spray field it was determined that the disposed water is causing a mound beneath the spray fields area. This mound extends in all direction (See Figure 6). If this operation continues, under the existing conditions, this mound will probably reach the boundary of the landfill in few years and will lead to spreading of leachate and expanding the extent of contamination.

In Table 9 samples where obtained from W-1, W-2, W-3 and W-4 to provide comparison of analyzed parameters. The results of the analyzed water from the four wells did not indicate the presence of any contamination of any sort. The TDS levels are high but this is expected because the chloride, sodium and sulfate levels in the groundwater in the Eastern Province are high in general. The water obtained from these community water supply wells is treated at a reverse osmosis plant before it is supplied to the community.

4.2.3 SOIL ANALYSIS

Soil samples were obtained from three lysimeters, L-2, L-3 and L-4. One sample was obtained from L-2 at a depth of 17 feet, two samples were obtained from L-3 at depths of 14 and 18 feet and two samples were obtained from L-4 at depths of 7.5 and 18 feet. The samples were extracted using EPA test methods for evaluating solid wastes, method no. 1310. The results of the soil analysis are shown in Table 10. The analysis of all heavy metals with the exception of cadmium, chromium and silver are high. This is specially true for barium, iron, manganese and zinc. But this is expected since landfill contained all sorts of wastes. The soils had pieces of metals such as iron that are large enough to be seen. In addition, the fluoride values in all

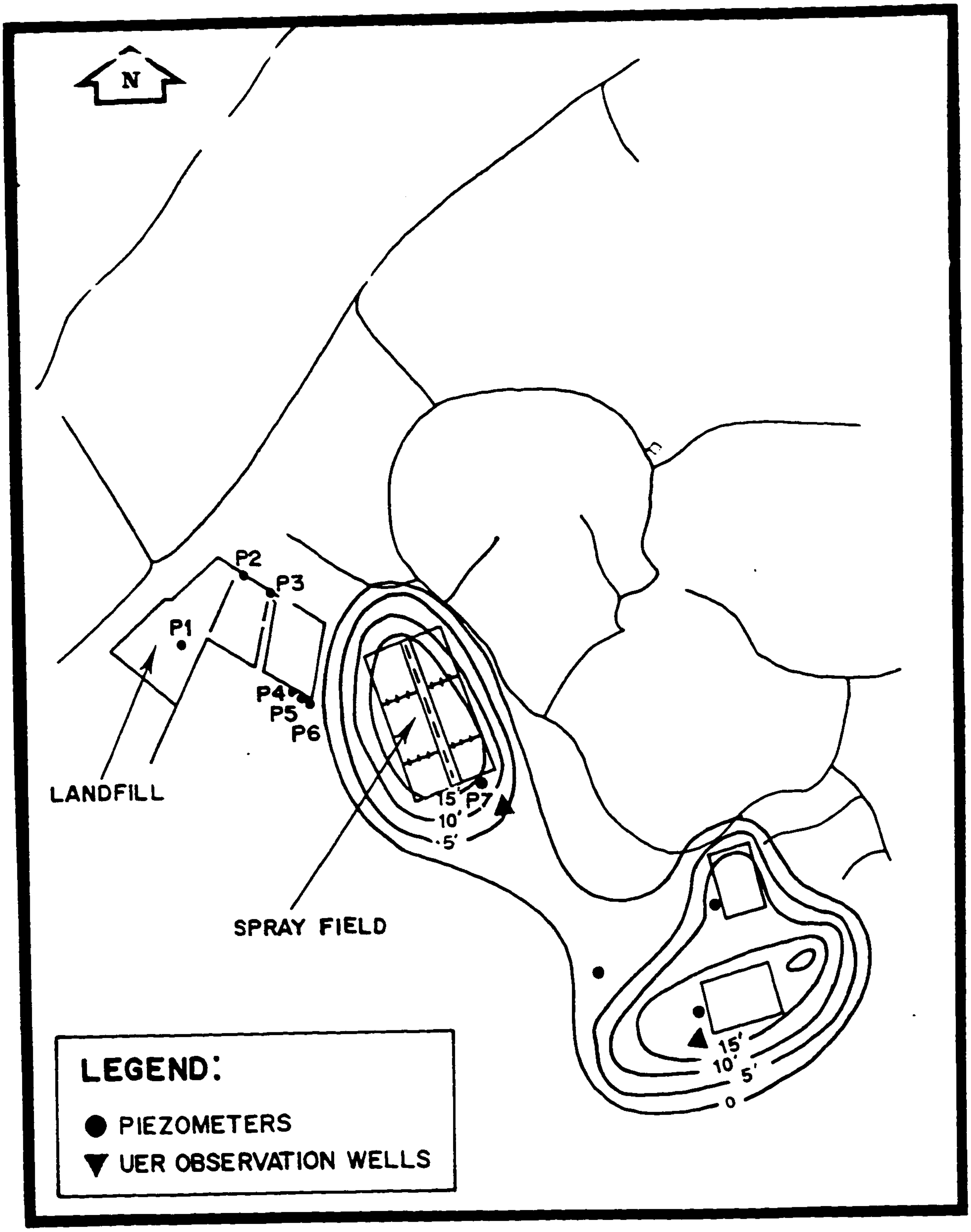


FIGURE 6. GROUNDWATER MOUNDING CONTOURS

Table 10 Soil Concentration Data

Parameters (mg/l)	Lysimeters No.				
	L-2	L-3		L-4	
	SAMPLING DEPTHS				
	17'	14'	18'	7.5'	18'
TDS	2000	1125	400	850	850
Arsenic	.24	.192	.208	.208	.208
Barium	2.88	4.16	4.64	3.2	8.96
Cadmium	ND	ND	ND	ND	ND
Chromium (total)	ND	ND	ND	ND	ND
Copper	1.12	.05	1.12	.8	.05
Iron	15.68	16.96	9.6	23.2	38.08
Lead	.8	ND	ND	1.44	ND
Manganese	32.64	29.44	34.56	25.28	43.68
Mercury	.032	.144	.032	.096	.112
Nickel	ND	ND	ND	ND	.8
Selenum	.8	.8	.64	.48	.8
Sodium	200	100.8	137.6	123.2	145.6
Silver	ND	ND	ND	ND	ND
Zinc	2.72	1.28	2.24	6.08	3.36
Chloride	336	240	360	352	400
Fluoride	9.8	7.2	8.5	8.2	9.3
Nitrite	ND	ND	ND	ND	ND
Nitrate	.6	ND	ND	ND	ND
Sulfate	1024	176	384	240	176
Ammonia-N	56	9.6	3.2	4.8	44.8
Organic-N	121	118.4	108.8	139.2	83.2

ND = Not Detected

samples were relatively high. The values of both ammonia-N and organic-N were high especially the organic-N. This indicates the presence of organic activity (biodegradation) in the soil. Again this is expected in a soil rich in organic matter.

4.2.4 GAS ANALYSIS

Gases found in landfills include air, ammonia, carbon doxide, carbon monoxide, hydrogen, hydrogen sulfide, methane, nitrogen and oxygen. Carbon dioxide and methane are the principal, gases produced.

Gas samples were taken and analyzed from the four lysimeters. Analyses were conducted both on-site and in the laboratory, . The on-site analyses were carried out for hydrogen sulfide, ammonia and hydrocarbons using Drager® indicator tubes. A general test for various gases and vapors was also carried out using a polytest Drager tube. In the laboratory the samples were analyzed for oxygen, nitrogen, carbon dioxide and methane.

The results of the gas analysis are shown in Table 11. The level of ammonia were less than 5 PPM for all lysimeters. The level of hydrogen sulfide in L-1, L-2 and L-3 was less than 5 ppm. But in L-4 at a depth of 8.25 feet from top of the lysimeter the level was 55 ppm. Tests for hydrocarbons and polytest were positive at L-2, L-3 and L-4.

As stated earlier, lysimeter L-1 was drilled in sand. No garbage came out during drilling. The results of gas samples for that lysimeter

Table 11 Gas Concentration Data

Lysimeter No.	Parameters (volume %)					
	O_2	N_2	CO_2	CH_4	NH_3*	H_2S*
L-1	19.3	77.6	3.1	ND	ND	ND
L-2	1.0	70.2	27.0	1.8	ND	ND
L-3	1.3	71.1	26.7	0.8	ND	ND
L-4	1.3	30.3	34.8	33.6	ND	55

* All parameters are in mg/l

ND = Not Detected

indicate a normal air component ratio: 19.3% O_2, 77.6% N_2 and 3.1% CO_2. For L-2 and L-3 the O_2 level is about 1% of air component and the CO_2 level is about 27%. This indicates the presence of biological activities where O_2 is consumed and CO_2 is generated. In addition a small percentage of methane gas was detected, 1.8% in L-2 and .8% in L-3. Both L-2 and L-3 were drilled in an area where the fill is young (2 years old). For L-4 the O_2 level is 1.3%, the N_2 level is 30.3%, the CO_2 level is 34.8% and the methane level is 33.6%. When solid waste is disposed to landfills it decomposes under aerobic conditions. Aerobic decomposition continues to occur until the oxygen depletes. Thereafter, decomposition will proceed anaerobically. After 18 months the composition of the gases will be stable, (Tchobanoglous, et al., (1977)). The high level of methane in L-4 is another indication that this fill in this part of the landfill is old. The problem related to methane is that when methane concentration reaches between 5% and 15% in presence of oxygen, explosive combination will form. However, there is no oxygen in landfills when methane concentration reaches this critical level and so there is no danger of explosion. However, proper ventilation of methane should be part of any landfill design. And additional problem is related to CO_2 which relates to its density being 1.5 times as dens as the air and 2.8 times as dens as methane (Tchobanoglous, et al., (1977). As a result CO_2 moves toward the bottom of landfills then penetrates through the soil and eventually reaches the groundwater, forming a carbonic acid which will increase the hardness as more calcium carbonate will dissolve in water.

CHAPTER V

REMEDIAL ACTIONS

5.1 Leachate Collection Systems

Leachate collection is another important element in sanitary landfill design and is used at landfills where liners are either installed or occur naturally to prevent leachate from reaching the groundwater. As leachate is formed, it accumulates on top of the landfill liner. If this leachate is not removed a pressure head develops over the liner and one of two things might happen; either (a) the leachate discharges through (or over) the landfill's side walls onto the adjacent ground surface; or (b) the pressure increases to such magnitude that unacceptable quantities of leachate are forced under pressure (via leaks, ruptures, etc.) through the liner. A leachate collection system consists of a network of pipes and sumps laid in the base of a landfill over the liner in such a manner to prevent the contamination of groundwater. There are two systems that are most commonly used at sanitary landfills: The Shallow Drain which is applicable when the subsurface is of a naturally occurring impervious material such as clay or bedrock (see Figure 7), and the Well System which is applicable if artificial liner is installed to protect groundwater (see Figure 8).

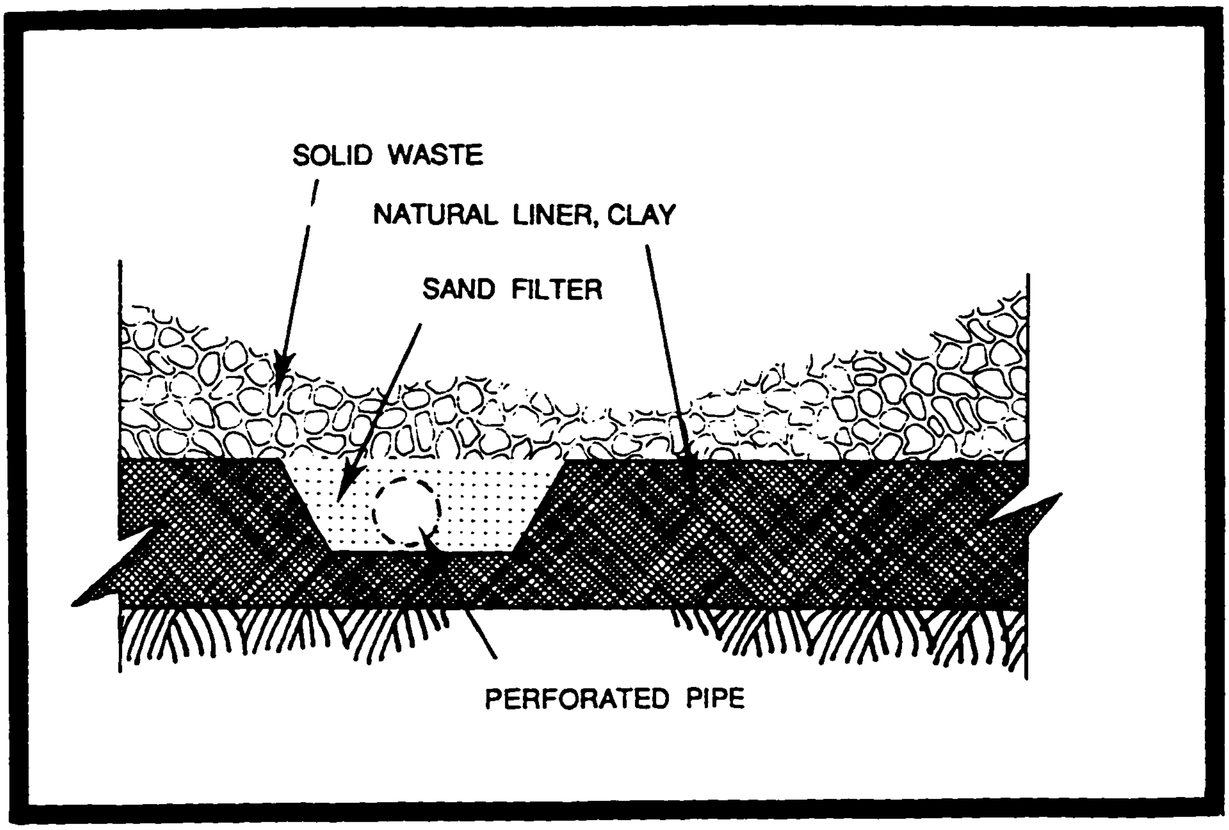


FIGURE 7. SHALLOW DRAIN SYSTEM

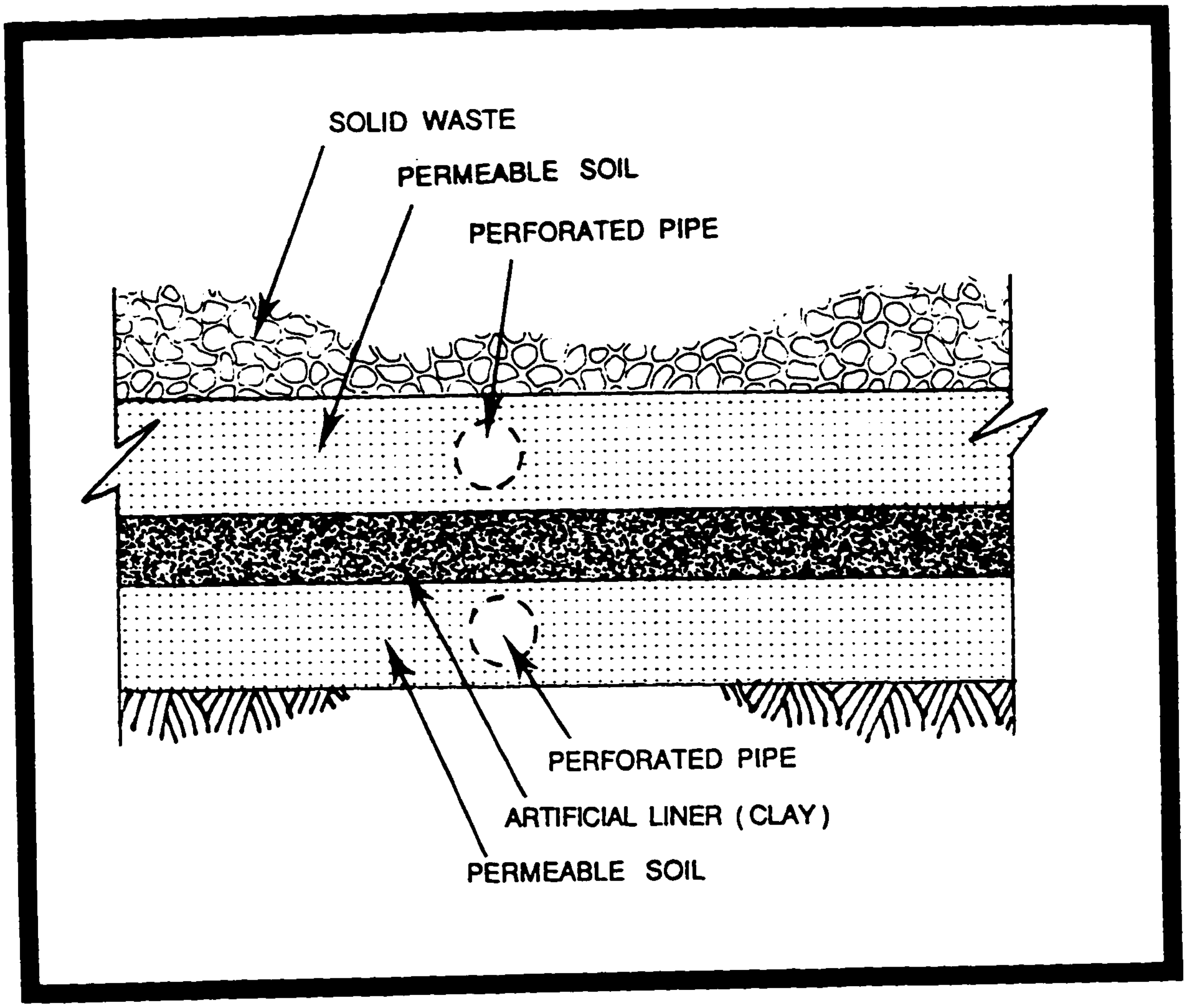


FIGURE 8. WELL SYSTEM

Because the studied landfill was not properly designed and does not have liners or a leachate collection system, as is the case of most landfills in Saudi Arabia, the leachate cannot be collected. What could be collected is the contaminated groundwater. The following are three suggested methods for collecting contaminated groundwater from beneath the studied landfill. These three methods are applicable for landfills having a similar hydrogeological setting to the subject landfill.

5.1.1 Slurry Trench Cut-off (Method No. 1)

The basic purpose of a slurry trench is to serve as a low permeability seepage barrier. The whole idea here is to build a wall with permeability between 1×10^{-6} and 1×10^{-8} cm/sec. This wall will prevent the groundwater from entering the site. The slurry wall can be placed upgradient, downgradient or completely surrounding the waste site. Slurry treanch can be made using two options: a soil-bentonite (S-B) slurry and a cement-bentonite (C-B) slurry. The main differences between both are cost, permeability and chemicals present in the water. An EPA handbook titled "Remedial Action at Waste Disposal Sites" dated October 1985 stated that C-B walls averages over 30% higher in cost than S-B walls. It also stated that the permeability of a C-B wall is normally around 1×10^{-6} cm/sec while a well designed S-B wall is capable of achieving 1×10^{-8} cm/sec and the C-B backfills are more susceptible to chemical attack than most soil-bentonite mixtures. C-B is susceptible to attacks by sulfate, strong acids and bases and other highly ionic substances.

I Recommended Option for the Subject Site

The S-B wall is the method recommended for the subject site because:

- Cost of S-B type will be less than C-B wall.
- S-B type will have better permeability and
- The presence of high sulfate in the water beneath the site (673 to 1260 ppm see Table 7) will effect the C-B structure.

II Design Consideration

Permeability: This is the most important design consideration of the completed wall. The S-B walls permeability should range between 1 x 10^{-6} and 1 x 10^{-8} cm/sec. This range is dependent on the backfill mixture. The lowest permeability is obtained from backfills having high percentage of fine soil material. Knowing the subsurface conditions and materials will assess on deciding the optimum configuration and selecting any ancillary measures needed to enhance the performance of the wall. The S-B walls permeability is dependent on the following:

Mixing: Three items will be used to construct the wall. The on-site material, the off-site material and bentonite. Percentage of these three materials should be determined in the laboratory so that the obtained hydraulic conductivity will be equal or very close to the required range. The mixing percentage should be determined as follows:

A- Evaluating of in Situ Soils: The hydraulic conductivity of the in situ soils at the site will determine their suitability for incorporation as part of the backfill mix. For example if the on-site soils consist of course-grained granular deposits, then large quantity of bentonite or a proportion of finer-grained soils from off-site source and smaller amount of bentonite would be required. If the site has variable soil conditions then several in-situ soils and possible off-site barrow gradations may need to be evaluated. Because the soil condition of the proposed site in not known, 12 borholes at 100 meters intervals should be drilled along the line of the proposed wall to the depth of the first impermeable layer which is expected to be at a depth less than 43 feet (see boring log of P-4). A continous soils samples should be obtained for each of the 12 borholes to determine the exact composition of the strata beneath.

B- Determination of Percent Fines: If it is determined that fine material is needed then a series of 11 backfill mixes should be prepared where off-site fines are added to on-site soil. The percentage of fines will be 0, 10, 20, 30, ... 100 percent of the mix. These mixes should be saturated with water and placed in constant volume molds at near minimum density. A graph showing % fine versus dry unit weight should be plotted from which the required amount of fine material to fill the voids will be determined. The point of maximum density which corresponds to minimum void ratio, should be chosen because it will yield a minimum hydraulic conductivity.

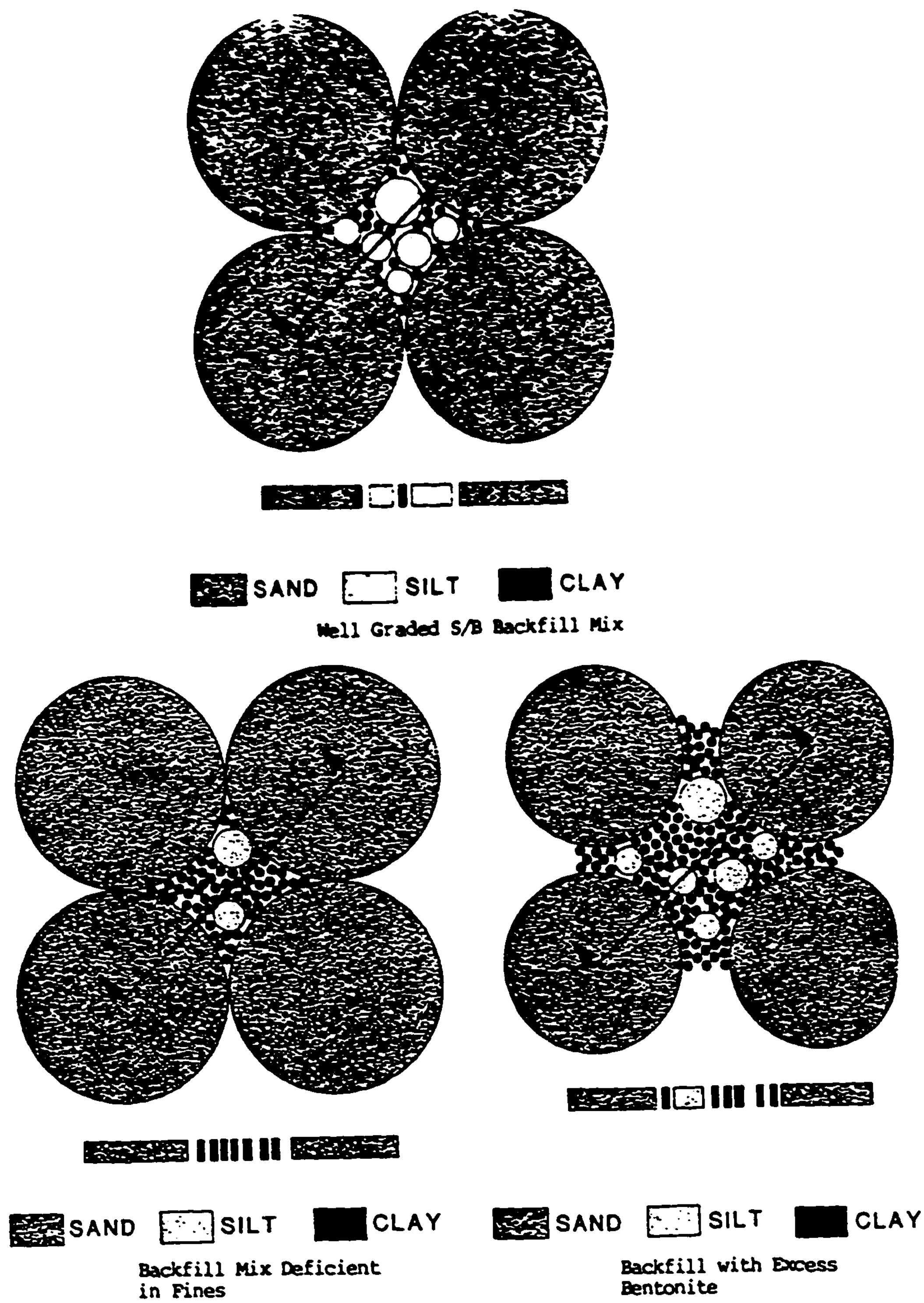
C- **Determination of Percent Bentonite:** After choosing the mix with maximum density, the hydraulic conductivity is determined. If the hydraulic conductivity is not between 1 x 10^{-6} and 1 x 10^{-8} cm/sec this samples should be divided into 5 groups and bentonite should be added as 1, 2, 4, 6 and 8%. Hydraulic conductivity should be determined for each. A curve should be drawn showing percent bentonite versus hydraulic conductivity. The point which yields the minimum hydraulic conductivity should be chosen as the percentage of bentonite to be added to the mix.

Failure to determine the percentage of fines and bentonite can result in a mix with too few fines or too much bentonite. Figure 9 shows 3 cases where the S-B backfill is well grader, deficient in fines and excess in bentonite. Other factors that should be considered includes: stress, temperature, and gradient. These are discussed below.

Stress: The higher the stress will lead to consolidation of the backfill, which will decrease the void ratio. This decrease will result in lower hydraulic conductivity.

Temperature: As temperature decreases the viscosity will increased. This will result in a lower hydraulic conductivity.

Gradient: As the gradient increases the void ratio will decrease. This will lead to a lower hydraulic conductivity.



SOURCE : BARVENIK et al; 1986

FIGURE 9. EFFECT OF DIFFERENT MIXING RATIOS

III Construction of the S-B Wall at the Subject Site

If the S-B wall is to be applied at this site it should be constructed so that it will extend from the Northeast to the Southern corner at a distance of 4167 feet (See Figure 10). The construction activity should be as follows:

Step 1: Determine the depth of the impervious layer at a distance of 3.3 feet from the edge of the upgradient side of the landfill (north east to south east). This was done when evaluating the in situ soils conditions. The wall will extend from the ground surface down to the impervious layer where it will penetrate one meter into the layer.

Step 2: Excavate a trench 3.3 feet wide using backhoe, clamshell or other suitable trenching equipment until the determined impervious layer from Step 1 is reached. The trench will look like semicircle. (See Figure 10).

S-B slurry should be introduced into the trench at the beginning of excavation and before the water table is reached. Mixing of the slurry should be at the edge of the trench. The primary function of the slurry is to prevent the sides of the trench from collapsing as the slurry will keep the pressure against the sides. It will also result in depositing an impervious flat cake on the treanch walls which will improve the cut-off's performance. The slurry trench should be keyed 3.3 feet into the impervious located material.

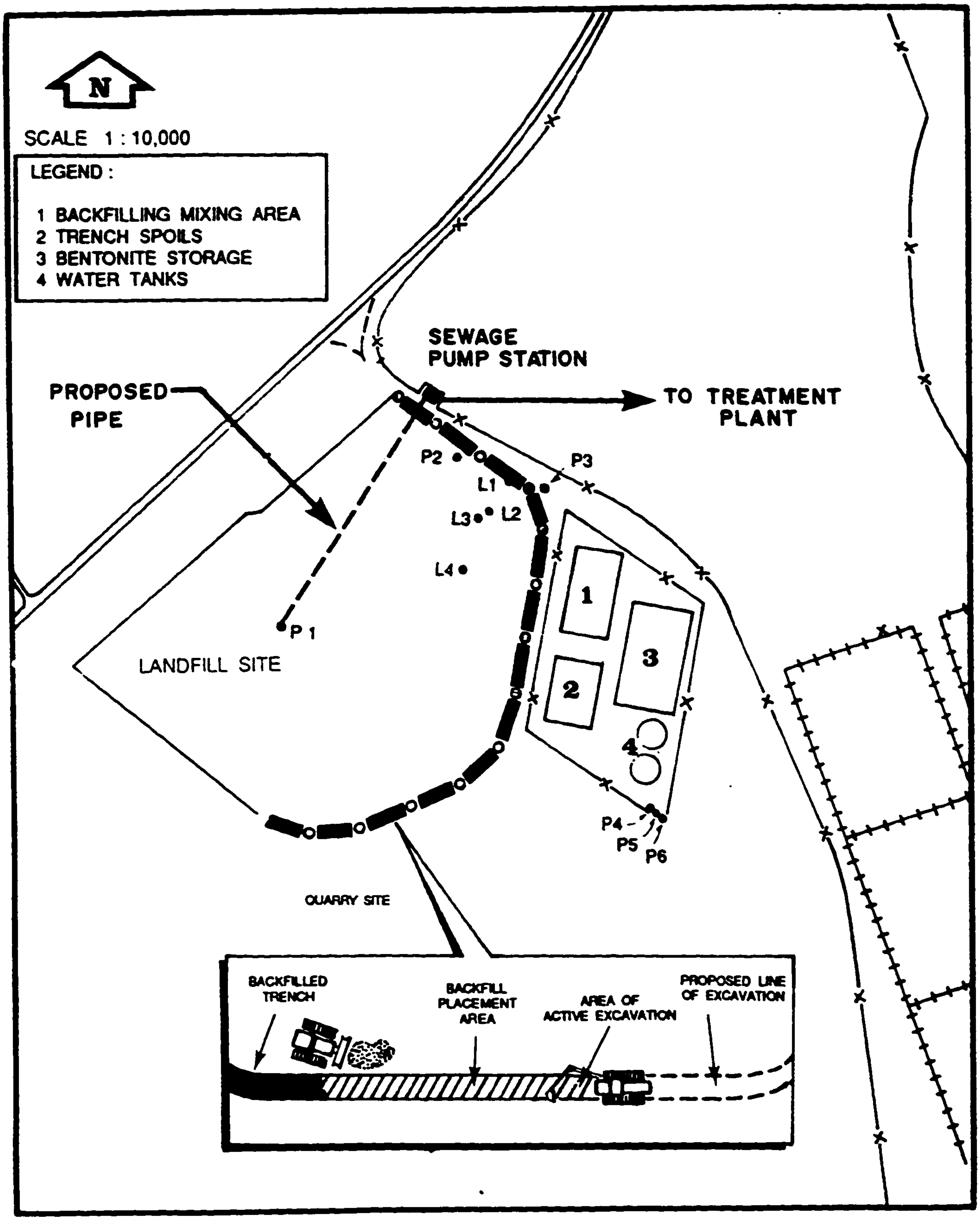
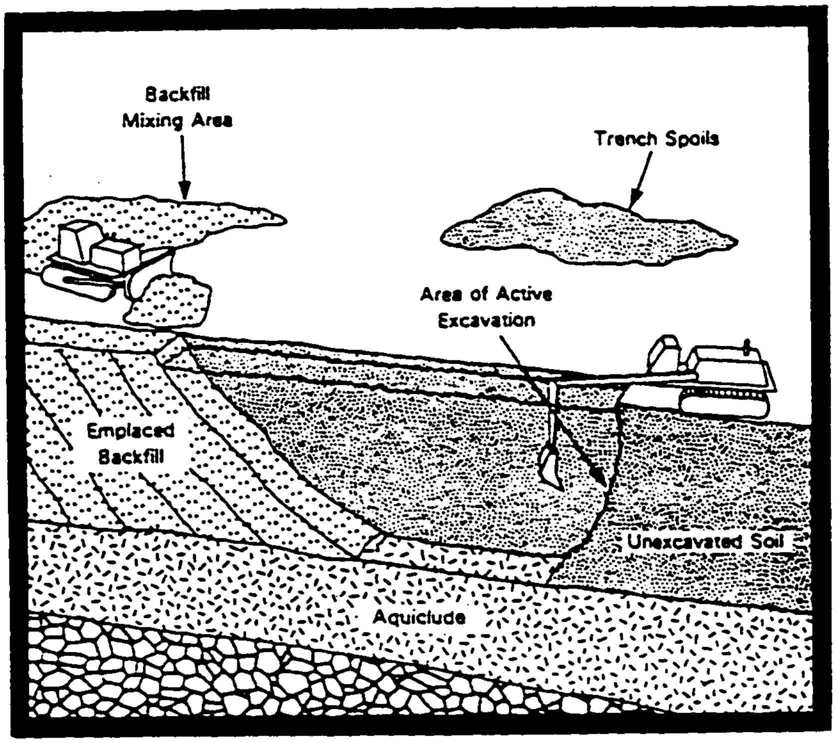


FIGURE 10. LOCATION OF PROPOSED SLURRY TRENCH WALL AT THE LANDFILL SITE

Step 3: After a sufficient length of the trench is excavated to the design depth, the excavated soil should be mixed with the bentonite slurry at the edge of the trench, bladed and tracked by a bulldozer. Backfilling can then begin using clamshell to lower mixed backfill to the trench bottom until the sloped backfill extends to the surface. Then the backfill should be pushed into the trench with a bulldozer or poured from trucks using a through, and allowed to flow down the sloped backfill see Figure (11). Backfill must be fluid enough to flow freely into the trench. As the trench is backfilled, the slurry is displaced, leaving a solid impermeable wall. When the trench completely surrounds the site from North East to South East, the cut-off and the wall will be completed. Figure 12 shows how the wall will prevent water from entering the site.

Step 4: At least one leachate collection well should be drilled in an area of the landfill toward which the remaining groundwater and leachate flows. From the hydrogeological study, this area will be at the same location of P-1. If P-1, can be developed to become a collection well there will be no need to install a new well. Factors such as well diameter, size of pump that can fit inside the well and the draw-down capacity shall be evaluated before the decision to develope this well is made. If it is found that P-1 cannot be developed, then a new well should be installed. The pumping capacity of the collection well should be determined based on the treatment scheme of the pumped water. Water should be pumped out (until the underlying strata is dry), treated and then discharged outside this area.



SOURCE : SPOONER et al; 1984-a

FIGURE 11. CROSS SECTION OF SLURRY TRENCH SHOWING EXCAVATION AND BACK FILLING OPERATIONS.

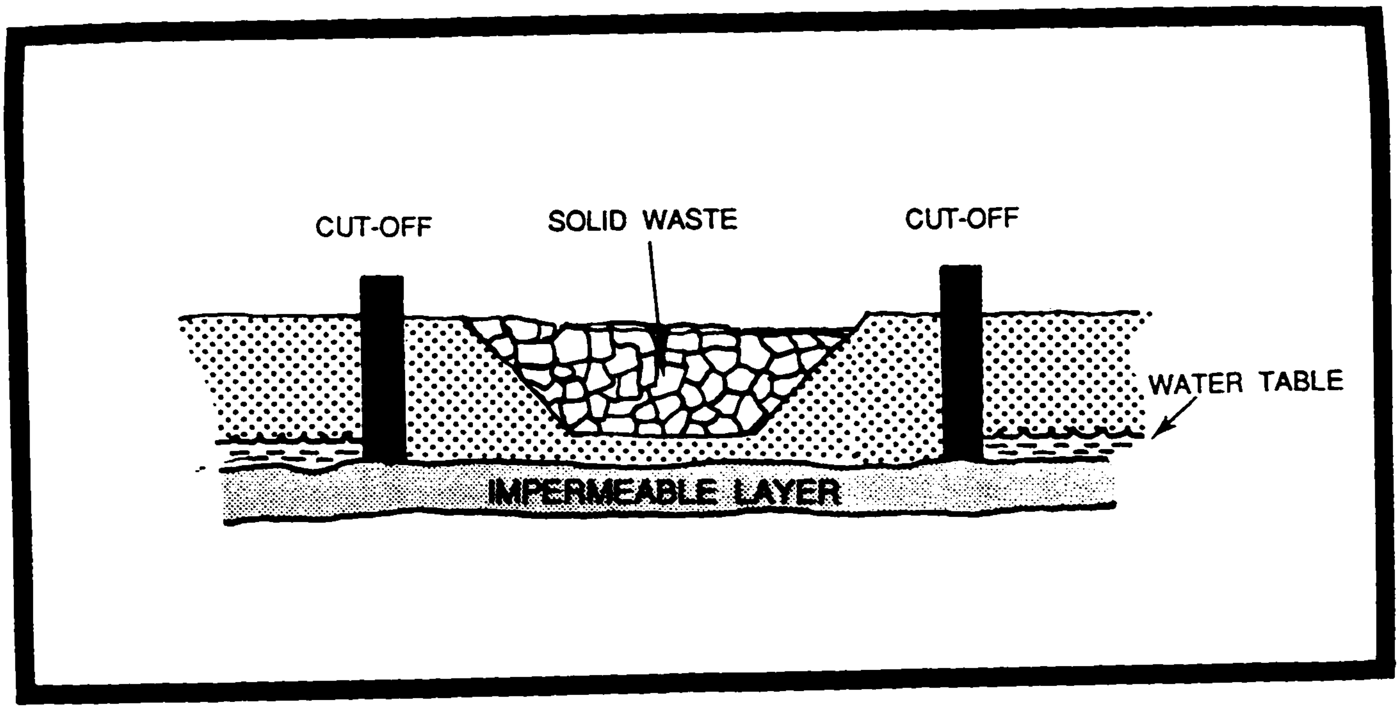


FIGURE 12. SLURRY TRENCH CUT-OFF METHOD

Step 5: Continue monitoring the existing piezometers (P-1, P-2, and P-3) to insure that water is not leaking through the constructed cut-off trench.

The installation of the slurry cut-off trench will prevent groundwater from entering the site. This will result in preventing the shallow groundwater from becoming contaminated. But this is not enough. It is very important to cap the site either as the landfilling progresses or when the landfill is totally filled. This will prevent rainfall from infiltrating the site and generating more leachate. Clay should be used to cap the site and is available from a nearby location at a distance of approximately 1800 feet to South of this site. The cap should be 2 feet thick and should also be graded (2% to 4%) to induce drainage and prevent the ponding of rain water. The surface drainage should be consistent with the surrounding area (slop should be towards the North of the landfill).

5.1.2 Suction Lift (Method No. 2)

The basic of this method is to pump contaminated groundwater to the surface downstream of the landfill, treat it , and then pump it back upstream of the landfill or to another disposal location. If this method is to be applied at the site, it should be done as follows:

Step 1: Install a minimum of one recovery well downgradient of the landfill. This well is generally aligned perpendicular to the direction of groundwater flow. As stated in Step 4 of the previous method, if P-1 can be developed to become a recovery well, it should then be used. If P-1 cannot be developed, a new well should be installed.

Step 2: Select a vacuum unit. This can be a common vacuum truck or specialized pumping equipment. The capacity of this vacuum unit depends on the speed of the treatment systems.

Step 3: Draw the contaminated groundwater into the receiver (i.e., vacuum truck, etc.) using suction lift of the pumping equipment and then transfer for proper treatment. To ensure efficient recovery, the borehole annular must be sealed.

Step 4: Following treatment, uncontaminated water can either be reacharged back into the aquifer or discharged on the ground surface away from the site.

Step 5: As in method No. 1 the surface must be capped to prevent any rainfall infiltration. Figure (13) shows how this method works.

5.1.3 The Grout Curtain (Method No. 3)

Basically the grout curtains are constructed by injecting cement mixture under pressure into subsurface soils to fill the voids between grains, thus restricting ground-water-flow. Generally, the grout mixture is injected into a series of closely-spaced holes. One raw of holes is drilled, grout is injected and a second raw of holes, stagged from the first, is drilled and grout is again injected (Figure 14). Spacing of holes depends upon site geology and hydraulic characteristics

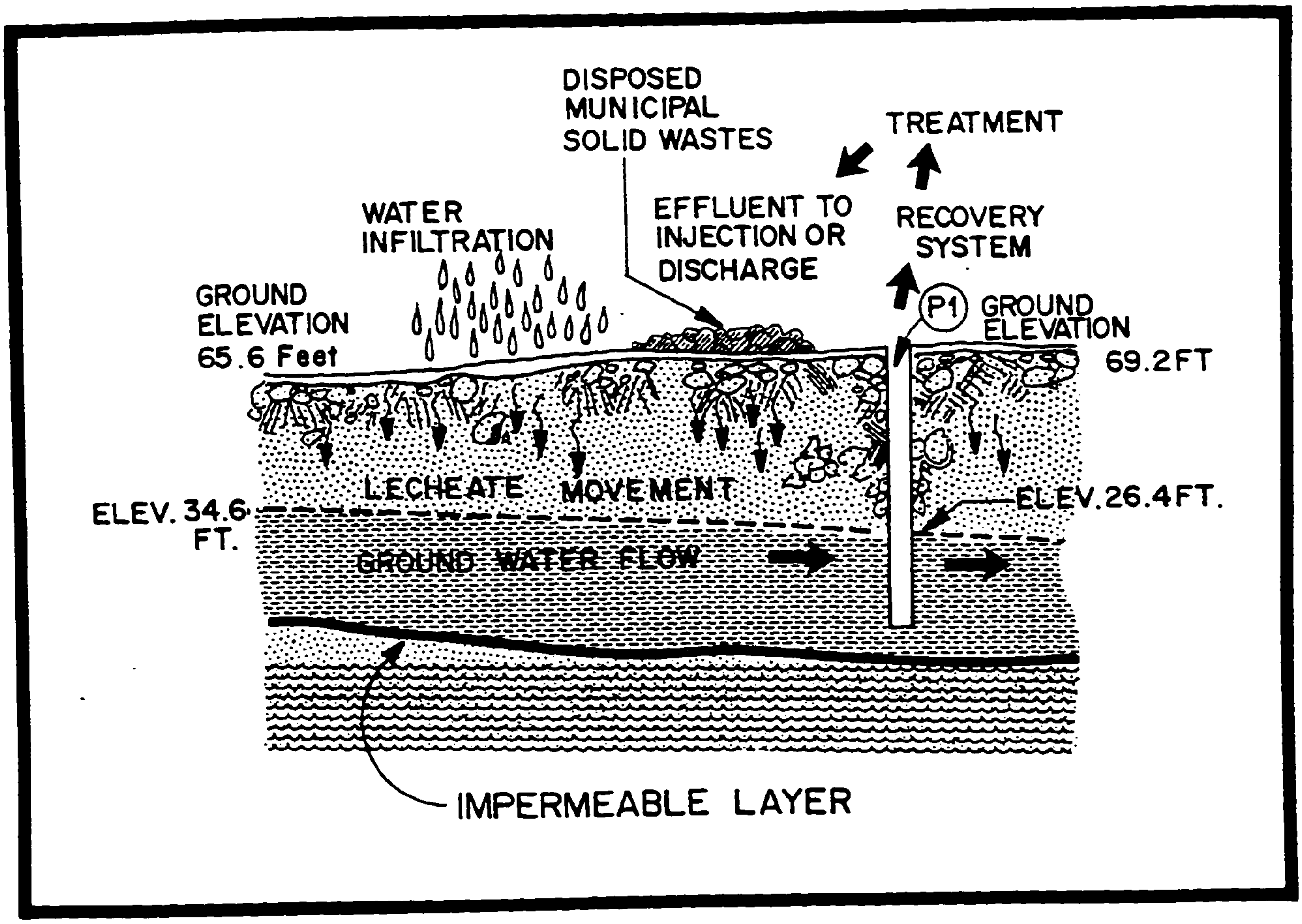
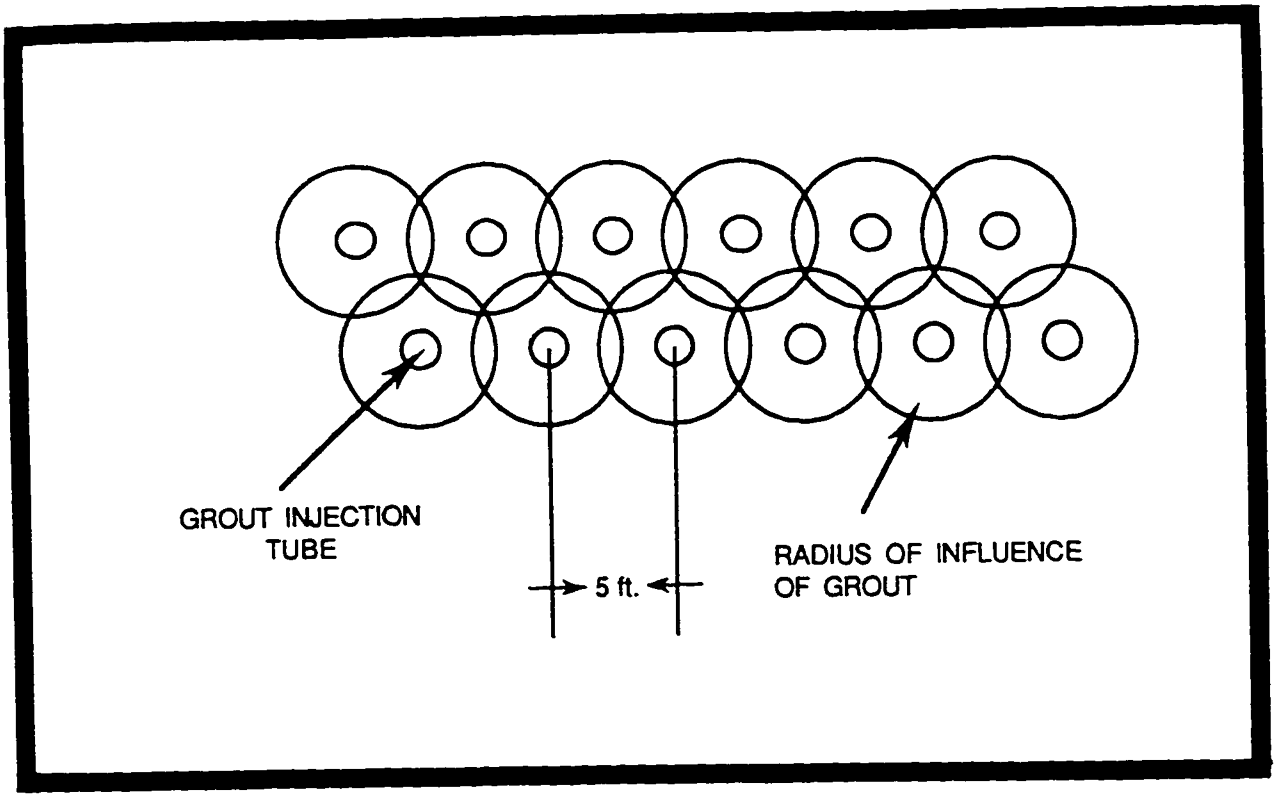


FIGURE 13. SUCTION LIFT METHOD

and is determined by the penetration radius of the grout away from the holes. The amount of grout needed to produce an effective impervious barrier is a function of available void space, density of the grout and pressure used in setting the grout (Nielson, 1984). Figure (15) shows how a semicircular grout curtain would look like. This method was not considered because it is very costly and it is difficult to ascertain the degree of completeness of the grout curtain.

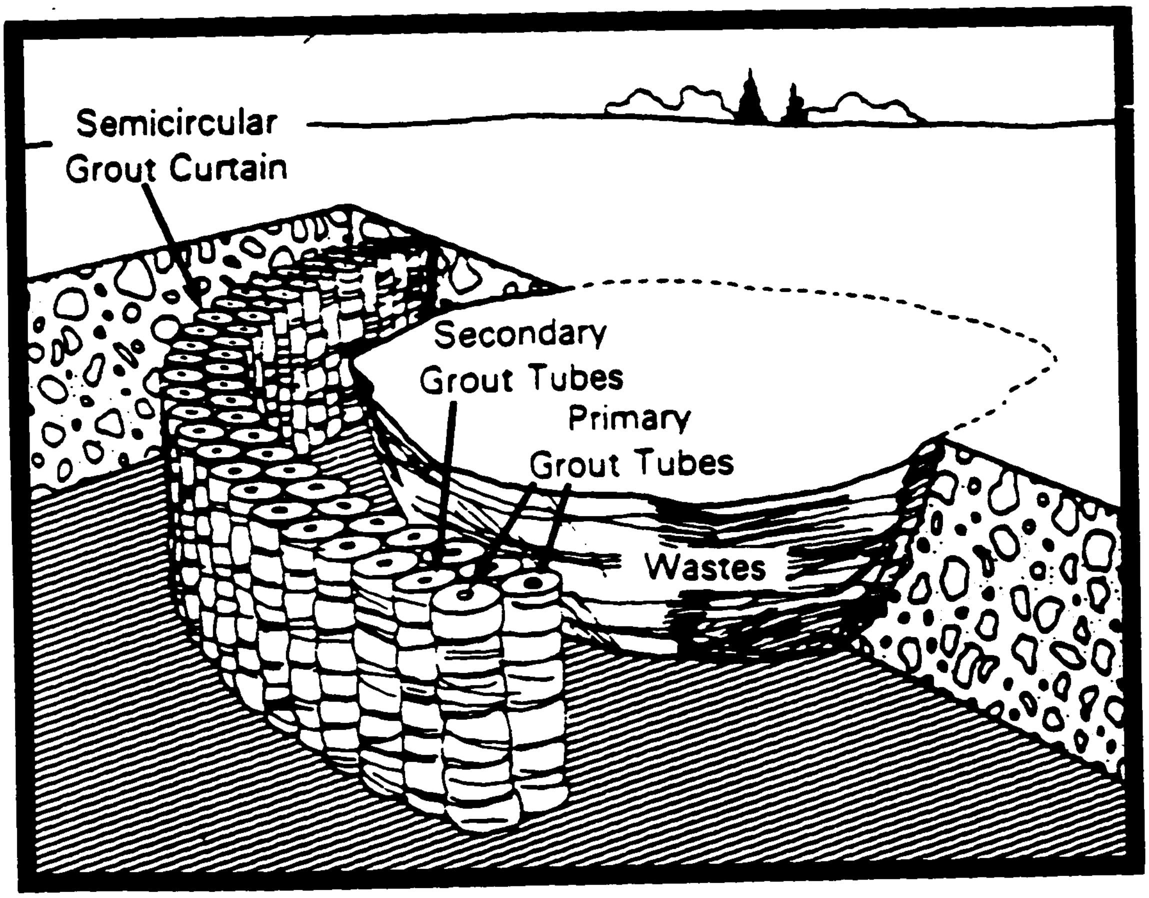
5.1.4 Recommended Method

The slurry trench cut-off, the grout curtain, and the suction lift methods can be applied at the landfill. From a technical point of view the slurry trench cut-off is the best method as it will prevent the groundwater from flowing beneath this site and will eventually result in completely eliminating leachate. The grout curtain method will not guarantee completely that water will be prevented from flowing beneath the site. The suction lift method will result in treating contaminated groundwater indefinitely. It is believed that the grout curtain will be the most expensive method followed by the slurry trench cut-off. However, a complete cost analysis is required to determine this. The construction of the lift suction will be the cheapest; however this method will require ongoing maintenance and operational costs that will escalate with time. Therefore, the slurry trench cut-off is the recommended method.



SOURCE : (U.S. EPA 1978)

Figure 14. TYPICAL TWO-ROW GRID PATTERN FOR GROUT CURTAIN



Source : Spooner et al., 1984b

FIGURE 15. SEMI-CIRCULAR GROUT CURTAIN AROUND WASTE SITE

5.2 Leachate Treatment Systems

Treatment of raw leachate has been and still remains the subject of many studies. All of the conducted studies in the U.S. indicated that leachate can be treated biologically or through physical and chemical processes. The biological treatment of leachate includes both aerobic processes (activated sludge, extended-aeration, aeration lagoons and oxidation ditch processes) and anaerobic processes(anaerobic lagoons, anaerobic digesters and anaerobic filters). The physical/chemical treatment of leachate includes activated carbon, adsorption, chemical precipitation and chemical oxidation. All of the conducted studies indicated that aerobic and anaerobic treatment processes were the most effective in removing organic matter compared to the physical/chemical treatment. In a study conducted by Keenan, et al., (1983), it was determined that a plant consisting of equalization, lime precipitation, sedimentation, and air stripping of ammonia resulted in the following percentage removals: 69 BOD, 53 TKN, 38 Cu, 98 Fe, 66, Pb, and 45 Zn. This study also showed that when physical/chemical treatment is followed by biological treatment (activated sludge system) the efficiency of both treatments was excellent. The following percentage removal was obtained: 94 BOD, 75 Cu, 94 Fe, 93 Pb, and 47 Zn. Other studies also indicated that a combination of biological and physical/chemical treatment was most effective in removing both organics and heavy metals (Chain and DeWall (1976), Boyle and Ham (1974) and Robinson and Maris (1983)).

Between 1971 and 1972 a study conducted at the University of Kentucky in the U.S.A. indicated that using an anaerobic filter to achieve the best COD removal require a loading of 80 lb COD/1000 ft^3/day and a 10-day detention time. The achieved COD percentage removal was 96. The study also indicated that with activated sludge unit, the best operational condition is a detention time of 10 days which resulted in a MLVSS concentration of 4400 mg/l. The COD percentage removal was 97 and the BOD percentage removal was 99.7. It also indicated that when the effluent from the activated sludge is treated by physical/chemical processes such as filtration and activated carbon, the percentage removal was as high as 99.4. The ideal system should consist of physical/chemical treatment followed by biological treatment.

The question of which system should be used in Saudi Arabia can be best answered as, choose whatever biological system that exist near or at your area. Once leachate is obtained and analyzed then it can be determined whether a physical/chemical treatment is needed. If such treatment is needed and not available then the least expensive and easiest system should be used. This system can be part of the plant by having a coagulation and precipitation process in which lime is to be used. The effluent should then be sent to the biological processes.

5.2.1 Wastewater Treatment Plant

A plant treating wastewater is located to the east of the landfill: The Plant capacity is 30,300 m^3/day (8,000,000 gpd). At present it receives about 22,700 m^3/day (6,000,000 gpd). Treatment, shown in Figure 16 includes extended aeration activated sludge, disinfection by chlorination, and a final holding pond. Discharge from this plants is disposed of by evapotransporation using spray fields. Also, a project is now underway to provide tertiary treatment for 11,400 m^3/day (3,000,000 gal/day) of the wastewater from the plant. The treated effluent will then be reused as landscape irrigation water. The tertiary plant will have a coagulation step and will carry a high chlorine residual to further insure a low virus and coliform count in the irrigation water.

5.2.2 Treatment of Leachate From the Subject Landfill

Pure leachate from the subject landfill cannot be collected because as stated earlier, there is no collection system at this landfill. The leachate can be collected as part of the shallow groundwater aquifer which the leachate has reached and contaminated. When the contaminated groundwater is pumped out from this site, this water can be sent to a wastewater treatment plant and treated. The chemical analysis of the water from beneath the landfill (Table 7) indicates that the quality of the water will not cause any threat to a wastewater treatment plant. Table 12 shows the composition of the contaminated groundwater and the leachate and a typical concentration of wastewater and inhibitory concentration for activated sludge process. From this table and knowing that the contaminated water and leachate will be diluted (100-200 times), then it can be concluded that there will be no threat to the treatment plant from the contaminated water and leachate. In addition Table 13 which shows a typical effluent from the treatment plant located east of the landfill, indicates that the contaminated groundwater composition is similar to the concentration of the effluent. This again will emphasize that this water will not cause any threat to the plant.

5.2.3 Proposed Scheme for Treating the Contaminated Groundwater

The only concern for sending this water directly to the treatment plant is the presence of the heavy metals. However, Table 7 indicates that heavy metals are not a concern due to their low concentrations. In addition, the analysis of collected leachate (Table 6) does not show the presence of any heavy metal in high concentration. The following is a proposed scheme for treating the contaminated water:

Step 1: A pump with capacity of 30 gpm should be installed at the collection well and a 3 inch plastic pipe should be installed to connect the pump at the well to an existing sewage pump station located 500 meters to the east of the well (Figure 10). This pump station is connected to the Sewage Treatment Plant.

Step 2: Pump the water at a rate of 30 gpm continuously which will be equal to 43,000 gallons per day. The contaminated water will be mixed with the treatment plant's incoming 6 millions gallons per day. This will insure that the organic concentration (BOD, COD, etc.) and other contaminants will be diluted and will not cause any shock to the system. The dilution rate will vary from 10 to 20.

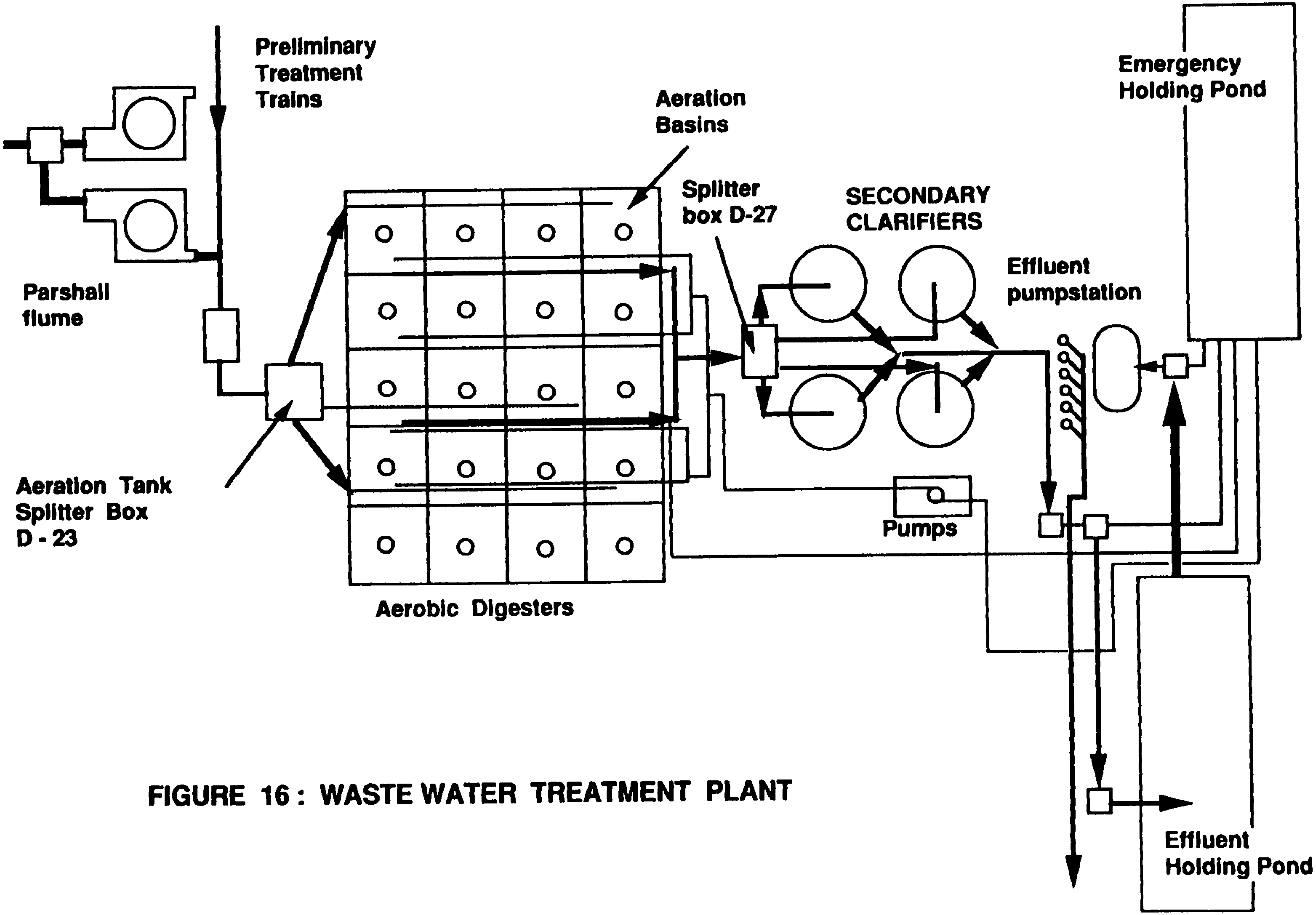


FIGURE 16 : WASTE WATER TREATMENT PLANT

Table 12 Leachate and Contaminated Groundwater Concentration Data and a Typical Concentration in Municipal Wastewater and the Inhibitory Concentration for Activated Sludge Process.

Parameter	Landfill(1) Leachate L-3 (mg/l)	Landfill(1) Leachate L-4 (mg/l)	Landfill(1) Groundwater (mg/l)	"Typical"(2) Concentration In Municipal Wastewater(mg/l)	Inhibitory Concentration(3) for Activated Sludge Process (mg/l)
Arsenic	.029	.041	.024		0.1
BOD_5	2006	104	2-11	200	
Cadmium	.012	.015	ND	0.002-0.009	10-100
Chloride			611-2166	20-100	8000-15000
Chromium	.13	.05	ND	0.1-0.15	50
COD	3320	875	12-36	400	
Copper	.11	.07	ND	0.02-0.1	1.0
Iron	.86	.44	.13-1.23	0.12-0.2	1000
Lead			.06-.115	0.05-0.1	0.1
Manganese			.105	0.02-0.03	10
Mercury			ND	0.00005-0.00015	0.1-5.0
Ammonia-N			.5-4.6	25-60	480-1600
NO_2+NO_3-N	96	245	.5-1.1	0-1.0	
Nickel			ND	0.075-0.170	1.0-2.5
pH	7.4	7.8	6.9-7.65	6-8.5	
Silver	ND	ND	ND		5
Sodium			297-1097	23-80	
TDS	1500	2000	2630-5998	250-850	16000
Sulfate			673-1260	15-80	
Zinc			.05-17.7	0.04-0.1	0.08-10

(1) Actual data derived from this study

(2) WPCF, ASCE (1977); Klei, et al (1980)

(3) WPCF, ASCE (1977); Eckenfelder, et al (1970); USEPA (1977)

ND = Not Detected

Table 13 Maximum Allowable Limit for the Effluent from the Wastewater Treatment Plant

TOXIC SUBSTANCE	MILLIGRAMS/LITER
Nickel	0.2
Lead	0.1
Arsenic	0.1
Barium	1.0
Cadmium	0.02
Chromium	0.1
Copper	0.2
Fluoride	0.80
Mercury	0.0001
Selenium	0.01
Iron	1.0
Zinc	1.0
Phenis	0.1
Total Nitrogen (N)	5
BOD	25
COD	150
TOC	50
TKN	5

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The following conclusions are drawn for this study:

1. Even-though the landfill is located in an arid region, leachate is produced but in small quantity. The production of leachate is completely dependable on the quantity of water infiltrating the refuse. When rainfall is the source of the infiltrating water, the intensity of the rain and types of soil material covering the wastes are what govern the production of leachate. The only time leachate was collected, followed an intense rainfall.

2. The ability to predict the quantity of leachate from unlined landfills is very difficult. Standard methods to calculate the generated quantities such as the water balance equation are not applicable to arid regions in general and to this landfill in particular.

3. The leachate has a high concentration of organic matter and low concentrations of heavy metals. The variation on the leachate concentration of organics is function of the age of the fill. The older part of the site (more than 5 years) has a BOD, COD and TOC concentrations of 104, 875 and 76 ppm respectively while the younger part (two years) had values of BOD, COD and TOC of 2006,

3320 and 1020 ppm respectively. The neutral pH values for the leachate (7.4 - 7.8) justify the low concentration of heavy metals in the leachate. Also the high concentration of these metals in the soil indicates that heavy metals are absorbed by the soil.

4. It has been determined that sanitary landfills are potentially dangerous sources of pollutants such as organic compounds, heavy metals and bacteria. The shallow aquifer beneath the studied landfill is being polluted by leachate. The presence of contaminants, especially the heavy metals in the soil at high concentrations, is an indication of such contamination. Over time as water infiltrates the soil, these contaminants may reach the groundwater.

5. If the shallow aquifer is non-usable and the deep aquifer is protected by impermeable material and if both the shallow and deep aquifers are not connected, then it is not necessary to clean the aquifer and the area can continue to be used as long as deep groundwater monitoring is conducted. The uncertainty of the contact between the shallow and deep aquifers in the site makes it necessary to recover and treat the contaminated shallow water.

6. Leachate collection methods are not applicable to this site due to the absence of collection systems. Because leachate has reached the shallow water, it can be collected by pumping the water up to the surface.

7. The literature indicates that activated sludge process is an effective and efficient means of leachate treatment. The contaminated water can be easily transported and treated in a nearby sewage treatment plant. The fact that the contaminated water will be diluted with wastewater at a dilution factor of 100 to 200 makes it safer to discharge this water into the sewer system directly without any pretreatment or addition of raw water.

6.2 RECOMMENDATIONS

The following recommendations are made in this study:

1. Proper landfill design is essential to assure the protection of groundwater. This should include proper site selection, groundwater protection and monitoring, leachate collection and treatment and proper cover material.

2. Laws and regulations are needed to assure that landfills are properly designed and operated.

3. Flood-zone areas, a low-lying site that might be drainage basin for surrounding areas, or a groundwater recharge area should not be selected for landfilling.

4. Leachate should be collected and treated if it poses any threat to underlying groundwater. For the studied site the slurry trench cut-off's method is most applicable, feasible and recommended.

5. Biological treatments are applicable for leachate treatment. An activated sludge plant near the landfill should be used for treating the contaminated water. Dilution should also take place to assure that all metals and organics will not cause a shock to the systems.

6. Preventing leachate generation should be the first measure to be applied at this site. This includes placing proper cover material such as clay to ensure that no water will infiltrate the site and placing a barrier upgradient of the landfill to prevent groundwater from flowing beneath the landfill.

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