CHAPTER 2: LITERATURE REVIEW

2.1 Historical background to waste management

Problems of waste management have existed ever since humans made the transition from hunting and gathering societies to settled communities. In early references to problems associated with waste generated by humans, the primary concern seems to have been with the nuisance factor and its potential impact on health. Wastes are unsightly, filthy, and foul-smelling, thereby bringing discomfort and inconvenience. Technological innovations in the construction of houses designed to remove garbage and human wastes from the immediate presence of the household appeared to have occurred in India, Egypt, and China as early as the third and second centuries B.C. According to Melosi (1981), the first municipal dumps were established in Athens, around 500 B.C. and the Council of Athens began requiring scavengers to dispose of wastes no less than a mile form the city walls. In about 1400 A.D., a regulation was enacted in Paris which stated that those who brought a cart of sand or gravel into the city were to leave with a load of mud or refuse (Melosi, 1981).

The late nineteenth and early twentieth centuries witnessed the appearance of several types of municipal sanitation services, including garbage collection, street cleaning, and wastewater collection and treatment. However, even after the institution of garbage collection services, waste disposal methods in developing countries remained rudimentary and consisted mainly of indiscriminate discharging of wastes in town dumps, on open land, and sometimes into watercourses. As the inadequacies of waste disposal began to be recognized, interest developed in new technologies of waste handling. Attention was given to the "cremation" or burning of waste. The first incinerator of solid waste was developed in England in the 1870s (Melosi, 1981).

Changes in the nature of wastes, concern for environmental protection, and the desire to recover resources from the waste stream have stimulated the development of new waste management technologies and processes. Carefully engineered sanitary landfills have replaced open dumps and incinerator technology has been greatly improved.

2.2 Municipal solid waste management

In general terms, solid waste can be defined as waste not transported by water, that has been rejected for further use. For municipal solid waste, more specific terms are applied to the biodegradable (putrescible) food waste, called garbage and the non putrescible solid waste, referred to as rubbish. Rubbish can include a variety of materials, which may be combustible (paper, plastic, textiles etc) or noncombustibles (glass, metal masonry, etc) (Henry,1996).

Municipal solid waste includes wastes such as durable and nondurable goods, containers and packaging, food scraps, yard trimmings and miscellaneous organic and inorganic wastes from residential, commercial, institutional and industrial sources.

Residential wastes are produced by households and other types of dwelling units. Commercial waste results from retail, wholesale, and service activities in a community. Institutional waste is produced by schools, hospitals and in buildings housing governmental functions. The industrial waste that is included is primarily from the office and support operations and does not include waste produced by processing and manufacturing operations.

Within the range of management options, Environmental Protection Agency (EPA) suggests a four level hierarchy to consider when planning and implementing integrated waste management (U.S. EPA, 1989). The first level of the hierarchy is waste prevention followed by source reduction. Individuals, government and commercial establishments and industries are expected to participate in source reduction by reducing the quantity of solid and toxic waste. The third level of the hierarchy is recycling. This involves collecting, reprocessing, marketing, and using materials that were once considered trash. Many of the components in our waste stream, from metals to plastics, to used oil and yard waste can be recycled. The next level in EPA's hierarchy is waste treatment and disposal like combustion. Combustion can be used to reduce the volume of the waste stream and to recover energy. Finally, the last level of hierarchy is landfilling. Landfilling is the only true disposal option. It is a necessary component of waste management, since all management options produce some residue that must be disposed of through landfilling.

A typical Malaysian town or city dweller generates on average 0.5-0.8kg of solid waste a day. Residents in Klang Valley generates about 3500 tonnes daily (Hassan, 1998). Table 2.1 gives the contents of the municipal waste in

Malaysia. In general, organic matter constitutes the highest percentage followed by paper and plastic.

Table 2.1 : Contents Of The Nation's Rubbish Bins

Contents	Percentage (% by dry weight)
Paper and card	27
Organic matter	37
Plastic	16.5
Wood	7
Metal	4
Glass	3
Cloth	3
Others	0.5

Source: Hassan (1998)

Table 2.2 shows the waste generation characteristics in the Municipality of Petaling Jaya, Kuala Lumpur and Penang respectively. These three areas are considered the most populated and industrialized areas in Malaysia. Kuala Lumpur which has the largest population generates the largest amount of waste compared to the other two cities. Meanwhile, the population in Penang is higher than in Petaling Jaya, but the total waste generation in Petaling Jaya was observed to be higher. This is because of a higher standard of living in Petaling Jaya which gives rise to the generation of more food packages and paper.

Table 2.2 : Projected Waste Generation For Kuala Lumpur, Petaling Jaya And Penang

Year	Kuala Lumpur		Petaling Jaya		Penang	
	Total population	Total waste generation (tonnes/day)	Total population	Total waste generation (tonnes/day)	Total population	Total waste generation (tonnes/day)
1990	1 207 000	2 286	419 000	469.3	562 300	452
1995	1 490 000	2 619	508 000	604.5	615 700	556
2000	2 150 000	3 070	607 200	777.2	676 000	680
2005	3 050 000	3 478	695 000	959.1	718 000	784

Source: Agamuthu (1997)

Table 2.3 compares the waste composition in some Asian countries. The countries produce more vegetable putrescible waste but developed countries like Singapore and Japan generate more paper. Industrial nations like Taiwan generate more incombustible waste.

Table 2.3: Comparative Municipal Solid Waste Analysis (Wt %) In Some Asian Countries

Waste composition	Kuala Lumpur	Bangalore	Taiwan	Singapore	Japan
Metal	6.4	0.1	1.1	3.0	5.9
Glass/ ceramics	2.5	0.2	2.8	1.3	15.0
Vegetable putrescible	63.7	75.2	24.6	4.6	11.7
Paper	11.7	1.5	7.5	43.1	38.5
Textile	-	3.1	3.7	9.3	4.0
Plastic/ rubber	7.0	0.9	7.3	6.1	11.9

Source: Agamuthu (1997)

Over the years, the amount of municipal solid waste generated in the United States has grown steadily, in part because of increasing population, but more so because of changing lifestyles and the increasing use of disposal materials and excessive packaging. Municipal solid waste now amounts to somewhat over 2 kg per person per day. Currently (1998) U.S population of 270 million, generate enough waste to fill 80,000 garbage trucks each day, with a total output of 209 million tonnes per year (Nebel and Wright, 1998).

Quantity and composition of municipal solid waste vary greatly for different municipalities and time of the year. Factors influencing the characteristics of MSW are climate, social customs, per capita income and degree of urbanization and industrialization. The characteristics of municipal solid waste changes with time as the society evolves to the needs of development. Although changes are observed, general trends in the developing countries are still visible, the organic vegetable waste being the most generated followed by paper waste.

2.3 Recycling And Process Recovery

Worldwide population growth, urbanization, technological development, and growth in economic activity generate large quantities of waste, but they also place great pressures on the finite material and energy resources on earth. Recycling, the third element in the integrated waste management list has captured the imagination of environmental groups and the public in the early 1970s.

In 1990, an estimated 30 million tonnes of municipal solid wastes were recycled out of a total of 177 million tonnes of solid waste generated in the United States (U.S. EPA, 1992). This represents a recycling rate of approximately 16.9%, but also does not include recovery of such materials as sewage sludge, automobiles , and construction and demolition debris. In 1994, recover (recycling and/or composting) levels for U.S. MSW had reduced landfill volume requirements by 23%. Source reduction by removal of 85% of yard waste mass would increase the savings to 28% (Douglas, 1998). The US state of Arkansas has achieved its planned recycling rate of 40%, two years ahead of the schedule. In 1998, Arkansas recycled more than 800,000 tonnes, saving RM 87 million (US $23 million) in disposal costs. The success has sustained 700 public sector jobs, with 4,000 jobs in the private recycling sector (Warmer Bulletin, 2000).

What does recycling means? Recycling is the putting back into use of products or materials that have completed their original function. The term recycling often refers to a wide range of activities such as collecting, sorting, transporting and re-processing previously used items. Items can be recycled in three main ways which are re-use, re-claim and re-make.

Re-use refers to item which is used again without having to change its original shape. It may be a simple case of cleaning and repairing before being put back into use. An example of this is the washing and refilling of bottles.

Re-claim is the extraction of some useful part of a used item in a way that usually totally destroys the item in order to take out the useful part. An example of this is to burn waste paper for fuel, releasing its heat energy but destroying the original material. Re-make is the process by which used material is re-moulded or reformed into a 'brand-new' product. This is the most complete form of recycling as it is often the method used to make identical new items from old waste items. A good example of this is the remelting of aluminum cans to produce new aluminum cans. This is sometimes referred to as re-processing or recycling (Alam Flora Sdn. Bhd, 1998).

The most obvious environmental impact of recycling is the conservation of materials. For example, when secondary fiber is used to manufacture newsprint it takes the place of virgin fiber obtained from trees, or when scrap ferrous metal is used in the manufacture of steel, iron ore is saved. But there are limits to the quantities of materials which can be conserved through recycling.

Another potential environmental benefit from recycling is energy conservation. Table 2.4 shows that major energy savings occur when aluminum and steel are manufactured from secondary materials instead of virgin materials.

Table 2.4: Environmental Benefits Derived From Substituting Secondary Materials For Virgin Resources

	Percentage reduction			
Environmental benefit	Aluminum	Steel	Paper	Glass
Reduction of:				
Energy use	90-97	47-74	23-74	4-32
Air pollution	95	85	74	20
Water pollution	97	76	35	-
Mining wastes	-	97	-	80
Water use	-	40	58	50

Source : Pollock (1987)

For most paper products, energy savings occur when wastepaper is used as a raw material instead of 100% virgin fiber; for a few paperboard products, however, more energy may be required. On the negative side, it must be recognized that additional energy expenditures may be required in order to collect recyclables and haul them to processing site than would be the case if these materials were all mingled together with other refuse components and transported to a landfill or an incinerator.

2.4 Landfilling Of Waste

Economic considerations continue to keep landfills as the most attractive disposal route of municipal solid waste. The great majority of solid waste generated world wide is currently disposed of in landfills (Bingemer and Crutzen 1987; Cossu 1989; Lee *et. al.* 1993; Nozhevnikova *et. al.* 1992). Landfills are a necessary component of any municipal solid waste management system. Waste reduction efforts, recycling, incineration and composting can reduce the quantity of materials sent to a landfill, but there will always be residual materials which require landfilling.

In Malaysia the solid waste management services were initially under the responsibilities of the 144 local authorities. However, under the privatization concession of solid waste disposal, four consortiums have been given the task to provide the services. The consortiums were given the contract to undertake the cleaning, sweeping of roads, cutting of grass and garbage disposal and are also faced with the need to up keep the cleanliness of the townships and environment where people live.

Hicom was awarded a privatisation concession on 21st December 1995 for 20 years to serve the states of Selangor, Kelantan, Pahang, Terengganu and the

Federal Territory. Three other consortiums serve the north and south of Penisular Malaysia and East Malaysia respectively. Under the terms, the consortiums will undergo an interim period of between one to three years and stage by stage takeover of the services from the local authorities. The dumpsites still belong to the local authorities but are only to be managed by the consortiums (Kuppusamy, 1998).

In 1990, there were about 230 official municipal dumping sites in Malaysia and 82% of the landfill sites were categorised as controlled tipping, 14 % as crude open dumps and only 4% have been categorised as sanitary landfills (Matsufuji and Sinha, 1990). Over the next 20 years, Alam Flora Sdn. Bhd. (the private consortium handling municipal solid waste management in central Malaysia) has projected a total expenditure of RM 4.7 billion to upgrade its facilities which will include upgrading present landfills and opening up new sites, recycling, bin provision, transfer station and incinerator construction, vehicle depots and waste transportation. Under Alam Flora's plan, 83 landfills currently in use within its operating areas will be upgraded or closed down. Table 2.5 lists the existing landfills and additional infrastructure available in selected states.

Table 2.5 : Existing Landfills And Additional Infrastructures Available In Selected States

STATE	EXISTING		ADDITIONAL INFRASTRUCTURE			
	Landfill	Incinerations	Landfill upgrades	New landfills	Transfer stations	Incinerators
KUALA LUMPUR	1	0	1	0	3	0
SELANGOR	17	0	1	3	8	1
KELANTAN	17	0	0	2	3	0
PAHANG	31	1	1	5	8	1
TERENGGANU	17	1	0	3	5	0
TOTAL	83	2	3	13	27	2

Source : Gomes (1997)

Although there are 83 landfills in the 5 selected states, only three landfills are upgraded and serve as sanitary landfill whereas others are just open dumps. There are only two incinerators available, one in Pahang and another in Selangor. Although incineration solves the landfilling problems it is less preferred because of its high maintenance and operational cost.

In the United States, sanitary landfills have been the most popular method for municipal solid waste disposal. It was estimated that about 6,500 solid waste landfills existed prior to 1988. As the Subtitle D of regulations of the Resource Conservation and Recovery Act (RCRA) took effect on October 9, 1993, many landfills were closed because of space limitations or noncompliance (U.S. EPA 1991). In the year 2000, EPA estimated that in spite of increased recycling, waste reduction, and incineration , approximately 49 percent of the municipal waste will still be landfilled.

Fresh Kills is listed in the Guiness Book of Records as the largest garbage dump in the world and is located 20 miles from Manhattan. Fresh Kills receives

16,000 tonnes of waste of the 20,000 tonnes produced daily in New York City. It is 3000 acre in area and contains 6.24 billion cubic meter of trash (Wentz, 1995).

Table 2.6 lists some of the problems of landfill sites in Malaysia.

Table 2.6: Problems Of Landfill Sites (%)

	SERIOUS		NOT SO SERIOUS		NO PROBLEM	
	M	D	M	D	M	D
Ground water pollution	71.4	12.0	28.6	76.0	0.0	12.0
Leachate	57.2	7.2	42.8	78.5	0.0	14.3
Scavengers	50.0	8.6	37.5	74.0	12.5	17.4
Water pollution	37.5	12.0	50.0	72.0	12.5	16.0
Cover material	25.0	50.0	25.0	26.9	50.0	23.1
Littering	25.0	37.5	37.5	58.3	37.5	4.2
Open dumping	25.0	48.0	50.0	48..0	25.0	4.0
Odour	22.2	40.0	77.8	60.0	0.0	0
Fly	12.5	45.8	62.5	54.2	25.0	0
Air Pollution	12.5	21.7	50.0	74.0	37.5	4.3
Crow	0	4.2	36.4	37.5	63.6	58.3
Noise	0	0	37.5	29.2	62.5	70.8

Source : Hassan *et. al.* (1999)

NOTE: **M-** Municipal Councils, 9
D- District Councils, 26

The odour or smell emitted from a landfill can be an important factor to justify whether such landfill is acceptable by the public. There are many factors that could cause odour problem in a landfill site. However, this odour problem is usually directly associated with the improper management of the landfill and also the distance of the landfill from the residential area. The impact of an abandoned landfill on the community residents is always negative, causing concern and fear not only about the pollution of water resources or gas explosion, but also the odour emitted from such landfill sites (Hassan and Theng, 1999).

Generation of landfill leachate remains an inevitable consequence of the practice of waste disposal in landfills. The subsequent migration of leachate away from landfill boundaries and the release to the adjacent environment is a serious environmental pollution concern and a threat to public health and safety.

Ground water pollution is by far the most significant concern arising from leachate migration. Once leachate reaches the bottom of a landfill or an impermeable layer within the landfill, it travels laterally either to a point where it discharges to the ground surface as a seep, or it moves through the base of the landfill and into subsurface formations. Depending upon the nature of these formations and in the absence of a leachate collection system, leachate has been associated with contamination of aquifers underlying landfills which prompted extensive investigations over the past four decades (El-Fadel *et. al.*, 1997).

In developing countries, municipal solid waste contains two thirds of organic material and is potentially subject to natural decomposition. However, buried waste do not have access to oxygen. Therefore their decomposition is anaerobic and a major byproduct of this process is biogas, which is about two thirds methane and the rest hydrogen and carbon dioxide, a highly flammable mixture. This is produced deep in landfill and biogas may seep horizontally through the soil and rock, enter basements and even cause explosions if it accumulates and ignited. Also, gases seeping to the surface kill vegetation by poisoning the roots (Nebel and Wright, 1998).

The largest sources of US anthropogenic methane emissions are landfills, which produce methane during the anaerobic decomposition of organic waste. In 1990, landfills generated 9.8 Mega tonnes (Mt) of methane, a figure which increased to 11.6 Mt in 1997. EPA expects that this will decline to 9.1 Mega tonnes per acre (Mtpa) by 2000, due to the effects of new legislation, the Landfill Rule. This instrument requires the larger landfills to reduce emissions of non methane organic compounds (U.S. EPA, 1999).

Waste settles as it compacts and decomposes. Settling presents a problem where landfills have been converted to playgrounds and golf courses, because it creates shallow depressions that collect and hold water.

2.5 Sanitary landfills

Sanitary landfilling is the compaction of refuse in a lined pit and covering of the compacted refuse with a cover, usually earth. Typically, refuse is unloaded, compacted with bulldozers or compactors, and covered with soil. The landfill is built up in units called cells. The daily soil cover is between 15 and 30 cm thick depending on soil composition, and a final cover at least 5cm thick is used to close the landfill (Vesilind *et. al.*, 1994). But nowadays it is recommended that the final cover should be 60 cm. Cross section of a typical sanitary landfill is shown in Figure 2.1.

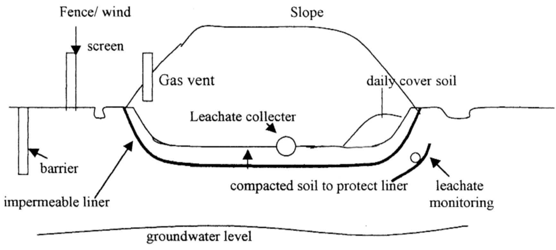

Figure 2.1: Cross Section Through A Sanitary Landfill

There are two basic methods of landfilling: area method, and trench method. In area method, the landfilling is operated in depression, canyon, flat or rolling terrain. The cover material is obtained from the site or imported. A bulldozer spreads and compacts the waste on the natural surface of the ground, and a scraper is used to haul the cover material at the end of the day's operation. In trench method, a trench is excavated, and soil is stock piled for use as cover material. The depth of the trench depends on the location of the groundwater and character of the soil. The collection truck deposits its load into a trench where a bulldozer spreads and compacts it. At the end of the day, the excavated soil is used as daily cover material (Syed and Walter, 1994).

2.5.1 Leachate formation mechanisms

Leachate is a contaminated liquid that accumulates beneath a landfill site resulting from the infiltration process, whereby the water dissolves some of the chemicals produced in the waste. During this infiltration process, the water may also dissolve the liquid produced during the natural degradation of waste and the liquid that is squeezed out due to weight of the waste. This leachate often contains a high concentration of organic matter and inorganic ions including heavy metals therefore it is highly contaminating and can degrade surface and ground water resources.

The process of landfill leachate generation passes through five phases (Figure 2.2) namely Initial Adjustment phase (phase1), Transition phase (phase 2), Acid phase (phase 3), Methane Fermentation phase (phase 4), and Maturation phase (phase 5) (Noor Mohamed *et. al.*, 1999). In phase 1, most of the biodegradable component in municipal solid waste begins to undergo bacterial decomposition. Biological decomposition occurs under aerobic conditions because of air trapped within the landfill. In the Transition phase (phase 2), oxygen is depleted and anaerobic conditions begin to develop. pH of the leachate drops due to the presence of organic acids and the effect of the elevated concentration of CO_2 within the landfill. In phase 3, the Acid Phase, because of the acids produced during this phase, the pH of the leachate drops to value of 5 or lower. The BOD, COD and conductivity of the leachate will increase significantly during phase 3 due to the dissolution of the organic acids in the leachate. A number of inorganic constituents, principally heavy metals, will be solubilized in this phase.

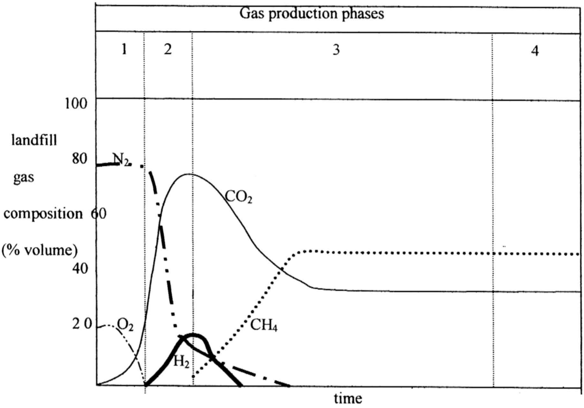

Figure 2.2: Typical Production Pattern For Landfill Gas

Many essential nutrients are also removed from the leachate and, if the leachate is not recycled the essential nutrients will be lost from the system.

In the Methane Fermentation phase (phase 4), acids and the hydrogen gas produced have been converted to CH_4 and CO_2 . The pH of the leachate will rise to the range of 6.8 to 8. The concentration of BOD, COD and the conductivity value of the leachate will be reduced. With higher pH values, fewer inorganic constituents are solubilized, as a result, the concentration of the heavy metals present in the leachate will also be reduced.

In the Maturation phase (phase 5) occurs after all the readily biodegradable organic has been converted to CH_4 and CO_2. During this phase, the leachate will often contain higher concentration of humic and fulvic acids, which are difficult to process further biologically (Tchobanoglous, *et. al.*, 1993).

Leachate formation in landfills is influenced by many factors: climatic and hydrogeologic, site operation and management, refuse characteristics, and internal landfill processes (Table 2.7).

Table 2.7 : Factors Influencing Leachate Formation And Leachate Composition In Landfills

Factors influencing leachate formation	Factors influencing leachate composition
1. CLIMATIC AND HYDROGEOLOGIC Rainfall, snowfall, ground water intrusion	-
2. SITE OPERATION AND MANAGEMENT Refuse pretreatment, compaction, vegetation cover, sidewalls and liner material, irrigation, recirculation, liquid waste co-disposal	2. SITE OPERATION AND MANAGEMENT Refuse pretreatment, irrigation, recirculation, liquid waste co-disposal
3. REFUSE CHARACTERISTICS Permeability, age, particle size, density, initial moisture content.	3. REFUSE CHARACTERISTICS Composition, Age
4. INTERNAL PROCESSES Refuse settlement Organic material decomposition Gas and heat generation and transport.	4. INTERNAL PROCESSES Hydrolysis, adsorption, biodegradation, speciation, dissolution, dilution, ion-exchange, partitioning, precipitation, gas and heat generation and transport

Source : El-Fadel *et. al.* (1997)

These factors can be divided into those that contribute directly to landfill moisture (rainfall, snowmelt, ground water intrusion, initial moisture content, irrigation, recirculation, liquid waste co-disposal, and refuse decomposition) and those that affect leachate or moisture distribution within the landfill (refuse age-pretreatment, compaction, permeability, particle size, density, settlement, vegetation, cover, sidewall and liner material, gas and heat generation and transport). While increased moisture content is the major contributor to leachate formation , it is also commonly associated with enhancing biodegradation processes in landfills (Jenkins and Pettus, 1985; Halvadakis, 1983; Emberton, 1986). As a result, it is not unusual to design a landfill cover to capture water (increase filtration) to enhance biodegradation thus promoting rapid stabilization and reducing the time required for the return of the landfill to beneficial land use (Reinhart, 1995).

Amongst the many factors contributing to increased landfill moisture, leachate recirculation has received significant attention as a leachate management option. Leachate recirculation also has the potential to significantly reduce leachate contaminant concentrations in a relatively short period of time through either dilution or by aerobic treatment within the landfill (El-Fadel *et. al.*, 1997).

2.5.2 Leachate composition and characteristics

Leachate formation creates a nonuniform and intermitten percolation of moisture through the refuse mass which results in the removal of the soluble organic and inorganic compounds from the refuse and their dissolution and suspension in the leachate. In addition, as mentioned previously, leachate formation is indicative of increased moisture content which is associated with enhancing biochemical processes in landfills. The composition of landfill leachate can exhibit considerable spatial and temporal variations depending upon site operations and management practices, refuse characteristics, and internal landfill processes (Hoeks and Harmsen, 1980; Harmsen, 1983)

Table 2.8 lists the characteristics of leachate obtained from a landfill in City of Vancouver, British Columbia. The table summarizes the data collected over a 14 month period commencing in August 1993. The Vancouver landfill is a 635 ha municipal solid waste landfill, receiving approximately 450,000 tonnes of municipal solid waste annually, serving a population of approximately 760,000 people. The landfill has been in operation since 1966 , and to date, an area of approximately 172 hectares has been filled to a final height of approximately 13 meters.

Table 2.8 : Leachate Characteristics From A Landfill In Vancouver Of 27 Years Old

Parameter	Monitoring Frequency	mean (mg/l)	min (mg/l)	max (mg/l)	no of samples	detection limit
Conductivity (mS)	tri-weekly	4.7	2.4	7.5	77	
site pH (units)	tri-weekly	7.4	7.0	7.8	110	
Lab pH (units)	Weekly	7.5	6.8	8.5	62	
TSS	Weekly	67	10	308	60	
Alkalinity as Ca $_2$CO3	Weekly	2380	453	3810	60	0.5
NO_3-N	Weekly	0.34	ND	3.40	63	0.02
NO_2-N	Weekly	0.026	ND	1.100	62	0.002
COD	Weekly	368	146	532	60	25
NH_3-N	Weekly	202	83	336	94	0.02
BOD_5	Monthly	50	27	89	12	10
TKN	Monthly	230	136	392	11	0.5
TKN:NH_3-N (ratio)	-	1.1:1	!:1	1.4:1	11	
BOD_5: COD (ratio)	-	0.13:1	0.08:1	0.19:1	11	
Cr	Monthly	ND	ND	ND	13	0.03
Fe	Monthly	15.1	11.8	20.2	13	0.03
Pb	Monthly	ND	ND	ND	13	0.08
Mn	Monthly	1.2	0.8	1.5	13	0.003
Ni	Monthly	0.019	ND	0.041	13	0.025
Zn	Monthly	0.129	0.035	0.310	13	0.015

Source : Handerson *et. al.* (1997)

The mean BOD : COD ratio of the leachate was 0.13 which is indicative of a mature or methanogenic landfill (Handerson *et. al.*, 1997).

Table 2.9 lists the characteristics of leachate samples collected from Sabak Bernam landfill. Sabak Bernam landfill is one of the extensively studied landfill in our country. Sabak Bernam district is an agricultural area with coconut, rubber and oil palm plantations. The landfill site commenced operation in 1993 and is 10 acres in area. It is estimated that the disposal site can be used until the year 2001 (Alam Flora Sdn.Bhd.).

Table 2.9 : Composition Of Landfill Leachate From Sabak Bernam Landfill Site

PARAMETER	Quantity (MEAN)
BOD (mg/l)	726
COD (mg/l)	1250
Ph	7.96
TSS (mg/l)	111.58
Specific Conductance µS	16.2
Alkalinity ($CaCO_3$)(mg/l)	1200
Hardness ($CaCO_3$) (mg/l)	850
Total P(mg/l)	5.76
Ortho P (mg/l)	103.39
NH_4-N (mg/l)	8.0
Calcium (mg/l)	437.86
Chloride (mg/l)	420
Sodium (mg/l)	1287
Pottasium (mg/l)	540
Sulfate (mg/l)	36
Magnesium (mg/l)	55.3
Iron (mg/l)	8.56
Zinc (mg/l)	1.36
Copper (mg/l)	0.02
Cadmium (mg/l)	0.001
Lead (mg/l)	0.03
Total C (mg/l)	2057

Source : Harsha (1999)

The average values of the BOD and COD in the leachate samples were found to be 729 and 1250 mg/l respectively. The ratio of the BOD to COD value is approximately 0.58. According to Mizanur *et. al.*, ratio of BOD/COD which falls in the range between 0.4-0.6 indicates that the organic matter in the leachate is readily biodegradable. The high concentration of sodium, potassium, calcium, magnesium, chloride and sulphide ions in the leachate samples could be attributed to the large amount of agrowaste and industrial waste received by this landfill.

Variation in leachate composition is greatly attributed to age factors, such as time since refuse placement or time since the first appearance of the leachate. The concentration of many constituents, including pollutants, in landfill leachates decreases with refuse age. Leachate concentration peaks when landfill life is within 2-3 years of refuse placement and gradually declines in enssuing years. The concentration of iron, zinc, phosphate, chloride, sodium, copper, organic nitrogen, total solids and suspended solids decreases over the next 3-5 years. The steady decrease is attributed to the continued flushing of the refuse, thereby removing the easily decomposable and soluble materials. This trend generally applies to the organic constituents and general organic indicators (BOD, COD, TOC).

With increasing landfill age, humic-carbohydrate-like compounds and fulvic-like materials become more predominate. The volatile acids production, corresponding to the first stage of anaerobic degradation, represent the major organic fraction during the early years of landfill life.

Table 2.10 : Leachate Concentration Changes With Landfill Age

Parameter (mg/l)	Landfill age (yr)			
	0	5	10	20
BOD	17500	2500	500	50
COD	27500	15000	3000	1000
Nitrogen	1000	400	125	30
TDS	17500	7500	3500	1000
pH	4.5	6.5	7.3	7.5
Calcium	3000	1250	400	300
Sodium and Potassium	3000	1000	300	100
Magnesium and Iron	1000	750	300	100
Zinc and Aluminium	150	75	30	10
Chloride	1500	1250	300	100
Sulphate	1250	600	125	50
Phosphorus	150	55	-	10

Source : Noor Mohamed *et. al*. (1999)

Table 2.10, is indicative of the extent of the variation of leachate quality with landfill age. It is therefore, difficult to generalize as to the concentration of a particular chemical in leachate at a specific time. However, in most cases, concentrations continually decrease with time.

Inefficient leachate collection and treatment often causes adjacent water bodies to be heavily contaminated. Table 2.11 shows the water quality status of the water bodies within the vicinity of the Taman Beringin landfill site.

Table 2.11: Average Water Quality Of The Water Bodies Within The Vicinity Of Taman Beringin Landfill

Parameter	Units	Pond (W1)	Stream (downstream) (W2)	Standard A	Standard B
pH		7.765	7.005	6.0-9.0	5.5-9.0
Temperature	C°	31.650	27.400		
Electrical conductivity	µmhos/cm	5890	240		
Dissolved oxygen	mg/l	0.200	1.000		
Turbidity	FTU	416.500	25.500		
BOD_5	mg/l	68.250	10.335	20	50
COD	mg/l	438.000	27.500	50	100
Ammonia nitrogen	mg/l	1750.000	60.000		
Phosphate	mg/l	10.575	1.875		
Chromium	mg/l	0.000	0.005		
Plumbum	mg/l	0.133	0.079	0.01	0.5
Mercury	mg/l	0.001	0.001		
Manganese	mg/l	2.000	0.050		
Nitrate	mg/l	0.000	0.850		
Nitrite	mg/l	0.049	0.053		
Soluble iron	mg/l	0.125	0.020	1.0	5.0
Total suspended solid	mg/l	20.000	67.500	50	100
Total dissolved solid	mg/l	1273.000	642.500		
Total solid	mg/l	1415.000	115.000		
Water quality index		46.50	66.68		

Source : Mohd Kamil (1999)

W1 represents water sample from the pond nearby the landfill and this pond falls under class IV (refer to Appendix 1). The stream (W2), adjacent to the pond has been affected by the leachate from the landfill site and also some contamination from the upstream areas. This stream falls under class III (refer to Appendix 1). Most of the parameters at W1 (pond) were found to exceed the limit set in the Standard A except the concentration of soluble iron and total suspended solid.

2.5.3 Leachate treatment

Leachate treatment techniques which are far advanced and tested includes aerobic, anaerobic, physical-chemical, combination with municipal sewage and recirculation and spray. The effectiveness of leachate treatment processes varies with the leachate from the landfills of different ages. Biological treatment was found to be more effective in treating leachate from a relatively young landfill and physical and chemical method showed better performance in treating old leachates (Boyle and Ham, 1974).

Mc Bean *et. al.* (1982) summarized the practical considerations in the use of different leachate treatment processes as shown in the Table 2.12. Biological treatment was found to be effective in treating leachate from a young landfill (less than 5 years) whereas reverse osmosis and activated carbon works better on leachate from old landfills (more than 10 years). However, cost constraint is always a limiting factor in the selection of an efficient treatment method.

Table 2.12: Relationship Between The Nature Of Leachates And The Treatment Process.

Characteristics of leachate	BOD/TOC	>2.8	2.0-2.8	<2.0
	BOD/COD	>0.5	0.1-0.5	<0.1
	Age of landfill	Young (5 years)	Medium (5-10 years)	Old (>10 years)
	COD	> 10 000	500-10 000	<500
Efficiency of treatment	Biological treatment	Good	Fair	Poor
	Chemical precipitation	Poor	Fair	Poor
	Chemical oxidation	Poor	Fair	Fair
	Ozonation	Poor	Fair	Fair
	Reverse osmosis	Fair	Good	Good
	Activated carbon	Poor	Fair	Good
	Ion exchange	Poor	Fair	Fair

Source : Mc Bean *et. al.* (1982)

2.5.4 Leachate Recycle.

Some researchers suggest that the decomposition process could be enhanced by collecting leachate and recycling it back into the organic material. One study in Pennsylvania landfill concluded that recycling of leachate resulted in more rapid decomposition, enhanced methane production and increased stabilization (U.S. EPA, 1988a, 1988b). In this study, two 0.5 ha landfill cells for household solid wastes only were set up; leachate was collected and removed for external disposal from one cell, and recycled in the other cell. Decomposition rates were measured after 5 years (U.S. Congress, 1989).

The results of this study indicate several potential benefits: methane production could be maximized, making recovery more viable; the time needed to decompose organic material might be reduced from 15 years to a few years; landfill could be used as an equalization basin and collected leachate will have lower biodegradable organics to be treated at wastewater treatment plants. However several problems were also discovered. Harper and Pohland (1988) have noted that the increased volume of leachate may clog the leachate system. Also small tears in the liner during construction or daily operation may cause leachate migration due to recycling. These potential problems suggest that enhanced decomposition be used only at sites that are not located near groundwater sources.

2.6 River pollution

Pollution refers to the introduction by human action, directly or indirectly, of substances or energy into the environment, resulting in deterioration effects of such in a nature as to endanger human health, harm living resources or ecosystems, and impair or interfere with amenities and other legitimate uses of the environment (Owen and Owen,1991). Whereas, water pollution may be defined as any chemical or physical change in water detrimental to living organisms. Although the causes of water pollution may be natural, the majority results from human activities.

Types of water pollution can be grouped into numerous categories, including oxygen demanding, disease causing, synthetic organic chemicals, plant nutrients, inorganic chemicals and minerals, sediments, radioactive substances, and thermal pollution or heat. Table 2.14 lists the major types of pollutants.

Table 2.14: Major Types Of Pollutants

Pollutant	Major sources	Effects
Oxygen demanding waste	Sewage effluent; agricultural run-off including animal waste; industrial effluents	Decomposition by aerobic bacteria depletes level of dissolved oxygen in water; flora and fauna perish; decomposition by anaerobic bacteria produces foul-smelling toxic substances
Plant nutrients	Sewage effluents including phosphates from detergents; agricultural runoff, especially nitrate from fertilizers	Algal blooms, death of submerged vegetation, production of large amounts of dead organic matter with subsequent problems of oxygen depletion (see above)
Acids	Acid rain; mine drainage; planting of extensive areas of coniferous forests, which acidify the soil	Acidification of natural waters, sharp decline in species richness, fish killed
Toxic metals	Ore mining, associated industries, vehicle exhaust emissions	Biomagnification of toxic metals with each successive stage of food chain; threat to consumers including human
Oil	Drilling operations; oil tanker spills; natural seepage; waste disposal	Contamination of the aquatic environment; death of birds and mammals
DDT (an organochlorine)	Agricultural runoff	Biomagnification, top carnivores (especially birds) at risk
PCB s (a series of organochlorine)	Landfill sites, toxic dumps, waste incineration	Biomagnification, top carnivores (especially birds) at risk, joint pain in human, fatigue
Radiation	80% from natural sources, 20% from nuclear weapons testing, medical X-rays, nuclear energy industry, etc	Degree of tissue damage and risk of death dependent on exposure; radionuclides can be biomagnified, and some are very persistent in the environment
heat	Coolant waters from industry, principally the electricity generating industry	Change in species composition usually accompanied by a decrease in species richness, reproductive cycle of fish and other aquatic organisms disrupted

Source : Andrew (1996)

Oxygen demanding pollutants are those natural or unnatural substances that deplete the available dissolved oxygen content in the water, usually some form of bacterial decomposition. Disease causing agents include viruses, parasites and bacteria that are contained in both human and animal excrement. Synthetic organic chemicals include many industrial chemicals, pesticides and household products. Plant nutrients, such as nitrogen and phosphorus, result from fertilizer runoff, laundry detergents and sewage treatment plant effluents. Inorganic chemicals and minerals include many industrial chemicals and heavy metals such as chromium, mercury, cadmium and lead. Sediments are particles and other matter from eroded soil, sand and minerals. Thermal discharges and radioactive substances occur naturally; however the industrial activities that result in these two types of pollutants are a more serious concern to the society (William, 1996).

Most natural waters are polluted to some extent by a number of the pollutants mentioned previously. In some cases, pollutants are discharged directly into water. For example, rivers are viewed as an effective transport medium for the removal of waste products from factory sites and sewage works. In other instances, water pollution occurs indirectly, for example through surface runoff from agriculture and urban areas and from air pollutants such as lead and oxides of sulfur.

One of the hidden source of water pollution is landfill. Landfills built in wetlands, near rivers and in other places where groundwater is close to the land surface pose specific groundwater and surface water contamination problems.

Data from the 1980s indicate that thousands of municipal landfills are located less than one mile from surface water bodies, with the majority located within a one quarter mile radius (U.S. EPA, 1988b). Leachate travelling with groundwater can reach these surface waters and therefore contribute a wide range of contaminants to the surface water system. Direct discharge of contaminated leachate into surface waters may result in the loss of recreation, agriculture, drinking water and create environmental degradation (U.S EPA 1988c).

A census on landfills in the United States conducted by the EPA during 1985 and 1986 analysed 9 284 municipal solid waste landfills. Of these landfills, 586 had recorded at least one violation for contamination of groundwater and 660 had received at least one surface water violation (U.S. EPA, 1988b).

Until lately, insufficient attention was paid to river water quality and pollution control. This issue needs to be addressed urgently since 97% of the total water use originates from the rivers. River water pollution leads to three effects (Keizrul, 1998). Firstly, it increases 'quantity scarcity' since there is less volume. Next, it increases the water treatment costs due to the presence of new pollutants and an increase in the concentration of existing pollutants. And lastly, it degrades the ecological health of the water bodies and the surrounding ecosystems affecting fish and other aquatic habitat and the safety of the recreational activities.

In Malaysia, the control of water pollution and the monitoring of water quality is the responsibility of the Department of Environment. The department has to date established a network of about 892 water quality monitoring stations throughout the country. The river water quality results published annually indicate the extent of the threat faced by freshwater resources.

Four major activities in Malaysia were identified as significant water pollution sources. These are manufacturing industry, agro based industry (crude palm oil and raw natural rubber), animal husbandary (pig rearing) and sewage were identified as significant water pollution sources. A total of 13 398 sources were recorded from these four activities in 1998. Sewerage activities accounted for 5 665 (42.3%) sources followed by manufacturing (5 029 ; 37.5%) , pig rearing activity (2 235; 16.7%) and agro based industry (469 ; 3.5%) (DOE, 1998).

2.6.1 River pollution from metals

In the last decade, concern among scientist about the distribution and effects of heavy metals in the environment has increased markedly. Through extraction and use of minerals, man has increased the environmental concentrations of many metals over wide geographic areas.

Heavy metals are involved in many types of electron transfer reactions. Replacement in an enzyme of an essential metal by another metal, such as substitution of cadmium or lead for zinc in dehydrogenase reaction or the substitution of mercury, lead or copper for manganese in ATPase can result in structural instability of the enzyme and can lead to toxicity if the replacement occurs in a large proportion of the enzyme molecules (Harry, 1975). Thus, these reactions, together with the heavy metals ability to accumulate in plants and animals certainly poses a health hazard to human. Table 2.15 lists the major uses of selected heavy metals.

Table 2.15: Major Uses Of Several Heavy Metals

Metal	Major uses
Arsenic and compounds	Pesticides, wood preservatives, contaminant of phosphate fertilizer, metallurgy, chemical industry
Cadmium and compounds	Electroplating, production of Cu, Pb, Al and Ag alloys, batteries, fungicides.
Chromium (as chromates) Cr (IV)	Corrosion inhibitors, explosives, paper, dyes, paints, plating and tanning.
Cr (III)	Textile, ceramics, photography, glass.
Lead and compounds	Gasoline, additives, batteries, pigments, brass and bronze, galvanizing, miscellaneous metal products.
Mercury and compounds	Electrolysis, chlor-alkali production, electrical apparatus, fungicides, paints, industrial instruments, pharmaceuticals, paper, plastics.
Zinc and compounds	Galvanizing, brass products, die-casting alloys, rod alloys, rubber, paint, chemical industry, photocopying.

There are a number of sources of heavy metal pollution (metals with high atomic weights). Natural geological weathering is the chief source of the low background levels in pristine waters. However, in a few locations where surface waters receive water from metal rich ores, very high natural concentration can occur. The processing of metal ores is also a major source of water pollution in areas remote from urbanisation, and can result in concentrations so high that all life in the affected water may be killed (Andrew, 1997). A particularly problematic source of pollution is abandoned mines, which fill with water and spill into nearby rivers.

Animals do secrete some metals (especially zinc) and many sewers contain other small sources of metal. Inefficient treatment of sewage can lead to significant pollution by metals. Leachate from landfill is also a significant source of heavy metals in water. Many landfill sites contain metal waste which slowly corrodes and becomes soluble. If such leachate enters surface water, then heavy metal pollution in water can result (Cheung *et. al.*, 1993).

There are some cases of acute toxicity to humans arising from metal pollution in water. One example occurred in Taiwan, where high levels of arsenic in water were reported following volcanic activity, and this led to blood diseases and skin cancer (Andrew, 1997). Perhaps the best known example of metal pollution affecting humans is that of lead from the water distribution system itself. In many countries, lead pipes have historically been used to convey water to domestic users. If the water is acidic (soft water) then the lead will slowly dissolve and can result in lead poisoning.

2.6.2 Groundwater resources

Groundwater is a very important source of drinking water. Historically, groundwater was considered to be so safe that it has been consumed directly from wells without further treatment. In underdeveloped countries, practically all villages rely on groundwater from shallow wells. Cebu City, the second largest city in the Philippines, has relied solely on groundwater, after its impounding reservoir was silted up due to poor management. Water pumps are distributed strategically throughout the city to supply water directly to consumers (Sincero and Sincero, 1996).

Groundwater is the subsurface water that resides in the zone of saturation. In this zone, the pores between the soil particles are filled with water. The water table is the upper boundary of this zone of saturation. The water table is also defined as the surface at which the fluid pressure in the pores is equal to the atmospheric pressure. Above the water table, is the zone of aeration, or unsaturated zone.

Groundwater is still the source of water for wells and many springs, and lately an important source of commercial mineral water for Malaysian consumption. Groundwater provides readily fresh water in many areas of the world. In Malaysia, groundwater is currently being used mainly for municipal/domestic supplies (estimated at 60%), industrial supply (30%) and agricultural usage (10%). However our existing groundwater resources are subjected to two main threats: 1. contamination and 2. over development (Hasan, 1996).

The landfill sites of different ages, located in Kuala Lumpur area, have been studied to investigate the level of groundwater contamination by the leachate. These landfills were Taman Beringin (in operation for the last 8 years), Kg Paka 1 (closed and ten years of age) and Sri Petaling (closed and 20 years of age). None of these landfills were provided with liner for leachate collection and thus freely contaminate the groundwater below. Groundwater samples taken from the landfill site through boreholes have been analysed and the results are shown in Table 2.16.

Table 2.16: Groundwater Contamination In And Around The Landfills

Parameter	Landfill		
	Taman Beringin	Kg. Paka 1	Sri Petaling
Age (year)	8	10	20
pH	7.80	7.30	7.30
BOD (mg/l)	84.60	34.58	11.06
COD (mg/l)	1594.00	130.85	39.00
TDS (mg/l)	1234.00	107.00	166.00
Ammonia-Nitrogen (mg/l)	585.00	77.50	77.10
Phosphate (mg/l)	6.98	4.30	1.56
Chromium (mg/l)	0.03	0.01	0.00
Plumbum (mg/l)	100.43	0.08	0.07

Source : Noor Mohamed *et. al.* (1999)

The BOD, COD, TDS, ammoniacal nitrogen and plumbum concentrations found in the leachate from Taman Beringin landfill was much higher compared to the other landfills. This is most probably because Taman Beringin landfill is still actively operating whereas the other two landfills have been closed.

An example of severe economic damage incurred by pollution of a drinking water aquifer by leachate from a country landfill occurred in New

Castle. Leachate from the landfill migrated more than 244 km and contaminated the Potomac drinking water aquifer four years after the landfill site had been closed. The drinking water was contaminated with such high levels of organic compounds and metal ions that it was no longer portable. This problem has cost the country RM 3 040 000 (US $ 800 000) for interim solutions and if the dump must be moved to completely remedy the situation, the cost may go as high as RM 76 million (US $ 20 million) (Griffin and Shimp, 1975).

Landfills must be designed to protect groundwater quality. Subsurface conditions, such as types of soil, underlying rock strata, and groundwater conditions are important factors for determining whether an environmentally safe landfill can be economically designed for a specific site. Therefore it is important to obtain information regarding the distance from the bottom of the proposed fill to the groundwater, the type of soils and other unconsolidated materials as well as bedrock beneath the site, the volume and direction of flow of the groundwater and the existence of any impervious bedrock or clay layers between the fill and the groundwater. Impervious bedrock or clay layers are important because of their potential for isolating the leachate produced by the landfill from important groundwater aquifers (Rhyner, 1995).

The use of clay has been the favored method of reducing or eliminating the percolation of leachate. Membrane liners have also been used, but they are expensive and require care so that they will not be damaged during the filling operations. With the use of an impermeable clay layer, and appropriate surface slope (1 to 2 percent) and adequate drainage, surface infiltration can be controlled effectively. Generalized ratings for the suitability of various types of soil for use as a landfill cover are reported in Table 2.17.

Table 2.17 : Generalized Ratings Of The Suitability Of Various Types Of Soils For Use As Landfill Cover Material

Function	General soil types					
	Clean gravel	**Clay-silt gravel**	**Clean sand**	**Clay-silt sand**	**Silt**	**Clay**
Prevents rodents form burrowing or tunneling	G	F-G	G	P	P	P
Keeps flies from emerging	P	F	P	G	G	E*
Minimizes moisture entering fill	P	F-G	P	G-E	G-E	E*
Minimizes landfill gas venting through cover	P	F-G	P	G-E	G-E	E*
Provides pleasing appearance and controls blowing paper	E	E	E	E	E	E
Supports vegetation	P	G	P-F	E	G-E	F-G

Source :Tchobanoglous *et. al.*, (1977) E - excellent; G- good, F-fair, P- poor
* except when cracks extend through the entire cover

2.6.3 Groundwater pollution caused by leachate

Municipal dumps and landfills have long been recognized as potential source of ground water pollution. The refuse disposed of in sanitary landfills and dumps, except in arid region, is subject to leaching when in contact with water. The leachate produced in landfills contains large number of organic and inorganic contaminants and is considered as extremely polluting liquor.

Early studies on landfills reported by Todd and McNulty (1976) indicated that pollution was limited to small increases in total dissolved solids where water table was in contact with the landfill. Pollution moved in the direction of groundwater flow. Coe (1970) summarized the results of four experimental landfills in California and reported that groundwater impairment could be assumed as temporary increases in organic materials and permanent increases in total dissolved solids, chloride, sulfate and in addition water hardness and bicarbonate from the effects of carbon dioxide.

A survey of information on landfill pollution by Weaver (1964) led to the statements that leaching of refuse can produce organic, mineral and bacteriological pollution and that when refuse is in contact with water table, the water may become unfit for domestic irrigation uses. Although bacterial and organic pollution may be limited in extent, chemical pollution including methane, carbon dioxide and hydrogen sulfide may range over long distances. Robertson *et. al.* (1974) identified more than 40 organic compounds in leachate contaminated groundwater in a sandy aquifer in Oklahoma. He concluded that many of these compounds were produced by leaching of plastics.

Since leachate is a highly polluting liquor, leachate management strategies should be adopted to prevent groundwater contamination. Prevention of water entry from surface drainage and rainfall is the best option for control of leachate production in landfills. Containment of contaminants within the landfill by properly designed lining and collection of leachate for treatment and safe disposal can prevent seepage of leachate into groundwater. The use of high strength, durable and leak proof synthetic geo-membrane in lining provides satisfactory protection against leakage from landfills. Proper design of landfills considering soil conditions, topography of land climatological conditions, surface water hydrology, geological and hydrogeological conditions can reduce the risk of groundwater contamination from landfills.

2.7 Leachate movement

2.7.1 Leachate seepage in Groundwater

Leachate in landfills accumulate at the bottom and then moves downward through liner or underlying soil strata. Lateral movement of leachate may also take place depending on the characteristics of surrounding soils. The rate of seepage from a landfill can be estimated by Darcy's Law which can be expressed as;

$$q = K \frac{dh}{dL} \qquad \ldots\ldots 1$$

where q is the leachate discharge per unit area per unit time, k is the coefficient of permeability and dh/dL is the hydraulic gradient. When depth of leachate at the bottom of the landfill is h and thickness of the underlying strata is d, then the equation becomes

$$q = K(1 + h/d) \qquad \ldots\ldots 2$$

the above equations are on the basis of the assumptions that diffusion of leachate does not exist and steady state saturated Darcian flow occurs through the underlying strata. If the underlying strata is of coarse 'rained material of high permeability, all the leachate generated in the aquifer will quickly reach the groundwater. To avoid this, clay or combinations of clay and membrane liners are provided in landfills. If a clay liner of thickness d is provided on coarse 'rained soils', the pore fluid pressure at the bottom of the liner would be equal to atmospheric and equation 2 would be applicable for computation of seepage.

2.7.2 Contaminant transport in Groundwater

Leachate that escapes from a landfill and reaches groundwater, either by design or by accident, is not diluted by the entire body of groundwater, but it forms a plume of diluted solute which broadens both along and perpendicular to the direction of flow. The plume travels in the direction of the groundwater flow. Two processes contribute to this phenomenon of longitudinal and transverse movement of contaminants. The first one is the molecular diffusion in the direction of the concentration gradient due to the thermal kinetic energy of solute particles. The process is important at low velocities of water. The second one is the mechanical dispersion which arises from the tortuosity of the pore channels in granular aquifer and from variation of velocity of groundwater flow within a pore channel of variable size as well as among the pores of different sizes.

Because the leachate moves primarily with the groundwater, any contamination of groundwater by leachate should be detected in down-gradient wells but not in up-gradient wells. Figure 4.3 depicts the flow of leachate as a plume.

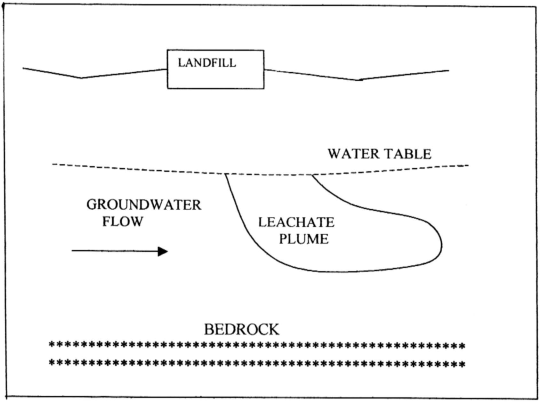

Figure 2.3: The Flow Of Leachate For Simple Subsurface Conditions

2.8 Water Quality Management

'Water quality' is a term used to express the suitability of water to sustain various uses or processes. Any particular use will have certain requirements for the physical, chemical or biological characteristics of water; for example limits on the concentration of toxic substances for drinking water use. Consequently, water quality can be defined by a range of variables which limit water use (Meybeck *et. al.*, 1996). The quality of water may be described in terms of the concentration and state (dissolved or particulate) of some or all of the organic and inorganic materials present in the water, together with certain physical characeristics of the water.

The general public's initial perception of river and coastal environment quality is often based solely upon the aesthetic appearance of the water and its surroundings (House and Sangster, 1991; House *et. al.*, 1994). Visual and odourous characteristics such as water colour, surface scum, foam and oil, smell and the presence of litter and other solid wastes have been shown to be important factors in the perception of water quality and its suitability for use, but may bear little or no relationship to actual physico-chemical or biological water quality (Margaret, 1996).

Water quality is affected by a wide range of natural and human influences. The most important of the natural influences are geological, hydrological and climatic, since these affect the quality and the quantity of water available. The effects of human activities on water quality are both widespread and varied in the degree to which they disrupt the ecosystem and/or restrict the water use. Pollution of water by human feces, inorganic fertilisers, eutrophication and industrial waste are very destructive and difficult to control.

Certain natural phenomena can also result in water quality degradation. Natural events such as torrential rainfall and hurricanes lead to excessive erosion and landslides, which in turn increase the content of suspended material in affected rivers and lakes. Permanent natural conditions in some areas may make water unfit for drinking or for specific uses, such as irrigation. Common example of this is high salt content in groundwater. Groundwaters in some regions contain specific ions (such as flouride) and toxic elements (such as arsenic and selenium) in quantities that are harmful.

2.8.1 Laws and policies

Currently, Malaysia has more than 30 directly related water laws for water resources development and management. This is particularly so because water is a fundamental natural resource which relates to all aspects of the socioeconomic life of man. Some of the laws were legislated as state laws while others as federal laws.

As far as water environment is concerned, the restriction on pollution is well backed by many state and federal water related laws. As early as 1971, the Waters Enactment (1920) of some states was amended to provide for the prohibition of pollution of rivers. The Environmental Quality Act (1974) was enacted as a federal law providing for the restriction of pollution of inland waters. The local authority is also vested with the power to administer matters such as the pollution of streams in the local authority area in accordance with the Local Government Act (Act 171) 1976. The Street, Drainage and Building Act (Act 133) 1974, a federal law, forbids any water closet or privy or any trade effluent to be discharged into or communicate with any river, canal, stream or any storm water drain without the prior written permission of the local authority. As far as schemes for water monitoring are concerned, the Environmental Quality Act (1974) provides that the holder of the license may be required by the Director General of Environment to conduct a monitoring program on water discharges (Abdullah and Jusoh, 1996).

Malaysia suffers from an over abundance of sectoral-based water laws, both at federal and state level and a lack of comprehensive water law. At present, the water legislation is contained within the laws which are enforced by the various related government agencies and many are outdated, redundant or ambiguous (Keizrul, 1998). There is a need to undertake the preparation of a comprehensive water law which can deal effectively with current issues relating to water resources planning and development.

2.8.2 Water Quality Standards.

Water contains a variety of chemical, physical, and biological substances that are either dissolved or suspended. From the moment it condenses as rain, water dissolves the chemical components of its surroundings as it falls through the atmosphere, runs over ground surfaces, and percolates through the soil. Water also contains living organisms that react with its physical and chemical elements. Water containing certain chemicals or microscopic organisms may be harmful to some industrial processes while being perfectly adequate for others.

Good water quality is important to human health; for drinking, cooking and hygiene. Adequate supplies of clean fresh water are also crucial to many aspects of sustainable development, including agriculture and industry. Water quality can be measured in terms of physical, chemical and biological variables, all of which show local and regional variations depending on the geological, biological and climatological conditions of the area (UNEP, 1994).

Water quality requirements are established in accordance with the intended use of the water. Specific uses of water, such as for drinking, water supplies or irrigation usually have a minimum acceptable quality which can be defined in terms of selected and measurable variables. Appendix 1 lists the Proposed Water Quality Standard for Malaysia.

2.8.3 Drinking Water Standards

The quality of drinking water is evaluated firstly in terms of parameters which are or may be of significance to public health, and secondly in terms of parameters that affect the acceptability of water to consumers because of effects on appearance , taste, odour or other properties which are not directly related to health but important in relation to normal water use. Health-related parameters may be subdivided into microbiological, chemical and radioactive components (Packham, 1993).

2.8.3.1 Microbiological Parameters

Water used for drinking and bathing can serve as a vehicle for the transmission of a variety of human enteric pathogens that cause waterborne diseases. The detection of pathogens in water is difficult, uneconomical and impractical in routine water analysis. Therefore, to monitor water quality, water is tested for indicator organisms that are present when fecal contamination occurs. The main characteristics of a good indicator organism are that its absence implies the absence of enteric pathogens, the density of the indicator organism is related to the probability of the presence of pathogens and in the environment the indicator organisms will survive slightly longer than will the pathogens (Gary, 1996).

Of many indicator organisms, the total coliform group of bacteria is the one most commonly used. It includes by definition ' all aerobic and facultative anaerobic, gram negative, non-spore forming, rod shaped bacteria that ferment lactose with gas formation in 48 hours at 35°C (APHA *et. al.*, 1985). *Escherichia coli* bacteria from the coliform group inhabit the intestinal tract of humans and animals and are isolated from feces. They can be easily tested in a laboratory and are considered nonpathogenic.

The enumeration of the bacterial indicators is carried out by two alternative methods, namely, the multiple tube fermentation technique, also called the most probable number or MPN procedure, and the membrane filter or MF method.

Microbiological pathogens of fecal origin represent the greatest potential threat to the safety of public water supplies. The treatment of drinking water and the separation of drinking water and sewerage systems has been of prime importance in the reduction of waterborne disease in most countries.

2.8.3.2 Chemical Parameters

The many chemical compounds dissolved in water may be of natural or industrial origin and may be beneficial or harmful depending on their composition and concentration. For example, small amounts of iron and manganese may not just cause color: they can also be oxidized to form deposits of ferric hydroxide and manganese oxide in water mains and industrial equipment. A major change has taken place over the last two decades in the importance attached to the chemical constituents of water and their significance to health. This is well illustrated by the increase in the number of limits set by the WHO in drinking water standards and guidelines within 35 years as shown in Table 2.18.

Table 2.18: Number Of WHO Health-Related Limits For Chemicals

Type	Year	Inorganic	Organic	Total
Standard- I*	1958	5	0	5
Standard E**	1961	6	0	6
Standard- I	1963	9	0	9
Standard- E	1970	8	1	9
Standard- I	1971	8	1	9
Guidelines	1984	9	18	27
Guidelines	1993	22	72	94

Source: WHO (1970)
*I = International **E = European

In the WHO guidelines published in 1993, there was a significant increase in the number of limits set for inorganics. A more detailed analysis of the 1984 and 1993 WHO Guidelines is given in Table 2.19.

Table 2.19: Number Of WHO Guideline Values Set For Various Classes Of Chemicals In 1984 And 1993

General inorganic parameters	1984	1993
Metals	4	10
Non-metals	5	7
Disinfectants And Disinfection Byproducts		
Inorganic	0	15
Organic	1	12
General organic parameters		
Pesticides	8	33
Chlorinated alkanes	2	4
Chlorinated ethenes	3	5
Aromatic hydrocarbon	2	6
Chlorinated benzenes	0	4
Miscellaneous	2	8

Source : WHO (1984, 1993)

2.8.3.3 Radiochemical Parameters

The WHO limits for radioactive constituents in water are an important consideration in the event of any contamination incident involving radioactive substances. Fortunately, such incidents are rare and day-to-day water supply operations are not normally affected by these limits which are relatively uncontroversial.

An obvious conclusion is that water quality monitoring and water treatment will become even more complex. It is possible that, at some future time, this situation will be simplified on the monitoring side by the identification of a number of satisfactory 'indicator parameters'.